Carcass Disposal: A Comprehensive Review

August 2004

Report prepared by the National Agricultural Biosecurity Center Consortium
Carcass Disposal Working Group

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Consortium Partners:

Kansas State University, National Agricultural Biosecurity Center

Purdue University, School of Agriculture and Animal Disease Diagnostic Laboratory

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Preface

Background

The US agricultural sector represents one of the world's most bountiful, healthy, and economically valuable food systems. The US agricultural sector accounts for about 13% of the US gross domestic product and nearly 17% of US jobs. Animal agriculture comprises a substantial portion of the overall agricultural sector. According to the USDA Economic Research Service, the value of US livestock commodities amounted to $105 billion during 2003. Each year, US animal agriculture contributes approximately 26 billion pounds of beef, 19 billion pounds of pork, and 35 billion pounds of poultry to the food supply.

The enormity of US animal agriculture magnifies a number of agricultural security problems, one of which is carcass disposal. Typically, animal-production mortalities and natural disasters in the US create an annual disposal requirement of about three billion pounds of carcasses. This number, while already considerable, could easily escalate in the event of an intentional or accidental introduction of foreign animal disease(s). Whether at the hand of accidental disease entry, the weather, or an act of bioterrorism, widespread livestock deaths pose daunting carcass-disposal challenges that, if not met quickly and effectively, can spiral into major food security problems and result in devastating economic losses. The ever-increasing concentration of modern animal production operations, combined with the tremendous mobility of food-animal populations, accentuates the country's vulnerability to high death losses due to disease outbreaks.

A rapid and effective disease eradication response is vital to minimizing livestock losses, economic impacts, and public health hazards. Speed is of the essence; and rapid slaughter and disposal of livestock are integral parts of effective disease eradication efforts. However, realization of a rapid response requires emergency management plans that are based on a thorough understanding of disposal alternatives appropriate in various circumstances. This report was commissioned to provide a comprehensive summary of the scientific, technical, and social aspects of various carcass disposal technologies. This report is therefore intended to serve as an evidence-based resource for officials tasked with planning for the safe and timely disposal of animal carcasses.

Terms of Reference

2002 witnessed the establishment at Kansas State University (KSU) of the National Agricultural Biosecurity Center (NABC), which evolved from KSU's ongoing Food Safety and Security program. Commissioned to collaborate with other land-grant universities and strategic partners, including the US Department of Agriculture Animal & Plant Health Inspection Service (USDA-APHIS), the NABC coordinates the development, implementation, and enhancement of diverse capabilities for addressing threats to the nation's agricultural economy and food supply. The NABC participates in planning, training, outreach, and research activities related to vulnerability (threat and risk) analyses, incident response (including assessment of intergovernmental management issues), and detection/prevention technologies.

In 2002, USDA-AHPIS entered into a cooperative agreement project with the NABC to address three critical agricultural security needs. These included the evaluation of pertinent aspects for the disposal of potentially contaminated animal carcasses; the assessment of agro-terrorism exercises with regard to their execution, inter-governmental management, and effectiveness; and the analysis of pathways by which agricultural pathogens might enter the country, including life-cycle analysis for the most significant threat agents.

This report addresses solely the findings related to the first topic area (evaluation of carcass disposal options and related issues) of the cooperative agreement project. The objectives of this topic area included the following:

- characterize, summarize, and integrate available information relative to existing carcass disposal technologies,

- frame the cross-cutting logistical, social, and economic considerations of general large-scale carcass disposal, and
- identify knowledge gaps warranting research or educational efforts.

To address these objectives, a consortium of collaborators was assembled to form the Carcass Disposal Working Group (CDWG). This body included experts from a variety of institutions, including Texas A&M University's Institute for Countermeasures Against Agricultural Bioterrorism, Purdue University's School of Agriculture and Animal Disease Diagnostic Laboratory, Sandia National Laboratories' International Environmental Analysis Unit, as well as KSU's National Agricultural Biosecurity Center.

The Working Group's Approach

The working group approached the objectives of the project by considering two broad categories of subject matter: the carcass disposal technologies currently available and the cross-cutting issues related to carcass disposal. In concert with this categorization, the CDWG elaborated a two-part report; Part 1 is comprised of chapters addressing carcass disposal technologies, and Part 2 is comprised of chapters addressing cross-cutting issues. An Executive Summary is also provided which summarizes key information from each chapter.

Part 1: Carcass disposal technologies

Within the category regarding carcass disposal technologies, task groups were formed to address burial, incineration, composting, rendering, lactic acid fermentation, alkaline hydrolysis, anaerobic digestion, and non-traditional/novel technologies. For each of these technologies, task groups were charged with characterizing the following information:

- **Principles of operation** – Including the general process overview; expertise and/or personnel requirements; throughput or capacity constraints; materials, fuel, chemical, and/or energy or utility requirements; location considerations; remediation requirements; and cost considerations.
- **Disease agent considerations** – Including the fate of disease agents during disposal, and disease agents (or classes of disease agents) for which the disposal method is or is not appropriate.
- **Implications to the environment** – Including the potential or documented effects on ground water, surface water, soil, air quality, etc.; the regulatory considerations (i.e., local, state, and federal) to address environmental issues; and monitoring requirements.
- **Advantages & Disadvantages** – A discussion of the advantages and limitations of the disposal technology, and historical lessons learned.

Part 2: Cross-cutting and policy issues

Within the category regarding cross-cutting issues, task groups were formed to address the following topics, all of which have a bearing on the carcass disposal problem: economic and cost considerations, historical documentation, regulatory issues and cooperation, public relations efforts, physical security of disposal sites, evaluation of environmental impacts, geographic information systems (GIS) technology, decontamination strategies, and transportation issues.

Acknowledgements

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The carcass disposal working group extends its gratitude to the many individuals who provided valuable information and support during the course of this project. Without the tremendous efforts put forth by the many participants, it would not have been possible to complete this multi-faceted project in a timely manner. The following individuals provided project leadership, served as primary authors of the material contained in this report, or served as supporting authors and/or reviewers of various portions of this report.

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USDA APHIS Cooperative Agreement Project
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Executive Summary

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Special Note Regarding Reference Citations:

All references cited within the text of this Executive Summary are identified in the References section of the corresponding full-length chapter.

Introduction to Part 1 – Disposal Technologies

Whether at the hand of accidental disease entry, typical animal-production mortality, natural disaster, or an act of terrorism, livestock deaths pose daunting carcass-disposal challenges. Effective means of carcass disposal are essential regardless of the cause of mortality but are perhaps most crucial for disease eradication efforts. Rapid slaughter and disposal of livestock are integral parts of effective disease eradication strategies.

Realization of a rapid response requires emergency management plans that are rooted in a thorough understanding of disposal alternatives. Strategies for carcass disposal—especially large-scale carcass disposal—require preparation well in advance of an emergency in order to maximize the efficiency of response.

The most effective disposal strategies will be those that exploit every available and suitable disposal option to the fullest extent possible, regardless of what those options might be. It may seem straightforward—or even tempting—to suggest a step-wise, disposal-option hierarchy outlining the most and least preferred methods of disposal. However, for a multi-dimensional enterprise such as carcass disposal, hierarchies may be of limited value as they are incapable of fully capturing and systematizing the relevant dimensions at stake (e.g., environmental considerations, disease agent considerations, availability of the technology, cost, etc.). Even with a disposal-option hierarchy that, for example, ranks the most environmentally preferred disposal technologies for a particular disease, difficulties arise when the most preferred methods are not available or when capacity has been exhausted. In these situations, decision-makers may have to consider the least preferred means. In such a scenario (one that is likely to occur in the midst of an emergency), there are tremendous benefits of being armed with a comprehensive understanding of an array of carcass disposal technologies. It is on this basis that Part 1 considers, in no particular order, eight separate carcass disposal technologies (see Figure 1).

Decision-makers should come to understand each disposal technology available to them, thereby equipping themselves with a comprehensive toolkit of knowledge. Such awareness implies an understanding of an array of factors for each technology, including the principles of operation, logistical details, personnel requirements, likely costs, environmental considerations, disease agent considerations, advantages and disadvantages, and lessons learned for each technology. The eight chapters comprising Part 1 of this report discuss, technology-by-technology, these very issues. For policymakers interested in technology-specific research and educational needs, these are also provided within each chapter.

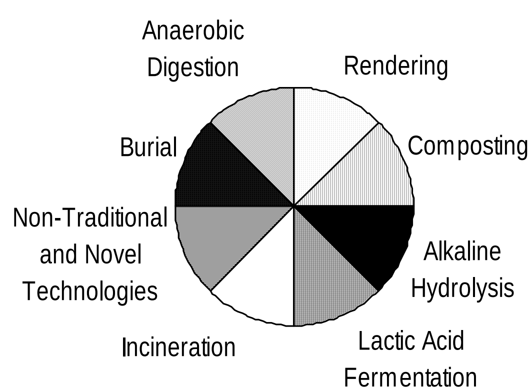

FIGURE 1. Equal consideration given to each of several carcass disposal technologies.

Chapter 1 – Burial

Chapter 1 addresses three burial techniques, trench burial, landfill, and mass burial sites. For animal disease eradication efforts, trench burial traditionally has been a commonly used, and in some cases, even a preferred, disposal option (USDA, 1981; USDA, APHIS, 1978). In spite of potential logistical and economic advantages, concerns about possible effects on the environment and subsequently public health have resulted in a less favorable standing for this method. Landfills represent a significant means of waste disposal in the US and throughout the world, and have been used as a means of carcass disposal in several major disease eradication efforts, including the 1984 and 2002 avian influenza (AI) outbreaks in Virginia (Brglez, 2003), the 2001 outbreak of foot and mouth disease (FMD) in the United Kingdom (UK) (UK Environment Agency, 2001b), and the 2002 outbreak of exotic Newcastle disease (END) in southern California (Riverside County Waste Management Department, 2003). For purposes of this report, the term "mass burial site" is used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed, and which may incorporate systems and controls to collect, treat, and/or dispose of leachate and gas. Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the information pertaining to this technique is garnered from this event.

1.1 – Burial Techniques

Trench burial

Disposal by trench burial involves excavating a trough into the earth, placing carcasses in the trench, and covering with the excavated material (backfill). Relatively little expertise is required to perform trench burial, and the required equipment is commonly used for other purposes. Large-capacity excavation equipment is commonly available from companies that either rent the equipment or operate for hire. The primary resources required for trench burial include excavation equipment and a source of cover material. Cover material is often obtained from the excavation process itself and reused as backfill.

Important characteristics in determining the suitability of a site for burial include soil properties; slope or topography; hydrological properties; proximity to water bodies, wells, public areas, roadways, dwellings, residences, municipalities, and property lines; accessibility; and the subsequent intended use of the site. Although many sources concur that these characteristics are important, the criteria for each that would render a site suitable or unsuitable vary considerably.

Estimates of the land area that may be required for disposal of mature cattle include 1.2 yd^3 (McDaniel, 1991; USDA, 2001a), 2 yd^3 (Agriculture and Resource Management Council of Australia and New Zealand, 1996), 3 yd^3 (Lund, Kruger, & Weldon), and 3.5 yd^3 (Ollis, 2002), with 1 adult bovine considered equivalent to 5 adult sheep or 5 mature hogs (McDaniel, 1991; Ollis, 2002; USDA, 1980). Excavation requirements in terms of the weight of mortality per volume were estimated as 40 lbs/ft^3 (1,080 lbs/yd^3) (Anonymous, 1973), and 62.4 lbs/ft^3 (1,680 lbs/yd^3) (USDA, Natural Resources Conservation Service, Texas, 2002). One source estimated that a volume of about 92,000 yd^3 would be required to bury 30,000 head of cattle (about 7 acres, assuming a trench depth of 8.5 ft) (Lund, Kruger, & Weldon).

Most cost estimates for trench burial refer only to the use of trench burial for disposal of daily mortality losses, which may be considerably different from the costs incurred during an emergency situation. Using information adapted from the Sparks Companies, Inc. (2002), costs for burial of daily mortalities were estimated to be about $15 per mature cattle carcass, and about $7-8 for smaller animals such as calves and hogs. Another source estimated about $198/100 head of hogs marketed (however, it is not clear how this estimate relates to actual cost per mortality) (Schwager, Baas, Glanville, Lorimor, & Lawrence). The cost of trench burial of poultry during the 1984 AI outbreak in Virginia was estimated to be approximately $25/ton (Brglez, 2003).

Advantages & disadvantages

Trench burial is cited as a relatively economical option for carcass disposal as compared to other available methods. It is also reported to be convenient, logistically simple, and relatively quick, especially for daily mortalities, as the equipment necessary is generally widely available and the technique is relatively straightforward. If performed on-farm or on-site, it eliminates the need for transportation of potentially infectious material. The technique is perhaps more discrete than other methods (e.g., open burning), especially when performed on-site (on-farm) and may be less likely to attract significant attention from the public.

Disadvantages of trench burial include the potential for detrimental environmental effects, specifically water quality issues, as well as the risk of disease agents persisting in the environment (e.g., anthrax, transmissible spongiform encephalopathy [TSE] agents, etc.). Trench burial serves as a means of placing carcasses "out of site, out of mind" while they decompose, but it does not represent a consistent, validated means of eliminating disease agents. Because the residue within a burial site has been shown to persist for many years, even decades, ultimate elimination of the carcass material represents a long-term process, and there is a considerable lack of knowledge regarding potential long-term impacts. Trench burial may be limited by regulatory constraints or exclusions, a lack of sites with suitable geological and/or hydrological properties, and the fact that burial may be prohibitively difficult when the ground is wet or frozen. In some cases, the presence of an animal carcass burial site may negatively impact land value or options for future use. Lastly, as compared to some other disposal options, burial of carcasses does not generate a useable by-product of any value.

Landfill

Modern Subtitle D landfills are highly regulated operations, engineered and built with technically complex systems specifically designed to protect the environment. Many older landfills in the US (sometimes called small arid landfills) were constructed before Subtitle D regulations were effective, and therefore were not constructed with sophisticated containment systems (US EPA). The environmental protection systems of a Subtitle D landfill are generally more robust than those of a small arid landfill, and would likely be less prone to failure following challenge by high organic loading (as would occur in disposal of large quantities of carcass material). An excellent overview of the design and operation of municipal solid waste (MSW) landfills is provided by O'Leary & Walsh (2002).

In many states, disposal of animal carcasses in landfills is an allowed option; however, it is not necessarily an available option, as individual landfill operators generally decide whether or not to accept carcass material (Wineland & Carter, 1997; Sander, Warbington, & Myers, 2002; Morrow & Ferket, 2001; Bagley, Kirk, & Farrell-Poe, 1999; Hermel, 1992, p. 36; Morrow & Ferket, 1993, p. 9; Kansas Department of Health and Environment, Bureau of Waste Management, 2001a; Kansas Department of Health and Environment, Bureau of Waste Management, 2001b; Fulhage, 1994; Britton; Talley, 2001; Ohio Environmental Protection Agency, 1997; Indiana State Board of Animal Health; Pope, 1991, p. 1124). Whether real or perceived, potential risks to public health from disposing of animal carcasses in landfills will likely be the most influential factor in the operator's decision to accept carcass material, as evidenced by the UK experience during the 2001 FMD outbreak (UK Environment Agency, 2002b; Hickman & Hughes, 2002), and by the Wisconsin experience in disposing of deer and elk carcasses stemming from the chronic wasting disease (CWD) eradication effort (Wisconsin Department of Natural Resources, 2003, p. 127). The US EPA recently outlined recommended interim practices for disposal of carcasses potentially contaminated with CWD agents (US EPA, Office of Solid Waste, 2004).

Because a landfill site is in existence prior to a time of emergency, set-up time would in theory be minimal. However, some time may be required to agree on the terms of use for the site if not arranged in advance (prior to time of emergency). The Riverside County California Waste Management Department developed an excellent training video to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003). The primary by-products resulting from decomposition of wastes, including carcasses, in the landfill are leachate and landfill gas. As per Subtitle D regulations, systems are already in place to collect and treat these outputs and therefore additional systems would not likely be necessary. It is noteworthy that carcass material is likely of greater density and different composition than typical MSW, thus the disposal of significant quantities of carcass material could affect the quantity and composition of leachate and landfill gas generated.

Average fees charged by landfills for MSW in various regions of the US in 1999 ranged from about $21 to $58/ton, with the national average approximately $36/ton (Anonymous, 1999). Fees for disposal of animal carcasses at three different landfills in Colorado were reportedly $10 per animal, $4 per 50 pounds (approximately $160/ton), and $7.80 per yd^3 (Talley, 2001). As of 2003, fees for carcass disposal in Riverside County, California, consisted of a $20 flat fee for quantities less than 1,000 lbs, and $40/ton for quantities greater than 1,000 lbs (Riverside County Waste Management Department). In Souix Falls, South Dakota, disposal fees for deer and elk carcasses at the city landfill were established as $50/ton for deer or elk carcasses originating within the state, and $500/ton for carcasses originating outside the state (Tucker, 2002). During the 2002 outbreak of AI in Virginia, fees at landfills for disposal of poultry carcasses were approximately $45/ton (Brglez, 2003). During the 2002 outbreak of END in southern California, fees were approximately $40/ton for disposing of poultry waste at landfills (Hickman, 2003).

Advantages & disadvantages

During an emergency or instance of catastrophic loss, time is often very limited, and therefore landfills offer the advantage of infrastructures for waste disposal that are pre-existing and immediately available. Furthermore, the quantity of carcass material that can be disposed of via landfills can be relatively large. Landfill sites, especially Subtitle D landfill sites, will have been previously approved, and the necessary environmental protection measures will be pre-existing; therefore, landfills represent a disposal option that would generally pose little risk to the environment. (Note that these advantages related to adequate containment systems may not apply to small arid landfills that rely on natural attenuation to manage waste by-products). Another advantage of landfills is their wide geographic dispersion. The cost to dispose of carcasses by landfill has been referred to as both an advantage and a disadvantage, and would likely depend on the situation.

Even though disposal by landfill may be an allowed option, and a suitable landfill site may be located in close proximity, landfill operators may not be willing to accept animal carcasses. Additionally, because approval and development of a landfill site is lengthy, difficult, and expensive, landfill owners and planning authorities may not want to sacrifice domestic waste capacity to accommodate carcass material. Those landfill sites that do accept animal carcasses may not be open for access when needed or when convenient. Landfilling of carcasses represents a means of containment rather than of elimination, and long-term management of the waste is required. Although several risk assessments conclude that disposal of potentially TSE-infected carcasses in an appropriately engineered landfill site represents very little risk to human or animal health, further research is warranted in this area as the mechanism and time required for degradation are not known. Another possible disadvantage associated with landfill disposal is the potential spread of disease agents during transport of infected material to the landfill (a potential concern for any off-site disposal method).

Mass burial

The scale of the 2001 UK FMD epidemic presented unprecedented challenges in terms of carcass disposal, prompting authorities to seek sites on which mass burials could be undertaken. A total of seven sites were identified as suitable and work began almost immediately to bring them into use (5 of the 7 sites were operational within 8 days of identification). In total, some 1.3 million carcasses (about 20% of the total 6 million) were disposed of in these mass burial sites (National Audit Office, or NAO, 2002, p. 74).

The disposal of carcasses in these mass burial sites was a hugely controversial issue and aroused significant public reaction, including frequent demonstrations and community action to limit their use (NAO, 2002, p. 77). Most of the negative reaction stemmed from the haste with which the sites were identified and developed (Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002, p. 778), and the consequences of this haste (including damaged public relations as well as site management issues due to poor design) will undoubtedly be long-lasting and costly. Although UK authorities have indicated reluctance towards use of this disposal route in the future, the potential advantages of the method, when appropriate planning and site evaluation could be conducted prior to time of emergency, warrant further investigation.

As demonstrated by the UK experience, thorough site assessments prior to initiation of site development are critical for minimizing subsequent engineering and operational difficulties. The total amount of space required for a mass burial site would depend on the volume of carcass material to be disposed and the amount of space needed for operational activities. The total land area occupied by the seven mass burial sites in the UK ranged from 42 to 1,500 acres (NAO, 2002). In general, the resources and inputs required for a mass burial site would be similar in many respects, although likely not as complex, as those required for a landfill. However, whereas the infrastructure at an established landfill would be pre-existing, the resources for a mass burial site likely would not.

The estimated total capacity of the various UK mass burial sites ranged from 200,000 to 1,000,000 sheep carcasses (each approx. 50 kg [about 110 lbs]) (NAO, 2002). In terms of cattle carcasses (each approx. 500 kg [about 1,100 lbs]), these capacities would be reduced by a factor of 10. The sites generated tremendous volumes of leachate requiring management and disposal, the strategies for which in some cases were similar to those employed in MSW landfills, although some sites relied solely on natural attenuation. In many cases, leachate was taken off-site to a treatment facility.

Costs associated with the various UK mass burial sites ranged from £5 to £35 million, and the costs of all sites totaled nearly £114 million (NAO, 2002). Based on the estimated total number of carcasses buried at the sites, the approximate cost for this disposal option was about £90/carcass (ranged from approximately £20 to £337 at the various sites) (NAO, 2002). At the Throckmorton site, 13,572 tonnes of carcasses were disposed (Det Norske Veritas, 2003) at an estimated cost of £1,665/tonne.

Advantages & disadvantages

The most significant advantage of mass burial sites is the capacity to dispose of a tremendous number (volume) of carcasses. Assuming adequate site assessment, planning, and appropriate containment systems are employed, mass burial sites may be similar to landfills in terms of posing little risk to the environment. However, tremendous public opposition to the development and use of such sites during the UK experience caused officials to state that it is very unlikely that mass burial sites would be used as a method of disposal in the future (FMD Inquiry Secretariat, 2002). Other disadvantages included the significant costs involved, problems with site design leading to brief episodes of environmental contamination, and the need for continuous, long-term, costly monitoring and management of the facilities. Other potential disadvantages of mass burial sites would be similar to those outlined for landfills, namely serving as a means of containment rather than of elimination, lack of adequate research into long-term consequences associated with various disease agents (especially TSEs), presenting opportunities for spread of disease during transport from farm sites to the mass burial site, and not generating a usable by-product of any value. In spite of these potential disadvantages, mass burial sites could potentially serve as an effective means of carcass disposal in an emergency situation, although thorough site assessment, planning, and design would be required well in advance of the need.

1.2 – Disease Agent Considerations

In general, very little information is available regarding the length of time disease agents persist in the burial environment, or the potential for dissemination from the burial site. Concerns stem from the fact that burial, unlike some other disposal methods such as incineration or rendering, serves only as a means of ridding carcass material, but does not necessarily eliminate disease agents that may be present. The question arises as to the possibility of those disease agents disseminating from the burial site and posing a risk to either human or animal health. The most relevant hazards to human health resulting from burial identified by the UK Department of Health were bacteria pathogenic to humans, water-borne protozoa, and the bovine spongiform encephalopathy (BSE) agent (UK Department of Health, 2001c). Contaminated water supplies were identified as the main exposure route of concern, and the report generally concluded that an engineered licensed landfill would always be preferable to unlined burial.

Generally, the conditions of deep burial and associated pressures, oxygen levels, and temperatures are thought to limit the survival of the majority of bacterial and viral organisms (Gunn, 2001; Gale, 2002); however, precise survival times are unpredictable, and spore-forming organisms are known to survive in the environment for very long periods of time. Survival would be governed by conditions such as temperature, moisture content, organic content, and pH; transport of microbes within groundwater would be affected by the characteristics of the organism as well as the method of transport through the aquifer (UK Environment Agency, 2002a).

The FMD virus is generally rapidly inactivated in skeletal and heart muscle tissue of carcasses as a result of the drop in pH that accompanies rigor mortis (Gale, 2002, p. 102). However, it may survive at 4°C for approximately two months on wool, for 2-3 months in bovine feces or slurry, and has reportedly survived more than six months when located on the soil surface under snow (Bartley, Donnelly, & Anderson, 2002). Pre-treatment of leachate from the UK Throckmorton mass burial site with lime was discontinued 60 days after burial of the last carcass because FMD virus was reportedly unlikely to survive more than 40 days in a burial cell (Det Norske Veritas, 2003, p. II.21). However, no studies were cited to indicate from what data the 40-day estimate was derived. An evaluation was conducted in 1985 in Denmark to estimate whether burying animals infected with FMD would constitute a risk to groundwater (Lei, 1985). The authors concluded that the probability of groundwater contamination from burial of FMD-infected animals was very small, and that even if virus were able to reach groundwater sources, the concentration would likely be inadequate to present an animal-health risk.

The agents (known as prions) believed to be responsible for TSEs, such as BSE in cattle, scrapie in sheep, CWD in deer and elk, and Creutzfeldt-Jakob disease (CJD) in humans, have been demonstrated to be highly resistant to inactivation processes effective against bacterial and viral disease agents (Taylor, 1996; Taylor, 2000), and the scrapie agent has been demonstrated to retain at least a portion of its infectivity following burial for three years (Brown & Gajdusek, 1991).

Risk assessments conducted in the UK after the BSE epidemic, and after the 2001 FMD outbreak, addressed the issue of survival of the BSE agent in the environment as a result of disposal of infected or potentially infected carcasses (DNV Technica, 1997b; DNV Technica, 1997a; Comer & Spouge, 2001). Ultimately the risk assessments concluded that the risk to human health was very low (could be generally regarded as an acceptable level of risk). The Wisconsin Department of Natural Resources conducted a risk assessment to address the risks posed by disposal of deer and elk carcasses infected with CWD in landfills (Wisconsin Department of Natural Resources, 2002). The risk assessment concluded that the available knowledge about CWD and other TSEs suggested that landfilling CWD infected deer would not pose a significant risk to human health, and the risk of spreading CWD among the state's deer population by landfill disposal of infected carcasses would be small (Wisconsin Department of Natural Resources, 2002). Other sources have also reiterated this finding of very low levels of risk to human health from disposing of TSE-infected animal carcasses in landfill sites (Gunn, 2001; Gale, Young, Stanfield, & Oakes, 1998).

In spite of these risk assessment findings, additional research efforts are needed relative to TSE infectivity in the environment, including the communities of soil microorganisms and animals involved in carcass degradation, effect of anaerobic conditions and soil type on the degradation, persistence, and migration of TSEs in the soil environment, detection systems which can be used to identify infectivity in soil matrices, and a need to validate assumptions on the behavior of TSE agents which have been used in risk assessments (UK

DEFRA, 2002b). In a speech to the US Animal Health Association, Taylor (2001) indicated that "the present evidence suggests that TSE infectivity is capable of long-term survival in the general environment, but does not permit any conclusions to be drawn with regard to the maximum period that it might survive under landfill conditions." In 2003, the European Commission Scientific Steering Committee emphasized that the "extent to which [potential TSE] infectivity reduction can occur as a consequence of burial is poorly characterized" (European Commission Scientific Steering Committee, 2003). Based on this lack of understanding, along with concerns for groundwater contamination and dispersal or transmission by vectors, the committee indicated that burial of animal material which could possibly be contaminated with BSE/TSEs "poses a risk except under highly controlled conditions" (e.g., controlled landfill) (European Commission Scientific Steering Committee, 2003).

1.3 – Implications to the Environment

Animal carcass decomposition

From the point at which an animal (or human) succumbs to death, degradation of bodily tissues commences, the rate of which is strongly influenced by various endogenous and environmental factors (Pounder, 1995). Soft tissue is degraded by the postmortem processes of putrefaction (anaerobic degradation) and decay (aerobic degradation) (Micozzi, 1991, p. 37). Putrefaction results in the gradual dissolution of tissues into gases, liquids, and salts as a result of the actions of bacteria and enzymes (Pounder, 1995). A corpse or carcass is degraded by microorganisms both from within (within the gastrointestinal tract) and from without (from the surrounding atmosphere or soil) (Munro, 2001, p. 7; Micozzi, 1986). Generally body fluids and soft tissues other than fat (i.e., brain, liver, kidney, muscle and muscular organs) degrade first, followed by fats, then skin, cartilage, and hair or feathers, with bones, horns, and hooves degrading most slowly (McDaniel, 1991, p. 873; Munro, 2001, p. 7).

Relative to the quantity of leachate that may be expected, it has been estimated that about 50% of the total available fluid volume would "leak out" in the first week following death, and that nearly all of the immediately available fluid would have drained from the carcass within the first two months (Munro, 2001). For example, for each mature cattle carcass, it was estimated that approximately 80 L (~21 gal) of fluid would be released in the first week postmortem, and about 160 L (~42 gal) would be released in the first two months postmortem. However, the author noted that these estimates were based on the rates of decomposition established for single non-coffined human burials, which may not accurately reflect the conditions in mass burials of livestock (Munro, 2001). Another source estimated the volume of body fluids released within two months postmortem would be approximately 16 m^3 (16,000 L, or ~4,230 gallons) per 1000 adult sheep, and 17 m^3 (17,000 L, or ~4,500 gallons) per 100 adult cows (UK Environment Agency, 2001b, p. 11).

Regarding the gaseous by-products that may be observed from the decomposition of animal carcasses, one report estimated the composition would be approximately 45% carbon dioxide, 35% methane, 10% nitrogen, and the remainder comprised of traces of other gases such as hydrogen sulfide (Munro, 2001). Although this report suggested that the methane proportion would decrease over time, with very little methane being produced after two months, a report of monitoring activities at one of the UK mass burial sites suggests that gas production, including methane, increases over time, rather than decreases (Enviros Aspinwall, 2002b).

The amount of time required for buried animal carcasses (or human corpses) to decompose depends most importantly on temperature, moisture, and burial depth, but also on soil type and drainability, species and size of carcass, humidity/aridity, rainfall, and other factors (McDaniel, 1991; Pounder, 1995; Mann, Bass, & Meadows, 1990). A human corpse left exposed to the elements can become skeletonized in a matter of two to four weeks (Mann, Bass, & Meadows, 1990; Iserson, 2001, p. 384); however, an unembalmed adult human corpse buried six feet deep in ordinary soil without a coffin requires approximately ten to twelve years or more to skeletonize (UK Environment Agency, 2002a;

Pounder, 1995; Munro, 2001; Iserson, 2001). In addition to actual carcass material in a burial site, leachates or other pollutants may also persist for an extended period. Although much of the pollutant load would likely be released during the earlier stages of decomposition (i.e., during the first 1-5 years) (UK Environment Agency, 2001b; McDaniel, 1991; UK Environment Agency, 2002a; Munro, 2001), several reports suggest that mass burial sites could continue to produce both leachate and gas for as long as 20 years (UK Environment Agency, 2001b; Det Norske Veritas, 2003).

Environmental impacts

Various works have estimated the potential environmental impacts and/or public health risks associated with animal carcass burial techniques. Several sources identify the primary environmental risk associated with burial to be the potential contamination of groundwater or surface waters with chemical products of carcass decay (McDaniel, 1991; Ryan, 1999; Crane, 1997). Freedman & Fleming (2003) stated that there "has been very little research done in the area of environmental impacts of livestock mortality burial," and concluded that there is little evidence to demonstrate that the majority of regulations and guidelines governing burial of dead stock have been based on any research findings directly related to the environmental impacts of livestock or human burials. They also conclude that further study of the environmental impacts of livestock burial is warranted.

During the 2001 outbreak of FMD in the UK, various agencies assessed the potential risks to human health associated with various methods of carcass disposal (UK Department of Health, 2001c; UK Environment Agency, 2001b). The identified potential hazards associated with burials included body fluids, chemical and biological leachate components, and hazardous gases. Further summaries of environmental impacts are outlined in investigations into the operation of various mass disposal sites (Det Norske Veritas, 2003; UK Environment Agency, 2001c).

Since precipitation amount and soil permeability are key to the rate at which contaminants are "flushed out" of burial sites, the natural attenuation properties of the surrounding soils are a primary factor determining the potential for these products of decomposition to reach groundwater sources (UK Environment Agency, 2002a). The most useful soil type for maximizing natural attenuation properties was reported to be a clay-sand mix of low porosity and small to fine grain texture (Ucisik & Rushbrook, 1998).

Glanville (1993 & 2000) evaluated the quantity and type of contaminants released from two shallow pits containing approximately 62,000 lbs of turkeys. High levels of ammonia, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chloride in the monitoring well closest to the burial site (within 2 ft) were observed, and average ammonia and BOD concentrations were observed to be very high for 15 months. However, little evidence of contaminant migration was observed more than a few feet from the burial site.

The impact of dead bird disposal pits (old metal feed bins with the bottom removed, placed in the ground to serve as a disposal pit) on groundwater quality was evaluated by Ritter & Chirnside (1995 & 1990). Based on results obtained over a three-year monitoring period, they concluded that three of the six disposal pits evaluated had likely impacted groundwater quality (with nitrogen being more problematic than bacterial contamination) although probably no more so than an individual septic tank and soil absorption bed. However, they cautioned that serious groundwater contamination may occur if a large number of birds are disposed of in this manner.

In the aftermath of the 2001 UK FMD outbreak, the UK Environment Agency (2001b) published an interim assessment of the environmental impact of the outbreak. The most notable actual environmental pressures associated with burial included odor from mass burial sites and landfills, and burial of items such as machinery and building materials during the cleansing and disinfection process on farms. The interim environmental impact assessment concluded that no significant negative impacts to air quality, water quality, soil, or wildlife had occurred, nor was any evidence of harm to public health observed. Monitoring results of groundwater, leachate, and landfill gas at the mass disposal sites indicated no cause for concern (UK Public Health Laboratory Service, 2001c).

Monitoring programs

Following the disposal activities of the 2001 FMD outbreak, the UK Department of Health outlined environmental monitoring regimes focused on the key issues of human health, air quality, water supplies, and the food chain (UK Department of Health, 2001b; UK Public Health Laboratory Service); these programs might serve as models for monitoring programs in the aftermath of an animal disease eradication effort. The UK programs included monitoring of public drinking water supplies, private water supplies, leachate (levels, composition, and migration), and surveillance of human illness (such as gastrointestinal infections). Chemical parameters and indicators were reported to likely be better than microbiological parameters for demonstrating contamination of private water supplies with leachate from an animal burial pit, but testing for both was recommended. It was recommended that at-risk private water supplies should be tested for chloride, ammonium, nitrate, conductivity, coliforms, and *E. coli*. Because baseline data with which to compare would likely not exist, caution in interpretation of results was stressed (i.e., increased levels of an analyte may not necessarily indicate contamination by a disposal site; other sources may be involved) (UK Public Health Laboratory Service).

Chapter 2 – Incineration

Incineration has historically played an important role in carcass disposal. Advances in science and technology, increased awareness of public health, growing concerns about the environment, and evolving economic circumstances have all affected the application of incineration to carcass disposal. Today there are three broad categories of incineration techniques: open-air burning, fixed-facility incineration, and air-curtain incineration.

2.1 – Open-Air Burning

Open-air carcass burning—including the burning of carcasses on combustible heaps known as pyres—dates back to biblical times. It is resource intensive, and both historically and recently it has been necessarily supplemented by or substituted with other disposal methods. Nevertheless, open-air burning has persisted throughout history as a utilized method of carcass disposal. For example, open-air burning was used extensively in the 1967 and 2001 foot and mouth disease (FMD) outbreaks in the United Kingdom (UK) (NAO, 2002; Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002), in smaller-scale outbreaks of anthrax in Canada in 1993 (Gates, Elkin, & Dragon, 1995, p.258), and in southeast Missouri in 2001 (Sifford, 2003).

Open-air burning includes burning carcasses (a) in open fields, (b) on combustible heaps called pyres (Dictionary.com, 2003), and (c) with other burning techniques that are unassisted by incineration equipment. Generally, one must have a state permit to open-air burn (APHIS, 2003, p.2707). Open-air burning is not permitted in every state, but it may be possible to waive state regulations in a declared animal carcass disposal emergency (Ellis, 2001, p.27; Henry, Wills, & Bitney, 2001; Morrow, Ferket, & Middleton, 2000, p.106).

Open-air burning should be conducted as far away as possible from the public. For large pyres involving 1,000 or more bovine carcasses, a minimum distance of 3 kilometers (~2 miles) has been suggested in the UK (Scudamore et al., 2002, p.779). Based on the UK experience, an important site-selection rule is to first communicate with local communities about open-air burning intentions (Widdrington FMD Liaison Committee).

Material requirements for open-air burning include straw or hay, untreated timbers, kindling wood, coal, and diesel fuel (McDonald, 2001, p.6; Smith, Southall, & Taylor, 2002, pp.24-26). Although diesel fuel is typically used in open-air burning, other fuels (e.g., jet fuel and powder metallic fuels) have also been used or studied (Gates et al., 1995, p.258; Sobolev et al., 1999; Sobolev et al., 1997). Tires, rubber, and plastic should not be burned as they generate dark smoke (MAFF, 2001, p.36). To promote clean combustion, it is advisable to dig a shallow pit with shallow trenches to provide a good supply of air for open-air burning. Kindling wood should be dry, have a low moisture content, and not come from green vegetation (MAFF, 2001, pp.36-37). Open-air burning, particularly in windy areas, can pose a fire hazard.

Open-air burning of carcasses yields a relatively benign waste—ash—that does not attract pests (Damron, 2002). However, the volume of ash generated by open-air burning can be significant (NAO, 2002, p.92). Open-air burning poses additional clean-up challenges vis-à-vis groundwater and soil contamination caused by hydrocarbons used as fuel (Crane, 1997, p.3).

2.2 – Fixed-Facility Incineration

Historically, fixed-facility incineration of carcasses has taken a variety of forms—as crematoria, small carcass incinerators at veterinary colleges, large waste incineration plants, on-farm carcass incinerators, and power plants. During the 1970s, rising fuel prices reduced the popularity of fixed-facility incinerators, but technological improvements in efficiency soon followed (Wineland, Carter, & Anderson, 1997). Small animal carcass incinerators have been used to dispose of on-farm mortalities for years in both North America and Europe, and the pet crematoria industry has grown over time (Hofmann & Wilson, 2000). Since the advent of bovine spongiform encephalopathy (BSE) in the UK, fixed-facility incineration has been used to dispose of BSE-infected carcasses as well as rendered meat-and-bone meal (MBM) and tallow from cattle carcasses considered to be at-risk of BSE (Herbert, 2001). During the 2001 FMD outbreak in the Netherlands, diseased animals were first rendered and then the resultant MBM and tallow were taken to incineration plants (de Klerk, 2002). In Japan, cattle testing positive for BSE are disposed of by incineration (Anonymous, 2003d).

Fixed-facility incinerators include (a) small on-farm incinerators, (b) small and large incineration facilities, (c) crematoria, and (d) power plant incinerators. Unlike open-air burning and air-curtain incineration, fixed-facility incineration is wholly contained and, usually, highly controlled. Fixed-facility incinerators are typically fueled by diesel, natural gas, or propane. Newer designs of fixed-facility incinerators are fitted with afterburner chambers designed to completely burn hydrocarbon gases and particulate matter (PM) exiting from the main combustion chamber (Rosenhaft, 1974).

One can operate an incinerator if properly licensed, usually by a state government (APHIS, 2003, p.2707). Properly trained operators are critical (Collings, 2002). Small, fixed-facility incinerators may be operated on farms provided one has a permit, although there are increasing regulatory costs associated with maintaining this permit.

In the United States (US), the idea of incinerating carcasses in large hazardous waste, municipal solid waste, and power plants has been suggested. While the acceptance of MBM and tallow from rendered carcasses could be accommodated in the US, large-scale whole-carcass disposal would be problematic given the batch-feed requirements at most biological waste incineration plants (Anonymous, 2003f; Heller, 2003). Many waste incineration facilities refuse to accept whole animals, noting that carcasses are 70 percent water and preferred waste is 25 percent water (Thacker, 2003). The possibilities of combining incineration with rendering (i.e., incinerating MBM and tallow) are more promising and should be explored (see Chapter 2, Section 7.1).

Many incinerators are fitted with afterburners that further reduce emissions by burning the smoke exiting the primary incineration chamber (Walawender, 2003). Compared to open-air burning, clean-up of ash is less problematic with fixed-facility incineration; ash is typically considered safe and may be disposed of in landfills (Ahlvers, 2003). However, if residual transmissible spongiform encephalopathy (TSE) infectivity is of concern, burial may not be suitable. Although more controlled than open-air burning, fixed-facility incineration also poses a fire hazard.

2.3 – Air-Curtain Incineration

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, thereby creating a turbulent environment in which incineration is greatly accelerated—up to six times faster than open-air burning (W.B. Ford, 1994, p.3). Air-curtain incineration technology—which has traditionally been used for eliminating land-clearing debris, reducing clean wood waste for landfill disposal, and eliminating storm debris—is a relatively new technology for carcass disposal (Brglez, 2003, p.18; Ellis, 2001, p.28). Air-curtain incinerators have been used for carcass disposal in the wake of natural disasters in the US (Ellis, 2001, pp.29-30), and imported air-curtain incinerators were used to a small degree during the UK 2001 FMD outbreak (G. Ford, 2003; NAO, 2002, p.74; Scudamore et al., 2002, p.777). Air-curtain incinerators have been used in Colorado and Montana to dispose of animals infected with chronic wasting disease (CWD) (APHIS, 2003, p.2707) and throughout the US in other livestock disasters (G. Ford, 2003).

In air-curtain incineration, large-capacity fans driven by diesel engines deliver high-velocity air down into either a metal refractory box or burn pit (trench). Air-curtain systems vary in size according to the amount of carcasses to be incinerated (Ellis, 2001, p.29). Air-curtain equipment can be made mobile. Companies that manufacture air-curtain incinerators include Air Burners LLC and McPherson Systems (G. Ford, 2003; McPherson Systems Inc., 2003). Secondary contractors, such as Dragon Trenchburning or Phillips and Jordan, are prepared to conduct actual air-curtain operations (Smith et al., 2002, p.28).

Materials needed for air-curtain incineration include wood (preferably pallets in a wood-to-carcass ratio varying between 1:1 and 2:1), fuel (e.g., diesel fuel) for both the fire and the air-curtain fan, and properly trained personnel (G. Ford, 2003; McPherson Systems Inc., 2003). For an incident involving the air-curtain incineration of 500 adult swine, 30 cords of wood and 200 gallons of diesel fuel were used (Ellis, 2001, p.29). Dry wood for fuel is critical to ensuring a proper air/fuel mixture (Ellis, 2001, p.30).

Air-curtain incinerators have met regulatory approval in the US and around the world (G. Ford, 2003). If placed far from residential centers and the general public, they are generally not nuisances (APHIS, 2002, p.11).

Like open-air burning and fixed-facility incineration, air-curtain incineration poses a fire hazard and the requisite precautions should always be taken. Air-curtain incineration, like other combustion processes, yields ash. From an ash-disposal standpoint, air-curtain incineration in pits is advantageous if the ash may be left and buried in the pits (Smith et al., 2002, p.27). However, in sensitive groundwater areas—or if burning TSE-infected carcasses—ash will most likely be disposed of in licensed landfills.

Unlike fixed-facility incineration, air-curtain incineration is not wholly contained and is at the mercy of many variable factors (e.g., human operation, the weather, local community preferences, etc.). In past disposal incidents involving air-curtain incineration, both ingenuity and trial-and-error have been necessary to deal with problems (Brglez, 2003, pp.34-35).

2.4 – Comparison of Incineration Methods

Capacity

The efficiency and throughput of all three incineration methods—including open-air burning—depend on the type of species burned; the greater the percentage of animal fat, the more efficiently a carcass will burn (Brglez, 2003, p.32). Swine have a higher fat content than other species and will burn more quickly than other species (Ellis, 2001, p.28).

For fixed-facility incinerators, throughput will depend on the chamber's size. For small animal carcass incinerators, throughput may reach only 110 lbs (50 kg) per hour (Anonymous, 2003e). Larger facilities dedicated to the incineration of animal remains may be able to accommodate higher numbers. In Australia, for example, one public incinerator is prepared to accept, during times of emergency, 10 tonnes of poultry carcasses per day (Western Australia Department of Agriculture, 2002, p.7). In the US, fixed-facility capacity is generally recognized to not be of an order capable of handling large numbers of whole animal carcasses; however, incineration plants are quite capable of taking pre-processed, relatively homogenous carcass material (Anonymous, 2003f; Ellis, 2001).

Air-curtain incinerator capacity depends on the manufacturer, design, and on-site management. One manufacturer reports that, using its larger refractory box, six tons of carcasses may be burned per hour (G. Ford, 2003). In a burn pit, using a 35-foot-long air-curtain manifold, up to four tons of carcasses may be burned per hour (W.B. Ford, 1994, pp.2, 11). Other studies have shown that air-curtain incinerators have efficiently burned 37.5 tons of carcasses per day (150 elk, weighing an average of 500 pounds each) (APHIS, 2002, p.11).

Cost

Synthesizing information from a variety of sources (see Chapter 2, Sections 3.1, 3.2, and 3.3), "intervals of approximation" have been used to describe the costs for each incineration technology. These are summarized in Table 1.

Disease agent considerations

Regardless of method used, bacteria, including spore-formers, and viruses should not survive incineration. There has, however, been much speculation that open-air burning can help spread the FMD virus; several studies have examined this question, and while the theoretical possibility cannot be eliminated, there is no such evidence (Champion et al., 2002; J. Gloster et al., 2001).

The disease agents responsible for TSEs (e.g., scrapie, BSE, and CWD) are highly durable (Brown, 1998). This raises important questions about incineration's suitability for disposing of TSE-infected—or potentially TSE-infected—carcasses. The UK Spongiform Encephalopathy Advisory Committee (SEAC) and the European Commission Scientific Steering Committee (SSC) agree that the risk of TSE-infectivity from ash is extremely small if incineration is conducted at 850°C (1562°F) (SEAC, 2003; SSC, 2003a).

TSE experts agree that open-air burning should not be considered a legitimate TSE-related disposal option. Instead, fixed-facility incineration is preferred (SSC, 2003b, p.4; Taylor, 2001). While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs (Grady, 2004), under controlled conditions fixed-facility incineration is also an effective means by which to dispose of TSE-infected material (Powers, 2003).

Because fixed-facility incineration is highly controlled, it may be validated to reach the requisite (850°C or 1562°F) TSE-destruction temperature.

While air-curtain incinerators reportedly achieve higher temperatures than open-air burning, and may reach 1600°F (~871°C) (G. Ford, 2003; McPherson Systems Inc., 2003), these claims need to be further substantiated (Scudamore et al., 2002, p.779). Noting that "with wet wastes, such as CWD-contaminated carcasses, temperatures...can fluctuate and dip below recommended temperatures," an Environmental Protection Agency (EPA) Region 8 draft document hesitates to endorse air-curtain incineration as a robust method for dealing with CWD (Anonymous, 2003c, p.4). In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) has conducted experiments to elucidate the temperatures reached during air-curtain incineration in fireboxes; but despite efforts that included the placement of temperature probes in the carcass mass, researchers could confirm only a range of attained temperatures (600-1000°C, or 1112-1832°F). This information may be a useful guide, but further studies to confirm the temperatures reached are needed (Hickman, 2003).

TABLE 1. "Intervals of approximation" for carcass disposal costs of open-air burning, fixed-facility incineration, and air-curtain incineration (Ahlvers, 2003; Brglez, 2003, p. 86; Cooper, Hart, Kimball, & Scoby, 2003, pp. 30-31; W.B. Ford, 1994; FT.com, 2004; Heller, 2003; Henry et al., 2001; Jordan, 2003; Morrow et al., 2000, p.106; NAO, 2002, p.92; Sander, Warbington, & Myers, 2002; Sparks Companies, 2002, pp. v, 11; Waste Reduction by Waste Reduction Inc.; Western Australia Department of Agriculture, 2002, p.7).

	Open-air burning	Fixed-facility incineration	Air-curtain incineration
Interval approximating the cost (in US$) per ton of carcasses	$196 to $723	$98 to $2000	$143 to $506

Environmental implications

It is generally accepted that open-air burning pollutes (Anonymous, 2003b). The nature of open-air emissions hinges on many factors, including fuel type. Both real and perceived environmental risks of open-air burning were the subjects of studies and complaints during the UK 2001 FMD outbreak. Studies focused on dioxins, furans, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals, nitrogen oxides, sulphur dioxide, carbon monoxide, carbon dioxide, organic gases, and PM—especially PM less than 10 micrometers in diameter that can be drawn into the lungs (McDonald, 2001). The fear of dioxins and smoke inhalation, along with the generally poor public perception of pyres, eventually compelled the discontinuation of the use of mass burn sites in the UK (Scudamore et al., 2002, pp.777-779). However, pollution levels never exceed levels in other (urban) parts of the UK, did not violate air quality regulations, and were deemed to have not unduly affected the public health (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76; Hankin & McRae, 2001, p.5; McDonald, 2001; UK Department of Health, 2001a, 2001b).

In contrast to open-air burning, properly operated fixed-facility and air-curtain incineration pose fewer pollution concerns. During the UK 2001 FMD outbreak, air-curtain incinerators provided by Air Burners LLC offered conspicuous environmental advantages over open-air burning (G. Ford, 2003). Air-curtain technology in general has been shown to cause little pollution, with fireboxes burning cleaner than trench-burners (G. Ford, 2003). When compared to open-burning, air-curtain incineration is superior, with higher combustion efficiencies and less carbon monoxide and PM emissions (G. Ford, 2003). Individuals within the UK government, who have conducted testing on air-curtain fireboxes, are indeed satisfied with this technology's combustion efficiency (Hickman, 2003).

If operated in accordance with best practices and existing environmental regulations, both small and large afterburner-equipped incinerators should not pose serious problems for the environment (Crane, 1997, p.3). However, if not operated properly, small animal carcass incinerators have the potential to pollute. Therefore, it may be environmentally worthwhile to send carcasses to larger, centralized, and better managed incineration facilities (Collings, 2002).

While open-air burning, poorly managed fixed-facility incineration, and poorly managed air-curtain incineration can pose legitimate pollution concerns, they should be considered when other environmental factors (e.g., a high water table, soils of high permeability, etc.) rule out burial (Damron, 2002).

Advantages and disadvantages

Open-air burning can be relatively inexpensive, but it is not suitable for managing TSE-infected carcasses. Significant disadvantages include its labor- and fuel-intensive nature, dependence on favorable weather conditions, environmental problems, and poor public perception (Ellis, 2001, p.76).

Fixed-facility incineration is capable of thoroughly destroying TSE-infected carcasses, and it is highly biosecure. However, fixed-facility incinerators are expensive and difficult to operate and manage from a regulatory perspective. Most on-farm and veterinary-college incinerators are incapable of handling large volumes of carcasses that typify most carcass disposal emergencies. Meanwhile, larger industrial facility incinerators are difficult to access and may not be configured to handle carcasses (Ellis, 2001, p.28).

Air-curtain incineration is mobile, usually environmentally sound, and suitable for combination with debris removal (e.g., in the wake of a hurricane). However, air-curtain incinerators are fuel-intensive and logistically challenging (Ellis, 2001, p.76). Currently, air-curtain incinerators are not validated to safely dispose of TSE-infected carcasses.

2.5 – Lessons Learned

Open-air burning to be avoided

Open-air burning can pose significant public perception, psychological, and economic problems. During the UK 2001 FMD outbreak, carcasses burning on mass pyres "generated negative images in the media" and "had profound effects on the tourist industry" (NAO, 2002, pp.7, 74). In 2001, on-farm pyre burning sent smoke plumes into the air and contributed to an environment of despair for the UK farming community (Battista, Kastner, & Kastner, 2002).

Personnel and professional development

Past emergency carcass disposal events have revealed the need for readily available logistical expertise, leadership, and managerial skills (Anderson, 2002, p.82). Indeed, professional development is important. Simulation exercises are key components of preparing for carcass disposal. US federal, state, and local officials responsible for carcass disposal should seek out opportunities to participate in real-life emergencies that can be anticipated ahead of time (e.g., 2003's Hurricane Isabel). The extra personnel would, of course, offer assistance that is valuable in and of itself; but equally importantly, the extra personnel would learn about carcass disposal in a real-life, pressure-filled context. In addition, and parallel to a recommendation made in the UK (Anderson, 2002, p.82), a bank of volunteers should be available in the event that labor is in short supply to manage mass carcass disposal events, including those involving incineration.

The "digester vs. incinerator" debate

One of the great questions facing US animal disease officials is whether alkaline-hydrolysis digestion or fixed-facility incineration should be preferred for disposal of TSE-infected animals. While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident in recent debates in Larimer County, Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of the heads of CWD-infected deer and elk. While incinerators exist in other parts of the state (e.g., Craig, Colorado), a new incinerator is needed to deal specifically with populations in northeastern Colorado, where there is a high prevalence of CWD among gaming populations.

Despite the need, Larimer County commissioners have heeded local, anti-incinerator sentiments and have, for now, successfully blocked approval of the incinerator. Meanwhile, an alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997b) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003) (see Chapter 2, Section 7.2).

Based on the UK experience, moves to push for controversial disposal methods (e.g., fixed-facility incineration in Colorado) must include communication with local communities and stakeholders, something that was all too often neglected in the UK (Widdrington FMD Liaison Committee). At the same time, clear regulatory affirmation of technologies (e.g., fixed-facility incineration to manage TSEs) may also hedge against public concerns. In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the EPA; following meetings with laboratory diagnosticians, state veterinarians, and wastewater managers (O'Toole, 2003), EPA Region 8 is close to clearly endorsing fixed-facility incineration as a technology for managing CWD-infected carcasses (Anonymous, 2003c, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like these are needed to respond to attitudes, witnessed in Larimer County, that alkaline hydrolysis is the only way to deal with TSE-infected material (Powers, 2003).

Water-logged materials and carcasses

Carcasses are generally composed of 70 percent water; this places them in the worst combustible classification of waste (Brglez, 2003, p.32). This accentuates the need for fuel and dry burning materials. Experience gained in North Carolina in 1999 (following Hurricane Floyd) and Texas (following flooding in 1998) confirms the importance of having dry wood for incineration. Moist debris was used to burn carcasses in air-curtain incinerators, and the resultant poor air/fuel mixture produced noxious smoke and incomplete combustion (Ellis, 2001, p.30).

Chapter 3 – Composting

Chapter 3 provides a summary of various aspects of carcass composting, including processing options, effective parameters, co-composting materials, heat-energy, formulations, sizing, machinery, equipment, cost analysis, and environmental impacts. Guidelines and procedures for windrow and bin composting systems, especially for large numbers of animal mortalities, are discussed. This information was adapted from Murphy and Carr (1991), Diaz et al. (1993), Haug (1993), Adams et al. (1994), Crews et al. (1995), Fulhage (1997), Glanville and Trampel (1997), Mescher et al. (1997), Morris et al. (1997), Carr et al. (1998), Dougherty (1999), Monnin (2000), Henry et al. (2001), Keener et al. (2001), Lasaridi and Stentiford (2001), Morse (2001), Ritz (2001), Bagley (2002), Diaz et al. (2002), Hansen (2002), Harper et al. (2002), Langston et al. (2002), Looper (2002), McGahan (2002), Sander et al. (2002), Sparks Companies Inc. or SCI (2002), Tablante et al. (2002), Colorado Governor's Office of Energy Management and Conservation or CGOEMC (2003), Jiang et al. (2003), Mukhtar et al. (2003), Oregon Department of Environmental Quality or ODEQ (2003), and Rynk (2003).

3.1 – General Guidelines for Composting Carcasses in Windrow or Bin Systems

Definition, preparation, formulation, and general principles

Carcass composting is a natural biological decomposition process that takes place in the presence of oxygen (air). Under optimum conditions, during the first phase of composting the temperature of the compost pile increases, the organic materials of mortalities break down into relatively small compounds, soft tissue decomposes, and bones soften partially. In the second phase, the remaining materials (mainly bones) break down fully and the compost turns to a consistent dark brown to black soil or “humus” with a musty odor containing primarily non-pathogenic bacteria and plant nutrients. In this document the term “composting” is used when referring to composting of carcass material, and the term “organic composting” is used when referring to composting of other biomass such as yard waste, food waste, manure, etc.

Carcass composting systems require a variety of ingredients or co-composting materials, including carbon sources, bulking agents, and biofilter layers.

Carbon sources

Various materials can be used as a carbon source, including materials such as sawdust, straw, corn stover (mature cured stalks of corn with the ears removed and used as feed for livestock), poultry litter, ground corn cobs, baled corn stalks, wheat straw, semi-dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, yard wastes, vermiculite, and a variety of waste materials like matured compost.

A 50:50 (w/w) mixture of separated solids from manure and a carbon source can be used as a base material for carcass composting. Finished compost retains nearly 50% of the original carbon sources. Use of finished compost for recycling heat and bacteria in the compost process minimizes the needed amount of fresh raw materials, and reduces the amount of finished compost to be handled.

A carbon-to-nitrogen (C:N) ratio in the range of 25:1 to 40:1 generates enough energy and produces little odor during the composting process. Depending on the availability of carbon sources, this ratio can sometimes be economically extended to 50:1. As a general rule, the weight ratio of carbon source materials to mortalities is approximately 1:1 for high C:N materials such as sawdust, 2:1 for medium C:N materials such as litter, and 4:1 for low C:N materials such as straw.

Bulking agents

Bulking agents or amendments also provide some nutrients for composting. They usually have bigger particle sizes than carbon sources and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials. They should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contact. Bulking agents typically include materials such as sludge cake, spent horse bedding (a mixture of horse manure and pinewood shavings), wood chips, refused pellets, rotting hay bales, peanut shells, and tree trimmings.

The ratio of bulking agent to carcasses should result in a bulk density of final compost mixture that does not exceed 600 kg/m^3 (37.5 lb/ft^3). As a general rule, the weight of compost mixture in a 19-L (5-gal) bucket should not be more than 11.4 kg (25 lb); otherwise, the compost mixture will be too compact and lack adequate airspace.

Biofilters

A biofilter is a layer of carbon source and/or bulking agent material that 1) enhances microbial activity by maintaining proper conditions of moisture, pH, nutrients, and temperature, 2) deodorizes the gases released at ground level from the compost piles, and 3) prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Site selection

Although specific site selection criteria may vary from state to state, a variety of general site characteristics should be considered. A compost site should be located in a well-drained area that is at least 90 cm (3 ft) above the high water table level, at least 90 m (300 ft) from sensitive water resources (such as streams, ponds, wells, etc.), and that has adequate slope (1-3%) to allow proper drainage and prevent pooling of water. Runoff from the composting facility should be collected and directed away from production facilities and treated through a filter strip or infiltration area. Composting facilities should be located downwind of nearby residences to minimize potential odors or dust being carried to neighboring residences by prevailing winds. The location should have all-weather access to the compost site and to storage for co-composting materials, and should also have minimal interference with other operations and traffic. The site should also allow clearance from underground or overhead utilities.

Preparation and management of compost piles

Staging mortalities

Mortalities should be quickly removed from corrals, pens, or houses and transferred directly to the composting area. In the event of a catastrophic mortality loss or the unavailability of adequate composting amendments, carcasses should be held in an area of temporary storage located in a dry area downwind of other operations and away from property lines (ideally should not be visible from off-site). Storage time should be minimized.

Preparation and monitoring of compost piles

Co-composting materials should be ground to 2.5-5 cm (1-2 inches) and mixed. Compost materials should be lifted and dropped, rather than pushed into place (unless carcasses have been ground and mixed with the co-composting materials prior to the composting process). Compost piles should be covered by a biofilter layer during both phases of composting. If warranted, fencing should be installed to prevent access by livestock and scavenging animals.

The moisture content of the carcass compost pile should be 40-60% (wet basis), and can be tested accurately using analytical equipment or approximated using a hand-squeeze method. In the hand-squeeze method, a handful of compost material is squeezed firmly several times to form a ball. If the ball crumbles or breaks into fragments, the moisture content is much less than 50%. If it remains intact after being gently bounced 3-4 times, the moisture content is nearly 50%. If the ball texture is slimy with a musty soil-like odor, the moisture content is much higher than 50%.

A temperature probe should be inserted carefully and straight down into each quadrant of the pile to allow daily and weekly monitoring of internal temperatures at depths of 25, 50, 75, and 100 cm (10, 20, 30, and 40 in) after stabilization during the first and second phases of composting. During the first phase, the temperature at the core of the pile should rise to at least 55-60°C (130-140°F) within 10 days and remain there for several weeks. A temperature of 65°C (149°F) at the core of the pile maintained for 1-2 days will reduce pathogenic bacterial activity and weed seed germination.

Proper aeration is important in maintaining uniform temperature and moisture contents throughout the pile during the first and second phases of the composting process. Uniform airflow and temperature throughout a composting pile are important to avoid clumping of solids and to minimize the survival of microorganisms such as coliforms, *Salmonella*, and fecal *Streptococcus*. During composting, actinomycetes and fungi produce a variety of antibiotics which destroy some pathogens; however, spore-formers, such as *Bacillus anthracis* (the causative agent of anthrax), and other pathogens, such as *Mycobacterium tuberculosis*, will survive.

After the first phase of composting, the volume and weight of piles may be reduced by 50-75%. After the first phase the entire compost pile should be mixed, displaced, and reconstituted for the secondary phase. In the second phase, if needed, moisture should be added to the materials to reheat the composting materials until an acceptable product is achieved. The end of the second phase is marked by an internal temperature of 25-30°C (77-86°F), a reduction in bulk density of approximately 25%, a finished product color of dark brown to black, and the lack of an unpleasant odor upon turning of the pile.

Odor can be evaluated by placing two handfuls of compost material into a re-sealable plastic bag, closing the bag, and allowing it to remain undisturbed for approximately one hour (5-10 min is adequate if the sealed bag is placed in the sun). If, immediately after opening the bag, the compost has a musty soil odor (dirt cellar odor), the compost has matured. If the compost has a sweetish odor (such as slightly burned cookies), the process is almost complete but requires a couple more weeks for adequate maturation. If the compost odor is similar to rotting meat/flesh, is overpowering, is reminiscent of manure, or has a strong ammonia smell, the compost process is not complete and may require adjustments. After the primary and secondary phases of composting are complete, the finished product can be recycled, temporarily stored, or, if appropriate, added to the land as a soil amendment.

Compost equipment and accessories

Transport vehicles, such as trucks, front-end loaders, backhoes, tractors, or skid loaders outfitted with different bucket sizes (0.88-3.06 m^3 or 1-4 yd^3), can be used for a variety of purposes, including to construct and maintain composting piles for bin or windrow formation, to place mortalities on compost piles, to lift, mix, and place co-composting materials, to move compost from one place to another as needed for aeration, and to feed finished product into compost screeners or shredders.

Grinding or milling equipment used for the composting process includes tub grinders or tub mills, hammer mills, continuous mix pug mills (machines in which materials are mixed, blended, or kneaded into a desired consistency) and vertical grinders. A bale processor can be used to grind baled cornstalks, hay, straw, and grass. Several types of batch mixers (which may be truck- or wagon-mounted), including mixers with augers, rotating paddles, rotating drum mixers, and slats on a continuous chain can be used for mixing operations.

Tanker trucks with side-delivery, flail-type spreaders, honey wagons with pumps, or pump trucks can be used for hauling water to, or spreading water on, the composting piles.

Bucket loaders and rotating-tiller turners (rototillers) are commonly used for turning windrow piles. If a bucket loader is used, it should be operated such that the bucket contents are discharged in a cascading manner rather than dropped as a single mass. For large windrows, self-propelled windrow turners should be used. Turning capacities range from about 727 to 2,727 metric tons/h (800 to 3,000 US tons/h).

Trommel screens with perforations of less than 2.5 cm (1 in) can be used to remove any remaining bones from the finished compost product, and the larger materials remaining on the screen can be recycled back into active windrows.

Instruments and supplies necessary for monitoring and recording physical and chemical properties of a composting system include thermometers (usually four-foot temperature probes), pH meters, bulk density testing devices (a weighing box made of 1.25 mm or 0.5 inch plywood, and volume of 0.028 m^3 or 1 ft^3 with a strap or wire, which can be suspended from a hanging scale), odor testing materials (re-sealable plastic bags), and log books to record compost activities and status along with test results.

Trouble shooting

In the event that liquids leach out of the pile, a well absorbing carbon source material should be spread around the pile to absorb the liquids and increase the base depth. If the pile appears damp or wet and is marked by a strong offensive odor and a brown gooey appearance, it should be transferred onto a fresh layer of bulking agent in a new location.

During the first phase, if the moisture content is low (less than 40%) and the internal pile temperature is high (more than 65°C [149°F]), the compost pile coverage or its cap should be raked back and water should be added at several locations. Conversely, if the internal pile temperature is very low (less than 55°C [130°F]), the compost pile may have been too moist (wet) and/or lacked oxygen, resulting in anaerobic rather than aerobic conditions. Samples should be collected and the moisture content determined by a hand squeeze moisture test.

If the compost temperature does not rise to expected levels within 1-2 weeks of the pile being covered and capped, the initial pile formulation should be evaluated for proper C:N ratio and mixture of co-composting materials and mortalities. Alternatively, cattle, chicken, or horse manure can be added to the compost pile.

In cold climates or winter, compost piles should be protected from the elements prior to loading. Carcasses should be stored in a barn, shed, or other covered space to protect them from freezing temperatures if they cannot be immediately loaded into the pile. Frozen mortalities may not compost until thawed. Bulking agents and other compost ingredients should also be kept dry to prevent freezing into unusable clumps.

Land application

The finished product resulting from composting of mortalities has an organic matter content of approximately 35-70%, a pH of about 5.5 to 8.0, and a bulk density of about 474 to 592 kg/m^3 (29.6- 40 lb/ft^3). Therefore, the material is a good soil amendment. Finished compost may be land spread according to a farm nutrient management plan. State regulations should be consulted prior to land application of finished compost.

Cost analysis

According to Sparks Companies, Inc. (SCI, 2002), the total annual costs of carcass composting are $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses. The cost of machinery (the major fixed cost) represents almost 50% of the total cost per head. Other researchers have estimated carcass composting costs to range from $50-104 per US ton (Kube, 2002). Due to the value of the finished compost product, some estimates suggest the total cost of composting per unit weight of poultry carcasses is similar to that of burial. Reports indicate that only 30% of the total livestock operations in the US are large enough to justify the costs of installing and operating composting facilities. Of those production operations that do compost mortalities, at least 75% are composting poultry mortalities.

3.2 – Specific Procedures for Composting Carcasses in Windrow or Bin Systems

Although windrow and bin composting systems share some common guidelines, differences exist in the operation and management of the two systems. Specific guidelines and procedures for primary and secondary phases of windrow and bin composting are outlined below.

Windrow composting

While the procedure for constructing a windrow pile is similar for carcasses of various animal species, carcass size dictates the layering configuration within the pile. Regardless of mortality size, the length of a windrow can be increased to accommodate more carcasses. Carcasses can be generally categorized as small (e.g., poultry and turkey), medium (e.g., sheep and young swine), large (e.g., mature swine), or very large (e.g., cattle and horses).

Constructing a windrow pile

The most appropriate location for a windrow is the highest point on the identified site. A plastic liner (0.24 in [0.6 cm] thick) of length and width adequate to cover the base dimensions of the windrow (see following dimensions) should be placed on crushed and compacted rock as a moisture barrier, particularly if the water table is high or the site drains poorly. The liner should then be completely covered with a base of co-composting material (such as wood chips, sawdust, dry loose litter, straw, etc). The co-composting material layer should have a thickness of 1 ft for small carcasses, 1.5 ft for medium carcasses, and 2 ft for large and very large carcasses. A layer of highly porous, pack-resistant bulking material (such as litter) should then be placed on top of the co-composing material to absorb moisture from the carcasses and to maintain adequate porosity. The thickness of the bulking material should be 0.5 ft for small carcasses, and 1 ft for all others.

An evenly spaced layer of mortalities should then be placed directly on the bulking material layer. In the case of small and medium carcasses, mortalities can be covered with a layer of co-composting materials (thickness of 1 ft [30 cm]), and a second layer of evenly spaced mortalities can be placed on top of the co-composting material. This layering process can be repeated until the windrow reaches a height of approximately 6 ft (1.8 m). Mortalities should not be stacked on top of one another without an appropriate layer of co-composting materials in between. For large and very large carcasses, only a single layer of mortality should be placed in the windrow. After placing mortalities (or the final layer of mortalities in the case of small and medium carcasses) on the pile, the entire windrow should be covered with a 1-ft (30-cm) thick layer of biofilter material (such as carbon sources and/or bulking agents).

Using this construction procedure, the dimensions of completed windrows will be as follows for the various categories of mortality (note that windrow length would be that which is adequate to accommodate the number of carcasses to be composted):

- Small carcasses: bottom width, 12 ft (3.6 m); top width, 5 ft (1.5 m); and height 6 ft (1.8 m)
- Medium carcasses: bottom width, 13 ft (3.9 m); top width, 1 ft (0.3 m); and height 6 ft (1.8 m)
- Large and very large carcasses: bottom width, 15 ft (4.5 m); top width, 1 ft (0.3 m); and height, 7 ft (2.1 m)

Bin composting

For a bin composting system, the required bin capacity depends on the kind of co-composting materials used. As a general rule, approximately 10 m^3 of bin capacity is required for every 1,000 kg of mortality (160 ft^3 per 1,000 lb of mortality). Because bin composting of large and very large carcasses is sometimes impractical, these carcasses may best be accommodated by a windrow system. This section provides specific guidelines for two-phase, bin composting of both small- and medium-sized mortalities.

Constructing a bin

Bins can be constructed of any material (such as concrete, wood, hay bales, etc.) structurally adequate to confine the compost pile. Simple and economical bin structures can be created using large round bales placed end-to-end to form three-sided enclosures or bins (sometimes called bale composters). A mini-composter can be constructed by fastening panels with metal hooks to form a box open at the top and at the bottom. Structures should be located and situated so as to protect the pile from predators, pests, and runoff. Bins may or may not be covered by a roof. A roof is advantageous, especially in high rainfall areas (more than 1,000 mm or 40 in annual average), as it results in reduced potential for leaching from the pile and better working conditions for the operator during inclement weather.

An impervious concrete floor (5 in [12.5 cm] thick) with a weight-bearing foundation is recommended to accommodate heavy machinery, allow for all-weather use, and prevent contamination of soil and surrounding areas. If an entire bin is constructed of concrete, bin walls of 6-in (15-cm) thickness are recommended. Walls and panels can also be constructed with pressure-treated lumber (e.g., 1-in treated plywood backed with 2 x 6 studs). To improve wet weather operation, access to primary and secondary bins can be paved with concrete or compacted crushed rock.

The wall height for primary and secondary bins should be 5-6 ft (1.5-1.8 m), and the bin width should be adequate for the material-handling equipment, but generally should not exceed 8 ft (2.4 m). The minimum front dimension should be 2 ft (61 cm) greater than the loading bucket width. The front of the bin should be designed such that carcasses need not be lifted over a 5-ft (1.5-m) high door. This can be accomplished with removable drop-boards that slide into a vertical channel at each end of the bin, or with hinged doors that split horizontally.

Bin composting process

Primary phase. A base of litter (or litter-sawdust, litter-shavings mixture) with a thickness of 1.5-2 ft (45-60 cm) should be placed in a fresh bin about two days before adding carcasses to allow for preheating of the litter. Immediately prior to introducing carcasses, the surface of the pre-heated litter (about 6 in [15 cm] in depth) should be raked back and the carcasses should be placed in the hot litter. A minimum of 1 ft (30 cm) of litter should remain in the base of the compost pile for absorbing fluids and preventing leakage. Carcasses should not be placed within about 8-12 in (20-30 cm) of the sides, front, or rear of the compost bin to prevent heat loss. Carcasses should be completely covered and surrounded with the preheated litter.

Carcasses can be placed in the bin in layers, although a 1-ft (30–cm) thick layer of carbon source material is necessary between layers of carcasses to insulate and maintain compost temperature. As a final cover material, carcasses should be completely covered with approximately 2 ft (60 cm) of sawdust, or a minimum of 2.5 lb (1.1 kg) of moist litter per pound of carcass, to avoid exposed parts or odors that attract flies, vermin, or predators to the pile and to minimize fluids leaching out of the pile.

Secondary phase. After moving the pile to the secondary bin, it should be covered with a minimum of 4 in (10 cm) of co-composting materials (such as straw and woodchips) to ensure that exposed carcass pieces are covered. This additional cover helps insulate the pile, reduce odor potential, and ensure decomposition of remaining carcass parts. Moisture should be added to the materials to allow the pile to reheat and achieve an acceptable end product. An adequately composted finished product can be identified by a brown color (similar to humus) and an absence of unpleasant odor upon pile turning. Note that some identifiable carcass parts, such as pieces of skull, leg or pelvic bones, hoofs, or teeth, may remain. However, these should be relatively small and brittle (or rubbery) and will rapidly disappear when exposed to nature.

3.3 – Disease Agent Considerations

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. Although the heat generated during carcass composting results in some microbial destruction, because it is not sufficient to completely sterilize the end product, some potential exists for survival and growth of pathogens. The levels of pathogenic bacteria remaining in the end product depend on the heating processes of the first and second phases, and also on cross contamination or recontamination of the end product.

In order to maximize pathogen destruction, it is important to have uniform airflow and temperature throughout the composting process. Because carcass compost is an inconsistent, non-uniform mixture, pathogen survival may vary within different areas of the compost. Temperature uniformity is facilitated by proper aeration, and reduces the probability of microbes escaping the high-temperature zone. In spite of non-uniform temperatures, pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days. That is, a high core temperature provides more confidence for the carcass composting pasteurization process. Achieving an average temperature of 55 to 60°C (131 to 140°F) for a day or two is generally sufficient to reduce pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to an acceptably low level. However, the endospores produced by spore-forming bacteria would not be inactivated under these conditions.

3.4 – Conclusions

Composting can potentially serve as an acceptable disposal method for management of catastrophic mortality losses. Furthermore, the principles for composting catastrophic mortality losses are the same as for normal daily mortalities. Successful conversion of whole materials into dark, humic-rich, good-quality compost that has a soil- or dirt cellar-like odor requires daily and weekly control of odor, temperature, and moisture during the first and second phases of composting. This stringent management and control will prevent the need for major corrective actions.

Bin composting may not be economically suitable or logistically feasible for large volumes of small and medium carcasses. In such instances, windrow composting may be preferable in terms of ease of operation.

Chapter 4 – Rendering

Chapter 4 provides a discussion of various aspects of carcass rendering, including effective parameters, raw materials, heat-energy, specifications, machinery, necessary equipment, cost analysis, and environmental impacts. This information has been adopted from Pelz (1980), Thiemann and Willinger (1980), Bisping et al. (1981), Hansen and Olgaard (1984), Clottey (1985), Machin et al. (1986), Kumar (1989), Ristic et al. (1993), Kaarstad (1995), Expert Group on Animal Feeding Stuffs (1996), Prokop (1996), Haas et al. (1998), Turnbull (1998), United Kingdom Department for Environment, Food and Rural Affairs or UKDEFRA (2000), Mona Environmental Ltd. (2000), Ockerman and Hansen (2000), Texas Department of Health or TDH (2000), Food and Drug Administration or FDA (2001), Romans et al. (2001), Alberta Agriculture, Food and Rural Development or AAFRD (2002), Arnold (2002), Atlas-Stord (2003), Dormont (2002), Environment Protection Authority of Australia or EPAA (2002), UKDEFRA (2002), US Environmental Protection Agency or USEPA (2002), Giles (2002), Ravindran et al. (2002), Sander et al. (2002), Sparks Companies, Inc., or SCI (2002), Hamilton (2003), Kaye (2003), Pocket Information Manual (2003), Morley (2003), Pearl (2003), Provo City Corporation (2003), Scan American Corporation (2003), and The Dupps Company (2003).

4.1 – Definition and Principles

Rendering of animal mortalities involves conversion of carcasses into three end products—namely, carcass meal (proteinaceous solids), melted fat or tallow, and water—using mechanical processes (e.g., grinding, mixing, pressing, decanting and separating), thermal processes (e.g., cooking, evaporating, and drying), and sometimes chemical processes (e.g., solvent extraction). The main carcass rendering processes include size reduction followed by cooking and separation of fat, water, and protein materials using techniques such as screening, pressing, sequential centrifugation, solvent extraction, and drying. Resulting carcass meal can sometimes be used as an animal feed ingredient. If prohibited for animal feed use, or if produced from keratin materials of carcasses such as hooves and horns, the product will be classified as inedible and can be used as a fertilizer. Tallow can be used in livestock feed, production of fatty acids, or can be manufactured into soaps.

4.2 – Livestock Mortality and Biosecurity

Livestock mortality is a tremendous source of organic matter. A typical fresh carcass contains approximately 32% dry matter, of which 52% is protein, 41% is fat, and 6% is ash. Rendering offers several benefits to food animal and poultry production operations, including providing a source of protein for use in animal feed, and providing a hygienic means of disposing of fallen and condemned animals. The end products of rendering have economic value and can be stored for long periods of time. Using proper processing conditions, final products will be free of pathogenic bacteria and unpleasant odors.

In an outbreak of disease such as foot and mouth disease, transport and travel restrictions may make it impossible for rendering plants to obtain material from traditional sources within a quarantine area. Additionally, animals killed as a result of a natural disaster, such as a hurricane, might not be accessible before they decompose to the point that they can not be transported to a rendering facility and have to be disposed of on-site.

To overcome the impacts of catastrophic animal losses on public safety and the environment, some independent rendering plants should be sustainable and designated for rendering only species of animals which have the potential to produce end products contaminated with resistant prions believed to be responsible for transmissible spongiform encephalopathy (TSE) diseases, such as bovine spongiform encephalopathy (BSE; also known as mad cow disease), and the products from these facilities should be used only for amending agricultural soils (meat and bone meal or MBM) or as burning fuels (tallow).

4.3 – Capacity, Design, and Construction

While independent rendering plants in the United States (US) have an annual input capacity of about 20 billion pounds (10 million tons), the total weight of dead livestock in 2002 was less than 50% of this number (about 4.3 million tons). In order to justify costs and be economically feasible, a rendering plant must process at least 50-65 metric tons/day (60-70 tons/day), assuming 20 working hours per day. In the event of large-scale mortalities, rendering facilities may not be able to process all the animal mortalities, especially if disposal must be completed within 1-2 days. Providing facilities for temporary cold storage of carcasses, and increasing the capacities of small rendering plants are alternatives that should be studied in advance.

Rendering facilities should be constructed according to the minimum requirements of Health and Safety Code, §§144.051-144.055 of the Texas Department of Health (TDH) (2000). More clearly, construction must be appropriate for sanitary operations and environmental conditions; prevent the spread of disease-producing organisms, infectious or noxious materials and development of a malodorous condition or a nuisance; and provide sufficient space for placement of equipment, storage of carcasses, auxiliary materials, and finished products.

Plant structures and equipment should be designed and built in a manner that allows adequate cleaning, sanitation, and maintenance. Adulteration of raw materials should be prevented by proper equipment design, use of appropriate construction materials, and efficient processing operations. Appropriate odor control systems, including condensers, odor scrubbers, afterburners, and biofilters, should be employed.

4.4 – Handling and Storage

Animal mortalities should be collected and transferred in a hygienically safe manner according to the rules and regulations of TDH (2000). Because raw materials in an advanced stage of decay result in poor-quality end products, carcasses should be processed as soon as possible; if storage prior to rendering is necessary, carcasses should be refrigerated or otherwise preserved to retard decay. The cooking step of the rendering process kills most bacteria, but does not eliminate endotoxins produced by some bacteria during the decay of carcass tissue. These toxins can cause disease, and pet food manufacturers do not test their products for endotoxins.

4.5 – Processing and Management

The American rendering industry uses mainly continuous rendering processes, and continually attempts to improve the quality of final rendering products and to develop new markets. Further, the first reduced-temperature system, and later more advanced continuous systems, were designed and used in the US before their introduction into Europe. The maximum temperatures used in these processes varied between 124 and 154°C (255 to 309°F). The industry put forth considerable effort to preserve the nutritional quality of finished products by reducing the cooking temperatures used in rendering processes.

Batch cookers are not recommended for carcass rendering as they release odor and produce fat particles which tend to become airborne and are deposited on equipment and building surfaces within the plant. The contents and biological activities of lysine, methionine, and cystine (nutritional values) of meat meals produced by the conventional batch dry rendering method are lower than that of meat meals obtained by the semi-continuous wet rendering method because of protein degradation.

In dry high temperature rendering (HTR) processes, cookers operate at 120°C (250°F) and 2.8 bar for 45 min, or at 135°C (275°F) and 2 bar for 30 min, until the moisture content falls below 10%. While there is no free water in this method, the resulting meal is deep-fried in hot fat.

Low temperature rendering (LTR) operates in the temperature range of 70-100°C (158-212°F) with and without direct heating. While this process produces higher chemical oxygen demand (COD) loadings in wastewater, it has lower air pollutants (gases and odors), ash content in final meal, and an easier phase separation than HTR. The fat contents of meals from LTR processes are about 3-8%, and those from HTR processes are about 10-16%.

If LTR is selected to have less odors and obtain the final products with better color quality, nearly all tallow and more than 60% of the water from the minced raw materials should be recovered from a process at 95°C (203°F) for 3-7 minutes and by means of a pressing or centrifuging processes at (50-60°C or 122-140°F) just above the melting point of the animal fat. The resultant solids should be sterilized and dried at temperatures ranging from 120 to 130°C (248 to 266°F).

LTR systems that incorporate both wet and dry rendering systems appear to be the method of choice. This process prevents amino acid destruction, maintains biological activities of lysine, methionine, and cystine in the protein component of the final meal, produces good-quality MBM (high content of amino acids, high digestibility, low amount of ash and 3-8% fat), and generates tallow with good color.

Contamination of finished products is undesirable. Salmonellae can be frequently isolated from samples of carcass-meal taken from rendering plants; Bisping et al. (1981) found salmonellae in 21.3% of carcass-meal samples. Despite the fact that salmonellae from rendered animal protein meals may not cause diseases in livestock/poultry and humans, it will provide much more confidence for the users if they are completely free of any salmonellae.

Carcass meal and MBM are the same as long as phosphorus content exceeds 4.4% and protein content is below 55%. MBM is an excellent source of calcium (7-10%), phosphorus (4.5-6%), and other minerals (K, Mg, Na, etc., ranges from 28-36%). As are other animal products, MBM is a good source of vitamin B-12 and has a good amino acid profile with high digestibility (81-87%).

4.6 – Cleaning and Sanitation

Discrete "clean" and "dirty" areas of a rendering plant are maintained and strictly separated. "Dirty" areas must be suitably prepared for disinfection of all equipment including transport vehicles, as well as collection and disposal of wastewater. Processing equipment is sanitized with live steam or suitable chemicals (such as perchloroethylene) that produce hygienically unobjectionable animal meal and fat. The sanitary condition of carcasses and resulting products is facilitated by an enclosed flow from receiving through packaging.

Effective disinfection processes are verified by the presence of only small numbers of gram-positive bacteria (like aerobic bacilli) within the facility, and by the absence of *Clostridium perfringens* spores in waste effluent.

Condenser units, which use cold water to liquefy all condensable materials (mainly steam and water-soluble odorous chemical compounds), are used to reduce the strongest odors which arise from cooking and, to some extent, drying processes. The cooling water removes up to 90% of odors, and recovers heat energy from the cooking steam thus reducing the temperature of the non-condensable substances to around 35-40°C (95-104°F). Scrubber units for chemical absorption of non-condensable odorous gases (using hypochlorite, multi-stage acid and alkali units) and chlorination may be employed. Remaining odorous gases can be transferred to a biofilter bed constructed of materials such as concrete, blockwork, and earth, and layered with products such as compost, rice hulls, coarse gravel, sand, pinebark, and woodchips. Microorganisms in the bed break down organic and inorganic odors through aerobic microbial activity under damp conditions. Modern biofilter units (such as Monafil) provide odor removal efficiency of more than 95% for hydrogen sulfide (H_2S) and 100% for ammonium hydroxide (NH_4OH). Odor control equipment may incorporate monitoring devices and recorders to control key parameters.

All runoff from the rendering facility should be collected, directed away from production facilities, and finally directed to sanitary sewer systems or wastewater treatment plants.

4.7 – Energy Savings

Semi-continuous processes, incorporating both wet and dry rendering, use 40% less steam compared with dry rendering alone. Energy consumption in rendering plants can be reduced by concentrating the waste stream and recovering the soluble and insoluble materials as valuable products. Clean fuels, free of heavy metals and toxic wastes, should be used for all boilers, steam raising plants, and afterburners.

Energy for separation of nearly all fat and more than 60% of the water from carcasses can be conserved by means of a pressing process at low temperature (50-60°C or 122-140°F, just above the melting point of animal fat). This process reduces energy consumption from 75 kg oil/metric ton of raw material in the traditional rendering process, to an expected figure of approximately 35 kg oil/metric ton raw material, saving 60-70% of the energy without changing generating and heating equipment (e.g., boiler and cooker equipment).

The animal fat (tallow) produced by mortality rendering can be used as an alternative burner fuel. A mixture of chicken fat and beef tallow was blended with No. 2 fuel oil in a ratio of 33% chicken fat/beef tallow and 77% No. 2 fuel oil. The energy content of unblended animal biofuels was very consistent among the sources and averaged about 39,600 KJ/kg (16,900 Btu/lb). Blended fuels averaged nearly 43,250 KJ/kg (18,450 Btu/lb), and all were within 95% of the heating value of No. 2 fuel oil alone.

4.8 – Cost and Marketing

Over the last decade, the number of "independent" rendering plants has decreased, with an increasing trend towards "integrated" or "dependent" rendering plants (i.e., those that operate in conjunction with meat or poultry processing facilities). Out of 250 rendering plants operating in the US, only 150 are independent. While in 1995, production of MBM was roughly evenly split between integrated (livestock packer/renderers) and independent renderers, recent expert reports show that in the present situation, integrated operations produce at least 60% of all MBM, with independents accounting for the remaining 40% or less.

Current renderers' fees are estimated at $8.25 per head (average for both cattle and calves) if the final MBM product is used as an animal feed ingredient. If the use of MBM as a feed ingredient is prohibited (due to concerns regarding possible BSE contamination), it could increase renderers' collection fees to an average of over $24 per bovine.

According to the Sparks Companies, Inc. (SCI) (2002), independent renderers produced more than 433 million pounds of MBM from livestock mortalities, or approximately 6.5% of the 6.65 billion pounds of total MBM produced annually in the US (this total amount is in addition to the quantities of fats, tallow, and grease used in various feed and industrial sectors). The raw materials for these products comprised about 50% of all livestock mortalities.

Carcass meals are sold as open commodities in the market and can generate a competition with other sources of animal feed, thereby helping to stabilize animal feed prices. The percentage of feed mills using MBM declined from 75% in 1999 to 40% in 2002, and the market price for MBM dropped from about $300/metric ton in 1997 to almost $180/metric ton in 2003. The total quantity of MBM exported by the US increased from 400,000 metric tons in 1999 to about 600,000 metric tons in 2002 (Hamilton, 2003).

The quality of the final MBM produced from carcasses has a considerable effect on its international marketability. Besides BSE, *Salmonella* contamination may result in banned products. While export of MBM from some other countries to Japan has been significantly reduced in recent years because of potential for these contaminants, some countries like New Zealand made considerable progress in this trade. According to Arnold (2002), New Zealand MBM exports to Japan have attracted a premium payment over Australian product of between $15-$30/ton. Japanese buyers and end-users have come to accept MBM from New Zealand as being extremely low in *Salmonella* contamination and have accordingly paid a premium for this type of product. According to Arnold (2002), New Zealand exported 34,284 tons of MBM to Japan during 2000, representing 18.5% of the market share. During the first nine months of 2001, New Zealand exports to Japan had increased to 32.6% of the market share. In contrast, US MBM products represented 1.8% of the market share in 2000, and 3.2% of the market share during the first nine months of 2001.

4.9 – Disease Agent Considerations

The proper operation of rendering processes leads to production of safe and valuable end products. The heat treatment of rendering processes significantly increases the storage time of finished products by killing microorganisms present in the raw material, and removing moisture needed for microbial activity. Rendering outputs, such as carcass meal, should be free of pathogenic bacteria as the processing conditions are adequate to eliminate most bacterial pathogens. However, recontamination following processing can occur.

The emergence of BSE has been largely attributed to cattle being fed formulations that contained prion-infected MBM. As Dormont (2002) explained, TSE agents (also called prions) are generally regarded as being responsible for various fatal neurodegenerative diseases, including Creutzfeldt-Jakob disease in humans and BSE in cattle. According to UKDEFRA (2000), epidemiological work carried out in 1988 revealed that compounds of animal feeds containing infective MBM were the primary mechanism by which BSE was spread throughout the UK. Thus the rendering industry played a central role in the BSE story. Experts subsequently concluded that changes to rendering processes in the early 1980s might have led to the emergence of the disease.

Various policy decisions have been implemented to attempt to control the spread of BSE in the cattle population. Many countries have established rules and regulation for imported MBM. The recently identified cases of BSE in Japan have resulted in a temporary ban being imposed on the use of all MBM as an animal protein source (Arnold, 2002). FDA (2001) implemented a final rule that prohibits the use of most mammalian protein in feeds for ruminant animals. These limitations dramatically changed the logistical as well as the economical preconditions of the rendering industry.

According to UKDEFRA (2000), in 1994 the Spongiform Encephalopathy Advisory Committee stated that the minimum conditions necessary to inactivate the most heat-resistant forms of the scrapie agent were to autoclave at 136-138°C (277-280°F) at a pressure of ~2 bar (29.4 lb/in^2) for 18 minutes. The Committee noted that the BSE agent responded like scrapie in this respect. Ristic et al. (2001) reported that mad cow disease was due to prions which are more resistant than bacteria, and that the BSE epidemic may have been sparked by use of MBM produced from dead sheep, and processing of inedible by-products of slaughtered sheep by inadequate technological processes.

Chapter 5 – Lactic Acid Fermentation

Chapter 5 addresses lactic acid fermentation, a process that provides a way to store carcasses for at least 25 weeks and produce an end product that may be both pathogen-free and nutrient-rich. Lactic acid fermentation should be viewed as a means to preserve carcasses until they can be rendered. The low pH prevents undesirable degradation processes.

The process of lactic acid fermentation is simple and requires little equipment. Indeed, the process needs only a tank and a grinder. Fermentation is an anaerobic process that can proceed in any sized non-corrosive container provided it is sealed and vented for carbon dioxide release. During this process, carcasses can be decontaminated and there is a possibility of recycling the final products into feedstuff. Fermentation products can be stored until they are transported to a disposal site.

Carcasses are ground to fine particles, mixed with a fermentable carbohydrate source and culture innoculant, and then added to a fermentation container. Grinding aids in homogenizing the ingredients. For lactic acid fermentation, lactose, glucose, sucrose, whey, whey permeates, and molasses are all suitable carbohydrate sources. The carbohydrate source is fermented to lactic acid by *Lactobacillus acidophilus*.

Under optimal conditions, including a fermentation temperature of about 35°C (95°F), the pH of fresh carcasses is reduced to less than 4.5 within 2 days. Fermentation with *L. acidophilus* destroys many bacteria including *Salmonella* spp. There may be some microorganisms that can survive lactic acid fermentation, but these can be destroyed by heat treatment through rendering.

Biogenic amines produced during putrefaction are present in broiler carcasses. Tamim and Doerr (2000) argue that the presence of a single amine (tyramine) at a concentration above 550 ppm indicates a real risk of toxicity to animals being fed. This concentration is higher in the final product after rendering because the rendered product has less moisture than the fermentation broth. Thus, efforts should be made to reduce putrefaction. Properly prepared products will remain biologically stable until they are accepted for other processes such as rendering.

Taking into account the value of fermentation by-products, Crews et al. (1995) estimate the cost of fermention of poultry carcasses to be $68-171 per ton. Other calculations that exclude the value of fermentation by-products suggest the costs of fermentation of cattle carcasses to be about $650 per ton. The challenges with lactic acid fermentation are complete pathogen containment, fermentation tank contamination, and corrosion problems.

An intriguing idea is to plan for fermentation during the actual transportation of carcasses to the rendering sites; in such a scenario, railroad tank cars could be used for fermentation. This might prove useful, even in the case of an emergency carcass disposal situation. Fermentation could likely be carried out easily in these tank cars, perhaps in less time and with lower costs than other techniques requiring the actual construction of a fermentation tank. Of course, research is needed to ascertain the commercial feasibility of this idea.

Chapter 6 – Alkaline Hydrolysis

Alkaline hydrolysis, addressed in Chapter 6, represents a relatively new carcass disposal technology. It has been adapted for biological tissue disposal (e.g., in medical research institutions) as well as carcass disposal (e.g., in small and large managed culls of diseased animals). One company—Waste Reduction by Waste Reduction, Inc. (WR^2)—reports that it currently has 30 to 40 alkaline hydrolysis digestion units in operation in the United States (US), several of which are used to dispose of deer carcasses infected with chronic wasting disease (CWD) (Grady, 2004).

6.1 – Process Overview

Alkaline hydrolysis uses sodium hydroxide or potassium hydroxide to catalyze the hydrolysis of biological material (protein, nucleic acids, carbohydrates, lipids, etc.) into a sterile aqueous solution consisting of small peptides, amino acids, sugars, and soaps. Heat is also applied (150°C, or ~300°F) to significantly accelerate the process. The only solid byproducts of alkaline hydrolysis are the mineral constituents of the bones and teeth of vertebrates (WR^2, 2003). This undigested residue, which typically constitutes approximately two percent of the original weight and volume of carcass material, is sterile and easily crushed into a powder that may be used as a soil additive (WR^2, 2003).

Proteins—the major solid constituent of all animal cells and tissues—are degraded into salts of free amino acids. Some amino acids (e.g., arginine, asparagine, glutamine, and serine) are completely destroyed while others are racemized (i.e., structurally modified from a left-handed configuration to a mixture of left-handed and right-handed molecules). The temperature conditions and alkali concentrations of this process destroy the protein coats of viruses and the peptide bonds of prions (Taylor, 2001a). During alkaline hydrolysis, both lipids and nucleic acids are degraded.

Carbohydrates represent the cell and tissue constituents most slowly affected by alkaline hydrolysis. Both glycogen (in animals) and starch (in plants) are immediately solubilized; however, the actual breakdown of these polymers requires much longer treatment than is required for other polymers. Once broken down, the constituent monosaccharides (e.g., glucose, galactose, and mannose) are rapidly destroyed by the hot aqueous alkaline solution (WR^2, 2003). Significantly, large carbohydrate molecules such as cellulose are resistant to alkaline hydrolysis digestion. Items such as paper, string, undigested plant fibers, and wood shavings, although sterilized by the process, are not digestible by alkaline hydrolysis.

Alkaline hydrolysis is carried out in a tissue digester that consists of an insulated, steam-jacketed, stainless-steel pressure vessel with a lid that is manually or automatically clamped. The vessel contains a retainer basket for bone remnants and other materials (e.g., indigestible cellulose-based materials, latex, metal, etc.). The vessel is operated at up to 70 psig to achieve a processing temperature of 150°C (~300°F). According to WR^2, one individual can load and operate an alkaline hydrolysis unit. In addition to loading and operation, personnel resources must also be devoted to testing and monitoring of effluent (e.g., for temperature and pH) prior to release into the sanitary sewer system (Powers, 2003). Once loaded with carcasses, the system is activated by the push of a button and is thereafter computer-controlled. The weight of tissue in the vessel is determined by built-in load cells, a proportional amount of alkali and water is automatically added, and the vessel is sealed pressure-tight by way of an automatic valve. The contents are heated and continuously circulated by a fluid circulating system (WR^2, 2003).

The process releases no emissions into the atmosphere and results in only minor odor production. The end product is a sterile, coffee-colored, alkaline solution with a soap-like odor that can be released into a sanitary sewer in accordance with local and federal guidelines regarding pH and temperature (Kaye, 2003). This can require careful monitoring of temperature (to ensure release of the effluent at or above 190°C [374°F], a temperature below which the effluent solidifies), pH, and biochemical oxygen demand (BOD) (Powers, 2003). The pH of undiluted hydrolyzate is normally between 10.3 and 11.5. For those sewer districts that have upper limits of pH 9 or 10, bubbling carbon dioxide into the hydrolyzate at the end of the digestion lowers the pH to the range of pH 8 or less (Kaye, 2003). As an example of the quantity of effluent generated by the process, WR^2 (2003) estimates that a unit of 4,000 lb capacity would generate approximately 1,250 gal (2,500 L) of undiluted hydrolyzate, and approximately 2,500 gal (9,466 L) of total effluent (including hydrolyzate, cooling water, rinse water, and coflush water).

The average BOD of undiluted hydrolyzate is approximately 70,000 mg/L. However, WR^2 indicates that in many instances the digester is located in a facility that releases in excess of 1,900,000 L (500,000 gal) per day, and, therefore, the added BOD is a fraction of the material being presented to the sewer district daily (Kaye, 2003). WR^2 also suggests that although the BOD is high, the carbon-containing molecules in the hydrolyzate have been broken down to single amino acids, small peptides, and fatty acids, all of which are nutrients for the microorganisms of sanitary treatment plants (Kaye, 2003). These aspects notwithstanding, disposal of effluent from alkaline hydrolysis units is a significant issue and must be so treated when considering this technology. In fact, some operators are contemplating alternative means of handling effluent, including solidification of effluent prior to disposal.

The total process time required for alkaline hydrolysis digestion of carcass material is three to eight hours, largely depending on the disease agent(s) of concern. For conventional (e.g., bacterial and viral) contaminated waste, four hours is sufficient. However, for material infected (or potentially infected) with a transmissible spongiform encephalopathy (TSE) agent, six hours is recommended (European Commission Scientific Steering Committee, 2002; European Commission Scientific Steering Committee, 2003). WR^2 notes that mobile-trailer units consisting of a digester vessel, boiler, and containment tank have a capacity of digesting 4,000 pounds of carcasses every 8 hours, or approximately 12,000 pounds (5,443 kg) in a 24-hour day. Others, however, note that loading and unloading of the digester can take time—as much as one hour in between processing cycles. Furthermore, temperature and pH monitoring of effluent takes time (Powers, 2003).

WR^2 estimates the cost of disposal of animal carcasses via alkaline hydrolysis at \$0.02 to \$0.03 per pound (\$40 to \$60/ton) of material (excluding capital and labor costs) (Wilson, 2003). Others have estimated the cost to be \$0.16 per pound (\$320/ton) including labor and sanitary sewer costs (Powers, 2003). WR^2's mobile trailer unit capable of digesting 4,000 pounds of carcasses every 8 hours has a capital cost of approximately \$1.2 million (Wilson, 2003).

6.2 – Disease Agent Considerations

The alkaline hydrolysis process destroys all pathogens listed as index organisms by the State and Territorial Association on Alternative Treatment Technologies (STAATT I and STAATT II), which require a 6-log (99.9999%) reduction in vegetative agents and a 4-log (99.99%) reduction in spore-forming agents. Significantly, the alkaline hydrolysis process has been approved for the treatment of infectious waste in all states in which specific application for such approval has been made (Taylor, 2000; Taylor, 2001b).

The efficacy of alkaline hydrolysis was evaluated against pure cultures of selected infectious microorganisms during processing of animal carcasses in a digester at the Albany Medical

College. The organisms tested included *Staphylococcus aureus, Mycobacterium fortuitum, Candida albicans, Bacillus subtilis, Pseudomonas aeruginosa, Aspergillus fumigatus, Mycobacterium bovis* BCG, MS-2 bacteriophage, and *Giardia muris.* Animal carcasses included pigs, sheep, rabbits, dogs, rats, mice, and guinea pigs. The tissue digester was operated at 110-120°C (230-248°F) and approximately 15 psig for 18 hours before the system was allowed to cool to 50°C (122°F), at which point samples were retrieved and submitted for microbial culture. The process completely destroyed all representative classes of potentially infectious agents as well as disposing of animal carcasses by solubilization and digestion (Kaye et al., 1998).

A study conducted at the Institute of Animal Health at the University of Edinburgh examined the capacity of alkaline hydrolysis to destroy bovine spongiform encephalopathy (BSE) prions grown in the brains of mice. Two mice heads were digested for three hours and one head for six hours. Samples of the hydrolyzate from each digestion were neutralized, diluted, and injected intracerebrally into naïve mice known to be susceptible to the effects of BSE. After two years, mice were sacrificed and their brains examined for signs of TSE. Evidence of TSE was found in the brains of some mice injected with hydrolyzate taken from three-hour-long digestions. Significantly, no evidence of TSE was found in the brains of mice injected with hydrolyzate from the six-hour-long digestion. The persistence of infectivity in the three-hour samples may have been due to the fact that material was introduced into the digestion vessel in a frozen state and was contained inside a polyethylene bag (i.e., the actual exposure of the prion-containing samples to the alkaline hydrolysis process may have been much less than 3 hours) (Taylor, 2001a). Based on these experiments, the European Commission Scientific Steering Committee has approved alkaline hydrolysis for TSE-infected material with the recommendation that TSE-infected material be digested for six hours (European Commission Scientific Steering Committee, 2002; European Commission Scientific Steering Committee, 2003). As a safety measure, one US-based facility disposing of CWD-infected carcasses uses an eight-hour-long digestion process to ensure destruction of any prion-contaminated material (Powers, 2003).

6.3 – Advantages & Disadvantages

Advantages of alkaline hydrolysis digestion of animal carcasses include the following:

- Combination of sterilization and digestion into one operation,
- Reduction of waste volume and weight by as much as 97 percent,
- Complete destruction of pathogens, including prions,
- Production of limited odor or public nuisances, and
- Elimination of radioactively contaminated tissues.

Disadvantages of alkaline hydrolysis process of animal carcass disposal include the following:

- At present, limited capacity for destruction of large volumes of carcasses in the US and
- Potential issues regarding disposal of effluent.

Chapter 7 – Anaerobic Digestion

The management of dead animals has always been and continues to be a concern in animal production operations, slaughter plants, and other facilities that involve animals. In addition, episodes of exotic Newcastle disease (END) in the United States (US), bovine spongiform encephalopathy (BSE, or mad cow disease) in Europe and elsewhere, chronic wasting disease (CWD) in deer and elk in North America, and foot and mouth disease (FMD) in the United Kingdom (UK) have raised questions about how to provide proper, biosecure disposal of diseased animals. Carcass disposal is of concern in other situations—

from major disease outbreaks among wildlife to road-kill and injured-animal events.

Proper disposal systems are especially important due to the potential for disease transfer to humans and other animals, and due to the risk of soil, air, and groundwater pollution. Anaerobic digestion represents one method for the disposal of carcasses. It can eliminate carcasses and, at the same time, produce energy; but in some cases it is necessary to conduct size-reduction and sterilization of carcasses on-site before applying anaerobic digestion technology. These preliminary measures prevent the risk of spreading the pathogen during transportation and reduce the number of digesters needed. Sometimes, if the quantity of carcasses is large, it may be necessary to distribute carcasses between several digesters and to transport them to different locations.

Chapter 7 addresses the disposal of carcasses of animals such as cattle, swine, poultry, sheep, goats, fish, and wild birds using anaerobic digestion. The chapter considers anaerobic digestion's economic and environmental competitiveness as a carcass disposal option for either emergencies or routine daily mortalities. This process is suited for large-scale operations, reduces odor, and reduces pollution by greenhouse gases due to combustion of methane. The phases for carrying out these processes and their advantages are presented in detail in the chapter, along with the economics involved.

A simple anaerobic digester installation may cost less than $50 per kg of daily capacity ($22.73 per lb of daily capacity) and construction could be done in less than a month, whereas a permanent installation requires about six months to construct with costs of construction ranging from $70 to $90 per kg of fresh carcass daily capacity ($31.82 to $40.91 per lb of fresh carcass daily capacity). If utilization of the digester is temporary, it is not necessary to use special corrosion resistant equipment, but corrosion will become a problem if the installation is used for several years.

Pathogen containment is a high priority. Though anaerobic digestion is less expensive with mesophilic organisms at 35°C (95°F) than with thermophilic organisms at 55°C (131°F), a temperature of 55°C (131°F) is preferred as the additional heat destroys many pathogens. Many pathogens such as bacteria, viruses, helminthes, and protozoa are controlled at this temperature; however, it is advisable to use additional heat treatment at the end of the process to fully inactivate pathogenic agents capable of surviving in the digester (i.e., spore-formers). Even with an additional heat treatment, inactivation of prions would almost certainly not be achieved.

There are several environmental implications. Anaerobic digestion transforms waste into fertilizer, and from a public relations perspective people generally accept biodigesters. Other concerns include the recycling of nutrients.

Anaerobic digestion has been used for many years for processing a variety of wastes. Research has demonstrated that poultry carcasses can be processed using anaerobic digestion, and this technology has been used commercially. Carcasses have higher nitrogen content than most wastes, and the resulting high ammonia concentration can inhibit anaerobic digestion. This limits the loading rate for anaerobic digesters that are treating carcass wastes.

Anaerobic digestion is a technology worthy of future research. A new process called ANAMMOX—"anaerobic ammonium oxidation"—is proposed for nitrogen removal in waste treatment; this process should be further explored. There is also a need for research regarding how to optimally load carcasses into thermophilic digesters and thereby greatly reduce costs. Finally, there is a need to identify good criteria to measure pathogen reduction of anaerobic digestion processes.

Chapter 8 – Non-Traditional & Novel Technologies

Chapter 8 summarizes novel or non-traditional methods that might be used to deal with large-scale animal mortalities that result from natural or man-made disasters. The chapter identifies specific methods that represent innovative approaches to disposing of animal carcasses. These carcass disposal methods include the following:

- Thermal depolymerization
- Plasma arc process
- Refeeding
- Napalm
- Ocean disposal
- Non-traditional rendering (including flash dehydration, fluidized-bed drying, and extrusion/expeller press)
- Novel pyrolysis technology (*ETL EnergyBeam™*)

A key conclusion of the chapter is that pre-processing of carcasses on-site increases biosecurity and will increase the number of process options available to utilize mortalities. Pre-processing methods examined in this chapter include the following:

- Freezing
- Grinding
- Fermentation
- STI Chem-Clav grinding and sterilization

8.1 – Pre-Processing

Several of the carcass disposal methods described in this chapter would benefit from, or require, on-farm pre-processing and transportation of carcasses to central facilities because of their complexity and cost. One possible solution for pre-processing and transporting carcasses involves a large portable grinder that could be taken to an affected farm to grind up to 15 tons of animal carcasses per hour. The processed material could be preserved with chemicals or heat and placed in heavy, sealed, plastic-lined roll-off containers. The containers could then be taken off-site to a central processing facility. Fermentation is yet another method of pre-processing mortalities on site which has been used in the poultry industry since the early 1980s. Carcasses are stored for at least 25 weeks. Fermentation is an anaerobic process that proceeds when ground carcasses are mixed with a fermentable carbohydrate source and culture inoculants and then added to a watertight fermentation vessel. Another approach, likely to be most suitable to normal day-to-day mortalities, is to place carcasses in a freezer until they can be taken to a central processing site. Freezing is currently being used by some large poultry and swine producers. Typically, a truck with a refrigeration unit is stored on site until it is full and then taken to a rendering operation. The refrigeration unit is operated via on-farm power when in a stationary position, and by the truck motor when in transit. This approach might not be feasible for large-scale die-offs or even for large carcasses unless they are first cut into smaller portions.

Any pre-processing option must minimize on-site contamination risks and maximize the options for disposing of, or eventually finding efficient uses for, the raw materials embodied in the carcass material. Transportation of pre-processed or frozen carcasses in sealed containers should minimize the risk of disease transmission during transit through populated or animal production areas.

Several options with limited throughput, such as rendering and incineration, could also benefit from the on-farm preprocessing and central processing strategy. This general approach is referred to here as a "de-centralized/centralized" model: de-centralized preprocessing to produce a stable organic feedstock that can be transported to a centrally-located facility in a controlled, orderly manner. Figure 2 shows a schematic of how the model might work for animal mortalities. Note that it may be necessary to process all manure from the production site as well as carcasses in the event of some types of communicable disease outbreaks. At other times, separated manure solids and other organic material could be transported and processed at the central plant if economical. Note also that processes suited for handling daily mortalities may or may not be appropriate for dealing with a mass die-off of animals or birds.

8.2 – Disposal Methods

There are several unconventional options for disposing of animal mortalities. Many of these would benefit from the de-centralized/centralized model discussed earlier.

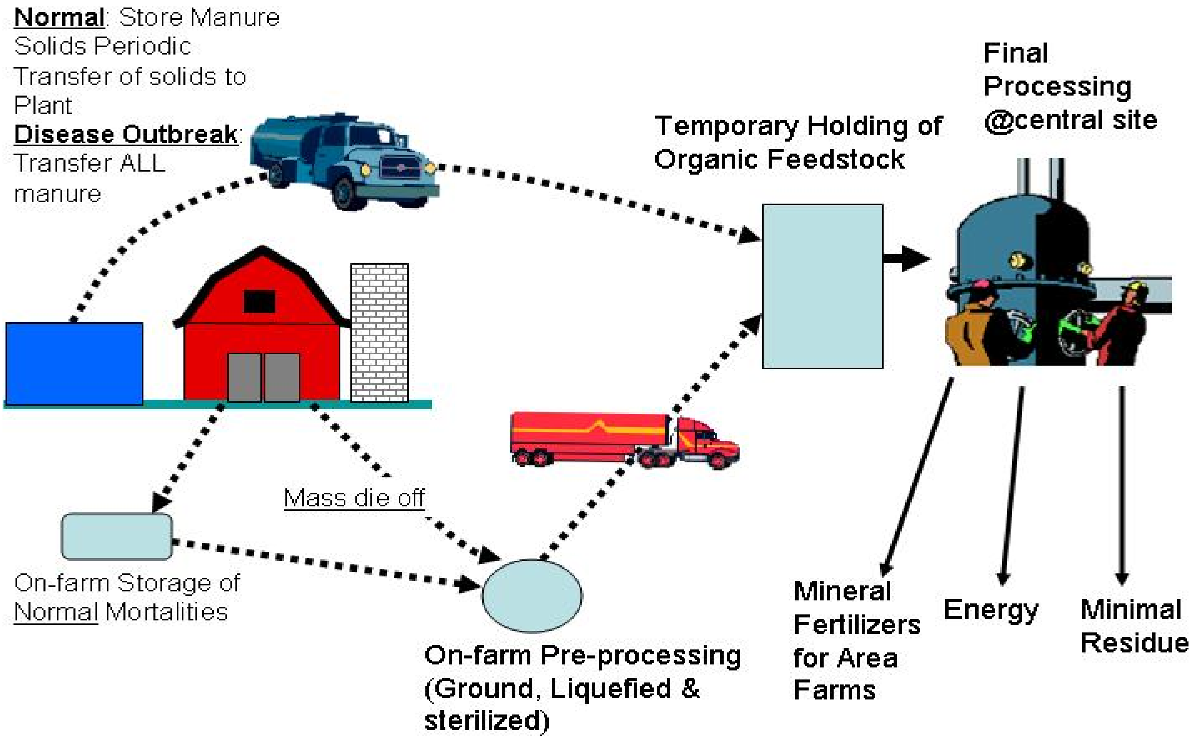

FIGURE 2. Model of decentralized collection and centralized processing. In the event of a mass die-off due to communicable disease, it may be necessary to process all affected stored manure on the farm.

Thermal depolymerization is an intriguing possibility for processing large-scale mortality events. This is a relatively new process that uses high heat and pressure to convert organic feedstock (e.g., pre-processed carcasses) into a type of fuel oil. The thermal depolymerization process has been studied by researchers at the University of Illinois and others. Since depolymerization disassembles materials at the molecular level, it may be effective at destroying pathogens, but this needs to be confirmed. While this alternative is still being evaluated in the laboratory, a large commercial-scale plant is being installed in Missouri to process organic byproducts from a poultry processing plant.

The plasma arc process relies on extremely hot plasma-arc torches to vitrify and gasify hazardous wastes, contaminated soils, or the contents of landfills. It can vitrify material in place with reduced costs and less chance of further contamination. The resulting rock-like substance is highly resistant to leaching. When treating landfill contents, it has reduced material volume by up to 90 percent. The process also generates fuel gases that can be collected and sold to help defray operational costs.

There are no references indicating that plasma arc processing has been used to dispose of livestock mortalities; however, it has several potentially useful characteristics from the standpoint of biosecurity that should be investigated. Specifically, it may be useful when coupled with burial systems because of the potential for treating the material in place. Plasma arc technology has been successfully used to process landfill waste, and there is no reason it should not be effective with mass burials of animal mortalities.

Refeeding of animal carcasses is already important in the poultry industry. There are currently a number of poultry producers using predators, particularly alligators, to consume mortalities.

There is typically very little processing involved in the refeeding process, with most carcasses being fed whole. Some poultry and/or alligator producers grind carcasses to create a liquefied feed that can be consumed by hatchling alligators.

While refeeding is an attractive option in areas where alligator farming is legal and practical, particularly in some southeastern states, many questions remain about the ability of such systems to accommodate the volume of mortalities associated with large-scale die-offs. Start-up costs and skill levels for workers on alligator farms can be high. Another concern relates to the potential for disease transmission through the predator herds.

Other non-traditional methods (including flash dehydration, ocean disposal, napalm, fluidized-bed drying and extrusion/expeller press) would require carcass handling and transportation to a processing site or the development of portable systems. Flash dehydration, fluidized-bed drying, or extrusion/expeller processing would result in a potentially useful by-product. Ocean disposal would not directly result in a beneficial or usable product; however, the addition of a protein source could positively impact aquatic life in the area over time.

Table 2 below summarizes the various innovative methods of handling animal mortalities discussed in this chapter (Chapter 8).

TABLE 2. Overview of innovative options for processing or disposing of large-scale animal mortality events.

Technology/ Method	Applicable To: Non-Diseased Carcasses	Applicable To: Infectious Diseased Carcasses[a]	Requires Stabilization or Pre-Processing	Portable	Centralized	Salvage Product(s)	Residue
Refeeding	✓	--[b]	✓	No	--	Nutrients	Bones
Thermal Depolymerization	✓	✓	--	Perhaps	Yes	Energy	Minerals
Plasma Arc Technology	✓	✓	✓	Yes	Yes	Energy	Vitrified material
On-Farm Autoclaving[c]	✓	✓	--	Yes	No	--	--
Napalm	✓	✓	--	Yes	--	--	Ash
Ocean Disposal	✓	--	--	No	--	--	None
Extrusion	✓	--	--	No	Yes	Energy	--
Novel Pyrolysis Technology (*ETL EnergyBeam*™)	✓	--	--	Perhaps	Yes	--	--

[a]Infectious diseases are handled in the most part by the various processes discussed here. Transmissible degenerative encephalopathy (TDE) and other prion-related agents need further study in all cases.

[b](--) indicates an unknown.

[c]Discussed in Chapter 8 as STI Chem-Clav.

Introduction to Part 2 – Cross-Cutting & Policy Issues

A number of issues beyond the carcass disposal technologies themselves require appropriate consideration; in order to make sound decisions, decision-makers must balance the scientific, economic, and social issues at stake. Part 2 of this report therefore examines carcass disposal from the perspective of a host of cross-cutting issues: economic and costs considerations, historical documentation, regulatory issues and cooperation, public relations efforts, physical security of carcass disposal sites, evaluation of environmental impacts, geographic information systems (GIS) technology, decontamination of sites and carcasses, and transportation.

As this introduction sets forth, there are numerous issues that will impact large-scale carcass disposal decisions. For any policy designed to provide decision-making guidance, it is necessary to identify the numerous factors that must be considered. Historical documentation of events related to large-scale carcass disposal will prove invaluable to decision-makers facing this dilemma. The selection of the appropriate technology must incorporate the scientific basis for the technology along with the associated needs of security, transportation, location, and decontamination. An understanding of the regulatory factors, the importance of agencies and other entities to work together, and the consideration of public opinion are all key to successfully handling a carcass disposal emergency. Decision-makers must understand the associated economic costs as well as the environmental and societal impacts.

To convey the relevance of these cross-cutting issues, this introduction considers four episodes of historical carcass disposal experience, and then extracts from these episodes preliminary lessons regarding each cross-cutting issue. Subsequent chapters (chapters 9-17) follow and, issue-by-issue, provide more analysis.

Historical Experience

United Kingdom – foot and mouth disease

In 2001, the United Kingdom (UK) experienced an outbreak of foot and mouth disease (FMD), which has, to date, provided the best "lesson in history" on large-scale carcass disposal. The UK government faced the challenge of disposing of a large number of carcasses with limited disposal resources in a tight time frame. In June 2002, the National Audit Office (NAO) published a summary on the 2001 outbreak of FMD. The NAO report summarizes the governmental issues related to the disease outbreak, including carcass disposal. The 2001 epidemic lasted 32 weeks, impacted 44 counties, invaded over 2,000 premises, and impacted the sheep, swine, and cattle industries. During the height of the outbreak, an average of 100,000 animals were slaughtered and disposed of each day in a large and complex operation. In total, more than six million animals were slaughtered over the course of the outbreak for both disease-control and welfare reasons (NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002). In the areas where less infection occurred, authorities were able to keep up with the disposal needs. However, in the worst-hit areas, there were long delays in the slaughter and disposal of infected and exposed animals. The existing contingency plan simply did not allow for sufficient handling of a situation of that scale (NAO, 2002; Hickman & Hughes, 2002).

In the UK, the Department for Environment, Food and Rural Affairs (DEFRA, formerly the Ministry of Agriculture, Fisheries and Foods) maintained lead responsibility for the FMD outbreak and disposal of all animals. DEFRA's organizational structure in regards to Animal Health is comprised of a policy-making wing and an operational wing, the State Veterinary Service. A variety of other departments and agencies also participated in managing the outbreak and producers, contractors, and other stakeholders assisted as well (NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

DEFRA's veterinary officers initially directed the disposal operations. About a month after the outbreak was detected, it was determined that the State Veterinary Service could not handle all aspects of the epidemic and additional organizational structures were created. Broadening the cooperative structure gave state veterinarians more time for veterinary work, especially for slaughter and disposal management. Increasing the role of other agencies and departments took time, but other government entities, local agencies, voluntary organizations, and other stakeholders made critical contributions to stopping the spread of FMD. The military was not immediately involved but within a month began to play a key role in the slaughter, transportation, and disposal of animals (NAO, 2002).

Timely slaughter is critical to disease control. While rapid disposal of infected and exposed carcasses may not be crucial in controlling the spread of some diseases, it can be if it holds up the slaughter process (NAO, 2002).

The magnitude of the FMD epidemic made carcass disposal a serious problem. In addition, the massive scale of disposal required by destroying livestock on both infected and "exposed" farms led to problems in disease control, communication, and public perception (Cumbria Foot and Mouth Disease Inquiry Panel, 2002). By mid-April, a backlog of 200,000 carcasses awaiting disposal existed. During the first seven weeks of the epidemic, it was commonplace for dead animals to remain on the ground awaiting disposal for four days or more. The scale of the epidemic combined with resource shortages in both animal health officers and leak-proof transport for off-farm disposal contributed to the problem. The risk of disease spread resulting from off-farm disposal and the need for "robust biosecurity protocols" to minimize virus spread during transport and subsequent disposal was of major concern. The shortage of environmentally suitable and safe disposal sites also led to the delay (NAO, 2002; Hickman & Hughes, 2002).

The legal and environmental framework for disposal of carcasses and animal by-products had changed significantly since the UK's previous outbreak in 1967-68. Plans recognized that disposal methods needed to meet these environmental constraints and be acceptable to the UK Environment Agency and local authorities. Slaughter at a location close to the infected premises was critical to slowing the spread of the disease. At that time, on-farm burial was initially considered the preferred method followed by on-farm burning. However, on-farm disposal proved to be impractical because of environmental constraints and high water tables. In mid-March 2001, the Environment Agency began conducting rapid (within 3 hours) groundwater site assessments and advised on appropriate disposal. The Environment Agency also approved a disposal hierarchy for different species and age of stock. In addition, the Department of Public Health issued guides on how the risks to public health could be minimized. The stakeholders then agreed on a disposal hierarchy that attempted to protect public health, safeguard the environment and ensure FMD disease control. Cost was a material but much less important factor. This new focus on environment and public health was substantially different from the initial approach based on animal health risks and logistics (NAO, 2002; Hickman & Hughes, 2002).

Rendering and fixed-facility incineration were preferred, but the necessary resources were not immediately available and UK officials soon learned that the capacity would only cover a portion of the disposal needs. Disposal in commercial landfills was seen as the next best environmental solution, but legal, commercial, and local community problems limited landfill use. With these limitations in mind, pyre burning was the actual initial method used but was subsequently discontinued following increasing public, scientific, and political concerns. Mass burial and on-farm burial were last on the preferred method list due to the complicating matter of bovine spongiform encephalopathy (BSE) and the risk posed to groundwater (Hickman & Hughes, 2002). The hierarchy and case-specific circumstances determined the methods utilized. Decisions were impacted by the availability of nearby rendering capacity, the relative risks of transporting carcasses, and suitability of sites for burial and burning. Even with the new hierarchy in place, burial and burning remained common choices because of the need to slaughter expeditiously and limit transportation of carcasses. Overall, burning was the most common method of carcass disposal (29%), followed by rendering (28%), landfill (22%) and burial (18%)

(NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

TABLE 1. UK 2001 FMD outbreak – approved disposal routes for different species and age of stock (NAO, 2002).

Preferred Method of Disposal	Permitted Animals
Rendering	All
High-temperature Incineration	All
Landfill, on approved sites	Sheep, pigs of any age & cattle younger than 5 (due to BSE concerns)
Burning	All (with a limit of 1,000 cattle per pyre)
Mass Burial or approved on-farm Burial	Sheep, pigs of any age & cattle younger than 5 (due to BSE concerns)

Huge logistical problems developed in the disposal of millions of slaughtered animals. DEFRA cited problems with all disposal methods. Rendering was unavailable until rendering plants complied with necessary biosecurity protocols and transportation vehicles were adequately sealed. In March 2001, protocols for biosecurity of rendering plants and vehicles were approved. However, until late in the epidemic, the rendering plants could not handle the necessary capacity. High-temperature incineration was also difficult to utilize because the facilities were committed to the disposal of BSE-affected cattle. Air-curtain incinerators were used on occasion. Landfill operators and local communities were resistant to the use of landfills for disposal because they were often located near large population centers. While 111 suitable facilities were identified, only 29 were utilized. Over 950 locations were used for burning with most located on-farms. However, the use of mass pyres generated a negative response from the media and devastated the tourism industry. These mass burnings ended in two months because of public opposition. Mass burial was the selected alternative when carcasses began to pile up. However, public protests and technical problems—such as seepage of carcass liquid—resulted when 1.3 million carcasses were disposed of in mass burial sites. Regardless of public concerns, the efforts of DEFRA, the Environment Agency, the military, and others helped eliminate the backlog of carcasses (NAO, 2002).

Carcass disposal was a highly controversial issue. Public backlash, especially in response to burning and mass burial, was significant and long-term economic impacts remain in question. DEFRA's Contingency Plan for future FMD outbreaks is to use commercial incineration for the first few cases, followed by rendering and then commercial landfills. The plan would include agreements ensuring minimum rendering capacity and use of national landfill sites. DEFRA also stated that it is unlikely that pyre burning or mass burial would be used again (NAO, 2002). Burning of carcasses on open pyres was an enormous task requiring substantial materials and generating significant amounts of ash for disposal. These pyres were viewed unfavorably by local residents and producers. The images of burning carcasses were broadcast via television around the world and likely contributed to the wider economic damage, especially to the tourism industry. Local residents disliked mass burial as well. The general public reacted most positively to the rendering alternative (Rossides, 2002). At the beginning of the outbreak, the priority was to eradicate the disease. While the Department realized cost control was important, it was also clear that all steps to stop the disease needed to be taken regardless of expense (Hickman & Hughes, 2002).

NAO offered multiple recommendations for future contingency plans. One example of their recommendations is to develop a clear chain of command with defined responsibilities, roles, reporting lines, and accountabilities. They also recommended researching the effectiveness and efficiency of disposal methods of slaughtered animals and continually inspecting and monitoring the environmental impacts of disposal sites (NAO, 2002).

In response to the Government-commissioned inquiries, the UK Government notes the need for multiple strategies for different disease situations. The Government is committed to reviewing preventive culling and vaccination policies. The Government also noted that the disposal hierarchy in its current contingency plan differs from the hierarchy agreed upon during the actual FMD outbreak by the Environment Agency and Department of Health. The new plan states that first preference will be commercial incineration followed by rendering and disposal in licensed landfills. Mass burn pyres are not advised and on-farm burial will only be used if demand exceeds capacity of the preferred options (Anonymous, 2002).

Further review of the environmental impact by the Environment Agency found 212 reported water pollution incidents, mostly minor, and only 24% were related to carcass disposal. None of the pollution problems were on-going problems in private or public water supplies. Additional monitoring has not shown any ongoing air quality deterioration, and concentrations of dioxins in soil samples near pyres are the same as before the outbreak (UK Environment Agency, 2002).

Taiwan – foot and mouth disease

In 1997, Taiwan experienced an outbreak of FMD that resulted in slaughter and disposal of about five million animals. Carcass disposal methods included burying, rendering, and incineration/burning. With the disposal choice very dependent on farm locations, burial in landfills (80% of carcasses) was the most common method. Swine producers were allowed to send hogs to nearby rendering plants. High water tables and complex environmental regulations complicated disposal. In areas where water resources were endangered, incineration (with portable incinerators or open burning) was the only approved method. Army personnel completed the majority of the disposal work. At the peak of the crisis, disposal capacity reached 200,000 pigs per day. The eradication campaign lagged well behind the identification of potential FMD cases, causing many farms to wait from one to four weeks before animals could be slaughtered. The delay was blamed on lack of manpower and equipment, and large-scale death loss experience combined with the difficulty of disposal. The manpower shortage was alleviated with military assistance. The disposal method selected was dependent on the availability of landfill sites, level of the water table, proximity to residences, availability of equipment and other environmental factors. Major issues related to carcass disposal included the number of animals involved, biosecurity concerns over movement of infected and exposed animals, people and equipment, environmental concerns, and extreme psychological distress and anxiety felt by emergency workers (Ekboir, 1999; Ellis, 2001; Yang et al., 1999).

United States – natural disasters

Two natural disasters, floods in Texas in 1998 and Hurricane Floyd in North Carolina in 1999, have provided similar yet smaller-scale carcass disposal experience. Dr. Dee Ellis of the Texas Animal Health Commission reviewed these two disasters, collected data, and performed numerous personal interviews (Ellis, 2001). His findings are summarized below.

In October 1998, torrential rains in south central Texas resulted in the flooding of the San Marcos, Guadalupe, San Antonio, and Colorado River Basins. Over 23,000 cattle were drowned or lost in addition to hundreds of swine, sheep, and horses. The Texas Animal Health Commission (TAHC) worked with state emergency personnel from the Governor's Division of Emergency Management, the Texas Department of Transportation, and the Texas Forest Service to manage the disposal of animal carcasses. Local emergency response personnel played integral roles in the actual disposal process. Most animal carcasses were buried (where found if possible) or burned in air-curtain incinerators. Two air-curtain incinerators were utilized. One difficulty that arose was finding a burn site that was not located on saturated ground. Some carcasses were inaccessible and began to decompose before actual disposal could take place. According to Ellis, the main carcass disposal issues were (1) lack of prior delineation or responsibilities between agencies, (2) non-existent carcass disposal plans and pre-selected disposal sites, (3) a short window of time to complete disposal, (4) minimal pre-disaster involvement between animal health and local emergency officials, and (5) inaccessibility of some carcasses (Ellis, 2001).

In September 1999, Hurricane Floyd devastated North Carolina. The hurricane, combined with prior heavy rains, resulted in the worst floods in state history. Animal loss was estimated at 28,000 swine, 2.8 million poultry, and 600 cattle. Disposal of dead animals was coordinated by the North Carolina Department of Agriculture. Costs were partially subsidized at a cost of $5 million by the USDA's Emergency Watershed Protection program. The North Carolina State Veterinarian coordinated disposal to ensure safety for both human health and the environment. Major problems related to carcass disposal included contamination of drinking water sources, fly control, odor control, zoonotic disease introduction, and removal and transport of carcasses. These problems were compounded in the cases of highly concentrated swine and poultry losses on heavily flooded property. The order of preference for disposal in North Carolina is rendering, burial, composting, and incineration. However, rendering capacity was so limited that it was not a viable option. Burial was the most widely used option and was utilized for 80% of the swine, 99% of the poultry, and 35% of the cattle. Incineration was used for the remainder of the carcasses. Most burial took place on the land of the livestock producers. They were offered a financial incentive to bury on their own land in order to minimize transport of carcasses. However, this process led to additional environmental concerns as producers often buried carcasses in saturated ground that allowed carcass runoff to leach back into ground water or local water resources. This threat caught the attention of both environmental watch groups and the national media, resulting in a study group that created a multi-agency approach and animal burial guidelines for future use. Ellis noted the major issues in North Carolina to be (1) high number of dead swine located near populated areas, (2) environmental threats to groundwater and water resources, (3) interagency jurisdictional conflicts, (4) lack of well-developed carcass disposal plans, and (5) minimal involvement of animal health officials with the state emergency management system (Ellis, 2001).

United States – chronic wasting disease

In February 2002, chronic wasting disease (CWD) was identified in whitetail deer in southwest Wisconsin. CWD is a transmissible spongiform encephalopathy (TSE). In order to control the disease, a 360-square-mile disease eradication zone and surrounding management zone were developed. All deer within the eradication zone were designated for elimination, and deer in the surrounding area were designated to be reduced. Many of the deer were destroyed by citizen-hunters, who were not permitted to use the deer for venison. Disposal methods were selected that do not endanger animal or human health or environmental quality. Selected methods had to be able to handle a large number of carcasses and comply with regulations. Cost was also a consideration, and it is anticipated that disposal costs will be one of the most significant expenses of the CWD control program. The four preferred methods used were landfilling, rendering, incineration, and chemical digestion (alkaline hydrolysis) (Wisconsin Department of Natural Resources, 2002).

Lessons Learned Regarding Cross-Cutting and Policy Issues

The historical experiences related to large-scale carcass disposal have provided "lessons" from which the livestock industry and regulatory agencies can learn. Many of these lessons are discussed in terms of the cross-cutting and policy issues addressed in subsequent chapters:

- **Economic & Cost Considerations.** Any large-scale animal death loss will present significant economic costs. The disposal of large numbers of carcasses will be expensive and fixed and variable costs will vary with the choice of disposal method. In addition, each method used will result in indirect costs on the environment, local economies, producers, and the livestock industry. Decision-makers need to better understand the economic impact of various disposal technologies. Broader policy considerations involving carcass disposal and a large-scale animal disaster need to be identified and discussed as well. Chapter 9 discusses these issues.
- **Historical Documentation.** An important resource for the development of a carcass disposal plan is historical documentation from previous large-scale animal death losses. However, serious deficiencies exist in historical documentation of past events and significant variances occur among agencies relative to planning, experience, and preparation for a catastrophic event. Chapter 10 examines the state of historical documentation of past carcass

disposal events within the United States and explores the potential for developing a Historic Incidents Database and Archive (HIDA).

- **Regulatory Issues and Cooperation.** Previous experiences dictate that strong interagency relations and communications are critical to effectively dealing with a large-scale animal disaster. Federal, state, and county regulations related to carcass disposal may be unclear or perhaps in conflict with one another. Interagency issues may result in additional problems or the extension of the disaster. Steps must be taken to identify interagency relationship problems and develop a plan for dealing with large-scale carcass disposal. Chapter 11 identifies opportunities for agency coordination and plan development.

- **Public Relations Efforts.** A disaster-related animal death loss will cause significant public concern. Historical experience shows that the disposal of carcasses creates public dismay and apprehension. To facilitate positive public perception, decision-makers handling massive livestock mortality and carcass disposal must have access to expert public-information professionals and agree to make communicating with the public a top priority. Chapter 12 provides guidance to public information professionals, subject matter experts, and disposal managers to understand the role and importance of communicating with the public about large-scale carcass disposal.

- **Physical Security of Carcass Disposal Sites.** History suggests a need for security systems during carcass disposal operations. Examples of security threats related to carcass disposal include potential equipment theft, angry and discontented livestock owners and citizens, and unintentional animal or human activity. The most important aspect of security is keeping the disease from spreading from the site to other areas. A well-designed security system would control these issues. Chapter 13 identifies potential threats, security technology, and potential security designs.

- **Evaluating Environmental Impacts.** Carcass disposal events can result in detrimental effects on the environment. The specific impacts vary by carcass disposal technology, site specific properties of the location, weather, the type and number of carcasses, and other factors. To accurately determine the impacts of a specific carcass disposal event on the environment, environmental monitoring will be necessary. Chapter 14 provides an overview of monitoring that may be necessary or desirable to quantify environmental impacts for a carcass disposal event, and introduces models that may be useful in this regard.

- **Geographic Information Systems (GIS) Technology.** GIS technology should play a significant role in the management of mapped or spatial data prior to, during, and after carcass disposal events. At the simplest level, GIS can provide maps while, at the more complex level, can serve as a decision support capability. Chapter 15 contains an overview of GIS and how it has been used in recent livestock disease and carcass disposal efforts.

- **Decontamination of Sites & Carcasses.** Regardless of the carcass disposal method utilized, concern must be given to contain the disease and limit any potential disease spread. Decontamination will prove to be vital in this endeavor. The first, and most important, step in the process of decontamination is the identification of the disease agent present and assessment of the situation. Those involved must understand how the causative agent works and exactly how it spreads. Chapter 16 identifies various infectious agents, groups of disinfectants, and decontamination procedures.

- **Transportation.** The disposal of carcasses following a large-animal disease event will likely require transportation to an off-site disposal location. The transportation of large numbers of diseased animals or carcasses requires significant planning and preparation in order to prevent further dissemination of the disease. Chapter 17 focuses on critical issues related to transportation during a carcass-disposal event.

Chapters 9-17 serve as an overview of these cross-cutting and policy issues by highlighting critical information, summarizing available background material, offering recommendations to decision-makers, and identifying critical research needs.

Chapter 9 – Economic & Cost Considerations

A complete and multidimensional strategy is necessary when planning for the disposal of livestock and poultry in the event of high death losses resulting from an intentional bioterrorism attack on agriculture, an accidental introduction of dangerous pathogens, or a natural disaster. A critically important part of that strategy is the ability to dispose of large numbers of animal carcasses in a cost effective and socially and environmentally effective manner.

While many technologies exist, the "best" method for carcass disposal remains an issue of uncertainty and matter of circumstance. Contingency plans must consider the economic costs and the availability of resources for the actual disposal, as well as numerous related costs. A complete cost-benefit analysis of alternative methods of disposal for various situations is a necessity to determine the "best" alternative.

Chapter 9, which reviews economic and cost considerations, (1) highlights previous carcass disposal experiences and costs, (2) summarizes costs and economic factors related to disposal technologies, (3) presents broad regulatory and policy issues related to carcass disposal, and (4) identifies future research needs.

In 2001, the United Kingdom experienced an outbreak of foot and mouth disease (FMD), which has, to date, provided the best "lesson in history" on large-scale carcass disposal. The Government faced the challenge of disposing of approximately six million carcasses with limited disposal resources in a tight time frame. The large scale of the epidemic made carcass disposal a serious problem. Total expenditures by the Government were estimated to be over £2.8 billion, with over £1 billion related to direct costs of control measures. This included £252 million for haulage and disposal.

During the 1997 FMD outbreak in Taiwan, approximately five million carcasses required disposal. The costs born by the government associated with the epidemic were estimated at $187.5 million, with expenses for carcass disposal of approximately $24.6 million.

In order to understand the economic issues related to carcass disposal, it is critical to understand the cost data available. An effective control strategy will not only limit disease spread but will keep direct and indirect costs low. There is relatively little data on the costs of carcass disposal, and consistency regarding both direct and indirect costs is lacking.

Various direct and indirect costs need to be identified, including those related to direct disposal, transportation, facilities and equipment, energy requirements, environmental impact, and social costs. Major economic factors and implications also need to be identified and the different disposal options need to be compared and contrasted. In Chapter 9, examples of direct costs are identified and potential indirect costs are discussed relative to each technology. Most existing data applies only to small-scale disposals, and few reliable cost estimates exist for large-scale disposal. In the case of a foreign animal disease outbreak or natural disaster, total actual costs are difficult to estimate. In addition, little to no attention has been paid to indirect costs of these technologies in previous research. The impact on the environment, land values, public opinion, and general economic factors must be evaluated and quantified as well. This type of economic analysis is critical to any decision-making process. Figure 3 summarizes the technology costs found in the literature.

Technology	Range of cost estimates per ton of carcass material disposed[a]	Direct Cost Indicators				Indirect Cost Indicators			Creates valuable or beneficial by-products
		Initial Capital[b]	Transportation[c]	Labor	Inputs	Environment /Public Health	Public Perception	Other cost considerations	
Burial (on- and off-site)	$15-200	$	$	$$$	$	$$$	$$$$	Land use and values Predator activity	
Landfill usage	$10-500	$$	$$$	$	$	$$	$$$	Municipal costs Management costs	
Open burning	$200-725	$	$	$$$	$$$$	$$$	$$$$	Disposal of ash Permit Fees	
Fixed-facility incineration	$35-2000	$$	$$$	$$	$$	$$	$$$	Disposal of ash Permit Fees	
Air-curtain incineration	$140-510	$$	$$	$$	$$$	$$	$$$	Disposal of ash Permit Fees	
Bin- and in-vessel composting	$6-230	$$	$	$$$	$$$	$	$$	Land use Time efficiency	√
Windrow composting	$10-105	$	$	$$$	$$$	$	$$	Land use Time efficiency Predator activity	√
Rendering	$40-460	$$	$$$	$	$$	$	$$	Biosecurity risk	√
Fermentation	$65-650	$$$$	$	$$	$$	$	$	Time efficiency	√
Anaerobic digestion	$25-125	$$$$	$	$$	$$	$	$	Time efficiency	√
Alkaline hydrolysis	$40-320	$$$	$$	$	$$	$	$	Disposal of effluent	

[a] These estimates are the result of an extensive literature review which utilized numerous sources. The data available is based on a variety of assumptions, including differing circumstances, cause of death, scale of disposal efforts, species, dates, and geographical locations. In addition, different cost estimates do not consistently incorporate capital, transportation, labor or input costs.
[b] Includes capital costs directly associated with carcass disposal only.
[c] Transportation costs depends on the location of the technology. These indicators assume minimal transportation for more likely available technologies.

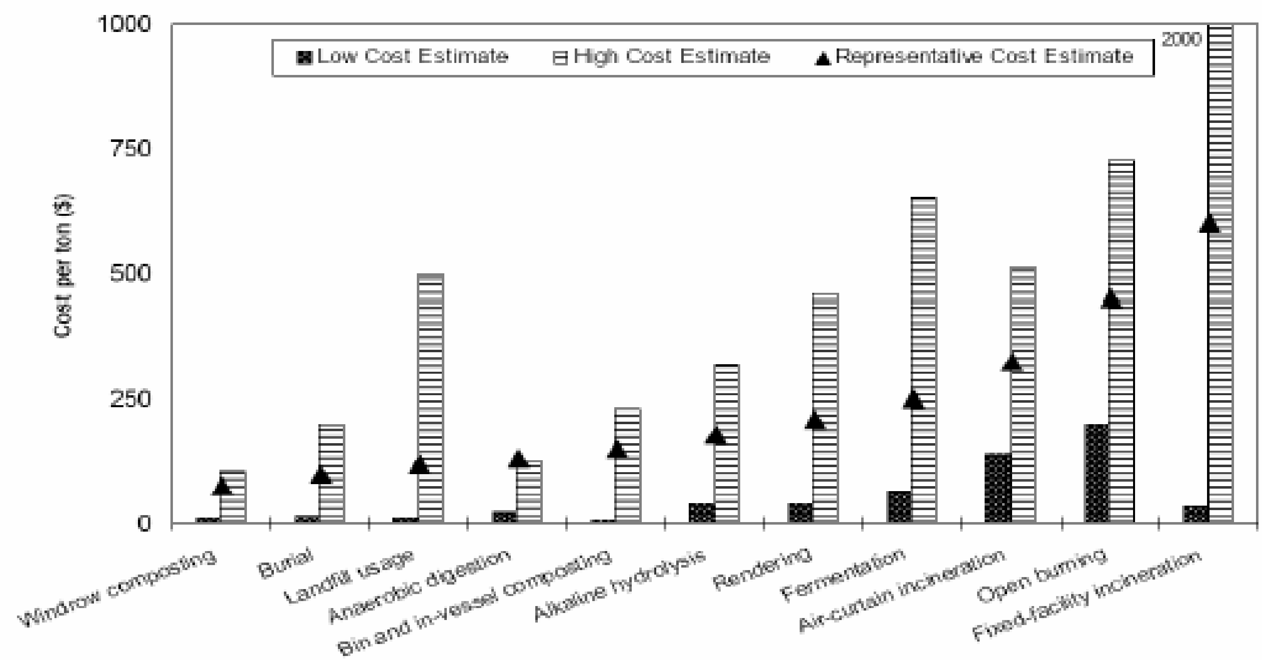

FIGURE 3. Summary of technology costs.

In order to determine the optimal investment in disposal technology and capacity, the cost-benefit ratio of alternative methods for carcass disposal needs to be analyzed. Economics cannot and should not be the sole factor in a decision-making process, but economics should be part of the equation. Economically attractive disposal methods may not meet regulatory requirements; the most cost-effective method may be prohibited by local, state, or federal regulations. Additional efforts are necessary to assess state-by-state regulations, investigate opportunities for individual states and the federal government to work together, have disposal plans in place before an emergency, and delineate clear decision-making responsibilities. Balancing economic considerations with regulatory requirements is necessary to determine the best options for carcass disposal. Furthermore, in order to minimize direct costs, contracts with technology providers should be negotiated in advance.

Improvement of the decision-making process related to large-scale carcass disposal is the ultimate goal. Further review and response to the research needs noted in Chapter 9 will provide regulators and policymakers with the necessary information to make decisions. These results, combined with increased research from the scientific community on each disposal technology, will help government and industry be better prepared for any large-scale carcass disposal event.

Chapter 10 – Historical Documentation

The objectives of this research were to examine the state of historical documentation relative to past carcass disposal events within the United States, and explore the potential for developing a Historic Incidents Database and Archive (HIDA). Based on research into past incidents of catastrophic losses of livestock and their associated large-scale disposal efforts, deficiencies were observed to exist in historical documentation, with significant variances occurring among states relative to planning, experience, and preparation for a catastrophic event. There was also an evident problem in sharing information, expertise, and experiences among the states in regard to handling a catastrophic carcass disposal event.

Research indicated that California, Georgia, Indiana, Maryland, North Carolina, North Dakota, Pennsylvania, and Texas have accumulated a great deal of experience and expertise in catastrophic animal disposal incidents. The most frequent causes of carcass disposal events included avian influenza, pseudorabies, and natural disasters. The states of Florida, Hawaii, Idaho, Iowa, Maine, Michigan, Missouri, Oregon, and Washington have had experience with relatively small carcass disposal incidents due to avian influenza, accidents, or natural disasters. Other states have indicated they have had no recent experience with large-scale carcass disposal operations but have provided information on their states' carcass disposal regulations. All the officials contacted in the course of this research expressed enthusiasm for opportunities to communicate and exchange information, experience, and expertise on carcass disposal with officials in other states.

During the course of this research it became evident that US officials concerned with managing a catastrophic animal disposal incident could benefit from a rigorous historical program. A historical team dedicated to issues of agricultural biosecurity and carcass disposal could provide officials on both the state and federal level with information that would be invaluable for emergency planning and incident management. A historical program for agricultural biosecurity and carcass disposal would also help to assure both the media and the general public that the carcass disposal methods used in dealing with any future catastrophe are both necessary and effective. A well-documented history of both past and emerging catastrophic carcass disposal incidents would also provide additional credibility to emergency management officials when dealing with governors, state legislatures, and the US Congress.

Although documentation of past large-scale animal disposal events is limited, a number of incidents were investigated that yield important lessons for emergency management officials concerned about the possibility of a catastrophic event (see detailed summaries in Chapter 10). While the lessons from these experiences should serve as guides for other states and localities preparing for a catastrophic event, dissemination of these lessons is hampered by the almost total absence of historical records documenting catastrophic animal disposal events. Large-scale animal disposal events caused by natural disasters or epidemics are certainly nothing new, and states and localities have encountered these problems in the past; however, interviews and correspondence with officials from various states confirm that state agencies dealing with this problem generally have no institutional memory. The documents that do exist provide only rudimentary data, and states often purge what are deemed as inconsequential records at five- or ten-year intervals. As a result, detailed information about carcass disposal incidents that occurred more than ten years ago can be very difficult, if not impossible, to obtain.

As a consequence of the generally inadequate historical documentation of animal disposal events, a majority of the information that can be gleaned about past events has to be obtained from interviews of the persons involved in such events. Although information obtained from interviews can certainly be useful and the knowledge and experience of those involved in past events is worthy of documentation and distribution, oral history can have significant shortcomings. Human memory can be problematic and hard facts concerning numbers of livestock lost, economic losses, disposal expenses, and the exact location of disposal sites can be difficult or even impossible to obtain. In addition, the death, retirement, or career changes of those individuals with the most knowledge of past incidents means that the ability to learn lessons from past incidents dissipates with each passing year. The absence of any institutional memory or written history of past incidents robs current government officials of a useful pool of knowledge concerning how best to handle any future large-scale animal disposal emergency.

Another major deficiency lies in communicating and distributing current information concerning carcass disposal technologies, planning, problem solving, and historic incidents. It appears that the various states and localities operate as independent islands with each one attempting to plan and prepare for potential emergencies as if in a vacuum. Communication is lacking among officials in various state agencies involved in regulating or directing animal disposal projects, academics involved in the study of carcass disposal, and the various federal agencies that might provide assistance. Consequently, evaluation of opportunities and means to facilitate communication between state and federal officials, producers, and academics is warranted. Possible means include virtual forums—or other electronic formats—that could provide an inexpensive and effective channel to share past experiences and problems and to distribute information on carcass disposal technologies, emergency planning, laws and regulations, logistics, and a variety of other relevant topics. Information from these forums could then be captured for further development. Many officials attending an August 2003 Midwest Regional Carcass Disposal Conference expressed great interest and enthusiasm for opportunities to increase communication with outside experts or other experienced individuals.

Chapter 11 – Regulatory Issues & Cooperation

Not all potential problems can be anticipated and addressed in advance of a major biosecurity event, but two overall actions which might prevent a large-scale animal disaster from taking larger tolls are education and facilitation.

Factors related to education include:

- Better understanding of the Incident Command System (ICS) by agricultural industry leaders and participants.
- Better understanding of the ICS, standard operating procedures (SOPs), and agriculture by county governments and agricultural groups.

- Better understanding of agriculture by the emergency management and county government systems.
- Better understanding of agricultural disaster response by state and local agencies (public health, legal, etc.).

A primary factor related to facilitation includes:

- Encouragement of periodic (annual or semi-annual) meetings at the state level to discuss specific operational, legal, and future research needs in the area of animal disaster management.

In Indiana, for example, two specific actions will enhance the response efforts during a major disaster. First, acting agencies need to know they are part of the Comprehensive Emergency Management Plan (CEMP). Second, more people within agencies should have a comprehensive awareness and understanding of all others involved, in addition to understanding their own agency's SOPs. In order to enhance the functionality of the CEMP, the State Emergency Management Agency (SEMA) also incorporates the use of the ICS during the management of a disaster. At the time of writing, Indiana's SEMA was just learning how the ICS will evolve to the National Incident Management System (NIMS). In 2003, US President George W. Bush issued directives which provide the Secretary of Homeland Security with the responsibility to manage major domestic incidents by establishing a single, comprehensive national incident management system. The introduction of the NIMS will not change the recommendations of this document, but rather enhance the possibilities of these recommendations being implemented. The key is how thoroughly the NIMS is utilized from federal to state to local agencies.

An idealistic approach to a disaster would be to know, in detail, what needs to be done, what protocols need to be enacted, and who is going to take the lead. However, no real-life disaster plays out as a textbook example. General disaster plans are created with a number of annexes and SOPs attributed to specific situations. Regardless of the tragedy or the number of agencies involved, there are several areas that should be addressed to achieve a higher level of preparedness and response:

- An interagency working group should be created that meets periodically (e.g., at least two times a year) and consists of at least the state environmental, animal health, public health, contract service, emergency management, extension service, transportation, and wildlife agencies.
- An analysis should be conducted of the agencies' (state and county) awareness level of the functionality of the CEMP and its components, as well as the overall functions of the ICS. Have enough agencies been included? Are there enough training opportunities for agency employees? Do the involved agencies have a well-established representation of their SOPs within the annexes of the CEMP?
- A training program should be established that:
    - Requires ICS training for all agencies involved in the CEMP—state and county level. The training should include enough people from various agencies to ensure a widespread understanding of the ICS and various agencies' roles.
    - Establishes programs at the county level to bridge the gap between the legal system and agricultural issues in a biosecurity event.

Results of a roundtable discussion demonstrated that (1) more could be known about how critically involved agencies will react to a large-scale animal carcass disposal situation, and (2) in an environment of short-staffing and high workloads, agency personnel will likely not place a high priority on planning for theoretical animal carcass disposal issues.

Therefore, to facilitate planning efforts and provide structure for interagency discussions and exercises, research into (and summarization of) the actual laws, regulations, guidelines, and SOPs of key agencies is warranted on a state-by-state basis.

This research is critical to the development of comprehensive plans for state and county governments to more easily identify their roles. These could be used in training programs for state and local agencies to develop pertinent SOPs and memorandums of agreement.

Chapter 12 – Public Relations Efforts

To assure positive public perception, decision-makers handling large-scale livestock mortality and carcass disposal events must have access to expert public information professionals and must agree to make communicating with the public a top priority. Before a disposal method is chosen, the incident commander and public information leader should consider potential public perception.

If the disposal of large numbers of animal carcasses is necessary, it can be safely assumed a disaster has occurred. Whether by natural or human means, the public most likely will be aware of the circumstances and will notice efforts to dispose of carcasses. All methods of disposal deserve consideration. No method of disposal should be ruled out in advance, because circumstances can change and locales may have conditions that favor one type of disposal over another.

It is incumbent on decision-makers to communicate quickly and often with the public via a capable public information officer. Depending on the type of disaster that caused the loss of livestock, the general public itself may already be suffering from a high-stress situation (if there has been a devastating hurricane, for example, or an act of terrorism).

While one agency will lead the effort, numerous other state and federal agencies, as well as private entities, should be involved. Unified communication amongst the public information staffs of all involved parties is vital to shape positive public perception.

As reported after the foot and mouth disease outbreak in the United Kingdom (UK) (Parker, 2002), "Communications were extremely difficult both to and from DEFRA [UK Department for Environment, Food & Rural Affairs] during this period and this led to a complete loss of confidence from the public, local authorities and partners involved." Parker (2002) also reported "poor communications led to confusion and the perception that there was little control." Thus the most important factor is to communicate well with the public initially, throughout, and beyond the episode.

The strategy for effective communication involves two time frames: Issue Management in the short-term, and Issue Education in the long-term. These two efforts must be pursued simultaneously in three areas: factual information collection, communications techniques, and resource allocation.

Chapter 12 provides guidance to public information professionals and helps subject matter experts and disposal managers understand the role and importance of communicating with the public about large-scale carcass disposal.

Chapter 13 – Physical Security of Carcass Disposal Sites

13.1 – Overview

Serious issues mandate the need for a security system during carcass disposal operations. Relatively high-value equipment may be used in the operation that would be vulnerable to theft. Angry and discontented livestock owners who believe the destruction of their animals is unnecessary could put the operators of the system at risk. Unauthorized, graphic photographs or descriptions of the operation could also impact the effort through negative publicity. Most important is that the disease could be spread from the site to other areas. A well-designed security system would control these issues.

The type of security required for carcass disposal operations is obviously not the same as that required for a bank, a nuclear weapon facility, or an infrastructure system; however, an understanding of basic security concepts and design methodology is required for the development of any security system. This basic understanding underlies the design of a system that meets the desired performance objectives. A carcass disposal security system will need to be designed and implemented within a large number of very serious constraints such as time (for design) and cost (of operation). Applying proven physical security design concepts will assure that the best system possible is designed and operated within these real-world constraints.

When designing the carcass disposal security system, clear objectives regarding the actions and outcomes the system is trying to prevent are a necessity. Regardless of the performance goals, all effective security systems must include the elements of detection, assessment, communication, and response.

Three types of adversaries are considered when designing a physical protection system: outsiders, insiders, and outsiders in collusion with insiders. These adversaries can use tactics of force, stealth, or deceit in achieving their goals.

The security system requirements for a carcass disposal system also carry unique characteristics. However, in each case a threat analysis is needed to answer the following questions:

- Who is the threat?
- What are the motivations?
- What are the capabilities?

Before any type of security system can be designed, it is necessary to define the goals of the security system as well as the threats that could disrupt the achievement of these goals.

13.2 – Performance Goals

There will likely be two main components in any large-scale carcass disposal operation. The first component will be the site(s) where processing and disposal operations occur. The second component is the transportation link. In some cases a third component, a regional quarantine boundary, could be considered. For each of these components, a brief description of the action or situation that needs to be prevented provides the basis for the performance goals of an ideal system.

Appropriate security must be provided for these fixed-site operations for all credible threat scenarios. Some unique challenges are presented for mobile operations quickly moving from location to location, but all fixed-site operations share common vulnerabilities that could result in actions that disrupt the controlled disposal of carcasses. At any given fixed disposal site, a range of actions could engage the security system.

This is not to suggest all or even any of these actions *would* occur, only that they *could* occur. It is also important to realize that given the real-world constraints, no security system can be completely effective against all potential actions. In actually designing the system, the designer and analyst must select those actions considered to be the most important and credible and design the system to be most effective against these actions.

The performance goals for the ideal fixed-site security system would be to prevent the following events:

- Interruption of operations.
- Destruction/sabotage of equipment.
- Equipment theft.
- Intimidation of operating personnel.
- Spread of contamination.
- Unauthorized access.

The performance goals for the ideal transportation-link security system would be to prevent the following events:

- Interrupted transfer of people, equipment, and materials (including carcasses).
- Spread of contamination.
- Equipment theft or sabotage.

The performance goal for a regional security system would be to:

- Prevent the unauthorized movement of animals, materials, products, and people across the defined boundary of the region.

Additional performance goals may be determined in collaboration with carcass disposal operations stakeholders.

13.3 – Design Considerations

The design considerations for the ideal security system include (but are not limited to):

- Disposal technology.
- Disposal rationale.
- Prescribed haul routes.
- Disposal system administration.
- Staffing.
- Funding.
- Training.
- Advanced planning and preparation.
- Operational period.
- Geography.

Additional design considerations may be determined in collaboration with carcass disposal operations stakeholders.

13.4 – Threat Analysis

The threat may be very different in cases where there is a natural disaster as opposed to a disease outbreak. In the natural disaster situation the animals will already be dead and there is no question about the need for disposal. In the disease outbreak situation, however, there may be the slaughter of both diseased and healthy, or apparently-healthy, animals. Decisions about the number of animals that need to be destroyed and the geographic area where the animals will be destroyed could become quite controversial.

The threat spectrum for the carcass disposal operations security system design is likely to include two types of threats:

- Malevolent threats (adversaries who intend to produce, create, or otherwise cause unwanted events).
- Nonmalevolent threats (adversaries who unintentionally produce, create, or cause unwanted events).

Carcass disposal operations are unusual in that some of the nonmalevolent adversaries posing a threat to the operations are nonhuman. For example, animals, groundwater, and wind can all spread contamination. The ideal physical security system would prevent these nonhuman adversaries from completing such actions.

Threat analysis for the ideal fixed-site security system would include the following adversaries:

- Intentional malevolent threats, including:
  - Animal owners
  - Animal rights activists
  - Site workers/visitors/animals
  - Unauthorized media
  - Disgruntled employees
- Nonmalevolent threats, including:
  - Inadvertent intruders
  - Curious individuals
  - Unintentional insiders
  - Animals and other forces of nature

Additional adversaries may be identified in collaboration with carcass disposal operations stakeholders.

13.5 – Security Technology

There are many security technologies available to support the success of designed physical protection systems. Before security technologies can be applied to a carcass disposal operation, the performance goals of the system must be defined, the design considerations must be characterized, and the threat must be analyzed. Only then can a security system be designed to address the needs of the particular problem.

It is possible to expect that sensors, specifically exterior intrusion detection sensors, are likely to be a part of a physical protections system designed to provide security for a carcass disposal operation. For this reason, a technical description of the capabilities of these sensors is provided in Chapter 13, Section 7.

13.6 – Recommendations

Several general recommendations for designing an effective security system for carcass disposal operations are provided. The general recommendations include:

- Plan ahead.
- Include local law enforcement in planning.
- Focus on low-cost, rapidly deployable technologies.
- Provide pre-event training.
- Coordinate efforts.
- Understand the legal issues.
- Integrate security plans with biosecurity protocols and procedures

Additional specific requirements and recommendations need to be developed in collaboration with carcass disposal operations stakeholders.

13.7 – Critical Research Needs

In collaboration with owners, operators, and other stakeholders in carcass disposal operations, security designers must develop the performance goals and design constraints for the security system. A thorough threat analysis will be necessary to identify potential adversaries and credible threat scenarios. This information is required before the system can be designed. Design iterations are to be expected, not only because the facility characteristics change (changes in one part of the system may necessitate changes in other parts), but also because the threat analysis may change.

Chapter 14 – Evaluating Environmental Impacts

Carcass disposal events can result in detrimental effects on the environment. The specific impacts vary by carcass disposal technology, site-specific properties of the location, weather, type and number of carcasses, and other factors. To accurately determine the impacts of a specific carcass disposal event on the environment, environmental monitoring will be necessary. Chapter 14 provides an overview of the monitoring that may be necessary or desirable to quantify environmental impacts for a carcass disposal event.

Environmental models can be helpful in addressing environmental concerns associated with carcass disposal, and can be used at various stages, including:

1. **Prescreening.** Sites can be prescreened using environmental models to identify locations that might be investigated further in the event of an actual disposal event. The models would likely be used with geographic information systems (GIS) to create maps of potentially suitable sites for each carcass disposal technology.
2. **Screening.** In the event of a carcass disposal incident, environmental models might be used to further screen sites and disposal technologies being considered. Such models would require more site-specific data than those used for prescreening.
3. **Real-time environmental assessment.** Models might be used to predict the environmental impact of carcass disposal at a particular location for the observed conditions (site and weather) during a carcass disposal event. These predictions would be helpful for real-time management decision-making, and would provide estimates of environmental impact.
4. **Post-disposal assessment.** Once a carcass disposal event is over, the activities at the location may continue to impact the environment. A combination of monitoring and modeling may be useful to assess the likely impacts.

Some of the most promising environmental models that might be used for the various tasks described above have been reviewed and summarized in Chapter 14. Models were reviewed for water (surface and ground), soil erosion, soil quality, and air. Brief summaries of the models are included.

Chapter 15 – Geographic Information Systems (GIS) Technology

Geographic information systems (GIS) should play a significant role in the management of mapped or spatial data prior to, during, and after carcass disposal events. At the simplest level, GIS can provide maps, while at the more complex level can serve as a decision support capability. Chapter 15 contains an overview of GIS and its applications. Examples of how GIS has been used in recent livestock disease and carcass disposal efforts are also provided.

The site requirements for specific carcass disposal technologies vary, as do their site-specific impacts on the environment. GIS can play a significant role in the analysis or screening of potential sites by considering the requirements of carcass disposal technologies and identifying and mapping locations within a region that meet these criteria. For example, burial sites should be some distance from surface waters and various cultural features, should not impact groundwater, may require certain geologies, and may have other site requirements. The results of analysis of these requirements in a GIS is a map or series of maps that identify sites where carcass disposal technologies would likely be suitable. Further on-site analysis of locations would be required prior to actual site-selection for carcass disposal.

GIS data layers are critical to determining the appropriate use of carcass disposal technologies. Chapter 15 expands on the GIS data layers that would be useful. Checklists describing the data layers that can be used to refine the selection of the specific GIS data layers are included. Note that it is important to collect, organize, and preliminarily analyze data prior to a carcass disposal event due to the time required for such efforts.

Web-based GIS capabilities have improved significantly in the last few years. The creation of web-based GIS capabilities to support carcass disposal efforts could overcome some of the access and other issues related to desktop GIS and make mapped information available to decision-makers and field personnel in real time.

GIS are important in the application of environmental models to address environmental concerns associated with carcass disposal. GIS can provide the data required by these models and can provide visualization of the modeled results in map form.

Chapter 16 – Decontamination of Sites & Carcasses

16.1 – Situation Assessment

The first, and most important, step in the process of decontamination is the identification of the disease agent present.

The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) decontamination procedures manual identifies three categories of viruses that should be considered. These three categories are:

- **Category A** includes those viruses that are lipid-containing and intermediate-to-large in size. These viruses are very susceptible to detergents, soaps, and disinfectants because of their outer lipid envelope. Examples include paramyxoviridae and poxviridae.
- **Category B** viruses are hydrophilic and resistant to detergents. They are also sensitive, but less susceptible to other disinfectants. Classical disinfectants like quaternary ammonium compounds are not effective against them. Examples include picornaviruses and parvoviruses.

- **Category C** viruses are between Category A and Category B viruses in sensitivity to the best antiviral disinfectants. Examples include adenoviruses and reoviruses.

16.2 – Possible Infectious Agents

A list of selected possible infectious agents would include bovine spongiform encephalopathy (BSE), foot and mouth disease (FMD), exotic Newcastle disease (END), swine vesicular disease, vesicular stomatitis, and anthrax. Each of these diseases has specific symptoms and concerns, which are addressed in Chapter 16, Section 2. Table 4 summarizes the information available on these particular diseases, and further information can be gathered by visiting the Animal and Plant Health Inspection Service (APHIS) web sites listed for each agent in the References section of Chapter 16.

16.3 – Six General Groups of Disinfectants

The six most common disinfectant groups include soaps and detergents, oxidizing agents, alkalis, acids, aldehydes, and insecticides. Choosing the correct disinfectant is crucial to ensuring the most efficient decontamination. Example compounds from each group are described in Chapter 16, and summarized in Table 5.

16.4 – Decontamination Preparation

After a presumptive or confirmed diagnosis is made, a state quarantine should be placed on the farm, and a zone of infection established (USDA, 2002e). Within this infected zone, movement restrictions will apply, and no animals or animal products will be allowed to leave.

Decontamination of personnel is essential for the prevention of cross-contamination so that people can leave an infected premise with minimal risk of transporting the disease agent (ARMCANZ, 2000). There should be an area designated near an exit point of the property as the site for personnel decontamination. The area should be decontaminated with the proper disinfectant and be equipped with a water and drainage supply. A disinfectant should be available at this site for anyone entering or leaving the property. Personnel should be provided with overalls, footwear, head covering, gloves, and goggles. All clothing items should be decontaminated by disinfection every time the person enters or leaves the area. Disinfectant mats or wheel baths filled with disinfectant should be accessible at all vehicle entrances and exits. Every effort should be made to ensure that no vehicles leave an infected property without thorough decontamination.

TABLE 4. List of common infectious agents with recommendations on disposal and disinfection (ARMCANZ, 2000; Geering et al., 2001)

Agent	Classification	Preferred Disposal Method	Recommended Disinfectants
BSE/ Scrapie	Prion, non-viral	Bury, burn, or alkaline hydrolysis	Bury or burn any contaminated materials, then use soap and detergent followed by sodium hypochlorite
Avian influenza/ Newcastle	Category A virus	Bury or burn	Soaps and detergents, sodium hypochlorite, calcium hypochlorite, VirkonS®, alkalis
FMD/ Swine vesicular disease	Category B virus	Bury or burn	Acids for FMD; oxidizing agents and alkalis for animal housing and equipment; soaps, detergents, and citric acid for humans
Vesicular stomatitis	Category A virus (vector-borne)	Bury or burn	Soaps and detergents; alkalis and acids; insecticides – organophosphates, synthetic pyrethroids, and Ivermectin®
Anthrax	Bacterial spore	Burn	Formaldehyde, gluteraldehyde, hydrogen peroxide, peracetic acid

16.5 – Property Cleanup

The aim of the cleanup process is to remove all manure, dirt, debris, and contaminated articles that cannot be disinfected. This will allow all surfaces to be exposed to detergents and disinfectants. This is the most crucial phase of the cleanup process because the presence of organic material reduces the effectiveness of disinfectants (ARMCANZ, 2000). All gross organic material should be flushed using a cleaner/sanitizer or detergent compound. The entire building should be treated with a detergent solution and left for at least 24 hours if possible. The detergent or sanitizer must be completely rinsed or flushed away after cleanup is complete.

16.6 – Disinfection

The selected disinfectant should be applied using a low-pressure sprayer, beginning at the apex of the building and working downwards. Disinfectant must be left on surfaces for as long as possible and then thoroughly rinsed. The property should be left vacant for as long as possible before post-disinfection samples are collected (Kahrs, 1995). Upon completion, the premises should be left empty for some period of time and sentinel (susceptible) animals introduced to detect any remaining contamination (Fotheringham, 1995a).

TABLE 5. Background information on six major disinfectant groups (ARMCANZ, 2000; Geering et al., 2001).

Disinfectant Group	Form	Contact Time	Applications	Precautions
Soaps and detergents				
Quaternary Ammonium Compounds (QACs)	Solid or liquid	10 min.	Use for thorough cleaning before decontamination and for Cat. A viruses	N/A
Oxidizing Agents				
Sodium hypochlorite	Concentrated liquid	10-30 min.	Use for Cat. A, B, and C viruses except in the presence of organic material	N/A
Calcium hypochlorite	Solid	10-30 min.	Use for Cat. A, B, and C viruses except in the presence of organic material	N/A
Virkon S®	Powder	10 min.	Effective against all virus families	N/A
Alkalis				
Sodium hydroxide	Pellets	10 min.	Cat. A, B, and C if no aluminum	Caustic to eyes and skin
Sodium carbonate	Powder/crystals	10-30 min.	Use with high concentrations of organic material	Mildly caustic
Acids				
Hydrochloric acid	Concentrated liquid	10 min.	Corrosive, use only if nothing better is available	Toxic to eyes, skin, and respiratory passages
Citric acid	Powder	30 min.	Use for FMD on clothes and person	N/A
Aldehydes				
Gluteraldehyde	Concentrated liquid	10-30 min.	Cat. A, B, and C viruses	Avoid eye and skin contact
Formalin	40% formaldehyde	10-30 min.	Cat. A, B, and C viruses	Releases toxic gas
Formaldehyde gas	Gas	15-24 hours	Cat. A, B, and C viruses	Releases toxic gas

Chapter 17 – Transportation

The transportation of large numbers of diseased animals/carcasses resulting from a natural disaster or terrorism event requires significant planning and preparation in order to prevent further dissemination of the disease to susceptible animal or human populations. Defining and following critical protocols will be essential to the safe and successful transportation of such animals to an off-site disposal location following a disaster. While carcass disposal information is widely available, relatively little is currently predefined concerning the transportation of such cargo.

Specific guidelines should be developed prior to disasters that define necessary preparations, response, and recovery methods for potential animal disease outbreaks and/or significant death losses. Providing transportation equipment operators, supervisors, and drivers with the necessary guidelines and training in the use of personal protective gear, handling diseased animals/carcasses in various states of decay, responding to inquisitive public sources such as the media, and becoming familiar with all pertinent permits and other transportation documents are vital to planned preparation for a disaster. There may be significant health risks, stress variables, manpower issues, and emotional trauma associated with the handling and transportation of diseased animals in an emergency situation. Employers must be prepared to credibly explain the risks and safety precautions necessary to minimize the negative impact a potential disaster can have on the transportation workforce. In addition, workers involved in the transportation between multiple city, county, and state jurisdictions must be made aware of the regulations regarding public health, transportation, agriculture, and the environment of those jurisdictions along the selected travel route.

The logistics issues involved in the transportation of diseased animals or carcasses include the use of skilled labor and necessary equipment to dispose of the potential health threat and/or emotional impact of a visible disaster. As a result of Hurricane Floyd, North Carolina's State Animal Response Team recommends the pre-arrangement of contracts for such resources, including plans for financial reimbursement for such contracts. Local emergency responders must be aware of the process of acquiring these resources and develop resource lists in order to expedite a successful disaster response.

Transportation issues involving off-site disposal include carefully selecting a travel route to limit human exposure, minimizing the number of stops required, and ensuring close proximity to the infected site in order to limit refueling. The load may require special permitting for hazardous waste. There may be a need for prepared public announcements regarding the transportation of diseased animals/carcasses, as well as the need for law enforcement involvement to assist with the safe, uneventful completion of the transportation and disposal process.

When biosecurity is a primary concern, disease confinement is a necessity. Planning for the possibility of disease control may be defined by conducting a vulnerability assessment which will help determine the most likely scenarios that are possible for a breakdown in the transportation process. The response to an incident involves containment and correction of the unfolding situation. Regulatory agencies must be prepared to work together in the best interests of the public in these situations. Emergency managers must assess the situation quickly and quantify information pertaining to the disaster. Completion of a preliminary or initial damage assessment will quantify disaster information necessary to determine response needs.

The physical condition of the diseased animals/carcasses will determine the required transportation equipment. Separate loads are required for live animals and carcasses. Containment within the transport is critical. The location of the selected disposal site will affect load requirements and limits for transportation. Containment of possible pathogenic organisms may require particular vehicles equipped with an absorption and/or liquid collection system. Air-filtering systems will be required for live animal transport, and may be used in carcass transport as well.

A breach in biosecurity is possible during transit. An inspection of the selected travel route may be necessary. For security measures, an escort service may be used to guard against terrorist activity. Upon arrival at the disposal site, biosecurity measures must continue until the completion of disposal. The disposal rate will depend on the method of disposal.

Once disposal is complete, the recovery phase will include the disinfection of transportation workers and equipment prior to returning to the highways. In addition, payment for transportation services must be handled in the recovery phase. An estimate of the cost of animal disposal can be difficult to determine. A unit price contract is commonly used, where costs are assigned to an agreed unit then counted to determine cost. While it is impossible to predetermine an exact transportation cost of a disaster, the development of some pre-established contracts is possible, and can improve the disaster response time. The transportation of diseased animals/carcasses is a part of debris management. In order to improve emergency response time nationwide, cities, counties, and states are developing preestablished debris management contracts. Final recovery phase considerations involve the health and well-being of those involved in the disaster. Post-incident health monitoring and/or counseling should be considered for all who came in contact with the diseased animals.

Finally, the resolution of any incident requires a review of the outcome and the identification of any lessons learned. The transportation of diseased animals/carcasses as a result of a terrorist incident should be carefully reviewed. More documentation of the transportation experience may improve the success of combating a large-scale carcass disposal event. Suggested courses of action include developing an emergency action plan and exercising it, participating in educational training for emergency responders, and maintaining a list of resources and subject matter experts to be consulted upon incident.

Future research should be done on special purpose designs for mass animal transportation. This may include a combination of disposal methods. Issues such as disease containment, processing, and cargo disposal methods regarding transportation are essential to improving emergency response.

Introduction to Part 1 – Disposal Technologies

Whether at the hand of accidental disease entry, typical animal-production mortality, natural disaster, or an act of terrorism, livestock deaths pose daunting carcass-disposal challenges. Effective means of carcass disposal are essential regardless of the cause of mortality but are perhaps most crucial for disease eradication efforts. Rapid slaughter and disposal of livestock are integral parts of effective disease eradication strategies.

Realization of a rapid response requires emergency management plans that are rooted in a thorough understanding of disposal alternatives. Strategies for carcass disposal—especially large-scale carcass disposal—require preparation well in advance of an emergency in order to maximize the efficiency of response.

The most effective disposal strategies will be those that exploit every available and suitable disposal option to the fullest extent possible, regardless of what those options might be. It may seem straightforward—or even tempting—to suggest a step-wise, disposal-option hierarchy outlining the most and least preferred methods of disposal. However, for a multi-dimensional enterprise such as carcass disposal, hierarchies may be of limited value as they are incapable of fully capturing and systematizing the relevant dimensions at stake (e.g., environmental considerations, disease agent considerations, availability of the technology, cost, etc.). Even with a disposal-option hierarchy that, for example, ranks the most environmentally preferred disposal technologies for a particular disease, difficulties arise when the most preferred methods are not available or when capacity has been exhausted. In these situations, decision-makers may have to consider the least preferred means. In such a scenario (one that is likely to occur in the midst of an emergency), there are tremendous benefits of being armed with a comprehensive understanding of an array of carcass disposal technologies. It is on this basis that Part 1 considers, in no particular order, eight separate carcass disposal technologies (see Figure 1).

Decision-makers should come to understand each disposal technology available to them, thereby equipping themselves with a comprehensive toolkit of knowledge. Such awareness implies an understanding of an array of factors for each technology, including the principles of operation, logistical details, personnel requirements, likely costs, environmental considerations, disease agent considerations, advantages and disadvantages, and lessons learned for each technology. The eight chapters comprising Part 1 of this report discuss, technology-by-technology, these very issues. For policymakers interested in technology-specific research and educational needs, these are also provided within each chapter.

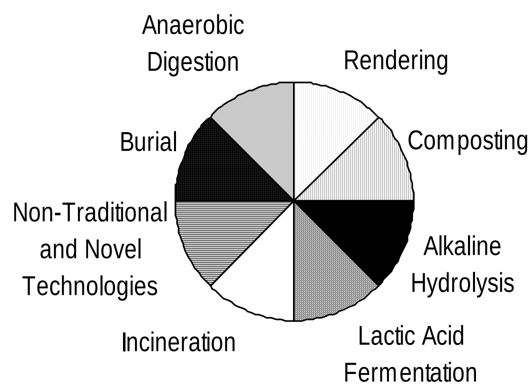

FIGURE 1. Equal consideration given to each of several carcass disposal technologies.

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

1

Burial

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Abbreviations

AI	avian influenza
APHIS	USDA Animal and Plant Health Inspection Service
BOD	biochemical oxygen demand
BSE	bovine spongiform encephalopathy
COD	chemical oxygen demand
CWD	chronic wasting disease
CAFO	confined animal feeding operation
CJD	Creutzfeldt-Jakob disease
DEFRA	UK Department for Environment Food and Rural Affairs (formerly MAFF, UK Ministry of Agriculture, Fisheries and Food)
EA	UK Environment Agency
END	exotic Newcastle disease
EPA	US Environmental Protection Agency
FMD	foot and mouth disease
MAFF	UK Ministry of Agriculture, Fisheries & Food
MSW	municipal solid waste
NAO	UK NAO
RHD	rabbit hemorrhagic disease
SEAC	Spongiform Encephalopathy Advisory Committee
TDS	total dissolved solids
TOC	total organic carbon
Ton	US ton (2,000 lbs)
Tonne	Metric ton (2,204 lbs)
TSE	transmissible spongiform encephalopathy
TVOC	total volatile organic compounds
UK	United Kingdom
US	United States
USDA	United States Department of Agriculture
VOC	volatile organic compounds
WHO	World Health Organization

Section 1 – Key Content

This report addresses three burial techniques, trench burial, landfill, and mass burial sites. For animal disease eradication efforts, trench burial traditionally has been a commonly used, and in some cases, even a preferred, disposal option (USDA, 1981; USDA, APHIS, 1978). In spite of potential logistical and economic advantages, concerns about possible effects on the environment and subsequently public health have resulted in a less favorable standing for this method. Landfills represent a significant means of waste disposal in the US and throughout the world, and have been used as a means of carcass disposal in several major disease eradication efforts, including the 1984 and 2002 avian influenza (AI) outbreaks in Virginia (Brglez, 2003), the 2001 outbreak of foot and mouth disease (FMD) in the United Kingdom (UK) (UK Environment Agency, 2001b), and the 2002 outbreak of exotic Newcastle disease (END) in southern California (Riverside County Waste Management Department, 2003). For purposes of this report, the term "mass burial site" is used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed, and which may incorporate systems and controls to collect, treat, and/or dispose of leachate and gas. Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the information pertaining to this technique is garnered from this event.

1.1 – Burial Techniques

Trench burial

Disposal by trench burial involves excavating a trough into the earth, placing carcasses in the trench, and covering with the excavated material (backfill). Relatively little expertise is required to perform trench burial, and the required equipment is commonly used for other purposes. Large-capacity excavation equipment is commonly available from companies that either rent the equipment or operate for hire. The primary resources required for trench burial include excavation equipment and a source of cover material. Cover material is often obtained from the excavation process itself and reused as backfill.

Important characteristics in determining the suitability of a site for burial include soil properties; slope or topography; hydrological properties; proximity to water bodies, wells, public areas, roadways, dwellings, residences, municipalities, and property lines; accessibility; and the subsequent intended use of the site. Although many sources concur that these characteristics are important, the criteria for each that would render a site suitable or unsuitable vary considerably.

Estimates of the land area that may be required for disposal of mature cattle include 1.2 yd^3 (McDaniel, 1991; USDA, 2001a), 2 yd^3 (Agriculture and Resource Management Council of Australia and New Zealand, 1996), 3 yd^3 (Lund, Kruger, & Weldon), and 3.5 yd^3 (Ollis, 2002), with 1 adult bovine considered equivalent to 5 adult sheep or 5 mature hogs (McDaniel, 1991; Ollis, 2002; USDA, 1980). Excavation requirements in terms of the weight of mortality per volume were estimated as 40 lbs/ft^3 (1,080 lbs/yd^3) (Anonymous, 1973), and 62.4 lbs/ft^3 (1,680 lbs/yd^3) (USDA, Natural Resources Conservation Service, Texas, 2002). One source estimated that a volume of about 92,000 yd^3 would be required to bury 30,000 head of cattle (about 7 acres, assuming a trench depth of 8.5 ft) (Lund, Kruger, & Weldon).

Most cost estimates for trench burial refer only to the use of trench burial for disposal of daily mortality losses, which may be considerably different from those incurred during an emergency situation. Using information adapted from the Sparks Companies, Inc. (2002), costs for burial of daily mortalities were estimated to be about $15 per mature cattle carcass, and about $7-8 for smaller animals such as calves and hogs. Another source estimated about $198/100 head of hogs marketed (however, it is not clear how this estimate relates to actual cost per mortality) (Schwager, Baas, Glanville, Lorimor, & Lawrence). The cost of trench burial of poultry during the 1984 AI outbreak in Virginia was estimated to be approximately $25/ton (Brglez, 2003).

Advantages & disadvantages

Trench burial is cited as a relatively economical option for carcass disposal as compared to other available methods. It is also reported to be convenient, logistically simple, and relatively quick, especially for daily mortalities, as the equipment necessary is generally widely available and the technique is relatively straightforward. If performed on-farm or on-site, it eliminates the need for transportation of potentially infectious material. The technique is perhaps more discrete than other methods (e.g., open burning), especially when performed on-site (on-farm) and may be less likely to attract significant attention from the public.

Disadvantages of trench burial include the potential for detrimental environmental effects, specifically water quality issues, as well as the risk of disease agents persisting in the environment (e.g., anthrax, transmissible spongiform encephalopathy [TSE] agents, etc.). Trench burial serves as a means of placing carcasses "out of site, out of mind" while they decompose, but it does not represent a consistent, validated means of eliminating disease agents. Because the residue within a burial site has been shown to persist for many years, even decades, ultimate elimination of the carcass material represents a long-term process, and there is a considerable lack of knowledge regarding potential long-term impacts. Trench burial may be limited by regulatory constraints or exclusions, a lack of sites with suitable geological and/or hydrological properties, and the fact that burial may be prohibitively difficult when the ground is wet or frozen. In some cases, the presence of an animal carcass burial site may negatively impact land value or options for future use. Lastly, as compared to some other disposal options, burial of carcasses does not generate a useable by-product of any value.

Landfill

Modern Subtitle D landfills are highly regulated operations, engineered and built with technically complex systems specifically designed to protect the environment. Many older landfills in the US (sometimes called small arid landfills) were constructed before Subtitle D regulations were effective, and therefore were not constructed with sophisticated containment systems (US EPA). The environmental protection systems of a Subtitle D landfill are generally more robust than those of a small arid landfill, and would likely be less prone to failure following challenge by high organic loading (as would occur in disposal of large quantities of carcass material). An excellent overview of the design and operation of municipal solid waste (MSW) landfills is provided by O'Leary & Walsh (2002).

In many states, disposal of animal carcasses in landfills is an allowed option; however, it is not necessarily an available option, as individual landfill operators generally decide whether or not to accept carcass material (Wineland & Carter, 1997; Sander, Warbington, & Myers, 2002; Morrow & Ferket, 2001; Bagley, Kirk, & Farrell-Poe, 1999; Hermel, 1992, p. 36; Morrow & Ferket, 1993, p. 9; Kansas Department of Health and Environment, Bureau of Waste Management, 2001a; Kansas Department of Health and Environment, Bureau of Waste Management, 2001b; Fulhage, 1994; Britton; Talley, 2001; Ohio Environmental Protection Agency, 1997; Indiana State Board of Animal Health; Pope, 1991, p. 1124). Whether real or perceived, potential risks to public health from disposing of animal carcasses in landfills will likely be the most influential factor in the operator's decision to accept carcass material, as evidenced by the UK experience during the 2001 FMD outbreak (UK Environment Agency, 2002b; Hickman & Hughes, 2002), and by the Wisconsin experience in disposing of deer and elk carcasses stemming from the chronic wasting disease (CWD) eradication effort (Wisconsin Department of Natural Resources, 2003, p. 127). The US EPA recently outlined recommended interim practices for disposal of carcasses potentially contaminated with CWD agents (US EPA, Office of Solid Waste, 2004).

Because a landfill site is in existence prior to a time of emergency, set-up time would in theory be minimal. However, some time may be required to agree on the terms of use for the site if not arranged in advance (prior to time of emergency). The Riverside County California Waste Management Department developed an excellent training video to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003). The primary by-products resulting from decomposition of wastes, including carcasses, in the landfill are leachate and landfill gas. As per Subtitle D regulations, systems are already in place to collect and treat these outputs and therefore additional systems would not likely be necessary. It is noteworthy that carcass material is likely of greater density and different composition than typical MSW, thus the disposal of significant quantities of carcass material could affect the quantity and composition of leachate and landfill gas generated.

Average fees charged by landfills for MSW in various regions of the US in 1999 ranged from about \$21 to \$58/ton, with the national average approximately \$36/ton (Anonymous, 1999). Fees for disposal of animal carcasses at three different landfills in Colorado were reportedly \$10 per animal, \$4 per 50 pounds (approximately \$160/ton), and \$7.80 per yd^3 (Talley, 2001). As of 2003, fees for carcass disposal in Riverside County, CA, consisted of a \$20 flat fee for quantities less than 1,000 lbs, and \$40/ton for quantities greater than 1,000 lbs (Riverside County Waste Management Department). In Souix Falls, South Dakota, disposal fees for deer and elk carcasses at the city landfill were established as \$50/ton for deer or elk carcasses originating within the state, and \$500/ton for carcasses originating outside the state (Tucker, 2002). During the 2002 outbreak of AI in Virginia, fees at landfills for disposal of poultry carcasses were approximately \$45/ton (Brglez, 2003). During the 2002 outbreak of END in southern California, fees were approximately \$40/ton for disposing of poultry waste at landfills (Hickman, 2003).

Advantages & disadvantages

During an emergency or instance of catastrophic loss, time is often very limited, and therefore landfills offer the advantage of infrastructures for waste disposal that are pre-existing and immediately available. Furthermore, the quantity of carcass material that can be disposed of via landfills can be relatively large. Landfill sites, especially Subtitle D landfill sites, will have been previously approved, and the necessary environmental protection measures will be pre-existing; therefore, landfills represent a disposal option that would generally pose little risk to the environment. (Note that these advantages related to adequate containment systems may not apply to small arid landfills that rely on natural attenuation to manage waste by-products). Another advantage of landfills is their wide geographic dispersion. The cost to dispose of carcasses by landfill has been referred to as both an advantage and a disadvantage, and would likely depend on the situation.

Even though disposal by landfill may be an allowed option, and a suitable landfill site may be located in close proximity, landfill operators may not be willing to accept animal carcasses. Additionally, because approval and development of a landfill site is lengthy, difficult, and expensive, landfill owners and planning authorities may not want to sacrifice domestic waste capacity to accommodate carcass material. Those landfill sites that do accept animal carcasses may not be open for access when needed or when convenient. Landfilling of carcasses represents a means of containment rather than of elimination, and long-term management of the waste is required. Although several risk assessments conclude that disposal of potentially TSE-infected carcasses in an appropriately engineered landfill site represents very little risk to human or animal health, further research is warranted in this area as the mechanism and time required for degradation are not known. Another possible disadvantage associated with landfill disposal is the potential spread of disease agents during transport of infected material to the landfill (a potential concern for any off-site disposal method).

Mass burial

The scale of the 2001 UK FMD epidemic presented unprecedented challenges in terms of carcass disposal, prompting authorities to seek sites on which mass burials could be undertaken. A total of seven sites were identified as suitable and work began almost immediately to bring them into use (5 of the 7 sites were operational within 8 days of identification). In total, some 1.3 million carcasses (about 20% of the total 6 million) were disposed of in these mass burial sites (National Audit Office, or NAO, 2002, p. 74).

The disposal of carcasses in these mass burial sites was a hugely controversial issue and aroused significant public reaction, including frequent demonstrations and community action to limit their use (NAO, 2002, p. 77). Most of the negative reaction stemmed from the haste with which the sites were identified and developed (Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002, p. 778), and the consequences of this haste (including damaged public relations as well as site management issues due to poor design) will undoubtedly be long-lasting and costly. Although UK authorities have indicated reluctance towards use of this disposal route in the future, the potential advantages of the method, when appropriate planning and site evaluation could be conducted prior to time of emergency, warrant further investigation.

As demonstrated by the UK experience, thorough site assessments prior to initiation of site development are critical for minimizing subsequent engineering and operational difficulties. The total amount of space required for a mass burial site would depend on the volume of carcass material to be disposed and the amount of space needed for operational activities. The total land area occupied by the seven mass burial sites in the UK ranged from 42 to 1,500 acres (NAO, 2002). In general, the resources and inputs required for a mass burial site would be similar in many respects, although likely not as complex, as those required for a landfill. However, whereas the infrastructure at an established landfill would be pre-existing, the resources for a mass burial site likely would not.

The estimated total capacity of the various UK mass burial sites ranged from 200,000 to 1,000,000 sheep carcasses (each approx. 50 kg [about 110 lbs]) (NAO, 2002). In terms of cattle carcasses (each approx. 500 kg [about 1,100 lbs]), these capacities would be reduced by a factor of 10. The sites generated tremendous volumes of leachate requiring management and disposal, the strategies for which in some cases were similar to those employed in MSW landfills, although some sites relied solely on natural attenuation. In many cases, leachate was taken off-site to a treatment facility.

Costs associated with the various UK mass burial sites ranged from £5 to £35 million, and the costs of all sites totaled nearly £114 million (NAO, 2002). Based on the estimated total number of carcasses buried at the sites, the approximate cost for this disposal option was about £90/carcass (ranged from approximately £20 to £337 at the various sites) (NAO, 2002). At the Throckmorton site, 13,572 tonnes of carcasses were disposed (Det Norske Veritas, 2003) at an estimated cost of £1,665/tonne.

Advantages & disadvantages

The most significant advantage of mass burial sites is the capacity to dispose of a tremendous number (volume) of carcasses. Assuming adequate site assessment, planning, and appropriate containment systems are employed, mass burial sites may be similar to landfills in terms of posing little risk to the environment. However, tremendous public opposition to the development and use of such sites during the UK experience caused officials to state that it is very unlikely that mass burial sites would be used as a method of disposal in the future (FMD Inquiry Secretariat, 2002). Other disadvantages included the significant costs involved, problems with site design leading to brief episodes of environmental contamination, and the need for continuous, long-term, costly monitoring and management of the facilities. Other potential disadvantages of mass burial sites would be similar to those outlined for landfills, namely serving as a means of containment rather than of elimination, lack of adequate research into long-term consequences associated with various disease agents (especially TSEs), presenting opportunities for spread of disease during transport from farm sites to the mass burial site, and not generating a usable by-product of any value. In spite of these potential disadvantages, mass burial sites could potentially serve as an effective means of carcass disposal in an emergency situation, although thorough site assessment, planning, and design would be required well in advance of the need.

1.2 – Disease Agent Considerations

In general, very little information is available regarding the length of time disease agents persist in the burial environment, or the potential for dissemination from the burial site. Concerns stem from the fact that burial, unlike some other disposal methods such as incineration or rendering, serves only as a means of ridding carcass material, but does not necessarily eliminate disease agents that may be present. The question arises as to the possibility of those disease agents disseminating from the burial site and posing a risk to either human or animal health. The most relevant hazards to human health resulting from burial identified by the UK Department of Health were bacteria pathogenic to humans, water-borne protozoa, and the bovine spongiform encephalopathy (BSE) agent (UK Department of Health, 2001c). Contaminated water supplies were identified as the main exposure route of concern, and the report generally concluded that an engineered licensed landfill would always be preferable to unlined burial.

Generally, the conditions of deep burial and associated pressures, oxygen levels, and temperatures are thought to limit the survival of the majority of bacterial and viral organisms (Gunn, 2001; Gale, 2002); however, precise survival times are unpredictable, and spore-forming organisms are known to survive in the environment for very long periods of time. Survival would be governed by conditions such as temperature, moisture content, organic content, and pH; transport of microbes within groundwater would be affected by the characteristics of the organism as well as the method of transport through the aquifer (UK Environment Agency, 2002a).

The FMD virus is generally rapidly inactivated in skeletal and heart muscle tissue of carcasses as a result of the drop in pH that accompanies rigor mortis (Gale, 2002, p. 102). However, it may survive at 4°C for approximately two months on wool, for two to three months in bovine feces or slurry, and has reportedly survived more than six months when located on the soil surface under snow (Bartley, Donnelly, & Anderson, 2002). Pre-treatment of leachate from the UK Throckmorton mass burial site with lime was discontinued 60 days after burial of the last carcass because FMD virus was reportedly unlikely to survive more than 40 days in a burial cell (Det Norske Veritas, 2003, p. II.21). However, no studies were cited to indicate from what data the 40-day estimate was derived. An evaluation was conducted in 1985 in Denmark to estimate whether burying animals infected with FMD would constitute a risk to groundwater (Lei, 1985). The authors concluded that the probability of groundwater contamination from burial of FMD-infected animals was very small, and that even if virus were able to reach groundwater sources, the concentration would likely be inadequate to present an animal-health risk.

The agents (known as prions) believed to be responsible for TSEs, such as BSE in cattle, scrapie in sheep, CWD in deer and elk, and Creutzfeldt-Jakob disease (CJD) in humans, have been demonstrated to be highly resistant to inactivation processes effective against bacterial and viral disease agents (Taylor, 1996; Taylor, 2000), and the scrapie agent has been demonstrated to retain at least a portion of its infectivity following burial for three years (Brown & Gajdusek, 1991).

Risk assessments conducted in the UK after the BSE epidemic, and after the 2001 FMD outbreak, addressed the issue of survival of the BSE agent in the environment as a result of disposal of infected or potentially infected carcasses (DNV Technica, 1997b; DNV Technica, 1997a; Comer & Spouge, 2001). Ultimately the risk assessments concluded that the risk to human health was very low (could be generally regarded as an acceptable level of risk). The Wisconsin Department of Natural Resources conducted a risk assessment to address the risks posed by disposal of deer and elk carcasses infected with CWD in landfills (Wisconsin Department of Natural Resources, 2002). The risk assessment concluded that the available knowledge about CWD and other TSEs suggested that landfilling CWD infected deer would not pose a significant risk to human health, and the risk of spreading CWD among the state's deer population by landfill disposal of infected carcasses would be small (Wisconsin Department of Natural Resources, 2002). Other sources have also reiterated this finding of very low levels of risk to human health from disposing of TSE-infected animal carcasses in landfill sites (Gunn, 2001; Gale, Young, Stanfield, & Oakes, 1998).

In spite of these risk assessment findings, additional research efforts are needed relative to TSE infectivity in the environment, including the communities of soil microorganisms and animals involved in carcass degradation, effect of anaerobic conditions and soil type on the degradation, persistence, and migration of TSEs in the soil environment, detection systems which can be used to identify infectivity in soil matrices, and a need to validate assumptions on the behavior of TSE agents which have been used in risk assessments (UK

DEFRA, 2002b). In a speech to the US Animal Health Association, Taylor (2001) indicated that "the present evidence suggests that TSE infectivity is capable of long-term survival in the general environment, but does not permit any conclusions to be drawn with regard to the maximum period that it might survive under landfill conditions." In 2003, the European Commission Scientific Steering Committee emphasized that the "extent to which [potential TSE] infectivity reduction can occur as a consequence of burial is poorly characterized" (European Commission Scientific Steering Committee, 2003). Based on this lack of understanding, along with concerns for groundwater contamination and dispersal or transmission by vectors, the committee indicated that burial of animal material which could possibly be contaminated with BSE/TSEs "poses a risk except under highly controlled conditions" (e.g., controlled landfill) (European Commission Scientific Steering Committee, 2003).

1.3 – Implications to the Environment

Animal carcass decomposition

From the point at which an animal (or human) succumbs to death, degradation of bodily tissues commences, the rate of which is strongly influenced by various endogenous and environmental factors (Pounder, 1995). Soft tissue is degraded by the postmortem processes of putrefaction (anaerobic degradation) and decay (aerobic degradation) (Micozzi, 1991, p. 37). Putrefaction results in the gradual dissolution of tissues into gases, liquids, and salts as a result of the actions of bacteria and enzymes (Pounder, 1995). A corpse or carcass is degraded by microorganisms both from within (within the gastrointestinal tract) and from without (from the surrounding atmosphere or soil) (Munro, 2001, p. 7; Micozzi, 1986). Generally body fluids and soft tissues other than fat (i.e., brain, liver, kidney, muscle and muscular organs) degrade first, followed by fats, then skin, cartilage, and hair or feathers, with bones, horns, and hooves degrading most slowly (McDaniel, 1991, p. 873; Munro, 2001, p. 7).

Relative to the quantity of leachate that may be expected, it has been estimated that about 50% of the total available fluid volume would "leak out" in the first week following death, and that nearly all of the immediately available fluid would have drained from the carcass within the first two months (Munro, 2001). For example, for each mature cattle carcass, it was estimated that approximately 80 L (~21 gal) of fluid would be released in the first week postmortem, and about 160 L (~42 gal) would be released in the first two months postmortem. However, the author noted that these estimates were based on the rates of decomposition established for single non-coffined human burials, which may not accurately reflect the conditions in mass burials of livestock (Munro, 2001). Another source estimated the volume of body fluids released within two months postmortem would be approximately 16 m^3 (16,000 L, or ~4,230 gallons) per 1000 adult sheep, and 17 m^3 (17,000 L, or ~4,500 gallons) per 100 adult cows (UK Environment Agency, 2001b, p. 11).

Regarding the gaseous by-products that may be observed from the decomposition of animal carcasses, one report estimated the composition would be approximately 45% carbon dioxide, 35% methane, 10% nitrogen, with the remainder comprised of traces of other gases such as hydrogen sulfide (Munro, 2001). Although this report suggested that the methane proportion would decrease over time, with very little methane being produced after two months, a report of monitoring activities at one of the UK mass burial sites suggests that gas production, including methane, increases over time, rather than decreases (Enviros Aspinwall, 2002b).

The amount of time required for buried animal carcasses (or human corpses) to decompose depends most importantly on temperature, moisture, and burial depth, but also on soil type and drainability, species and size of carcass, humidity/aridity, rainfall, and other factors (McDaniel, 1991; Pounder, 1995; Mann, Bass, & Meadows, 1990). A human corpse left exposed to the elements can become skeletonized in a matter of two to four weeks (Mann, Bass, & Meadows, 1990; Iserson, 2001, p. 384); however, an unembalmed adult human corpse buried six feet deep in ordinary soil without a coffin requires approximately ten to twelve years or more to skeletonize (UK Environment Agency, 2002a; Pounder, 1995; Munro, 2001; Iserson, 2001). In addition to actual carcass material in a burial site, leachates or other pollutants may also persist for an extended period. Although much of the pollutant load would likely be released during the earlier stages of decomposition (i.e., during the first 1-5 years) (UK Environment Agency, 2001b; McDaniel, 1991; UK Environment Agency, 2002a; Munro, 2001), several reports suggest that mass burial sites could continue to produce both leachate and gas for as long as 20 years (UK Environment Agency, 2001b; Det Norske Veritas, 2003).

Environmental impacts

Various works have estimated the potential environmental impacts and/or public health risks associated with animal carcass burial techniques. Several sources identify the primary environmental risk associated with burial to be the potential contamination of groundwater or surface waters with chemical products of carcass decay (McDaniel, 1991; Ryan, 1999; Crane, 1997). Freedman & Fleming (2003) stated that there "has been very little research done in the area of environmental impacts of livestock mortality burial," and concluded that there is little evidence to demonstrate that the majority of regulations and guidelines governing burial of dead stock have been based on any research findings directly related to the environmental impacts of livestock or human burials. They also conclude that further study of the environmental impacts of livestock burial is warranted.

During the 2001 outbreak of FMD in the UK, various agencies assessed the potential risks to human health associated with various methods of carcass disposal (UK Department of Health, 2001c; UK Environment Agency, 2001b). The identified potential hazards associated with burials included body fluids, chemical and biological leachate components, and hazardous gases. Further summaries of environmental impacts are outlined in investigations into the operation of various mass disposal sites (Det Norske Veritas, 2003; UK Environment Agency, 2001c).

Since precipitation amount and soil permeability are key to the rate at which contaminants are "flushed out" of burial sites, the natural attenuation properties of the surrounding soils are a primary factor determining the potential for these products of decomposition to reach groundwater sources (UK Environment Agency, 2002a). The most useful soil type for maximizing natural attenuation properties was reported to be a clay-sand mix of low porosity and small to fine grain texture (Ucisik & Rushbrook, 1998).

Glanville (1993 & 2000) evaluated the quantity and type of contaminants released from two shallow pits containing approximately 62,000 lbs of turkeys. High levels of ammonia, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chloride in the monitoring well closest to the burial site (within 2 ft) were observed, and average ammonia and BOD concentrations were observed to be very high for 15 months. However, little evidence of contaminant migration was observed more than a few feet from the burial site.

The impact of dead bird disposal pits (old metal feed bins with the bottom removed, placed in the ground to serve as a disposal pit) on groundwater quality was evaluated by Ritter & Chirnside (1995 & 1990). Based on results obtained over a three-year monitoring period, they concluded that three of the six disposal pits evaluated had likely impacted groundwater quality (with nitrogen being more problematic than bacterial contamination) although probably no more so than an individual septic tank and soil absorption bed. However, they cautioned that serious groundwater contamination may occur if a large number of birds are disposed of in this manner.

In the aftermath of the 2001 UK FMD outbreak, the UK Environment Agency (2001b) published an interim assessment of the environmental impact of the outbreak. The most notable actual environmental pressures associated with burial included odor from mass burial sites and landfills, and burial of items such as machinery and building materials during the cleansing and disinfection process on farms. The interim environmental impact assessment concluded that no significant negative impacts to air quality, water quality, soil, or wildlife had occurred, nor was any evidence of harm to public health observed. Monitoring results of groundwater, leachate, and landfill gas at the mass disposal sites indicated no cause for concern (UK Public Health Laboratory Service, 2001c).

Monitoring programs

Following the disposal activities of the 2001 FMD outbreak, the UK Department of Health outlined environmental monitoring regimes focused on the key issues of human health, air quality, water supplies, and the food chain (UK Department of Health, 2001b; UK Public Health Laboratory Service); these programs might serve as models for monitoring programs in the aftermath of an animal disease eradication effort. The UK programs included monitoring of public drinking water supplies, private water supplies, leachate (levels, composition, and migration), and surveillance of human illness (such as gastrointestinal infections). Chemical parameters and indicators were reported to likely be better than microbiological parameters for demonstrating contamination of private water supplies with leachate from an animal burial pit, but testing for both was recommended. It was recommended that at-risk private water supplies should be tested for chloride, ammonium, nitrate, conductivity, coliforms, and *E. coli*. Because baseline data with which to compare would likely not exist, caution in interpretation of results was stressed (i.e., increased levels of an analyte may not necessarily indicate contamination by a disposal site; other sources may be involved) (UK Public Health Laboratory Service).

Section 2 – Historical Use

This chapter primarily addresses three burial techniques, namely trench burial, landfill, and mass burial sites. This section contains a brief overview of the historical use of these methods for disposal of animal carcasses.

One burial technique not addressed in this report is that of a "burial pit," which consists of a hole dug into the earth, the sides of which may be lined with concrete, metal, or wood. The bottom of the pit is left exposed to the earth below, and the top is closed with a tight-fitting cover or lid. In the past, this technique was used extensively by the poultry industry as a convenient means of disposing of daily mortalities. However, this technique is not specifically addressed in this chapter, as it is not well-suited to the disposal of large quantities of material, and the use of such pits is generally being phased out due to environmental concerns.

The general frequency with which burial techniques, and other methods, are used by various livestock or food animal operations to dispose of daily mortalities is outlined in Table 1. The information contained in this table was summarized from various reports prepared under the National Animal Health Monitoring System of the Veterinary Services Division of the United States Department of Agriculture (USDA), Animal & Plant Health Inspection Service (APHIS). While these values may not reflect the situation that may occur during an animal health emergency, they provide some insight into the disposal methods used on an ongoing basis to dispose of daily production mortalities.

2.1 – Trench Burial

Background

Trench burial has been used throughout history as a method of carcass disposal. For animal disease eradication efforts in the US, trench burial has traditionally been a commonly used, and, in some cases even a preferred, disposal option (USDA, 1981; USDA, APHIS, 1978). In spite of its logistical and economic advantages, concerns about possible effects on the environment and subsequently public health have resulted in a less favorable standing for this method, especially when large numbers of carcasses may be involved.

TABLE 1. Percent of operations using (percent of mortalities disposed by) various disposal methods. Note values may not total 100% as operations may use more than one disposal method.

Disposal Method	Feedlot Cattle[a]	Dairy Cows[b]	Weaned Pigs[c]	Sheep[d]	Layer Hens[e]
Buried on operation	10.7 (5.3)	22.7	37.8 (11.5)	51.7 (27.1)	--
Landfill	1.6 (0.5)	1.9	--	7.5 (6.9)	--
Rendering	94.4 (94.1)	62.4	45.5 (68.0)	2.3 (4.2)	32.0 (41.4)
Incineration/Burn	--	2.2	11.6 (6.0)	12.9 (7.5)	9.0 (10.4)
Composting	--	6.9	18.0 (12.7)	6.9 (5.0)	15.0 (11.7)
Leave for scavengers	--	--	--	25.3 (47.4)	--
Covered deep pit	--	--	--	--	32.0 (17.9)
Other	0.4 (0.1)	3.9	2.5 (1.8)	2.6 (1.9)	16.1 (18.6)

[a](USDA, 2000a)
[b](USDA, 2002a)
[c](USDA, 2001a)
[d](USDA, 2002b)
[e](USDA, 2000b)

Over time, views on the appropriateness of using trench burial for disposal have changed. For example, at the outset of the 2001 foot and mouth disease (FMD) outbreak in the United Kingdom (UK), on-farm burial was the first preferred means of carcass disposal. However, within a few weeks revised guidelines were issued placing on-farm burial as the least preferred of a list of five disposal options, largely due to concerns about environmental impacts and bovine spongiform encephalopathy (BSE) risks (UK Department of Health, 2001a; Northumberland FMD Inquiry Panel, 2002, p. 61). The panel of one inquiry conducted subsequent to the outbreak disagreed with this sweeping change, arguing that more effort should have gone into identifying suitable burial sites on or near farms (Northumberland FMD Inquiry Panel, 2002, p. 61). Not only in the UK, but within the US and throughout the world, large-scale burial remains a controversial technique during a situation of catastrophic loss.

Use of trench burial for carcass disposal

1984 avian influenza outbreak in Virginia

An outbreak of avian influenza (AI) in Virginia in 1984 resulted in the disposal of 5,700 tons of carcass material (Brglez, 2003). On-site burial was the primary means of disposal during this outbreak, accounting for approximately 85% of the carcasses disposed. Although a variety of trench designs and methods were used early in the outbreak, towards the end of the outbreak burial trenches were somewhat standardized using a width of 20 ft, a depth of 10 ft, with a length necessary to accommodate the quantity of carcasses. Based on the experience of this outbreak, approximately 20 ft^3 were required per 800 lbs of poultry carcasses.

2.2 – Landfill

Background

Landfills represent a significant means of waste disposal in the US and throughout the world. In 2000, approximately 232 million tons of municipal solid waste (MSW) was generated in the US—equivalent to approximately 4.5 pounds per person per day. Although source reduction, composting, and recycling are on the rise, landfills were still used to dispose of approximately 55% of the total MSW generated, or about 128 million tons. Over the past decade, the number of MSW landfills in the US has decreased dramatically from 8,000 in 1988 to 1,967 in 2000; however, average landfill size has increased (US EPA, Office of Solid Waste and Emergency Response, 2002).

The term landfill may conjure up images of what is more appropriately termed a "dump." Up until the 1950s, disposal of refuse in open pit dumps was common; these dumps were generally sited away from areas where people lived and worked and were havens for rats, flies, and other disease vectors. Fires sometimes arose spontaneously, but were also set intentionally to reduce the volume of waste and create more space in the dump. Garbage was generally left open to the elements, resulting in blowing garbage, vermin infestation, overpowering odors of decay, and contamination of streams and groundwater by runoff from rain water (McBean, Rovers, & Farquhar, 1995). The term "sanitary landfill" refers to improvements upon the open dump whereby refuse was covered at the end of each day to minimize these nuisance problems.

In stark contrast to the image of a "dump," the modern MSW landfill is a highly regulated operation, engineered and built with technically complex systems specifically designed to protect the environment. In 1991 the US Environmental Protection Agency (EPA) published the Resource Conservation and Recovery Act (RCRA; 40 CFR Parts 257 and 258). This regulation imposed a variety of requirements designed to protect the environment, including facility design and operating standards, groundwater monitoring programs, corrective action measures, as well as conditions for ultimately closing sites and conducting post-closure monitoring (US EPA, Office of Solid Waste and Emergency Response, 1995, p. 9-18). Sites operating under the design criteria outlined in this regulation are often referred to as "Subtitle D landfills." In addition to the federal Subtitle D regulations, states and local authorities may have additional, or even more stringent, regulatory criteria.

Some key design characteristics required by the Subtitle D regulations include (US EPA):

1. **Location.** Restricts proximity of landfills to floodplains, wetlands, fault areas, etc.
2. **Composite liners.** Upper component must consist of a flexible membrane liner (at least 30 mil thick; 60 mil thickness required if material is high density polyethylene, HDPE), lower component must consist of at least 2 ft of compacted soil with hydraulic conductivity no more than 1 x 10^{-7} cm/sec
3. **Leachate.** Restricts leachate to a depth of less than 30 cm over the liner
4. **Monitoring.** Requires groundwater monitoring systems
5. **Gases.** Requires a means of controlling explosive gases

Many landfills in the US were in existence long before Subtitle D regulations were effective, and therefore were not constructed with sophisticated containment systems (liners, leachate collection and treatment systems, etc). In some circumstances, small landfill facilities (those that accept less than 20 tons of MSW per day) located in arid regions (no more than 25 inches of precipitation annually) may be exempt from some aspects of the Subtitle D regulations, such as the requirement for composite liners. Such facilities may be referred to as "small arid landfills." These sites must demonstrate that the naturally occurring geological conditions provide sufficient protection against groundwater contamination and must verify this protection through groundwater monitoring programs (US EPA). This protection by natural geological conditions is known as "natural attenuation." Natural attenuation refers to the ability of soil to absorb (remove or reduce in concentration) and/or convert the chemical components in leachate (Figure 1). For example, as leachate moves through a clay soil, most of the heavy metals are retained by the soil. Natural attenuation is a variable and relatively unpredictable process, making it difficult to estimate the degree of protection afforded (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-41).

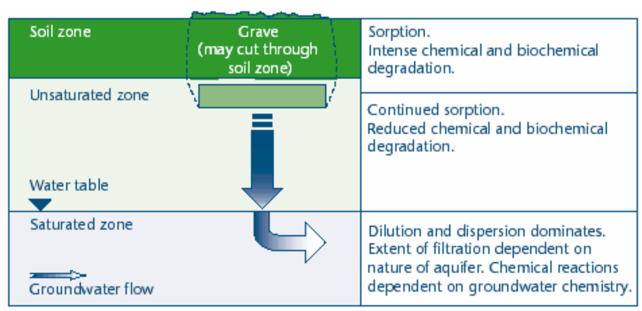

FIGURE 1. Representation of natural attenuation processes (UK Environment Agency, 2002a).

Use of landfills for carcass disposal

1984 and 2002 avian influenza outbreaks in Virginia

In 1984 an outbreak of AI in Virginia resulted in the disposal of approximately 5,700 tons of poultry carcass material. Approximately 15% of this total, or 655 tons, was disposed of in the Rockingham County sanitary landfill (Brglez, 2003, p. 26). From the standpoint of potential groundwater and surface water contamination, the geological and hydrological properties of the site, which was originally used as an unregulated dump, were not well-suited to the disposal of such carcass material. Although subsequent water quality tests from two domestic wells located in relatively close proximity to the site did not indicate groundwater contamination, a 240-fold increase in fecal coliform levels was observed in surface waters near the landfill (Brglez, 2003, p. 24). These environmental concerns resulted in limited use of the site for disposal purposes.

In 2002, this same region of Virginia experienced another, larger outbreak of AI. During this event, a total of approximately 16,900 tons of poultry carcass material was generated for disposal. In this outbreak, commercial landfills played a much more prominent role in the disposal process, as approximately 85% of this total, or about 14,500 tons, was disposed of in landfills (Brglez, 2003, p. 28-30). A summary of the quantity of carcass material disposed at various landfills, and the reported limitations of these landfill sites, is shown in Table 2.

TABLE 2. Carcass disposal by landfill during 2002 Virginia avian influenza outbreak (adapted from Brglez, 2003).

Landfill	Tons of poultry carcasses accepted	Distance from outbreak	Limitations/Problems
Rockingham County	3,400	Closest	Small capacity, odor concerns
Page County	951	40 miles	Small capacity
Frederick County	842		Inadequate capacity to handle leachate; ammonia levels in leachate tripled, and as of March 2003 remain too high for release into surface waters
Charles City	4,610	Over 160 miles	Transportation distance
Sussex County	4,625	Over 160 miles	Transportation distance

Note that the Charles City and Sussex County sites are very large landfills and were both prepared to accept up to 10,000 tons of poultry carcasses. Almost $1 million was paid for the use of both landfill sites. Although the fees charged by these larger landfills were similar to the closer, smaller landfills ($45/ton), significant additional cost was incurred due to the greatly increased transportation distance (Brglez, 2003, p. 30). Transportation proved to be a significant bottleneck, as a given truck could deliver only two loads per day (four-hour round trip) and only 14 appropriately-configured (sealed) trucks were available (Brglez, 2003, p. 30).

BSE epidemic in the UK

Between 1988 and 1991 (the early stages of the BSE epidemic) an estimated 6,000 carcasses infected with BSE were disposed of in 59 different landfill sites around the UK. Most of the landfill sites used for disposal were mature landfills (had been in operation for some time), and most did not have any engineered containment or leachate management systems but were operated as dilute and disperse sites. A risk assessment was undertaken to determine what, if any, hazard these carcasses posed to human health. After determining the most likely source of potential risk would result from possible contamination of leachate, the assessment concluded that the risk of infection was well below an individual risk of 1 in a million years (DNV Technica, 1997a, p. 3).

2001 FMD outbreak in the UK

During the 2001 outbreak of FMD in the UK, a total of approximately 6 million animal carcasses, totaling about 600,000 tonnes, were disposed. Estimates indicate that about 16% of this total (96,000 tons) was disposed of via licensed commercial landfills (UK Environment Agency, 2001b, p. 1). It is interesting to note that, in theory, the available capacity of the licensed commercial landfills could have easily accommodated all of the carcass material disposed during the outbreak. However, opposition by the local public, local authorities, pressure groups, and farmers near the sites was the primary reason for the limited use of this disposal route (Hickman & Hughes, 2002; Hamlen, 2002). Additional factors included BSE concerns, local opposition to heavy transport vehicle traffic carrying carcasses to the sites, operator opposition, cost, and significant transportation distances as large landfill sites were typically located near urban rather than rural centers (NAO, 2002, p. 74). During the outbreak, the UK Environment Agency (EA) (2002b) developed a best practice document for landfills disposing of animal carcasses. The document contains detailed instructions to landfill operators, with special emphasis on biosecurity measures.

During this outbreak, of the 111 landfill sites identified in England and Wales by the UK EA as suitable for carcass disposal, only 29 were used. A total of approximately 95,000 tonnes of carcasses were deposited in these sites, and the majority, 69,000 tonnes, was disposed of in three sites in Cumbria (UK Environment Agency, 2001b, p. 9; NAO, 2002, p. 74). Landfills were also used to dispose of approximately 100,000 tonnes of ash and associated material. Although seemingly significant quantities, these amounts actually represent only a small portion of the 280,000 tonnes of waste generally received at UK landfills on a daily basis (UK Environment Agency, 2001b, p. 9).

2002-03 exotic Newcastle disease outbreak in Southern California

An outbreak of exotic Newcastle disease (END) was confirmed on 1 October 2002 in a backyard farm in southern California. During the eradication effort, approximately 3,160,000 birds were depopulated from 2,148 premises. Landfilling was the primary route of disposal for poultry carcass waste from this eradication campaign. The fee charged by the landfills for accepting this waste was about $40/ton (Hickman, 2003). In the midst of this outbreak, the Riverside County Waste Management Division developed an outstanding training video for landfill operators on how to properly handle waste from this outbreak (Riverside County Waste Management Department, 2003).

2.3 –Mass Burial Site

Background

For purposes of this report, the term "mass burial site" will be used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed. As discussed in the following sections, ideally a mass burial site would be engineered to incorporate systems and controls to collect, treat, and/or dispose of leachate and gas. Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the information pertaining to this technique is garnered from this event.

Use of mass burial sites for carcass disposal

2001 FMD outbreak in the UK

During the 2001 outbreak of FMD in the UK, approximately 6 million animal carcasses were disposed. The scale of this epidemic presented unprecedented challenges in terms of carcass disposal. As a matter of perspective, on the peak day of 5 April 2001, more than 100,000 animals were disposed of for disease-control purposes; in contrast, during the 1967-68 outbreak of FMD in the UK, the peak *weekly* disposal was 13,500 animals (NAO, 2002, p. 73). The need for rapid slaughter of infected or potentially infected animals, combined with the logistical challenges of carcass disposal, created a backlog of slaughtered animal carcasses awaiting disposal that peaked at over 200,000 in early April 2001 (NAO, 2002). Some estimates suggest that in the hardest-hit areas, over a third of farms experienced delays of more than a week from the time animals were slaughtered until they were disposed (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 44). This situation prompted the UK Department for Environment Food & Rural Affairs (DEFRA) to seek to identify sites on which mass burials could be undertaken, preferably sites with impermeable clay soils, far removed from residential properties, but accessible by large vehicles. After rapid assessment of several hundred possible locations, a total of seven sites were identified as suitable and work began almost immediately to bring them into use. In total, some 1.3 million carcasses (about 20% of the total 6 million) were disposed of at these mass burial sites (NAO, 2002, p. 74).

The disposal of carcasses in these mass burial sites was a hugely controversial issue and aroused significant public reaction, including frequent demonstrations and community action to limit their use. The extremely negative public opinion is at least one reason why DEFRA has indicated that this disposal method would not likely be used in the future (NAO, 2002, p. 77). Most of the negative public reaction stemmed from the fact that the sites were brought into use with very little planning or assessment (most pits took less than a week to bring into operation), and in most cases with no input from the surrounding communities. Risk assessments, groundwater authorizations, and planning consents were generally performed retrospectively (Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002, p. 778). Although the use of these sites has been reported by one source to have "saved the campaign," by allowing the disposal rate to catch up to the slaughter rate, the consequences of the haste with which these sites were brought into use will undoubtedly be long-lasting and costly. Although DEFRA has indicated reluctance towards use of this disposal route in the future, the potential advantages of the method, when appropriate planning and site evaluation could be conducted prior to time of emergency, warrant further investigation. A detailed discussion of the technical aspects of the mass burial sites used in the UK is provided later in this report.

Section 3 – Principles of Operation

This section describes the principles of operation for trench burial, burial in landfills, and use of mass burial sites (sites designed and constructed specifically for the disposal of animal carcasses). As stated previously, the "burial pit" technique is not specifically addressed in this report as it is not well-suited to the disposal of large quantities of material, and the use of such pits is generally being phased out due to environmental concerns.

3.1 – Trench Burial

General overview

Disposal by trench burial involves excavating a trough into the earth, placing carcasses in the trench, and covering with the excavated material (backfill). Use of this method is widespread as it is relatively convenient and cheap. Regions where the water table is deep and the soil type is relatively impermeable are best suited to this disposal method. Although burial is generally allowed in most states that regulate carcass disposal, specific regulations differ in terms of burial depth, covering required, separation distances, etc. (Sander, Warbington, & Myers, 2002). Schematic examples of trench burial are provided in Figures 2 & 3 below.

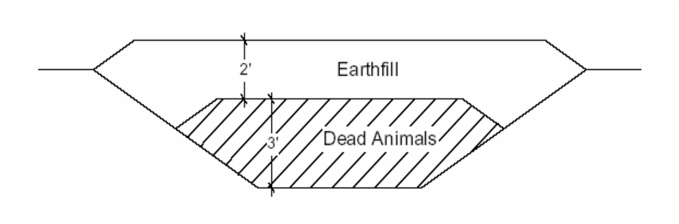

FIGURE 2. Cross section of trench burial (typical for deeper depth for larger animals) (USDA, Natural Resources Conservation Service, Texas, 2002).

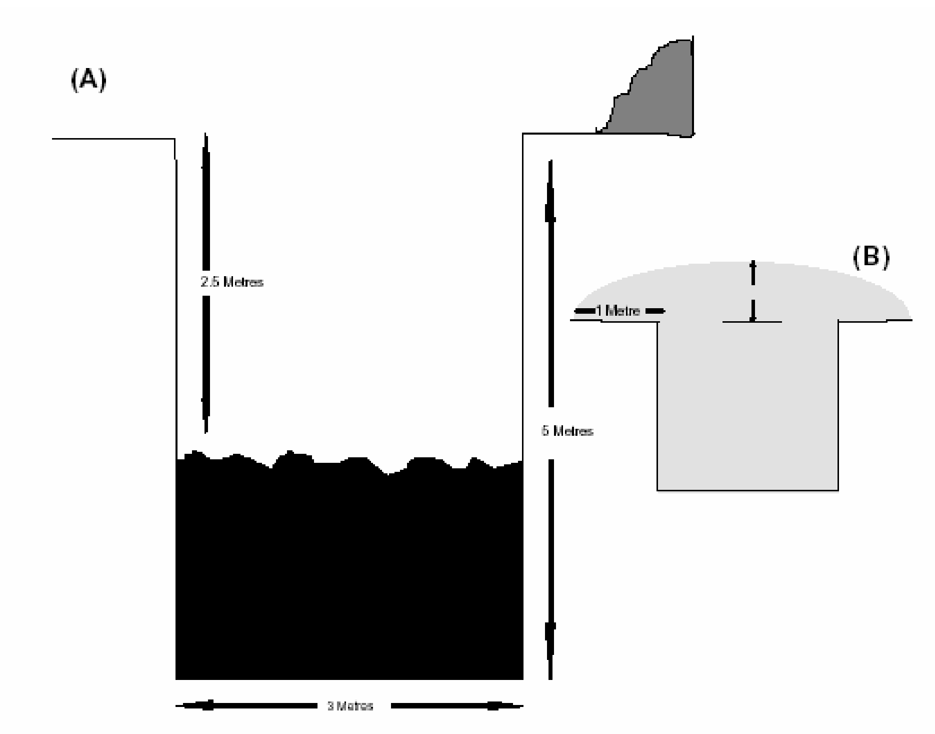

FIGURE 3. Disposal of carcasses by trench burial; (A) open pit; (B) freshly closed pit (Agriculture and Resource Management Council of Australia and New Zealand, 1996).

Expertise and/or personnel requirements

An advantage of trench burial, especially in instances where only small numbers of carcasses are involved, is that relatively little expertise is required and the equipment to perform the operation is commonly used for other purposes. Even in instances where large-capacity excavation equipment is required, companies that either rent the equipment, or operate for hire, are widely available in nearly all geographic areas.

Location considerations

Site selection criteria and regulatory considerations

Several characteristics should be evaluated when identifying a suitable site for the burial of animal carcasses; these characteristics include, but are not limited to the following:

- Soil properties (texture, permeability, surface fragments, depth to water table, depth to bedrock)
- Slope or topography
- Hydrological properties
- Proximity to water bodies, wells, public areas, roadways, dwellings, residences, municipalities, or property lines
- Accessibility
- Subsequent intended use of site

Although many sources concur that these characteristics are important, the criteria for each that would render a site suitable or unsuitable vary. As indicated previously, in states where carcass disposal is regulated, simple trench burial is frequently one of the options allowed. However, state regulations vary considerably in terms of specific criteria required for a suitable burial site. A summary of site selection guidelines, from both literature and regulatory sources, is shown in Table A1 (Appendix).

Space or land area required (footprint)

A variety of sources provide guidelines for the land area required for burial of animal carcasses. A summary of these guidelines is provided in Table A2 (Appendix).

Based on the information in Table A2, estimates of the required excavation volume to accommodate mature cattle carcasses include 1.2 yd^3 (McDaniel, 1991; USDA, 2001a), 2 yd^3 (Agriculture and Resource Management Council of Australia and New Zealand, 1996), 3 yd^3 (Lund, Kruger, & Weldon), and 3.5 yd^3 (Ollis, 2002). Several sources indicate that for purposes of determining necessary excavation volume, one adult bovine can be considered equivalent to five adult sheep or five mature hogs (McDaniel, 1991; Ollis, 2002; USDA, 1980). At least two sources provide estimates of excavation requirements in terms of the weight of mortality per volume. One source suggests approximately 40 lb/ft^3 (1,080 lbs/yd^3) (Anonymous, 1973), while another suggests 62.4 lbs/ft^3 (1,680 lbs/yd^3) (USDA, Natural Resources Conservation Service, Texas, 2002).

One source estimated that a volume of about 92,000 yd^3 (2,484,000 ft^3) would be required to bury 30,000 head of cattle (about 3 yd^3 per carcass) (Lund, Kruger, & Weldon). Based on the assumed trench depth of about 8.5 ft cited by the source, this would be equivalent to about 292,200 ft^2 of land surface, or about 6.7 acres (approximately 5 football fields).

Another source estimated that burial of 25,000 head of cattle would require a trench 13 ft deep (allowing for a cover depth of 6.5 ft), 6.5 ft wide, and 5 miles long (equivalent to about 3.3 yd^3 per carcass) (Ollis, 2002). This would be equivalent to a land surface of about 171,600 ft^2, or about 4 acres (approximately 3 football fields). This same source concluded that 189,852 head of cattle could be buried on a quarter section of land (160 acres), assuming trenches were 13 ft deep, 6.5 ft wide, and spaced about 30 feet apart.

Resource requirements

The primary resources required for trench burial include excavation equipment and a source of cover material. The cover material is often obtained from the excavation process itself and reused as backfill. Equipment needed for the operation is generally widely available either from rental companies or on a for-hire basis via contractors. In circumstances where the soil type is not necessarily conducive to minimizing potential environmental contamination, a source of clay may be needed to supplement the base (bottom layer) of the trench.

Pre-processing requirements

A pre-processing step prior to burial may or may not be warranted depending on the animal species involved. As a carcass decomposes, significant amounts of gas are produced and, when entrapped within the carcass, cause extensive bloating. As a result of bloating, buried carcasses can actually be displaced, shift, or even rise to the surface of a burial pit, similar to the way bodies of drowning victims rise to the surface of water (McDaniel, 1991). To prevent this phenomenon, some sources suggest puncturing or venting carcasses (especially those of large animals) to minimize gas entrapment (Agriculture and Resource Management Council of Australia and New Zealand, 1996). During the 2001 outbreak of FMD in the UK, guidance materials issued jointly by the UK EA and DEFRA included a requirement that all carcasses be ruptured via deep stab wound posterior to the ribs before burial in a landfill to help stabilize the mass (UK Environment Agency, 2002b, p. 9). United States Department of Agriculture (USDA) Animal & Plant Health Inspection Service (APHIS) guidelines for the eradication of FMD also recommend venting the thoracic and abdominal cavities of carcasses prior to burial (USDA, 1980). However, other sources suggest this process may be only minimally effective in preventing entrapment of gases in decaying tissues, and subsequently shifting within burial sites (McDaniel, 1991). It is likely that a venting step would not be practical or necessary for smaller carcasses, such as poultry.

Time considerations

The length of time required to establish a site for trench burial would depend on various factors, including the time required to identify an appropriate site, the time required to gain approval of the site by regulatory bodies (e.g., environmental regulatory agencies), as well as the type and quantity of excavation equipment available. Response time can likely be minimized if these issues are addressed prior to the time of need.

Throughput or capacity constraints

The length of time required to dispose of carcasses via trench burial will depend on (a) the species and total number of carcasses to be buried, since this determines the total excavation area required (refer to Table A2), and (b) the type and availability of excavation equipment, as this determines the time required to excavate the necessary area. An estimate of the typical capacity of excavator-type equipment (i.e., a backhoe) can be roughly equated to the bucket size. Approximately 100 yd^3/hr can be excavated for each yard of bucket size (Martin, 2003). Some general excavation capacities relative to CAT equipment are provided in Table 3.

Estimates of the time required to excavate burial trenches of various volumes using equipment of three different sizes were compiled by emergency planners in Ford County, Kansas. These estimates are summarized in Table 4. While these estimates are useful, it is important to note that the times shown are based on the use of a single piece of equipment; in reality, during an emergency situation it is likely that multiple pieces of equipment would be utilized simultaneously.

TABLE 3. Approximate excavation capacity for various types of CAT equipment (Martin, 2003).

Equipment	Approx. Bucket Size (yd)	Approx. Excavation Per Hour (yd^3)	Equipment Weight (lbs)	Transportability
CAT 320 hoe	1.5 – 2	150-200	45,000	Can haul on one trailer
CAT 322 hoe	1.5 – 2	150-200	52,000	Can haul on one trailer
CAT 325 hoe			60,000	Can haul on one trailer
CAT 330 hoe	3	300	65,000	Can haul on one trailer
CAT 345 hoe	4.5	450		Too large to haul in 1 pc. unless weight restrictions are waived

TABLE 4. Approximate time required to excavate burial trenches of various volume using three equipment types (adapted from Lane, 2003).

Carcass Units @ 1000 lbs ea	Approx. Excavation Volume Required[a]	Approx. Alternative Trench Dimensions (L x W x D)	Approximate Excavation Time (Hours)		
			13 yd scraper (78 cu yd/hr)	15 yd scraper (103.3 cu yd/hr)	27 yd scraper (162.03 cu yd/hr)
5,000	7,500 cu yd (202,500 cu ft)	450 ft. x 45 ft x 10 ft 250 ft x 81 ft x 10 ft	96.2	72.6	46.3
10,000	15,000 cu yd (405,000 cu ft)	450 ft x 90 ft x 10 ft 250 ft x 162 ft x 10 ft	192.3	145.2	92.6
25,000	37,500 cu yd (1,012,500 cu ft)	450 ft x 225ft x 10 ft 180 ft x 562 ft x 10 ft	480.8	363.1	231.5
50,000	75,000 cu yd (2,025,000 cu ft)	450 ft x 450 ft x 10 ft 180 ft x 1125 ft x 10 ft	961.5	726.2	462.9

[a]Assume 1.5 yd^3 of excavation area required per 1000 lb carcass unit.

Clean-up/remediation requirements

Output material generated and means of disposal

The principal by-products resulting from burial of carcasses are those that result from the decay process, namely leachate (liquid or fluid released from the decaying carcasses) and gases such as methane, carbon dioxide, hydrogen sulfide, and others. The quantity of these by-products produced will relate to the volume of carcass material buried. For the most part, these by-products simply represent additional waste streams which, if present in significant quantity, may themselves warrant containment or disposal strategies. Generally these by-products are of no commercial value (although methane generated in significant quantities may potentially be captured for subsequent energy recovery). Additional information regarding the generation of by-products and possible management strategies can be found in the landfill and mass burial sections of this report.

Site or facility remediation issues

As the carcass mass decomposes over time, settlement of the site will occur. Additional backfill may be required to prevent pooling of water at the site and to help restore the natural land surface. Depending on the volume of carcass material buried, some additional remediation steps to contain gas or leachate (similar to those described for landfill or mass burial) may be required.

Cost considerations

Many sources report that burial is a relatively low-cost means of carcass disposal; however, few provide estimates of the actual costs that may be involved. Cost estimates from some sources refer only to the use of trench burial for disposal of daily mortality losses, which may be considerably different from those incurred during an emergency situation.

Costs estimates for trench burial of daily mortalities

A report by Sparks Companies, Inc. (2002) prepared on behalf of the National Renderer's Association evaluated various methods of daily mortality disposal and their potential costs. Estimated costs of on-farm burial of daily mortalities (Table 5) were based on the following assumptions:

- All daily mortality losses are buried, with each mortality buried individually
- All environmental safeguards are followed (although the report does not provide any detail as to the nature of these safeguard procedures)
- All livestock operations could employ on-farm burial regardless of geographic region or climate

- The only direct costs associated with burial are labor (estimated at $10/hr) and machinery (rental or depreciation estimated at $35/hr)

Based on the costs of on-farm burial for all daily mortality losses estimated by Sparks Companies, Inc. (2002), the estimated cost per individual mortality can be calculated (this value is also shown in Table 5). These estimates are likely not representative of the costs that may be incurred during a catastrophic mortality loss, since multiple mortalities would be buried together, rather than individually as estimated here. Furthermore, actual hourly rates for labor and equipment may be significantly different during an emergency than estimated here.

TABLE 5. Costs associated with on-farm trench burial of daily mortalities (Adapted from Sparks Companies, Inc., 2002).

Species	Total Annual Mortalities	Labor Required for Burial per Mortality[a]	Total Hours Required for Burial	Estimated Costs			Estimated Cost Per Mortality[b]
				Total Labor Cost ($10/hr)	Equipment Cost ($35/hr)	Total Cost	
Cattle (over 500 lbs)	1,721,800	20 min ea	573,930	$5,739,300	$20,087,670	$25,827,000	$15.00
Calves	2,410,000	10 min ea	401,660	$4,016,600	$14,058,330	$18,075,000	$7.50
Weaned hogs	6,860,000	10 min ea	1,143,330	$11,433,330	$40,016,670	$51,450,000	$7.50
Pre-weaned hogs	11,067,700	10 min per group of 10	184,460	$1,844,610	$6,456,100	$8,300,780	$7.50 per group of 10
Other	832,700	10 min ea	138,780	$1,387,830	$4,857,300	$6,245,250	$7.50
TOTAL	22,892,200		2,442,160	$24,421,670	$85,476,070	$109,898,030	

[a]Labor = time in minutes to excavate trench, deposit carcass, and backfill trench.

[b]Estimated Cost per Mortality = Total Cost / Total Annual Mortality.

A survey of Iowa Pork Producers Association members was conducted in March 2001 to determine the disposal methods used for daily mortalities, as well as associated costs (Schwager, Baas, Glanville, Lorimor, & Lawrence). Of the 299 respondents, 94 reported using the burial method either alone or in conjunction with other disposal methods. Based on information from 69 respondents, average costs for machinery were estimated to be $50/hr for tractors, trenchers, and backhoes, and $40/hr for skid-loaders. The authors defined the total estimated cost for disposal by burial (including labor, machinery, contractors, and land) as a function of operation size, rather than as a function of the number of mortalities disposed. They estimated that the total cost for burial was approximately $198 per 100 head marketed. However, it is not clear how this estimate may relate to actual cost per mortality.

A report on various carcass disposal options available in Colorado identified the cost of renting excavation equipment as $50-75/hr (Talley, 2001). Based on this estimate, it was suggested that burial may represent a relatively costly option.

Doyle and Groves (1993) report the cost of on-farm burial of daily mortalities in Scotland to be £49-79/tonne. Based on the exchange rate as of 14 October 2003, this would equate to approximately $74-120/ton.

Costs estimates for trench burial of catastrophic mortalities

As stated previously, very little information is available regarding the costs associated with carcass burial during emergency situations. During the 1984 AI outbreak in Virginia, a total of 5,700 tons of poultry carcasses (about 1.4 million birds) were disposed. Approximately 85% of this total (about 4,845 tons) was disposed by trench burial at an estimated cost of approximately $25/ton. This was the same cost that was estimated for disposal in landfills during this outbreak (Brglez, 2003).

Other considerations

Alternate processes

Above-ground mounding is a variation of trench burial in which little or no excavation into the natural surface of the landform is used. Instead, carcasses are placed on top of the natural surface of the land and essentially "buried" within cover material obtained from another source. This technique could prove useful in areas where hydrology and geology are not well suited to trench burial. However, caution may be warranted as carcass material placed in these mounds will still generate leachate and gas and areas poorly suited to trench burial may also represent areas of poor natural attenuation. In the event that natural attenuation is insufficient to control these products of decomposition, environmental contamination may still occur.

Potential for use in combination with other disposal methods

In some situations trench burial may provide a good alternative for the disposal of outputs or by-products from other carcass disposal methods (e.g., ash from incineration processes, etc.).

Use of lime

Various sources discuss the use of lime during burial; however, there appears to be significant disagreement among the various sources as to the appropriateness, and even the intended purpose, of this practice. Some sources suggest that lime should be used to cover carcasses to discourage scavenging by predators, to prevent odors, to retard decomposition (and therefore limit leachate production), or even to hasten decomposition. However, other sources directly contradict these assertions and maintain that lime should not be used because it can slow the decomposition process, the products of which are critical in helping to inactivate disease agents. Following is a listing of selected excerpts from various sources regarding lime use:

- "Lime is not to be used on carcasses because it is believed to retard natural decay processes which in themselves bring about virus inactivation" (USDA, 1980, p. 33).
- Relative to the mass burial site at Throckmorton, "No lime was added to the burial cells because this would also kill the bacteria necessary for degrading the carcasses" (Det Norske Veritas, 2003, p. II.21).
- Lime may be added to prevent earthworms bringing contaminated material to the surface; however, do not place directly on carcasses because it slows and may prevent decomposition (Agriculture and Resource Management Council of Australia and New Zealand, 1996).
- "If quicklime is available, cover carcasses with it before filling. Quicklime will hasten decomposition" (Bilbo & Todd, 1994).
- "Sprinkle lime or fuel oil on carcasses to discourage uncovering by scavengers, and cover with at least 3-4 ft. of soil" (Friend & Franson, 1987).
- "Sprinkle a covering of lime over the carcasses sufficient to help limit liquid production" (California Water Resources Control Board and Regional Water Quality Control Boards, 2003).
- "Slaked lime may be added to the burial pit to break down the tissue of the carcasses, and, in effect, chemically sterilize the remains" (Wineland & Carter, 1997).

3.2 – Landfill

General overview

As discussed in section 2, modern landfills are required to meet design and operating standards outlined in the federal Subtitle D regulations. A schematic of a typical Subtitle D landfill is provided in Figure 4. Key features of the landfill design include composite liners, leachate containment systems, and gas collection systems. It is important to note that sites classified as "small arid landfills" may not include these design criteria, but instead rely on natural attenuation to adequately protect the surrounding environment. The environmental protection systems of a Subtitle D landfill are generally more robust than those of a small arid landfill, and would likely be less prone to failure following challenge by high organic loading (as would occur in disposal of large quantities of carcass material). An excellent overview of the design and operation of MSW landfills is provided by O'Leary & Walsh (2002).

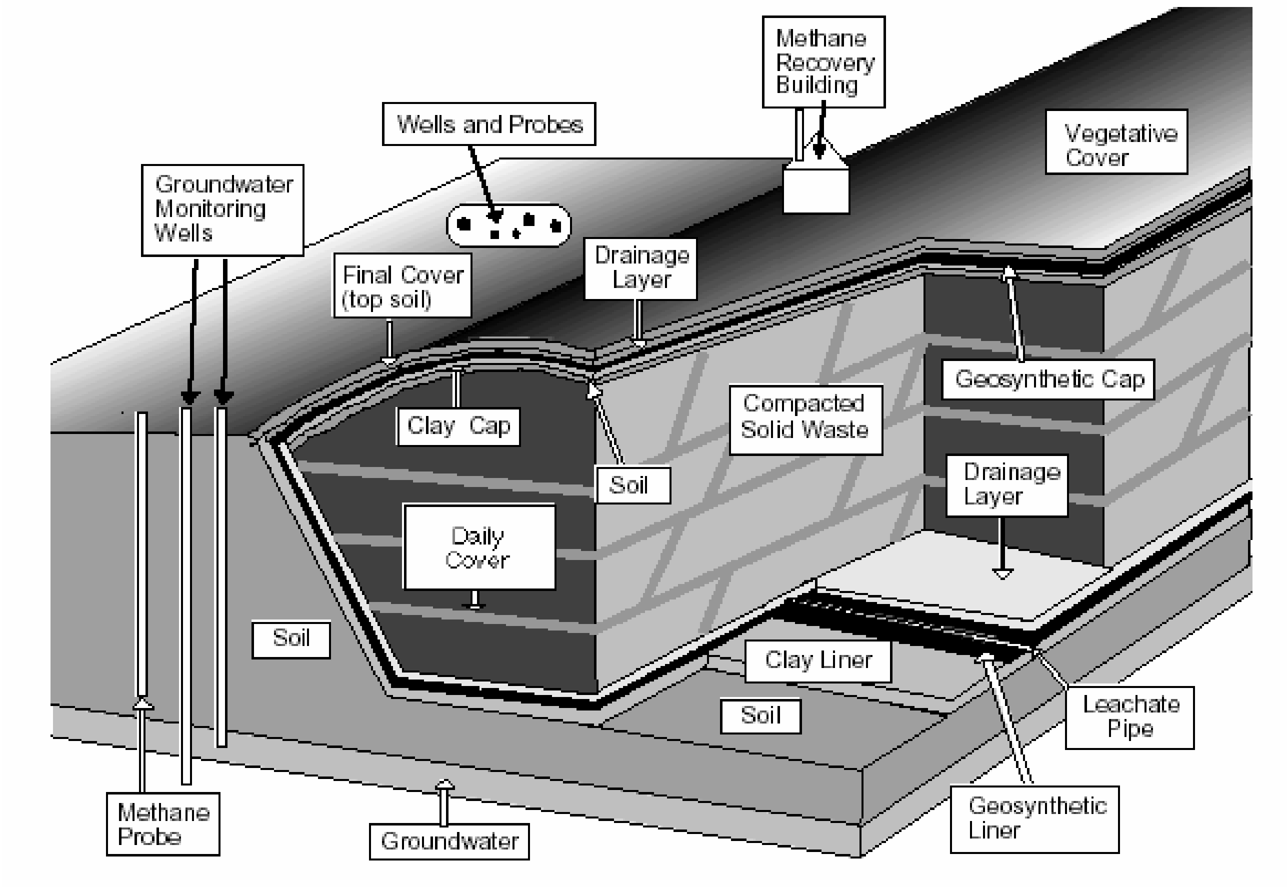

FIGURE 4. Schematic of a typical municipal solid waste (MSW) landfill (US EPA, Office of Solid Waste and Emergency Response, 1995; as reprinted from Waste Age, 1991-1992, P. O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center).

Regardless of whether classified as a Subtitle D or small arid site, the purpose of a landfill is to effectively contain waste such that the components of the waste and/or the by-products of decomposition do not escape into the environment. The environment within a landfill is such that degradation of waste is minimized. In fact, newspapers excavated from landfills after 15-20 years have been observed to be in relatively good condition—even readable (Loupe, 1990).

Various types of refuse contain decomposable matter in varying amounts. Decomposition of waste in a MSW landfill is complex, involving physical, chemical, and biological processes that ultimately result in solid, liquid, and gaseous by-products. These degradation processes fall into three categories:

1. **Physical.** Mechanical action of compaction and the rinsing/flushing action of water (McBean, Rovers, & Farquhar, 1995; The BioScan Group)
2. **Chemical.** Oxidation and acid-metal reactions (The BioScan Group)
3. **Biological.** Three stages: aerobic, acid-phase anaerobic, and anaerobic (methanogenic) (McBean, Rovers, & Farquhar, 1995)

The limiting factor controlling the amount of decomposition taking place in a MSW landfill is usually the availability of moisture (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-32). The primary by-products resulting from decomposition of wastes in the landfill are leachate and landfill gas.

Leachate. Leachate is defined as "a liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste" (US EPA, 258.2). Leachate generation rates depend on the amount of liquid originally contained in the waste (primary leachate) and the quantity of precipitation that enters the landfill through the cover or falls directly on the waste (secondary leachate) (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-33). The composition of leachate changes as a landfill proceeds through various decomposition phases (acetic phase vs. methanogenic phase). If left unmanaged, leachate can be released from the landfill and pollute groundwaters or surface waters.

Subtitle D regulations require liners and leachate control systems to prevent migration of leachate from the site (see Figure 4). Liners provide a hydraulic barrier that impedes the flow of liquids, thus allowing leachate to be captured and removed from the site for treatment and controlled disposal (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-36).

Landfill gas. The anaerobic decomposition of organic materials in a landfill generates a combination of gases, collectively called landfill gas. Uncontrolled landfill gas migration can be a major problem; the gas must be controlled to avoid explosions and damage to vegetation in the vicinity of the landfill. The composition of gas produced is controlled primarily by microbial processes and reactions in the refuse; typically, landfill gas is composed of approximately 50% methane and 50% carbon dioxide (with trace amounts of other gases such as hydrogen, hydrogen sulfide, and carbon monoxide). Methane is typically the gas of concern as it can quickly asphyxiate a person and concentrations as low as 5% are explosive. Subtitle D standards limit the amount of methane present in the atmosphere of a building to 1.25% and in the atmosphere of the soil at the property line of the landfill to 5% (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-43 to 9-47). If left unmanaged, the gas generated in a landfill will either vent to the atmosphere or migrate underground (migration distances of greater than 1,000 feet have been observed). Passive gas control systems (relying on natural pressure and convection mechanisms to vent gas to the atmosphere) are becoming less common due to the unpredictable nature of gas movement in landfills. Active systems employ gas recovery wells or trenches and vacuum pumps to control the migration of landfill gas, and may even allow capture of the gas for energy recovery.

Expertise/personnel requirements

Service or equipment providers

Landfill sites may be privately owned or may be operated by municipalities. A listing of landfills located in various geographic areas can generally be obtained from the state agency which regulates the sites. For example, the Kansas Department of Health and Environment maintains a directory of MSW landfills, transfer stations, construction/demolition landfills, and composting operations located throughout the state. As of March 2003, 33 small arid landfills, 18 Subtitle D landfills, and 50 transfer stations were in operation in Kansas. However, it is important to note that not all landfills accept animal carcasses; this is generally left to the discretion of individual landfill operators.

Personnel requirements

One advantage of landfill disposal is that landfill sites are staffed and operated on an ongoing basis, regardless of the need for disposal of animal carcasses. In the event that a landfill is used to dispose of significant volumes of carcass material during a catastrophic event, it is possible that additional staff may be required as a result of extended hours of operation, additional security or traffic control, or additional biosecurity measures (e.g., cleaning and disinfecting of transport vehicles, etc.).

Regarding the need for education, additional training for landfill employees on the biosecurity measures necessary to prevent the spread of transmissible diseases may be warranted. For this very need, an excellent training video has been made available by the Riverside County California Waste Management Department to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003).

Location considerations

Site selection criteria and regulatory considerations

Most states have regulations that define allowed carcass disposal options, and in many states disposal in landfills is allowed, although different options may be allowed under different circumstances (i.e., normal daily mortality vs. catastrophic mortality). However, the fact that landfilling may be an *allowed* option does not necessarily mean it will be an *available* option; it is generally up to the landfill operator's discretion as to whether or not carcass material will be accepted (Wineland & Carter, 1997; Sander, Warbington, & Myers, 2002; Morrow & Ferket, 2001; Bagley, Kirk, & Farrell-Poe, 1999; Hermel, 1992, p. 36; Morrow & Ferket, 1993, p. 9; Kansas Department of Health and Environment, Bureau of Waste Management, 2001a; Kansas Department of Health and Environment, Bureau of Waste Management, 2001b; Fulhage, 1994; Britton; Talley, 2001; Ohio Environmental Protection Agency, 1997; Indiana State Board of Animal Health; Pope, 1991, p. 1124).

Whether real or perceived, potential risks to public health from disposing of animal carcasses in landfills greatly influences the operator's decision to accept carcass material. For example, during the 2001 outbreak of FMD in the UK, the capacity available in suitably engineered landfill sites (those with adequate containment characteristics, leachate and gas collection and treatment systems, proximity to water protection zones, etc.) could have easily accommodated 100% of the carcasses material generated by the outbreak (approximately 600,000 tonnes). However, opposition by the local public near these sites resulted in only about 16% of the total carcass material (95,000 tonnes) being disposed of by this route (UK Environment Agency, 2002b; Hickman & Hughes, 2002). As a further example, after chronic wasting disease (CWD) was identified in deer in Wisconsin in 2002, the Wisconsin Department of Natural Resources conducted a risk assessment and concluded that disposal of infected deer in Subtitle D landfills did not pose a significant threat to human or animal health. Although landfill operators generally agreed with this conclusion, they were nonetheless unwilling to accept deer carcasses based on the fear of public opposition due to lingering perception of risk to human or animal health (Wisconsin Department of Natural Resources, 2003, p. 127).

Where disposal in landfills is an allowed option, state regulations generally do not impose limitations on which landfills (small arid landfills vs. Subtitle D landfills) may be used for disposal of animal carcasses. However, it would be prudent to evaluate both (a) the volume of mortality and (b) the circumstances by which the mortality arose to determine whether a particular site is suitable for carcass disposal. A qualitative representation of the relative potential risks associated with various disease agents and volumes of mortality are shown in Table 6. Generally, in most cases the more robust environmental protection systems afforded by Subtitle D landfills would make them preferable to small arid landfills.

TABLE 6. Relative potential risk (or degree of uncertainty regarding risk) to public health or the environment resulting from the disposal of carcasses in landfills under various circumstances.

	Mortality Volume	
Disease Agent	**LOW**	**HIGH**
None		
Bacterial, viral		
TSE agent		

Darker shading indicates greater potential risk and/or greater degree of uncertainty regarding risk.

During the 2001 outbreak of FMD, the UK EA identified minimum criteria for determining the suitability of a landfill for disposal of infected animal carcasses (UK Environment Agency, 2002b, Annex 2). The criteria were based on the assumptions that infectivity of material deposited in the landfill would be low and short-lived, and that the carcass material could generate organic loads for up to 20 years after disposal. Key criteria/site characteristics included the following:

1. **Location.** Prohibited use of some sites based on proximity to various source protection zones, aquifers, water tables, floodplains, etc.
2. **Liner.** Required that the base and sides be comprised of at least 1 m of a well engineered clay liner with a permeability of 10^{-9} m/s or less at a hydraulic gradient of 1. Prohibited use of sites that employed a flexible membrane liner alone.
3. **Leachate management.** Required an effective and robust leachate management system to ensure efficient collection of leachate for the next 20 years. Required contingency planning for treatment and disposal of leachate of very high organic loading for a period of at least 20 years.
4. **Gas management.** Required adequate gas management infrastructures to collect gas from the whole of the site.
5. **Monitoring.** Required a monitoring plan for groundwater, surface water, and leachate as well as an associated contingency plan in the event of an identified problem.
6. **Odor & vermin control.** Required effective odor and vermin control plans.
7. **Documentation.** Required documentation of the location, number, and extent of animal carcasses deposited within the site for future reference.

Space or land area required (footprint)

Total landfill space

The space or land area required for a landfill depends on the planned size of the facility, which will be influenced by factors such as the population it will serve, the length of time it will operate, the type of waste it will receive, and various operating parameters (i.e., compaction, etc). As an example of the area required for a landfill, the North Wake County Landfill in Raleigh, North Carolina occupies 230 acres of land, only 70 of which are dedicated to the actual landfill. The additional land is required for support areas such as runoff collection and leachate collection ponds, drop-off stations, buffer areas (50-100 ft), and areas for obtaining or "borrowing" cover soil (Freudenrich).

Landfills are comprised of various sections called "cells." A cell typically contains waste from one day of operation which is covered by six inches of soil (daily cover) (Figure 5).

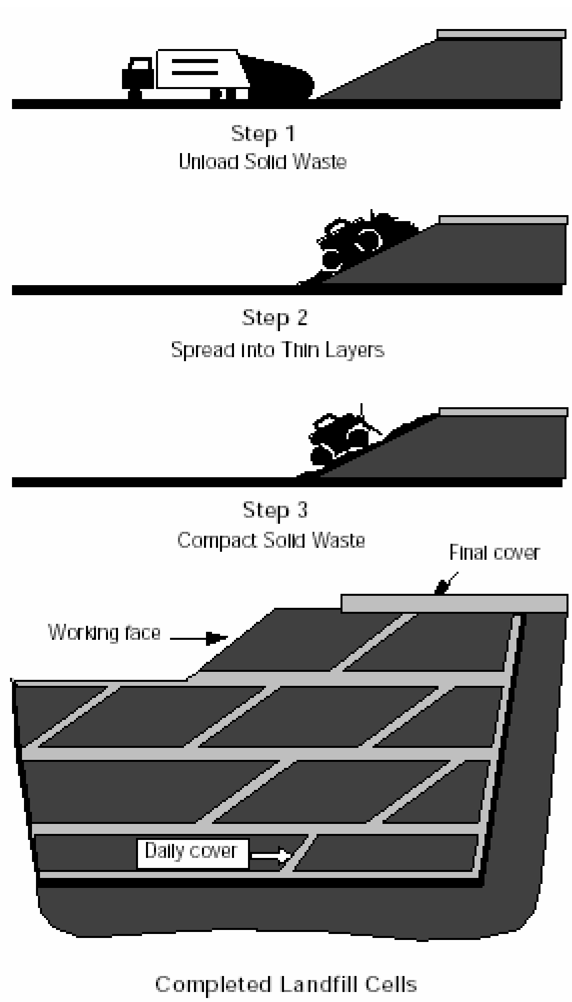

FIGURE 5. Solid waste placement and compaction (US EPA, Office of Solid Waste and Emergency Response, 1995, as reprinted from P. O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center, Waste Age Correspondence Course 1991-1992).

Cells are arranged in rows and layers of adjoining cells called "lifts." The amount of material that can be placed in a cell depends on the original density of the material and the amount of compaction achieved. For example, a typical cell in the North Wake County Landfill is approximately 50 feet long by 50 feet wide by 14 feet high and contains about 2,500 tons of waste compressed at 1,500 pounds per cubic yard (Freudenrich). Table 7 provides typical densities of various common waste materials.

For purposes of comparison, sources have estimated the density of carcass material to be approximately 1,080 lbs/yd^3 (Anonymous, 1973) to 1,680 lbs/yd^3 (USDA, Natural Resources Conservation Service, Texas, 2002). Furthermore, Brglez (2003) reported that 20 ft^3 (approximately 0.74 yd^3) was required to accommodate 800 lbs of poultry mortality. Therefore, the density of this poultry mortality can be assumed to be approximately 1,080 lb/yd^3. These estimates suggest that carcass material would be of greater density than the various types of non-compacted MSW typically received at landfills (Table 7).

TABLE 7. Typical density of various common municipal solid waste materials (adapted from Table 9-1, US EPA, Office of Solid Waste and Emergency Response, 1995).

Waste	Average Density (lbs/yd^3)
Residential (non-compacted)	
Cardboard	85
Plastics	110
Paper	150
Yard trimmings	170
Glass	330
Green grass – loose & moist	400
Food wastes	490
Commercial (non-compacted)	
Wooden crates	185
Food wastes	910
MSW – Compacted	
Compactor truck	500
Landfill – normally compacted	760
Landfill – well compacted	1010

Space required for carcasses

The space required to accommodate a given volume of animal carcass material would likely be similar to the estimates provided for trench burial. For illustration purposes, a typical cell in the North Wake County Landfill was reported to be approximately 50 ft. x 50 ft. x 14 ft (Freudenrich). This is equivalent to 1,296 yd^3. Based on the range of estimated volume of space required per cattle carcass from Table A2 (1.2 to 3.5 yd^3 per carcass), a cell of this size may be anticipated to accommodate from 370 to 1,080 mature cattle carcasses, or 1,850 to 5,400 mature hog carcasses. These wide ranges further highlight the significant variance among estimated burial volumes per carcass. These estimates may be further influenced by the fact that a significant amount of compaction is achieved in a landfill that may not be achieved by trench burial practices.

Resource requirements

In general, the resources and infrastructure necessary to dispose of animal carcasses at a landfill site are much the same as those required to operate the landfill on a daily basis. The purpose of a landfill is to provide a means of disposing of waste, and in some respects animal carcasses simply represent another form of waste. Because the infrastructure of a typical landfill site has already been discussed, it will not be repeated here. In some instances, such as the disposal of large volumes of carcass material resulting from a disease outbreak, resources unique to the disposal of animal carcass material may be required. Examples might include cleaning and disinfecting supplies and additional personal protective equipment.

Pre-processing requirements

As discussed previously for trench burial, puncturing or venting of carcasses (especially for large animals) to minimize gas entrapment may be warranted. During the 2001 outbreak of FMD in the UK, DEFRA required that all carcasses be ruptured before burial in a landfill to help stabilize the mass (UK Environment Agency, 2002b, p. 9). Again, the true benefit of this technique has been questioned.

Site security or biosecurity issues

A certain degree of site security would likely be inherent to a landfill site (e.g., fencing, central entrance, vermin/pest control, etc.). For instances of carcass disposal involving transmissible disease agents, some additional biosecurity measures would likely be warranted as illustrated by the guidelines issued to landfills receiving carcasses during the 2001 FMD outbreak (UK Environment Agency, 2002b), paraphrased as follows.

1. Carcasses shall be buried as soon as practicable following deposit, and must be buried prior to closure at day's end.
2. Carcasses shall not be buried within 2 metres of the final level of the landform.
3. Adequate controls must be in place for birds, vermin, and odor.
4. The area on site where animal carcasses are being deposited should be closed to all non-essential vehicles and personnel. All other vehicles should be kept clear of the area accepting animal carcasses.
5. Cover material should be stockpiled or available above the working face prior to the vehicle arriving at the tipping point.
6. Prepare trenches or pits in advance and tip the vehicle into the hollow under the working face. Where possible, the vehicle should be parallel to the face.
7. Drivers should remain in the cab of the transport vehicle; the tailgate should be opened by site operatives.
8. Backfill material should be placed and compacted into a manner to prevent or minimize contact of the excavator or compactor with carcasses. Compactors should not contact the carcass material until the backfill material is in place.
9. After deposit, the route taken by the transport vehicle on the site should be covered over with material to reduce potential contact with the virus by other vehicles.
10. All site machinery involved in the operation should be jet washed and subsequently disinfected after the carcasses are buried. Cleaning and disinfecting – clean the vehicle with water to remove all debris from the underside of the vehicle and wheels and wheel arches (top down). Clean the inside of the storage compartment. Disinfect vehicle when clean, including the underside, wheel arches, and wheels. All vehicles should then pass through a manual vehicle wheel wash before leaving the site.
11. Drivers and staff must wear personal protective equipment. Areas for showering and changing clothes are recommended when possible. Protective clothing such as overalls and gloves worn by operatives in the area of carcass disposal should be disposable and deposited and buried when the operative leaves the area. Work boots should be washed to remove any debris and operatives should pass through a footbath with disinfectant.

As mentioned previously, an excellent training video was developed by the Riverside County California Waste Management Department to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003). This video highlights appropriate procedures for deterring scavengers, techniques to prevent contamination of equipment and personnel, and appropriate decontamination procedures.

In response to wildfires that occurred in California in late 2003, the agencies responsible for protecting water quality in the state developed recommendations for disposal of animals destroyed by the fires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). Included in those recommendations were guidelines for disposing of carcasses at MSW landfills. A variety of guidelines were outlined in order to avoid fluid-production-related problems, including the following:

- Limiting the thickness of each animal mortality layer to no more than two feet, or in the case of large animals such as cattle, to one animal thickness.
- Covering each layer of animal mortality with an even thicker layer of soil or other absorbent waste.
- If the landfill is composite-lined, depositing no more than two layers of mortality in any given area; if the landfill is not composite-lined,

depositing no more than one layer of mortality in any given area.

- Depositing animal mortality only to portions of the landfill underlain by a considerable thickness of other waste.
- If the mortality is mixed with material containing a significant percentage of water (such as saturated debris), mixing the waste with an absorbent material such as sawdust or soil prior to placement in the landfill.

Time considerations

Construction, set-up, or response time

Because the landfill site is in existence prior to a time of emergency, the set-up time would in theory be minimal. However, some time may be required to agree on the terms of use for the site. This time can be minimized by making arrangements with landfill sites for disposal of carcass material prior to a time of emergency.

Throughput or capacity constraints

The capacity of a landfill site to receive carcass material is dependent on the characteristics of the particular landfill site. Small arid landfill facilities would likely have less capacity than Subtitle D landfill sites. In some cases, restrictions on capacity may be imposed by local or state regulations. For example, during the 2001 FMD outbreak in the UK, government regulations limited the amount of carcass material that could be accepted at a landfill site to 5% of the total weekly waste inputs (UK Environment Agency, 2002b).

As an example of potential landfill capacity for disposal of animal carcass material, over three million birds were depopulated from 2,148 premises during the 2002 END outbreak in southern California, with landfills serving as a primary means of disposal. In addition to carcass material, other outbreak-associated materials, such as eggs and litter, were also disposed by landfill.

Species considerations

Clearly, significant differences exist in the size, weight, and volume of space occupied by carcasses of various animal species; significant differences even exist within a species for animals of various ages. For example, from Table A2, one mature bovine can reportedly be assumed equivalent to approximately five mature hogs, five mature sheep, or 40 market weight broiler chickens. Obviously, a significantly larger volume of space would be required to contain the same number of bovine vs. poultry carcasses.

Clean-up/remediation requirements

Output material generated and means of disposal

The output material resulting from the disposal of animal carcasses in landfills would be generally similar to that resulting from typical MSW: leachate and landfill gas. Because these are normal by-products of the landfill operation, systems are already in place to collect and treat these outputs and therefore no additional systems would likely be necessary. However, because the composition of animal carcasses differs from that of typical MSW, the disposal of significant quantities of carcass material in a landfill could affect the quantity and composition of leachate and landfill gas generated, and may warrant adjustments to the collection and/or treatment systems.

Site or facility remediation issues

Landfill sites are generally designed to be used over a period of decades, and part of the planning process for modern landfill sites includes identifying plans for final use of the site after closure. Therefore, ultimate remediation of a landfill site will have already been determined and would likely not change following use of the landfill to dispose of animal carcasses.

Cost considerations

The fee charged by a landfill for accepting waste is termed a “tipping” fee. For general waste disposal, these fees are based on either weight or volume, and may vary with the type of waste deposited. Average landfill tipping fees for MSW in various regions of the US are shown in Table 8.

TABLE 8. Average tipping fees in 1999 for typical municipal solid waste at US landfills by region (Anonymous, 1999).

Region	1999 ($/ton)
Northeast (CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT)	$57.68
Southern (AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA, WV)	$34.36
Midwest (IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD, WI)	$32.22
Western (AZ, CO, ID, MT, NV, NM, OK, TX, UT, WY)	$21.17
Pacific (AK, CA, HI, OR, WA)	$36.27
National	$36.26

For landfill disposal of small numbers of animal carcasses – such as companion animal remains, carcasses resulting from hunting activities (such as deer or elk), or small numbers of daily mortalities from livestock production facilities – fees may be based either on weight or on the number of carcasses. Fees at three landfills in Colorado were reportedly $10 per animal, $4 per 50 pounds (approximately $160/ton), and $7.80 per yd^3, respectively (Talley, 2001). As of 2003, tipping fees for carcass disposal in Riverside County, California consist of a $20 flat fee for quantities less than 1,000 lbs, and $40/ton for quantities greater than 1,000 lbs. These fees are slightly higher than those charged at the same facility for general MSW because animal carcasses are classified as "hard-to-handle" waste as they require immediate burial (immediate cover) (Riverside County Waste Management Department). Landfill costs for disposing of animal byproducts in European countries range from 30 to 80 Euros per tonne of material (Commission of the European Communities, 2001).

Following confirmation of two cases of CWD in South Dakota, the City Council of Souix Falls established disposal fees for deer and elk carcasses at the city landfill. A mono-fill area (mono-fill indicating waste of only one type) designed to accommodate 10,000 deer carcasses was developed in an unused expansion of the landfill at a reported cost of about $50,000. Fees of $50/ton were established for deer or elk carcasses originating within the state, and $500/ton for carcasses originating outside the state. However, private individuals are exempt from the ordinance and may dispose of up to 10 carcasses without charge (Tucker, 2002).

In situations involving significant volumes of carcass material (e.g., an animal disease outbreak), tipping fees would most likely be based on weight (i.e., per ton of carcass material). Tipping fees do not include costs associated with transportation of carcass material from the site of the outbreak to the landfill. In instances where this distance is great, transportation costs can be significant. Not unique to landfilling, transportation costs would be incurred for any off-site disposal method. During the 2002 outbreak of AI in Virginia, tipping fees were approximately $45/ton for disposing of poultry carcasses at landfills. However, significant additional cost was incurred due to lengthy transportation distance (Brglez, 2003, p. 30). During the 2002 outbreak of END in southern California, tipping fees were approximately $40/ton for disposing of poultry waste at landfills (Hickman, 2003).

Other considerations

Alternate processes

Bioreactors. In the field of MSW disposal, a process known as bioreactor technology is developing. Whereas a landfill is designed to minimize the degradation of waste material in order to lessen the formation of leachate and landfill gas, a bioreactor is designed to promote the degradation of waste through control of aeration and moisture contents. Reported benefits of bioreactor technology include a decreased concentration of most leachate constituents, removal of contaminants by recycling leachate, a reduction in the amount of leachate discharged to water treatment facilities, potential increased recovery of methane as a fuel source, and a reduction in post-closure care and maintenance (Walsh & O'Leary, 2002b; SCS Engineers). Detailed coverage of the history and background of landfill technology, research studies of actual bioreactor landfills, expected leachate and gas yields, specific design criteria, operation guidelines, and reuse of landfill sites to avoid having to establish new sites is provided by Reinhart & Townsend (Reinhart & Townsend, 1998).

Dedicated landfill sites. Several sources mention the creation of a designated landfill site specifically for the purpose of disposing of large quantities of carcasses in the event of an animal health emergency (Australian Department of Agriculture, 2002). This concept is not entirely different from pre-determining appropriate burial sites in advance of an emergency, and would be somewhat analogous to identifying, engineering, and approving mass burial sites in advance of an emergency. This approach has been suggested by several sources (The Royal Society of Edinburgh, 2002; Anonymous, 2002).

Potential for use in combination with other disposal methods

Landfills likely represent an attractive alternative for the disposal of outputs or by-products from other carcass disposal methods, such as ash from incineration processes, meat-and-bone meal or other products of rendering, or residues of alkaline hydrolysis treatments.

Public perception

Depending on the situation, the role of public perception and/or the degree of opposition to the use of a landfills for disposal of animal carcass material may be significant (e.g., 2001 UK FMD outbreak), or essentially negligible (e.g., 2002 California END outbreak). Although landfill capacity could have accommodated 100% of the carcass material requiring disposal during the UK FMD outbreak, only about 16% was disposed of via this route due primarily to significant local opposition (UK Environment Agency, 2001b, p. 1). Conversely, the vast majority of carcass material disposed during the 2002 California END outbreak was disposed of by landfill.

3.3 – Mass Burial Site

General overview

In this report, the term "mass burial site" is used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed. As will be discussed in the following sections, ideally a mass burial site would be engineered to incorporate systems and controls to collect, treat, and/or dispose of leachate and gas.

Simple mass burial sites have likely been used numerous times during animal disease outbreaks. The most common situation would occur when sufficient land area, or appropriate geology, is lacking on one property but is available on a relatively nearby property. In this situation, animals from multiple holdings may be taken to a common burial site for disposal; this merely represents a form of trench burial. In fact the distinction between a large trench burial site and a mass burial site is not necessarily clear and may simply be a matter of opinion. A mass burial site that employs a more sophisticated approach and incorporates containment measures similar to a Subtitle D landfill would perhaps more appropriately be termed an "engineered mass burial site." Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the following information pertaining to this technique is garnered from this event.

Table 9 summarizes various key characteristics of the seven mass burial sites developed during the 2001 UK outbreak of FMD. Note that one of the seven sites, Ash Moor, was ultimately never used for disposal.

Expertise and/or personnel requirements

Development of mass burial sites, especially engineered mass burial sites, would likely be best performed by companies with expertise in the design and construction of Subtitle D landfills. As evidenced by the UK experience, hastily planned or inadequately assessed sites can create significant operational and management problems.

TABLE 9. Mass burial sites created for carcass disposal during the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Site name & location	Former use	Approx. area (acres)	Potential capacity in sheep carcasses (avg sheep carcass = 50 kg)	Approx. actual number of carcasses buried
Great Orton (Watchtree), Cumbria	Airfield	516	750,000	460,000
Tow Law (Stonefoot Hill), County Durham	Former open cast coal working, used for heathland grazing	240	200,000	45,000
Widdrington (Seven Sisters), Northumberland	Open-cast coal working that had been used for landfill	62	200,000	134,000
Throckmorton, Worcestershire	Open farmland	1,549	750,000	133,000
Birkshaw Forest, Dumfries and Galloway, Scotland	Commercial forest	124	1,000,000	490,000
Eppynt (Sennybridge), Powys, Wales	Crown land adjacent to a clay quarry	42	300,000	0[a]
Ash Moor, Devon	Fields and clay pits	101	350,000	0[b]
TOTAL			3,550,000	1,262,000

[a]18,000 carcasses originally buried, but were subsequently exhumed and burned due to groundwater contamination.
[b]By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

Location considerations

Site selection criteria

Sites that would be appropriate for Subtitle D landfill construction would likely also be suitable for engineered mass burial sites. As demonstrated by the UK experience, thorough site assessments prior to initiation of site development are critical for minimizing subsequent engineering and operational difficulties.

As a result of wildfires in late 2003, the agencies governing water quality in the state of California developed recommendations for disposing of animal carcasses associated with the fires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). Included in those recommendations were guidelines for the creation of what was termed an "emergency landfill" for large quantities of carcasses (essentially analogous to a large trench burial site or mass burial site). They noted the difficulties associated with such sites used in the UK during the 2001 FMD outbreak, and recommended such sites (a) be located at least 500 feet from any surface water bodies and any wells, (b) have the base of the excavation at least 10 feet above the historical high groundwater level, and (c) not be located in highly permeable soils such as gravels, sands, loamy sands, old gravel quarries, etc. Recommendations were also made to include adequate containment and collection systems for leachate and gas by-products.

Space or land area required (footprint)

The total amount of space required for a mass burial site would depend on the volume of carcass material to be disposed and the amount of space needed for operational activities. The total land area occupied by the seven mass burial sites in the UK is shown in

Table 9 above. The specific excavation area required to accommodate carcasses would likely be similar to that described for trench burial or landfill (see Table A2). However, in the case of mass burial sites, additional land area beyond that required for actual burial may be required (i.e., for the North Wake County Landfill, only about 30% of the total land area is dedicated to burial of waste, with the remaining 70% required for support areas [Freudenrich]).

The land area required for an "emergency landfill" (analogous to a large trench burial site or mass burial site) was estimated by the California state water control boards in recommendations issued during the 2003 wildfires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). This estimate suggested that a one-acre area, constructed as described below, should accommodate over 1,500 tons of mortality. The following construction guidelines were used in the estimate:

- Excavating the area to a depth of 10 feet.
- Placing two layers of mortality (with 2 ft maximum thickness, or 1 animal thickness in the case of large animals) each covered by a layer of soil 3 feet deep.
- The completed site would have a soil mound about four feet above the original grade, with the top of the uppermost layer of mortality three feet below the original grade.

Resource requirements

In general, the resources and inputs required for a mass burial site would be similar in many respects, although likely not as complex, as those required for a landfill. However, whereas the infrastructure necessary to dispose of animal carcasses at an established landfill would be pre-existing, the resources for a mass burial site likely would not.

Site security or biosecurity issues

The site security and/or biosecurity requirements of a mass burial site would be expected to be similar to those outlined for landfill sites.

Time considerations

Construction, set-up, or response time

As used in the UK FMD outbreak of 2001, mass burial sites were brought online and into use very quickly (the time required to bring mass burial sites into operation is shown in Table 10). Of the six sites that were actually used to bury carcasses, five were receiving carcasses within eight days of being identified as suitable. It should be noted that the haste in which these sites were used caused significant subsequent problems, not only in terms of relations with the surrounding communities, but also in the operational aspects of the sites. Some sites required almost immediate remediation measures to contain leachate as the hastily-derived estimates regarding natural attenuation properties proved inaccurate.

Throughput or capacity constraints

The estimated total capacity of the various mass burial sites is shown above in Table 9. Note that these capacities were estimated based on the number of sheep carcasses that could be contained (one sheep carcass was estimated to weigh 50 kg [about 110 lbs]). These capacities would be reduced by a factor of 10 if reported in terms of the number of cattle carcasses that could be contained (assuming an average carcass weight of 500 kg [about 1,100 lbs]). Additional information for the Throckmorton site provides the estimated number of carcasses buried by species (Table 11). Note from the table that, in spite of the fact that the majority of carcasses buried in the site were sheep (83%), the majority of the mass (64%) was represented by cattle.

TABLE 10. Time required to bring mass burial sites into use, and total time of operation during the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Site Name & Location	Date in 2001			Days from site identification to operation (receipt of first carcasses)	Total days operational (days from receipt of first carcass to receipt of last carcass)
	Identified	Operational	Final Carcass		
Great Orton	23 March	26 March	7 May	3	42
Tow Law	5 April	3 May	28 October	28	178
Widdrington	30 March	3 April	28 May	4	55
Throckmorton	28 March	4 April	19 May	7	45
Birkshaw Forest	26 March	29 March	25 May	3	57
Eppynt	28 March	5 April	14 April	8	9[a]
Ash Moor	15 March	2 May	14 May (mothballed)	48	--[b]

[a]18,000 carcasses were buried, but subsequently exhumed and burned due to groundwater contamination.
[b]By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

TABLE 11. Estimated number of carcasses and approximate total carcass mass by species in Throckmorton mass burial site (adapted from Table VI.2.5, p. VI.10, Det Norske Veritas, 2003).

	Cattle	Sheep	Pigs	Deer	Total
Number of carcasses (% of total carcasses)	17,400 (13%)	111,200 (83%)	4,800 (3.5%)	400 (0.5%)	133,800
Typical carcass mass (kg)	500	40	80	100	
Estimated total mass in tonnes (% of total mass)	8,700 (64%)	4,448 (33%)	384 (2.8%)	40 (0.2%)	13,572

Clean-up/remediation requirements

Output material generated and site remediation issues

Burial of significant numbers of carcasses in mass burial sites, as during the UK FMD outbreak, will create tremendous volumes of leachate requiring management and disposal. Additionally, gaseous products may require management if produced in significant quantities. The strategies and means to contain these by-products may be similar to those employed in MSW landfills. Some examples of the quantities of leachate and/or gas by-products generated by the UK mass burial sites, as well as the containment or remediation systems implemented, follow.

Great Orton (Watchtree), Cumbria. The largest single burial site in the UK is at Watchtree near Great Orton. The facility was designed on a containment principle using the hydrogeology of the site as well as a system of barriers and drains to safeguard against seepage of effluent. The site was originally authorized to receive 500,000 carcasses and, upon completion of burial activities, the site had received a total of 466,312 carcasses, 96% of which were sheep (two-thirds of these sheep were slaughtered on-site) The site also received 12,085 cattle but was prohibited from receiving cattle born before 1 August

1996 (Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

Leachate from the site was initially tankered off-site and discharged directly into the Irish Sea through a long outfall; however, later the material was, and continues to be, processed through wastewater treatment plants in Cumbria and elsewhere. The UK EA reports "some minor localized pollution incidents" due to works on the site, but these reportedly were rapidly brought under control (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 75). Information from the EA suggests that the site will require monitoring for at least 20 years. Reportedly a proposal exists to develop the site into nature reserve.

Tow Law (Stonefoot Hill), County Durham. The design of the site had to take into consideration the high water table in the area in order to contain the products of decomposition (required about four weeks to plan and construct the site). The site consisted of a number of trenches or cells each designed to hold approximately 30,000 carcasses. The cells were designed with sloping sides and were lined with 1-m thick compacted clay. They were then lined with a geo-clay liner to prevent seepage from the cells. Cells were installed with vents, to collect and burn off the gasses produced by decomposition, and with pumps, to remove leachate. The leachate removed from the cells was treated on site to remove FMD virus and then taken away by tanker to a treatment facility (Tow Law Council, 2002).

This site, one of the last to be opened and therefore benefiting from design and construction knowledge gained from the previous sites, was constructed more to landfill specifications with lined pits. Despite this, significant odor issues presented problems adjacent to the site and to surrounding communities, depending on wind direction. Following completion of burial activities, further engineering of the site was necessary to ensure the adequate handling of anticipated winter rainfall (Tow Law Council, 2002).

At the height of the decomposition of the animals in the trenches, 50-60 tankers per week were taking treated leachate from the site to a treatment facility, although leachate production subsequently stabilized at approximately 20 tankers per week (Tow Law Council, 2002).

Widdrington (Seven Sisters), Northumberland. According to the UK EA, the Widdrington mass burial site in Northumberland is located on low lying, level ground close to the sea and on old opencast coal workings (UK Environment Agency, 2001a, p. 10). It was determined that collection and treatment of leachate would not be necessary and therefore the site was constructed using a "dilute and disperse" concept – that is, no measures are in place to contain leachate from the site. Effluent from the burial pits soaks into permeable backfill, and there are no surface waters, streams, or springs which can be polluted by effluent from the burial pits. The fact that the groundwater at this site is below sea level means that surface outflows of groundwater contaminated with effluent could not occur. Natural attenuation during flow through the thick unsaturated backfill is expected to greatly assist in rendering less harmful the effluent from the burial. The groundwater below the burial pits is already contaminated by the old opencast and deep mining activities in the area and is, for all practical purposes, unusable. Minewater pumping to the sea will continue indefinitely to prevent the overflow of the minewater into streams and rivers in more sensitive locations (UK Environment Agency, 2001a, p. 10).

Throckmorton, Worcestershire. A comprehensive detailing of the design, construction, and operating aspects of the Throckmorton site are provided in Det Norske Veritas (2003). In this geographic region of the UK, the high water table and unsuitable soil conditions effectively ruled out on-site burial in the majority of cases. The Throckmorton site, an unused airfield owned by the UK Ministry of Defense, was chosen as likely to be most suitable for mass burial because it offered good access and, in terms of geology, the advantage of relatively impermeable layers of clay subsoil. The UK EA conducted a prior assessment of the site and concluded the risk to surface waters and groundwater was minimal (UK DEFRA, 2002a, p. 5).

Nine cells, each approximately 50 m in length, 25 m wide, and 5 m deep, were dug to contain the animal carcasses. The cells were not lined. Prior to placement of carcasses, drainage systems (consisting of basal drainage trenches and extraction wells) were installed to collect and remove leachate. Carcasses were buried over a period of about seven weeks (4 April to 19 May 2001). Six of the nine cells were ultimately used for burial of a total of 133,000 carcasses (similar in number, though a greater tonnage, than at Widdrington) (UK DEFRA, 2002a, pp. 8-9). In addition to carcasses which had been sprayed with disinfectant, plastic sheeting, straw and materials such as sawdust were buried in the cells. Estimates suggest that the decay should be substantially complete within 5 to 20 years (UK DEFRA, 2002a, p. 9).

After burial had commenced it was recognized that limestone bands, many times more permeable than clay, intersected the burial pits and represented a potential pathway for migration of leachate into the environment. As a remediation measure, an in-ground clay wall (barrier) 7-14 m deep was constructed in stages over an 18-month period to encircle the site (Det Norske Veritas, 2003, p. 3). The objective was to isolate the limestone bands in contact with the cells from the surrounding strata. During construction, leachate was observed seeping into portions of the excavation for the clay barrier, indicating leachate had escaped from the cells and entered groundwater (Det Norske Veritas, 2003, p. II.11). A schematic representation of a cell in the Throckmorton site is provided in Figure 6.

Risk assessments indicated that without the clay barrier, unacceptable levels of ammonia and dissolved organic carbon would have reached a nearby watercourse in about 80 days, and would have remained above the target concentration for over 100 years. In contrast, the time required for unacceptable levels of ammonia to cross the clay barrier was estimated to be 200 years; however, once past the clay barrier, only 42 additional days would be required to reach the nearby watercourse, demonstrating that the low permeability of the barrier was essential to containing leachate (Det Norske Veritas, 2003, p. II.36).

Leachate was pumped from the cells, held in storage tanks, and periodically tankered away by road to a licensed sewage treatment site (UK DEFRA, 2002a, p. 9). During the nine-month period from April 2001 to January 2002, the total quantity of leachate removed from the site was 7,651 tonnes, suggesting an annual quantity of about 10,000 tonnes (Det Norske Veritas, 2003, p. VI.11). The total quantity of leachate collected from the site between the beginning of February 2002 and end of February 2003 (393 day period) was 4,848 m^3 (4,848,000 L, or ~1,280,706 gallons), which is equivalent to about 12.3 m^3/day (12,300 L/day, or 3,249 gallons/day).

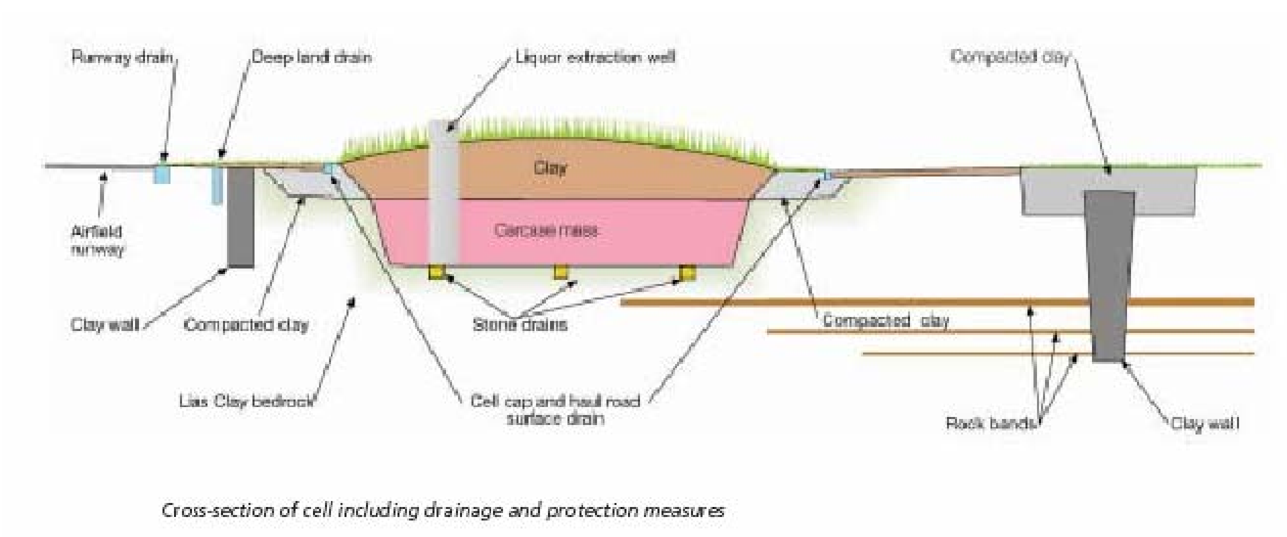

FIGURE 6. Schematic (cross-section) of cell at the Throckmorton mass burial site (UK DEFRA, 2002a).

A sample of leachate analyzed for suspended solids indicated a content of 2 g per liter of leachate, which would therefore give a suspended solids content of 25 kg/day, or 9 tonnes per year. Based on an estimated total carcass mass of 13,572 tonnes contained in the site, the annual fraction of suspended solids released is then estimated as 9/13600 = 6.6 x 10^{-4}. Assuming this flow remained constant for 20 years, this would result in the release of about 1.3% of the original disposed mass. Other estimates have indicated 0.7% for burial in shallow pits (DNV Technica, 1997b, App III.5.4) and 0.07% for burial in landfills (DNV Technica, 1997b, App III.6.3).

During operation, site gas was recorded as bubbling through ponded water on the site, although no damage to vegetation was recorded. No specific provision had been made for gas management other than gas vents from the deep ground drain. Subsequently, consideration has been given to the installation of a gas collection network as part of the final capping of the cells (Det Norske Veritas, 2003, p. II.12). No comprehensive measurements are available to estimate the quantity of site gas being generated. Although it is possible to estimate the quantity of gas generated at municipal waste sites, these methods may or may not be applicable for carcass burial sites. Based on estimates for MSW landfills, the quantity anticipated for the carcass disposal site was estimated to be about 2 kg of methane per tonne of waste per year. Based on a total of 13,600 tonnes of carcasses disposed in the site, this suggested a methane generation rate of 41,000 m^3 per year, or 27,000 kg per year (10^{-3} kg/s) from the site as a whole. This is reportedly an extremely low rate (Det Norske Veritas, 2003, p. VI.24).

Eppynt (Sennybridge), Powys, Wales. Preliminary hydrogeological investigations indicated that the geology of this site was of low permeability and published maps indicated the groundwater in this location was of "low vulnerable" status (UK Environment Agency, 2001c, p. 5). The site was adequately distant from licensed surface and groundwater abstractions, private water supplies, and surface water courses (500 m from the nearest surface water course) (UK Environment Agency, 2001c, p. 5). A quantitative risk assessment was performed using risk assessment software and a range of inputs for geological, hydrogeological, and geochemical parameters (described in detail in UK Environment Agency, 2001c, p. 9). The results of the computer modeling indicated the site would be suitable for mass burial. However, it was noted that further assessment and monitoring would be required to confirm the assumptions and conclusions from the modeling (UK Environment Agency, 2001c, p. 9).

A number of design measures were required for the site by the UK EA to ensure groundwater and surface water protection, including the following (UK Environment Agency, 2001c, p. 6):

- **Leachate collection systems.** Gravel drainage trenches running to collection sumps which were connected to leachate extraction wells.
- **Cover.** Replacement of soil removed during pit construction was required to encourage runoff.
- **Capping.** Placement of an impermeable membrane just under the topsoil layer to prevent surface water ingress into the pit.
- **Surface water diversion.** Construction of a cut-off ditch along the up gradient side of the pit was required to divert surface water.
- **Monitoring.** Boreholes were required for monitoring groundwater quality and levels.

In addition, a system of gas management was to be required. However, it was thought to be inappropriate to immediately construct a venting system for the gas due to the remote possibility that any virus in the carcasses could escape with the gas. Instead, the pit was to be sealed for a period of at least 40 days (the authority's estimation of the longevity of the virus) before venting the methane (UK Environment Agency, 2001c, p. 13).

Burial at the Sennybridge site commenced on 6 April 2001, but ceased just 5 days later due to significant escape of leachate from the site and the resulting threat to surface waters. In fact, all carcasses already buried at the site were exhumed and subsequently burned (UK Environment Agency, 2001d).

Ash Moor, Devon. The Ash Moor site, located adjacent to a clay quarry, was developed for use as a mass burial site but ultimately was never used for burial of carcasses. By the time the site was operational, the urgent need for disposal capacity had passed. Had the site been fully developed, it would have consisted of 15 lined cells which, once filled, would have been capped with additional liners followed by topsoil so that they would resemble raised barrows. Initially it was calculated that the site could accommodate 350,000 sheep carcasses. This figure was subsequently revised following experience at other sites, and was ultimately considered that it could take more than twice the original estimate. Three cells were excavated and lined; a fourth was excavated but not lined. The original intent was to have three cells in use at any one time – one being capped, one being filled, and one being excavated. This working procedure was designed to minimize odor and soil movements. The rest of the site was cleared in preparation for rapid excavation and use. The cells were lined with three liners using methodology employed in waste disposal sites. In addition, separate pipes were laid to extract leachate and methane. The leachate would have been disposed at an approved disposal site and the methane would have been burnt off by flare on-site (Workman, 2002).

Birkshaw Forest, Dumfries and Galloway, Scotland. During peak culling operations at the Birkshaw Forest mass disposal site (around the first week of May 2001), leachate disposal peaked at 400,000 liters per day. Leachate was pumped into static holding tanks which were treated with sodium hydroxide to raise the pH (Enviros Aspinwall, 2001c). As of October 2002, almost 18 months after burial operations ended, an estimated leachate production rate of 3.3 tonnes per day was observed (1-2 tankers per week). The leachate was reported to display characteristics of a high-strength, methanogenic leachate (Enviros Aspinwall, 2002b). Monitoring of gas at the Birkshaw Forest site demonstrated no measured methane at any boreholes in May 2001 (Enviros Aspinwall, 2001c), June 2001 (Enviros Aspinwall, 2001a), or August 2001 (Enviros Aspinwall, 2001b). Measured carbon dioxide levels were recorded as high as 4.2% in May 2001 (Enviros Aspinwall, 2001c), 2.5% in June 2001 (Enviros Aspinwall, 2001a), and near atmospheric levels in August 2001 (Enviros Aspinwall, 2001b). In December 2001, boreholes demonstrated sporadic instances of elevated methane and carbon dioxide levels; however, leachate extraction wells demonstrated methane levels occasionally as high as 38.5% (Enviros Aspinwall, 2002b). It was concluded that the marked increase in gas activity was consistent with maturing waste and did not represent a significant risk.

Cost considerations

The reported costs of mass burial sites used during the 2001 UK FMD outbreak are shown in Table 12. Based on the estimated number of carcasses buried at each site, the approximate cost per carcass has been calculated. Although cost per tonne would be a more preferred basis for comparison, for all sites except Throckmorton it was not possible to determine this value because few reports provided either the total weight of carcasses buried at each site, or the number of carcasses by species at each site (although reportedly the majority of carcasses were sheep). For the Throckmorton site, based on an estimated total weight buried in the site of 13,572 tonnes (see Table 11), the cost of using this site on a per-tonne basis is estimated to be £1,665/tonne.

Other considerations

Possible future technological improvements or alternate processes

The sites were constructed with varying complexities of environmental protection systems. Some sites were designed and constructed with sophisticated containment systems similar to those outlined in Subtitle D standards; however, some relied completely on natural attenuation to manage leachate (i.e., no engineered drainage, collection, or pumping system for leachate). In the future, sites such as these should all be planned, designed, and constructed in a manner similar to Subtitle D landfill requirements. This will likely not be possible if all planning and design takes place during the time of emergency, as was the case in the UK. If mass burial sites are to be a carcass disposal option, preliminary planning, assessment, and design work must be done in advance of the actual need.

TABLE 12. Estimated expenditures on mass burial sites resulting from the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Mass Burial Site	Cost in million £: Purchase (includes purchase and/or rent)	Initial construction, operation, & maintenance	Est long-term restoration and maintenance	Estimated total	Est. no. carcasses buried	Approx. cost (£) per carcass[a]
Great Orton	3.8	17.9	13.4	35.1	460,000	£76.30
Tow Law	0.5	7.6	7.1	15.2	45,000	£337.77
Widdrington	0.5	3.2	1.4	5.1	134,000	£38.06
Throckmorton	3.9	11.4	7.3	22.6	133,000	£169.92
Birkshaw Forest	0.5	5.0	4.5	10.0	490,000	£20.41
Eppynt	--	18.5	0.4	18.9	0[b]	--
Ash Moor	0.3	5.5	1.2	7.0	0[c]	--
TOTAL	9.5	69.1	35.3	113.9	1,262,000	£90.26

[a]Approx cost per carcass = Estimated total cost / Est. no. carcasses buried.
[b]18,000 carcasses originally buried, but were subsequently exhumed and burned due to groundwater contamination.
[c]By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

Public perception

As evidenced by the UK experience, there was tremendous public opposition to the use of mass burial sites, sometimes even escalating to the point of violence and vandalism. Because burial of such large numbers of animals in one site had not been done previously, the public viewed the operation as an experiment conducted at their expense. Much of the opposition was likely well-founded given that (a) thorough site assessments were not performed until after burial operations had commenced (in some cases until after burial operations were already completed), (b) surrounding communities, and even local regulatory bodies were not consulted prior to commencement of the operations, and (c) in one case the site chosen and approved by desktop analysis was subsequently proven to be unsuitable as evidenced by leachate escape, and the 18,000+ carcasses buried there had to be exhumed. Some additional examples of public opposition to various mass burial sites are provided below.

Great Orton (Watchtree), Cumbria. From its inception, disposal efforts at Watchtree were highly contentious. During construction and disposal, great disruption and distress was reported by the local communities; large numbers of heavy transport vehicles and the pervasive smell from the site were major problems until late 2001. Because the site is government owned, local planning approvals were not required, and the local authorities reported little or no pre-consultation. Concerns regarding long-term regulatory and enforcement issues continue to be expressed by the local authorities and the community (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 74). The way in which the Watchtree mass burial site was established left a legacy of resentment amongst the nearby local communities. The Cumbria inquiry panel recommended that the operators of the Watchtree mass burial site build on existing initiatives to ensure that complaints of smell or other environmental intrusions on the local community be fully addressed (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 81).

Tow Law (Stonefoot Hill), County Durham. Because the site was purchased by the government, use of the site was authorized without normal planning procedures, which caused great concern within the surrounding community. The former mining activities conducted on the site (resulting in numerous shafts on the site) caused the stability of the site to be of concern to local residents. A risk assessment was carried out concurrently with, rather than prior to, site construction (Tow Law Council, 2002). From the community standpoint, a major concern was the seemingly experimental nature of the site in that carcasses had never been buried on such a scale before, and, therefore, no models existed on which to base safety conclusions (Tow Law Council, 2002).

Widdrington (Seven Sisters), Northumberland. As with other mass burial sites, the local community expressed significant opposition to the site, to the extent that protests were staged. A local liaison committee was formed and detailed many of the community issues in a submission to the Anderson inquiry (Widdrington FMD Liaison Committee).

Ash Moor, Devon. Although this site was engineered to the highest standards, there remained significant active opposition to the site. Due to the urgent nature of the disposal problem, normal planning and consultation processes were not followed, planning applications were filed retrospectively, and environmental impact assessments were not completed prior to development. Opposition was most vocal from the non-farming community whose concerns included accidental leakages from the pits and from transport to and from the site (Workman, 2002). The site was purchased at a cost of £295,000, and construction of the site cost more than £5 million. Local opinion is that the site should be restored to its former condition, though restoration would be costly. Another alternative would be to mothboll the site, perhaps by making ponds out of the cells but retaining the ability to convert the site back to its original purpose in the event of a subsequent outbreak (Workman, 2002).

Section 4 – Disease Agent Considerations

This section includes information on the fate of selected disease agents (bacterial, viral, and prion) as a result of burial of infected animal carcasses. In many cases, very little information is available regarding (a) the length of time disease agents persist in the burial environment, or (b) the potential for dissemination from the burial site.

Concerns relative to disease agents stem from the fact that burial in and of itself is not a decontamination technique. That is, unlike some other disposal methods such as incineration or rendering, burial serves only as a means of ridding carcass material, but does not necessarily eliminate disease agents that may be present. The question arises as to the possibility of those disease agents to disseminate from the burial site and represent a risk to either human or animal health.

During the 2001 outbreak of FMD in the UK, the Department of Health prepared a rapid qualitative assessment of the potential risks to human health associated with various methods of carcass disposal (UK Department of Health, 2001c). The most relevant hazards to human health resulting from burial were identified as bacteria pathogenic to humans, water-borne protozoa, and BSE. The main potential route identified was contaminated water supplies, and the report generally concluded that an engineered licensed landfill would always be preferable to unlined burial. In general terms, the findings of the qualitative assessment relative to biological agents are summarized in Table 13.

4.1 – Bacterial Agents

Non-spore-forming organisms

Little information is available specifically concerning the survival of non-spore-forming bacteria and subsequent dissemination from actual carcass burial sites. Generally, the conditions of deep burial and associated pressures, oxygen levels, and temperatures are thought to limit the survival of the majority of such organisms (Gunn, 2001).

TABLE 13. Potential health hazards and associated pathways of exposure resulting from landfill or burial of animal carcasses (adapted from UK Department of Health, 2001c).

Potential public health hazard	Pathway of agent to humans	Potential exposure of humans to hazard	
		Landfill	Burial
Campylobacter, E. coli (VTEC), Listeria, Salmonella, Bacillus anthracis, C. botulinum, Leptospira, Mycobacterium tuberculosis var bovis, Yersinia	Private water supplies, Direct contact, Recreational water use, (possibly also shellfish)	Some	Greater
Cryptosporidium, Giardia	Water supplies (mains and private) Crops, shellfish, Direct contact, Recreational water use	Some	Greater
Clostridium tetani	Contact with contaminated soil	Some	Greater
Prions for BSE, scrapie	Water supplies via leachate, runoff, ash burial	Some	Greater

A study was undertaken in 1996 to ascertain the dissemination and persistence of *Salmonella typhimurium*, *Salmonella enteritidis*, *Bacillus cereus*, and *Clostridium perfringens*, in the environment after disposal of contaminated calf carcasses by deep burial (Davies & Wray, 1996). Calves were anaesthetized and inoculated intravenously with a solution containing 10^{12} of an equal combination of the four organisms. The calves were then killed and placed in a conventional grave dug to a depth of 2.5 m (about 8 ft). The authors report that within one week of placing the calves, extensive contamination of the soil surrounding the grave occurred, and there was an unexpected rapid passage of Salmonellae through the soil to a drainage ditch. Salmonellae were isolated from the soil around the burial site for 15 weeks, and reappeared in soil samples during cold winter weather after an apparent 68-week absence from the burial site (total of 88 weeks after the start of the experiment). *B. cereus* was also increasingly isolated during colder winter months. *C. perfringens* was more prevalent in samples during spring. However, the authors do not state how, or if, the isolates obtained from the environmental samples were confirmed as having originated from the inoculated calf carcasses.

As a result of land application of sewage sludge, considerable research has evaluated the potential for bacterial agents to survive in soil following such application. Although likely not entirely representative of the potential survival of bacterial agents in a burial environment (as it does not take into account several factors, including the potential bactericidal compounds produced by the decay process), such data could serve as approximations. Table 14 summarizes the estimates outlined by Gale (2002).

TABLE 14. Decay of bacterial pathogens in soil following application of sewage sludge (adapted from Gale, 2002).

Pathogen	Decay in soil as $\log_{10}$ units	Time frame and experimental conditions
Salmonellae	2.0	5 weeks; winter
Campylobacter spp.	2.0	16 days
E. coli O157:H7	1.0	49 days; 18°C

The potential for bacterial pathogens to disseminate and survive within the environment surrounding human cemeteries was evaluated (UK Environment Agency, 2002a). The authors indicated that although pathogens may be present, they will likely die off naturally and rapidly reduce in concentration with increasing distance from the grave site. Survival would be governed by physical conditions, such as temperature, moisture content, organic content, and pH (UK Environment Agency, 2002a, p. 7). The transport of microbes/pathogens within groundwater would be affected by the characteristics of the organism (size, shape, activity) as well as the method of transport through the aquifer. Water extracted from shallow depth with a shorter travel-time since recharge would have a higher pollution risk than an extraction drawing on water with a long residence time. Therefore, spring systems and shallow wells would be more vulnerable to microbial pollution problems than deep wells or boreholes (UK Environment Agency, 2002a, p. 8). The potential for an aquifer matrix to remove pathogens by filtration would depend on the nature of the matrix. Where the major route of groundwater flow is through porous intergranular matrix (intergranular flow), such as sandstone aquifers, there would be higher filtration potential. Conversely, in aquifers where fractures provide the predominant flow route, such as chalk aquifers, the potential for filtration of microbes would be limited.

Spore-forming organisms

In general, spore-forming organisms are known to survive in the environment for very long periods of time. Therefore, it is expected that spore-forming organisms within the burial environment will persist, perhaps indefinitely. Dissemination of such organisms would be dependent on many characteristics unique to the burial site, such as hydrological and geological properties.

Sporulation of *Bacillus anthracis* requires oxygen and does not occur inside an intact carcass. Consequently, regulations in most countries forbid postmortem examination of animals when anthrax is suspected (Turnbull, 2001). Most, if not all, vegetative *B. anthracis* cells in the carcass are killed by putrefactive processes in a few days, although the exact length of time required is unpredictable and greatly depends on climatic conditions such as temperature. *B. anthracis* organisms may escape from the carcass via exudates from the nose, mouth, and anus, and may lead to environmental contamination.

In most countries, the preferred method of disposal of an anthrax contaminated carcass is incineration, although some countries also consider rendering an effective approach (Turnbull, 2001). Where neither of these options is possible or practical, burial is the remaining best alternative. Burial is relatively unreliable for long term control of anthrax; this is reaffirmed by periodic reports of viable anthrax spores at burial sites of animals which died many years previously. Disturbances (e.g., ploughing, laying drainage, or scavenging of wildlife) at such burial sites can bring spores to the surface. Spores can sometimes migrate to the soil surface even in the absence of mechanical disturbances (Turnbull, 2001).

The prevalence of anthrax spores from the environment (soil) in the area of sites previously used to dispose of anthrax-infected bison carcasses was investigated (Dragon, Rennie, & Elkin, 2001). No anthrax spores were detected from the environment of burial sites 14-30 years old at the time of sampling; however, anthrax spores were detected from burial sites that were less than two years old at the time of sampling. Anthrax spores were isolated from the bone beds of cremation sites, especially those which contained residual mats of bison hair. The authors concluded that both incineration and deep burial appear to be equally effective at removing anthrax spores from the immediate environment.

4.2 – Viral Agents

As stated for bacterial agents, little published information is available specifically concerning the survival of viruses and subsequent dissemination from actual carcass burial sites. Again, the pressures, oxygen levels, and temperatures associated with deep burial, combined with the antimicrobial products generated by decaying processes, are thought to limit survival (Gunn, 2001; Gale, 2002).

Foot and mouth disease virus

Bartley, Donnelly, & Anderson published a review of the survival of FMD virus in animal excretions and on fomites (2002). The virus can survive in the absence of animal hosts, with potential reservoirs including the excretions and secretions of infected livestock as well as contaminated inanimate objects or fomites. The virus may survive at 4°C (39°F) for approximately two months on wool, and for two to three months in bovine feces or slurry. The virus has reportedly survived more than 6 months when located on the soil surface under snow (temperature range of -17.7 to 5.1°C [0 to 41°F]). In general, at ambient temperatures survival was longer when the virus was located beneath the soil surface or under leaves (>19 days) than when it was situated on the soil surface or on plant stems (<5 days). Results also generally showed decreasing survival with increasing temperature. The authors highlight the insufficiency of available data for evaluating disease control strategies (appropriate timeframe for movement and restocking restrictions, declaration of disease-free status, etc.), and identify a need for further evaluation of virus survival using large-scale, long-term field studies conducted in FMD endemic areas (Bartley, Donnelly, & Anderson, 2002).

In the carcasses of animals infected with FMD, the virus is rapidly inactivated in skeletal and heart muscle tissue as a result of the drop in pH that accompanies rigor mortis (Gale, 2002, p. 102). The virus may persist for longer periods in blood clots, bone marrow, lymph nodes, and offals (e.g., kidney and liver) because these tissues are protected from the pH changes that accompany rigor mortis. Liver, kidney, rumen, lymph node, and blood from diseased cattle have all been shown to be highly infective and to remain so if stored frozen. Acid formation in these tissues and in blood is not on the same scale as in muscle, and prolonged survival of virus is more likely. This remains true of lymph node and of residual blood in vessels of a carcass in which the development of rigor mortis is complete. In the absence of specific data for soil, Gale (2002) assumed decay in soil to be similar to that of decay in bovine fecal slurry (at 4°C [39°F], a 5-log reduction [99.999% reduction] was predicted after 103 days).

Information about the operation of the Throckmorton mass burial site in the UK indicated that initially leachate extracted from the site was treated with lime in order to adjust the pH to kill FMD virus prior to disposal at an off-site sewage treatment works. However, pre-treatment of leachate with lime was discontinued 60 days after burial of the last carcass because the FMD virus was reportedly unlikely to survive more than 40 days in a burial cell. (Det Norske Veritas, 2003, p. II.21). Unfortunately, no details are provided to indicate from what data the 40-day estimate was derived.

An evaluation was conducted in 1985 in Denmark to estimate whether burying animals infected with FMD would constitute a risk to groundwater (Lei, 1985). The evaluation considered characteristics of the virus, survival within various tissues, likely disposition within the grave, adsorption to and transport within soil, soil characteristics, influence of leachate and precipitation, and the characteristics of local geography and hydrology. Although not specifically indicated, the evaluation appeared not to address the issue of burial of significant numbers of carcasses in a given site, but rather was related to burial of small numbers of animals. The authors ultimately concluded that the probability of groundwater contamination from burial of FMD-infected animals was very small, although in situations of atypical or unfavorable circumstances the possibility could exist. They further suggested that even if viruses were able to reach groundwater sources, the concentration would likely be inadequate to present an animal-health risk.

Classical swine fever virus

Classical swine fever (CSF) virus is stable in the pH range of 5-10, but inactivated below pH 3 or above pH 10. Unlike FMD virus, little to no destruction of CSF virus would occur solely as a result of a drop in pH levels due to rigor mortis in the muscle of an infected animal (Gale, 2002, p. 117). In the absence of data for soil, Gale (2002) assumed decay in soil to be similar to that of decay in pig fecal slurry (at 4°C [39°F], a 5-log reduction [99.999% reduction] after 92 days). Survival of the virus in water ranged from 6-24 days at 20°C (68°F).

Other viral agents

The persistence of rabbit hemorrhagic disease (RHD) virus in decomposing rabbit carcasses was evaluated by McColl, Morrissy, Collins, & Westbury (2002). This study is discussed here because it represents one of the few that actually measured, under controlled conditions, the survival of a disease agent within decomposing carcasses. In laboratory experiments, rabbits were infected with RHD virus and all died within 36 hours. Carcasses were allowed to decompose in cages for 30 days at about 20°C (68°F). Liver samples were obtained and tested weekly for the presence of viral antigen, as well as for the presence of infectious RHD virus (by inoculation into healthy rabbits). Results indicated that infectious RHD virus survived in the liver tissue of rabbit carcasses for 20-26 days. These results suggest that, in addition to direct rabbit-to-rabbit transmission of the virus and the possibility of vector-borne transmission, the persistence of viruses in infected carcasses may be an important factor in the epidemiology of RHD.

4.3 – TSE Agents

The agents (known as prions) thought to be responsible for transmissible spongiform encephalopathies (TSEs), such as BSE in cattle, scrapie in sheep, CWD in deer and elk, and Creutzfeldt-Jakob disease (CJD) in humans, are highly resistant to inactivation processes effective against bacterial and viral disease agents. Prions have been demonstrated to be highly resistant to inactivation by chemical means, thermal means, as well as ionizing, ultraviolet, and microwave irradiation processes (Taylor, 1996; Taylor, 2000). Additionally, the scrapie agent has been demonstrated to retain at least a portion of its infectivity following burial for three years (Brown & Gajdusek, 1991). In a speech to the US Animal Health Association, Taylor (2001) indicated that "the present evidence suggests that TSE infectivity is capable of long-term survival in the general environment, but does not permit any conclusions to be drawn with regard to the maximum period that it might survive under landfill conditions. Experiments on the longterm survival of the BSE agent after burial are about to be initiated at the Neuropathogenesis Unit in Edinburgh, UK, but it will take up to ten years to gather results from these experiments."

As a result of the BSE epidemic in the UK, resources were increasingly focused on determining the potential for TSE agents to survive in the environment as a result of disposing of infected animal carcasses. In 1997, a series of risk assessments were conducted in the UK to specifically address the issue of survival of the BSE agent in the environment as a result of disposal of infected or potentially infected carcasses (DNV Technica, 1997b; DNV Technica, 1997a). These assessments estimated that some 6,000 carcasses were disposed of in 59 different landfill sites around the UK in the early stages of the epidemic (from 1988 to 1991). Possible routes of human infection from BSE-infected carcasses disposed in a landfill include landfill gas, which is not thought to contain any infectivity, and leachate. The possible contamination of leachate, which might then possibly contaminate water supplies, was determined to be the most likely source of risk. Ultimately the risk assessments concluded that the risk of infection was well below an individual risk of one in a million years, which would be generally regarded as an acceptable level of risk. It is interesting to note that this low level of risk was identified even though most of the landfill sites were generally mature operations employing only natural attenuation (no engineered leachate containment systems) (DNV Technica, 1997a, p. 3). Other sources have reiterated this finding of very low levels of risk to human health from disposing of TSE-infected animal carcasses in landfill sites (Gunn, 2001; Gale, Young, Stanfield, & Oakes, 1998).

Following the 2001 FMD epidemic in the UK, the Ministry of Agriculture, Fisheries and Food (MAFF; subsequently DEFRA) asked DNV to assess the risk of BSE from disposal of carcasses resulting from the FMD epidemic. DNV used the modeling approach and assumptions from the 1997 risk assessments (DNV Technica, 1997b; DNV Technica, 1997a) and concluded that the risk of exposure to humans would be entirely due to contamination of groundwater, and that these risks were again very low (dose received by any one person would be extremely small) (Comer & Spouge, 2001). In a note issued on 24 May 2001, the UK Spongiform Encephalopathy Advisory Committee (SEAC) Working Group indicated that although considerable uncertainty existed as to exact location and number, as many as 10,000 cattle over five years of age may have been buried in the early period of the FMD outbreak (prior to EA guidance) (UK SEAC, 2001). With an assumed prevalence of 0.4%, it would be possible that about 40 carcasses with late-stage BSE may have been buried. The SEAC Working Group had discussed potential risks associated with various courses of action. Although the potential for release of BSE agent into the environment existed from these burials, exhuming these sites to remove the carcasses may result in even higher risks than leaving the burial site undisturbed. The group concluded that there was a need for site-specific risk assessments, with the number of older animals buried at any one site being of central importance (UK SEAC, 2001).

The increasing emergence of CWD in deer and elk populations in various regions of the US has also resulted in assessment of risk relative to disposal of carcasses potentially infected with a TSE agent. The Wisconsin Department of Natural Resources also conducted a risk assessment to address the risks posed by disposal of such carcasses in landfills (Wisconsin Department of Natural Resources, 2002). As was the case in other risk assessments, the risk assessment supported the following:

1. The disease specific agent is hydrophobic and is expected to adhere to organic materials present in landfills,
2. It is likely to take the CWD agent several months to move through a landfill, during which time the agent will be subjected to biodegradation and is likely to lose a significant amount of its infectivity,
3. Any infectivity that exits the landfill will be captured in the effluent and transferred to a wastewater treatment plant or re-circulated within the landfill,
4. CWD prions present in wastewater are expected to partition with the sludge fraction, and
5. Land-applied sludge will be greatly diluted by surface soils and incorporated with soil at a depth of 9 inches.

Based on these findings, the risk assessment concluded that the available knowledge about CWD and other TSEs suggested that landfilling CWD infected deer would not pose a significant risk to human health, and the risk of spreading CWD among the state's deer population by landfill disposal of infected carcasses would be quite small (Wisconsin Department of Natural Resources, 2002).

In 2002, a meeting was convened to identify the research required to address possible contamination of the soil and water environment by TSE agents as a result of agricultural practices (UK DEFRA, 2002b). Burial of animal carcasses infected with a TSE agent was identified as a significant potential source of environmental contamination. Results of the meeting highlighted several areas in which additional research efforts are needed relative to TSE infectivity in the environment, including the communities of soil microorganisms and animals involved in carcass degradation; the effect of anaerobic conditions and soil type on the degradation, persistence, and migration of TSEs in the soil environment; detection systems which can be used to identify infectivity in soil matrices; and a need to validate assumptions on the behavior of TSE agents which have been used in risk assessments (UK DEFRA, 2002b).

An opinion published in 2003 by the European Commission Scientific Steering Committee addressed the use of burial to dispose of carcasses potentially infected with TSE agents. This opinion emphasized the fact that the "extent to which infectivity reduction can occur as a consequence of burial is poorly characterized" (European Commission Scientific Steering Committee, 2003). Based on this lack of understanding, along with concerns for groundwater contamination and dispersal or transmission by vectors, the committee indicated that burial of animal material which could possibly be contaminated with BSE/TSEs "poses a risk except under highly controlled conditions" (e.g., controlled landfill) (European Commission Scientific Steering Committee, 2003).

In 2004 the US EPA outlined recommended interim practices for landfill disposal of materials potentially contaminated with CWD (US EPA, Office of Solid Waste, 2004). These practices, intended to minimize the potential for release of infectious agents, included the recommendation that only those sites compliant with Subtitle D regulations and having no uncontrolled release from disposal cells be used.

Section 5 – Implications to the Environment

5.1 – Animal Carcass Decomposition

Biodegradation of organic matter

Based on the concept of waste degradation within a landfill, degradation of material within a burial site generally proceeds in three stages: aerobic decomposition, acid-phase anaerobic decomposition (non-methanogenic), and anaerobic decomposition (methanogenic) (McBean, Rovers, & Farquhar, 1995). During the aerobic stage of decomposition, aerobic microorganisms degrade organic materials to carbon dioxide, water, partially degraded residual organics, and heat. Compared to the subsequent anaerobic stages, this aerobic decomposition stage is relatively rapid (McBean, Rovers, & Farquhar, 1995, p. 61).

Ultimately, aerobic decomposition is responsible for only a small proportion of the total degradation that occurs. As oxygen levels decrease, the process transitions to the second stage of decomposition, acid-phase anaerobic decomposition in which facultative organisms are dominant and high concentrations of organic acids, ammonia, hydrogen, and carbon dioxide are produced. Acid fermentation prevails, with characteristic end products being high levels of carbon dioxide, partially degraded organics (especially organic acids) and some heat. As oxygen is depleted, activity becomes dominated by anaerobic organisms that generate methane as a primary by-product. This stage of decomposition can continue for many years (McBean, Rovers, & Farquhar, 1995, p. 62).

Process and products of carcass decomposition

From the point at which an animal (or human) dies, degradation of bodily tissues commences. However, the rate at which decay proceeds is strongly influenced by various endogenous and environmental factors (Pounder, 1995). Because of the relevance to human forensic science (specifically pertaining to time of death determinations), much is known about the processes and rates of decay of human corpses in various environments. In contrast, relatively little research has been conducted specifically regarding the decomposition processes of animal corpses, except in those instances where animal corpses have been used as surrogates for human subjects, for example (Micozzi, 1986; Hewadikaram & Goff, 1991; Turner & Wiltshire, 1999; Payne & King, 1972). Additionally, research often focuses on the decay rates that occur when human or animal remains are left exposed to the elements, rather than buried. Various human forensic studies may have reasonable application to animal carcass burial, such as (Mann, Bass, & Meadows, 1990; Hopkins, Wiltshire, & Turner, 2000; Rodriguez & Bass, 1985; Spennemann & Franke, 1995; Galloway, Birkby, Jones, Henry, & Parks, 1989).

In spite of the shallow pool of direct experimental evidence, some generalizations regarding the degradation of animal carcasses are possible. Soft tissue, in the absence of any means of preservation, is degraded by the postmortem processes of putrefaction (anaerobic degradation) and decay (aerobic degradation) (Micozzi, 1991, p. 37). Putrefaction results in the gradual dissolution of tissues into gases, liquids, and salts as a result of the actions of bacteria and enzymes. Key indicators of putrefaction include changes in tissue color (especially notable in human corpses), evolution of gases, liquefaction of tissues, and development of a putrid odor (Pounder, 1995). Color changes and development of foul odors occur as a result of the sulfur-containing gas produced by intestinal or rumen bacteria. Accumulation of this gas can then result in physical distortions such as bloating of the body, protrusion of the tongue and eyes, expulsion of the intestines through the vagina or rectum, and discharge of large amounts of foul-smelling fluid from the nose, mouth, and other orifices (Iserson, 2001, p. 50).

A corpse or carcass is degraded by microorganisms both from within (from the gastrointestinal tract) and from without (from the surrounding atmosphere or soil) (Munro, 2001, p. 7; Micozzi, 1986), and these organisms may include both aerobes and anaerobes.

The component tissues of a carcass degrade at varying rates, the order of which is generally (1) body fluids and soft tissues other than fat (brain, epithelial, liver, and kidney tissues decompose fairly early, followed by muscle and muscular organs), (2) fats, (3) skin, cartilage, and hair or feathers, and (4) bones, horns, and hooves (McDaniel, 1991, p. 873; Munro, 2001, p. 7). A report on the proportions of degradable matter in a coffined human corpse indicates 60% to be readily degradable, 15% to be moderately degradable, 20% to be slowly degradable, and 5% to be inert or non-degradable (UK Environment Agency, 2002a, Table 3).

Some of the best information available on the decomposition of animal carcasses in burial sites stems from the 2001 outbreak of FMD in the UK. Although a devastating event, this incident provides unique and valuable information relative to decomposition of mass quantities of animal carcasses. A report commissioned at the very early stages of the outbreak as a result of problems related to the use of mass burial sites attempted to estimate the volume of fluid leachate which could be expected to originate from cattle, sheep, and pig carcasses. It was estimated that about 50% of the total available fluid volume would "leak out" in the first week following death, and that nearly all of the immediately available fluid would have drained from the carcass within the first 2 months (Table 15).

TABLE 15. Estimated volume of leachate released per animal following death (adapted from Munro, 2001).

Species	Est. volume of fluid released per animal, in L: First week postmortem	Est. volume of fluid released per animal, in L: First 2 months postmortem
Cattle – Adult (500-600 kg; 1100-1300 lbs)	80	160
Cattle – Calf	10	20
Sheep – Adult (50 kg; 110 lbs)	7-8	14-16
Sheep – Lamb	1	2
Pig – Adult	6	12
Pig – Grower/finisher	3	6
Pig – Piglets	0.4	0.8

The author of this report highlighted the fact that much of the information used to generate the estimates was obtained from the rates of decomposition established for single non-coffined human burials, and these estimates may not accurately reflect the conditions in mass burials of livestock (Munro, 2001).

A UK EA report which assessed the environmental impact of the 2001 FMD outbreak suggests that the estimated volume of body fluids released within two months postmortem would be approximately 16 m^3 (16,000 L, or ~4,230 gallons) per 1000 adult sheep, and 17 m^3 (17,000 L, or ~4,500 gallons) per 100 adult cows (UK Environment Agency, 2001b, p. 11).

In addition to leachate, gaseous products will also be generated from the decomposition of animal carcasses. Munro (2001) estimated that the composition of the gas produced would be approximately 45% carbon dioxide, 35% methane, 10% nitrogen, with the remainder comprised of traces of other gases such as hydrogen sulfide. This report suggested that the methane proportion would decrease over time, with very little methane being produced after 2 months. A drop in methane production would reportedly result from decreased pH within the burial environment which would be detrimental to methane-producing bacteria. As was reported for leachate, it was estimated that the majority of the gas would be released immediately after burial, with decreasing amounts thereafter (Munro, 2001). However, this estimation of decreasing amounts of gas over time seems to contradict, somewhat, the conventional knowledge that gas production in MSW landfills generally increases over time as the waste matures. Additionally, a report of monitoring activities at one of the UK mass burial sites also suggests that gas production increases over time, rather than decreases (Enviros Aspinwall, 2002b).

Time required

The amount of time required for buried animal carcasses (or human corpses) to decompose depends on many factors including temperature, moisture, burial depth, soil type and drainability, species and size of carcass, humidity/aridity, rainfall, and possibly other factors (McDaniel, 1991). The factors of most significance will likely be temperature, moisture level, and burial depth. Warm temperatures hasten decomposition by the body's natural enzymes found in many of the body's cells and in the digestive juices (Iserson, 2001, p. 384).

A carcass left on the surface of the ground generally decays much more quickly than a buried carcass due in large part to destruction of much of the soft tissue by insects, carnivores, and rodents (Micozzi, 1991; Mann, Bass, & Meadows, 1990; Iserson, 2001; Rodriguez & Bass, 1985). In ideal conditions (warm to hot weather), a human corpse left exposed to the elements can become skeletonized in a matter of two to four weeks (Mann, Bass, & Meadows, 1990; Iserson, 2001, p. 384). However, an unembalmed adult human corpse buried six feet deep in ordinary soil without a coffin requires approximately 10 to 12 years to skeletonize (UK Environment Agency, 2002a; Pounder, 1995; Munro, 2001; Iserson, 2001). Other sources indicate that even longer may be required:

> Scottish lore held that a grave was 'ripe' for twenty years after burial, meaning that it was likely more than bones would turn up if the grave was reopened before twenty years had passed. Since the Scots frequently reused gravesites, this maxim was well founded.
>
> (Iserson, 2001, p. 391)

Given relatively equal factors (temperature, body size, etc.), a corpse placed in water (with no fish or reptiles present) will generally decompose about four times faster than a corpse that is buried (Iserson, 2001, p. 390). One source indicates that a buried whale carcass remained largely intact and putrid after 10-20 years (Gaudet, 1998).

In addition to the lengthy persistence of actual carcass material in a burial site, leachates or other pollutants may also be long-lived. Although much of the pollutant load would likely be released during the earlier stages of decomposition (i.e., during the first 1-5 years) (UK Environment Agency, 2001b; McDaniel, 1991; UK Environment Agency, 2002a; Munro, 2001), several reports suggest that mass burial sites could continue to produce both leachate and gas for as long as 20 years (UK Environment Agency, 2001b; Det Norske Veritas, 2003).

Some insight into the possible longevity of material within mass animal burial sites can be gathered from research into the environmental impacts of human cemeteries. The UK Environment Agency (2002a), in a study of the potential of human cemeteries to pollute groundwater, identified the primary factors affecting the decay rate of human remains to be those that affect microbial activity, as this is the primary means of decay. Factors listed as important included the following:

- availability of nutrients (carbon, nitrogen, phosphorus, and sulfur) and moisture
- pH, with neutral conditions being most favorable to decay
- climate, with warm temperatures accelerating decay
- soil lithology (well drained soil accelerates decomposition whereas poorly drained soil has the reverse effect)
- burial practice (depth of burial, use of a coffin, etc.)

In addition to these extrinsic factors, characteristics of the carcass material can also affect decay rates. One study evaluated the effect of freezing, thawing, or mechanical injury of carcasses on the time required for decomposition. The study found that rat carcasses which were frozen and then thawed were more susceptible to invasion by insects and microorganisms from the outside than were fresh-killed carcasses (Micozzi, 1986). These results may have relevance for situations such as the frozen storage of deer carcasses suspected of harboring CWD. In some cases carcasses may be held in frozen storage until results of testing are complete.

5.2 – Environmental Impacts

The potential exists for the decay products of buried animal carcasses to be released into the surrounding environment, with subsequent negative environmental and/or public health consequences resulting from chemical or biological pollutants. The potential effects arising from burial will be similar regardless of the technique used (e.g., trench burial vs. landfill); however, the likelihood and scale of the effects may differ. Another important consideration is the total volume of material buried; the impacts resulting from burial of 30 carcasses would likely be of an entirely different magnitude than those resulting from burial of 30,000 carcasses.

Estimating potential impacts

Various works have attempted to estimate the potential environmental impacts and/or public health risks associated with animal carcass burial techniques. Several sources identify the primary environmental risk associated with burial to be the potential contamination of groundwater or surface waters with chemical products of carcass decay (McDaniel, 1991; Ryan, 1999; Crane, 1997). See Figure 7.

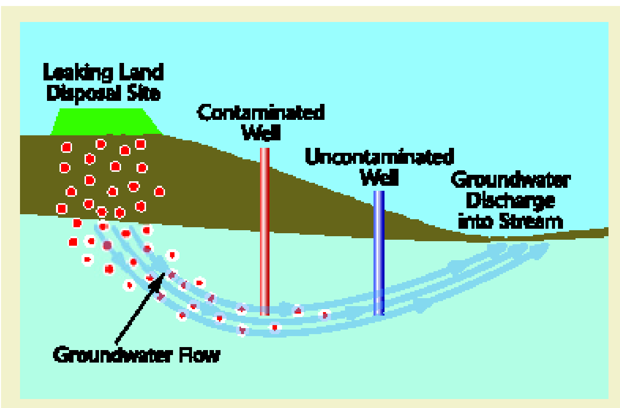

FIGURE 7. Contamination of groundwater by leachate leaking from a land disposal site (Walsh & O'Leary, 2002a).

Freedman & Fleming (2003) sought to evaluate the scientific basis for, as well as the appropriateness and adequacy of, regulations governing the burial of dead stock. They state in their report there "has been very little research done in the area of environmental impacts of livestock mortality burial." Due to this information void, they conclude that there is little evidence to demonstrate that the majority of regulations and guidelines governing burial of dead stock have been based on any research findings directly related to the environmental impacts of livestock or human burials. They also conclude that further study of the environmental impacts of livestock burial is warranted.

During the 2001 outbreak of FMD in the UK, a significant volume of information was generated by various agencies with the intent of attempting to assess the risks involved in disposing of carcasses by various means. A particular challenge faced by these agencies was the need to generate information in a very rapid timeframe. As in the case of other previous assessments, leaching of decay products into water courses was identified as a significant potential environmental impact (UK Environment Agency, 2001b; UK Department of Health, 2001c; Munro, 2001).

The UK Department of Health (2001c) prepared a rapid qualitative assessment of the potential risks to human health associated with various methods of carcass disposal. Annex C of this qualitative risk assessment provides an exhaustive summary of the potential hazards associated with the various carcass disposal options, including biological, chemical, and other types of hazards (UK Department of Health, 2001c, Annex C). Each hazard is characterized as to the following:

- **Release.** Source, mechanism of release, and timescale of release.
- **Exposure pathway.** Likely location of contaminant (soil, air, or water), and pathway to human exposure.
- **Public health consequences.** Likelihood of exposure, population exposed (at-risk groups), leading indicators, individual outcomes, as well as existing preventive measures.

The UK EA conducted an interim assessment of the environmental impacts of FMD carcass disposal (UK Environment Agency, 2001b). In that assessment, hazards which may potentially be associated with on-farm burial, landfilling, or mass burial included:

- **Body fluids.**
- **Leachate components.** Including high concentrations of ammonia (up to 2,000 mg/L) and high chemical oxygen demand (COD; up to 100,000 mg/L, about 100 times that of raw sewage).
- **Pathogens in the leachate.** Including *E. coli* O157:H7, *Campylobacter*, *Salmonella*, *Leptospira*, *Cryptosporidium*, *Giardia,* and BSE prions.

- **Release of gases.** Including carbon dioxide, methane, or other foul-smelling gases.

Following the FMD epidemic, inquiries were conducted by several bodies at both the national and regional levels. In many of the submissions to these inquiries, potential environmental impacts are outlined (Aldridge, Pratt, Dawson, & Skinner, 2001; Natural Environment Research Council, 2001). Additionally, investigations into the operation of various mass disposal sites include a summary of potential environmental impacts (Det Norske Veritas, 2003; UK Environment Agency, 2001c). Relative to BSE risks in particular, because as many as 10,000 cattle over five years of age may have been buried in the early period of the FMD outbreak, a study was also conducted to specifically assess the risk due to BSE from disposal of carcasses resulting from the FMD epidemic (Comer & Spouge, 2001).

Human cemeteries

Although perhaps not entirely representative of burial of animal carcasses, some information on potential environmental impacts can be inferred from the potential effects that may arise from human cemeteries. Because little published information was available on the potential sources of pollutants from cemeteries, an assessment was conducted in 1998 to evaluate the potential impact on the environment and to public health (Ucisik & Rushbrook, 1998). This assessment also identified products arising from decay of corpses as a risk to water courses, with possible contaminants including bacteria, viruses, and organic and inorganic chemical decomposition products. Soil type was identified as a significant factor in movement of bacteria and viruses as an unsaturated soil layer acts as a filter and an adsorbent. Most microorganisms were reportedly filtered out on or near the soil surface (however, adsorption was reported to decrease with increasing water velocity). The most useful soil type for maximizing natural attenuation properties was reported to be a clay-sand mix of low porosity and small- to fine-grain texture (Ucisik & Rushbrook, 1998).

A 2002 report by the UK EA provided a review of the published literature relating to the potential environmental threat posed by cemeteries to identify and quantify the risks of pollution (UK Environment Agency, 2002a). This report identified the primary pollutants derived from human corpses as dissolved and gaseous organic compounds and dissolved nitrogenous forms (particularly ammonia nitrogen). One of the most important factors governing the rate of release of these contaminants was reported to be the rate of microbial decay. This report estimated that over half of the pollutant load leaches from a corpse within the first year, and halves year-on-year thereafter. That is, less than 0.1% of the original loading may remain after 10 years (see Table 16).

TABLE 16. Potential contaminant release (kg) from a single 70 kg human burial (adapted from UK Environment Agency, 2002a).

Year	TOC[a]	NH_4	Ca	Mg	Na	K	P	SO_4	Cl	Fe
1	6.00	0.87	0.56	0.010	0.050	0.070	0.250	0.210	0.048	0.020
2	3.00	0.44	0.28	0.005	0.025	0.035	0.125	0.110	0.024	0.010
3	1.50	0.22	0.14	0.003	0.013	0.018	0.063	0.054	0.012	0.005
4	0.75	0.11	0.07	0.001	0.006	0.009	0.032	0.027	0.006	0.003
5	0.37	0.05	0.03	<0.001	0.003	0.004	0.016	0.012	0.003	0.001
6	0.19	0.03	0.02	<0.001	0.002	0.002	0.008	0.006	0.002	<0.001
7	0.10	0.01	0.01	<0.001	0.001	0.001	0.004	0.003	<0.001	<0.001
8	0.05	<0.01	<0.01	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001
9	0.02	<0.01	<0.01	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
10	0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[a]TOC = Total organic carbon.

Since precipitation amount and soil permeability are key to the rate at which contaminants are "flushed out" of burial sites, the natural attenuation properties of the surrounding soils would be a primary factor determining the potential for these products of decomposition to reach groundwater sources (UK Environment Agency, 2002a). Several other works have also attempted to determine the environmental impacts of human burials (cemeteries) (Spongberg & Becks, 1999; Spongberg & Becks, 2000; Pacheco, Mendes, Martins, Hassuda, & Kimmelmann, 1991).

Trench burial

Contaminants released from Iowa burial sites

In 1990 the Iowa Department of Natural Resources developed rules for on-farm burial which established maximum loading rates, minimum burial depths, and separation distances. During the rulemaking process, questions arose regarding the likely rate of carcass decay, the quantity and type of contaminants released, and the potential effects on groundwater. To attempt to gain insight into these questions, a study was initiated to monitor two animal burial sites (Glanville, 1993).

On "Site #1" (a small research plot with well drained soils), approximately 165 lbs of 25- to 30-lb pigs were buried in each of two 20-foot-long trenches. The bottom and sides of one trench were lined to permit capture and analysis of decay products; the second trench was unlined. To evaluate groundwater effects of leachate from the unlined trench, eight shallow wells located immediately down-gradient were monitored. During the 19-month period after leachate production began, mean biochemical oxygen demand (BOD) concentrations in the leachate collected from the lined trench exceeded 4,000 mg/L, ammonia nitrogen averaged 740 mg/L, average total dissolved solids (TDS) were nearly 1600 mg/L, and chloride averaged 120 mg/L (Glanville, 1993).

The total mass of BOD recovered in the trench leachate during the 21-month period following burial would have been sufficient to contaminate more than 36,000 L of water at a concentration of 200 mg/L (strength of typical untreated municipal sewage). Similarly, the total mass of ammonia nitrogen recovered (if oxidized to nitrate) would be sufficient to raise the nitrate concentration in more than 85,000 L of water above the drinking water standard of 10 mg/L. Furthermore, large scale burial at the same area loading rate would be equivalent to applying 510 lbs of nitrogen per acre. Since much of the nitrogen released from the burial site occurred during late fall and winter, a time when crop uptake would be negligible, continuous large-scale on-farm burial has considerable potential to cause excess nitrogen loading (Glanville, 1993).

"Site #2" in this study was established on a commercial turkey farm in northwest Iowa following a catastrophic ventilation failure that killed 2,500 birds. Approval was given to bury approximately 62,000 lbs of turkeys in two shallow pits. Soils in the site were wet, and the water table fluctuated between depths of one to five feet. Monitoring results demonstrated high levels of ammonia, TDS, BOD, and chloride in the monitoring well closest (within two ft) to the burial site. Average ammonia and BOD concentrations (monthly sampling during 15 months) exceeded 300 mg/L, and average TDS reached nearly 2,000 mg/L. Nitrate levels were very low, indicating an anaerobic environment. However, little evidence of contaminant migration was observed in wells located more than a few feet from the burial site (Glanville, 1993; Glanville, 2000).

One of the monitoring wells used during this same study was inadvertently located within or near an older burial site. Although the exact age of the older burial pit was unknown, it was believed to have been constructed at least nine years prior to the time of the study. Despite its advanced age, drill cuttings at the old site revealed very dark colored, odorous material at a depth of approximately two to six feet. Monthly groundwater sampling at this location showed average ammonia nitrogen concentrations of nearly 200 mg/L, TDS levels of about 1300 mg/L were twice the background levels, and BOD levels of 25 mg/L were two to three times apparent background levels (Glanville, 1993).

Groundwater quality impacts of disposal pits

The impact of dead bird disposal pits (old metal feed bins with the bottom removed placed in the ground to serve as a disposal pit) on groundwater quality was evaluated by Ritter & Chirnside (1995 & 1990). Disposal pits represent a slightly different technique than trench burial (a disposal pit generally consists of a hole dug into the earth, the sides of which may be lined with concrete, metal, or wood. The bottom of the pit is left exposed to the earth below, and the top is closed with a tight-fitting cover or lid). However, the data provides some insight as to the pollution potential associated with trench burial. In the past, the use of disposal pits was relatively common for poultry operations as a means of disposing of daily mortalities. Because of the high water table on the Delmarva Peninsula, the bottoms of many of the disposal pits are located in the groundwater during part or most of the year (Ritter & Chirnside, 1995).

In this study a total of six existing disposal pits were evaluated by means of monitoring wells placed around each pit at distances of 3 and 6 m. Wells were sampled every four to eight weeks for approximately three years (from March 1987 to March 1990). Although no EPA drinking-water standard exists for ammonia, it is undesirable to have ammonia present in drinking-water supplies at any level. Around several of the disposal pits the ammonia levels were much higher than 10 mg/L (the EPA standard for nitrate), and one ammonia concentration of 366 mg/L was observed. Most samples around the disposal pits had concentrations of nitrate, chloride, and fecal coliforms which were below EPA drinking-water standards. The researchers concluded that three of the six disposal pits evaluated had likely impacted groundwater quality (with nitrogen being more problematic than bacterial contamination) although probably no more so than an individual septic tank and soil absorption bed. However, they cautioned that serious groundwater contamination may occur if a large number of birds are disposed of in this manner (Ritter & Chirnside, 1995).

Impacts of poultry disposal pits in Georgia

Myers (1998) evaluated the environmental impacts of poultry disposal pits in Georgia. Four counties representing long-term concentrated poultry production, as well as four major soil provinces were selected for study. Electromagnetic conductivity surveys were conducted to determine local groundwater flow and the relationships to disposal pits and domestic wells. Domestic wells were monitored for a variety of chemical and microbiological contaminants. At the time of publication (1998), data were still being collected and therefore no conclusions were presented. A 2003 personal communication from the author cited by Freedman & Fleming (2003) suggests that the final report of these studies should be available soon.

Findings following the 2001 UK FMD outbreak

In the aftermath of the 2001 UK FMD outbreak, considerable monitoring of various disposal sites has been conducted, and is ongoing. As a result of the outbreak, monitoring and surveillance programs were established jointly by various UK agencies to evaluate public health impacts, as well as environmental impacts, resulting from the handling and culling of animals and disposal of carcasses (UK Public Health Laboratory Service, 2001c). Results of this monitoring program were published periodically during the outbreak, namely in July 2001 (UK Public Health Laboratory Service, 2001a), August 2001 (UK Public Health Laboratory Service, 2001b), and November 2001 (UK Public Health Laboratory Service, 2001c).

In December 2001, the UK EA published an interim assessment of the environmental impact of the outbreak (UK Environment Agency, 2001b). The most notable actual environmental pressures that were identified included the following:

- Emissions to air from pyres.
- The delay in the disposal of carcasses early in the outbreak.
- The storage of slurry on farms for longer periods than normal.
- The inappropriate disposal of some carcasses and ash early on in the outbreak.
- Odor from mass burials and landfill sites.
- The burial of items such as machinery and building materials during the cleansing and disinfection process on farms.

The primary conclusions of the interim environmental impact assessment identified in this report are summarized in Table 17. In general, the report concluded that no significant negative impacts to air quality, water quality, soil, or wildlife had occurred. Additionally, no evidence of harm to public health was observed.

TABLE 17. Summary of negative environmental impacts following the 2001 UK FMD outbreak (UK Environment Agency, 2001b).

Impact	Short-term effects (during the outbreak)	Medium-term effects (within a year)	Long-term effects (more than a year)
Air pollution	Pyre emissions elevated local concentrations of some pollutants but did not breach air quality standards. The fumes and odor caused public concern. Odor from some of the landfills caused public concern.		Possible soil contamination from emissions of dioxins, PCBs, and PAHs.
Groundwater pollution	Seepage from burials and pits under pyres has contaminated a small number of groundwaters.	Seepage will continue and could contaminate groundwater.	Seepage to groundwater could occur over 20 years.
Surface water pollution	212 reported pollution incidents, 14 causing significant harm, mainly from disinfection, carcass fluids and slurry. Unable to access farmland to maintain small sewage works or to attend pollution incidents.	Seepage from burial and pits under pyres could reach surface waters.	
Soils	Increased local soil erosion where animals could not be moved. Pyre emissions led to small risk of local soil and food contamination by dioxins, PCBs, and PAHs.		Any significant dioxin, PCB, or PAH contamination could persist for several years.
Wildlife and fisheries	Rat poison could be picked up by birds of prey. Three large fish kills reported; unrecorded disinfectant pollution could cause local harm to fish populations.	Local changes in grazing pressure would benefit some habitats and degrade others.	Changes depend on the response of the farming industry and any changes to agricultural policy.
Landscape	Pyre smoke, loss of farm stock, footpath restrictions.	Lack of farm stock in some areas and changes in vegetation will affect the landscape.	Changes depend on the response of the farming industry and any changes to agricultural policy.

Although the report identified only minor overall impacts on the environment, it was acknowledged that many instances of local nuisance occurred. For example, runoff of blood and body fluids from slaughtered animals awaiting disposal occurred on many sites, especially during the early months of the crisis when disposal operations were outpaced by slaughter rates. As a result the public reported many pollution incidents, although the report states that relatively few cases of significant water pollution actually occurred. It is noted, however, that these exposed carcasses caused an increased risk of pathogen or disease agent transmission by pests or wildlife (e.g., rats, crows, and gulls), and created a local odor nuisance.

Mass burial

Monitoring of groundwater, leachate, and landfill gas has been conducted at UK FMD mass burial sites by both the operators of the sites and by the UK EA. Surface waters, groundwaters, and leachates were tested for BOD, ammonia, and suspended solids as well as chloride and potassium levels. Microbiological testing of water supplies conducted around two mass burial sites demonstrated no deterioration in microbiological quality of any private water supplies nor of waters around the sites. The EA reported that the monitoring results from the mass disposal sites indicated no cause for concern (UK Public Health Laboratory Service, 2001c).

All seven mass burial sites intended for disposal of carcasses were met with significant opposition from local communities located near them. Although the

UK EA assessment indicated that at all sites consideration was given to minimizing the risk of surface and groundwater pollution, it also noted that, at the time of publication, some site management controls were still in development. At all the mass burial sites except for Widdrington, leachate was collected/contained, and in some cases taken off-site for disposal. For example, at the Throckmorton site by September 2001 some 74,000 m^3 (74,000,000 L) of leachate had been collected and removed by tanker for treatment and disposal at sewage treatment plants. Significant findings resulting from monitoring efforts through December 2001 at mass burial sites included the following (UK Environment Agency, 2001b):

- **Great Orton.** Small quantities of carbon monoxide, methane, and hydrogen sulfide were detected via monitoring at 71 boreholes and manholes.
- **Great Orton.** Monitoring of 20 surface water sites since April 2001 resulted in the observance of one incident; the incident was caused by leachate and was quickly stopped.
- **Tow Law and Widdrington.** No impact on surface waters.
- **Throckmorton.** Airfield drains showed some contamination with leachate and disinfectant, but no effect on downstream watercourses either chemically or biologically.
- **Sennybridge.** Stream showed some contamination.

Additional details regarding key findings of environmental monitoring efforts at some of the mass burial sites are outlined below.

Eppynt (Sennybridge, Wales)

Key monitoring results from the Eppynt burial site as of August 2002 indicate that some residual environmental issues remain. For example, at the head of a small stream downhill from the burial site, dissolved oxygen levels continue to be reduced, suggesting some residual contamination with localized impact. Furthermore, groundwater in a borehole 12 m deep located at the southwest end of the burial pit still shows slight contamination, although concentrations of all chemical contaminants are approaching background levels. Table 18 provides key monitoring data from the Eppynt burial site (UK Environment Agency, 2001d; UK Environment Agency, 2002c).

TABLE 18. Key results of water quality monitoring conducted at the Eppynt (Sennybridge) mass burial site, Powys, Wales (adapted from UK Environment Agency, 2001d; UK Environment Agency, 2002c).

Contaminant	Date – Level	
	Borehole 12 meters deep, southwest end of burial site (ID = Borehole 2)	Stream head downhill from burial site (ID = Sample Point #1)
Biochemical Oxygen Demand (BOD)	April 2001 – 7400 mg/L July 2001 - >100 mg/L October 2001 – below 10 mg/L August 2002 – Below 4 mg/L	April 2001 – Rose from 0.7 to 70 mg/L August 2002 – at background (1 mg/L)
Chemical Oxygen Demand (COD)	April 2001 – 13,000 mg/L July 2001 - >200 mg/L October 2001 - >100 mg/L August 2002 - ~30 mg/L	April 2001 – Rose from 12 to 90 mg/L July 2001 – At background
Dissolved oxygen	N/A	April 2001 – Fell from 80% to 30% saturation August 2002 – Variable, occasionally below RE1
Ammonia	April 2001 – 340 mg/L October 2001 – 10-20 mg/L August 2002 - <5 mg/L	April 2001 – 0.5 mg/L August 2002 – Around DL of 0.01 mg/L
Chloride	April 2001 – 360 mg/L August 2002 – at background	April 2001 – Rose from 7 to 14 mg/L August 2002 – Less than 5 mg/L

Throckmorton

Monitoring results demonstrated that the leachate from the Throckmorton site had the following characteristics (Det Norske Veritas, 2003, p. II.25):

- **BOD.** Very high in all cells initially (360,000 mg/l); steadying to below 50,000 mg/l within 4 months; typically below 5,000 mg/l within 6 months; and typically below 3,000 mg/l within 13 months.
- **Ammonia as nitrogen.** Initially 2,000 – 10,000 mg/l; reducing to less than 3,000 mg/l within 6 months; thereafter fluctuating below this level.
- **Chloride.** Fluctuated greatly up to 1,400 mg/l during the first 9 months; thereafter generally less than 350 mg/l, although some cells fluctuated up to 550 mg/l.

Birkshaw Forest, Lockerbie, Scotland

In May 2001, as a result of complaints regarding the odors emanating from the mass burial site at Birkshaw Forest, monitoring of the air quality near the site was performed to determine the presence of compounds that may be injurious to human health (Glasgow Scientific Services Colston Laboratory, 2001). The monitoring regime included total volatile organic compounds (TVOC), flammable and other bulk gases, individual volatile organic compounds (VOC), and hydrogen sulfide. It was concluded that although odor causing compounds were identified, the concentration of contaminants were within air quality guidelines and, although a source of annoyance, were not expected to result in adverse health affects.

A monitoring program (for groundwater, leachate, and gas) was undertaken at the Birkshaw Forest site by Enviros Aspinwall on behalf of the Scottish Executive. A series of reports provide the results of this monitoring program (Enviros Aspinwall, 2001c; Enviros Aspinwall, 2001a; Enviros Aspinwall, 2001b; Enviros Aspinwall, 2001d; Enviros Aspinwall, 2002a). These reports, in conjunction with quarterly site management reports (Enviros Aspinwall, 2002b; Enviros Aspinwall, 2003), provide operational details for the site. Key observations from these monitoring reports are summarized in Table 19. It is noteworthy that the February 2003 report (Enviros Aspinwall, 2003) indicated that the leachate produced continued to be of very high strength, even 1½ years after burial operations ended. In spite of the potent nature of the leachate, monitoring results provided no evidence of widespread groundwater contamination, confirming the effectiveness (and necessity) of the sophisticated containment systems and operational procedures implemented (Enviros Aspinwall, 2003).

5.3 – Monitoring Requirements

Following the disposal activities of the 2001 FMD outbreak, the UK Department of Health (2001b) outlined environmental monitoring regimes focused upon the key issues of human health, air quality, water supplies, and the food chain. The methods of surveillance employed in these programs include the following:

- **Public drinking water supplies.** Water companies carry out routine monitoring of microbiological and chemical quality of their supplies.
- **Private water supplies.** Guidance for monitoring included testing for both chemical and microbiological parameters (although chemical parameters were reported to be better indicators of contamination) (UK Public Health Laboratory Service).
- **Leachate.** At landfill and mass burial sites, leachate is managed as well as monitored for both composition and migration. Groundwater and surface water sources are tested in the vicinity of these sites.
- **Surveillance of human illness.** Illnesses, such as gastrointestinal infections, that might arise in connection with FMD carcass disposal is monitored.

It was noted that, although baseline data with which to compare would be useful, for most private water supplies such baseline data would not exist. Therefore, caution in interpretation of results was stressed (i.e., increased levels of an analyte may not necessarily indicate contamination by a disposal site, other sources may be involved) (UK Public Health Laboratory Service).

TABLE 19. Key results and conclusions from the monitoring program of the Birkshaw Forest (Lockerbie) mass burial site.

Reporting Period	Key Observations/Conclusions	Significant Monitoring Results
May 2001 (Enviros Aspinwall, 2001c)	Of 8 boreholes, 2 demonstrated evidence of contamination (located to the east of the site). Likely sources of contamination included a leachate spill and runoff from decontamination stations.	Borehole east of site COD[a] 5,270 mg/l; TOC[b] 1,280 mg/l; Leachate COD 74,200 mg/l; BOD[c] 47,550 mg/l; pH 6.6
June 2001 (Enviros Aspinwall, 2001a)	The majority of sample locations continued to demonstrate no groundwater contamination. Of the two boreholes previously identified as contaminated, measured parameters showed improvement.	Borehole east of site COD 1,200 mg/l; pH 8.6
August 2001 (Enviros Aspinwall, 2001b)	Monitoring results indicate no widespread leachate release, although limited release from one unlined pit. Monitoring results from the spill-contaminated borehole showed a continued trend toward improvement. No risk from gas identified.	Borehole east of site COD 1,000 mg/l; pH below 7
October 2001 (Enviros Aspinwall, 2001d)	Monitoring results continued to show no evidence of groundwater contamination. Levels in the spill-contaminated borehole reduced considerably.	--
December 2001 (Enviros Aspinwall, 2002a)	Monitoring results continued to show no evidence of widespread groundwater contamination, although one borehole east of the site showed some signs of leachate contamination. Levels in the spill-contaminated borehole continued to decline.	--
July-Sep 2002 (Enviros Aspinwall, 2002b) Oct-Dec 2002 (Enviros Aspinwall, 2003)	No evidence of significant surface water or groundwater pollution. Gas monitoring suggests the pits are methanogenic and producing gas at low levels. Leachate of very high strength continues to be produced (COD in the thousands of mg/l).	--

[a]COD: chemical oxygen demand.

[b]TOC: total organic carbon.

[c]BOD: biochemical oxygen demand.

Section 6 – Advantages & Disadvantages

6.1 – Trench Burial

The advantages and disadvantages associated with trench burial, as reported by a wide variety of sources, are summarized below. The advantages have been summarized from sources including Agriculture and Resource Management Council of Australia and New Zealand (1996), Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Ryan (1999), Blake & Donald (1992), Damron (2002), and Minnesota Board of Animal Health (2003).

Sources reporting disadvantages include Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Hermel (1992), Pope (1991), UK DEFRA (2002b), Ryan (1999), Ritter & Chirnside (1995), Doyle & Groves (1993), Myers (1998), Blake & Donald (1992), Minnesota Board of Animal Health (2003), Alberta Agriculture, Food and Rural

Development (2002c), Minnesota Board of Animal Health (1996), Franco (2002), and Moorhouse (1992). In some cases, certain advantages or disadvantages may have varying degrees of relevance depending on whether viewed in the context of disposal of daily mortalities or disposal of mortalities from an emergency situation (e.g., natural disaster or animal disease).

Advantages

Several sources report trench burial to be a relatively economical option for carcass disposal as compared to other available methods. However, a variety of factors would likely impact the cost effectiveness of trench burial, including the circumstances under which it is used (i.e., whether used for an emergency situation or for disposal of daily mortalities), whether equipment is owned or rented, and whether any environmental protection measures are necessary. Trench burial is reported to be convenient and logistically simple, especially for daily mortalities, as the equipment necessary is generally widely available and the technique is relatively straightforward. This also allows trench burial to be performed relatively quickly. If performed on-farm or on-site, it eliminates the need for transportation of potentially infectious material, reducing the potential for disease spread or breaches in biosecurity. The technique is perhaps more discrete than other methods (e.g., open burning), especially when performed on-site (on-farm) and may therefore be less likely to attract significant attention from the public. Furthermore, bacteria and viruses reportedly seem not to move very far from the burial site, although this would be highly dependent on the specific individual circumstances (e.g., volume of mortality buried, geological and hydrological properties of the site, disease agent of concern, etc.). These attributes, particularly those of convenience, logistical simplicity, and rapid completion, have resulted in trench burial being a traditionally favored option for carcass disposal.

Disadvantages

Conversely, there are also a wide variety of disadvantages associated with trench burial. Perhaps most significant among them is the potential for detrimental environmental effects, specifically water quality issues. Again, the effects that may arise would depend on the specific circumstances, such as volume of mortality buried, geological and hydrological properties of the site, etc. Additionally, the risk of disease agents persisting in the environment may be of concern (e.g., anthrax and TSE agents). Trench burial, in effect, serves as a means of placing carcasses "out of site, out of mind" while they decompose, but does not represent a consistent, validated means of eliminating disease agents. Because the residue within a burial site has been shown to persist for many years, even decades, although the actual placement of carcasses within a trench can be completed relatively rapidly, ultimate elimination of the carcass material represents a long-term process. Furthermore, there is a considerable lack of knowledge and research regarding the potential long-term impacts of trench burial. From a practical standpoint, the use of trench burial may be limited by several factors, including a lack of sites with suitable geological and/or hydrological properties in some regions, regulatory constraints or exclusions relative to suitable locations, and the fact that burial may be prohibitively difficult in winter or when the ground is wet or frozen. In some cases, the presence of an animal carcass burial site may negatively impact land value or options for future use. Lastly, as compared to other disposal options, burial of carcasses does not generate a useable by-product of any value.

6.2 – Landfill

Advantages

The following advantages associated with landfill disposal of animal carcasses have been summarized from the following sources: Brglez (2003), Wisconsin Department of Natural Resources (2003, p. 128), Gunn (2001), DNV Technica (1997a), Wisconsin Department of Natural Resources (2002), Gale, Young, Stanfield, & Oakes (1998), and Ryan (1999).

Perhaps the most significant advantages of landfill disposal are the fact that the infrastructure for disposing of waste already exists, and capacity can be relatively large. Landfill sites, especially Subtitle D landfill sites, will have been previously evaluated for suitability, and the necessary environmental protection measures will already have been designed and implemented. During an emergency or instance of catastrophic loss, time is often very limited, and therefore landfills offer the advantage of pre-existing and immediately-available infrastructures for waste disposal (including equipment, personnel, procedures, and importantly, containment systems). Because landfill sites are already equipped with the necessary engineered containment systems for handling waste by-products such as leachate and gas, landfills represent a disposal option that would generally pose little risk to the environment. (Note that these advantages related to adequate containment systems may not apply to small arid landfills that rely on natural attenuation to manage waste by-products.) As an example of the significant capacity potentially available in landfill sites, approximately 95,000 tonnes of carcass material was deposited in landfills during the 2001 UK FMD outbreak (UK Environment Agency, 2001b, p. 9; NAO, 2002, p. 74), in addition to approximately 100,000 tonnes of ash and associated material (UK Environment Agency, 2001b, p. 9). Furthermore, during the 2002 END outbreak in southern California over three million birds were depopulated, with landfills serving as a primary route of disposal.

Another advantage of landfills is their wide geographic dispersion. Many, although certainly not all, geographic areas would have a landfill site in relatively close proximity. However, as will be discussed below, not all landfills that can accept carcasses will do so. The cost to dispose of carcasses by landfill has been referred to as both as an advantage and a disadvantage, and would likely depend on the situation. For purposes of disposing of daily mortalities, costs to dispose via landfill may be higher than for alternative methods. However, costs in an emergency situation or for certain disease agents may be comparable or favorable for landfills versus alternative methods.

Disadvantages

The following disadvantages associated with landfill disposal of animal carcasses have been summarized from sources including Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Bagley, Kirk, & Farrell-Poe (1999), UK Environment Agency (2002b), Hickman & Hughes (2002), Wisconsin Department of Natural Resources (2003, p. 128), UK DEFRA (2002b), and Ryan (1999).

Even though disposal by landfill may be an allowed option, and a suitable landfill site may be located in close proximity, landfill operators may not be willing to accept animal carcasses. A commonly cited reason for this is the fear of public opposition (as occurred during the 2001 UK FMD outbreak, and during the management of CWD deer in Wisconsin). Additionally, because the development of a landfill site is an extremely lengthy, difficult, and expensive process, landfill owners and planning authorities may not want to sacrifice domestic waste capacity to accommodate carcass material. Those landfill sites that do accept animal carcasses may not be open for access when needed or when convenient.

As was described for trench burial, landfilling of carcasses represents a means of containment rather than of elimination, and long-term management of the waste is required. However, this long-term commitment will be in effect for landfill sites regardless of whether or not carcass material is accepted. Relative to disease agent concerns, and TSEs in particular, several risk assessments conclude that disposal in an appropriately engineered landfill site represents very little risk to human or animal health due to robust containment systems and some degree of anticipated degradation of prions over time. However, further research is warranted in this area as the mechanism and time required for degradation are not known. An additional possible disadvantage associated with landfill disposal is that of potential spread of disease agents during transport of infected material from the site of origin to the landfill. It should be noted that this potential for disease spread would be equally associated with other off-site disposal methods. Although the potential exists for disease spread, rigorous biosecurity efforts have allowed landfill disposal to be successfully used in several infectious disease eradication efforts (such as the 2002 outbreak of END in southern California).

Compared to some other disposal options, a disadvantage of all burial techniques including landfill is the fact that they do not generate a useable by-product of value. As previously stated, the costs associated with landfill disposal have been cited as a disadvantage, and in some cases are even termed "prohibitive." Again, depending on the circumstances, the cost of landfill disposal may be higher than, or comparable to, other disposal alternatives.

6.3 – Mass burial

The most significant advantage of mass burial sites is the capacity to dispose of a tremendous number (volume) of carcasses. For mass burial sites created in the midst of an emergency, this may perhaps be one of the only advantages. Assuming appropriate containment systems are employed in the design, mass burial sites may be similar to landfills in terms of posing little risk to the environment. However, the significant disadvantages associated with mass burial sites, as used during the 2001 UK FMD outbreak, caused UK officials to state that it is very unlikely that mass burial sites would be used as a method of disposal in the future (FMD Inquiry Secretariat, 2002). One of the most significant disadvantages from the UK experience was the massive public opposition to the development and use of such sites. From a practical standpoint, other disadvantages included the significant costs involved, problems with site design leading to brief episodes of environmental contamination, and the need for continuous, long-term, costly monitoring and management of the facilities. From a theoretical standpoint, other potential disadvantages of mass burial sites would be similar to those outlined for landfills, namely serving as a means of containment rather than of elimination, lack of adequate research into long-term consequences associated with various disease agents (especially TSEs), presenting opportunities for spread of disease during transport from farm sites to the mass burial site, and not generating a usable by-product of any value.

In spite of these potential disadvantages, mass burial sites may have the potential to serve as an effective means of carcass disposal in an emergency situation. However, this would require thorough site assessment, planning, and design well in advance of the need.

Section 7 – Critical Research Needs

7.1 – Relevant Research In-Progress

1. A study to retrospectively evaluate burial sites used in the UK during the 1967-68 FMD outbreak is in progress by the UK EA. The EA website indicates the study, titled "Sampling of 1967 FMD Remains" is in progress, but the report is not yet available. The reported purpose of the project is "to gather analytical data on the degraded remains of animals culled during the 1967 FMD outbreak." Additional details are available at http://www.environment-agency.gov.uk/science/scienceprojects/304016/334745/.
2. In a speech at the 2001 US Animal Health Association meeting, Taylor (2001) reported,

   Experiments on the longterm survival of the BSE agent after burial are about to be initiated at the Neuropathogenesis Unit in Edinburgh, UK, but it will take up to ten years to gather results from these experiments. However, burial is not the same as landfill because the latter process usually involves an enhanced degree of microbiological activity because of the variety of waste materials that are present. As far as the author is aware, there are no experiments in progress to study the degradation effects on TSE agents when they are land-filled.

3. Extensive research on the transport and fate of prions in the environment, particularly in landfill environments, is currently in progress at the University of Wisconsin, Madison. Objectives of the research include:

- Investigation of the processes affecting the preservation of prions in soils (including evaluation of the extent to which prions associate with various soil constituents, whether association with soil constituents protects prions from degradation, and the extent to which infectivity is retained by particle-associated prions).
- Investigation of the factors influencing the mobility of prions in soils and landfills, including the infectivity of leached prion proteins.
- Investigation of the fate of prions in wastewater treatment plants, including sorption to sludge and sedimentation, and degradation by sludge microbial populations.

7.2 – Research Needed

1. Investigate means to make on-farm burial more environmentally sound.

   Explore potential design and construction techniques that may improve the environmental soundness of on-farm burial sites, especially for those sites in locations with marginally acceptable geology. Some design aspects used in Subtitle D landfills may be relevant. Also evaluate pre-planning steps that can facilitate the rapid use of on-farm burial sites in an environmentally sound manner at time of emergency.

2. Thoroughly evaluate the design, construction, operation, management, and environmental impacts of mass burial sites used in the UK during the 2001 FMD outbreak and use this information to establish best practice guidelines for similar sites that may be used in the US.

   Because burial is included as a disposal option in many states' contingency plans, burial sites in livestock-dense areas may contain significant numbers (or volumes) of carcasses. These sites could be similar in scope to the mass burial sites used in the UK during the 2001 FMD outbreak. The UK sites provide a unique opportunity to learn from the experiences of others in order to establish suggested guidelines for such sites in advance of a need for them.

3. Retrospectively evaluate burial sites used in the past to better understand the decomposition processes that occur, as well as the possible environmental impacts of the sites.

   Few if any investigations of the nature and dynamics of decomposition within mass burial sites of cattle, sheep or pigs have been conducted (Munro, 2001). As mentioned in section 7.1, a study of burial sites used in the UK during the 1967-68 FMD outbreak is in progress. In addition to the insights from the UK work, previous burial sites used in the US should be identified for evaluation. Potential candidates might include burial sites from the 1984 AI outbreak in Virginia, as well as burial sites used during Hurricane Floyd in North Carolina.

4. Conduct controlled studies to gain a better understanding of the potential environmental impacts associated with various burial techniques. Use this information as a basis for developing scientifically valid burial regulations and guidelines.

   A recent evaluation of the water quality impacts of burying livestock mortalities concluded that the majority of regulations and guidelines governing burial are not based on scientific information regarding the potential environmental impacts of such operations, largely due to the fact that critical information in the following areas is lacking (Freedman & Fleming, 2003):

   - Measurement of the relative impacts of different types of contaminants, including nutrients, pathogens, antibiotics, etc.
   - Movement of contaminants from buried large animals (e.g., cattle)
   - Movement of contaminants through different types and textures of soils.

In their interim environmental impact assessment, the UK EA identified a need for a decision-making framework for management including a review of the "best practicable environmental options" for the disposal of carcasses to protect human health and the environment (UK Environment Agency, 2001b, p. 27).

A briefing by the World Health Organization (WHO) on the impact of human cemeteries on the environment and public health identified the following areas of needed research (Ucisik & Rushbrook, 1998), which are analogous to areas of study needed relative to animal burials:

- Identify safe distances between aquifers and cemeteries in various geological and hydrogeological situations.
- Investigate why and how most microorganisms arising during the putrefaction process do not appear in the groundwaters beneath cemeteries.
- Determine the desirable minimum thickness of the unsaturated zone beneath cemeteries.
- Collect together existing regulations on cemetery siting and design from various countries and prepare, with the latest scientific findings, a set of common practices.

5. Conduct studies to better understand the survival and potential migration of various disease agents within burial systems.

   In an interim environmental impact assessment following the 2001 FMD outbreak, the UK EA identified a need for improved technical information on pollutant sources, pathways, and impacts of various disposal options including burial (UK Environment Agency, 2001b, p. 27). For example, a specific need for information on the microbiological contaminants in groundwaters from the burial of carcasses and other materials was identified.

6. Pre-identify and assess the carcass disposal options available, including potential burial (or mass burial) sites, particularly in regions densely populated with confined animal feeding operations (CAFOs).

   The strategic assessment of options for the disposal of infected wastes in the event of a disease outbreak in the poultry industry conducted by the Department of Agriculture in Western Australia is an excellent model that could be used by various geographic regions or by states (e.g., by state within the US) as a tool for developing contingency plans and disposal hierarchies appropriate to the unique circumstances of each region (Australian Department of Agriculture, 2002). The approach used in this strategic assessment ensures that all available options are investigated and would help to maximize the number of available options in an emergency.

   As demonstrated unequivocally by the experiences of the UK during the 2001 FMD outbreak, it is not possible to adequately plan for and design mass burial sites during the time constraints of an emergency situation. It would be wise to identify CAFO-dense areas (e.g., the southwestern areas of Kansas) and conduct preliminary assessments of possible mass burial sites.

7. Evaluate the potential for designing carcass burial sites as "bioreactors" or for using existing bioreactors for carcass disposal.

   Bioreactors are generally a type of landfill that, unlike traditional landfills, are designed to promote the degradation of material rather than minimize it. The advantage of promoting degradation is the reduced long-term maintenance of the site. Several sources suggest advantages associated with such a design (Det Norske Veritas, 2003, p. II.7; Munro, 2001); however, additional research is needed to better understand the design and operating parameters of such a site.

8. Investigate the survival of TSE agents, specifically those related to BSE and CWD, in the

environment of carcass burial sites, including landfills.

This research area includes questions related to the management of burial sites: How do anaerobic conditions affect the degradation, persistence, and migration of TSEs in the soil environment? What detection systems can be used to identify TSE infectivity in soil systems? Can earthworms be used as an effective "sampling tool?" How does the TSE agent partition between solid and liquid fractions in burial environments?

In an opinion published in 2003 addressing the issue of TSEs, the European Commission Scientific Steering Committee (2003) emphasized the fact that the "extent to which infectivity reduction can occur as a consequence of burial is poorly characterized;" a fact reiterated by Taylor (2001).

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Appendix

TABLE A1. Summary of reported criteria for burial site selection.

Jurisdiction/Source	Minimum cover (distance between carcass and natural surface of the ground)	Separation Distances:				Other notes
		Between bottom of trench and water table	From wells, surface water intake structures, public/private drinking water supplies	From bodies of surface water (i.e. lakes, streams, rivers, etc.)	Other	
Recommended guidelines for burial site selection (literature)						
AL (USDA, Natural Resource Conservation Service, Alabama)	2 ft		300 ft up-gradient/ 150 ft down-gradient from any potable source	100 ft		Should be located in suitable soils; soils suitable for sanitary landfill are also suitable for this purpose
CA (Horney, 2002)	4-6 ft	5 ft	100 ft	100 ft	Property Lines: 25 ft Residences: 100 ft Roads, highways, parks, 0.25 mi.	Burial site should be in an area not likely to be disturbed in the near future. Recommend locating on a site of 5-10 acres minimum to allow for proper setbacks and other restrictions.
NE (Henry, Wills, & Bitney, 2001)	4 ft				Production facilities: 100 ft	Discourage use of burial for daily mortalities; consider primarily for occasional or catastrophic losses. Site should consist of deep, fine-textured soils (such as clay and silt) with underlying geology that poses little risk to groundwater.
TX (USDA, Natural Resources Conservation Service, Texas, 2002)	2 ft	2 ft	150 ft private 500 ft public	150 ft	Residences and Property Lines: 50 ft min 200 ft recom.	Do not locate where surface runoff could enter pit Extensive information on soil properties/classes
Canada (Winchell, 2001)	0.6 m (2 ft) min	1 m				Must be in low permeability soils (less than 10-7 cm/sec) Lime may be added to the layer of carcasses before being covered

Alberta, Can (Alberta Agriculture, Food and Rural Development, 2002a)						Extensive information on appropriate soil types. Should not bury on hilly land to reduce surface water contamination potential (slope should be less than 2% [2 m drop for every 100 m]) Difficult to bury in frozen ground – difficult to excavate and to cover mortalities Should not be less than 70-100 m apart Should not use more than ~10% of total land owned for burial per year. Therefore, only use a burial site once every 10 years.
British Columbia, Can (Government of British Columbia, Ministry of Agriculture, Food & Fisheries)	1 m (3 ft)	1.2 m (4 ft)	120 m (400 ft)	30 m (100 ft)		Burial pits should be sized for a max of 700 kg (1,500 lbs) of animals Sites should be staggered throughout the operation
UK/EU (Kay, 2000)	1 m (3 ft)	1 m (3 ft)	250 m (820 ft)	30 m (100 ft) from spring or watercourse	Field drain: 10 m (30 ft)	When first dug, must be free of standing water NOTE: Burial of animal carcasses, except in extraordinary circumstances, has effectively been banned in the EU as of May 2003 (European Parliament, 2002).
Regulatory requirements for burial site selection						
AR (Arkansas Livestock and Poultry Commission, 1993)	2 ft		300 ft from well			Carcasses are not to be buried in a landfill Anthrax carcasses must be covered with 1 inch of lime
GA (Georgia Department of Agriculture)	3 ft	1 ft Max pit depth is 8 ft	100 ft	100 ft		At least 15 ft from edge of any embankment. Must be in soil with moderate or slow permeability. Must not be located in areas with gullies, ravines, dry stream beds, natural/man-made drainage ways, sink holes, etc. Criteria outlined for disposal pits
ID (State of Idaho)	3 ft		300 ft	200 ft	Residences: 300 ft Property Lines: 50 ft Roadways: 100 ft	Sites shall not be located in low-lying areas subject to flooding, or in areas with high water table where seasonal high water level may contact burial pit
IA (Iowa Farm-A-	6 inches immediate;	Can not bury in flood	100 ft private; 200 ft public	100 ft		Soils must be classified as moderately well, well, somewhat excessively, or excessively drained.

Syst)	30 inches final	plains, wetlands, or on shore lines				Max/acre/year: 7 cattle, 44 swine, 73 sheep, 400 poultry, all others 2 animals
KS (State of Kansas)	3 ft					On-site burial of 6 or more animal units requires written approval of landowner and local gov't or zoning authority; approval must be submitted to Kansas Department of Health & Environment.
KY (National Association of State Departments of Agriculture Research Foundation)	4 ft		100 ft	100 ft	Residences & Highways: 100 ft	Burial site must be in a location that does not flood
MI (Michigan Department of Agriculture, Animal Industry Division)	2 ft final		200 ft			Individual graves: Max individual graves/acre = 100 (min 2-1/2 ft apart); total carcass weight/acre = 5 tons Common graves: min 100 ft apart; max carcass weight = 5,000 lbs/acre
MN (Minnesota Board of Animal Health, 2003; Minnesota Board of Animal Health, 1996)	3 ft	5 ft	Do not place near	Do not place near		Most suitable for small amounts of material (e.g. less than 2000-lb./burial pit/acre) Burial not recommended for catastrophic losses due to potential for groundwater pollution Cannot bury where water table is within 10 ft of surface Do not bury in "karst" or sandy areas; do not bury in areas subject to flooding
MS (Mississippi Board of Animal Health)	2 ft				Residences: 300 ft Property Lines: 150 ft	Trench/pit constructed so as not to allow rain water to drain. For large numbers of carcasses, contact Miss DNR for approval
MO (Fulhage, 1994)	6 inches immediate 30 inches final	Lowest elevation of burial pit 6 ft or less below surface of the ground	300 ft	100 ft	Residences: 300 ft Property Lines: 50 ft	Can bury animals on no more than 1 acre or 10% of total property owned (whichever is greater) per year Max loading rates/acre/year: High groundwater risk = 1 bovine, 6 swine, 7 sheep, 70 turkey, 300 poultry Low groundwater risk = 7 cattle, 44 swine, 47 sheep, 400 turkey, 2,000 poultry
NV	3 ft	5 ft (increase	200 ft	300 ft	Dwellings: 200 ft	Must be buried at least 3 ft underground

(Nevada Division of Environmental Protection)		distance in areas w/highly permeable soils)			Neighboring residences: 500 ft Property Lines: 50 ft	Consider covering animals with quicklime to control odors and promote decomposition
NH (New Hampshire Department of Environmental Services, 2001)		4 ft	75 ft	75 ft		Recommended that “quick lime” be applied during burial to reduce odors and promote decomposition
NC (North Carolina Department of Health and Human Services, 2000; North Carolina Department of Agriculture & Consumer Services)	3 ft	3 ft when possible; at least 12 inches	300 ft public well 100 ft other well	300 ft		Burial site cannot include any portion of a waste lagoon or lagoon wall. If burial in a waste disposal spray field, burial site not avail for waste spraying until new crop established Primarily for emergency situations. Not recommended for daily mortalities
OK (Britton)	2.5 ft					Site must have the type of soil that allows for proper drainage.
WV (State of West Virginia)	2 ft		100 ft	100 ft	Residences: 100 ft Roadways: 100 ft	Burial site shall not be subjected to overflow from ponds or streams Carcass shall be covered with quicklime to a depth not less than three inches
Alberta, Can (Alberta Agriculture, Food and Rural Development, 2002b)	1 m (3 ft) compacted soil	1 m (3 ft)	100 m (333 ft)	100 m (333 ft)	Residences: 100 m (333 ft) Livestock facilities: 100 m (333 ft) Primary highway: 300 m (1,000 ft); secondary highway: 100 m (333 ft); any other road: 50 m (150 ft)	Weight of dead animals in a trench may not exceed 2,500 kg (~5,500 lb)
Manitoba, Can (Province of Manitoba, 1998)	1 m (3 ft)		100 m (333 ft)	100 m (333 ft)		Site must be constructed so as to prevent the escape of any decomposition products of the mortalities that cause or may cause pollution of surface water, groundwater, or soil

TABLE A2. Land area or excavation volume required for trench burial.

Jurisdiction/ Source	Total Trench Depth (D)	Carcass Depth	Cover Depth	Trench Width (W)	Trench Length (L)	Est. Area or Volume Required	Carcass Equivalents	Other Notes
Literature								
NC (Wineland & Carter, 1997)						50-55 ft^3 (~2.0 yd^3) per 1,000 broilers or commercial layers 100 ft^3 (3.7 yd^3) per 1,000 turkeys		Note that the volume estimates were based on a disposal pit design, rather than trench burial.
Australia (Atkins & Brightling, 1985)	~3.5 m (11.5 ft)	1.5 m (5 ft)	2.0 m (6.5 ft) to ground level	3-5 m (10-16.5 ft) determined by equipment used	--	1 m^3 (~35 ft^3 or 1.3 yd^3) per 8-10 mature sheep (off-shears)	--	To calculate the necessary pit volume, including an allowance for cover, a value of 0.3 m^3 of excavation per sheep was used.
Australia (Lund, Kruger, & Weldon)	2.6 m (8.5 ft)	--	1 m (3.3 ft)	4 m (13 ft)	6.7 km (~4.2 mi) for 30,000 cattle	30,000 head of cattle requires trench of 70,000 m^3 (2.5 million ft^3, or 92,000 yd^3)	--	Equates to excavation volume of 2.3 m^3 (82 ft^3 or 3 yd^3) per cattle carcass.
N/A (McDaniel, 1991)	9 ft	3 ft	6 ft	7 ft	--	14 ft^2 at bottom of pit for each adult bovine (assuming 3 ft depth, equates to ~42 ft^3 or ~1.2 yd^3 per adult bovine)	1 adult bovine = 5 mature sheep or hogs	For every additional 3 ft of trench depth, the number of carcasses per 14 ft^2 can be doubled. Due to bulky feathers, poultry require more burial space per unit of weight than cattle, hogs, or sheep. Estimate space required for poultry by counting carcasses that fill a space of known volume (i.e. truck).
N/A (Sander, Warbington, & Myers, 2002)	9 ft	--	3-4 ft	7 ft	--	14 ft^2 per mature cow	--	
N/A (Anonymous, 1973)	--	--	--	--	--	Assume 40 lbs of poultry carcasses per 1 ft^3	--	Equates to approximately 1,080 lbs/yd^3.

Regulatory Agencies								
AL (USDA, Natural Resource Conservation Service, Alabama)	8 ft (for deep soils where bedrock not a concern)	1 ft max small animals 1 carcass max large animals	2 ft mounded	--	--	--	--	Max size of burial excavation should be 0.1 acre (~4,400 ft^2) Excavations over 3.5 ft deep should be sloped on sides at least 1.5 (horiz) to 1 (vert)
TX (USDA, Natural Resources Conservation Service, Texas, 2002)	3 ft min 8 ft max	1 ft small animals 1 carcass large animals	2 ft	4 ft	Adequate for mortality	Total mortality weight ÷ 62.4 lb/ft^3 = ~volume of mortality in ft^3 Pit excavation = 2-4 times the mortality volume to allow for voids and fill soil Spreadsheet avail on request	--	Pits 6 ft or greater in depth – perform soil tests to a depth two ft below lowest planned excavation Multiple pits – separate by 3 ft of undisturbed or compacted soil For deep soils, carcasses and soil can be placed in multiple layers up to a total depth of 8 ft 62.4 lb/ft^3 suggests a density of approximately 1,680 lbs/yd^3
APHIS (USDA, 1980)	9 ft or greater	--	--	7 ft or greater	--	14 ft^2 at bottom of pit for each adult bovine	1 adult bovine = 5 mature sheep or hogs	For every additional 3 ft of trench depth, the number of carcasses per 14 ft^2 can be doubled. Trench site should be mounded over and neatly graded. Do not pack the trench – decomposition and gas formation will crack a tightly packed trench causing it to bubble and leak fluids.
APHIS (USDA, 2001a)	--	--	--	--	--	42 ft^3 (~1.2 yd^3) required to bury 1 bovine, 5 pigs, or 5 sheep	--	
Australia (Agriculture and Resource Management Council of Australia and New Zealand, 1996)	~5 m (~16.5 ft)	--	2 m (6.5 ft)	~3 m (~10 ft)	--	1.5 m^3 (~53 ft^3 or ~2 yd^3) per each adult beast or 5 adult sheep	--	Example: Trench 5 m deep x 3 m wide filled with carcasses to within 2.5 m of ground level will accommodate 5 cattle or 25 sheep per linear meter (2.5 x 3 x 1 = 7.5 m^3; 7.5/1.5 = 5 cattle or 25 sheep)
Alberta, Canada (Ollis, 2002)	4-5 m (13-16.5 ft)	--	2 m (6.5 ft)	2 m (6.5 ft)	10 m (33 ft)	31 adult cattle carcasses require trench 4 x 2 x 10 m (DxWxL) (80m^3, 2,800	1 bovine = 5 adult hogs or sheep 1 bovine = 40	

	ft^3, or 105 yd^3 per 31 adult cattle) (~2.6 m^3, 92 ft^3, or 3.5 yd^3 per carcass) 46 adult cattle carcasses require trench 5 x 2 x 10 m (DxWxL)	broiler chickens (market-ready weight)	

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

2

Incineration

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Abbreviations Used

AI	avian influenza
APHIS	USDA Animal and Plant Health Inspection Service
BSE	bovine spongiform encephalopathy
CWD	chronic wasting disease
DEFRA	UK Department for Environment, Food and Rural Affairs
EPA	US Environmental Protection Agency
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FDA	US Food and Drug Administration
FMD	foot and mouth disease
FSIS	USDA Food Safety and Inspection Service
MAFF	UK Ministry of Agriculture, Fisheries and Food
MBM	meat-and-bone meal
NAO	UK National Audit Office
OTMS	UK Over Thirty Months Scheme
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PM	particulate matter
PMF	powder metallic fuel
SEAC	UK Spongiform Encephalopathy Advisory Committee
SSC	European Commission Scientific Steering Committee
TSE	transmissible spongiform encephalopathy
UK	United Kingdom
US	United States
USDA	US Department of Agriculture

Section 1 – Key Content

Incineration has historically played an important role in carcass disposal. Advances in science and technology, increased awareness of public health, growing concerns about the environment, and evolving economic circumstances have all affected the application of incineration to carcass disposal. Today there are three broad categories of incineration techniques: open-air burning, fixed-facility incineration, and air-curtain incineration.

1.1 – Open-Air Burning

Open-air carcass burning—including the burning of carcasses on combustible heaps known as pyres—dates back to biblical times. It is resource intensive, and both historically and recently it has been necessarily supplemented by or substituted with other disposal methods. Nevertheless, open-air burning has persisted throughout history as a utilized method of carcass disposal. For example, open-air burning was used extensively in the 1967 and 2001 foot and mouth disease (FMD) outbreaks in the United Kingdom (UK) (NAO, 2002; Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002), in smaller-scale outbreaks of anthrax in Canada in 1993 (Gates, Elkin, & Dragon, 1995, p.258), and in southeast Missouri in 2001 (Sifford, 2003).

Open-air burning includes burning carcasses (a) in open fields, (b) on combustible heaps called pyres (Dictionary.com, 2003), and (c) with other burning techniques that are unassisted by incineration equipment. Generally, one must have a state permit to open-air burn (APHIS, 2003, p.2707). Open-air burning is not permitted in every state, but it may be possible to waive state regulations in a declared animal carcass disposal emergency (Ellis, 2001, p.27; Henry, Wills, & Bitney, 2001; Morrow, Ferket, & Middleton, 2000, p.106).

Open-air burning should be conducted as far away as possible from the public. For large pyres involving 1,000 or more bovine carcasses, a minimum distance of 3 kilometers (~2 miles) has been suggested in the UK (Scudamore et al., 2002, p.779). Based on the UK experience, an important site-selection rule is to first communicate with local communities about open-air burning intentions (Widdrington FMD Liaison Committee).

Material requirements for open-air burning include straw or hay, untreated timbers, kindling wood, coal, and diesel fuel (see Table 2 in section 3.1) (McDonald, 2001, p.6; Smith, Southall, & Taylor, 2002, pp.24-26). Although diesel fuel is typically used in open-air burning, other fuels (e.g., jet fuel and powder metallic fuels) have also been used or studied (Gates et al., 1995, p.258; Sobolev et al., 1999; Sobolev et al., 1997). Tires, rubber, and plastic should not be burned as they generate dark smoke (MAFF, 2001, p.36). To promote clean combustion, it is advisable to dig a shallow pit with shallow trenches to provide a good supply of air for open-air burning. Kindling wood should be dry, have a low moisture content, and not come from green vegetation (MAFF, 2001, pp.36-37). Open-air burning, particularly in windy areas, can pose a fire hazard.

Open-air burning of carcasses yields a relatively benign waste—ash—that does not attract pests (Damron, 2002). However, the volume of ash generated by open-air burning can be significant (NAO, 2002, p.92). Open-air burning poses additional clean-up challenges vis-à-vis groundwater and soil contamination caused by hydrocarbons used as fuel (Crane, 1997, p.3).

1.2 – Fixed-Facility Incineration

Historically, fixed-facility incineration of carcasses has taken a variety of forms—as crematoria, small carcass incinerators at veterinary colleges, large waste incineration plants, on-farm carcass incinerators, and power plants. During the 1970s, rising fuel prices reduced the popularity of fixed-facility incinerators, but technological improvements in efficiency soon followed (Wineland, Carter, & Anderson, 1997). Small animal carcass incinerators have been used to dispose of on-farm mortalities for years in both North America and Europe, and the pet crematoria industry has grown over time (Hofmann &

Wilson, 2000). Since the advent of bovine spongiform encephalopathy (BSE) in the UK, fixed-facility incineration has been used to dispose of BSE-infected carcasses as well as rendered meat-and-bone meal (MBM) and tallow from cattle carcasses considered to be at-risk of BSE (Herbert, 2001). During the 2001 FMD outbreak in the Netherlands, diseased animals were first rendered and then the resultant MBM and tallow were taken to incineration plants (de Klerk, 2002). In Japan, cattle testing positive for BSE are disposed of by incineration (Anonymous, 2003d).

Fixed-facility incinerators include (a) small on-farm incinerators, (b) small and large incineration facilities, (c) crematoria, and (d) power plant incinerators. Unlike open-air burning and air-curtain incineration, fixed-facility incineration is wholly contained and, usually, highly controlled. Fixed-facility incinerators are typically fueled by diesel, natural gas, or propane. Newer designs of fixed-facility incinerators are fitted with afterburner chambers designed to completely burn hydrocarbon gases and particulate matter (PM) exiting from the main combustion chamber (Rosenhaft, 1974).

One can operate an incinerator if properly licensed, usually by a state government (APHIS, 2003, p.2707). Properly trained operators are critical (Collings, 2002). Small, fixed-facility incinerators may be operated on farms provided one has a permit, although there are increasing regulatory costs associated with maintaining this permit.

In the United States (US), the idea of incinerating carcasses in large hazardous waste, municipal solid waste, and power plants has been suggested. While the acceptance of MBM and tallow from rendered carcasses could be accommodated in the US, large-scale whole-carcass disposal would be problematic given the batch-feed requirements at most biological waste incineration plants (Anonymous, 2003f; Heller, 2003). Many waste incineration facilities refuse to accept whole animals, noting that carcasses are 70 percent water and preferred waste is 25 percent water (Thacker, 2003). The possibilities of combining incineration with rendering (i.e., incinerating MBM and tallow) are more promising and should be explored (see section 7.1).

Many incinerators are fitted with afterburners that further reduce emissions by burning the smoke exiting the primary incineration chamber (Walawender, 2003). Compared to open-air burning, clean-up of ash is less problematic with fixed-facility incineration; ash is typically considered safe and may be disposed of in landfills (Ahlvers, 2003). However, if residual transmissible spongiform encephalopathy (TSE) infectivity is of concern, burial may not be suitable. Although more controlled than open-air burning, fixed-facility incineration also poses a fire hazard.

1.3 – Air-Curtain Incineration

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, thereby creating a turbulent environment in which incineration is greatly accelerated—up to six times faster than open-air burning (W.B. Ford, 1994, p.3). Air-curtain incineration technology—which has traditionally been used for eliminating land-clearing debris, reducing clean wood waste for landfill disposal, and eliminating storm debris—is a relatively new technology for carcass disposal (Brglez, 2003, p.18; Ellis, 2001, p.28). Air-curtain incinerators have been used for carcass disposal in the wake of natural disasters in the US (Ellis, 2001, pp.29-30), and imported air-curtain incinerators were used to a small degree during the UK 2001 FMD outbreak (G. Ford, 2003; NAO, 2002, p.74; Scudamore et al., 2002, p.777). Air-curtain incinerators have been used in Colorado and Montana to dispose of animals infected with chronic wasting disease (CWD) (APHIS, 2003, p.2707) and throughout the US in other livestock disasters (G. Ford, 2003).

In air-curtain incineration, large-capacity fans driven by diesel engines deliver high-velocity air down into either a metal refractory box or burn pit (trench). Air-curtain systems vary in size according to the amount of carcasses to be incinerated (Ellis, 2001, p.29). Air-curtain equipment can be made mobile. Companies that manufacture air-curtain incinerators include Air Burners LLC and McPherson Systems (G. Ford, 2003; McPherson Systems Inc., 2003). Secondary contractors, such as Dragon Trenchburning or Phillips and Jordan, are prepared to conduct actual air-curtain operations (Smith et al., 2002, p.28).

Materials needed for air-curtain incineration include wood (preferably pallets in a wood-to-carcass ratio varying between 1:1 and 2:1), fuel (e.g., diesel fuel) for both the fire and the air-curtain fan, and properly trained personnel (G. Ford, 2003; McPherson Systems Inc., 2003). For an incident involving the air-curtain incineration of 500 adult swine, 30 cords of wood and 200 gallons of diesel fuel were used (Ellis, 2001, p.29). Dry wood for fuel is critical to ensuring a proper air/fuel mixture (Ellis, 2001, p.30).

Air-curtain incinerators have met regulatory approval in the US and around the world (G. Ford, 2003). If placed far from residential centers and the general public, they are generally not nuisances (APHIS, 2002, p.11).

Like open-air burning and fixed-facility incineration, air-curtain incineration poses a fire hazard and the requisite precautions should always be taken. Air-curtain incineration, like other combustion processes, yields ash. From an ash-disposal standpoint, air-curtain incineration in pits is advantageous if the ash may be left and buried in the pits (Smith et al., 2002, p.27). However, in sensitive groundwater areas—or if burning TSE-infected carcasses—ash will most likely be disposed of in licensed landfills.

Unlike fixed-facility incineration, air-curtain incineration is not wholly contained and is at the mercy of many variable factors (e.g., human operation, the weather, local community preferences, etc.). In past disposal incidents involving air-curtain incineration, both ingenuity and trial-and-error have been necessary to deal with problems (Brglez, 2003, pp.34-35).

1.4 – Comparison of Incineration Methods

Capacity

The efficiency and throughput of all three incineration methods—including open-air burning—depend on the type of species burned; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine have a higher fat content than other species and will burn more quickly than other species (Ellis, 2001, p.28).

For fixed-facility incinerators, throughput will depend on the chamber's size. For small animal carcass incinerators, throughput may reach only 110 lbs (50 kg) per hour (Anonymous, 2003e). Larger facilities dedicated to the incineration of animal remains may be able to accommodate higher numbers. In Australia, for example, one public incinerator is prepared to accept, during times of emergency, 10 tonnes of poultry carcasses per day (Western Australia Department of Agriculture, 2002, p.7). In the US, fixed-facility capacity is generally recognized to not be of an order capable of handling large numbers of whole animal carcasses; however, incineration plants are quite capable of taking pre-processed, relatively homogenous carcass material (Anonymous, 2003f; Ellis, 2001).

Air-curtain incinerator capacity depends on the manufacturer, design, and on-site management. One manufacturer reports that, using its larger refractory box, six tons of carcasses may be burned per hour (G. Ford, 2003). In a burn pit, using a 35-foot-long air-curtain manifold, up to four tons of carcasses may be burned per hour (W.B. Ford, 1994, pp.2, 11). Other studies have shown that air-curtain incinerators have efficiently burned 37.5 tons of carcasses per day (150 elk, weighing an average of 500 pounds each) (APHIS, 2002, p.11).

Cost

Synthesizing information from a variety of sources (see sections 3.1, 3.2, and 3.3), "intervals of approximation" have been used to describe the costs for each incineration technology. These are summarized in Table 1.

TABLE 1. "Intervals of approximation" for carcass disposal costs of open-air burning, fixed-facility incineration, and air-curtain incineration (Ahlvers, 2003; Brglez, 2003, p. 86; Cooper, Hart, Kimball, & Scoby, 2003, pp. 30-31; W.B. Ford, 1994; FT.com, 2004; Heller, 2003; Henry et al., 2001; Jordan, 2003; Morrow et al., 2000, p.106; NAO, 2002, p.92; Sander, Warbington, & Myers, 2002; Sparks Companies, 2002, pp. v, 11; Waste Reduction by Waste Reduction Inc.; Western Australia Department of Agriculture, 2002, p.7).

	Open-air burning	Fixed-facility incineration	Air-curtain incineration
Interval approximating the cost (in US$) per ton of carcass	$196 to $723	$98 to $2000	$143 to $506

Disease agent considerations

Regardless of method used, bacteria, including spore-formers, and viruses should not survive incineration. There has, however, been much speculation that open-air burning can help spread the FMD virus; several studies have examined this question, and while the theoretical possibility cannot be eliminated, there is no such evidence (Champion et al., 2002; J. Gloster et al., 2001).

The disease agents responsible for TSEs (e.g., scrapie, BSE, and CWD) are highly durable (Brown, 1998). This raises important questions about incineration's suitability for disposing of TSE-infected—or potentially TSE-infected—carcasses. The UK Spongiform Encephalopathy Advisory Committee (SEAC) and the European Commission Scientific Steering Committee (SSC) agree that the risk of TSE-infectivity from ash is extremely small if incineration is conducted at 850°C (1562°F) (SEAC, 2003; SSC, 2003a).

TSE experts agree that open-air burning should not be considered a legitimate TSE-related disposal option. Instead, fixed-facility incineration is preferred (SSC, 2003b, p.4; Taylor, 2001). While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs (Grady, 2004), under controlled conditions fixed-facility incineration is also an effective means by which to dispose of TSE-infected material (Powers, 2003).

Because fixed-facility incineration is highly controlled, it may be validated to reach the requisite (850°C or 1562°F) TSE-destruction temperature.

While air-curtain incinerators reportedly achieve higher temperatures than open-air burning, and may reach 1600°F (~871°C) (G. Ford, 2003; McPherson Systems Inc., 2003), these claims need to be further substantiated (Scudamore et al., 2002, p.779). Noting that "with wet wastes, such as CWD-contaminated carcasses, temperatures...can fluctuate and dip below recommended temperatures," an Environmental Protection Agency (EPA) Region 8 draft document hesitates to endorse air-curtain incineration as a robust method for dealing with CWD (Anonymous, 2003c, p.4). In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) has conducted experiments to elucidate the temperatures reached during air-curtain incineration in fireboxes; but despite efforts that included the placement of temperature probes in the carcass mass, researchers could confirm only a range of attained temperatures (600-1000°C, or 1112-1832°F). This information may be a useful guide, but further studies to confirm the temperatures reached are needed (Hickman, 2003).

Environmental implications

It is generally accepted that open-air burning pollutes (Anonymous, 2003b). The nature of open-air emissions hinges on many factors, including fuel type. Both real and perceived environmental risks of open-air burning were the subjects of studies and complaints during the UK 2001 FMD outbreak. Studies focused on dioxins, furans, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals, nitrogen oxides, sulphur dioxide, carbon monoxide, carbon dioxide, organic gases, and PM—especially PM less than 10 micrometers in diameter that can be drawn into the lungs (McDonald, 2001). The fear of dioxins and smoke inhalation, along with the generally poor public perception of pyres, eventually compelled the discontinuation of the use of mass burn sites in the UK (Scudamore et al., 2002, pp.777-779). However, pollution levels never exceed levels in other (urban) parts of the UK, did not violate air quality regulations, and were deemed to have not unduly affected the public health (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76; Hankin & McRae, 2001, p.5; McDonald, 2001; UK Department of Health, 2001a, 2001b).

In contrast to open-air burning, properly operated fixed-facility and air-curtain incineration pose fewer pollution concerns. During the UK 2001 FMD outbreak, air-curtain incinerators provided by Air Burners LLC offered conspicuous environmental advantages over open-air burning (G. Ford, 2003). Air-curtain technology in general has been shown to cause little pollution, with fireboxes burning cleaner than trench-burners (G. Ford, 2003). When compared to open-burning, air-curtain incineration is superior, with higher combustion efficiencies and less carbon monoxide and PM emissions (G. Ford, 2003). Individuals within the UK government, who have conducted testing on air-curtain fireboxes, are indeed satisfied with this technology's combustion efficiency (Hickman, 2003).

If operated in accordance with best practices and existing environmental regulations, both small and large afterburner-equipped incinerators should not pose serious problems for the environment (Crane, 1997, p.3). However, if not operated properly, small animal carcass incinerators have the potential to pollute. Therefore, it may be environmentally worthwhile to send carcasses to larger, centralized, and better managed incineration facilities (Collings, 2002).

While open-air burning, poorly managed fixed-facility incineration, and poorly managed air-curtain incineration can pose legitimate pollution concerns, they should be considered when other environmental factors (e.g., a high water table, soils of high permeability, etc.) rule out burial (Damron, 2002).

Advantages and disadvantages

Open-air burning can be relatively inexpensive, but it is not suitable for managing TSE-infected carcasses. Significant disadvantages include its labor- and fuel-intensive nature, dependence on favorable weather conditions, environmental problems, and poor public perception (Ellis, 2001, p.76).

Fixed-facility incineration is capable of thoroughly destroying TSE-infected carcasses, and it is highly biosecure. However, fixed-facility incinerators are expensive and difficult to operate and manage from a regulatory perspective. Most on-farm and veterinary-college incinerators are incapable of handling large volumes of carcasses that typify most carcass disposal emergencies. Meanwhile, larger industrial facility incinerators are difficult to access and may not be configured to handle carcasses (Ellis, 2001, p.28).

Air-curtain incineration is mobile, usually environmentally sound, and suitable for combination with debris removal (e.g., in the wake of a hurricane). However, air-curtain incinerators are fuel-intensive and logistically challenging (Ellis, 2001, p.76). Currently, air-curtain incinerators are not validated to safely dispose of TSE-infected carcasses.

1.5 – Lessons Learned

Open-air burning to be avoided

Open-air burning can pose significant public perception, psychological, and economic problems. During the UK 2001 FMD outbreak, carcasses burning on mass pyres "generated negative images in the media" and "had profound effects on the tourist industry" (NAO, 2002, pp.7, 74). In 2001, on-farm pyre burning sent smoke plumes into the air and contributed to an environment of despair for the UK farming community (Battista, Kastner, & Kastner, 2002).

Personnel and professional development

Past emergency carcass disposal events have revealed the need for readily available logistical expertise, leadership, and managerial skills (Anderson, 2002, p.82). Indeed, professional development is important. Simulation exercises are key components of preparing for carcass disposal.

US federal, state, and local officials responsible for carcass disposal should seek out opportunities to participate in real-life emergencies that can be anticipated ahead of time (e.g., 2003's Hurricane Isabel). The extra personnel would, of course, offer assistance that is valuable in and of itself; but equally importantly, the extra personnel would learn about carcass disposal in a real-life, pressure-filled context. In addition, and parallel to a recommendation made in the UK (Anderson, 2002, p.82), a bank of volunteers should be available in the event that labor is in short supply to manage mass carcass disposal events, including those involving incineration.

The "digester vs. incinerator" debate

One of the great questions facing US animal disease officials is whether alkaline-hydrolysis digestion or fixed-facility incineration should be preferred for disposal of TSE-infected animals. While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident in recent debates in Larimer County, Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of the heads of CWD-infected deer and elk. While incinerators exist in other parts of the state (e.g., Craig, Colorado), a new incinerator is needed to deal specifically with populations in northeastern Colorado, where there is a high prevalence of CWD among gaming populations.

Despite the need, Larimer County commissioners have heeded local, anti-incinerator sentiments and have, for now, successfully blocked approval of the incinerator. Meanwhile, an alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997b) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003) (see section 7.2).

Based on the UK experience, moves to push for controversial disposal methods (e.g., fixed-facility incineration in Colorado) must include communication with local communities and stakeholders, something that was all too often neglected in the UK (Widdrington FMD Liaison Committee). At the same time, clear regulatory affirmation of technologies (e.g., fixed-facility incineration to manage TSEs) may also hedge against public concerns. In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the EPA; following meetings with laboratory diagnosticians, state veterinarians, and wastewater managers (O'Toole, 2003), EPA Region 8 is close to clearly endorsing fixed-facility incineration as a technology for managing CWD-infected carcasses (Anonymous, 2003c, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like these are needed to respond to attitudes, witnessed in Larimer County, that alkaline hydrolysis is the only way to deal with TSE-infected material (Powers, 2003).

Water-logged materials and carcasses

Carcasses are generally composed of 70 percent water; this places them in the worst combustible classification of waste (Brglez, 2003, p.32). This accentuates the need for fuel and dry burning materials. Experience gained in North Carolina in 1999 (following Hurricane Floyd) and Texas (following flooding in 1998) confirms the importance of having dry wood for incineration. Moist debris was used to burn carcasses in air-curtain incinerators, and the resultant poor air/fuel mixture produced noxious smoke and incomplete combustion (Ellis, 2001, p.30).

Section 2 – Historical Use

Throughout history, incineration has played an important role in carcass disposal. Advances in science and technology, increased awareness of public health, growing concerns about the environment, and evolving economic circumstances have all affected the application of incineration to carcass disposal. This section surveys the historical and current use of three broadly categorized incineration techniques: open-air burning, fixed-facility incineration, and air-curtain incineration.

2.1 – Open-Air Burning

Open-air carcass burning—including the burning of carcasses on combustible heaps known as pyres—dates back to biblical times. The Old Testament is replete with accounts of burning carcasses in the open, often following sacrificial offerings (e.g., Leviticus 4:11-12). Ancient Athens used open-air pyres to incinerate human plague victims (Brown, 1998, p.1146), and by the seventeenth century, European nation-states had begun to officially rely upon burning as a means of disposing of diseased livestock. In the late 1600s, Holland and Prussia blamed improper carcass disposal for the spread of livestock diseases, and soon after it became a crime punishable by death to neglect to burn or bury fallen stock (Committee on Agriculture, 1860, p.4). In Britain and in response to an outbreak of rinderpest there in 1714, Thomas Bates, fellow of the Royal Society and surgeon to King George I, advised the burning of all infected cattle carcasses (MAFF, 1965, pp.3-4). The British government heeded Bates' counsel that all infected cattle should be "bought, killed, and burnt," but casualty numbers soon overwhelmed open-air burning efforts, and burial became the preferred disposal method (Committee on Agriculture, 1860, pp.5-6).

As Britain discovered in 1714, open-air burning is resource intensive and often must be supplemented or substituted with other disposal methods. Three centuries later, little has changed: "burning tends to be difficult and expensive in terms of labor and materials," United States Department of Agriculture (USDA) officials have remarked (Smith et al., 2002, p.22). Nevertheless, open-air burning has persisted throughout history as a utilized method of carcass disposal. Animal health officials have traditionally hesitated to remove carcasses from farms for fear of disease spread; therefore, on-farm open-air burning, along with on-farm burial, has remained a commonly used disposal technique (Hamlen, 2002, p.18). On-farm pyre burning was used extensively in the 1967 and 2001 foot and mouth disease (FMD) outbreaks in the United Kingdom (UK) (NAO, 2002; Scudamore et al., 2002), in smaller-scale outbreaks of anthrax in Canada 1993 (Gates et al., 1995, p.258), and in other recent disposal situations. In southeast Missouri in 2001, extenuating circumstances required the open-air burning of cattle carcasses (Sifford, 2003). During the UK 2001 FMD outbreak, approximately 30 percent of six million carcasses were disposed of by open-air burning; these occurred on 950 sites, some of which featured mass pyres but most of which were smaller, on-farm burns (NAO, 2002, p.74).

2.2 – Fixed-Facility Incineration

In 1882 Francis Vacher, a medical officer of health working near Liverpool, England, complained that burial was an unreliable form of carcass disposal; years before, he had prosecuted a person who had exhumed a buried, diseased carcass to sell as human food. "There is but one efficient way of destroying diseased meat," he concluded, "and that is by cremation" (Vacher, 1882, p.8). The officer explained how he had recently done this with 59,280 pounds of condemned livestock—by cutting the carcasses into pieces and placing them in the retorts used to burn coal for the city's gas-works system (Vacher, 1882).

Vacher's description provides an historical example of fixed-facility incineration. Today, fixed-facility incineration is available in a variety of forms—as crematoria, small carcass incinerators at veterinary colleges, large waste incineration plants, on-farm carcass incinerators, and, not unlike Vacher's example, power plants.

During the 1970s, rising fuel prices reduced the popularity of fixed-facility incinerators, but technological improvements in efficiency soon followed (Wineland et al., 1997). Small animal carcass incinerators have been used to dispose of on-farm mortalities for years in both North America and Europe, and the pet crematoria industry has grown over time (Hofmann & Wilson, 2000).

Since the advent of bovine spongiform encephalopathy (BSE) in the UK, fixed-facility incineration has been used to dispose of BSE-infected carcasses as well as rendered meat-and-bone meal (MBM) and tallow from cattle carcasses considered to be at-risk of BSE (Herbert, 2001). Fixed-facility incineration facilities would have been used during the UK 2001 FMD outbreak, but they were rarely available because of being fully committed to BSE-related disposal efforts (Anderson, 2002, p.112; NAO, 2002, p.74). Fixed-facility incineration is now formally included at the top of the UK FMD contingency plan's disposal hierarchy (DEFRA, 2003c, p.40), and animal carcass incinerator plants are available for the disposal of whole carcasses of livestock for other disease situations—even for diseased seals that are washed up on the shore (DEFRA, 2002).

Outside of the UK, fixed-facility incineration has been combined with other carcass-disposal techniques. During the 2001 FMD outbreak in the Netherlands, diseased animals were first rendered and then the resultant MBM and tallow were taken to incineration plants (de Klerk, 2002). In Japan, cattle testing positive for BSE are disposed of by incineration (Anonymous, 2003d).

2.3 – Air-Curtain Incineration

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, creating a turbulent environment in which incineration is greatly accelerated. Air-curtain technology may be used for carcass incineration in either a burn pit or a refractory box. Air-curtain incineration is a relatively new technology (Ellis, 2001, p.28). Its recent appearance on the carcass-disposal stage is evident in Virginia; air-curtain technology was not available to assist with a 1984 avian influenza (AI) outbreak in Virginia, but the technology was readily available to assist in disposing of turkey carcasses after AI returned to the state in 2002 (Brglez, 2003, p.18). Air-curtain incinerators have been used in the wake of natural disasters (e.g., in 1999 in North Carolina following Hurricane Floyd and in 1998 following flooding in Texas) (Ellis, 2001, pp.29-30). Imported air-curtain incinerators were used to a small degree during the UK 2001 FMD outbreak (G. Ford, 2003; NAO, 2002, p.74; Scudamore et al., 2002, p.777). Air-curtain incinerators have been used in Colorado and Montana to dispose of animals infected with chronic wasting disease (CWD) (APHIS, 2003, p.2707) and throughout the United States (US) in other livestock disasters (G. Ford, 2003).

Section 3 – Principles of Operation

Burning is a combustion process to which a range of measures may be applied to control emissions and ensure the completeness of combustion (SSC, 2003b, p.3). This section describes three combustion techniques. The first, open-air burning, is subject to few controls whereas the latter two, fixed-facility incineration and air-curtain incineration, can be generally contained and controlled.

3.1 – Open-Air Burning

How does it work?

Open-air burning includes burning carcasses (a) in open fields, (b) on combustible heaps called pyres (Dictionary.com, 2003), and (c) with other burning techniques that are unassisted by incineration equipment.

Who can do it?

Generally, one must have a state permit to open-air burn (APHIS, 2003, p.2707). From a personnel standpoint, leadership and decision-making skills are important because "the individual in charge of building the fire may have to use ingenuity in acquiring materials and putting them to optimal use" (Smith et al., 2002, p.23). As the UK learned, relevant leadership skills, decision-making ingenuity, and experience may be found in military units and waste-management contractors (NAO, 2002, pp.7, 66).

Where can it be done?

Open-air burning is not permitted in every state. For example, most hog-producing states generally allow for incineration of carcasses but specifically prohibit burning them in the open (Henry et al., 2001; Morrow et al., 2000, p.106). Nevertheless, it may be possible to waive state regulations such as these in a declared animal carcass disposal emergency (Ellis, 2001, p.27).

Open-air burning should be conducted as far away as possible from the public. For large pyres involving 1,000 or more bovine carcasses, a minimum distance of 3 kilometers (~2 miles) has been suggested in the UK (Scudamore et al., 2002, p.779). However, mass pyre burning has since been ruled out as an option in the UK; only small, on-farm open-air burning is allowed, and only as a last resort (DEFRA, 2003c, p.40). Based on the UK experience, an important site-selection rule is to first communicate with local communities about open-air burning intentions (Widdrington FMD Liaison Committee).

What is needed?

The US Animal and Plant Health Inspection Service (APHIS) has provided prescriptive directions for conducting an open-air burn (Smith et al., 2002, pp.22-27). The wide variety of material requirements associated with these directions are summarized in Table 2; all of these material requirements agree with pyre-construction procedures followed in the UK during 2001 (McDonald, 2001, p.6). Although diesel fuel is often used in open-air burning, other fuels have also been used or considered. These include turbo jet-B fuel, which was used in an open-air burn of anthrax-infected bison in northern Canada (Gates et al., 1995, p.258). Jet-B fuel is a mixture of naphtha and kerosene and is more difficult to handle (i.e., more flammable) than other jet fuels; however, jet-B's exceptional cold-weather performance makes it in high demand in very cold areas (CSG Network, 2004; Hildebrand, 2004). Other open-burning energy sources include powder metallic fuels (PMFs), which contain blends of metal powders (aluminum and magnesium) that interact well with water and have shown promise in raising the sustained temperatures in carcass-disposal experiments in the Czech Republic (Sobolev et al., 1999; Sobolev et al., 1997). Tires, rubber, and plastic should not be burned as they generate dark smoke (MAFF, 2001, p.36).

To promote clean combustion, it is advisable to dig a shallow pit with shallow trenches to provide a good supply of air for open-air burning. Kindling wood should be dry, have a low moisture content, and not come from green vegetation (MAFF, 2001, pp.36-37).

TABLE 2. Types and quantities of materials required for an open-air burn (McDonald, 2001; Smith et al., 2002, pp.24-26).

	Straw or hay	Untreated heavy timbers	Kindling wood	Coal	Liquid fuel (e.g., diesel fuel)
Per: 1 bovine carcass, 5 swine carcasses, or 5 sheep carcasses	3 bales	3 timbers, each 8ft (~2.5m) by 1ft sq (~0.3m sq)	50 lbs. (~23 kg)	500 lbs. in large clumps, 6-8 inches (~15-20 cm) in diameter	1 gallon (~4L)

Pre-developed contracts for materials and personnel are also critical to open-air burning. During the UK 2001 FMD outbreak, the organization of contractual agreements, management of contractors, and the urgent need for workers in a high-employment economy greatly complicated and delayed pyre-burning efforts. When poor-quality coal was supplied for the effort, personnel shortages made fire watching and tending inefficient (Scudamore et al., 2002), carcasses awaiting disposal eventually reached more than 200,000, and the military was called in to assist with the disposal effort (NAO, 2002, pp.7, 66).

How long does it take?

Open-air burning is the most lengthy of all incineration processes. The type of species burned influences the length of time; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine have a higher fat content than other species and will burn most quickly (Ellis, 2001, p.28).

What clean-up is necessary?

Open-air burning of carcasses yields a relatively benign waste—ash—that does not attract pests (Damron, 2002). However, the volume of ash generated by open-air burning can be significant. Depending on groundwater issues and the potential presence of transmissible spongiform encephalopathies (TSEs), ash-disposal options range from the inexpensive burying of ash on-site, as was done during the UK 1967 FMD outbreak, or the comparatively expensive transportation and disposal at landfills, as was done during the UK 2001 FMD outbreak. During the 2001 British experience, about 30 percent of six million animals were disposed of by pyre burning, and concerns about BSE residue in the ash required landfill disposal of ash. 120,000 metric tonnes were disposed of at an expense of £38 million (NAO, 2002, p.92).

Open-air burning poses additional clean-up challenges vis-à-vis groundwater and soil contamination caused by hydrocarbons used as fuel (Crane, 1997, p.3). In this way, clean-up of open-air burning may depend on the type of fuel used.

How much does it cost?

Although open-air burning has in fact been carried out in the past, precise information regarding cost is elusive. Nevertheless, one non-refereed analysis has approximated open-air pyre burning of cattle carcasses to cost $196 per ton of cattle carcasses (Cooper et al., 2003, pp. 30-31). This figure, however, does not take into account regulatory-compliance costs as well as public-perception problems, which in the UK during 2001 were tremendous for the tourism industry (see section 6.2). Ash disposal costs can also escalate out of control, depending on the situation. During the UK 2001 FMD outbreak, there were concerns about the on-farm burial of pyre-ash. Therefore, pyre-ash was disposed of at landfills at a cost of approximately £317 per tonne (NAO, 2002, p.92); converted into US dollars and US tons, this cost amounts to $527 per ton of ash (FT.com, 2004).

Based on the previous information, an "interval of approximation" for the cost of open-air burning is $196 to $723 per ton of carcass material.

Other considerations

All incineration processes, but especially open-air burning in windy areas, pose noteworthy fire hazards; the risk of fire must be addressed. Open-air burning also poses unique environmental and public-perception problems, which are further discussed in sections 5 and 6.2.

3.2 – Fixed-Facility Incineration

How does it work?

Fixed-facility incineration includes (a) small on-farm incinerators, (b) small and large incineration facilities, (c) crematoria, and (d) power plant incinerators. Unlike open-air burning and air-curtain incineration, fixed-facility incineration is wholly contained and, usually, highly controlled.

Typically fueled by diesel, natural gas, or propane, fixed-facility incinerators are, in essence, chambers in which the incineration process is contained. One report has described fixed-facility incineration of carcasses as a convection process in which carcass material is burned to ash in a controlled atmosphere (Sparks Companies, 2002, p.11). Newer designs of fixed-facility incinerators are fitted with afterburner chambers designed to completely burn hydrocarbon gases particulate matter (PM) exiting from the main combustion chamber (Rosenhaft, 1974). Incinerators have been used for years to incinerate both whole carcasses and carcass material.

Who can do it?

One can operate an incinerator if properly licensed, usually by a state government (APHIS, 2003, p.2707). Properly trained operators are absolutely critical. As one environmental scientist has found, afterburner-equipped incinerators that are poorly operated can actually emit more pollutants than non-afterburner-equipped incinerators that are carefully operated (Collings, 2002).

Where can it be done?

Small, fixed-facility incinerators may be operated on farms provided one has a permit, although there are increasing regulatory costs associated with maintaining this permit (see "How much does it cost?" below).

In the US, the idea of incinerating carcasses in large hazardous waste, municipal solid waste, and power plants has been suggested. While the acceptance of MBM and tallow from rendered carcasses could be accommodated in the US, large-scale whole-carcass disposal would be problematic given the batch-feed requirements at most biological waste incineration plants (Anonymous, 2003f; Heller, 2003). Many waste incineration facilities simply refuse to accept dead animals, noting that carcasses are 70 percent water and preferred waste is 25 percent water (Thacker, 2003). The possibilities of combining incineration with rendering products (i.e., MBM and tallow) are more promising and should be explored (see section 7.1).

What is needed?

In addition to the incinerator itself, fuel is more important. Fixed-facility incinerators are often powered by diesel, natural gas, or propane (Sparks Companies, 2002, p.11).

How long does it take?

The type of species greatly influences the speed at which carcasses are incinerated; the greater the percentage of animal fat, the more efficient the carcass will burn (Brglez, 2003, p.32). Swine, which have a comparatively high fat content, burn more quickly (as short as two hours for a hog) than do other species (Ellis, 2001, p.28; Walawender, 2003). The throughput of fixed-facility incinerators depends on the chamber's size. For small animal carcass incinerators, the kinds of which may be used on farms for fallen stock, the throughput may reach only 110 lbs (50 kg) per hour (Anonymous, 2003e). Conversely, larger facilities dedicated to the incineration of animal remains may be able to accommodate larger numbers. In Australia, for example, one public incinerator is prepared to accept, during times of emergency, 10 tonnes of poultry carcasses per day (Western Australia Department of Agriculture, 2002, p.7). In the US, fixed-facility capacity is generally recognized to not be of an order capable of handling large numbers of whole carcasses (Ellis, 2001).

What clean-up is necessary?

Most incinerators are fitted with afterburners that further reduce emissions by burning the smoke exiting the primary incineration chamber (Walawender, 2003). Compared to open-air burning, clean-up of ash is less problematic with fixed-facility incineration; ash is typically considered safe and may be disposed of in landfills (Ahlvers, 2003). However, if residual TSE infectivity is of concern, burial may not be suitable (see sections 4.2 and 7.2).

How much does it cost?

Fixed-facility incinerators offer a tremendously biosecure disposal option, but they are expensive. A 500-pound incinerator costs $3000 and will last for approximately four years (Sander et al., 2002). However, fixed-facility incinerators of all sizes are being closed down on account of increasing regulatory-compliance and inspection costs. In

Missouri, for example, the annual cost of maintaining a permit for a small, on-farm incinerator has reached $2000, a cost which has resulted in a "rapid phase-out of farm incinerators" (Morrow et al., 2000, p.106). For larger facility incinerators, the experience is the same. At colleges of veterinary medicine, new inspection requirements anticipated to cost $20,000 per year have led to the phasing out of incinerators (Ahlvers, 2003). Increasing regulatory cost requirements have also led to a significant reduction in the number of US plants capable of incinerating medical and hazardous waste (Heller, 2003).

Larger, fixed-facility incineration has been approximated at $460-$2000 per ton of carcass material in the US (Waste Reduction by Waste Reduction Inc.). This interval captures a forecasted during-emergency price at an Australian fixed-facility incinerator; converted into US dollars and US tons, emergency disposal of poultry carcasses would cost $1531 per ton (FT.com, 2004; Western Australia Department of Agriculture, 2002, p.7). For smaller (e.g., 500-pound-capacity) incinerators processing swine, costs are lower but depend on whether or not an afterburner is attached; costs range from $98 per ton of carcasses (incinerator without afterburner) to $146 (incinerator with afterburner) (Henry et al., 2001). For these smaller fixed-facility incinerators, costs for cattle would be slightly higher due to the need for pre-incineration processing (i.e., cutting into smaller pieces) of carcasses larger than 500 pounds (Sparks Companies, 2002, pp. v, 11).

Fixed-facility incineration costs are quite variable and may significantly vary as (a) incineration is combined with other disposal technologies and (b) governmental intervention is taken to manage waste (see section 7.1).

Based on the previous information, an "interval of approximation" for the cost of fixed-facility incineration is $98 to $2000 per ton of carcass material.

Other considerations

Fixed-facility incineration has been validated for the destruction of TSE disease agents (see section 4.2), poses environmental issues that may be best addressed by large incineration plants (see section 5.1), and has been the subject of public-perception concerns (see section 6.2). Although more controlled than open-air burning, fixed-facility incineration poses a fire hazard.

Several countries have combined rendering with fixed-facility incineration. In the Netherlands, this combination was used as incinerators were employed to dispose of MBM and tallow from rendered carcasses associated with the 2001 FMD outbreak (de Klerk, 2002, p.793). Rendering-incineration combinations have also been used to help manage the TSE situation in the UK and continental Europe (see section 7.1).

3.3 – Air-Curtain Incineration

How does it work?

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, thereby creating a turbulent environment in which incineration is greatly accelerated—up to six times faster than open-air burning (W.B. Ford, 1994, p.3). Air-curtain incineration is suitable for not only carcasses but also other waste material (McPherson Systems Inc., 2003; Scudamore et al., 2002, p.779; Smith et al., 2002, p.27). Large-capacity fans driven by diesel engines deliver the high-velocity air down into either a metal refractory box or burn pit (trench). Air-curtain systems vary in size according to the amount of carcasses to be incinerated (Ellis, 2001, p.29). Air-curtain equipment can be made mobile.

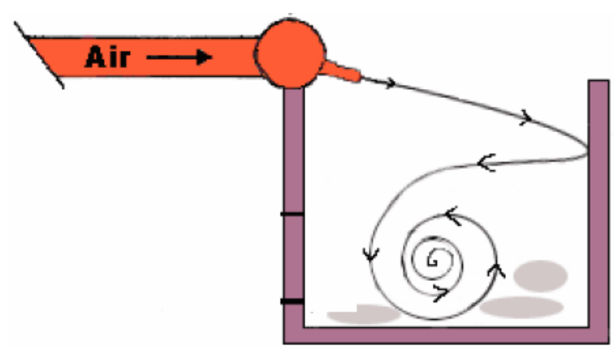

FIGURE 1. Depiction of air-curtain incineration technology, adapted from slide no. 9, entitled "Air Burners LLC: Principles of Operation," in Ford (2003).

Who can do it?

There are several companies that manufacture air-curtain incinerators. One of these, Air Burners LLC, manufactures equipment in Florida and has been involved in several emergency carcass disposals—from swine disposal in Texas to CWD-infected elk disposal in Colorado to disposal work for the Florida Department of Agriculture (G. Ford, 2003). Air-curtain equipment—whether manufactured by Air Burners or other firms such as McPherson Systems (McPherson Systems Inc., 2003)—is often operated by secondary contractors, such as Dragon Trenchburning or Phillips and Jordan (Smith et al., 2002, p.28).

Where can it be done?

Air-curtain incinerators have been used all over the US and around the world and met regulatory approval (G. Ford, 2003). According to an APHIS environmental assessment, air-curtain incinerators do produce a fair amount of noise, but if placed away from residential centers and the general public they are generally not nuisances (APHIS, 2002, p.11).

What is needed?

Materials needed for air-curtain incineration include wood (preferably pallets in a wood-to-carcass ratio varying between 1:1 and 2:1), fuel (e.g., diesel fuel) for both the fire and the air-curtain fan, and properly trained personnel (G. Ford, 2003; McPherson Systems Inc., 2003). For an incident involving the air-curtain incineration of 500 adult swine, 30 cords of wood and 200 gallons of diesel fuel were used (Ellis, 2001, p.29). Dry wood for fuel is critical to ensuring a proper air/fuel mixture (Ellis, 2001, p.30).

How long does it take?

Speed of throughput depends on the manufacturer, design, and management of the air-curtain system. The type of species also influences the throughput; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine carcasses, for example, have a higher fat content and burn more quickly than other species (Ellis, 2001, p.28).

One manufacturer of air-curtain technology reports that, using its larger refractory box, six tons of carcasses may be burned per hour (G. Ford, 2003). Using a burn pit, and a 35-foot-long air-curtain manifold, up to four tons of carcasses may be burned per hour (W.B. Ford, 1994, pp.2, 11). Air-curtain incinerators have been shown to efficiently burn 37.5 tons of carcasses per day (150 elk, weighing an average of 500 pounds each) (APHIS, 2002, p.11).

What clean-up is necessary?

Air-curtain incineration, like other combustion processes, yields ash. From an ash-disposal standpoint, air-curtain incineration in pits is advantageous if the ash may be left and buried in the pits (Smith et al., 2002, p.27). However, in sensitive groundwater areas—or if burning TSE-infected carcasses—ash will most likely be disposed of in licensed landfills.

How much does it cost?

Cost information for air-curtain incineration varies and depends on variables such as species type, fuel costs, and ash disposal. Cost reports (the first of which excludes "cross-cutting" costs related to decontamination and transportation) range from $143 to $471 to $506 per ton of carcass material (Brglez, 2003, p. 86; W.B. Ford, 1994; Jordan, 2003).

Based on the previous information, an "interval of approximation" for the cost of air-curtain incineration is $143 to $506 per ton of carcass material.

Other considerations

Unlike fixed-facility incineration, air-curtain incineration is not wholly contained and is at the mercy of many variable factors (e.g., human operation, the weather, local community preferences, etc.). In past disposal incidents involving air-curtain incineration, a process of trial-and-error has been necessary to deal with problems. An excellent example of trial-and-error occurred during the 2002 AI-related disposal effort in Virginia:

> After burning several tons of [poultry] carcasses at an extremely slow rate, it was quickly determined that wood from the

> landfill was not a good fuel source due to its high moisture content. The boxes are specially designed with electric fans to blow air onto wood to make the wood burn faster and also smokeless...However, due to the high content of moisture, the birds created a terrible stench that could be smelled miles away. People living nearby had to be moved into hotels. It was determined by trial and error that the best method of burning the carcasses was by layering the birds on top of wood pallets. This allowed sufficient air circulation to burn the birds efficiently. Thus, a combination of forest wood and pallets were used. The only drawback in using pallets was the nails that remained in the ash. The nails were required to be removed...when the ash was to be re-applied to land as a rich source of nutrients.
>
> (Brglez, 2003, pp.34-35)

Indeed, trial-and-error (and on-the-spot ingenuity!) is often necessary when using air-curtain incinerators in the field.

Like open-air burning and fixed-facility incineration, air-curtain incineration poses a fire hazard and the requisite precautions should always be taken. There are environmental and disease-agent considerations regarding air-curtain incineration; these are elaborated in sections 4.2, 5.1, and 7.2.

Section 4 – Disease Agent Considerations

This section considers separately conventional pathogens (bacteria, viruses, and spores) and TSE disease agents.

4.1 – Conventional Pathogens

Viruses and non-spore-forming bacteria

Bacteria and viruses are both generally temperature susceptible and cannot survive normal burning temperatures. However, FMD, a highly contagious viral disease, may be spread via airborne pathways. The virus is generally resistant to background environmental factors (e.g., air and sunlight) and can spread through the air (Donaldson & Ferris, 1975), as it did within the UK during the 2001 FMD outbreak (J. Gloster et al., 2003) and between Brittany, France, and the Isle of Wight, UK, in 1981 (Anderson, 2002, p.40). Other aspects of FMD spread, including dust- and bird-mediated transport of the virus from continental Europe to the UK on various occasions between 1965 and 1967, have been reported as well (Hurst, 1968). Curiosity about FMD's contagiousness continues to spread, and some have argued that pyre (open-air) burning efforts during the UK 2001 FMD outbreak actually helped spread the virus. This question has been examined thoroughly; and while the theoretical possibility cannot be eliminated, there is no evidence that open-air burning or air-curtain incineration contributed to virus spread (Champion et al., 2002; J. Gloster et al., 2001).

Spore-forming bacteria

Carcasses infected with spore-forming bacteria, such as *Bacillus anthracis* (the causative organism of anthrax), should be thoroughly incinerated (Everett, 2003). If not properly incinerated, the spores can persist in the environment for months, even years, and communicate disease to other animals, even humans (Anonymous, 2003a). If burning anthrax-infected carcasses is not immediately possible, a substitutional measure of protection may be taken by not cutting open the carcasses; normal, anaerobic decomposition processes prevent sporulation of this oxygen-requiring bacteria (Everett, 2003), and bacteria in their vegetative form are very unlikely to survive (Turnbull, 2001, p.29).

4.2 – TSE Disease Agents

Durability of TSE disease agents

The disease agents responsible for TSEs (e.g., scrapie, BSE, and CWD) are highly durable (Brown, 1998). For example, scientists have demonstrated the persistent infectivity of the scrapie agent in soil, and healthy sheep have contracted scrapie after grazing on land that had served, three years earlier, as pasture for scrapie-infected sheep (Brown & Gajdusek, 1991). While incineration is used to dispose of TSE-infected animals, including scrapie-infected sheep and goats, (EU, 2003, p.7) the disease agents responsible for TSEs (i.e., prions) are extremely heat resistant. This raises important questions about incineration's suitability for disposing of TSE-infected—or potentially TSE-infected—carcasses.

One study subjected the scrapie agent to varying time and temperature combinations—5 to 15 minutes at 150 to 1000°C (302 to 1832°F). Temperatures of 600°C (1112°F) completely ashed the samples, but some infectivity remained (Brown et al., 2000). The UK Spongiform Encephalopathy Advisory Committee (SEAC) has recently affirmed its belief that the risk of infectivity from ash would be extremely small if incineration was conducted at 850°C (1562°F) (SEAC, 2003), and the European Commission Scientific Steering Committee (SSC) recognizes the same temperature as a standard for disposing of TSE-infected material (SSC, 2003a).

Open-air burning

World-renowned TSE expert Dr. David Taylor explains that open-air burning is imprecise and not normally a legitimate TSE-related disposal option because of doubts it can completely destroy TSE infectivity (Taylor, 2001). For similar reasons, the European Commission SSC argues that fixed-facility incineration is preferred to open-air burning:

> There is no reliable data to indicate the extent of risk reduction that could be achieved by open burning. It is reasonable however to assume that overall it will be rather less effective in reducing the infectivity of BSE/TSE than well-conducted incineration. Moreover the reproducibility of the risk reduction is likely to be very variable even at a single location.
>
> (SSC, 2003b, p.4)

For now, open-air burning of TSE-infected carcasses should be prohibited. For exceptional cases in which open-air burning might include TSE-incubating carcasses (e.g., in the UK during 2001, when open-air burning of FMD-infected carcasses likely included some sheep and cattle incubating scrapie and BSE), studies conclude that the risk of TSE spread is acceptably low ($7x10^{-7}$) (Taylor, 2001, citing a risk assessment report by DNV Technica). It should also be noted that open-air burning temperatures have been greatly enhanced through the use of PMFs (see section 3.1). In the Czech Republic, for example, PMFs have been used to reach temperatures (1200-1400°C, or 2192-2552°F) capable of destroying TSE agents (Sobolev et al., 1999; Sobolev et al., 1997). While promising, environmental questions remain, and studies clearly validating PMF-assisted destruction of the TSE agent are needed (see section 7.3).

Fixed-facility incineration

Unlike open-air burning, fixed-facility incineration is highly controlled, lends itself to validation for reaching the requisite (850°C or 1562°F) TSE-destruction temperature, and is a reliable method for dealing with TSE-infected carcasses. While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs (Grady, 2004), this is not entirely accurate. Both fixed-facility incineration and alkaline hydrolysis may be used to dispose of TSE-infected material (Powers, 2003).

As discussed further in section 7.1, combinations of fixed-facility incineration and rendering have been used to manage risk in European countries that have been home to BSE. Although all animals confirmed to be TSE-infected are disposed of in fixed-facility incinerators, other "at-risk" animals and material have been disposed of by using a combination of rendering and incineration. These include carcasses or parts of carcasses suspected of TSE infection, animals that have died on the farm (fallen stock), and, in the UK, animals older than 30 months (DEFRA, 2003b; Herbert, 2001). The UK's Over Thirty Months Scheme (OTMS) is a precautionary policy requiring the removal from the food chain and destruction of cattle aged over 30 months, an age above which it is thought animals are at greater risk of developing BSE (MAFF, 1996). Under the OTMS, carcasses are rendered and, at a great cost to the UK government, the resultant MBM and tallow is stored and then disposed of in fixed-facility incinerators. At several of the incineration plants, including one waste-management incinerator that was the subject of an interview, energy is recovered from the MBM and tallow and an EU subsidy is received (Anonymous, 2003g; Hilliard, 2003; Scottish Parliament, 2002; Shanks, 2001).

Air-curtain incineration

Air-curtain incinerators reportedly achieve higher temperatures than open-air burning, and may reach 1600°F (~871°C) (G. Ford, 2003; McPherson Systems Inc., 2003). Such claims, particularly as they relate to reaching the requisite (850°C or 1562°F) TSE-destruction temperature, need to be further substantiated (Scudamore et al., 2002, p.779). Noting that "with wet wastes, such as CWD-contaminated carcasses, temperatures...can fluctuate and dip below recommended temperatures," an Environmental Protection Agency (EPA) Region 8 draft document hesitates to endorse air-curtain incineration as a robust method for dealing with CWD (Anonymous, 2003c, p.4). In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) has conducted experiments to elucidate the temperatures reached during air-curtain incineration in fireboxes; but despite efforts that included the placement of temperature probes in the carcass mass, researchers could confirm only a range of attained temperatures (600-1000°C, or 1112-1832°F). This information may be a useful guide, but further studies to confirm the temperatures reached are needed (Hickman, 2003).

Section 5 – Environmental Implications

5.1 – Air Pollution

Open-air burning, poorly managed fixed-facility incineration, and poorly managed air-curtain incineration all pose legitimate pollution concerns.

It is generally accepted that open-air burning poses pollution problems (Anonymous, 2003b). The nature of open-air emissions hinges on many factors, including fuel type. Both real and perceived environmental risks of open-air burning were the subjects of studies and complaints during the UK 2001 FMD outbreak. In the Dumfries and Galloway region of Scotland, environmental monitoring of open-air pyre burning focused on dioxins, furans, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals, nitrogen oxides, sulphur dioxide, carbon monoxide, carbon dioxide, organic gases, and PM—especially PM less than 10 micrometers in diameter that can be drawn into the lungs (McDonald, 2001). Elsewhere in the UK, in Cumbria, 130 pyres were used to dispose of carcasses, and officials there noted that open-air burning—particularly with slowly burning pyres—emanated an offensive, "acrid smoke" (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.75). According to the Food and Agricultural Organization (FAO) of the United Nations, the first six weeks of the UK pyre-burning campaign involved the release of dioxins in an amount equal to 18 percent of the UK's annual emissions (Brough, 2002). The fear of dioxins and smoke inhalation, along with the generally poor public perception of pyres, eventually compelled the discontinuation of the use of mass burn sites at Arscott Farm in Devon, three sites in Scotland, Eppynt in Wales, Catterick in Yorkshire, and Hemscott Hill in County Durham (Scudamore et al., 2002, p.777-779). As it turned out, pollution levels associated with pyre-burning never exceed levels in other (urban) parts of the UK, did not violate air quality regulations, and were deemed to have not unduly affected the public health (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76; Hankin &

McRae, 2001, p.5; McDonald, 2001; UK Department of Health, 2001a, 2001b).

In contrast to open-air burning, properly operated fixed-facility and air-curtain incineration significantly reduce pollution concerns. During the UK 2001 FMD outbreak, air-curtain incinerators provided by Air Burners LLC offered environmental advantages over open-air burning. In Devon, where the sky had previously been clouded with smoke from mass pyres, air-curtain incinerators were praised for providing complete combustion and reduced air emissions (G. Ford, 2003). Nevertheless, it should be noted that air-curtain incinerators can pose a pollution threat if the air curtain is broken (Anonymous, 2003c, p.4). Air-curtain technology in general has been shown to cause little pollution, but fireboxes burn cleaner than do trench-burners (G. Ford, 2003). When compared to open-burning, air-curtain incineration is superior, with higher combustion efficiencies, less carbon monoxide emissions and PM (G. Ford, 2003). Individuals within the UK government, who have conducted testing on air-curtain fireboxes, are indeed satisfied with this technology's combustion efficiency (Hickman, 2003).

If operated in accordance with best practices and existing environmental regulations, both small and large afterburner-equipped incinerators should not pose serious problems for the environment (Crane, 1997, p.3). However, if not operated properly, small animal carcass incinerators have the potential to pollute. Therefore, it may be environmentally worthwhile to send carcasses to larger, centralized, and better managed incineration facilities (Collings, 2002).

5.2 – Groundwater and Soil Pollution

During the UK 2001 FMD outbreak, Scotland was unique in that it burned, mostly through open-air burning on farms, over 98 percent of its carcasses. This was done primarily because burial was more environmentally problematic given the thin soils and vulnerable aquifers in the Dumfries and Galloway region primarily affected by the outbreak (NAO, 2002, p.124). Researchers in the US agree that incineration is a legitimate alternative when factors related to hydrology (e.g., a high water table) or geology (e.g., soils of high permeability) rule out burial (Damron, 2002).

Unfortunately, however, open-air burning itself poses problems for groundwater contamination, primarily in the form of the hydrocarbons used as fuel (Crane, 1997, p.3). Dioxins and PCBs, both of which are known to emanate from pyres, are also of soil- and food-pollution concern; but the UK Food Standards Agency confirmed that levels of these two pollutants, with a few exceptions, were within normal range throughout the 2001 pyre-burning campaign and "that no significant harm was expected from food produced near pyres" (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76). Nevertheless, the general risks that incineration, particularly open-air burning, pose to groundwater and the soil are real and should always be minimized.

Section 6 – Advantages, Disadvantages, & Lessons Learned

It is important to take stock of past experiences, but it is more important to actually learn from that stock-taking. One of the observations made in the wake of the UK 2001 FMD outbreak was the failure to have learned from the past; for example, a 1968 conclusion that burial was preferable to on-farm burning was not immediately heeded in 2001 (Anderson, 2002, pp.23-24). As the US joins Canada, Australia, New Zealand, and other nations in revising its animal disease management contingency plans (NAO, 2002, p.27), hopefully it can genuinely learn from the past and the comparative advantages and disadvantages of the various disposal methods.

6.1 – Advantages and Disadvantages

Dr. Dee Ellis of the Texas Animal Health Commission has conducted an in-depth review of the advantages and disadvantages, based on recent US and international experience, of carcass disposal methods. Some of Ellis' comments regarding incineration are summarized below.

Open-air burning

Open-air burning can be relatively inexpensive, but it is not suitable for managing TSE-infected carcasses. Significant disadvantages include its labor- and fuel-intensive nature, dependence on favorable weather conditions, environmental problems, and poor public perception (Ellis, 2001, p.76).

Fixed-facility incineration

Fixed-facility incineration is capable of thoroughly destroying TSE-infected carcasses, and it is highly biosecure. However, fixed-facility incinerators are expensive and difficult to operate and manage from a regulatory perspective. Most on-farm and veterinary-college incinerators are incapable of handling large volumes of carcasses that typify most carcass disposal emergencies. Meanwhile, larger industrial facility incinerators are difficult to access and may not be configured to handle carcasses (Ellis, 2001, p.28).

Air-curtain incineration

Air-curtain incineration is mobile, usually environmentally sound, and suitable for combination with debris removal (e.g., in the wake of a hurricane). However, air-curtain incinerators are fuel-intensive and logistically challenging (Ellis, 2001, p.76). Currently, air-curtain incinerators are not validated to safely dispose of TSE-infected carcasses.

6.2 – Lessons Learned

Open-air burning to be avoided

Open-air burning can pose significant public perception, psychological, and economic problems. During the UK 2001 FMD outbreak, carcasses burning on mass pyres "generated negative images in the media" and "had profound effects on the tourist industry" (NAO, 2002, pp.7, 74). In 2001, on-farm pyre burning sent smoke flumes into the air and contributed to an environment of despair for the UK farming community (Battista et al., 2002). The following statement illustrates the problematic nature of one mass pyre site:

> The greatest palpable impact came from the mass pyre at Hemscott Hill. This produced thick smoke, much of which blew inland over the houses nearby and the settlements up to several miles away, carrying with it a foul stench. This forced people to shut their windows and stay indoors. For some households, this became so unbearable that they moved away from the area for some weeks, assisted in some cases by MAFF.
>
> (Northumberland FMD Inquiry Panel, 2002, p.104)

Largely because of problems of public perception, open-air burning was stopped on 7 May 2001 (NAO, 2002, p.74) and quickly followed by the recommendation that mass pyres not be used again for carcass disposal (Anderson, 2002, pp.17, 108). Although small, on-farm open-air burning has not entirely been ruled out in the UK, open-air burning on a mass scale has in fact been ruled out in future FMD contingency planning (DEFRA, 2003c, p.40). Conversely, fixed-facility incineration remains a viable option. While fixed-facility incineration was not used during the UK 2001 FMD outbreak, revised contingency plans now prefer the use of such incineration during the early stages of such an outbreak (DEFRA, 2003c, p.40; NAO, 2002, p.74). Contracts between the UK government and nine animal carcass incinerators are currently being negotiated (DEFRA, 2003c, pp.40-41). If open-air burning must be conducted, it is important to select sites out of the public view, taking into account the prevailing winds (Ellis, 2001, p.28).

Personnel and professional development

Past emergency carcass disposal events have revealed the need for readily available logistical expertise, leadership, and managerial skills (Anderson, 2002, p.82). Indeed, professional development is important. Simulation exercises are key components of preparing for carcass disposal. However, training itself is not enough, as the UK National Audit Office (NAO) has reported regarding training efforts conducted within the UK State Veterinary Service:

> Generally, however, the exercises were seen as helpful in reinforcing theoretical training, though they could not simulate fully the pressures that would exist in a real situation or the long-term commitment that would be needed.
>
> (NAO, 2002, p.41)

From this observation, US federal, state, and local officials responsible for carcass disposal should seek out opportunities to participate in real-life emergencies that can be anticipated ahead of time (e.g., 2003's Hurricane Isabel). The extra personnel would, of course, offer assistance that is valuable in and of itself; but equally importantly, the extra personnel would learn about carcass disposal in a real-life, pressure-filled context.

In addition, and parallel to a recommendation made in the UK (Anderson, 2002, p.82), a bank of volunteers should be available in the event that labor is in short supply to manage mass carcass disposal events, including those involving incineration.

The "digester vs. incinerator" debate

One of the great questions facing US animal disease officials is whether to use alkaline-hydrolysis digestion or fixed-facility incineration to dispose of TSE-infected animals. While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident in recent debates in Larimer County, Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of the heads of CWD-infected deer and elk. While incinerators exist in other parts of the state (e.g., Craig, Colorado), a new incinerator is needed to deal specifically with populations in northeastern Colorado, where there is a high prevalence of CWD among gaming populations.

Despite the need, Larimer County commissioners have heeded local, anti-incinerator sentiments and have, for now, successfully blocked approval of the incinerator. Meanwhile, an alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997b) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003) (see section 7.2).

Based on the UK experience, moves to push for controversial disposal methods (e.g., fixed-facility incineration in Colorado) must include communication with local communities and stakeholders, something that was all too often neglected in the UK (Widdrington FMD Liaison Committee). At the same time, clear regulatory affirmation of technologies (e.g., fixed-facility incineration to manage TSEs) may also hedge against public concerns. In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the EPA; following meetings with laboratory diagnosticians, state veterinarians, and wastewater managers (O'Toole, 2003), EPA Region 8 is close to clearly endorsing fixed-facility incineration as a technology for managing CWD-infected carcasses (Anonymous, 2003c, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like these are needed to respond to attitudes, witnessed in Larimer County, that alkaline hydrolysis is the only way to deal with TSE-infected material (Powers, 2003).

Water-logged materials and carcasses

Carcasses are generally composed of 70 percent water; this places them in the worst combustible classification of waste (Brglez, 2003, p.32). This accentuates the need for fuel and dry burning materials. Experience gained in North Carolina in 1999 (following Hurricane Floyd) and Texas (following flooding in 1998) confirms the importance of having dry wood for incineration. Moist debris was used to burn carcasses in air-curtain incinerators, and the resultant poor air/fuel mixture produced noxious smoke and incomplete combustion (Ellis, 2001, p.30).

Section 7 – Critical Research Needs

7.1 – BSE-Related Disposal Involving Incineration

The December 2003 discovery of BSE in the US has spawned additional questions about carcass disposal and the role incineration might play.

In a January 2004 technical briefing on the BSE situation, USDA officials explained that they do not plan to use alkaline hydrolysis or incineration to dispose of young (less than 30 months) cattle associated with the Washington state BSE case; USDA's decision is being taken in light of science indicating that one cannot generally detect TSE infectivity in cattle less than 30 months of age (USDA, 2004). However, should the BSE situation in North America deteriorate, the US may need to consider precautionary (or public-perception preservation) culls of large numbers of cattle, both young and old. Although BSE-infected animals would have to be directly disposed of (presumably, by alkaline hydrolysis or fixed-facility incineration), "at-risk" animals (e.g., fallen stock, downer cattle, or members of BSE-infected herds) and specified risk materials (i.e., skull, brain, trigeminal ganglia, eyes, vertebral column, spinal cord, and dorsal root ganglia of cattle 30 months of age or older and the small intestine of all cattle) might be disposed of by combinations that include incineration. Such a scenario is not far-fetched or unthinkable; this is precisely what has been done in the UK and continental Europe, where at-risk cattle (e.g., in the UK, cattle over 30 months) have been rendered, with the resultant MBM and tallow incinerated. Significantly, USDA-APHIS publications citing the Harvard Center for Risk Analysis have asked for input on how to best dispose of at-risk animals should the US ever find a domestic case of BSE (APHIS, 2003), which has now occurred and has led to the quick promulgation of regulations prohibiting downer cattle and specified risk materials from the food supply (FSIS, 2004).

Taking a cue from the UK and continental Europe, one approach to disposing of at-risk carcasses and specified risk materials is to combine rendering with incineration. In the US, rendering plants have a capacity to reduce TSE infectivity by as much as 99.9 percent (APHIS, 2003); but, as Europe has learned, storage and incineration of rendered MBM and tallow would be required to ensure complete destruction of any potential TSE infectivity. In Europe, and as section 4.2 alluded, the situation has been managed by the introduction of a subsidy program rewarding incineration plants for recovering energy from the MBM and tallow (Anonymous, 2003g; Hilliard, 2003; Scottish Parliament, 2002; Shanks, 2001). The program has been shown to pose an insignificant risk to the public health (Spouge & Comer, 1997a).

USDA-APHIS should commission research to identify what kinds of government-intervention policy options might be appropriate for sustaining combination strategies, including a rendering-incineration strategy, for dealing with TSE situations (both BSE and CWD). The US EPA already has placed a high priority on waste combustion with energy recovery (EPA Office of Solid Waste and Emergency Response, 2002, p.11), and some private companies (e.g., Smithfield pig farms in North

Carolina) are experimenting with the use of biomaterial waste for electricity production (Anonymous, 2001). Animal fats have an energy value of 17,000 British Thermal Units per pound; rendering plants can re-sell them as fuel (Brglez, 2003, p.32). In the UK, EU subsidies have been central to the success of disposing of cattle deemed to be "at-risk" of TSEs (DEFRA, 2003a; Hilliard, 2003), and research should be conducted to ascertain if a similar program might ever be workable, or even necessary, in the US. Leaders of the rendering industry have signaled an interest in helping manage TSE-related disposal; however, there are significant policy hurdles (e.g., no clear, validated, government-endorsed "clean-out" procedures) and economic barriers (e.g., customers refusing to accept rendered products from plants that participate in TSE-related disposal) (Hamilton, 2003). If these hurdles were overcome, perhaps by government intervention, rendering plants could contribute the first phase of a robust rendering-incineration TSE management plan. Fixed-facility waste-incineration plants in the US are generally not well suited to take whole carcasses, but they are quite capable of taking homogenous material, such as MBM and tallow yielded from rendering plants (Anonymous, 2003f).

This is a critical research area for USDA as it contemplates how to deal with the reality of disposing of at-risk-of-TSE animals and specified risk materials. Already, USDA has suggested combining air-curtain incineration with alkaline-hydrolysis digestion. The suggestion includes separately disposing of the carcasses (in air-curtain incinerators) and the high-risk head tissues (in alkaline hydrolysis) (APHIS, 2002, pp.11-12). As USDA continues to evaluate how to combine disposal technologies, rendering-incineration combinations should be considered.

7.2 – Other TSE-Related Issues

For both the US and Europe, it would be helpful to have information on the potential for post-incineration airborne dispersal of heat stable disease agents, namely those responsible for TSEs. Although highly questionable in light of existing risk assessments (Spouge & Comer, 1997b), the TSE risks posed by incinerator emissions have nonetheless been raised in recent debates regarding CWD (in Larimer County, Colorado; see section 6.2). Recently, the Food and Drug Administration (FDA) Transmissible Spongiform Encephalopathies Advisory Committee (TSEAC) met to discuss the TSE risks posed by air emissions arising from the incineration of scrapie tissue. During this meeting, preliminary research conducted by TSE experts Paul Brown and Edward Rau were presented; although preliminary and not yet published, their research found no TSE infectivity in air emission samples arising from incinerated scrapie-infected brain tissue (Rau, 2003).

Research is also needed to ascertain how to improve the efficacy of the combustion process to ensure the inactivation of heat-resistant disease agents in carcass waste (SSC, 2003b, p.4). Research cited in this report has begun to look at PMFs as a way to enhance the temperatures reached in open-air burning and air-curtain incineration. As already mentioned (see section 4.2), testing has begun in the UK (at DEFRA) to discern whether or not air-curtain incinerators can in fact attain temperatures capable of inactivating TSE agents. Future research in this area might be coordinated transatlantically, with the research staff at DEFRA.

With respect to TSE risks posed by ash, the European Commission SSC urges research "to identify the residual risks…from the burial of ash…in uncontained sites" (SSC, 2003c, p.8).

7.3 – Validation Studies on Open-Air Burning

Even in the UK and continental Europe, it is recognized that open-air burning may need to be used, albeit as a last resort. For example, the revised UK FMD contingency plans rules out mass pyres but stops short of banning smaller, on-farm pyres, which might become necessary in future emergencies (DEFRA, 2003c, p.40). Validated protocols for safe burning in emergency situations need to be established (SSC, 2003b, p.2). Such protocols would, presumably, take into account much of the best-practices described in section 3.1. Researchers have looked at PMFs as a way to enhance the temperatures reached in open-air burning; perhaps these fuels could be included in the validation studies. Similarly, researchers should investigate broadening the use of highly flammable fuels (e.g., jet-B fuel) hitherto used only in cold climates. Research in this area would be of value to regulatory bodies and local government officials on both sides of the Atlantic and around the world.

7.4 – Efficiency, Cost, and Environmental Aspects of Incineration

Researchers should consider how to reduce the need for supplemental fuels in incineration, reduce the time for incineration, improve the throughput, and minimize the release of gaseous pollutants. Drying and pyrolysis are important parts of the overall incineration process. The material being incinerated must first be dried and then heated until it reaches temperatures suitable for pyrolysis or thermal degradation which converts the material into combustible volatile substances and a residual carbonaceous solid (char). The pyrolysis temperature influences the yield of volatiles and char. The rates of time for drying and pyrolysis depend on both the temperature of the surrounding environment and the size of the material. Considerable knowledge of these and other issues with respect to wood and other biomass is available. This knowledge base should be exploited and expanded for application to carcass incineration.

7.5 – Exploitation of the Calorific Value of Carcasses

Researchers should investigate how to exploit the calorific value of carcasses during incineration. There is some calorific value in the protein, fat and bone of animal carcasses. Although it is not as high as wood, this value should be exploited to reduce the fuel requirements for incineration. Experimental data on the effects of temperature and size on the times for drying and pyrolysis of meat and bone pieces is needed along with complementary data on the composition of the volatiles. Experimental data on the calorific value as well as heat capacity of meat and bone is also needed. This knowledge can be used to design rapid and energy-efficient incinerators capable of high throughput.

7.6 – Energy-Recovery Incineration Options

Investigate energy-recovery incineration options, including self-perpetuating systems. A variety of industrial equipment, including multiple hearth furnaces, rotary kilns, fluidized beds and stoker grates, has been adapted to municipal solid waste gasification for the purposes of energy recovery. This equipment should be explored for carcass disposal applications. Energy-recovery research would be a part of studies proposed in section 7.1.

7.7 – Education

In one of the UK FMD inquiry reports, an official concluded that biosecurity and related issues should be incorporated into agricultural education curricula (Anderson, 2002, p.14). Taking this cue, it is suggested that research be undertaken within the US land grant system to discern how best to educate an agricultural work force that is prepared to deal with a range of biosecurity issues, including carcass disposal techniques featuring incineration technologies.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter 3

Composting

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Table of Contents

Abbreviations & Definitions

Though most of the terms related directly and indirectly to carcass composting have been defined to some extent in the text, for convenience the following glossary of technical terms is provided. Definitions were adopted from Rynk (1992), Franco and Swanson (1996), Pocket Information Manual (2003), Ellis (2001), Merriam-Webster's Dictionary (2003), and Oregon Department of Environmental Quality (2003).

Actinomycete: A group of microorganisms, intermediate between bacteria and true fungi that usually produce a characteristic branched mycelium. These organisms are responsible for the earthy smell of compost.

ADL: average daily loss, or rate of animal mortality in kg/day

Aeration: The process by which the oxygen-deficient air in compost is replaced by air from the atmosphere. Aeration can be enhanced by turning.

Aerobic: An adjective describing an organism or process that requires oxygen (for example, an aerobic organism).

Ambient temperature: The temperature of the air in the vicinity of the compost pile.

Ammonia (NH_3): A gaseous compound comprised of nitrogen and hydrogen. Ammonia, which has a pungent odor, is commonly formed from organic nitrogen compounds during composting.

Anaerobic: An adjective describing an organism or process that does not require air or free oxygen.

AUSVETPLAN: Australian Veterinary Emergency Plan, Agricultural and Resource Management Council of Australia and New Zealand

APHIS: USDA Animal & Plant Health Inspection Service

Bacillus anthracis: The causative organism for anthrax.

Bacteria: A group of microorganisms having single-celled or noncellular bodies. Bacteria usually appear as spheroid, rod like, or curved entities but occasionally appear as sheets, chains or branched filaments.

Batch mixer: A type of mixer, which blends materials together in distinct loads or batches. The materials are loaded, mixed, and then unloaded in sequence rather than moved through in a continuous flow. Batch mixers for composting are often modified livestock feed mixers using paddles or augers as the mixing mechanisms.

Bin composting: A composting technique in which mixtures of materials are composted in simple structures (bins) rather than freestanding piles. Bins are considered a form of in-vessel composting, but they are usually not enclosed. Many composting bins include a means of forced aeration.

Biofilter: A layer or blanket of carbon source and/or bulking agent materials that maintains proper conditions of moisture, pH, nutrients, and temperature to enhance the microbial activities and that deodorizes the gases released at ground level from the compost piles.

Biosecurity: All processes to contain a disease or disease agent.

Bucket loader: A vehicle which employs a hydraulically operated bucket to lift materials. Includes farm tractors with bucket attachments, skid loaders, and large front-end loaders.

Bulking agent: A nutrient materials for composting that has bigger particle sizes than carbon sources and thus prevent packing of materials and maintain adequate air spaces (around 25-35% porosity) within the compost pile. They should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contacts.

BVS: bio-degradable volatile solids

Carbon dioxide (CO_2): An inorganic gaseous compound comprised of carbon and oxygen.

Carbon dioxide is produced by the oxidation of organic carbon compounds during composting.

Carcass composting: A natural biological decomposition process that takes place in the presence of oxygen (air).

Carcass compost pile: An inconsistent mixture that consists of an animal mass with large amounts of water, high-nitrogen and low-carbon content, and low-porosity surrounded by a co-composting material of good-porosity, high-carbon, low-nitrogen, and moderate moisture levels.

C:N (carbon-to-nitrogen ratio): The ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material.

Cellulose: A long chain of tightly bound sugar molecules that constitutes the chief part of the cell walls of plants.

COMPO-Matic: The equipment designed for measuring, controlling and optimizing both oxygen and temperature during the composting process. This device has a special insertion probe which contains an oxygen-temperature sensor.

CGOEMC: Colorado Governor's Office of Energy Management and Conservation

Curing: Final stage of composting in which stabilization of the compost continues but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures.

Dry matter: The portion of a substance that is not comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%)

END: exotic Newcastle disease

Enteric: Pertaining to the intestinal tract.

Enzymes: Any of numerous complex proteins produced by living cells to catalyze specific biochemical reactions.

Fecal coliform: Enteric organisms that serve as an indicator of possible presence of pathogens.

Finished compost: Compost that has undergone active composting and curing stage and it is a stable and hygienic product.

FMD (foot and mouth disease): A highly infectious viral infection of cattle, pigs, sheep, goats, buffalo and artiodactyls wildlife spies characterized by fever, vesicles (blisters) in the mouth and on the muzzle, teats, and/or feet; and death in young animals. Affected animals may become completely incapacitated or be unable to eat/drink due to pain associated with the vesicles.

Fungus (plural fungi): A group of simple plants that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae. The individual hyphae can grow together to form a visible body.

Grinding: An operation that cuts the raw materials and reduces their particle sizes. Grinding implies that particles are broken apart largely by smashing and crushing rather than tearing or slicing.

Groundwater: Water below the land surface in a zone of saturation.

Humus: The dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter.

Hydrogen sulfide (H_2S): A gas with the characteristic odor of rotten eggs, produced by anaerobic decomposition.

Inactive material: Carbon source substances with very low moisture and porosity, which have low heat conductivity.

Inoculum (plural inocula): Living organisms or material containing living organisms (such as bacteria or other microorganisms) which are added to initiate or accelerate a biological process (for example, biological seeding).

In-vessel composting: A diverse group of composting materials is contained in a reactor or vessel.

Land application: Application of manure, sewage sludge, municipal wastewater, and industrial wastes to land either for ultimate disposal or reuse of the nutrients and organic matter for their fertilizer value.

Leachate: The liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended, from the solid.

Lignin: A substance that together with cellulose forms the woody cell walls of plants, and the cementing material between them. Lignin is resistant to decomposition.

Litter, poultry: Dry absorbent bedding material such as straw, sawdust, and wood shavings that is spread on the floor of poultry barns to absorb and condition manure. Sometimes the manure-litter combination from the barn is also referred to as litter.

Manure: The fecal and urinary excretion of livestock and poultry, sometimes referred to as livestock waste. This material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris.

Mature (or maturation): A chemical condition of the compost. Immature compost will contain toxic chemical compounds that could affect plant growth.

Mesophilic: Operationally, the temperature range most conducive to the maintenance of optimum digestion by mesophilic bacteria, generally accepted as between 50 and 105°F (10 and 40°C).

Mesophilic temperatures: between 20°C (68°F) and 45°C (113°F), which mesophilic microorganisms grow well.

Mini composter: A smaller version of a bin composter.

Moisture content: The fraction or percentage of a substance comprised of water. Moisture content equals the weight of the water portion divided by the total weight (water plus dry matter portion). Moisture content is sometimes reported on a dry basis. Dry-basis moisture content equals the weight of the water divided by the weight of the dry matter.

MPN: most probable number

NAO: UK National Audit Office

NCSART: North Carolina State Animal Recovery Team

NRAES: Natural Resource, Agriculture, and Engineering Service

ODEQ: Oregon Department of Environmental Quality

Organic composting: As used in this document, refers to composting of biomass such as yard waste, food waste, manure, etc., (excludes composting of carcass material).

OSUE: Ohio State University Extension Service

OU: odor unit

Pathogen: Any organism capable of producing disease or infection. Often found in waste material, most pathogens are killed by high temperatures of composting processes.

pH: A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Thus, something that has a pH of 8 has ten times fewer hydrogen ions than something with a pH of 7. The lower the pH, the more hydrogen ions present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.

Phytotoxic: An adjective describing a substance that has a toxic effect on plants. Immature or anaerobic compost may contain acids or alcohols that can harm seedlings or sensitive plants.

Porosity: A measure of the pore space of a material or pile of materials. Porosity is equal to the volume of the pores divided by the total volume. In composting, the term porosity is sometimes used loosely, referring to the volume of the pores occupied by air only (without including the pore space occupied by water).

Poultry: Chickens or ducks being raised or kept on any premises in the state for profit.

Poultry carcass: The carcass or part of a carcass of poultry that died as a result of a cause other than intentional slaughter for use for human consumption.

Primary phase: The developing or heating phase that can take three weeks to three months is characterized by high oxygen-uptake rates, thermophilic temperatures, and high reductions in biodegradable volatile solids (BVS). This phase may last three weeks to three months, may harbor significant odor potential. The three sub-phases of primary phase are: initial, high rate, and stabilization.

PTO: Power take off. Drive shaft and coupling on a tractor which transmits power from the tractor engine.

Recipe: The ingredients and proportions used in blending together several raw materials for composting.

Runoff: Water that is generated on the site and runs off the site into ponds, swales, ditches, streams, and other water bodies.

Salmonella: Human pathogen that causes gastro-intestinal problems.

SCI: Sparks Companies Inc.

Secondary phase: Also called the maturation or curing phase, may require one month or longer. In this phase, aeration is not a determining factor for proper composting, and, therefore, it is possible to use a low-oxygen composting system. A series of retarding reactions, such as the breakdown of lignins, occurs during this maturation or curing stage and requires a relatively long time.

Shredding: An operation that reduces the particle size of materials. Shredding implies that the particles are broken apart by tearing and slicing.

SOER: surface odor emission rate

Stabilization: A stage in the composting process when the amount of available carbon that serves as a food source for microorganisms is very low. As a result, microbial activity is low and oxygen consumption by the microorganisms is low. Stable compost is a material that does not change rapidly, does not reheat, and has a very low respiration rate. Unstable compost will have great microbial activity because of carbon available as food for the microbes. Pathogenic microorganisms may regrow in unstable compost. As a result, the microbes will utilize soil nitrogen, and plants would not have enough nitrogen for their growth. Stable compost continues to decompose at a very slow rate and has a low oxygen demand.

Thermophilic: Heat-loving microorganisms that thrive in and generate temperatures above 105°F (40°C).

Thermophilic temperatures: Between 45°C (113°F) to 70°C to (158°F), which thermophilic microorganisms grow well.

TOC: threshold odor concentration

Ton: US ton, 2,000 lbs

Ton, metric: 1,000 kg (2,204.6 lb)

Turning: A composting operation, which mixes and agitates material in a windrow pile or vessel. Its main aeration effect is to increase the porosity of the windrow to enhance passive aeration. It can be accomplished with bucket loaders or specially designed turning machines.

US: United States

USDA: US Department of Agriculture

Windrow: A long, relatively narrow, low pile. Windrows have a large exposed surface area which encourages passive aeration and drying.

Windrow composting: This method involves placing the feedstock in long, relatively narrow, low piles called windrows. Windrows have a large exposed surface area which encourages passive aeration and drying. Aeration is achieved by convective airflow as well as turning. The windrow piles act like a chimney; the center gets hot, and air is drawn through the sides.

Section 1 – Key Content

This chapter provides a summary of various aspects of carcass composting, including processing options, effective parameters, co-composting materials, heat-energy, formulations, sizing, machinery, equipment, cost analysis, and environmental impacts. Guidelines and procedures for windrow and bin composting systems, especially for large numbers of animal mortalities, are discussed. This information was adapted from Murphy and Carr (1991), Diaz et al. (1993), Haug (1993), Adams et al. (1994), Crews et al. (1995), Fulhage (1997), Glanville and Trampel (1997), Mescher et al. (1997), Morris et al. (1997), Carr et al. (1998), Dougherty (1999), Monnin (2000), Henry et al. (2001), Keener et al. (2000), Lasaridi and Stentiford (2001), Morse (2001), Ritz (2001), Bagley (2002), Diaz et al. (2002), Hansen (2002), Harper et al. (2001), Langston et al. (2002), Looper (2002), McGahan (2002), Sander et al. (2002), Sparks Companies Inc. or SCI (2002), Tablante et al. (2002), Colorado Governor's Office of Energy Management and Conservation or CGOEMC (2003), Jiang et al. (2003), Mukhtar et al. (2003), Oregon Department of Environmental Quality or ODEQ (2003), and Rynk (2003).

1.1 – General Guidelines for Composting Carcasses in Windrow or Bin Systems

Definition, preparation, formulation, and general principles

Carcass composting is a natural biological decomposition process that takes place in the presence of oxygen (air). Under optimum conditions, during the first phase of composting the temperature of the compost pile increases, the organic materials of mortalities break down into relatively small compounds, soft tissue decomposes, and bones soften partially. In the second phase, the remaining materials (mainly bones) break down fully and the compost turns to a consistent dark brown to black soil or "humus" with a musty odor containing primarily non-pathogenic bacteria and plant nutrients. In this document the term "composting" is used when referring to composting of carcass material, and the term "organic composting" is used when referring to composting of other biomass such as yard waste, food waste, manure, etc.

Carcass composting systems require a variety of ingredients or co-composting materials, including carbon sources, bulking agents, and biofilter layers.

Carbon sources

Various materials can be used as a carbon source, including materials such as sawdust, straw, corn stover (mature cured stalks of corn with the ears removed and used as feed for livestock), poultry litter, ground corn cobs, baled corn stalks, wheat straw, semi-dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, yard wastes, vermiculite, and a variety of waste materials like matured compost.

A 50:50 (w/w) mixture of separated solids from manure and a carbon source can be used as a base material for carcass composting. Finished compost retains nearly 50% of the original carbon sources. Use of finished compost for recycling heat and bacteria in the compost process minimizes the needed amount of fresh raw materials, and reduces the amount of finished compost to be handled.

A carbon-to-nitrogen (C:N) ratio in the range of 25:1 to 40:1 generates enough energy and produces little odor during the composting process. Depending on the availability of carbon sources, this ratio can sometimes be economically extended to 50:1. As a general rule, the weight ratio of carbon source materials to mortalities is approximately 1:1 for high C:N materials such as sawdust, 2:1 for medium C:N materials such as litter, and 4:1 for low C:N materials such as straw.

Bulking agents

Bulking agents or amendments also provide some nutrients for composting. They usually have bigger particle sizes than carbon sources and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials. They should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contact. Bulking agents typically include materials such as sludge cake, spent horse bedding (a mixture of horse manure and pinewood shavings), wood chips, refused pellets, rotting hay bales, peanut shells, and tree trimmings.

The ratio of bulking agent to carcasses should result in a bulk density of final compost mixture that does not exceed 600 kg/m^3 (37.5 lb/ft^3). As a general rule, the weight of compost mixture in a 19-L (5-gal) bucket should not be more than 11.4 kg (25 lb); otherwise, the compost mixture will be too compact and lack adequate airspace.

Biofilters

A biofilter is a layer of carbon source and/or bulking agent material that 1) enhances microbial activity by maintaining proper conditions of moisture, pH, nutrients, and temperature, 2) deodorizes the gases released at ground level from the compost piles, and 3) prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Site selection

Although specific site selection criteria may vary from state to state, a variety of general site characteristics should be considered. A compost site should be located in a well-drained area that is at least 90 cm (3 ft) above the high water table level, at least 90 m (300 ft) from sensitive water resources (such as streams, ponds, wells, etc.), and that has adequate slope (1-3%) to allow proper drainage and prevent pooling of water. Runoff from the composting facility should be collected and directed away from production facilities and treated through a filter strip or infiltration area. Composting facilities should be located downwind of nearby residences to minimize potential odors or dust being carried to neighboring residences by prevailing winds. The location should have all-weather access to the compost site and to storage for co-composting materials, and should also have minimal interference with other operations and traffic. The site should also allow clearance from underground or overhead utilities.

Preparation and management of compost piles

Staging mortalities

Mortalities should be quickly removed from corrals, pens, or houses and transferred directly to the composting area. In the event of a catastrophic mortality loss or the unavailability of adequate composting amendments, carcasses should be held in an area of temporary storage located in a dry area downwind of other operations and away from property lines (ideally should not be visible from off-site). Storage time should be minimized.

Preparation and monitoring of compost piles

Co-composting materials should be ground to 2.5-5 cm (1-2 inches) and mixed. Compost materials should be lifted and dropped, rather than pushed into place (unless carcasses have been ground and mixed with the co-composting materials prior to the composting process). Compost piles should be covered by a biofilter layer during both phases of composting. If warranted, fencing should be installed to prevent access by livestock and scavenging animals.

The moisture content of the carcass compost pile should be 40-60% (wet basis), and can be tested accurately using analytical equipment or approximated using a hand-squeeze method. In the hand-squeeze method, a handful of compost material is squeezed firmly several times to form a ball. If the ball crumbles or breaks into fragments, the moisture content is much less than 50%. If it remains intact after being gently bounced 3-4 times, the moisture content is nearly 50%. If the ball texture is slimy with a musty soil-like odor, the moisture content is much higher than 50%.

A temperature probe should be inserted carefully and straight down into each quadrant of the pile to allow daily and weekly monitoring of internal temperatures at depths of 25, 50, 75, and 100 cm (10, 20, 30, and 40 in) after stabilization during the first and second phases of composting. During the first phase, the temperature at the core of the pile should rise to at least 55-60°C (130-140°F) within 10 days and remain there for several weeks. A temperature of 65°C (149°F) at the core of the pile maintained for 1-

2 days will reduce pathogenic bacterial activity and weed seed germination.

Proper aeration is important in maintaining uniform temperature and moisture contents throughout the pile during the first and second phases of the composting process. Uniform airflow and temperature throughout a composting pile are important to avoid clumping of solids and to minimize the survival of microorganisms such as coliforms, *Salmonella*, and fecal *Streptococcus*. During composting, actinomycetes and fungi produce a variety of antibiotics which destroy some pathogens; however, spore-formers, such as *Bacillus anthracis* (the causative agent of anthrax), and other pathogens, such as *Mycobacterium tuberculosis*, will survive.

After the first phase of composting, the volume and weight of piles may be reduced by 50-75%. After the first phase the entire compost pile should be mixed, displaced, and reconstituted for the secondary phase. In the second phase, if needed, moisture should be added to the materials to reheat the composting materials until an acceptable product is achieved. The end of the second phase is marked by an internal temperature of 25-30°C (77-86°F), a reduction in bulk density of approximately 25%, a finished product color of dark brown to black, and the lack of an unpleasant odor upon turning of the pile.

Odor can be evaluated by placing two handfuls of compost material into a re-sealable plastic bag, closing the bag, and allowing it to remain undisturbed for approximately one hour (5-10 min is adequate if the sealed bag is placed in the sun). If, immediately after opening the bag, the compost has a musty soil odor (dirt cellar odor), the compost has matured. If the compost has a sweetish odor (such as slightly burned cookies), the process is almost complete but requires a couple more weeks for adequate maturation. If the compost odor is similar to rotting meat/flesh, is overpowering, is reminiscent of manure, or has a strong ammonia smell, the compost process is not complete and may require adjustments. After the primary and secondary phases of composting are complete, the finished product can be recycled, temporarily stored, or, if appropriate, added to the land as a soil amendment.

Compost equipment and accessories

Transport vehicles, such as trucks, front-end loaders, backhoes, tractors, or skid loaders outfitted with different bucket sizes (0.88-3.06 m^3 or 1-4 yd^3), can be used for a variety of purposes, including to construct and maintain composting piles for bin or windrow formation, to place mortalities on compost piles, to lift, mix, and place co-composting materials, to move compost from one place to another as needed for aeration, and to feed finished product into compost screeners or shredders.

Grinding or milling equipment used for the composting process includes tub grinders or tub mills, hammer mills, continuous mix pug mills (machines in which materials are mixed, blended, or kneaded into a desired consistency) and vertical grinders. A bale processor can be used to grind baled cornstalks, hay, straw, and grass. Several types of batch mixers (which may be truck- or wagon-mounted), including mixers with augers, rotating paddles, rotating drum mixers, and slats on a continuous chain can be used for mixing operations.

Tanker trucks with side-delivery, flail-type spreaders, honey wagons with pumps, or pump trucks can be used for hauling water to, or spreading water on, the composting piles.

Bucket loaders and rotating-tiller turners (rototillers) are commonly used for turning windrow piles. If a bucket loader is used, it should be operated such that the bucket contents are discharged in a cascading manner rather than dropped as a single mass. For large windrows, self-propelled windrow turners should be used. Turning capacities range from about 727 to 2,727 metric tons/h (800 to 3,000 US tons/h).

Trommel screens with perforations of less than 2.5 cm (1 in) can be used to remove any remaining bones from the finished compost product, and the larger materials remaining on the screen can be recycled back into active windrows.

Instruments and supplies necessary for monitoring and recording physical and chemical properties of a composting system include thermometers (usually four-foot temperature probes), pH meters, bulk density testing devices (a weighing box made of 1.25 mm or 0.5 inch plywood, and volume of 0.028 m^3 or 1 ft^3 with a strap or wire, which can be suspended from a hanging scale), odor testing materials (re-sealable plastic bags), and log books to record compost activities and status along with test results.

Trouble shooting

In the event that liquids leach out of the pile, a well absorbing carbon source material should be spread around the pile to absorb the liquids and increase the base depth. If the pile appears damp or wet and is marked by a strong offensive odor and a brown gooey appearance, it should be transferred onto a fresh layer of bulking agent in a new location.

During the first phase, if the moisture content is low (less than 40%) and the internal pile temperature is high (more than 65°C [149°F]), the compost pile coverage or its cap should be raked back and water should be added at several locations. Conversely, if the internal pile temperature is very low (less than 55°C [130°F]), the compost pile may have been too moist (wet) and/or lacked oxygen, resulting in anaerobic rather than aerobic conditions. Samples should be collected and the moisture content determined by a hand squeeze moisture test.

If the compost temperature does not rise to expected levels within 1-2 weeks of the pile being covered and capped, the initial pile formulation should be evaluated for proper C:N ratio and mixture of co-composting materials and mortalities. Alternatively, cattle, chicken, or horse manure can be added to the compost pile.

In cold climates or winter, compost piles should be protected from the elements prior to loading. Carcasses should be stored in a barn, shed, or other covered space to protect them from freezing temperatures if they cannot be immediately loaded into the pile. Frozen mortalities may not compost until thawed. Bulking agents and other compost ingredients should also be kept dry to prevent freezing into unusable clumps.

Land application

The finished product resulting from composting of mortalities has an organic matter content of approximately 35-70%, a pH of about 5.5 to 8.0, and a bulk density of about 474 to 592 kg/m^3 (29.6- 40 lb/ft^3). Therefore, the material is a good soil amendment. Finished compost may be land spread according to a farm nutrient management plan. State regulations should be consulted prior to land application of finished compost.

Cost analysis

According to Sparks Companies, Inc. (SCI, 2002), the total annual costs of carcass composting are $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses. The cost of machinery (the major fixed cost) represents almost 50% of the total cost per head. Other researchers have estimated carcass composting costs to range from $50-104 per US ton (Kube, 2002). Due to the value of the finished compost product, some estimates suggest the total cost of composting per unit weight of poultry carcasses is similar to that of burial. Reports indicate that only 30% of the total livestock operations in the US are large enough to justify the costs of installing and operating composting facilities. Of those production operations that do compost mortalities, at least 75% are composting poultry mortalities.

1.2 – Specific Procedures for Composting Carcasses in Windrow or Bin Systems

Although windrow and bin composting systems share some common guidelines, differences exist in the operation and management of the two systems. Specific guidelines and procedures for primary and secondary phases of windrow and bin composting are outlined below.

Windrow composting

While the procedure for constructing a windrow pile is similar for carcasses of various animal species, carcass size dictates the layering configuration within the pile. Regardless of mortality size, the length of a windrow can be increased to accommodate more carcasses. Carcasses can be generally categorized as small (e.g., poultry and turkey), medium (e.g., sheep and young swine), large (e.g., mature swine), or very large (e.g., cattle and horses).

Constructing a windrow pile

The most appropriate location for a windrow is the highest point on the identified site. A plastic liner (0.24 in [0.6 cm] thick) of length and width adequate to cover the base dimensions of the windrow (see following dimensions) should be placed on crushed and compacted rock as a moisture barrier, particularly if the water table is high or the site drains poorly. The liner should then be completely covered with a base of co-composting material (such as wood chips, sawdust, dry loose litter, straw, etc). The co-composting material layer should have a thickness of 1 ft for small carcasses, 1.5 ft for medium carcasses, and 2 ft for large and very large carcasses. A layer of highly porous, pack-resistant bulking material (such as litter) should then be placed on top of the co-composing material to absorb moisture from the carcasses and to maintain adequate porosity. The thickness of the bulking material should be 0.5 ft for small carcasses, and 1 ft for all others.

An evenly spaced layer of mortalities should then be placed directly on the bulking material layer. In the case of small and medium carcasses, mortalities can be covered with a layer of co-composting materials (thickness of 1 ft [30 cm]), and a second layer of evenly spaced mortalities can be placed on top of the co-composting material. This layering process can be repeated until the windrow reaches a height of approximately 6 ft (1.8 m). Mortalities should not be stacked on top of one another without an appropriate layer of co-composting materials in between. For large and very large carcasses, only a single layer of mortality should be placed in the windrow. After placing mortalities (or the final layer of mortalities in the case of small and medium carcasses) on the pile, the entire windrow should be covered with a 1-ft (30-cm) thick layer of biofilter material (such as carbon sources and/or bulking agents).

Using this construction procedure, the dimensions of completed windrows will be as follows for the various categories of mortality (note that windrow length would be that which is adequate to accommodate the number of carcasses to be composted):

- Small carcasses: bottom width, 12 ft (3.6 m); top width, 5 ft (1.5 m); and height 6 ft (1.8 m)
- Medium carcasses: bottom width, 13 ft (3.9 m); top width, 1 ft (0.3 m); and height 6 ft (1.8 m)
- Large and very large carcasses: bottom width, 15 ft (4.5 m); top width, 1 ft (0.3 m); and height, 7 ft (2.1 m)

Bin composting

For a bin composting system, the required bin capacity depends on the kind of co-composting materials used. As a general rule, approximately 10 m^3 of bin capacity is required for every 1,000 kg of mortality (160 ft^3 per 1,000 lb of mortality). Because bin composting of large and very large carcasses is sometimes impractical, these carcasses may best be accommodated by a windrow system. This section provides specific guidelines for two-phase, bin composting of both small- and medium-sized mortalities.

Constructing a bin

Bins can be constructed of any material (such as concrete, wood, hay bales, etc.) structurally adequate to confine the compost pile. Simple and economical bin structures can be created using large round bales placed end-to-end to form three-sided enclosures or bins (sometimes called bale composters). A mini-composter can be constructed by fastening panels with metal hooks to form a box open at the top and at the bottom. Structures should be located and situated so as to protect the pile from predators, pests, and runoff. Bins may or may not be covered by a roof. A roof is advantageous, especially in high rainfall areas (more than 1,000 mm or 40 in annual average), as it results in reduced potential for leaching from the pile and better working conditions for the operator during inclement weather.

An impervious concrete floor (5 in [12.5 cm] thick) with a weight-bearing foundation is recommended to accommodate heavy machinery, allow for all-weather use, and prevent contamination of soil and surrounding areas. If an entire bin is constructed of concrete, bin walls of 6-in (15-cm) thickness are recommended. Walls and panels can also be constructed with pressure-treated lumber (e.g., 1-in treated plywood backed with 2 x 6 studs). To improve wet weather operation, access to primary and secondary bins can be paved with concrete or compacted crushed rock.

The wall height for primary and secondary bins should be 5-6 ft (1.5-1.8 m), and the bin width should be adequate for the material-handling equipment, but generally should not exceed 8 ft (2.4 m). The minimum front dimension should be 2 ft (61 cm) greater than the loading bucket width. The front of the bin should be designed such that carcasses need not be lifted over a 5-ft (1.5-m) high door. This can be accomplished with removable drop-boards that slide into a vertical channel at each end of the bin, or with hinged doors that split horizontally.

Bin composting process

Primary phase. A base of litter (or litter-sawdust, litter-shavings mixture) with a thickness of 1.5-2 ft (45-60 cm) should be placed in a fresh bin about two days before adding carcasses to allow for preheating of the litter. Immediately prior to introducing carcasses, the surface of the pre-heated litter (about 6 in [15 cm] in depth) should be raked back and the carcasses should be placed in the hot litter. A minimum of 1 ft (30 cm) of litter should remain in the base of the compost pile for absorbing fluids and preventing leakage. Carcasses should not be placed within about 8-12 in (20-30 cm) of the sides, front, or rear of the compost bin to prevent heat loss. Carcasses should be completely covered and surrounded with the preheated litter.

Carcasses can be placed in the bin in layers, although a 1-ft (30-cm) thick layer of carbon source material is necessary between layers of carcasses to insulate and maintain compost temperature. As a final cover material, carcasses should be completely covered with approximately 2 ft (60 cm) of sawdust, or a minimum of 2.5 lb (1.1 kg) of moist litter per pound of carcass, to avoid exposed parts or odors that attract flies, vermin, or predators to the pile and to minimize fluids leaching out of the pile.

Secondary phase. After moving the pile to the secondary bin, it should be covered with a minimum of 4 in (10 cm) of co-composting materials (such as straw and woodchips) to ensure that exposed carcass pieces are covered. This additional cover helps insulate the pile, reduce odor potential, and ensure decomposition of remaining carcass parts. Moisture should be added to the materials to allow the pile to reheat and achieve an acceptable end product. An adequately composted finished product can be identified by a brown color (similar to humus) and an absence of unpleasant odor upon pile turning. Note that some identifiable carcass parts, such as pieces of skull, leg or pelvic bones, hoofs, or teeth, may remain. However, these should be relatively small and brittle (or rubbery) and will rapidly disappear when exposed to nature.

1.3 – Disease Agent Considerations

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. Although the heat generated during carcass composting results in some microbial destruction, because it is not sufficient to completely sterilize the end product, some potential exists for survival and growth of pathogens. The levels of pathogenic bacteria remaining in the end product depend on the heating processes of the first and second phases, and also on cross contamination or recontamination of the end product.

In order to maximize pathogen destruction, it is important to have uniform airflow and temperature throughout the composting process. Because carcass compost is an inconsistent, non-uniform mixture, pathogen survival may vary within different areas of the compost. Temperature uniformity is facilitated by proper aeration, and reduces the probability of microbes escaping the high-temperature zone. In spite of non-uniform temperatures, pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days. That is, a high core temperature provides more confidence for the carcass composting pasteurization process. Achieving an average temperature of 55 to 60°C (131 to 140°F) for a day or two is generally sufficient to reduce pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to an acceptably low level. However, the endospores produced by spore-forming bacteria would not be inactivated under these conditions.

1.4 – Conclusions

Composting can potentially serve as an acceptable disposal method for management of catastrophic mortality losses. Furthermore, the principles for composting catastrophic mortality losses are the same as for normal daily mortalities. Successful conversion of whole materials into dark, humic-rich, good-quality compost that has a soil- or dirt cellar-like odor requires daily and weekly control of odor, temperature, and moisture during the first and second phases of composting. This stringent management and control will prevent the need for major corrective actions.

Bin composting may not be economically suitable or logistically feasible for large volumes of small and medium carcasses. In such instances, windrow composting may be preferable in terms of ease of operation.

Section 2 – General Information

The livestock and poultry industry has historically been one of the largest agricultural businesses in the United States (US). According to Sparks Companies, Inc. (SCI) (2002), the market for US meat and meat-based products results in the annual slaughter of roughly 139 million head of cattle, calves, sheep, hogs and other livestock, as well as 36 billion pounds of poultry (broiler chickens, layer chickens and turkeys). Every year, millions of animals, representing billions of pounds of mortality, perish due to typical production death losses.

2.1 – History of Animal Mortality from Disease and Disasters

According to USDA Economics and Statistics Systems (2002), more than 439 million poultry (excluding commercial broilers) were raised for commercial sale in the US in 2002. Out of this production, about 52 million birds (almost 12% of the total production) died of various causes before they were marketable. SCI (2002) reported that ruminants (cattle, sheep, lamb, and goats) combine to account for about 22%, and swine 78%, of all mammalian livestock that die prior to slaughter each year. However, because they are considerably larger and heavier, cattle account for about 67% by weight of the total death loss each year.

Infectious and non-infectious diseases worldwide cause heavy losses of animal populations every year. Some of the worst catastrophic mortality losses resulting from various diseases in different countries during the last 10 years are summarized below.

In 1993, an outbreak of Newcastle disease occurred on a Venezuela farm having nearly 100,000 chickens (Pakissan.com, 2001).

- In 1997 and in 2001, foot and mouth disease (FMD) outbreaks in Taiwan generated millions of dead swine, sheep, and cattle carcasses to be disposed of in a biosecure and time-sensitive manner (Wilson & Tsuzynski, 1997).
- In 1998, animal diseases took a heavy toll. Newcastle disease damaged three poultry farms in New South Wales (Province of Australia), and FMD damaged pig farms in Central Asia, Africa, South America, China, and Middle Eastern countries like Israel. In another case, Rift Valley fever led to the loss of 70% of the sheep and goat populations, and 20-30% of the cattle and camel populations in East and West Africa. During the same year, African swine fever broke out in Madagascar leading to the death of more than 107,000 pigs (Pakissan.com, 2001).
- In 2001, an outbreak of FMD in the United Kingdom resulted in the slaughter and disposal of over 6 million animals, including cattle, sheep, pigs, and goats (NAO, 2002). Approximately 4 million of these animals were culled for welfare reasons rather than for disease control purposes.
- An exotic Newcastle disease (END) outbreak in 2003 in Southern California resulted in the depopulation of nearly 4.5 million birds and is another example of a disease outbreak in poultry operations (Florida Department of Agriculture and Consumer Services, 2003).

Natural disasters have the potential to cause catastrophic animal mortalities that are just as devastating as infectious diseases. Mortality due to natural disasters can be attributed to a wide variety of events, such as floods, storms, lightning, heat extremes, fires, droughts, and earthquakes. Heat extremes, especially in unusually hot summers, have significant impact on increasing animal mortality. The following natural disasters caused massive animal mortalities.

- Floods that occurred in Texas in 1998 resulted in livestock losses estimated to be approximately $11 million over 20 counties (Ellis, 2001).
- In 1999 Hurricane Floyd in North Carolina resulted in estimated losses of livestock and poultry valued at approximately $13 million (North Carolina State Animal Recovery Team, NCSART, 2001). Losses included over 2 million chickens, 750,000 turkeys, 28,000 hogs, and over 1,100 cattle.
- During a period of intense heat in July 1995, the mortality of feedlot cattle in Iowa and Nebraska increased tremendously. A total of 10,000 feedlot cattle perished, 3,750 within a single day. The estimated losses to livestock and poultry producers in central Iowa, respectively, were $28 million and $25 million (USDA, 2002).

In each catastrophe, animal mortalities caused a considerable economic loss to producers. In addition to economic consequences, catastrophic mortality losses may potentially impact public health or the environment.

2.2 – Historical Use of Composting

"Carcass composting" can be described as burying dead animals above ground in a mound of carbon source with decomposition of carcass tissues resulting from the aerobic action of various microorganisms. Composting produces water vapor, carbon dioxide, heat, and stabilized organic residue. Composting carcasses is relatively new in comparison with "organic composting," or composting of crop and horticultural residues. According to Murphy and Handwerker (1988), "carcass composting" began in the poultry industry after research conducted in the 1980s at the University of Maryland demonstrated that poultry carcasses could be fully biodegraded in only 30 days. This research used a relatively simple bin composting process that was less labor intensive than burial. Glanville and Trampel (1997) indicated this process was quickly adopted by the poultry industry in the southern and eastern seaboard states, but concern regarding its year round applicability, particularly in colder climates, slowed its acceptance in northern states. Kashmanian and Rynk (1996) reported that cold weather does not seriously affect the process as long as bins are adequately sized and properly loaded. Some researchers believe that the end products of carcass composting and conventional organic (plant residue) composting are comparable in terms of agricultural land application.

The main disadvantages of carcass composting have been summarized by many sources, including AUSVETPLAN (1996) and Ellis (2001). It was reported that composting of dead animals is a slow process (taking months), which requires longer management throughout the decomposition process.

2.3 – Objectives

The purpose of this work is to discuss various aspects of carcass composting as a mortality disposal option. This work is intended to provide information to those with planning and decision making responsibility to determine whether composting is suitable to the circumstances at hand, and if so, to choose the most appropriate carcass composting method.

Section 3 – Principles of Operation

3.1 – General Carcass Composting Process

Composting is becoming an increasingly preferred alternative for disposing of mortalities at animal feeding operations. Carcass composting offers several benefits, including reduced environmental pollution, generation of a valuable by-product (soil amendment), and destruction of many pathogens. Because finished compost is different than the original materials from which it was derived, it is free of unpleasant odor, easy to handle, and can be stored for long periods. This section provides a thorough review and discussion of the principles of the composting process, including the definition of composting, the natural degradation process, factors critical to the conversion process, physical changes that occur in a compost pile, as well as the microorganisms involved in the composting process.

Compost definition

Based on the work of many researchers (Murphy & Carr, 1991; Haug, 1993; Diaz et al., 1993; Manser & Keeling, 1996; Reinikainen & Herranen, 1999; Keener, Elwell, & Monnin, 2000; and Harper et al., 2001), composting of plant and animal residues or mortalities can be defined as a natural biological decomposition process with the following properties:

- Stabilization of biomass components using predominantly aerobic reactions.
- Development of populations of thermophilic, gram-positive, spore-forming bacilli (for example, *Bacillus* spp.), fungi, and actinomycetes.
- Conversion of complex organic material into relatively short molecules of proteins, lignins, celluloses, hemicelluloses, and some inorganic materials (water, carbon dioxide, and ammonia).
- Generation of an end product or "humus" which is a consistent, dark brown, soil-like material containing largely mesophilic bacteria.

Keener et al. (2000) and Bagley (2002) explained that in the early stage of the first phase of carcass composting, the decomposition process is anaerobic in and around the carcasses, but later, liquids and gases move away from the carcass into the co-compost material, which is an aerobic zone. Subsequently these gases are trapped in the surrounding supplement material and degraded by microorganisms to carbon dioxide and water. The surrounding material supports bacteria and forms a biological filter (biofilter). According to this concept, naturally occurring organisms change and convert the body of a dead animal (a good source of organic nitrogen) and carbon material into a stable and relatively homogenous mixture of bacterial biomass and humic acids used for soil amendment.

What happens during composting

Due to the considerable physical, chemical, and biological changes that occur during the composting process, the natural degradation of biomass components does not occur in a steady state, but rather in unsteady conditions. Though there is no obvious or distinct delineation between the two phases or stages of the composting process, some researchers, including Haug (1993), Diaz et al. (1993), Manser and Keeling (1996), Glanville and Trampel (1997), Keener et al. (2000) and Kube (2002), have divided the entire composting process into two major phases. Haug (1993) indicated that the first phase (also called the developing or heating phase) is characterized by high oxygen-uptake rates, thermophilic temperatures, and high reductions in bio-degradable volatile solids (BVS). This phase, which may last three weeks to three months, is also characterized by a higher potential for significant odor than that of the second phase.

The second phase (also called the maturation or curing phase), may require one month or longer for completion. In this phase, aeration is not a determining factor for proper composting, and, therefore, it is possible to use a low-oxygen composting system. A series of retarding reactions, such as the breakdown of lignins, occurs during this maturation or curing stage and requires a relatively long time. According to Bollen et al. (1989), the maturation phase could be as long as five months at temperatures below 40°C (105°F).

Bollen et al. (1989) and Keener et al. (2000) categorized the first phase of the carcass composting process into three sub-phases: initial, high rate, and stabilization. In the initial sub-phase which lasts one to three days, the temperature increases from ambient to as high as 43°C (110°F), and mesophilic microorganisms degrade sugars, starches, and proteins. In the second sub-phase (high rate), which lasts 10-100 days, the temperature increases from 43°C (110°F) to nearly 71°C (160°F), and thermophilic microorganisms degrade fats, hemicelluloses, cellulose, and some lignins. Finally, in the third sub-phase (stabilization) which lasts 10-100 days, the temperature declines and remains above 40°C (105°F). During this final sub-phase, further degradation of specific celluloses (probably shorter chains), hemicelluloses, and lignins occurs, and mesophilic microorganisms recolonize. The high temperatures in the first two sub-phases (initial and high rate) of composting are a function of the amount and degree of uniformity in aeration, moisture content, and composition of required materials. During equivalent phases in the composting cycle, the temperature of a pile in which carcasses are composted will be in lower than that of a pile in which organic plant residues are composted, unless physical and chemical conditions are optimized to provide microbiological uniformity and adequate aeration. Additionally, the compost pile must be large or have insulating material to maintain high temperatures, as described by Keener et al. (2000).

Factors affecting the composting process

This section provides a summary of factors key to a successful composting process, including temperature, time, porosity, and aeration.

Temperature

One of the most critical factors in carcass composting (especially in the developing phase) is temperature. Studies by Harper et al. (2001), Keener and Elwell (2000), and Langston et al. (2002) demonstrated that the rate of the decomposition process at thermophilic temperatures (40 to 71°C [105 to 160°F]) is much faster than that at mesophilic temperatures (10 to 40°C [50 to 105°F]). They reported that the thermophilic process generates its own heat, and a properly constructed compost pile is self-insulating to maintain higher temperatures and encourage rapid decomposition. One of the advantages of thermophilic temperatures is inactivation of weed seeds which may be present if the animals ingested weeds. Looper (2002) reported that weed seeds are usually destroyed at 62°C (145°F). The temperature rise is affected not only by the type of microorganisms present and the co-composting materials used, but also by moisture content, as well as the size and depth of carcasses in the co-composting materials. Mukhtar et al. (2003), studying the compost process of large cow and horse carcasses with and without placement on pallets, measured the rise in pile temperature along with the corresponding ambient temperature and precipitation amount. Figures 1, 2, and 3 in Appendix B show that the following results were obtained from this study:

- Because the composting process for the horse and cow carcasses was initiated in different seasons with quite different rainfall amounts (1 in [2.5 cm] for the horse versus approximately 8 in [20 cm] for the cow), the rise in compost pile temperature lasted one month for the horse carcass and five months for the cow carcass (Figures 1 & 2, Appendix B).
- Within a few days of pile construction, the temperature both below (bottom) and above (top) the composted cow and horse carcasses on pallets exceeded 55°C (131°F), and the temperature below the carcasses remained 5-10°C (41-50°F) higher than that above the carcasses. This is explained by drying of the pile (Figure 2, Appendix B).
- Compost piles containing cow and horse carcasses without pallets were turned (aerated) after three months. This aeration, coupled with a series of rainfall events preceding aeration, caused a significant increase in microbial activity and resulted in the cow compost pile reaching the highest temperature of 74°C (165°F) within five days of aeration (Figure 3, Appendix B).
- Due to differences in moisture and nutrient contents of cow and horse carcasses, the

temperature within the cow compost pile remained above or near 55°C (131°F) for the three months after aeration, whereas the temperature within the horse compost pile continued to decrease, with occasional upward swings due to rainfall events (Figure 3, Appendix B).

Most researchers believe that when the overall compost temperature reaches 55-60°C (131-140°F), it should remain at this temperature for one to two weeks. For more confidence on pathogenic bacterial inactivation, the core temperature of carcass composting should reach 65°C (149°F) and remain at this level for one to two days. That is, the compost pile could be turned or displaced with minimal risk of spreading pathogenic bacteria when these time and temperature criteria have been achieved. Furthermore, if the compost pile temperature exceeds 65°C (149°F) for more than two days, it should be turned and aerated to prevent thermal inactivation of beneficial microorganisms.

That is, although higher compost temperatures are beneficial in terms of more rapid decomposition and more effective pathogen elimination, excessively high temperatures may inactivate desirable enzymes produced by beneficial microorganisms. Microorganisms, such as *Aspergillus niger* and *Trichoderma reesei*, that convert cellulose, hemicellulose, and lignin to smaller molecules are destroyed when exposed to high temperatures (60 to 70°C [140 to 158°F]) for more than two to three hours (Busto et al., 1997; Jimenez et al. 1995). Miller (1993) confirmed the fact that fungi effectively assimilate complex carbon sources such as lignin or cellulose that are not available to most bacteria; however, fungal activity is greatly restricted above 55°C (131°F). They observed that at high compost temperatures (60 to 70°C [140 to 158°F]), many carbon-digesting enzymes will be inactive, nitrogen compounds will be lost, and more unpleasant nitrogen gas odors will be produced. Kube (2002) mentioned that microbial activities declined at compost temperatures above 65°C (150°F), and retarded at temperatures of more than 71°C (160°F).

Time

The time required to complete the composting process depends on a variety of factors, including the temperature profile achieved, the species being composted, the compost formulation, as well as preparation, mixing, aeration, and monitoring conditions. Generally, composting time is shorter in warmer climates than in colder climates. The size and weight of carcasses has a direct effect on the time required for completion of the composting process. A longer time is required to decompose heavier and intact carcasses. In order to facilitate the use of mathematical models to predict the required space and time for carcass composting, Keener et al. (2000) classified carcasses into four different weight groups, as follows:

- Small – less than 50 lb (23 kg), such as poultry
- Medium – 50-250 lb (23 to 114 kg), such as swine
- Large – 250-500 lb (114 to 227 kg)
- Very large – those exceeding 500 lb (227 kg)

The time at which piles are moved from primary to secondary stages (turning time) for small carcasses (such as poultry) is about seven to ten days, for medium sized carcasses (such as pigs) is about 90 days, and for large carcasses is about six months. Table 1 in Appendix C, adapted from Monnin (2000), shows the time needed for primary, secondary, and storage stages.

Harper et al. (2001) reported that effective composting of 405 lb (184 kg) of porcine mortality tissue was successfully done in 171 days (about six months). Murphy and Carr (1991) reported that composting of broiler carcasses required two consecutive seven-day periods to reduce carcasses to bony residues, and the materials continued to react and stabilize for extended periods when stored for 6 or more months. Fulhage (1997) indicted that a composting time for medium weight carcasses (such as swine) of three months in the first phase and three months in the second phase usually provides an acceptable finished product. Keener and Elwell (2000) explained that the composting time for moderate size animals (pigs, sheep, etc.) is generally less than three months after the last carcass has been placed into the pile.

Sander et al. (2002) reported that composting of intact pig and cattle carcasses takes nine to ten months, but they may biodegrade more quickly if partitioned or cut open prior to composting. To decrease composting time and to allow the carcass to be laid flat, Bagley (2002) and Looper (2002) recommended opening the body cavity of the animal before composting.

Looper (2002) stated that decomposition of a mature dairy cow carcass generally takes six to eight months, with a few small bones remaining. It was noted that after eight weeks, 90% of the flesh was decomposed and the bones were cleaned. After four months, it was somewhat difficult to find carcasses in the pile with only several small bones present (seven to ten bones per carcass).

Porosity

The oxygen available for the composting process depends highly on the voids and porosity of the pile. These important factors are related to bulk, packed, and true densities of the compost mixture. According to Keener et al. (2000) and Looper (2002), particle size controls the porosity (air space) of the pile and allows air to penetrate and maintain oxygen concentrations to optimize microbial growth. They recommended the porosity, or small open spaces, should be around 35-40% of the pile volume. In a composting process, decomposition occurs on particle surfaces, and degradability can be improved by reducing the particle size (which increases the surface area) as long as porosity is not a problem (Rynk, 1992).

Optimum porosity is achieved by balancing particle size and water content of the materials in the compost pile. Porosity not only affects temperature, resistance of organic material to the decomposition process, and availability of oxygen, but also impacts the aeration process, microbial growth, kinetic reaction rates, and the time required for complete composting. Harper et al. (2001) indicated that the porosity of the bulking agent allows entry of oxygen and promotes the composting process. The decomposition process will not proceed fully in the absence of adequate air penetration, which can be due to "packing" of the pile or to excessive moisture content. Instead of homogenizing the compost content (for the purpose of increasing porosity), Harper et al. (2001) increased the porosity of the compost pile by mechanically disturbing or "turning" the pile thereby introducing oxygen into the material.

Aeration

The "aeration process" is important in maintaining uniform temperature and moisture content throughout the pile during the first and second phases. When the temperature appears to decline, the pile should be aerated (moved, turned, mixed, or stirred) to reactivate the process and increase the temperature. Lasaridi and Stentiford (2001) studied the effects of aeration by turning at weekly intervals a windrow pile in which organics were composted and found high core temperatures (up to 74°C [165°F]) due to high aerobic fermentation. Tiquia et al. (2002) also studied the temperature profiles and dynamics of yard trimmings composting in a windrow system and showed a rapid self-heating of the compost mass from an ambient temperature of 20°C (68°F) to 71°C (160°F) in the first 24 hours of the decomposition process. This thermophilic temperature generated by the aeration process was sustained until day 14, then decreased to ambient towards the end of the process (day 63).

To ensure adequate aeration, the particle size of composting materials should range from 1/8 to 1/2 inch (3.1 to 12.7 mm) in diameter (Looper, 2002). Moving and turning the compost pile helps to increase air penetration. Keener et al. (2000) suggested that moving a carcass compost pile from a primary to a secondary bin introduces air back into the pile and mixes the contents, leading to more uniformity in the finished compost.

Aeration has a considerable effect on the quality of the finished compost product. Umwelt Elektronic GmbH and Co. (2003) studied the odor units (OU) of an organic compost pile equipped with an Oxygen Regulated Aeration System, which worked on regular intervals and measured the odor units at its open rectangular heap. The OU of fresh material (0 days), and those observed after 3, 10, and 75 days, respectively, were 9,500, 1,805, 336, and 90 OU/m^3 (269, 51, 10, and 3 OU/ft^3). That is, within 3 days the odor level was reduced by more than 80% compared to the original fresh materials.

Measuring the oxygen content in windrow composting materials is very important. The oxygen content of the composting mass is mainly affected by the amount of aeration. According to Umwelt Elektronic GmbH and Co. (2003), air quantity above that which is necessary for the composting process unnecessarily withdraws water from the decomposition material. Furthermore, depending on the water content of the additional air and the temperature of the windrow, aeration can withdraw water in quantities up to 0.25 kg/m^3 (0.016 lb/ft^3) of injected air. In this case, degradation will be slowed and the windrow must be watered and re-stacked.

Changes in pile properties during composting

The most important changes that occur in a carcass compost pile are weight and volume loss, pH changes, and production of gases and odors.

Weight and volume loss

The biochemical reactions of the composting process transform large organic molecules into smaller ones, and produce different gases and odors. As a result, the weight of the end product becomes much less than that of the parent materials. Due to their different natures, carcasses and co-composting materials have different rates of shrinkage during the compost process. According to Langston et al. (2002) and Kube (2002), after three months of composting swine and cow carcasses, the final volume of the piles was 20% and 25% less, respectively, than that of their originals. Thus the average shrinkage rate of the whole compost pile was about 0.2-0.3% per day. Looper (2002) reported that in a properly managed compost pile in which a core temperature of around 63°C (145°F) was obtained in three to four days, the volume of cattle carcasses was reduced to one-half of the original after approximately two weeks. Harper et al. (2001) reported that the final weight of 26.1 kg (58 lb) of afterbirth and dead piglets after composting for two weeks was only 3.1 kg (6.9 lb), and the remaining tissue was easily crumbled in the sawdust medium. In this experiment, the average daily weight loss was more than 6% of the original animal mass. Due to significant changes in mass and volume of composted carcasses, the bulk density of finished product decreases considerably, and, if added to agricultural soils, may potentially increase the overall porosity and aeration.

pH

A high-alkali or low-acid environment is not well-suited to the composting process. Since the bio-degradation process releases carbon dioxide (CO_2, a weak acid) and ammonia (NH_3, a weak base), the compost process has the ability to buffer both high and low pH back to the neutral range as composting proceeds (Haug, 1993). Based on this fact, the right amount of carbon and nitrogen sources (for production of these two essential gases) is very important. Carr et al. (1998) remarked that a proper carbon-to-nitrogen (C:N) ratio keeps pH in the range of 6.5 to 7.2, which is optimum for composting. If the pH approaches 8, ammonia and other odors may become a problem. They suggested that the pH could be reduced by adding an inorganic compound, such as granular ferrous sulfate. Langston et al. (2002) indicated that a pH of 6.5-8.0 is one of the requirements for optimum conditions composting swine carcasses.

Gases and odors

Fermentation and oxidation of carcasses during composting produces unpleasant gases (CO_2, NH_3, hydrogen sulfide or H_2S, etc.) and odors associated with the liquid or solid biomass. Different methods have been suggested to neutralize the unpleasant effects of these gases. Some researchers used wood ash as an absorption medium. Rosenfeld and Henry (2001) studied the use of activated carbon and wood ash to neutralize odors produced from wastewater, compost, and biosolids including dimethyl-disulfide, dimethyl-sulfide, carbon disulfide, ammonia, trimethyl-amine, acetone, and methyl-ethyl-ketone. While the activated carbon had 87% carbon, they demonstrated that increasing carbon concentrations and surface areas of wood ash (as a co-composting material) increased the odor absorbing capacity. Wood ash with about 30% carbon possessed characteristics similar to activated carbon and was able to absorb compost odors effectively. A properly covered compost pile that is biodegrading carcasses under aerobic conditions should generate little or no odor.

Carcass composting microorganisms

The microorganisms necessary for carcass composting are often present naturally in the raw materials. According to Rynk (1992), Morris et al. (1997), and Langston et al. (2002), composting is a biochemical conversion of materials and is mainly carried out by sufficient catalytic bacteria, enzymes, etc. within the mortalities to degrade them over time. Rynk (1992) observed that larger organisms such as worms and insects also play a minor role in composting at lower temperatures (near room temperature).

Due to the heterogeneity of microorganisms in similar compost piles, and even within different sections of a single pile, and due to continuously changing microbial activities, no one species or organism dominates. Due to this diversity and mixture of microorganisms, the composting process continues even when conditions vary from pile to pile, or time to time.

The mesophilic and thermophilic species of three types of microorganisms (bacteria, fungi, and actinomycetes) are active in carcass composting. Rynk (1992) indicated that bacteria are the most numerous of the three, and generally are faster decomposers than other microbes. Conversely, fungi are larger than bacteria and form a network of individual cells in strands or filaments. While they are more tolerant of low-moisture and low-pH conditions than bacteria, they are less tolerant of low-oxygen environments. Fungi are also better at decomposing woody substrates and other decay-resistant materials (Rynk, 1992). Rynk also stated that the actinomycetes are smaller and form filaments like fungi, but have a low tolerance for acidic conditions. They tend to become more pronounced after compounds are easily degraded and when moisture levels are low.

Different types of microorganisms are more active at different stages of composting. According to Rynk (1992), bacteria tend to flourish especially in the early stages of composting before the easily degraded materials are consumed. The fungi and actinomycetes become more important near the end of the composting process, feeding on the resistant materials that remain.

As a compost pile heats up, thermophilic organisms play a major role and the activity of mesophilic organisms is retarded, though they may continue to survive. If the temperature rises to about 70°C (160°F), nearly all active microorganisms die, leaving only the heat-resistant spores formed by certain species of bacteria and actinomycetes. As the pile cools again, spore-formers, thermophilic populations, and then mesophilic populations recover. Eventually the pile cools enough to be inhabited by common soil microorganisms, protozoa, worms, mites, insects, and other large organisms that feed upon microorganisms and organic matter.

In a commercial composting operation where speed and uniformity of end product are important, trained staff can carefully control the composting process. Langston et al. (2002) indicated that specific organisms and enzymes or inocula cultured for specific environmental conditions can enhance and speed up the composting process. The inocula are arbitrarily added to the materials to improve the efficiency of composting. Although most studies have shown that inocula are neither necessary nor advantageous to composting, Rynk (1992) suggested that they might be beneficial for materials lacking in large colonies of microorganisms (such as sterilized food wastes). In general, it is best to inoculate fresh material with active compost made from that same material.

Like other aerobically-respiring organisms, bacteria involved in carcass composting have certain needs. Murphy and Carr (1991) remarked that providing good supplement materials, along with suitable physical and chemical conditions, leads to high biological activities. Providing oxygen (in 25 to 30% free airspace), nutrients in necessary proportions and adequate amounts (for example, 15 to 35 parts carbon to 1 part nitrogen), water (about 45 to 55%), bulky materials (mass retains heat and maintains optimal thermal environments for respiration), and time (enough for the degradation process) are essential for the efficient activities of mesophilic and thermophilic bacteria. Compost microorganisms continue to react with the materials and stabilize the compost for extended periods when stored for six months or more. As previously noted, a compost pile will fail to heat up, or may become malodorous, if the moisture content exceeds a certain level. This is because saturated piles quickly exclude the needed oxygen, retarding the growth and activities of some aerobic microorganisms and forcing them to survive by adapting to anaerobic conditions.

3.2 – Carcass Composting Options

Important factors in converting carcasses to high-quality end products are selecting an appropriate composting system and employing appropriate management techniques for the system selected. Composting can be carried out in a variety of configurations, namely windrow, bin, or in-vessel systems. Mescher et al. (1997) explained that both windrow and bin composting systems work well in spite of differences in initial cost and management requirements. This section provides a discussion of various composting system options.

Regardless of composting configuration, the carcass compost pile represents an inconsistent mixture that consists of an animal mass with large amounts of water, high-nitrogen and low-carbon content, and low-porosity surrounded by a co-composting material of good-porosity, high-carbon, low-nitrogen, and moderate moisture levels. Mortality composting has two different stages, primary and secondary. Monnin (2000) indicated that the primary stage reduces the mortality so that only large bones remain, and the secondary stage allows complete decomposition of the mortality and stabilizes the compost.

Windrow composting

A windrow design allows the composting process to take place in a static pile. No walls or roofs are employed in this system, thus loading, unloading, and turning from all sides of the pile is possible. Usually windrows are built in open spaces and not protected from weather, rain, or wind, thereby exposing the pile to more adverse weather conditions which can affect the operation of the pile. Figures 1, 2, and 3 in Appendix C illustrate the general windrow cross section and layout, layers of poultry carcasses in cross sections of a windrow, an actual photo of a poultry compost pile, completed poultry mortality composting, and finally the layout of a carcass compost site with large round bales.

Keener et al. (2000) recommended that static piles be established on a concrete pad, or on a geotextile-lined gravel base with low-permeability soil to control water infiltration. In windrow systems, the length of the pile can be extended to accommodate the quantity of mortality to be composted. Windrow piles are mounded to shed rainfall for better control of moisture, temperature, gases, and odors, and to maintain adequate biofilter cover. The recommended height for a static system is 5-7 ft (1.5-2.1 m).

This technique is most popular for composting large carcasses or significant quantities of mortality. Carcasses, nutrients, and bulking agents are placed in specific orders and turned periodically, usually by mechanical equipment. Haug (1993) stated that the required oxygen is supplied primarily by natural ventilation resulting from the buoyancy of hot gasses in the windrow, and, to a lesser extent, by gas exchange during turning. Aeration is also achieved by moving and turning the pile. Mescher et al. (1997) reported that after the windrow pile is allowed to compost for a minimum of 90 days (first phase period) it is aerated by moving to a secondary area where it completes another 90-day period (second phase of composting). At that time, a new primary compost pile can be constructed in the area previously occupied by the turned pile. In this management system, piles are continually being built and moved onto the composting pad. The initial cost for a windrow-composting facility is reportedly less than that of a bin-composting facility; however, more intense management is required for a windrow system.

Bin composting

Bin composting refers to the simplest form of a contained composting method. In this system, carcasses and co-composting materials are confined within a structure built from any materials that is structurally adequate to confine the compost pile material (Fulhage, 1997; Mukhtar et al., 2003). Bin structures may or may not be covered by a roof. A simple and cheap bin system can be constructed of large round bales placed end-to-end to form three-sided enclosures or bins, allowing the pile to be protected from predators, pests, and runoff. These types of bins, which sometimes are called bale composters, are located in free space without any roof. They are more susceptible to precipitation and weather variation. Figures 4, 5, and 6 in Appendix C show the schematic layouts and actual views for such structures. Conversely, roofed composters have the advantages of reduced weather effects, less moisture and potential leaching from the pile, and better working conditions for the operator during inclement weather (Fulhage, 1997).

A smaller version of a bin composter is called a mini-composter. As Keener and Elwell (2000) specified, the size of carcasses that can be placed in these bins is usually limited to less than 40 lb (18 kg). In cold climates additional insulation may be needed to enable the mini-composter to reach the desired temperatures (> 55°C or 131°F) for pathogen destruction and effective degradation.

While the costs of establishing some types of bin composting systems are higher than those of windrow systems, bin composting has some advantages. According to Rynk (1992), the structure of bin composting allows higher stacking of materials, better use of floor space than free-standing piles, elimination of weather problems, containment of odors, and better temperature control.

A summary of processing practices and management procedures used in the first and second phases of bin composting is discussed below.

Primary phase

A base of litter (or litter-sawdust, litter-shavings mixture) with a thickness of 1.5-2 ft (45-60 cm) should be placed in a fresh bin about two days before adding carcasses to allow for preheating of the litter. Immediately prior to introducing carcasses, the surface of the pre-heated litter (about 6 in [15 cm]in depth) should be raked back and the carcasses should be placed in the hot litter. A minimum of 1 ft (30 cm) of litter should remain in the base of the compost pile for absorbing fluids and preventing leakage. Carcasses should not be placed within about 8-12 in (20-30 cm) of the sides, front, or rear of the compost bin to prevent heat loss. Carcasses should be completely covered and surrounded with the preheated litter.

Carcasses can be placed in the bin in layers, although a 1-ft (30-cm) thick layer of carbon source material is necessary between layers of carcasses to insulate and maintain compost temperature. As a final cover material, carcasses should be completely covered with approximately 2 ft (60 cm) of sawdust, or a minimum of 2.5 lb (1.1 kg) of moist litter per pound of carcass, to avoid exposed parts or odors that attract flies, vermin, or predators to the pile and to minimize fluids leaching out of the pile.

Secondary phase

After moving the pile to the secondary bin, it is covered with a minimum of 4 in (10 cm) of co-composting materials (such as straw and woodchips) to ensure that exposed carcass pieces are covered. This additional cover helps insulate the pile, reduce odor potential, and ensure decomposition of remaining carcass parts. Moisture is added to the materials (40-60% wet basis) to allow the pile to reheat and achieve an acceptable end product. An adequately composted finished product can be identified by a brown color (similar to humus) and an absence of unpleasant odor upon pile turning. Note that some identifiable carcass parts, such as pieces of skull, leg or pelvic bones, hoofs, or teeth may remain. However, these should be relatively small and brittle (or rubbery) and will rapidly disappear when exposed to nature.

Table 2 in Appendix C provides a typical schedule that can be used for bin composting various small and medium size carcasses.

In-vessel carcass composting

Although bin composting of small numbers or volumes of carcasses has proven to be a practical method with advantages that include simplicity, low maintenance, and relatively low capital costs, composting of large numbers or volumes of carcasses in this way is more difficult. Various means of composting in fully contained systems (vessels) have been evaluated and are briefly reviewed here.

Aerated synthetic tube

An in-vessel system of composting organics using aerated synthetic tubes called EcoPOD (Preferred Organic Digester) or Ag-Bags has been available commercially for the past 10 years (Ag-Bag Environmental, 2003). As shown in Appendix C, Figure 7, the system consists of a plastic tube about 5-10 ft (1.5-3 m) in diameter and up to 200 ft (60 m) long. These tubes are equipped with an air distribution system connected to a blower. Raw materials are loaded into the tube with a feed hopper. Tubes used for medium or large intact carcasses are opened at the seam prior to loading raw materials and then sealed for forced air distribution during composting.

Farrell (2002) used the Ag-Bag system and successfully composted bio-solids with grass clippings and chipped brush and wood. The woody materials were ground to a 3-in (7.5-cm) size before composting, and reground to 1.5 in (3.8 cm) after composting. The materials were composted in the bags for eight to ten weeks at temperatures reaching 70°C (160°F). Finished product can remain in the bags long after composting is complete. In 2002, Ag-Bag Environmental (2003) in cooperation with the USDA Animal and Plant Health Inspection Service (APHIS) composted over 100,000 birds infected with avian flu virus depopulated from poultry houses in West Virginia. According to their reports, the composting process was completely aerobic and acceptable to USDA-APHIS.

Cawthon (1998) used this forced-air, in-vessel system for composting poultry mortalities. A mixture of hay and poultry carcasses at moisture contents of 30-35% was combined with poultry litter as a co-composting material. Temperatures inside the tube ranged from 70 to 82°C (160 to 180°F) after 5 to 7 days of composting. The high temperature of 82°C (180°F) was attributed to litter dust in the co-composting materials. This system was also used by Cawthon and Beran (1998) to compost dairy manure. Temperatures in the tube at different locations ranged from 60 to 70°C (140 to 160°F) after one week of composting. In both cases, some spoilage of ingredients and rotting parts of the carcasses were observed in the finished products. Figure 7 in Appendix C shows the poultry carcasses and carcass parts being added to the aerated synthetic tube (Ag-Bag). Experiments by Haywood (2003) demonstrated difficulties in composting medium to large size carcasses in the aerated synthetic tube system; end products were observed to have disintegrated into solid and liquid portions with visibly rotten carcasses remaining. These results were attributed to anaerobic conditions within the tube arising from non-uniform air distribution caused by inconsistent (non-homogeneous) mixing of materials prior to loading into the tube.

The aerated synthetic tube system offers several advantages, including a reduction in composting time, a reduction in the land area required, elimination of odors and leachate production, and a reduced potential for negative impacts by inclement weather. However, the system is not practical for composting larger carcasses (e.g., swine and cattle) unless they are ground and thoroughly mixed with an appropriate quantity of bulking agent to provide more than 30% porosity (Cawthon, 1998). While this aerated synthetic tube system currently has potential for composting small or ground carcasses, further research is needed to address issues of air distribution, porosity, uniform packing, and exhausting of accumulated gases to prevent incomplete and anaerobic digestion.

Other vessel systems

Using a vessel for the first phase of carcass composting is another approach to minimizing the time and management requirements. Although the application of vessel and rotary vessel composting for carcasses has not been practiced extensively, using this system for composting other similar products provides an indication of its practicality. Cekmecelioglu et al. (2003) evaluated a system for composting a mixture containing food waste, manure, and bulking agent in a stationary polypropylene vessel for 12 days with aeration based on a 1/40 minute (1.5 sec) on/off operation cycle and compared its performance and final product with a conventional windrow composting system. They obtained the highest temperature rise of 50°C (122°F) for vessel composting and reported that the best recipe for mixing food waste, manure, and bulking agent respectively was 50%, 40%, and 10% w/w. They observed similar inactivation trends for fecal coliforms and pathogenic microorganisms in both in-vessel and windrow composting systems. While further research is needed to determine the applicability of this system, these results indicate that in-vessel composting may be a good option for carcass composting.

Pre-processing (grinding) of carcasses

One factor being evaluated is preprocessing (e.g., grinding) of carcasses; this pre-processing step can be used in combination with almost any composting configuration. Any process that minimizes composting time will result in a more efficient operation that is easier to manage. In this respect, grinding of cow carcasses and mixing with carbon source materials prior to composting has been practiced by some. Kube (2002) mixed ground Holstein steers (approximately 450 kg or 1000 lb) with sawdust and composted in a windrow system. At the same time, he composted intact Holstein carcasses in a windrow system. The grinding process decreased the time required to compost cow carcasses from twelve months to six months, in spite of the fact that only one turning process was employed rather than the standard three. In fact, combining grinding and turning processes condensed the composting time considerably.

Recently Rynk (2003) evaluated ground carcasses mixed with co-composting material in a system in which the primary composting phase was carried out in a rotating vessel or drum followed by windrow composting. Results indicated that turning the mixture every 15 days reduced the composting time to 75 days. Although this system may require more capital investment, overall it is less expensive than conventional bin or windrow composting. When adequate grinding capacity is available, this system has the potential to speed up carcass composting and facilitate high capacity. According to Rynk (2003), this method has the following advantages:

- Diminishes the composting time and thus management cost.
- Reduces the co-composting materials up to one-fourth of the conventional system.
- Decreases the risk of odor production and risk of scavengers
- Allows better control over key composting parameters such as temperature pattern, pH, particle size, and color.
- Produces a more uniform product.

The Colorado Governor's Office of Energy Management and Conservation (CGOEMC, 2003) used a vertical dairy-type grinder-mixer (up to 500 revolutions per minute) for preparation and mixing of mortalities and bulking agent prior to composting. Because the grinder produced material with a much larger surface area exposed to oxygen, compost bacteria could attack and decompose the materials much easier. By using this grinding step, the weight ratio of bulking agent to carcasses was reduced from 4:1 (for typical bin composting) to 1:4. Compared to bin composting, the composting time was also decreased by 30 to 60%, resulting in reduced management, labor, and overall cost.

A key advantage of grinding is the possibility of directly cutting and mixing carcass material with proper amounts of various bulking agents such as straw, grass, weeds, non-woody yard waste, sawdust, wood shavings, old alfalfa, and woody materials (tree branches, processed wood, etc). Additionally, homogenizing and adjusting the moisture content to 60 to 70% is much easier than conventional bin or windrow carcass composting.

3.3 – Compost Design and Layout

The concept of design in carcass composting is to have suitable capacity and even flow of input and output materials while maintaining quality. Fulhage (1997) indicated that a composting system must be designed so that it can be filled and emptied on a schedule as needed to "keep up" with the flow of carcasses. However, undersized or oversized capacities (due to improper design) may cause anaerobic fermentation, insufficient thermophilic activities, inadequate temperature rise, incomplete destruction of pathogenic bacteria, production of unpleasant gases and odors, and may introduce some environmental contamination. In this section the issues of design parameters, layout, and construction features of bin and windrow composting systems are discussed.

Design parameters

Choosing the right design parameters for an effective composting facility is important for a successful operation. Researchers such as Dougherty (1999), Keener and Elwell (2000), Morse (2001), Langston et al. (2002), McGahan (2002), and Tablante et al. (2002) considered the following design principles for bin and windrow carcass composting systems:

- Two composting phases, namely primary and secondary.
- Storage of end products for recycling and flexibility in land application. The storage volume must be greater than or equal to the secondary bin size since it must hold all material emptied from a secondary bin.
- Daily mortality rate and composting time, which determines total loading for the primary phase.

Based on the original weight of carcasses, the weight of co-composting materials, and the daily weight loss of the compost, mathematical models have been developed for predicting the time, volume, and/or capacity of primary, secondary, and storage phases of composting systems. According to the CGOEMC (2003) manual, under standard conditions, for every 10 lbs (4.5 kg) of mortality, there is a need for about 4.25 L (1.5 ft^3) of combined bin capacity for the primary phase of composting (Rynk, 2003).

Murphy and Carr (1991) stated that the capacity of bin systems for composting poultry depends on theoretical farm live weight. They presented the following formula as a model for estimating the peak capacity of dead poultry for the first phase of composting, which was based on the market age and weight of birds (Example 1 in Appendix D shows how these formulae can be applied in different poultry and broilers operations):

Daily composting capacity = Theoretical farm live weight /400 (1)

Theoretical farm live weight = Farm capacity x market weight (2)

Morris et al. (1997) used the bulk density of composting materials to estimate the needed primary and secondary bin areas for mortality composting using the following equations (Example 2 in Appendix D shows how equations (3) and (4) can be applied):

$$A_1 = n.\ W / h.\ d_1 \quad (3)$$

$$A_2 = n.\ W / h.\ d_2 \quad (4)$$

Where: A_1 and A_2 are, respectively, the needed areas for the primary and secondary bins, W is the average weight in kg of each carcass to be disposed, n is the number of carcasses per year, h is the height of the bins, d_1 and d_2 are, respectively, the bulk densities of composting material at the beginning of first and second phase of composting (respectively, about 600 and 900 kg/m^3).

Keener and Elwell (2000) developed models based on the results of experiments for a bin system for poultry (broilers), a windrow system for swine (finishing), and a windrow system for cattle (mature). They assigned a specific volume coefficient of 0.0125 m^3/kg mortality/growth cycle (0.20 ft^3/lb mortality/growth cycle) for calculating primary, secondary, and storage volumes (V1, V2, and V3, respectively). As discussed earlier, the composting times of primary, secondary, and storage phases (T1, T2, and T3, respectively) are affected by various factors in the composting pile and are not equal to each other. Based on the above-mentioned information, they suggested the following models for calculating composting time and volume needed for primary, secondary and storage phases:

$$T_1 = (7.42)\ (W_1)^{0.5} \geq 10,\ \text{days} \quad (5)$$

$$V_1 \geq (0.0125)\ (ADL)\ (T_1),\ m^3 \quad (6)$$

$$T2 = (1/3)\ (T1) \geq 10,\ \text{days} \quad (7)$$

$$V2 \geq (0.0125)\ (ADL)\ (T2),\ m3 \quad (8)$$

$$T3 \geq 30,\ \text{days} \quad (9)$$

$$V3 \geq V2 \quad \text{or}$$

$$V3 \geq (0.0125)\ (ADL)\ T3),\ m3 \quad (10)$$

Where: W_1 is the average weight of mortality in kg, and ADL is an average daily loss or rate of mortality in kg/day. The Ohio State University Extension service (OSUE) in 2000 prepared data in regard to poultry, swine, cattle/horses and sheep/goats mortality rates and design weights, which are shown in Tables 1a and 1b of Appendix D. This will determine the mortality produced from operations in kg (lbs)/year, and the average daily-loss for composting in kg (lbs)/day. For using equations (5) to (10), Keener and Elwell (2000) considered the following items:

- The first parameter required for calculation of compost volume and capacity is annual livestock death loss. The worksheet of Table 2 in Appendix D shows how to calculate this important parameter.
- In estimating composting time, the primary and secondary composting times for heavy animals (exceeding 500 lb [227 kg]) were assumed as a ceiling time.
- Equations (6), (8), and (10) provide reasonable values of V1, V2, and V3 for composting small weight carcasses (less than 50 lb [23 kg], such as poultry) and medium weight animals (50 to 250 lbs [23 to 114 kg], such as swine) in bin and windrow systems.
- Table 3 in Appendix D represents the worksheet for calculating primary, secondary, and storage bin volumes, as well as the relation between bin volume, width, and length.
- For composting a large mass of carcasses (more than 250 lb [114 kg]) or very large carcasses (those exceeding 500 lb [227 kg]), a windrow system is recommended because individual primary bins would be large and the placement of animals would be difficult. For mature cattle or horses, a separate pile for individual mortalities is recommended. In these cases it is necessary to use the modified equations described in Table 4 of Appendix D.
- A value of 10 days was used as a minimum for poultry composting work. Since a secondary bin must hold all material emptied from a primary bin, it should be greater than or equal to the primary bin size. The secondary bin sometimes handles volumes up to three times that of the primary bin.
- Storage of the finished compost product is a key factor for having a uniform carcass composting process, and the storage volume should provide enough capacity for a minimum of 30 days. The main reasons were (1) land application of the finished compost may not be feasible at the time of removal from the secondary stage and (2) the finished compost could often be used in the primary stage if limited to less than one-half of the amendment.
- Sometimes an additional bin with dimensions equal to that of the primary bin is used to hold raw materials without initiation of the composting process and is called a waiting or preparation bin. Usually after a preparation process that may take a few days (because of insufficient raw materials), the bin becomes a primary bin of composting.

Based on these data and the prescribed equations, Keener and Elwell (2000) analyzed systems for a 10,000-bird broiler operation, a 2,940-head swine finishing operation, and a 154-cow herd. Results are shown in Tables 5-a, 5-b, and 5-c of Appendix D. Example 3 of Appendix D demonstrates the use of these data for calculating the time and volume for different stages of carcass composting.

Layout and construction features

As discussed earlier, layout and construction features are the two key points in successful carcass composting. Additional information about this matter for both windrow and bin composting systems is provided here.

Windrow composting

Although different cross-section designs for windrow systems have been used in organic composting, they have had limited applications in carcass composting. Recently, some researchers used ground carcasses as a uniform and consistent raw material for windrow composting and observed that, because of the higher rate of decomposition, the turning and mixing processes could be carried out in a manner very similar to that of an organic composting pile. Haug (1993) reported that in a modern windrow process, composted organic materials are turned at regular intervals by specialized mobile equipment that produce cross sections of various shapes (haystack, rectangular, trapezoidal, triangular, etc.) depending largely on characteristics of the composting material and the equipment used for turning. Figure 1 in Appendix D shows the typical cross section (high parabolic, low parabolic, trapezoidal, and triangular) and layout of different forms of windrow composting. Cross sections that push the water are useful in humid climates, and those that keep the water in the top of the piles are useful in dry climates. Mescher et al. (1997) proposed a trapezoidal windrow for primary and secondary carcass composting, and indicated that the side slopes of a windrow in most cases were 1:1 (α=45°). Figure 2 in Appendix D shows the trapezoidal cross-section used for windrow composting of swine mortality along with its pad layout.

The most appropriate location for a windrow is the highest point on the identified site. A plastic liner (0.24 in [0.6 cm] thick) of length and width adequate to cover the base dimensions of the windrow (see below) should be placed on crushed and compacted rock as a moisture barrier, particularly if the water table is high or the site drains poorly. The liner should then be completely covered with a base of co-composting material (such as wood chips, sawdust, dry loose litter, straw, etc). The co-composting material layer should have a thickness of 1 ft for small carcasses, 1.5 ft for medium carcasses, and 2 ft for large and very large carcasses. A layer of highly porous, pack-resistant bulking material (such as litter) should then be placed on top of the co-composing material to absorb moisture from the carcasses and to maintain adequate porosity. The thickness of the bulking material should be 0.5 ft for small carcasses, and 1 ft for all others.

An evenly spaced layer of mortalities should then be placed directly on the bulking material layer. In the case of small and medium carcasses, mortalities can be covered with a layer of co-composting materials (thickness of 1 ft [30 cm]), and a second layer of evenly spaced mortalities can be placed on top of the co-composting material. This layering process can be repeated until the windrow reaches a height of approximately 6 ft (1.8 m). Mortalities should not be stacked on top of one another without an appropriate layer of co-composting materials in between. For large and very large carcasses, only a single layer of mortality should be placed in the windrow. After placing mortalities (or the final layer of mortalities in the case of small and medium carcasses) on the pile, the entire windrow should be covered with a 1-ft (30-cm) thick layer of biofilter material (such as carbon sources and/or bulking agents). See Figures 1, 2, and 3 in Appendix A.

Using this construction procedure, the dimensions of completed windrows will be as follows for the various categories of mortality (note that windrow length would be that which is adequate to accommodate the number of carcasses to be composted):

- Small carcasses: bottom width, 12 ft (3.6 m); top width, 5 ft (1.5 m); and height 6 ft (1.8 m)
- Medium carcasses: bottom width, 13 ft (3.9 m); top width, 1 ft (0.3 m); and height 6 ft (1.8 m)
- Large and very large carcasses: bottom width, 15 ft (4.5 m); top width, 1 ft (0.3 m); and height, 7 ft (2.1 m)

Bin composting

For bin composting, a wide range of structures is possible, including new or existing facilities. Morse (2001) suggested new facilities, such as poured concrete, pole construction, and hoop houses, and for low cost options existing facilities such as machine sheds, corn cribs, or cattle sheds (as long as their ceiling is high enough to allow the front-end or skid loader to lift and turn the compost) have all been used for bin composting in Minnesota.

Fulhage (1997) recommended using bins enclosed on three sides with an opening wide enough for a front-end loader. One of the methods to increase the efficiency of bin composting is modularity, or making compartments in the construction of needed bins. In this respect, Murphy and Carr (1991) suggested the basic unit of carcass composting which includes a dead-bird composter and two multi-compartmentalized features of the bin system. Schematic diagrams of these bin composters are provided as Figures 3, 4, and 5 in Appendix D. Figure 6 in Appendix D shows the overall top and isometric views of a bin layout. According to Glanville (2001), a research unit was built in Iowa that consisted of six composting bins (three primary and three secondary bins) and two storage bins for the woodchip cover material. They were 10 ft (3 m) wide by 12 ft (3.6 m) deep, and designed to be loaded to a depth of 5 ft (1.5 m). These bins were 24 ft x 40 ft post-frame, metal-clad structures with 2-ft overhangs.

Murphy and Carr (1991), Mescher et al. (1997), Glanville (1999), and Langston et al. (2002) provided important guidelines for construction of bins. Bin composters can be constructed of any material structurally adequate to confine the compost pile material (such as concrete, wood, hay, bales etc). Simple and economical bin structures can be created using large round bales placed end-to-end to form three-sided enclosures or bins (sometimes called bale composters). A mini-composter can be constructed by fastening panels with metal hooks to form a box open at the top and at the bottom. Structures should be located and situated so as to protect the pile from predators, pests, and runoff. Bins may or may not be covered by a roof. A roof is advantageous, especially in high rainfall areas (more than 1,000 mm or 40 in annual average), as it results in reduced potential for leaching from the pile and better working conditions for the operator during inclement weather.

An impervious concrete floor (5 in [12.5 cm] thick) with a weight-bearing foundation is recommended to accommodate heavy machinery, allow for all-weather use, and prevent contamination of soil and surrounding areas. If an entire bin is constructed of concrete, bin walls of 6-in (15-cm) thickness are recommended. Walls and panels can also be constructed with pressure-treated lumber (e.g., 1-in treated plywood backed with 2 x 6 studs). To improve wet weather operation, access to primary and secondary bins can be paved with concrete or compacted crushed rock.

The wall height for primary and secondary bins should be 5-6 ft (1.5-1.8 m), and the bin width should be adequate for the material-handling equipment, but generally should not exceed 8 ft (2.4 m). The minimum front dimension should be 2 ft (61 cm) greater than the loading bucket width. The front of the bin should be designed such that carcasses need not be lifted over a 5-ft (1.5-m) high door. This can be accomplished with removable drop-boards that slide into a vertical channel at each end of the bin, or with hinged doors that split horizontally. Hinged doors should be designed to swing back flat against adjoining bins, and removable hinge-pins at both ends should permit the door to swing open from either end. As an alternative to building individual secondary bins, a large area to accommodate materials from more than one primary bin can be used.

3.4 – Raw Material, Energy, and Equipment Requirements

Since carcasses by themselves are not suitable substrates for making a good compost product, it is necessary to combine carcasses with supplementary co-composting materials and provide suitable environmental conditions to initiate the necessary biological, chemical, and physical changes. Additionally, in the event of significant quantities of mortality, equipment for moving, lifting, loading, unloading, dumping, displacement, and pile formation is critical. This section summarizes essential inputs and requirements for an efficient carcass composting process.

Co-composting materials and recipes

Co-composting materials, which serve as a source of moisture and carbon, included at an appropriate ratio are needed for a successful compost process. This section outlines the specifications of co-composting materials and typical “recipes” for use.

Moisture

Water in the compost process has an important role in providing nutrients to the beneficial microorganisms thereby facilitating production of required enzymes. The enzymes produced by the bacteria are responsible for most of the biochemical transformations and, in fact, break down large organic molecules. According to Murphy and Carr (1991), Keener et al. (2000), and Franco (2002), the required moisture content for carcass compost piles depends on the character of the material, but should generally be between 50 and 60% (wet basis). This means that in dry regions and in covered facilities, water must be added to maintain the biochemical reactions. Excess water should be avoided as it has the potential to generate odor and leaching conditions. Murphy and Carr (1991) reported that excessively wet carcass compost piles fail to heat up and become malodorous. Furthermore, saturated piles quickly become anaerobic and exclude needed oxygen. Looper (2002) reported that moisture content of greater than 60% will generate odors and increase the chance of runoff (leachate) from the compost pile. However, turning the compost and adding more dry materials will solve the problem.

Looper (2002) and other researchers suggested a general rule: if the compost mixture feels moist, without water dripping from a handful when squeezed, the moisture is adequate. Water consumption for carcass composting is based on the dryness of co-composting materials. For example, if sawdust is dry, water should be added to obtain a damp feel and appearance. Up to 1-1.5 gal/ft^3 (135-200 L/m^3) of water can be added to each unit volume of sawdust (Fulhage, 1997).

Carbon sources

Achieving a proper ratio of carbon to nitrogen is key to the necessary bacterial processes. A carbon source (co-composting material) is used to cover carcasses and provides a suitable physical, chemical, and biological environment for composting. According to Rynk (1992), Haug (1993), and Sander et al. (2002), carbon sources have properties that enhance the composting process by absorbing excess moisture from carcasses, equilibrating moisture content throughout the whole mass, reducing bulk-density, maintaining higher porosity, increasing air-voids thereby aiding diffusion of oxygen into the pile, allowing proper aeration, speeding the escape of potentially toxic gases like ammonia, reducing the accessibility of composted material to insects and rodents, and increasing the quantity of biodegradable organics in the mixture (and thereby the energy content of the mixture).

Organic materials provide adequate carbon for microbial—specifically fungal—activities, resulting in some scientists like Haug (1993) referring to these materials as "energy or fuel providers." In addition to providing adequate carbon, their physical and chemical composition effectively traps odors and gases released by the carcass composting process. For example, sawdust is an ideal carbon source because of its small particle size, high carbon-content, and ability to absorb moisture or potential leachate generated during composting (Fulhage, 1997). It is also easy to handle. Some researchers like Keener and Elwell (2000) have shown that mixtures of sawdust and straw could be used outside or in covered piles. In roofed piles, straight straw or corn stover can be used alone, but requires periodic water addition during composting to prevent inhibition of the process. Although corn stover does not have all the properties of sawdust, it does have a high C:N ratio, is a good absorbent, and helps facilitate uniform aeration in a compost pile. Looper (2002) indicated that a base material for carcass composting can be created from separated manure solids mixed in a 50:50 ratio with a carbon source. Table 1 in Appendix E shows the C:N ratio of different supplemental materials.

Haug (1993) and Sander et al. (2002) emphasized use of an amendment that is dry, has a low bulk weight, and is relatively degradable. In addition to sawdust and corn stover, many other carbon sources could be used, including poultry litter, ground corncobs, baled corn stalks, and semi dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, refuse fractions, yard wastes, vermiculite, and a variety of waste materials like matured compost. Recently, Mukhtar et al. (2003) used spent horse bedding (a mixture of horse manure and pinewood shavings) for composting cow and horse carcasses and obtained successful results.

Bulking agents. Bulking agents or amendments also provide some nutrients for composting. They usually have bigger particle sizes and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials. Haug (1993) suggested that bulking agents should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contact. That is, in order to achieve high porosity and void volumes in the co-composting materials, the particles should have three visible dimensions rather than being flat (having only two noticeable dimensions). Haug (1993) reported that sludge cake could be viewed as occupying part of the void volume between particles and, because of having organic content, it increases the energy of the compost mixture as a secondary benefit. Although wood chips (2.5-5 cm [1-2 inch]), refused pellets, shredded tires, peanut shells, and tree trimmings have been used commonly as bulking agents for organic composting, they have not been used in carcass composting. Hay and straw will also work well as bulking agents. Morse (2001) reported that drier hay or hay with more grass will have more carbon (higher C:N ratio) than greener hay or hay with more legumes (lower C:N ratio). Crop residues such as wheat straw or corn stalks can be used as co-composting materials for carcass composting but may require shredding or some other form of particle size reduction. In choosing a bulking agent, two important factors include availability and cost.

The ratio of bulking agent to carcasses should result in a bulk density of final compost mixture that does not exceed 600 kg/m^3 (37.5 lb/ft^3). As a general rule, the weight of compost mixture in a 19 L (5 gal) bucket should not be more than 11.4 kg (25 lb); otherwise, the compost mixture will be too compact and lack adequate airspace.

Biofilters. A biofilter is a layer of carbon source and/or bulking agent material that 1) enhances microbial activity by maintaining proper conditions of moisture, pH, nutrients, and temperature, and 2) deodorizes the gases released at ground level from the compost piles, and 3) prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Composting recipes

Producing a good end product without any offensive environmental aspects depends heavily on achieving an adequate balance of composting materials; a proper C:N ratio is key. Murphy and Carr (1991), Glanville and Trampel (1997), Keener and Elwell (2000), Franco (2002), and Bagley (2002) explained that a proper C:N ratio generates adequate energy and produces little odor during the composting process. Acceptable C:N ratios generally range from 25:1 to 40:1, and may even reach as high as 50:1. Reduction of the C:N ratio during the composting process is a good indication of digestion of carbon sources by microorganisms and production of CO_2 along with heat energy. Mukhtar et al. (2003) composted cow (2,000 lb [909 kg]) and horse (1,100 lb [500 kg]) carcasses using spent horse bedding as a co-composting material. They reported that the initial C:N ratio of 42:1-46:1 was reduced to nearly one-half of the original after nine months of composting in both small and large piles. This was mainly due to the reduced carbon and increased nitrogen contents for both piles. Fulhage (1997) obtained good results by adding 100 ft^3 (2.8 m^3) of sawdust per 1,000 lb (454 kg) of carcasses in a compost bin, and reported that good results could be achieved by amending the mixture with ammonium nitrate to increase the available nitrogen for the process. Werry (1999) observed sawdust to be one of the best mediums to mix with mortalities, and recommended 1 kg (2.2 lb) of sawdust per 1 kg (2.2 lb) of mortalities in a static-pile or windrow. Sussman (1982) suggested an appropriate recipe for converting nitrogenous materials (for example, manure and birds) and carboniferous materials (for example, cellulose paper, straw-stover, and sawdust). The detail of his experiment using poultry and straw as a carbon source has been provided in Table 2, Appendix E.

Dougherty (1999) outlined optimum values of various effective parameters, such as C:N ratio, moisture content, oxygen concentration, particle size, porosity, bulk density, pH, and temperature, of an active compost pile. More information about carbon and nitrogen sources is provided in Tables 3 and 4 in Appendix E, which show typical formulae for a suitable and successful compost process.

Since finished compost retains nearly one-half of the original carbon source content, Fulhage (1997) suggested using finished compost as a carbon source for initial composting. Recycling heat and bacteria in the compost process, minimizing the needed amount of fresh raw materials, and reducing the amount of finished compost to be handled are the main advantages of this procedure. Langston et al. (2002) reported that blending broiler litter and swine carcasses with high-carbon, low-nitrogen materials such as wheat straw and sawdust increased the low C:N ratios from 15:1 to 25 or 30:1 and improved porosity and aeration of the composting process. They reported that wheat straw has been the favored carbon amendment for poultry carcass composting because it has a C:N ratio that may be as high as 150 and is a good absorbent. They suggested that although wood shavings have C:N ratios around 500:1, they are not as absorbent as straw. Additionally, adding sawdust to poultry litter increases the carbon content without substantially increasing the nitrogen content of the compost. They recommended blending sawdust uniformly with the litter and using 2-2.5 lb (0.90-1.13 kg) of this mixture to 1 lb (0.45 kg) of swine carcasses (weight ratio of 2-2.5:1 for co-composting materials to mortality). Carr et al. (1998) suggested ratios of 20:1 to 35:1 for C:N, and 100:1 to 150:1 for carbon-to-phosphorus ratios, for desirable carcass composting.

Heat-energy

The activity of microorganisms inside the compost pile generates heat and causes a controlled or limited combustion. The heat-energy used for chemical reactions has a strong relation with the thermodynamics of the composting process. Since all chemical reactions have a standard free-energy change, Haug (1993) indicated that the free energy is extremely useful because most enzymatic processes occur under such conditions, and the spontaneous chemical reactions proceed in the direction of decreasing free energy. In other words, the available useful free energy is related directly to the feed substrate used by a microbial population. If the free energy change is zero, the reaction is at equilibrium and no substrate is utilized by microorganisms. Haug (1993) reported that if a substrate or mixture of substrates does not contain sufficient energy to drive the composting process, further conditioning for controlling the water at certain levels (either by limiting the drying process, reducing the substrate water content by improved dewatering, or adding supplemental energy amendments) is required to control the energy balance. According to Dougherty (1999), the ability to heat the compost pile and sustain high temperature is affected by the six following factors:

- Chemical, physical, and biological composition of the compost materials,
- Accessibility of nutrients, including carbon, to the composting microorganisms,
- Moisture contents in the source ingredients,
- Aeration rate in the compost pile,
- Structure of the compost pile (particle size, bulk density, and texture),
- Total size and surrounding environment (temperature, humidity, wind, etc.) of compost pile.

Maintaining necessary free-heat energy is critical in terms of the time-and-temperature relationship, which is in turn important in the inactivation of microbes. Proper sizing of composting facilities has considerable influence on heat retention during composting and becomes an important consideration in cold climates in which substantial heat loss can take place at the perimeter of the composting bin (Glanville & Trampel, 1997). Within the temperature range desirable for composting (45 to 65°C), bacterial activity roughly doubles with each 10°C-increase (18°F-increase) in temperature. Glanville and Trampel (1997) indicated that a small composting operation with a low volume (corresponding to a low heat-generating capacity) and high surface area (corresponding to a high potential for heat loss) could be significantly impaired by low temperatures. They studied a poultry carcass process conducted in outdoor bins during the winter with external temperatures ranging from −15 to 0°C (5 to 32°F). They observed that temperatures measured at locations less than 15 cm (0.5 ft) from bin walls were often 25 to 30°C (45 to 54°F) cooler than the temperature near the center of the bin. As the composting bins used in this work were relatively large (2.4 m long x 1.8 m wide x 1.5 m high), composting was not seriously hampered because the cool zone near the walls did not comprise a large portion of the total volume. Looper (2002) suggested that any compost pile requires a layer of inactive material approximately 30 cm (1 ft) thick to insulate and maintain its high temperature.

Equipment and devices

Carcass composting is becoming more widely used and animal producers are expanding their composting management strategies to use the best available and most economically feasible machinery for ease of operation and for avoiding any direct contact with raw materials. According to Dougherty (1999), over 8,000 farms are now composting animal mortalities, manure, crop residues, and selected organic materials from communities and industries. At least 75% of farm composting operations are composting poultry mortalities. Operations use various types of agricultural machinery and equipment for windrow and bin composting. The types of equipment, instruments, and machinery needed for different size carcass composting operations are discussed in this section.

Grinders and crushers

The composting process may be facilitated by the use of various pre- and post-composting practices. As discussed previously, composting time can be reduced by grinding carcasses and mixing with co-composting materials; this practice requires equipment such as crushers, mixers, mills, screeners, manure or compost spreaders, and sprinklers.

The initial experiments of grinding animal mortalities carried out by Kube (2002) and Rynk (2003) demonstrated several advantages. This process produces a relatively homogenous and uniform mixture of raw materials that can be composted in bins, vessels, or windrows. According to Rynk (2003), the basic design of the grinder-mixer has been modified and presently includes more knives on the auger, stationary knives mounted on the tub, and a different auger to adjust to the conditions of grinding and mixing large carcasses. In this system, the grinder-mixer is loaded with the appropriate amount (about 20% of the weight of the mortalities) of bulking agent such as wheat straw and corn stalks. Grinding and initial mixing of carcasses with co-composting materials should proceed for about 15-45 min (depending on the nature of materials and particle sizes), to achieve an optimum particle size for proper aeration of 1/8 to 1/2 inch (3.1 to 12.7 mm) (Looper, 2002).

The most common crushing machinery, which can be used for reducing the particle sizes of supplement materials, specifically carbon sources, includes shear shredders, handfed chippers (disc type), rotary augers with counter knives, and woodchoppers.

Dougherty (1999) recommended considering the following items (in order of importance) while selecting a size-reducing device:

- Capital and operating costs (including power consumption),
- Appropriateness in relation to feedstock characteristics and desired product,
- Capacity and speed,
- Safety,
- Compatibility with existing equipment, and
- Maintenance requirement.

Mixers

It may be necessary to mix and homogenize the supplement or co-composting materials, especially if they have different size and shape characteristics. In a bin composting method, batch mixers (similar to mixers used by livestock feed producers) may be used for preparation of co-composting materials. According to Rynk (1992), several types of batch mixers have been used and tested for composting operations, including mixers with augers, rotating paddles, and slats on a continuous chain. He indicated that most batch mixers could be truck or wagon-mounted and, if equipped with sizable loading hoppers, could eliminate the need for dump trucks or wagons. For a windrow operation, fertilizer or manure spreaders (especially side-delivery, flail-type spreaders) can be used for mixing and formation.

The mixing operation should not be too long (perhaps only a few minutes); otherwise, the size of particles may become very small, and free airspace created by the bulking agent may become filled with the wetter feedstock (like manure or water) which decreases porosity. Rynk (1992) recommended using a crusher for big pieces and placing drier bulking agents or amendments into the batch mixer first, and then adding denser and wetter materials on top. The most common mixers used in composting processes are auger-type batch mixers, reel-type batch mixers, and rotating drum mixers.

Mixing of ground carcasses with granules of carbon source can take place in a rotating drum. Rynk (2003) suggested using a rotating drum 3 m (10 ft) in diameter and 15 m (50 ft) long for complete mixing as well as to complete the first phase of the composting process. The rotating process keeps odors of mixed materials inside while it accelerates the decomposition process to the point where the material leaving the drum is unlikely to produce odors or attract pests.

Mills

In addition to the batch mixer, some of the most common milling equipment used for the composting process includes tub grinders, hammer mills, continuous mix pug mills, and vertical grinders. Rynk (1992) recommended using stationary pug mills (a machine in which materials are mixed, blended, or kneaded into a desired consistency) and rotating drum mixers for organic composting. Although this equipment has not been recommended for mixing co-composting materials, it may be necessary to use it for high-capacity mixing in carcass composting. Included below are properties of this mixing equipment.

Stationary pug mills. These devices work slowly using counter-rotating paddles or hammers to blend materials and provide a good mix on a continuous basis. The feedstock should be fed continuously in proper proportions. Although they are faster than batch-operated mixers, they lack the mobility provided by batch mixers.

Rotating drum mixers. Some of the larger rotating drums hold feedstock up to 90 cm (36 in). Residence times can vary from a few hours to several days, depending on the drum length, diameter, material depth, heat transfer coefficient of drum wall thickness, and rotation speed.

Compost spreader and screeners

A conventional, beater-type manure spreader, is recommended for hauling and spreading finished compost on fields. Presently, finished product is used directly for agricultural farm activities but not for horticultural activities. If the qualities of the carcass composting end product are to meet the USDA regulations similar to plant residue composted materials, the finished product may require refinement post-composting to meet regulatory and/or market requirements. In addition to size reduction or mixing, screening and removing foreign materials may also be required, and can be accomplished by either vibration and gravity forces, or vibration and suction forces (air-classification system).

The most common screeners, which may be used for separation of big particles from the finished compost product, include disc screens, flexible oscillating (shaker) screens, belt screens, trammel screens, and vibrating screens (Dougherty, 1999). Table 5 and Figure 1 in Appendix E show the capacity and horsepower ranges as well as schematic views of selected screening equipment. According to Rynk (2003), a trommel screen with perforations of less than 2.5 cm (1 in) is recommended for removing any remaining bones from the finished compost product. Larger material remaining on the screen (primarily bones) is recycled back into active piles.

Loaders

Different types of moving machinery, including bucket loaders, skid loaders, and dump trucks have been used for loading and unloading processes. According to Fulhage (1997), skid-steer or front-end loaders can be used for conveying carcasses to the composter; placing carcasses on the compost pile; lifting, mixing and pile/windrow formation; covering carcasses with fresh sawdust or finished compost; moving compost from one bin to another as needed for aeration and mixing; receiving, storing, and piling sawdust prepared by sawmills; and loading finished compost for field spreading.

Loaders, especially front-end loaders, require less labor and cost less than mixing equipment. Although loaders are not mixing equipment, they can be used to repeatedly bucket the co-compost materials to achieve mixing prior to the composting process. Additionally, loaders can also be used for handling materials needed for construction of walls and pads in bin composting. Dump trucks, wagons, and sometimes bucket loaders can be used to transport mixed ingredients to the site and to build the initial pile or windrow if the composting site is far from the mixing area.

Windrow turners

After carcass pile formation, under proper conditions there is no need for mechanical disturbance processes until the pile is ready for the second composting stage. In the bin system, an adjustable loader can be used to move materials from primary to secondary bins and can achieve optimum aeration. In static pile and windrow composting systems, windrow turning machinery will be used for the required mixing and aeration.

Windrow turning is traditionally and conventionally associated with composting. Haug (1993) and Diaz et al. (1993) defined the term "turned" or "turning" as a method used for aeration, tearing down a pile, and reconstructing it. They indicate the first automatic turner used was in the mushroom industry in the 1950s. In succeeding years, other mechanical turners began to appear in increasing numbers and design variations. The efficiency of this process arises from uniform decomposition that results from exposing, at one time or another, all of the composting material to the particularly active interior zone of a pile. While windrow turning has many advantages, it may also reduce the particle size of the material. Diaz et al. (1993) explained that the turning process would accelerate the loss of water from the compost materials, if the moisture content were overly high.

Windrow dimensions should not be so large as to inhibit proper aeration and must conform to the capabilities of the turning equipment. If a specialized turner is to be used, a specific pile configuration may be required. According to Rynk (1992), materials are often unloaded directly into windrows by backing up to the end of the existing windrow and tilting the bed of the truck or wagon while slowly moving the vehicle forward. The speed and vehicle bed dimensions will determine the pile/windrow height. If necessary, a front-end loader can be used to reshape or enlarge the pile/windrow formed. He observed that high-speed turning machines such as windrow turners, if overused, could physically destroy the porosity and texture of a compost mix. Excessive turning, grinding, or shredding may pulverize materials and should be avoided. If particle sizes are too small, piled materials will pack together and impede air movement.

Some operations use bulldozers and bucket loaders for turning windrows. Diaz et al. (2002) stated the simplest equipment for tearing down and reforming a windrow are bulldozers and bucket loaders, which provide minimal aeration and the materials are compacted instead of being mixed and fluffed. He preferred using a bucket loader instead of a bulldozer due to less compaction and more flexibility. Due to cost considerations, the use of a bulldozer or bucket loader for turning continues to be a fairly widespread practice. If a bucket loader is used, it should be operated such that the bucket contents are discharged in a cascading manner rather than dropped as a single mass.

Manser and Keeling (1996) classified windrow turners into three groups: rotating-tiller turners, straddle turners, and side-cutting turners. The rotating-tiller turner is more common in carcass composting systems. Other specialists classified windrow turners on the basis of required motivation forces (whether they are self-propelled or must be towed). Other types of turners include the auger turner, the elevating face conveyor, and the rotary drum with flails.

Diaz et al. (2002) reported that self-propelled types are more expensive than towed types. However, the tow vehicle (tractor) can be used for other purposes between turnings. In addition to convenience, the self-propelled type requires much less space for maneuvering and, therefore, the windrows can be closer to each other. Turning capacity of the machines ranges from about 727 to as much as 2,727 metric tons/h (800 to 3,000 US tons/h) with the larger, self-propelled versions. Similarly, the dimensions and configuration of the windrows vary with type of machine (e.g., 9-12 ft in width and 4-10 ft in height [2.7-4 m in width and 1.2-3.0 m in height]).

The rotating-tiller (rototiller) has a small capacity and, because of its maneuverability, is one of the most suitable types for small operations. According to Diaz et al. (1993), it has the ability to tear down the pile and spread the composting material to form a 30-60 cm (12-24 in) layer and accomplish the turning process. The rototiller is then passed back through the layer.

A partial listing and costs of self-powered and PTO (power take off) driven windrow turning equipment are presented in Tables 6 and 7 in Appendix E. The aerator-composter (PTO-driven) can process from 180-1080 metric tons of compost material per hour (200-1200 US tons/hr). Brown Bear Corp. (2003) has introduced a revised model of its farm tractor composter. The PTO PA35C-10.5 unit is designed to be attached to the front of 100-160 HP farm tractors. Figure 2 in Appendix E shows its general view during the windrow turning operation. Table 8 and Figure 3 in Appendix E show the specifications of turning and screening equipment with approximate capacity and horsepower ranges.

Instruments and supplies

The instruments required for monitoring and controlling physical properties of a composting system include thermometers, oxygen measurement equipment, data acquisition devices or composting logs, pH meters, and moisture testers.

Thermometers. Experience has shown that monitoring temperature during carcass composting is a key management factor of the operation. Many scientists have recommended using a probe-type dial thermometer with a 90 cm (3 ft) stainless steel stem. It will enable the operator to monitor internal pile temperature and judge the progress of the composting process.

Oxygen measurement and controlling devices. As mentioned earlier, measurement and control of oxygen content is critical. Umwelt Elektronic GmbH and Co. (2003) designed a system called COMPO-Matic for measuring, controlling, and optimizing both oxygen and temperature during the composting process. This device has a special insertion probe which contains an oxygen-temperature sensor. In this system, oxygen content is automatically regulated via an integrated aeration control mechanism, and a database-system enables the parallel measurement and control of up to 16 oxygen and temperature measuring points.

Data acquisition device or composting log. A logbook is needed where data such as dates, weights of carcasses placed in the composter, temperature, amounts of bulking agent used, dates when compost is turned, and amounts of finished compost can be recorded.

3.5 – Quality and Use of Composting End Product

The overall goal of carcass composting is not only to dispose of fallen carcasses properly, but also to produce a pathogen-free end product to serve as a soil amender for agricultural activities. The quality and applicability of the compost end product are significantly influenced by the characteristics of the feed substrates, the design parameters of the primary and secondary phases, the amount of pre- and post-processing, and the operating conditions maintained within the system. In the process of carcass composting, quality indicators are focused more on the co-composting materials, its balance with the carcasses, covering uniformity, temperature, composting procedures, water content, porosity, aeration, composting system, and design.

Compost quality

The compost facility must be designed and operated appropriately to produce the desired product. A number of different criteria have been established to define the end product of composting. According to Haug (1993), these include physical and chemical criteria such as particle size distribution, texture, color, odor, moisture content, general appearance, specific oxygen consumption rate (mg O_2/kg volatile solids per hour), absence of phytotoxic compounds, reduction of BVS across the system, nutrient content, nitrate/ammonia ratio, absence of readily degradable compounds (such as starch), and absence of anaerobic intermediates (such as acetic acid). Besides these parameters, the temperature of the compost at the end of the curing stage and before land application, along with a seed germination test, can be used to measure compost quality.

Analysis of compost at the final stage, or at the time of application to agricultural land, is a good tool for judging and evaluating the materials. The beneficial components of finished carcass compost, like finished compost from plant residues, include water, total nitrogen (N), available nitrogen (NH_4-N), phosphorus as P_2O_5, potash (K_2O), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), and copper (Cu). Analysis has shown nutrients found in manure and composted carcasses to be very similar. Murphy and Carr (1991) observed that the mineral content (phosphorus [P], potassium [K], Ca, Mg, S, Mn, Zn, and Cu) of dead bird compost and manure (built-up litter) was comparable. They observed that composted poultry mortalities provided a slower and more sustained release of nitrogen than did the built-up litter on which the birds were raised. This was caused by the conversion of mineral nitrogen to an organic form during composting. Manure had twice the water content and half the nitrogen content of poultry carcass compost. Furthermore, essential element content (including P_2O_5, K_2O, Mg, Mn, Zn, and Cu) of poultry carcass compost was similar to poultry manure. Nutrient analysis of other composted carcasses has shown similar results; Harper et al. (2001) reported the nutrient content of composted piglet mortality composted using mini-bins. Tables 1 and 2 in Appendix F show clearly the results of these two experiments. McGahan (2002) and Kube (2002) reported that the analysis or composition of finished compost depends upon the raw materials used, as well as the ratio of carcasses to other ingredients in the composting process. Details are shown in Tables 3 and 4 in Appendix F.

Total organic matter is also a good indicator of compost quality. According to Dougherty (1999), characteristics of composted carcasses include organic matter ranging from 35-70% (50-60% is optimum), pH ranging from 5.5 to 8.0, and bulk density ranging from 474 to 592 kg/m^3 (800 to 1,000 lb/yd^3). Comparison of the average bulk density of the original raw material (about 592 kg/m^3 [1,000lb/yd^3]) with the average bulk density of finished compost product (about 533 kg/m^3 [900 lb/yd^3]) showed a considerable reduction in bulk density. Soluble salt content (reported in units of decisiemens per meter [dS/m]) of finished compost ranges from 1 to 30 dS/m, but it is usually close to 10 dS/m. According to Dougherty (1999), the preferred soluble salt content is 5 dS/m or less.

Compost land application

Although the bacterial biomass and humus comprising the end product of animal carcass composting provide a beneficial fertilizer and soil amendment, biosecurity may be of concern. According to Dougherty (1999), it is recommended that composted mortality should be used solely for soil amendment on the land where the animals are produced. Based on their recommendation, mortality compost can be land spread as is manure, and can be included in the farm nutrient management plant. The nutrients, humus, and soil amending properties in mortality compost make it a valuable by-product to a livestock enterprise. Hansen (2002) land-applied the finished product of sheep, swine, and cattle carcasses composted with solid barn bedding as the co-composting material and reported that the soil moisture of compost-amended plots was higher than that of non-amended plots throughout the summer. He recommended that the finished product of composting should be applied in fall prior to spring planting.

At the end of curing or maturation, composted carcasses can be stored or land applied. Morris et al. (1997) indicated that this end product is still not completely stable, but the remaining small segments and bones are demineralized so that further degradation can be completed once spread on the land. Mukhtar et al. (2003) studied the end product of a combined pile of two cow carcasses and one horse carcass after nine months of composting. It was observed that most of the carcass material was completely biodegraded over this time period, and very few large bones remained. As Figure 1 in Appendix F shows, bones were easily disintegrated reducing the need for screening or mechanical crushing of bones prior to land application. However, if a separation process will be used to remove large particles from the compost end product, moisture content should not be high; otherwise, the efficiency of the screening process will be decreased. Diaz et al. (1993) recommended the moisture content of the final compost product be less than or equal to 30% to achieve adequate separation.

Finished compost should be applied to land in a manner similar to that used for spreading animal manure. Compost should be spread at agronomic rates so that applied nutrients do not exceed the uptake capabilities of the crop which will be planted in later years. Conventional agricultural manure spreaders are ideal for handling and spreading compost. Care should be taken not to spread compost in or near sensitive areas such as watercourses, gullies, public roads, etc.

In spite of the soil-amending quality, Dougherty (1999) emphasized that mortality compost should not be used as animal bedding, a feed supplement, or given to others for use off the farm.

3.6 – Cost of Carcass Composting

The feasibility of carcass composting, like any other agricultural processing activity, is closely related to its cost. For any specific carcass composting system to be a reasonable disposal method, the cost should be analyzed and compared with other composting methods. The most important factors involved in cost analysis of carcass composting processes have been described by Mescher (2000) and are listed below in order of importance:

- Volume and weight of mortality produced per established time period.

- Frequency of mortality occurrence.
- Labor requirements.
- Accessibility and timeliness.
- Impact on the environment.
- Required facilities and equipment (new and existing) and their useful life expectancy.

Cost factors can be divided into categories of variable and fixed; the first five above-mentioned factors relate to variable costs of operation, and the last one represents fixed costs. Variable and fixed costs of carcass composting process are discussed further below.

Variable costs

Variable costs include the value of carcasses (usually assumed to be zero), labor costs, and the cost of co-composting materials (oxygen and carbon sources) for a one-year period. According to SCI (2002), labor costs are influenced by the availability of laborers at the time of composting, type of labor (family size operation or company style situation), and level of composting mechanization. According to SCI (2002), labor costs for large animal carcasses are estimated as $10/carcass. The cost of carbon source materials depends on their accessibility in each livestock-producing district. For example, in Alabama the values of straw and litter, respectively, were about $60 and $20 per ton (Crews et al., 1995).

The cost of aeration depends on the system chosen for aeration. Continuous aeration processes have a considerable effect on the cost of the composting system. Furthermore, continuous aeration decreases the time required to complete the first and second phases of composting, and also eliminates the turning processes required in conventional carcass composting (bin and windrow). Umwelt Elektronic GmbH and Co. (2003) evaluated the effects of aeration time on the cost of finished product in windrow composting. They showed that continuous aeration of windrow composting piles for 8 weeks not only decreased the operational cost considerably, but also reduced the time and land required for composting. As demonstrated by Table 1 in Appendix G, when continuous aeration was applied to windrow composting of 10,000 lbs of raw material for 8 months, land requirements were reduced by 50% (from 6,426 to 3,136 m^2), time required was reduced by 60% (from 25 to 10 months), and operational costs were reduced by 70% (from €17.59 to €4.88 per metric ton, or from about $19.70 to $5.30 per US ton) as compared to composting a similar mass conventionally (non-aerated system).

The scale of operation also affects variable costs. Carcass composting operations that process a significant volume of mortalities are likely to experience relatively lower variable costs and, therefore, lower costs/head than smaller operations. Obviously, initial investment will vary greatly across alternative composting systems. According to SCI (2002), only 30% of the total livestock operations in the US are large enough to justify the costs of installing and operating composting facilities (see Table 2 in Appendix G). The SCI report indicated that most livestock production operations are quite small by industry standards, consisting of, for instance, fewer than 50 beef cattle, 30 dairy cows, or 100 hogs. For operations of this size, which incur relatively little mortality loss on an annual basis and receive modest revenues from their operation, it is better to use the facilities of one of their larger neighbors (perhaps paying a disposal fee for use of the proposed facility).

Crews et al. (1995) studied the annual net costs of six disposal methods for a flock size of 100,000 broilers per cycle. The disposal methods evaluated included disposal pit, large-bin composting, incineration, small-bin composting (mini-composter), fermentation, and refrigeration techniques. Results are summarized in Table 3 of Appendix G. According to their report, broiler farms have two options for composting. Large broiler operations (those who grow more than 40,000 birds per 45-day cycle) usually have tractor-loaders in their operations and prefer to use bin composting. Smaller operations, which may not have a tractor-loader, choose small-bin composting (mini-composters) and do not need major construction, machinery, or equipment. While the initial investment cost of large bin composting is more than three times that of small bin composting (mini-composter), the variable cost is about 15% less than that of mini-composters.

Fixed costs

For individual livestock producers, decisions regarding an appropriate carcass composting system will depend not only on the recurring expenses associated with the method, but also on the initial investment required for construction of the system (bin or windrow) and required agricultural machinery and equipment. For fixed cost evaluation, it is necessary to consider the initial investment in equipment and facilities, including facility construction (bin, pile or windrow system), number of bins (or pile area) required for the facility, as well as material and animal handling equipment. Additionally, the expected life of the carcass composting facility should be considered. According to SCI (2002), equipment and labor costs are likely to vary across operations based on availability and size of necessary equipment, machinery operating costs, assumptions used in depreciation, opportunity costs of time, and the extent to which family labor is employed and not counted as an expense. Estimating important cost items for constructing composting facilities for use on-farm is extremely difficult, and using different building materials, machinery, and equipment results in substantial variations. Mescher (2000) predicted the cost required for construction of bin and windrow composting systems (building raw materials + construction labor) with the following specifications:

Bin composting

- 4-5 ft (1.2-1.5 m) concrete base with 5-10 ft (1.5-3 m) front apron.
- 5 ft (1.5 m) treated sidewalk construction (min 3 sides).
- Steel roof.
- 6 in (15 cm) square posts.
- 2 ft x 4 ft (0.6 m x 1.2 m) purlin and 2 ft x 6 ft (0.6 m x 1.8 m) rafter supports.
- Construction labor.
- Estimated cost: $1,250-$1,700 per bin

Static pile or windrow systems

- Concrete pad of 4-5 in (10-12.5 cm) thickness.
- Site development, gravel access.
- Cost of geo-textile cloth and gravel base.
- Site development, accessibility.
- Estimated cost: one-third to two-thirds less than bin systems.

SCI (2002) indicated that the fixed cost of constructing a composting facility can be prohibitive, especially for smaller producers, and operating costs will vary based on the size and sophistication of the structure. As noted before, small-bin poultry composting systems do not require large capital investment, and therefore their fixed costs are less than large-bin systems (see Table 4 in Appendix G for more details). For example, cost estimates for the sheltering structure of a mini-composter (a 4 x 4 x 4 ft bin) for small broilers can be decreased to 25% of the cost of a full-scale bin composter for large broilers and will not exceed $1,500 (Crews et al., 1995).

Total costs

SCI (2002) evaluated the overall cost of composting carcasses of different species using the following assumptions:

- Equipment costs (rental or depreciation of a skid-steer loader) were assumed to be $35/hour.
- Cost of bulking agent (sawdust) at the rate of 11.3 L/kg (0.0067 yd^3/lb) of carcasses, was assumed to be about $22/metric ton ($20/US ton).
- For a typical on-farm facility, 95 hours of farm labor per year, plus 35 hours of machinery use would be needed to manage the process, turn the pile, move material between primary and secondary bins, and remove composted materials. Mature cattle would first need to be cut into smaller pieces, an activity estimated to take an additional 10 minutes per mortality. Labor costs were assumed to be $10/hour.

Using these assumptions, the report indicated the total annual costs of composting incurred by the livestock sector to be $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses. Refer to Table 4 in Appendix G for additional details. This table also demonstrates that, regardless of carcass weight, the cost of machinery (the major fixed cost) per head was almost 50% of the total cost per head.

Furthermore, the minimum feasible capacity is very critical for investment in carcass composting facilities. According to SCI (2002), only about 28% of livestock operations would be considered large enough to justify investment in composting structures.

Henry et al. (2001) estimated the required investment for two types of facilities designed to compost about 40,000 pounds of mortalities per year, approximately the amount of death loss generated from a 300 sow farrow-to-finish_hog operation. They calculated costs for "high investment" and "low investment" composting constructions. The "high investment" option, which included seven concrete bins, had an estimated cost of $15,200. The "low investment" option, which included six smaller bins and no roof, had an estimated cost of $7,850. For both cases, the concrete work and the wooden portion were done with farm labor. Based on these results, and the fact that the majority of livestock operations are relatively small, SCI (2002) assumed a $7,000 investment per carcass composting operation (Table 5 of Appendix G). With these assumptions and the fact that composting facilities have a useful life of about 15 years, the maximum investment cost per carcass will be less than $5 per year.

Henry et al. (2001) estimated the costs of disposal by incineration, composting, and rendering for a swine production system needing to dispose of 18,000 kg/year (40,000 lb/year) or 49.5 kg/day (110 lb/day), as would be the case in a 300-sow farrow-to-finish operation with average death losses. Their results (which are presented in Table 6 of Appendix G) indicated the cost of composting sow farrow mortality was about $0.22/kg ($0.10/lb), which is similar to the cost presented in the SCI report (2002).

Kube (2002) composted cattle carcasses (1,000 lb [450 kg] each) using various adaptations of a windrow system, including conventional composting (no grinding), grinding carcasses before composting, and grinding of the finished compost. The cost analysis of this experiment (shown in Table 7 of Appendix G) indicated that, depending on the option selected for carcass composting, the total estimated cost ranged from $55 to $115/metric ton of carcasses ($50 to $104/US ton of carcasses [$0.044 to $0.11/kg, or $0.025 to $0.05/lb]). Although grinding carcasses before composting increased the operation cost by about $6/head, the time, area, and management costs were all reduced by about 50% compared to the conventional windrow system. Furthermore, the value of finished compost was estimated to be $10-$30 per carcass or $5.56-$16.67 per metric ton ($5-$15 per US ton), and the net cost per carcass was estimated to be approximately $5 to $42. Table 8 in Appendix G provides some of the specifications of this experiment.

The average unit cost of composting is comparable to other mortality disposal techniques. Mescher (2000) reported that composting has some economic advantages, such as long-life of the facility or pad, minimal cost of depreciation after start-up, similar labor requirements, inexpensive and readily-accessible carbon sources in most livestock production areas, and, finally, no need for new equipment. The total costs of bin composting were more than the burial method. However, when other economic parameters such as end product value were accounted for, the mini-composter had the lowest net cost per pound of carcass disposed at 3.50¢, followed by the burial method at 3.68¢, and bin composting at 4.88¢ (Crews et al., 1995).

Section 4 – Disease Agent and Environmental Considerations

The by-products of carcass composting (such as wastewater, odors, and gases) as well as the finished compost product should be safe and have little or no negative impact on public safety or the environment. This section provides a discussion of these considerations.

4.1 – Disease Agent Considerations

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. Although the heat generated during carcass composting results in some microbial destruction, because it is not sufficient to completely sterilize the end product, some potential exists for survival and growth of pathogens. This justifies the emphasis researchers tend to place on extending the duration of thermophilic temperatures during the composting process. The levels of pathogenic bacteria remaining in the end product depend on the heating processes of the first and second phases, and also on cross contamination or recontamination of the end product. Haug (1993) observed that the following conditions can reduce actual pathogen inactivation during the composting process:

- Clumping of solids, which can isolate material from the temperature effects.
- Non-uniform temperature distribution, which can allow pathogens to survive in colder regions.
- Re-introduction of pathogens after the high temperature phase.

In order to avoid these conditions, it is important to have uniform airflow and temperature throughout the composting process. Keener and Elwell (2000) reported that because carcass compost is an inconsistent mixture, pathogen survival may be sporadic within the non-uniform composition of material in different areas of the compost. Keener indicated that preparation process (e.g., grinding and mixing of carcasses with co-composting materials) as well as modifications to the composting system (e.g., aeration) will provide more chemical and physical consistency and better conditions for controlling temperature and inactivation of pathogenic bacteria. For example, periodic turning aerates the compost pile and reduces the probability of microbes escaping the high temperature zone. In spite of non-uniform temperatures, Glanville and Trampel (1997) reported that pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days. That is, a high core temperature provides more confidence for the carcass composting pasteurization process.

As a result of its potential to harbor human or animal pathogens, much concern and attention has been focused on the use of municipal wastewater sludge (bio-solids) as a composting input. Sander et al. (2002) maintained that, regardless of the difference between the physical and chemical characteristics of sludge and animal wastes, the microbiological standards applied to composted sludge provide practical insight to procedures that could prove equally useful in carcass composting.

Haug (1993) pointed out that the inactivation energy (obtained from time/temperature relationship equation or Arrhenius Model) is between 50 and 100 kcal/mol for many spores and vegetative cells. Based on this theory, he calculated the heat inactivation of enteric (related alimentary tract or intestine) pathogens by considering the conditions common to composting, and concluded that the average temperatures of 55 to 60°C (131 to 140°F) for a day or two will provide this energy and should be sufficient to reduce pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to an acceptably low level. *Salmonella* and total coliform populations can normally be reduced to levels below 1 and 10 MPN/g dry solid (most probable number/g dry solid), respectively. However, the endospores produced by spore-forming bacteria would not be inactivated under these conditions.

Murphy and Carr (1991) showed the number of pathogenic viruses diminished significantly during composting of poultry carcasses (Table 1, Appendix H). Mukhtar et al. (2003) measured the pathogenic activities of carcass-compost piles after nine months of composting and observed very low levels of *salmonellae* and fecal coliform bacteria, which were used as indicators of pathogen populations in the compost end product. Harper et al. (2001) suggested that maintaining the internal stack temperature of a swine compost pile in a thermophilic range for an extended period of one or more weeks would be adequate to kill potential disease organisms such as *Pseudorabies* virus, *Salmonella* species, and *Actinobacillus pneumonia* species.

Salter and Cuyler (2003) composted food residuals in windrows and evaluated fecal coliform and *Salmonella* populations during the first and second phases (14 weeks for each phase). They documented temperatures of >55°C (>131°F) throughout the first phase, and observed that fecal coliform levels were below 1,000 MPN/g dry solids within the first five weeks of composting, and *Salmonella* levels remained above 3 MPN/4 g dry solids until seven weeks.

Bollen et al. (1989) used static compost heaps (2.5-4.6 m^3) with samples of crop residues heavily infested with soil-borne fungal plant pathogens. The temperature within the piles reached 50-70°C within 6 days. Of the 17 plant pathogens, only *Olpidium brassicae* and *Fusarium oxysporum* survived the composting process. They reported that the following three processes impact microbial activities during composting:

- Heat generated during the first phase.
- Toxicity of conversion products formed mainly during the first phase (fungitoxic volatiles have been detected in leachates and extracts from composted hardwood bark).
- Microbial antagonism during the first phase and maturation process (second phase).

The general presence of actinomycetes and fungi (like species of *Streptomyces* and *Aspergillus*) during composting and curing phases ensures the production of a variety of antibiotics that destroy some pathogenic bacteria (Diaz et al., 1993). However, microorganisms such as *Mycobacterium tuberculosis* and spore-formers like *Bacillus anthracis* will survive the typical composting process.

Biosecurity

In terms of biosecurity, composting facilities should not be located directly adjacent to livestock production units, and the vehicles associated with operation should be sanitized with appropriate cleaning and disinfecting agents for each trip. The site should be downwind from residential areas, provide a limited or appealing view for neighbors or passing motorists, and possibly have a pleasing appearance and landscape (Morse, 2001).

In addition to conserving energy and moisture content and minimizing odors, a biofilter also excludes insects and birds (as the most important carriers of disease microorganisms) from the compost pile, thus minimizing or preventing transmission of microorganisms from mortalities to livestock or humans. According to Schwartz (1997), ill or apparently healthy birds can carry the bacteria of infectious coryza, a respiratory disease affecting several avian species. Mosquitoes are also carriers of many diseases. According to the Harvard School of Public Health (2002), mosquitoes and ticks transfer viruses to people by their nature as blood-sucking arthropods, thereby serving as vectors for transmitting viruses (such as West Nile) from host to host.

4.2 – Site Selection in Relation to Environmental Factors

Disposal of animal carcasses may generate different environmental and health hazards. Various agricultural agencies (Alberta Agriculture, Food and Rural Development, 2002; AUSVETPLAN, 1996) indicated that improper carcass disposal processes might cause serious environmental and public health problems, including:

- Odor nuisance, resulting from the anaerobic breakdown of proteins by bacteria, reduces the quality of life and decreases property values.

- Pathogens which may be present in decomposed material are capable of spreading diseases in soil, plants, and in animals and humans.
- Leaching of harmful nitrogen and sulfur compounds from carcasses to groundwater.
- Attraction of insects and pests as potential vectors of harmful diseases for public health.

Location of a compost facility has an important role in meeting environmental interests. Choosing an appropriate site will help to protect water and soil quality, increase biosecurity, prevent complaints and negative reactions of neighbors, decrease nuisance problems, and minimize the challenges in operating and managing the composting operation. Based on The Ohio Livestock Mortality Composting Development Team (Keener & Elwell, 2000), a composting operation should:

- Protect surface and groundwaters from pollution.
- Reduce the risk of the spread of disease.
- Prevent nuisances such as flies, vermin, and scavenging animals.
- Maintain air quality.

Water

The location of the composting pile should be easily accessible, require minimal travel, be convenient for material handling, and maintain an adequate distance from live production animals. Sites near neighbors and water sources or streams should be avoided. Additionally, surface runoff and other pollution controls should be employed at the site. According to Mescher et al. (1997), leachate and runoff concerns are largely eliminated when using a bin system with a roof. A properly managed bin composter will not generate leachate from the pile, eliminating the need for a runoff storage or filter area. To control runoff, Looper (2002) suggested that a slope of approximately 1-3% should be incorporated to prevent pooling of water and allow proper drainage. McGahan (2002) stated that in higher rainfall areas (more than 1,000 mm or 40 in annual average.), a roof over the composting facility may be necessary. Fulhage (1997) indicated that composting facilities should be well-drained; away from sensitive water resources such as streams, ponds, and wells; accessible in all kinds of weather; and possibly located at or near the crest of a hill. Such a location will minimize the amount of surface water in the composting area.

Site preparation and runoff control structures are essential for static pile composting systems. Mescher et al. (1997), Morse (2001), and McGahan (2002) indicated that runoff from a carcass compost pile may contain organic compounds that could degrade the quality of nearby ground or surface water. To avoid this, all runoff from the composting facility should be collected and treated through a filter strip or infiltration area. The compost facility should be located at least 3 ft (1 m) above the high water table level and at least 300 ft (90 m) from streams, ponds, or lakes in the same drainage area. In addition, all clean surface water must be diverted away from the composting area to minimize the volume of water that must be treated or stored and keep the composting area dry. Excess water tends to exclude oxygen from the compost pile, slows the process, and makes the pile anaerobic which attracts flies and produces odors. Excessive drainage from such piles can potentially pollute not only surface waters but also soil.

Soil

Compost piles should be underlain with a water barrier in order to prevent compost leachate from penetrating and contaminating the soil or base underneath. Bagley (2002) suggested placing a plastic cover over the ground under the composting pile. Since a plastic barrier may complicate turning of the pile or windrow, a concrete or asphalt base (pad) is recommended instead of plastic materials. According to Looper (2002) and McGahan (2002), a composting pad should be compacted, but does not need to be paved. A compacted layer of sand or gravel about 15 cm (6 in) thick should be used when existing soil conditions are not acceptable.

Vegetation

Sciancalepore et al. (1996) measured the biological and enzymatic activity of several microbial groups (including pathogenic bacteria, *E. coli,* and salmonellae) during six months of composting a mixture of crude olive husks, oil mill wastewaters, and fresh olive tree leaves inoculated with cow manure. Results showed that total phytotoxicity encountered in raw composting materials fully disappeared due to enzymatic activities.

Air quality

A good composting operation will not generate an offensive odor; however, Fulhage (1997) and McGahan (2002) remarked that the daily handling of dead animals and compost may not be aesthetically pleasing, and these factors should be taken into account in locating a composter. Additionally, traffic patterns required for moving carcasses to the composter and removing finished compost must be considered. Rynk (1992) indicated that maintaining aerobic conditions is a key factor for minimizing odor release during carcass composting, as there is an increasing likelihood of significant odor when oxygen content is approximately 3% or less.

Organoleptic techniques based on the human olfactory system have been used as the standard method for characterization of odors. Different parameters such as threshold odor concentration (TOC), OU, surface odor emission rate (SOER), odor intensity, hedonic tone, and odor quality are used to characterize odor. According to Haug (1993), TOC is the minimum concentration of odorant that will arouse a sensation. OU is the number of dilutions with odor-free air required to achieve the minimum detectable odor concentration. Odor concentration is usually determined by supplying a number of diluted samples to a number of individuals until the odor is detected by only 50% of the panel members. Finally, SOER is usually expressed in m^3/min-m^2 and determined by placing a sample hood over the surface being analyzed. Improper carcass composting will increase the odor emission rates substantially. Haug (1993) reported that measured SOER values in different compost facilities tend to vary from about 0.5 to 10 m^3/min-m^2 and in compost with sewage sludge and wood-based amendments, the OU concentrations range from 100 to 1,000.

Fortunately, there has been significant progress on biological and chemical deodorization of compost gases. Currently odor absorption units use multistage chemical scrubbing. These stages include acid scrubbing for removal of ammonia; hypochlorite scrubbing (with a slightly acidic pH and with or without surfactant) for removal of inorganic, organo-sulfides, and other organics such as terpenes; and scrubbing with peroxide or caustic soda to remove residual chlorine odors and refine the gas effluent (Haug, 1993).

Biofilters are widely used in many compost facilities. Although new deodorization technologies have been substituted, biofilters have received a lot of attention. According to Haug (1993), biofilters are now enjoying a renewed interest in the US as more is learned about their proper design and operation. He also reported that blanket materials in a composting process must be used to maintain proper conditions of moisture, pH, nutrients, and temperature to enhance the microbial reaction rates. At this stage, deodorized gases from open biofilters are usually released at ground level.

Section 5 – Critical Research and Training Needs

Research and training are two areas of education that publicize and promote carcass composting techniques. Composting is relatively new, and a majority of livestock producers and others involved in animal agriculture research and education are not familiar with this relatively safe and harmless method of disposing of animal mortalities. They lack knowledge of the carcass composting process as well as the beneficial effects on the environment. Further study is warranted to develop scientific and practical answers for different issues and challenges associated with carcass composting. Deficiencies in research and training, along with active educational centers for carcass composting, are discussed in this section.

5.1 – Research

Extensive research has been conducted in the area of "organic material composting," and a wealth of articles, books, and technical documents have been published or presented on the topic during the last 50 years. At the same time, many academic, governmental, state, and regional institutions and agencies worked to promote this process and helped private sectors produce different organic compost products at the commercial level. The situation for "carcass composting," which has potentially stronger environmental and biosecurity impact, is quite different. Agricultural extension engineers and compost scientists at academic institutions have put forth efforts during the last 20 years to clarify the different aspects of composting this type of material. Although these efforts have furthered the establishment of composting as a practical method of carcass disposal, public health, animal health, and environmental hazards are not fully understood.

A preliminary study of 50 published technical and scientific research articles focused directly and indirectly on "carcass composting" showed that about 70% were generated by government agencies and university extension agencies, with very little information published by the private sector. While the available information was observed to be valuable, few of the informational sources appeared in the form of peer-reviewed journal articles, therefore their scientific validity is not known. A high proportion of published documents written on carcass composting have been concentrated on the definition, general principles, material requirements, and, to some extent, the microbiological aspects of the process. Due to the fact that composting of horticultural residues is safer than carcass composting from the stand point of presence of pathogenic bacteria, much more research is needed to address this safety issue. To compost massive amounts of mortality, produce a compost product free of pathogens, and possibly sell the product for growing horticultural produce, the following related issues should be studied in depth:

1. Investigate decontamination and deodorization of raw materials.

   To ensure that the end products of carcass composting are free of pathogenic and harmful microorganisms, to protect the environment, and to decrease the risk of odor production, extensive research on decontamination and deodorization processes of the raw materials and end product is needed. This research would also consider the fate of transmissible spongiform encephalopathies during composting.

2. Investigate temporary storage scenarios.

   In the case of high mortality losses, information will be needed regarding storage sites, time, and temperature and their appropriate relations to composting.

3. Investigate how to shorten the length of the composting process.

   To diminish the composting time, additional information is needed regarding pre-composting processes (e.g., grinding and mixing), enhanced composting processes (e.g., applicability of rotary vessel system, aerated synthetic tube and using forced air for carcass composting), and post-composting processes. By studying the physicochemical properties of carcass materials, valuable information might be gained and used to design improved composting processes.

4. Study how to improve composting machinery and equipment.

   Although most of the handling, moving, and turning machinery used in organic composting can be applied to carcass composting, certain readily sanitizeable machinery and equipment such as aeration devices and carcass grinders need to be designed specifically for carcass composting.

5. Shift the research focus from bin composting to windrow composting.

   Most carcass-composting studies have mainly focused on bin composting systems for small- and medium-sized carcasses. Such studies have neglected windrow carcass composting, which is seemingly appropriate for massive amount of animal mortalities; windrow carcass composting should be the focal point of future composting research.

6. Investigate economic issues related to composting.

   The current economic value of composted carcasses may not justify the cost of production. Research should focus on both (a) modifying the costs of composting and (b) marketing compost products following sanitation.

5.2 – Training

The facility size and, consequently, staff size, of each livestock operation will determine the extent of and expenditure on training. The allocation of resources between capital equipment and labor is also a factor in the extent of education and training. Diaz et al. (2002) reported that in an organic composting system, the number of personnel ranged from part-time employment for small, seasonal, leaf-composting operations to approximately 30 full-time employees for large compost operations. Labor requirements for manual carcass composting vary roughly in proportion to the plant throughput. Mechanical separation reduces the need for sorters. Diaz et al. (2002) also indicated that the requirements for skilled personnel usually do not vary markedly as facility size increases.

Training should not be limited only to personnel involved with carcass composting activities. This technology should be introduced to different commercial composting companies for producing a non-pathogenic soil-improver and amender while protecting the environment from the possible side effects of improper disposal of animal-carcasses. Educating the market is highly related to public education, which can be accomplished by cooperation with the media. Different presentations of carcass composting may deal with the advantages of using proper procedures and may provide information on the hazards and disadvantages of improper composting or disposal of animal mortalities.

Although some efforts have been made by extension services of academic institutes, and considerable educational materials have been prepared for training farm-animal producers, much more should be done to publicize the composting process among the interested and related parties through short courses, workshops, and training materials. Training tools, such as practical manuals, bulletins, pamphlets, posters, magazines, books, and web guides should be prepared and distributed for continuous education of personnel in livestock and livestock by-product industries.

5.3 – Educational Centers

Agricultural universities and schools which have initiated carcass composting programs in their teaching, research, and extension programs are able and willing to be more active in educational efforts. Of the many universities which are active in conducting research and extension activities on the subject of carcass composting, only a few are involved directly with training programs. Table 1 in Appendix I shows some of the most important centers active in providing education and training relative to carcass composting. These entities have the following training programs:

- Basics of a composting process, including composting methods, site selection, co-composting materials, equipment demonstration, quality control, and use of compost.
- New and emerging regulations and opportunities that impact the future of carcass composting.
- On-farm composting of cattle and poultry carcasses and the application of the end product.
- Environmental aspects of carcass composting.
- Cost management and evaluation.

Furthermore, agricultural universities and schools can provide effective educational and training programs for government personnel at the national, state, or local level. These educated government personnel would then be capable of providing training to managers and supervisors at livestock operations, and could inspect mortality composting operations.

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Appendices

Appendix A

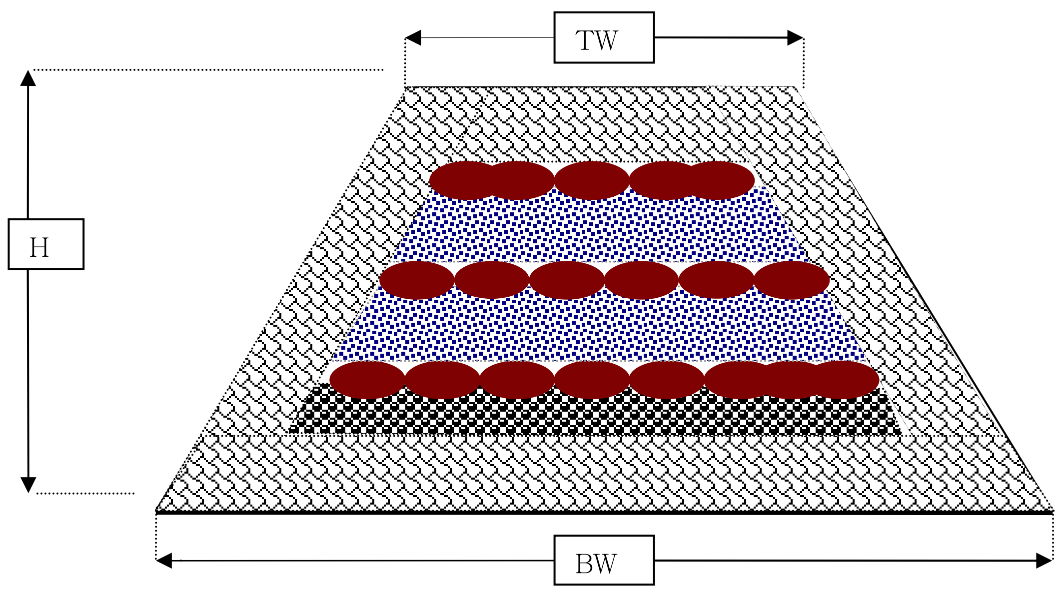
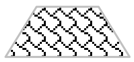
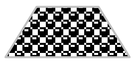


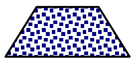
FIGURE 1. Cross-sectional dimensions of a trapezoidal-shaped windrow for small carcasses.



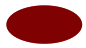
Two layers of carbon source materials are used as a base layer and a bio filter on top and two sides of windrow. Each layer is 30 cm (1 ft) thick.



One 15-cm (0.5 ft) thick layer of bulking agent (such as litter) is used.



Two layers of carbon sources. Each layer is 30-cm (1 ft) thick.



Layers of poultry carcasses.

A 0.6-cm (0.24in) thick plastic liner is used as an impermeable layer underneath composting materials.

Bottom Width (BW) = 360 cm (15 ft), Top Width (TW) = 150 cm (5 ft) and Height (H) = depends on the thickness of carcasses.

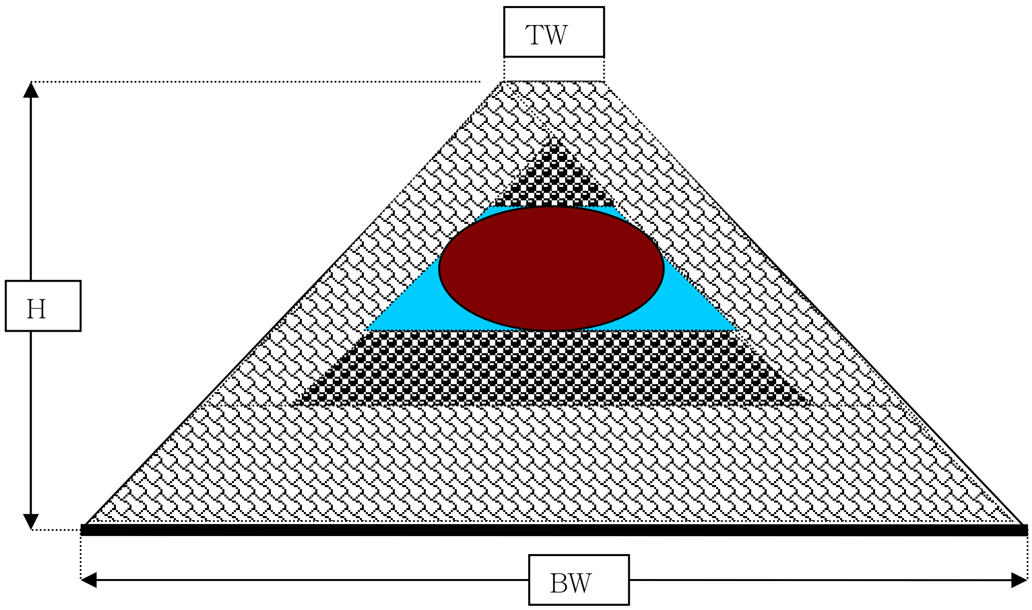
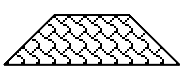
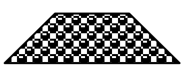


FIGURE 2. Cross-sectional dimensions of a trapezoidal-shaped windrow for medium carcasses.

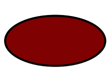
Plastic liner with the thickness of 0.6 cm (0.24in) used as an impermeable layer underneath composting materials.



Two layers of carbon source materials used as a base layer, 45 cm (1.5 ft) thick and a bio filter layer, 30-cm thick on top and two sides of windrow.



Two layers of bulking agent. Each layer is 30-cm (1 ft) thick.



One layer of medium size carcasses.

Bottom Width (BW) = 390 cm (13 ft), Top Width (TW) = 30 cm (1 ft), and Height (H) = depends on the thickness of carcasses.

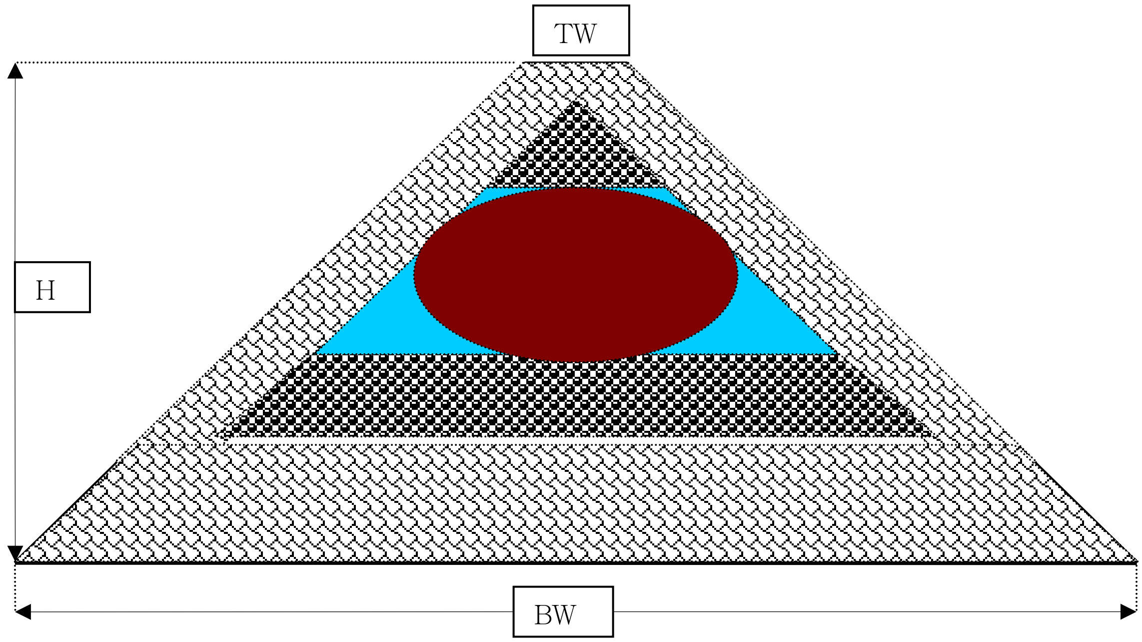
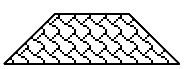
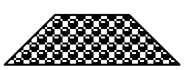


FIGURE 3. Cross-sectional dimensions of a trapezoidal-shaped windrow for large and heavy carcasses.

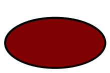
Plastic liner with the thickness of 0.6 cm (0.24in) used as an impermeable layer underneath composting materials.



Two layers of carbon source materials used as a base layer, 60-cm (2-ft) thick and a bio filter, 30-cm (1-ft) thick on top and two sides of windrow.



Two layers of bulking agent, each layer 30-cm (1-ft) thick.



One layer of large or heavy carcasses.

Bottom Width (BW) = 450 cm (15 ft), Top Width (TW) = 30 cm (1 ft), and Height (H) = depends on the thickness of carcasses.

Appendix B

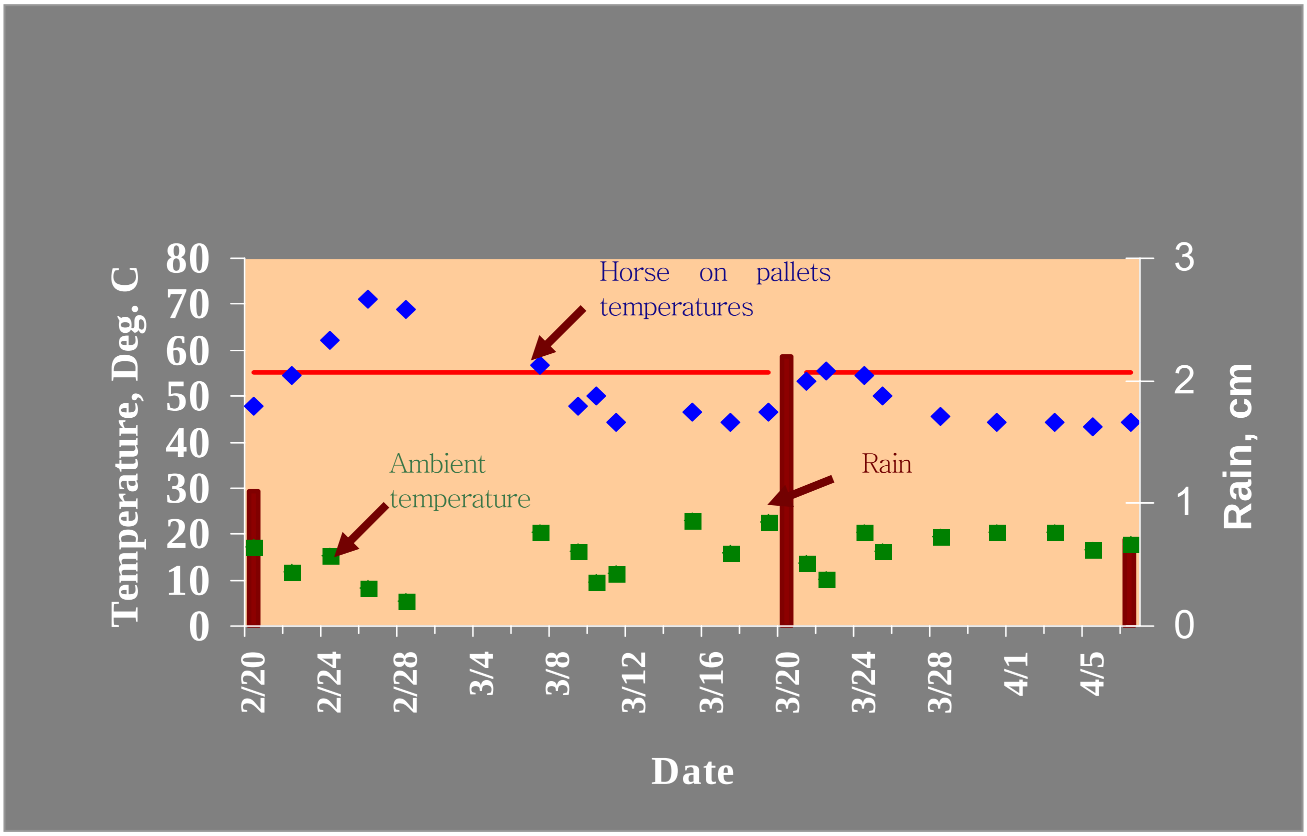


FIGURE 1. Bottom temperatures of horse compost pile (on pallets), ambient temperatures and rainfall data (Mukhtar et al., 2003).

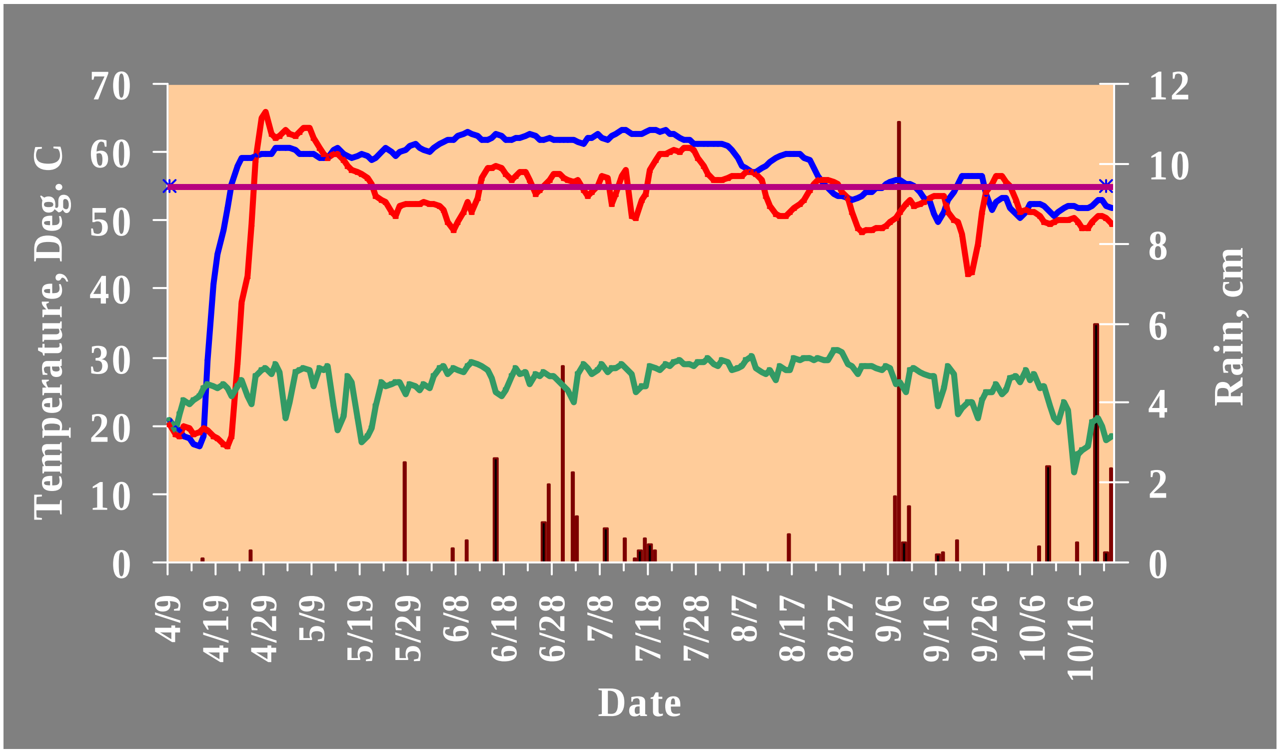


FIGURE 2. Ambient (green), top (red), and bottom (blue) temperatures of cow composting pile (on pallets) along with rainfall data (Mukhtar et al., 2003).

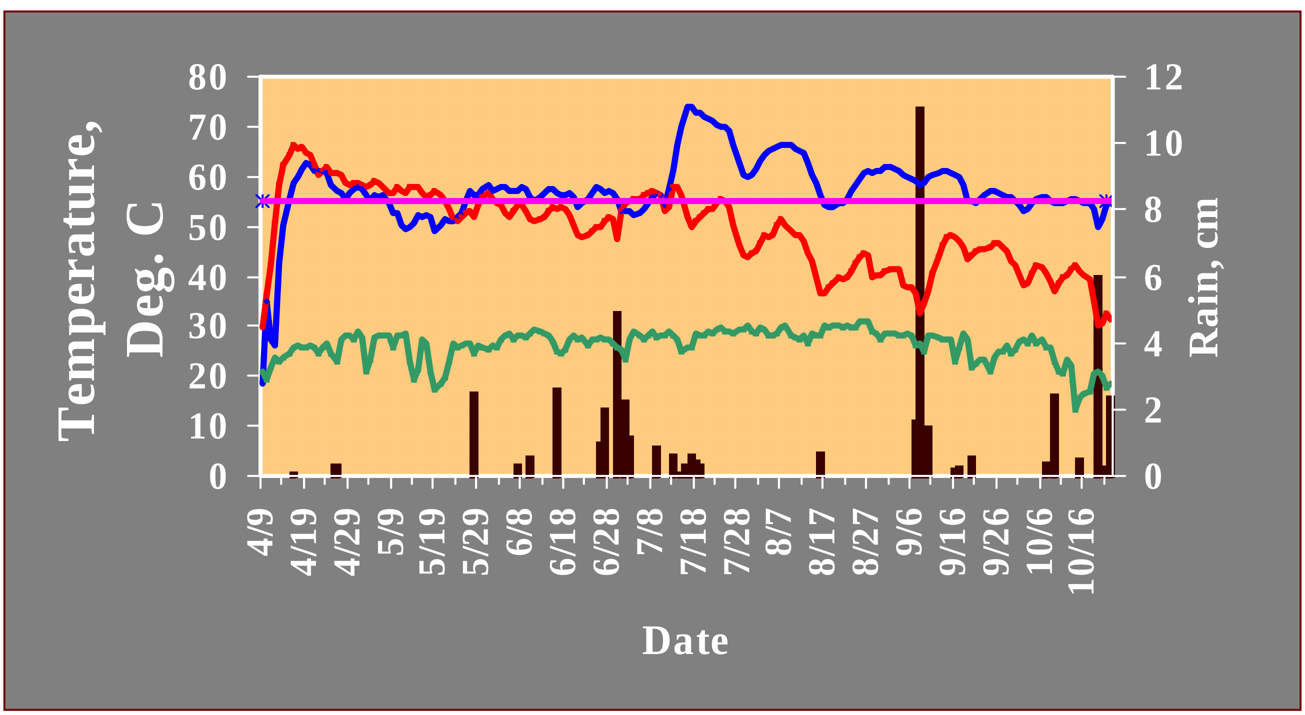


FIGURE 3. Bottom temperatures of cow compost (blue) and horse compost (red) piles (without using pallets) along with ambient temperature (green), and rainfall data (Mukhtar et al., 2003).

Appendix C

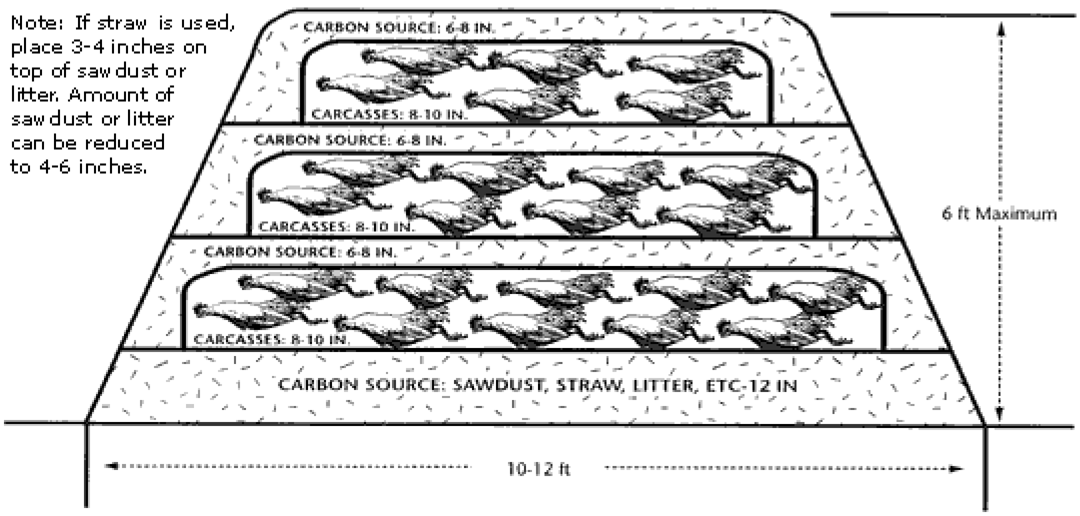


FIGURE 1. Cross-section of carcass composting in a windrow (Carr et al., 1998).

FIGURE 2. A layer of mortality in a compost windrow (Carr et al., 1998).

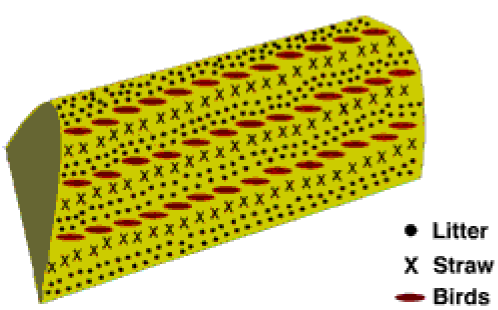


FIGURE 3. Completed windrow composting of poultry mortalities (Carr et al., 1998).

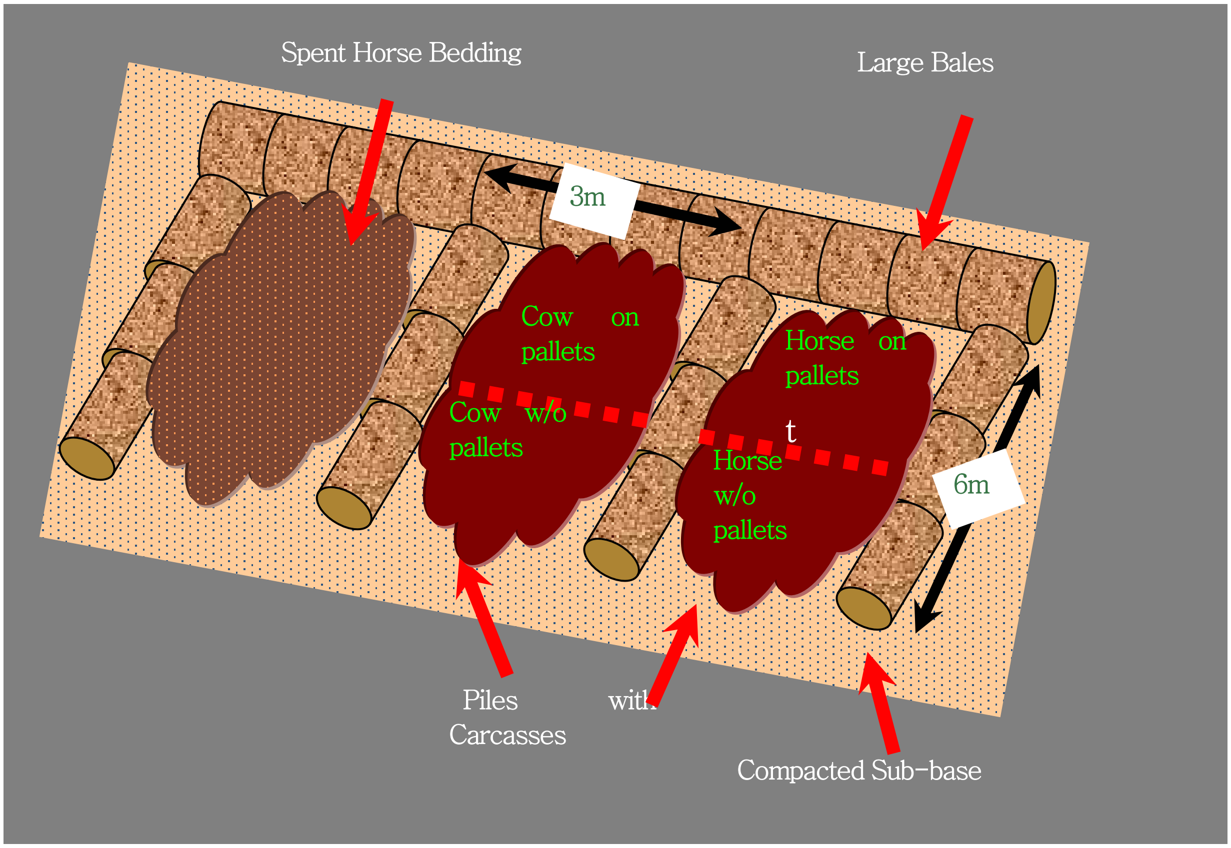


FIGURE 4. A three-bin large carcass composting set-up built with large hay bales (Mukhtar et al., 2003).

FIGURE 5. Layout of a carcass compost site using large round bales (McGahan, 2002).

FIGURE 6. Cow carcass without pallets (left) and the data logger location (right) for this carcass (Mukhtar et al., 2003).

FIGURE 7. Poultry carcasses and carcass parts being added to the inlet section of an aerated synthetic tube (Cawthon, 1998).

TABLE 1. The calculated time based on the original weight of the dead animals and mathematical model predicted for the first, second, and storage phases of composting (Monnin, 2000).

	Days Per Phase								
Mortality size in kg (lbs)	**1.8 (4)**	**4.5 (10)**	**22.7 (50)**	**45.5 (100)**	**100 (220)**	**159.1 (350)**	**227.3 (500)**	**454.5 (1000)**	**681.8 (1500)**
First phase (days)	10	16	35	50	75	95	115	160	195
Second phase (days)	10	10	12	15	25	30	40	55	65
Storage time (suggested minimum days)	30	30	30	30	30	30	30	30	30

TABLE 2. Management schedule for a system using three bins and two turns, with 15 days in primary (first) phase of carcass composting (Morse, 2001).

Days	Primary bin 1	Primary bin 2	Secondary bin
1-15	Filling	Empty	Empty
16-30	1st heat	Filling	Empty
31-45	Filling	1st heat	2nd heat (#1)
46-60	1st heat	Filling	2nd heat (#2)
61-85	Filling	1st heat	2nd heat (#1)

Appendix D

EXAMPLE 1. Bin composting of poultry carcasses (Murphy & Carr, 1991).

Example Calculation:

A poultry farm with 100,000 birds and 4.5 lb (2.02 kg) average market weight to compost carcasses using a bin system.

Available information

0.45 kg (1 lb) of the compost material needs a volume of approximately 0.027 m^3 (1 ft^3)

Daily composting capacity = Theoretical farm live weight **/**400

Theoretical farm live weight = Farm capacity x market weight

Determine daily composting capacity

The needed daily composting capacity will be:

Daily composting capacity =100,000 (birds) x 4.5(lb/birds)/ 400 (day) = 1125 lb/day (506.25 kg/day) or about 1125 ft^3/day

Suggested number of bins and associated dimensions

Based on the experimental data of Murphy and Carr (1991), the most appropriate bin dimensions are 7 ft length, 5 ft width, and 5 ft height Therefore:

N (number of primary treatment bins) = (compost capacity) / (L x W x H of a primary bin)

N = (1,125 ft^3/day) / (7 ft x 5 ft x 5 ft) = 6 primary treatment bins/day

The six bins can be arranged in any of several configurations to suit the needs of a particular situation.

The overall length = (1,125 ft^3) / (7 ft x 5 ft) = 32 ft (9.64 m)

Total area = 7 ft x 32 ft = 214 ft^2 (19.26 m^2)

Area for each primary bin= 214 ft^2 / 6 = 35 ft^2 (3.21 m^2)

EXAMPLE 2. Bin composting of cattle carcasses (Morris et al., 1997).

Example Calculation:

A cattle operation with 60 dead animals/year (average weight of 65 kg) to compost carcasses using a bin system.

Available information

Area of the primary bin or A_1 = n. W /h. d_1 and area of the secondary bin or A_2 = n. W /h. d_2

The recommended height for bin (suggested by many researchers) is 5 ft (1.5 m)

Composting materials had a bulk density of 600 kg/m^3 at the beginning of the first phase, and 900 kg/m^3 at the beginning of the second phase of composting.

Determine areas of primary and secondary bins

A_1 = (60 carcasses/year) (65 kg/carcass) / (1.5 m, bin height) (600 kg/m^3) = 4.33 m^2

A_2 = (60 carcasses/year) (65 kg/ carcass) / (1.5 m, bin height) (900 kg/m^3) = 2.89 m^2

EXAMPLE 3. Bin composting of poultry carcasses (Keener & Elwell, 2000).

Example Calculation:

A poultry farm, which has an average weight of 1.36 kg (3 lb) per carcass and ADL of 13.6 kg/day (30 lb/day), to compost carcasses using a bin system.

Available information

$T_1 = (7.42)(W_1)^{0.5} \geq 10$, days $V_1 \geq (0.0125)(ADL)(T_1)$, m^3

$T_2 = (1/3)(T_1) \geq 10$, days $V_2 \geq 0.0125)(ADL)(T_2)$, m^3

$T_3 \geq 30$, days $V_3 \geq V_2$ $V_3 \geq (0.0125)(ADL)\ T_3)$, m^3

The relation between bin volumes, width, and length with the constant depth or height of 1.50 m (5 ft).

Determine composting time and volume for primary, secondary, and storage phases.

From the above-mentioned equations, the required information will be:

$T_1 = (7.42)(1.36)^{0.5} \geq 10$ days, $T_2\ (1/3)(T_1) \geq 10$ days and $T_3 \geq 30$ days,

$V_1 \geq (0.0125)(13.6)(10) = 1.70\ m^3$, $V_2 \geq 0.0125)(13.6)(10) = 1.70\ m^3$ and

$V_3 \geq 3\ V_2$ (as recommended as a design parameter) = 3 (1.70) = 5.10 m^3

Determine the number of required bins and associated dimensions

The bin volume closest to a calculated value of 1.70 m^3 is 2.26 m^3 (80 ft^3) or a mini bin with dimensions of 1.22 m x 1.22 m x 1.52 m (4 ft x 4 ft x 5 ft).

In other words, there is a need for two primary bins, each with the areas of 1.22 m x 1.22 m =1.5 m^2 (16ft^2) or total of 3 m^2 (32 ft^2) and one secondary bin of 1.50 m^2 (16 ft^2).

The end product storage area will be: 5.10 m^3/ 1.5 m = 3.36 m^2.

TABLE 1a. Poultry mortality rates and design weights (adapted from OSUE, 2000).

Species & Growth stage	Avg. Wt. kg (lb)[a]	Poultry Loss Rate (%)[b]	Flock life (days)	Design Weight kg (lb)[c]
Poultry				
Broiler	1.8-3.6 (4-8)	4.5-5	42-49	Up to 3.6 (up to 8)
Layers	2.0 (4.5)	14	440	2.0 (4.5)
Breeding hens	1.8-3.6 (4-8)	10-12	440	3.6 (8)
Turkey, females	6.8-11.4 (15-25)	6-8	95-120	11.4 (25)
Turkey, males	11.4-19.1 (25-42)	12	112-140	15.9 (35)
Turkey, breeders replace	6.8; 0-13.6 (15; 0-30)	5-6	210	9.1 (20)
Turkey, breeding hen	12.7-13.6 (28-30)	5-6	180	13.6 (30)
Turkey, breeding tom	31.8-36.4 (70-80)	30	180	34.1 (75)

[a]Average weight used to calculate pounds of annual mortality.

[b]For mature animals, the % loss is an annual rate for the average number of head on the farm.

[c]Design weight used to calculate composting cycle periods.

TABLE 1b. Livestock mortality rates and design weights (adapted from OSUE, 2000).

Species & Growth stage	Avg. Wt. kg (lb)[a]	Loss Rate (%)[b]			Design Weight kg (lb)[c]
		Excellent	Good	Poor	
Swine					
Birth to weaning	2.7 (6)	< 10	10-12	> 12	4.5 (10)
Nursery	10.9 (24)	< 2	2-4	> 4	13.6 (35)
Growing/Finishing	63.6 (140)	< 2	2-4	> 4	95.5 (210)
Breeding herd	159 (350)	< 2	2-5	> 5	159 (350)
Cattle/Horses					
Birth	31.8-59.1 (70-130)	< 8	8-10	> 10	59.1 (130)
Weaning	273 (600)	< 2	2 -3	> 3	273 (600)
Yearling	409 (900)	< 1	1	> 1	409 (900)
Mature	636 (1400)	< 0.5	0.5-1	> 1	636(1400)
Sheep/Goats					
Birth	3.6 (8)	< 8	8-10	> 10	4.5 (10)
Lambs	22.7-36.4 (50-80)	< 4	4-6	> 6	36.4 (80)
Mature§	77.3 (170)	< 2	3-5	> 5	77.3(170)

[a]Average weight used to calculate pounds of annual mortality.

[b]For mature animals, the % loss is an annual rate for the average number of head on the farm.

[c]Design weight used to calculate composting cycle periods. The design weight for cattle, horses, sheep, and goats should be verified with the producer.

TABLE 2. Worksheet for calculating annual death loss of livestock (cattle, pig, poultry, sheep, etc.) for use in designing an animal mortality composting system (adapted from OSUE, 2000, and a 1999 Ohio NRCS publication).

Livestock Type:

Death Loss Per Year (use "average weight" to calculate death loss)

Birth Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Weanling Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Yearling Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Mature Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Total Weight Death Loss Per Year Per Species = ______________

Average Death Loss Per Day

(______________)	/ 365	=	______________
Total Weight Death Loss Per Year			Weight Death Loss Per Day

Note: For animals weighing less than 227 kg (500 lb), a bin composting system should initially be evaluated. For larger animals, a windrow or compost pile for an individual mature animal will likely be the most practical.

TABLE 3. Composting worksheet for bins.

Step 1 – Calculate volume of primary, secondary, and storage bins:						
Small & medium animals						
Primary Bin						
(0.0125)	x	(______)	x	(______)	=	______ m^3
		kg loss/day		primary stage time		primary bin volume
Secondary Bin						
(0.0125)	x	(______)	x	(______)	=	______ m^3
		kg loss/day		secondary stage time		secondary bin volume
Storage Bin						
(0.0125)	x	(______)	x	(30 days)	=	______ m^3
		kg loss/day				storage bin volume
Alternate calculations for large animals						
Primary Bin						
(0.0125)	x	(______)	x	(______)	=	______ m^3
		W1 (kg)		(ADL x T1/W1)		primary bin volume
Secondary Bin						
(0.0125)	x	(______)	x	(______)	=	______ m^3
		W1 (kg)		(ADL x T2/W1)		secondary bin volume
Storage Bin						
(0.0125)	x	(______)	x	(______)	=	______ m^3
		W1 (kg)		(ADL x T3/W1)		storage bin volume

Step 2 – Calculate the number of primary, secondary, and storage bins required:

Note that minimum requirements will be two primary bins, one secondary bin, and one storage bin. In doing calculations always round up to the next whole number (e.g., 2.1 bins = 3 bins, or increase the bin dimensions and recalculate).

Number of Primary Bins:

Based on the required volume calculated in Step 1, and using table 3a below, choose bin dimensions within the capability of the loading equipment. Also, account for the size of the animals to maintain at least 15.3-30.5 cm (0.5-1 ft) clearance between the carcass and the bin walls.

Trial Bin Volume

(__________)	x	(______________)	x	1.52 m (5 ft)	=	______________ m^3
Width, m (ft)		Length, m (ft)				trial bin volume

Number of Primary Bins

(__________)	/	(______________)	+	(___1___)	=	______________ bins
Primary volume		trial bin volume				number of primary bins

Number of Secondary Bins:

Select secondary bin volume. Each secondary bin must be greater than or equal to the volume of the primary bin since volume reduction during the compost stage is neglected. Minimum requirements will be one secondary bin per three primary bins (the 3:1 ratio requires immediate utilization or separate storage of compost following the secondary stage).

(__________)	/	(______________)	=	______________ bins
Secondary volume (from Step 1)		Selected primary bin volume		number of secondary bins

Number of Storage Bins:

Select storage bin size. Volume must be greater than or equal to secondary bin volume.

(__________)	/	(______________)	=	______________ bins
Storage volume (from Step 1)		Selected storage bin volume		number of storage bins

TABLE 3a. Bin volumes versus width and length (assumes depth of 1.52 m [5 ft]).

Width, m (ft)	1.22 (4)	1.83 (6)	2.44 (8)	3.05 (10)	3.66 (12)	4.27 (14)	4.88 (16)
Length, m (ft)	Bin Volume m^3 (ft^3)						
1.22 (4)	2.27 (80)	3.40 (120)	4.53 (160)				
1.83 (6)	3.40 (120)	5.01 (180)	6.80 (240)	8.50 (300)	10.20 (360)		
2.44 (8)	4.53 (160)	6.80 (240)	9.06 (320)	11.33 (400)	13.59 (480)	15.86 (560)	18.13 (640)
3.05 (10)		8.50 (300)	11.33 (400)	14.16 (500)	16.99 (600)	19.82 (700)	22.66 (800)
3.66 (12)		10.20 (360)	13.59 (480)	16.99 (600)	20.39 (720)	23.79 (840)	27.19 (960)

Step 3 – Calculate annual sawdust requirements:

Note that this assumes no reintroduction of finished compost to the primary bin; however, it is recommended that up to 50% of the fresh sawdust requirements be met with finished compost.

Sawdust volume

(__________)	x	(___0.0116______)	=	____________ m^3 (yd^3)	=	
kg (lb) loss/yr		(use 0.0069 if wt in lb)		sawdust volume		

Additional bins for fresh sawdust storage = ____________bins

Step 4 – Summary of bin numbers and dimensions required

	Primary	Secondary	Compost Storage	Sawdust Storage
Number of bins				
Dimensions (w x l)				

TABLE 4. Composting worksheet for windrows.

Step 1 – Calculate volume of primary, secondary, and storage stages:							
Small & medium animals							
Primary:							
(0.0125)	x	(______________)	x	(______________)	=	______________ m^3
		kg loss/day		primary stage time		primary volume
Secondary:						
(0.0125)	x	(______________)	x	(______________)	=	______________ m^3
		kg loss/day		secondary stage time		secondary volume
Storage:						
(0.0125)	x	(______________)	x	(30 days)	=	______________ m^3
		kg loss/day				storage volume
Alternate calculations for large animals						
Primary:						
(0.0125)	x	(______________)	x	(______________)	=	______________ m^3
		W1 (kg)		(ADL x T1/W1)		primary volume
Secondary:						
(0.0125)	x	(______________)	x	(______________)	=	______________ m^3
		W1 (kg)		(ADL x T2/W1)		secondary volume
Storage:						
(0.0125)	x	(______________)	x	(______________)	=	______________ m^3
		W1 (kg)		(ADL x T3/W1)		storage volume

Step 2 – Indicate the windrow height and resulting windrow area used.

Windrow height

Assign a windrow height (1.5-2.1 m; 5-7 ft) and continue. Windrow Height = __________________ m (ft)

Determine resulting windrow area used from the following windrow section area and base width (assumes 0.305 m top width and 1:1 side slopes).

Windrow Height	Windrow Section Area m^2 (ft^2)	Windrow Base Width m (ft)	Pad Width m (ft)
1.52 (5)	2.79 (30)	3.35 (11)	15.9 (52)
1.83 (6)	3.90 (42)	3.96 (13)	17.1 (56)
2.13 (7)	5.20 (56)	4.57 (15)	18.3 (60)

Step 3 – Calculate the length of the primary, secondary, and storage windrows and the pad.

Primary windrow:

(______________) / (______________) = ______________m (ft)

Primary volume / Primary windrow area = Primary windrow length (round to nearest 0.3 m [1 ft])

If the primary windrow length is less than twice the windrow height, reduce the height and go back to step 2. This indicates the composting configuration will be a compost pile versus a windrow.

Secondary windrow:

(______________) / (______________) = ______________m (ft)

Secondary volume / Primary windrow area = Secondary windrow length (round to nearest 0.3 m [1 ft])

Storage windrow:

(______________) / (______________) = ______________m (ft)

Storage volume / Primary windrow area = Storage windrow length (round to nearest 0.3 m [1 ft])

Pad:

(______________) + (3.05 m [or 10 ft]) = ______________m (ft)

Design windrow length** + 3.05 m [or 10 ft] = Pad length (round to nearest 0.3 m [1 ft])

***Design Windrow Length = the longer of the primary windrow length, or sum of the secondary and storage windrow lengths.*

Step 4 – Calculate composting pad width and area.

Pad width:

3 m [10 ft] + (____________) + 3 m [10 ft] + (__________) + 3 m [10 ft] = ______m (ft)

3 m [10 ft] + Primary windrow base* + 3 m [10 ft] + Secondary windrow base* + 3 m [10 ft] = Pad width

**refer to table in Step 2*

Pad area:

(__________) x (__________) = ______m^2 (ft^2)

Pad length x Pad width = Pad area

Step 5 – Calculate annual sawdust requirements:

Note that this assumes no reintroduction of finished compost to the primary windrow; however, it is recommended that up to 50% of the fresh sawdust requirements be met with finished compost.

Sawdust volume

(__________) x (0.0116) = ______________m^3 (yd^3) =

kg (lb) loss/yr x (use 0.0069 if wt in lb) = sawdust volume

TABLE 5a. Mortality composting using sawdust – bin system for poultry broilers (Keener & Elwell, 2000).

Bin system for poultry broilers:							
Assumptions:							
Number Animals	**10,000**	Design Wt (kg)	**2.0**	Avg Wt. (kg)	**1.9**	Animal Mortality	**0.045**
		Compost Time (day)	**11**	Growth Cycle (day)	**48.0**	Batches/ yr	**7.60**
Total Mortality (kg/yr)	**6,533**	Daily Mortality (kg/day)	**17.9**	Mortality (kg/bin)	**189.9**	Sawdust/ Mortality, v/v	**12**

Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**Wet volume ratio** m^3	**Wet volume ratio** %	**Wet mass ratio** kg	**Wet mass ratio** %
Mortality	45.0	7.50	6.0	65.0	1038	0.18	8	190	18
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	2.20	.92	601	57
Water	0.0	0.00		100.0				260	25
Averages/Sums	43.5	1.20	36.1	53.6	442	2.38	100	1051	100

Volume = 2.38 m^3	Total volume = 2.38 m^3	Cover depth = 0.305 m
Bin height = 1.22 m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.610 m
Bin length = 1.22 m	Side biofilter depth = 0.305 m	Composting vol. = 0.37 m^3
Bin width = 1.60 m	Base height = 0.305 m	Mortality/non-biofilter compost =0.50 m^3/ m^3

TABLE 5b. Mortality composting using sawdust – windrow system for finishing swine (Keener & Elwell, 2000).

Windrow system for finishing swine:							
Assumptions:							
Number Animals	**2940**	Design Wt (kg)	**95.5**	Avg Wt. (kg)	**63.6**	Animal Mortality	**0.030**
		Compost Time (day)	**72**	Growth Cycle (day)	**135**	Batches/ yr	**2.70**
Total Mortality (kg/yr)	**15,175**	Daily Mortality (kg/day)	**41.6**	Mortality (kg/bin)	**3014.0**	Sawdust/ Mortality, v/v	**12**

Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**Wet volume ratio** m^3	**Wet volume ratio** %	**Wet mass ratio** kg	**Wet mass ratio** %
Mortality	37.5	7.50	5.0	75.0	1038	2.90	0.08	3014	0.20
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	34.83	0.92	9542	0.62
Water	0.0	0.00		100.0				2727	0.18
Averages/Sums	42.7	0.95	45.0	51.4	405	37.74	1.00	15283	1.00

Windrow System (length does not include ends):

Volume = 37.74 m^3	Total volume = 37.74 m^3	Cover depth = 0.610 m
Windrow height = 2.13 m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.810 m
Windrow length = 7.28 m	Side bio filter depth = 0.610 m	Composting vol. = 4.77 m^3
Windrow base width = 4.57 m	Base height = 0.610 m	Mortality/non-biofilter compost =0.61 m^3/ m^3

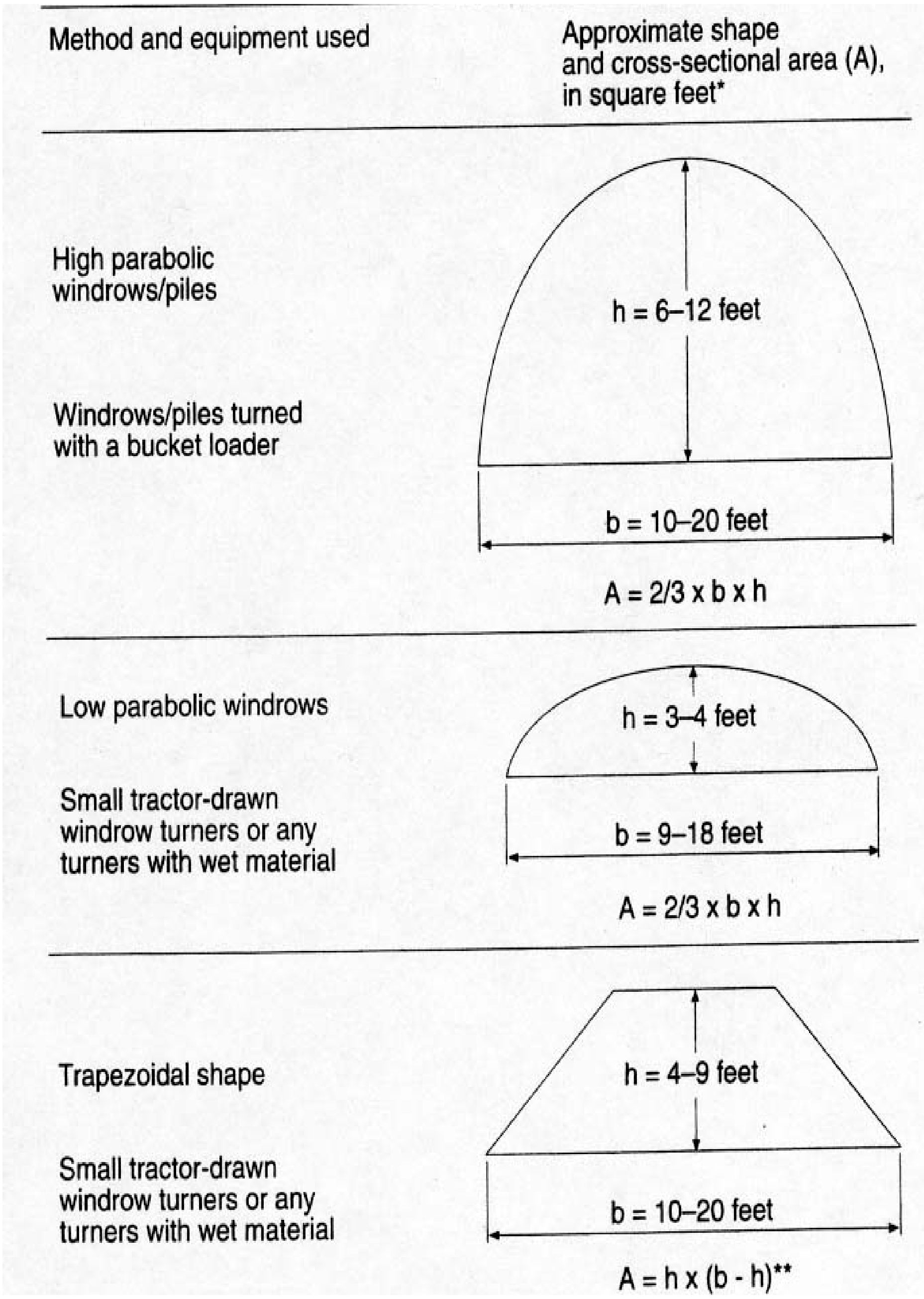
TABLE 5c. Mortality composting using sawdust – windrow system for cattle (mature)

Windrow system for cattle:							
Assumptions:							
Number Animals	**154**	Design Wt (kg)	**636.4**	Avg Wt. (kg)	**626.4**	Animal Mortality	**0.010**
		Compost Time (day)	**187**	Growth Cycle (day)	**365**	Batches/ yr	**1.00**
Total Mortality (kg/yr)	**980**	Daily Mortality (kg/day)	**2.7**	Mortality (kg/bin)	**636.4**	Sawdust/ Mortality, v/v	**12**

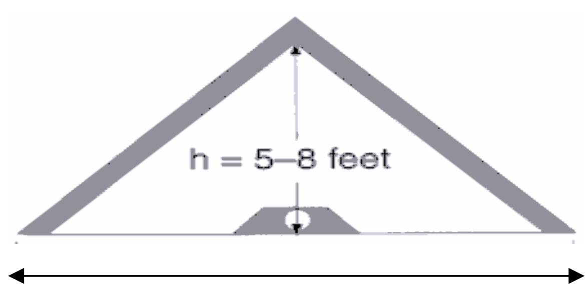
Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**Wet volume ratio** m^3	**Wet volume ratio** %	**Wet mass ratio** kg	**Wet mass ratio** %
Mortality	37.5	7.50	5.0	75.0	1040	0.61	8	636	19
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	7.34	92	2015	60
Water	0.0	0.00		100.0				682	20
Averages/Sums	42.7	0.95	45.0	52.9	419	7.95	100	3333	100

Windrow System (length does not include ends):

Volume = 7..95 m^3	Total volume = 7.95 m^3	Cover depth = 0.610 m
Windrow height = 2.13 0m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.810 m
Windrow length = 1.53 m	Side biofilter depth = 0.610 m	Composting vol. = 1.01 m^3
Windrow base width = 4.57 m	Base height = 0.610 m	Mortality/non-biofilter compost =0.61 m^3/ m^3



Triangular-shaped static piles. Individual aerated static piles and other piles with little or no turning.



A= $\frac{1}{2}$ x b x h, b=2 x h

FIGURE 1. Selected windrow cross-section shapes and their dimensions (Dougherty, 1999).

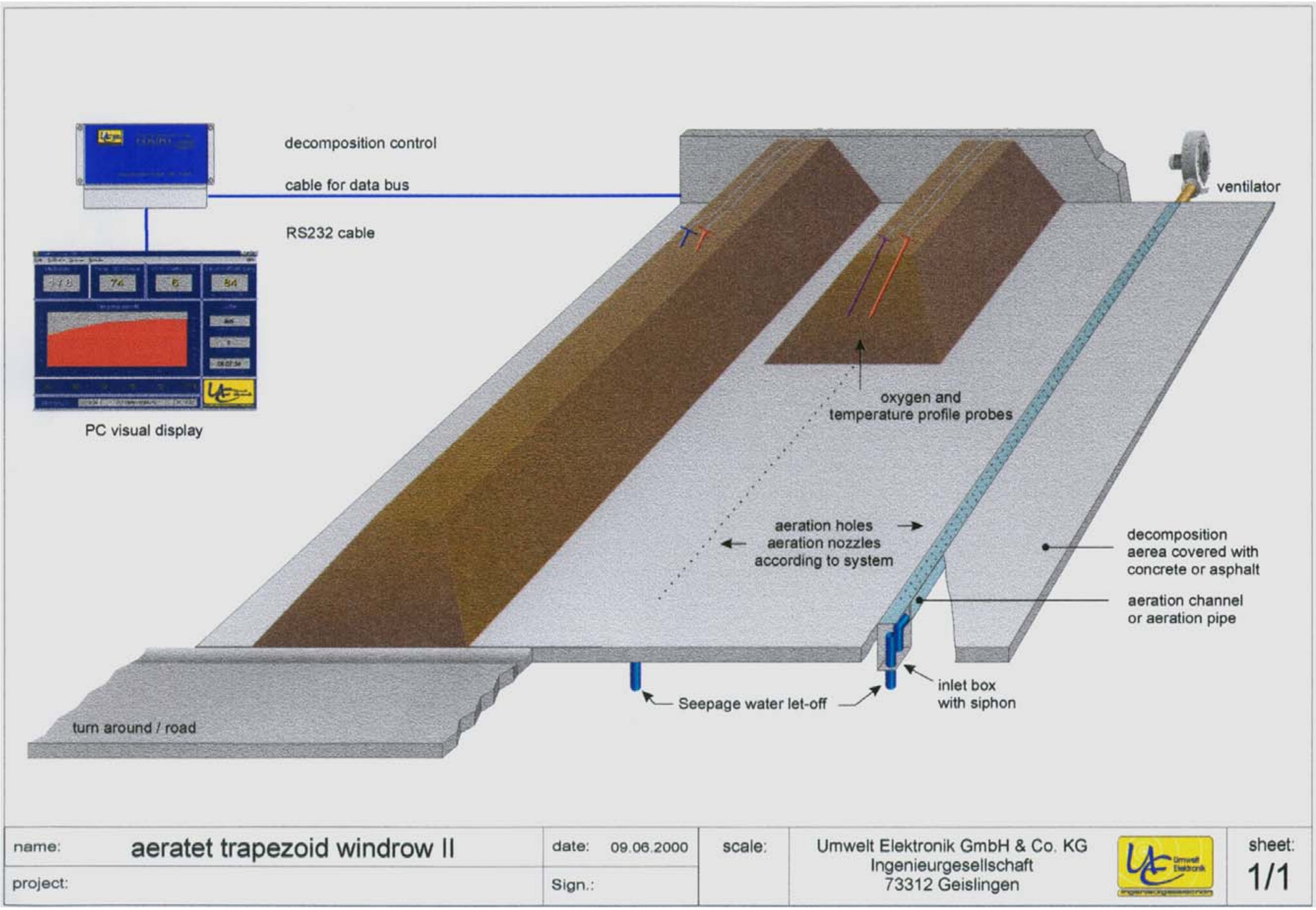


FIGURE 2. The trapezoid cross-section of sophisticated windrow composting along with oxygen and temperature measuring devices and data acquisition system (Umwelt Elektronic GmbH and Co., 2003).

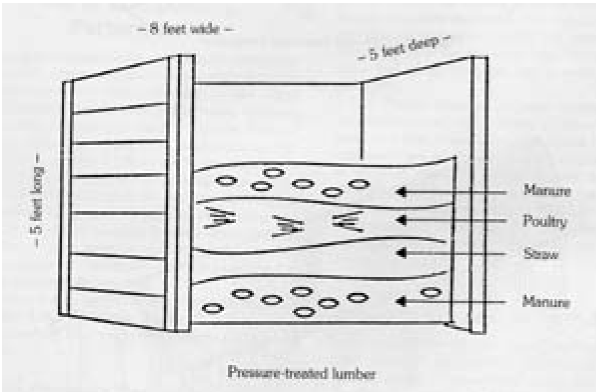


FIGURE 3. A simple poultry composter (Murphy & Carr, 1991).

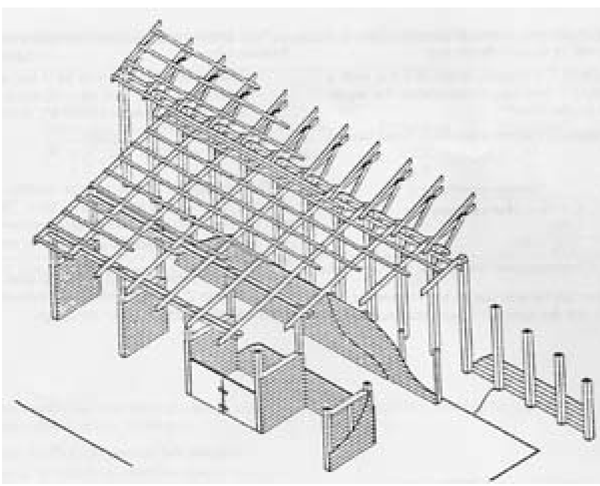


FIGURE 4. Delaware two-stage composter (Murphy & Carr, 1991).

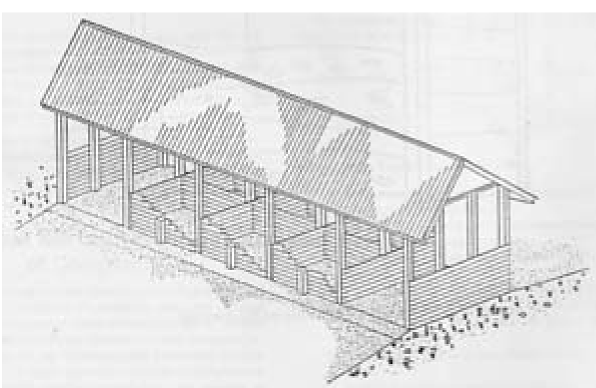
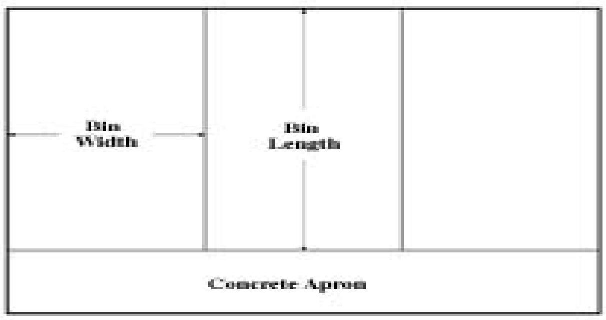
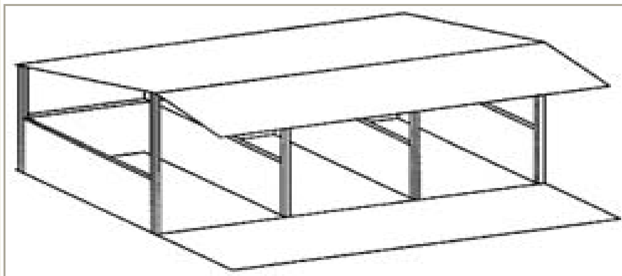


FIGURE 5. Maryland freestanding, two-stage composter (Murphy & Carr, 1991).



a) Bin layout, top view



b) Bin isometric

FIGURE 6. Bin system for composting swine mortality (Mescher et al., 1997*)*.

Appendix E

TABLE 1. Various properties of co-composting materials including C:N ratio, porosity, relative moisture content, degradability, odor level, and treatment required for usage in composting (Dougherty, 1999).

Origin	C:N Ratio, Nutrients	Structure, Porosity	Moisture-as is	Degradability	Treatment Required	Cautions
AGRICULTURAL RESIDUALS						
Poultry manure (fresh, no litter)	10	Poor	Moist	Good	Bulking material	Odor
Poultry manure (with litter)	13-30	Medium	Low-dry	Medium	-	Odor
Slurry(urine) liquid	2-3	Poor	Liquid	Good	Mix with dry matter	Odor
Manure (cattle) liquid	8-13	Poor	Liquid	Good	Mix with dry matter	Odor
Manure (pig)	5-7	Poor	High	Good	-	Odor, moisture
Cattle manure	20	Medium	Medium	High	-	-
Manure with straw	25-30	Good	Good	Medium	-	-
Horse manure	25	Good	Good	Medium	-	-
Vegetable wastes	13	Poor	Moist	High	-	Low pH, odor
Straw: -Oat/rye -Wheat -Barley/pulses	 60; 100; 40-50;	 Good; Good; Good	 Dry; Dry; Dry;	 Medium; Medium; Medium;	 Rough chopping Rough chopping -	 - - -
WOOD AND LUMBER INDUSTRY MATERIALS						
Bark	100-300;low P, Ca; low pH	Very good	Medium; good	Very good	Pre-grind	-
Paper sludge	100-110	Medium to poor	Very moist	Medium	Press cake	Dioxins
Cotton sludge	20-40; N-rich; low P,K	Poor	Very moist	Very good	Pressed	-
Sawdust:	Beech ~ 100 Fir ~230 Aged <100	Very good	≤ 50%; good	Excellent	Already ground	-
Cardboard	200-500	Medium to poor	Very low	Very good	Shred	Boron, colors

Wood ash [a]	n/a; K-Ca^- Rich; High in heavy metals	Poor	Very low	None	None	Metals, high pH
FRUIT PRESSING PRESIDUES						
Grapes	Poor in P, Ca	Poor/medium	Medium	Medium to low	Lime addition	Low pH, seed residues
Fruits	Poor in P, Ca	Poor	Medium	Fair to good	Lime addition	Low pH
GARDEN/ LANDSCAPE MATERIALS						
Wood chips	40-100	Good	Too dry	Low	Grinding	Coarseness
Garden wastes	20-60	Good	Medium	Medium	Grinding	-
Green foliage	30-60	Medium to good	Good/dry	Good	-	-
Leaves	-	Good	-	-	-	Matting
Grass clippings	12-25	Poor	Moist	High	Bulking material, pre-drying	Odor
Reeds/ swamp matter	20-50	Good	Dry	Medium	Grinding	Coarseness
Ditch scrapings	10-15	Poor	Moist	Medium	Occasionally Pressing	Salts/ lead on road-sides
OTHERS						
Peat (dark)	60-80	Good	Medium	Very low	-	Low pH
Peat (light)	60-80	Good	Medium	Low	-	Low pH
Slaughter wastes	15-18	Poor	Moist	High	-	Odor
Mushroom compost	40	Good	Good	Good/medium	-	-
Rock powders [b]	Ca, K, Mg, trace elements	Poor	None	None	-	-
MSW[c]	30-120	Medium to poor	Very low	Medium	Grinding, moisture	Metals, glass,etc
Biosolids(sewage sludge)	<20; high K, salt	Poor	High	Very good	Needs bulking material	Pathogens, metals
Food scraps	<25; high K, salt	Very poor	High	Very High	Bulking material	Pathogens, salt
Coffee grounds	-	Medium	Medium to high	Medium	-	-

TABLE 2. C:N ratios of various supplement materials used for carcass composting (Morse, 2001).

Substance	(W/W)
Sawdust[a]	200-750:1
Straw[a]	48-150:1
Corn stalks[a]	60-73:1
Finished compost[a]	30-50:1
Horse manure[a]	22-50:1
Turkey litter[a]	16:1
Animal carcass[b]	5:1
Swine manure[b]	1-3:1

[a]On-Farm Composting Handbook, NRAES-54, Natural Resource, Agriculture, and Engineering Service, Ithaca, New York.

[b] Compost Materials, 1996, EBAE 172-93, North Carolina Cooperative Extension Service, Raleigh, North Carolina.

TABLE 3. A compost recipe that satisfies the nutritional requirements for composting poultry mortalities (Sussman, 1982).

Ingredient	Volume ratio	Weight ratio	Weight	%	% moisture	C:N ratio
Manure	2.0	1.5	675 kg (1500 lb)	57.7	30	25
Dead birds	1.0	1.0	450 kg (1000 lb)	38.5	70	5
Straw	1.0	0.1	45 kg (100 lb)	3.8	10	85
Total			1170 kg (2600 lb)	100		
Weighted average					44.6	19.6

TABLE 4. Recommended conditions for active composting (Rynk,1992).

Parameter	Target range [a]
Carbon-to-nitrogen (C:N) ratio[b]	20:1-40:1
Moisture content[c]	40-65%
Oxygen concentration[d]	>5%
Particle size (diameter in inches)	0.5-2
Pile porosity	>40%[c]
Bulk density	474-711 kg/m^3 (800-1,200 lb/yd^3)
pH	5.5-9
Temperature (ºF)	110-150

[a] Although these recommendations are for active composting, conditions outside these ranges may also yield successful results.

[b] Weigh basis (w:w). C:N ratios above 30 will minimize the potential odors.

[c] Depends upon the specific materials, pile size, and/or weather conditions.

[d] An increasing likelihood of significant odors occurs at approximately 3% oxygen or less. Maintaining aerobic conditions is key to minimizing odors.

TABLE 5. Selected compost equipment: available capacity and horsepower ranges (Dougherty, 1999).

	Type & Description	Horsepower HP	Approximate Capacity yd^3/hr	Ton/hr
	Grinding/Shredding Equipment			
	Hand-fed chipper(disc-type) – max. diameter of materials 5-6 in	20-30		
	Hand-fed chipper (disc-type) – max. diameter of materials 9-12 in	35-120		
	Hammer mill	30-900	8-450	4-225
	Paper and wood shredder	2-100	1-30	0.5-15
	Rotary auger with counter knife	22-335	2-130	1-65
1[a]	Rotary shear shredder	7.5-600	0.4-200	0.2-100
2	Shear shredder (belt-type)	5-110	10-250	5-125
	Shredder with knives fixed to set of rotating disks	30-60	4-12	2-6
3	Tub grinder	80-990	20-200	10-100
	Vertical grinder	100-400	8-50	4-25
	Vertical grinder- large capacity	1,000-2,000	100-450	50-225
	Whole-tree-chopper-disc-type (towed or self-propelled) – max. diameter of materials 12-17 in	170-250		
	Whole-tree-chopper-disc-type (towed or self-propelled) – max. diameter of materials 19 in	400-500		
	Wood-chipper-cutting disc-type – max diameter of materials 6-9 in	20-40		
	Mixing Equipment			
4	Batch-mixer- auger -type (10-30-cubic-yard capacity while mixing)	75-165	40-100	20-50
	Batch-mixer-reel-type (4-18-cubic yard capacity while mixing)	10-50		
5	Rotating drum mixer		12-160	6-80
6	Continuous mix plug mill	10-100	2-1,000	1-500

[a]1-6 correspond to numbered items in Figure 1, Appendix E, below.

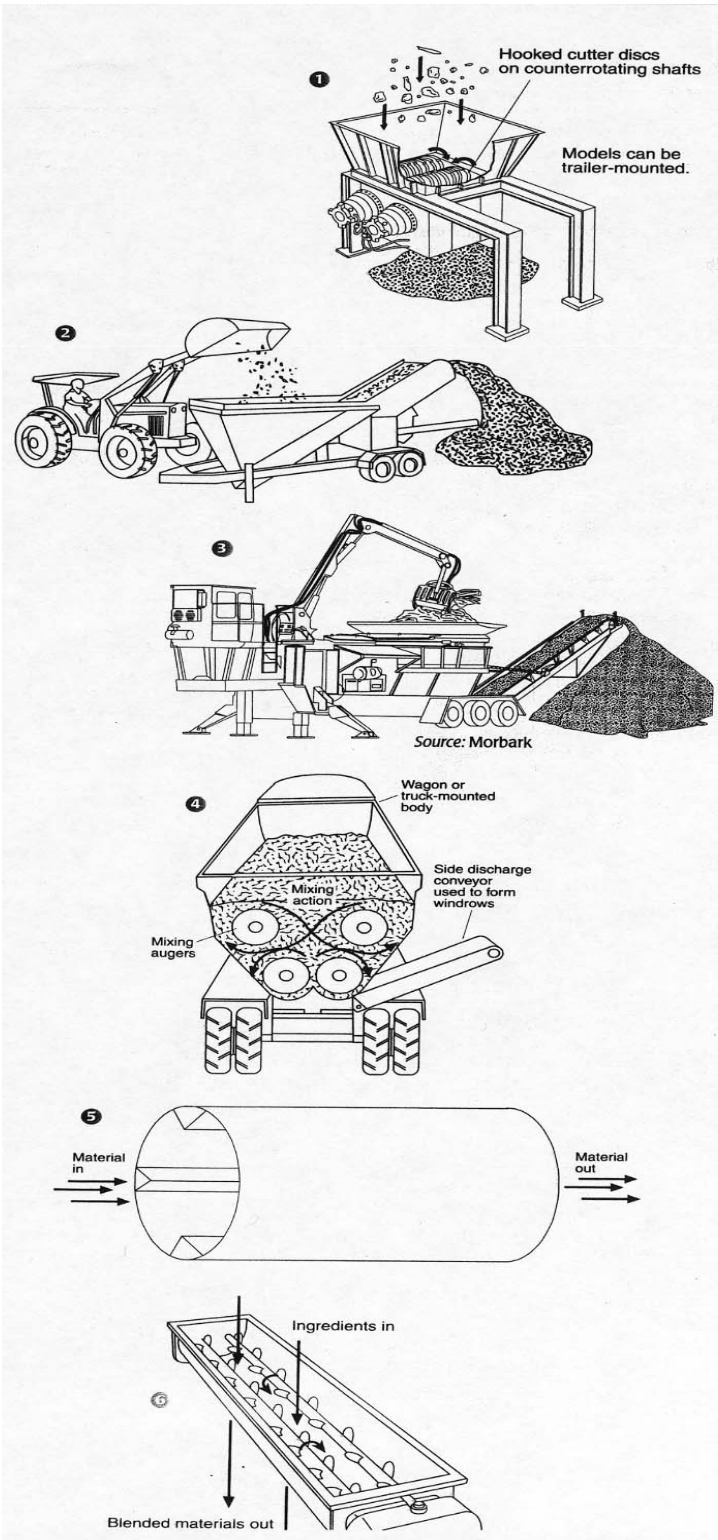


FIGURE 1. Selected compost equipment (Dougherty, 1999). Numbered items correspond to items in Table 5, Appendix E, above.

TABLE 6. Selected self-powered windrow turning equipment and associated cost (Diaz et al., 1993).

Manufacturer	Power (HP)	Capacity (TPH)	Approximate Cost (US$, 1991)
Brown Bear	115	1,500	$118,000
Brown Bear	225	3,000	$181,000
Cobey	225	1,000-2,000	$135,000-185,000
Resource Recovery Systems	300	2,000	$104,000
Resource Recovery Systems	400	3,000	$170,000
Scarab	234	2,000	$104,000
Scarab	360	3,000	$174,000
Scat	107	3,000	$176,000

TABLE 7. Selected PTO-driven windrow-turning equipment and associated cost (Diaz et al., 1993).

Manufacturer	Power (HP)	Capacity (TPH)	Approximate Cost (US$, 1991)
Centaur Walker	90	800	$7,400
Scat	65	2,000	$55,000
Wildcat	70	1,000	$46,500

FIGURE 2. The PTO PA35C-10.5 compost turning unit is designed to be attached to the front of 100-160 HP farm tractors (Brown Bear Corp., 2003).

TABLE-8. Selected compost windrow turning machinery and screening equipment with available capacity and horsepower ranges (Dougherty, 1999).

	Type & Description	Horsepower HP	Approximate Capacity yd^3/h	Approximate Capacity Tons/h
	Windrow Turning Machinery			
1[a]	Aerator-composter (PTO powered, rear-hitch-mounted to 60-130 hp tractor)	Tractor PTO	400-2,400	(200-1,200)
2	Aerator-auger (mounted on front of 40-130 hp tractor)	Hydraulics		
	Auger-style turner (self powered, self propelled)	115-300	2,000-40,000	(1,000-20,000)
3	Elevated face turner (self powered, towed by 40-100 hp tractor)	65-85	3,000-4,000	(1,000-3,000)
	Elevated face turner (self powered, self propelled)	100-150	2,000-6,000	(1,000-3,000)
4	Rotary drum turner (ground-driven, towed by 35-70 hp tractor)		1,200-1,800	(600-900)
5	Rotary drum turner (self powered, self propelled)	65-440	1,600-8,000	(800-4,000)
6	Rotary drum turner (PTO powered, towed by 60-140 hp tractor)	Tractor PTO	400-1,000	(200-500)
7	Rotary drum turner (self- powered, towed by 70 hp tractor)	90-125	1,800-2,200	(900-1,100)
	Rotary drum turner (self- powered, mounted on 3-cubic-yard front-end loader)	170-190	1,800-2,200	(900-1,100)
	Rotary drum turner (self- powered, mounted on 4-cubic-yard front-end loader)	325	5,000	(2,500)
	Screening Equipment			
	Disc Screen		20-80	(10-40)
	Flexible belt screen		30-200	(15-100)
	Oscillating (shaker) screen		Variable	
8	Trommel screen		20-150+	(10-75+)
9	Vibrating screen		50-150+	(25-75+)

[a]1-9 correspond to numbered items in Figure 3, Appendix E, below.

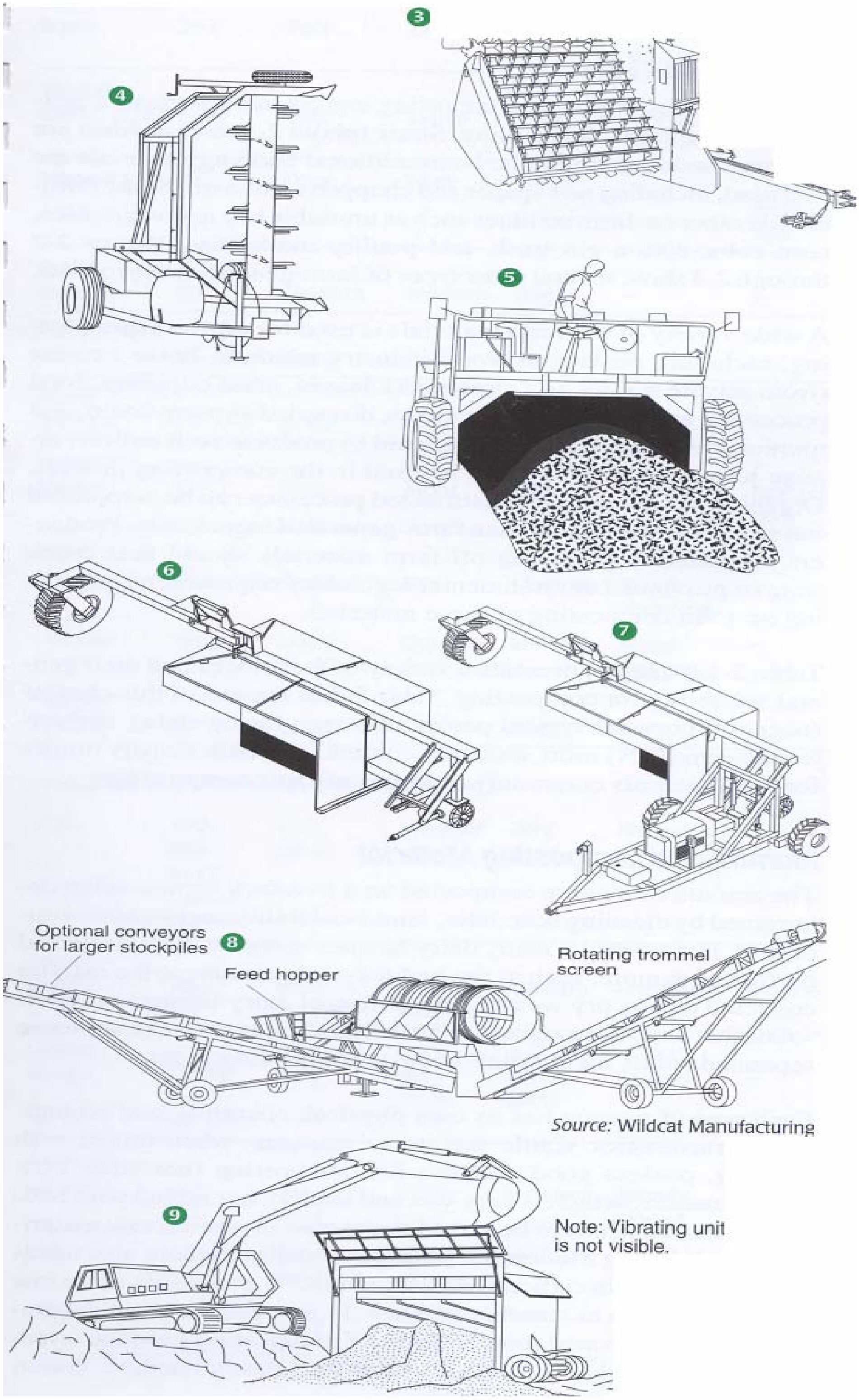


FIGURE 3. Selected compost equipment (Dougherty, 1999). Numbered items correspond to Table 8, Appendix E, above.

Appendix F

TABLE 1. Nutrient content of poultry manure (litter) and composted poultry mortalities (Murphy & Carr, 1991).

Analyte	Built up litter	Dead bird compost
Moisture, %age	21.00	46.10±2.19
Nitrogen, %age	4.15	2.20± 0.19
Phosphorus(P_2O_5), %age	3.80	3.27± 0.23
Potash (K_2O), %age	2.85	2.39±0.13
Calcium, %age	1.70	1.33±0.15
Magnesium, %age	0.91	0.82±0.10
Sulfur, %age	0.51	0.40±0.02
Manganese, parts per million	208.00	122.00±18.00
Zinc, parts per million	331.00	245.00±32.00
Copper, parts per million	205.00	197.00±28.00 <>

TABLE 2. Nutrient content of "active" sawdust–piglet mortality compost from mini-composter (Harper et al., 2001).

Unit	Moisture	Total-N	NH_4-N	P_2O_5	K_2O	Ca	Mg
%	32.4	1.59	.36	2.04	.28	1.58	.15
lbs./US ton (2,000lb)	648	31.75	7.27	40.89	5.58	31.52	2.98
kg/metric ton (1,000kg)	324	15.88	3.69	20.45	2.79	15.76	1.49

TABLE 3. Typical composition of composted carcasses (McGahan, 2002).

Nutrient	%	kg/metric ton
Total nitrogen (TKN-N)	1.28	13.00
Ammonia (NH_3-N)	0.22	2.00
Phosphorus (P)	0.27	2.84
Potassium (K)	0.28	2.90

TABLE 4. Nutrient content of the end product of cattle carcass composting (Kube, 2002).

Nutrients	kg of nutrients/US ton (2000 lb) of compost	kg of nutrients/metric ton (1000 kg) of compost
Total Kjeldahl Nitrogen	10-25	5-12.5
i. Potentially available nitrogen:	5-15	2.5-7.5
ii. Phosphorus:	2-20	1-10
iii. Potassium:	4-20	2-10

FIGURE 1. Condition of large bones at the end of carcass composting trials (Mukhtar et al., 2003).

Appendix G

TABLE 1. Effects of long- and short-term aeration on operational and fixed costs of windrow composting (Umwelt Elektronic GmbH and Co., 2003).

	Example 1	Example 2	Example 3
Input t/a	10.000	10.000	10.000
Period of main decomposition	8 weeks aerated	4 weeks aerated	25 weeks not aerated
Period of subsequent decomposition	2 weeks not aerated	12 weeks not aerated	-
Area of main decomposition	1,870 m^2	918 m^2	4,726 m^2
+ area roads	561 m^2	275 m^2	1,418 m^2
Area of subsequent decomposition	325 m^2	1,900 m^2	
+ area roads	98 m^2	570 m^2	
+ area for storage	282 m^2	282 m^2	282 m^2
Sum area	**3,136 m^2**	**3,945 m^2**	**6,426 m^2**
Capital costs per ton input	€34.60	€29.84	€35.74
(Without site costs)	(Without aeration and control)	(Without aeration and control)	(Without aeration and control)
Re-stacking costs per ton	-	€3.52	€7.03
Energy costs for main decomposition per ton	€0.64	€0.32	-
Necessary sum per ton required for redemption per ton for a plant use of 15 years	€4.24	€6.89	€10.56
OR: reduced redemption period in reference to a plant without aeration	6 years	9.8 years	15 years

TABLE 2. Number of livestock operations assumed large enough to install composting facilities (SCI, 2002).

Species	Total Number of US Operations	Large Operations[a]	
		Criteria	Number
Beef cattle	830,880	>50 Head	177,330
Dairy cattle	105,250	>30 Head	74,140
Hogs	81,130	>500 Head	35,118
Other	71,340[b]	--	20,000
Total	1,088,600		306,588

[a]Based on most recent USDA/NASS cattle, hogs and pigs, and sheep and goat reports.
[b]Estimated number of sheep, lamb, and goat operations.

TABLE 3. Economic analyses (annual net cost) of dead-bird disposal systems for a flock size of 100,000 birds (Crews et al., 1995).

Item	Existing Technologies			Emerging Technologies		
	Disposal Pit	Large-Bin Compost	Incineration	Small-Bin Compost	Fermentation	Refrigeration
Initial investment cost	$4,500	$7,500	$2,000	$2,016	$8,200	$14,500
Annual variable cost	$1,378	$3,281	$4,833	$3,661	$2,862	$5,378
Annual fixed cost	$829	$1,658	$522	$297	$1,190	$2,670
Annual fixed cost	$829	$1,658	$522	$297	$1,190	$2,670
Total cost	$2,207	$4,939	$5,355	$3,958	$4,052	$8,048
Value of by-product	$0	$2,010	$0	$1,860	$1,320	$1,200
Annual net cost	$2,207	$2,929	$5,355	$2,099	$2,732	$6,848
Cost per hundred-weight of carcass disposed	$3.68	$4.88	$8.92	$3.50	$4.55	$11.41

* **Key production and financial assumptions:**
Average weight of carcass (lbs.) 2.00
Length of grow-out cycle (days) 45.00
Cost of compost removal ($/ton) 7.00
Value of straw ($/ton) 60.00
Value of litter ($/ton) 20.00
Value of compost by-product ($/ton) 20.00
Value of fermented by-product ($/lb.) 0.02
Value of refrigerated by-product ($/lb.) 0.02
Mortality (%) 5.00
Flocks/batches per year 6.00
Labor rate ($/hr.) 5.00
Fuel/butane ($/gal.) 0.62
Tractor fuel ($/gal.) 0.83
Cost of electricity ($/kwh.) 0.08
Cost of carbohydrate ($/lb.) 0.07

TABLE 4. Variable costs of composting mortalities on-farm (SCI, 2002).

Species	Deaths		Sawdust		Operating Costs ($1,000)[a]		
	Number (1,000)[a]	Pounds (1,000)[a]	Volume (yd^3)	Cost ($1,000)[a]	Labor	Machinery ($/head)	Total ($/head)
Cattle & Calves	4,131.8	1,932,180	12,945.61	15,728.91	48,758.94	60,863.67 **(14.73)**	125,351.52 **(30.34)**
Weaned Hogs	6,860.0	915,249	6,132.17	7,450.58	21,737.16	28,830.34 **(4.20)**	58,018.09 **(8.45)**
Pre-weaned Hogs	11,067.7	66,406,	444.92	540.58	1,577.14	2,091.79 **(0.19)**	4,209.51 **(0.38)**
Other	832.7	64,105	429.50	521.85	1,522.49	2,091.31 **(2.51)**	4,063.65 **(4.88)**
Total							$191,642.77

[a]Where indicated, multiply values in the table (except $/hd) by 1000 to obtain actual values.

TABLE 5. Fixed investment costs of constructing on-farm composting facilities (SCI, 2002).

Species	Number of Facilities	Investment Cost/Facility	Total Investment Cost x$1,000
Beef Cattle	177,330	$7000	$1,241,310
Dairy Cattle	74,140	$7000	$518,980
Hogs	35,118	$7000	$245,826
Other	20,000	$7000	$140,000
Total	306,588		$2,146,116

TABLE 6. Budgeted annual costs for disposing of mortality from a pork production system with a mortality rate of 40,000 pounds per year – 300-sow farrow-to-finish system (Henry et al., 2001).

	Incineration without afterburner	Incineration with afterburner	Composting High investment	Composting Low investment	Rendering Four pickups/week
Disposal equipment	Incinerator and fuel tank	Incinerator and fuel tank	Compost bins and building	Compost bins	Screen storage area
Capital investment	$3,642	$4,642	$15,200	$7,850	$300
Other equipment needed	--	--	Skid Steer Loader Tractor Manure spreader	Skid Steer Loader Tractor Manure spreader	Skid Steer Loader
Labor hours per year	60.7	60.7	115.0	125.9	60.7
Budgeted Annual Costs	$710.19	$905.19	--	--	$51.00
Fixed costs-disposal equipment	--	--	$2,305.33	$1,190.58	--
Machinery costs	--	--	382.19	447.39	364.00
Fixed Operating	--	--	254.79	298.26	242.67
Other operating costs	572.00	1341.44	320.00	320.00	5,200.00
Labor	667.33	667.33	1,265.15	1,384.68	667.3
Total cost per year	$1,949.52	$2,913.96	$4,527.47	$3,640.92	$6,525.00
Total cost per pound of mortality	$0.049	$0.073	$0.113	$0.091	$0.163

TABLE 7. Estimated costs of composting cattle carcasses with three different options (Kube, 2002).

Item	No grind	Grind compost	Grind deaths
Lime base	$20/hd initial base preparation $5-8/hd after removal of a cured windrow		
Payloader	$3-8/hd		
Sawdust	$10-15/hd		
Grinder	$0	$3/hd	$6/hd
Time	12 months	9 months	6 months
Turns or grinds	3	2	1
Area (sq ft)	60-120/hd/yr	45-90/hd/yr	30-60/hd/yr
Cost of land application	$7-15/hd		
Total cost (excluding site preparation)	$25-52/hd		

TABLE 8. Characteristics and value of final product obtained from windrow composting of cattle carcasses (Kube, 2002)**.**

Characteristic	Value
Density of finished compost	about 652 kg/m^3 (1,100 lb/yd^3)
Volume of compost resulting per carcass	approximately 2.66 m^3 (3.5 yd^3) approximately 0.76 m^3 (1 yd^3) from carcass and 1.9 m^3 (2.5 yd^3) from amendment
Weight of compost resulting per carcass (wet-basis)	approximately 3,000 lb about 1,000 lb from carcass and 2,000 lb amendments
Value of compost from nutrients	$5-$15/ton
Nutrient value of compost per head	$10-$30

Appendix H

TABLE 1. Summary of virus isolations obtained from compost and composted bird samples (Murphy & Carr, 1991).

Sample identification	Area sampled		
	Neck	Bursa	Other
Positive control	2/4[a] (NDV[b])	4/4 (IBDV[c])	--
11 days (primary)	0/8	2/8 (IBDV)	--
18 days (secondary)	Not tested	0/7	--
Compost 3/2/89	--	--	0/3

[a] Number of samples containing viable virus over the total number assayed.
[b] Newcastle disease virus.
[c] Infectious Bursal Disease Virus.

Appendix I

TABLE 1. Some entities (schools and governmental agencies) involved in "carcass composting" training.

Name of the organization and academic institution:	Means of education	Link
Compost Education and Resources for Western Agriculture (CERWA), is a Professional Development Project funded by the Western Region SARE - USDA, 1998-2000.	This site provides the Internet links to course resources that covered everything from safety issues, basic biology, journal articles, compost quality, and videotapes.	http://www.aste.usu.edu/compost/qanda/mortc.pdf
Cornell University: Program Work Team (PWT).	1.Provides information on the internet, 2. Communication with other PWT, providing report to see the progress of the activities about the issues.	http://www.cfe.cornell.edu/wmi/PWTminutes.html
Cornell Waste Management Institute: Cornell University	Videotapes and information on the web.	http://www.cfe.cornell.edu/wmi/Compost/naturalrendering.pdf
Iowa State University (Funded by The Leopold Center for Sustainable Agriculture)	Conferences and workshops for farmers, landowners, educators, and researchers, and facilities construction for the swine hoops systems initiative	http://extension.agron.iastate.edu/immag/pr/Leopold.html
Maryland Cooperative Extension supported by the federal government, research and programs from other universities. They have composting school program (Better Composting School) which provides basic information on dead animal composting	School Program: Classes, tour to the compost facility. The Extension service also provides information on the web regarding animal mortality composting.	http://www.agnr.umd.edu/MCE/Publications/Category.cfm?ID=C http://www.agnr.umd.edu/users/wye/BetterCompSch.html
Michigan Agriculture Environmental Assurance Program (MAEAP).	Meeting, seminar, workshop to provide important updates for farmers across state.	http://www.michigan.gov/minewswire/0,1607,7-136-3452_3457-58142--,00.html
Natural Resource, Agriculture, and Engineering Service (NRAES): An interdisciplinary, issue-oriented program sponsored by cooperative extension of fourteen member land grant universities.	Videos, Hand books, Seminars	http://www.nraes.org/publications/n_pubs7.html
Ohio State University Fact Sheet (Extension). (Food, Agricultural and Biological Engineering Department).	Information on the Web	http://ohioline.osu.edu/aex-fact/0713.html
Texas A & M University, Commerce.	Information provided on web.	http://www7.tamu-commerce.edu/agscience/res-dlc/dairy/dlc-dair.html
Texas A & M University, Extension.	Provides useful links covering basic information including materials and processes of composting	http://agsearch.tamu.edu/cgibin/htserach
University of Arkansas	Information on the web	http://www.uaex.edu/Other_Areas/publications/HTML/MP397/Recipe

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

4

Rendering

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Abbreviations & Definitions

Though most of the terms related directly and indirectly to carcass rendering have been defined to some extent in the text, for convenience the following glossary of technical terms is provided. Definitions were adopted from Franco and Swanson (1996), Pocket Information Manual (2003), Morehead and Morehead (1995), and Merriam-Webster's Dictionary (2003).

AAFRD: Alberta Agriculture, Food and Rural Development.

Animal fat: An aggregate term generally understood to be fat from mammals.

Anvils: Raised rectangular solid sheet teeth in some of the reducing size equipment.

APHIS: Animal and Plant Health Inspection Service

AUSVETPLAN: Australian Veterinary Emergency Plan, Agricultural and Resource Management Council of Australia and New Zealand.

BOD (biochemical oxygen demand): The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. Normally five days at 20°C unless otherwise stated. A standard test used is assessing the biodegradable organic matter in municipal wastewater.

BSE: bovine spongiform encephalopathy

Byproducts: All discarded material from animals or poultry and other sources that are processed in a rendering plant.

Composting: A natural biological decomposition process that takes place in the presence of oxygen (air).

Carcass meal: Proteinaceous solids.

Centrifuge: Machine used radiating force to separate materials of different densities.

COD (chemical oxygen demand): A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand.

Clostridium perfringens: An indicator microorganism, which shows the sterilizing effect of rendering procedures.

Cooker: Horizontal, steam-jacketed cylinder equipped with a mechanical agitator. Raw material is heated to certain conditions and according to a repetitive cycle.

Continuous cooker: heating equipment used in rendering process, where the raw material through the system is flowing in an essentially constant manner and without cessation or interruption.

Cracklings: Solid protein material discharged from screw press of rendering process and after removal of liquid fat.

Crusher: Machine containing blades or knives that grind raw material to uniform size.

D Value: The time in minutes required to destroy 90 percent (or a one-log cycle) of a population of cells at a given reference temperature.

Digestibility: The Percentage of feeding stuff taken into the digestive tract that is absorbed into the body.

Dry matter: The portion of a substance that is not comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%)

Edible rendering: Fats and proteins produced for human consumption which is under the inspection and processing standards established by the US Department of Agriculture, Food and Safety Inspection Service (USDA/FSIS).

Edible tallow: Exclusively beef, this product is rendered from fat trimmings and bones taken from further processing at a slaughterhouse. Because of the associated processing and the limits of raw material, the product of light color and low moisture, insolubles, unsaponifiables, and free fatty acids. The tallow may be further refined, polished, and deodorized to become a cooking fat. The pet food industry generally uses the crude product not shipped under seal. This often is referred to as technical tallow.

END: exotic Newcastle disease

EPAA: Environment Protection Authority of Australia

FDA: US Food and Drug Administration

FMD (foot and mouth disease): A highly infectious viral infection of cattle, pigs, sheep, goats, buffalo and artiodactyls wildlife spies characterized by fever, vesicles (blisters) in the mouth and on the muzzle, teats, and/or feet; and death in young animals. Affected animals may become completely incapacitated or be unable to eat/drink due to pain associated with the vesicles.

FFA: free fatty acids

Grax: Suspended solid proteins.

Greaves: A high-protein solid which is left following the extraction of tallow from animal by-products during the rendering process with further processing this becomes MBM.

HACCP: hazard analysis critical control point

Hasher: A chopper of materials (a French word).

HTR: high temperature rendering

Ileal: The last division of the small intestine extending between the jejunum and large intestine.

Independent rendering plant: Obtains its byproduct material from a variety of sources and especially dead animals which are off-site or separate from the plant facility.

Inedible products: Fats and proteins produced from dead animals for feeding the animals with certain specifications and for other non-edible uses.

Integrated or dependent rendering plant: Operates in conjunction with a meat slaughterhouse, or poultry processor whose byproduct materials are processed on-site.

KOFO: Kodfodfabrikken Ostjyden

Lard or edible grease: Fat which is obtained from the pork tissue by the rendering process and its production is very similar to tallow.

LTR: low temperature rendering

MBM (meat and bone meal): Meat and bone meal is prepared from the rendering of dead animals or wastes materials associated with slaughtering operations (carcass trimmings, condemned carcasses, condemned livers, inedible offal (lungs) and bones). It is basically dry rendered protein product from mammal tissues with more than 4.4Percent phosphorus.

NCSART: North Carolina State Animal Recovery Team

Offal: All material from the animal's body cavity processed in a rendering plant.

Percolating pan: A tank with a perforated screen through which the liquid fat drains freely and separates from the tankage.

Post-rendering process: Screening the protein and fat materials, sequential centrifugations for separation of fat and water, drying and milling of protein materials.

Pre-rendering process: Size reduction and conveying.

Rendering process: A process of using high temperature and pressure to convert whole animal and poultry carcasses or their by-products with no or very low value to safe, nutritional, and economically valuable products. It is a combination of mixing, cooking, pressurizing, fat melting, water evaporation, microbial and enzyme inactivation.

***Salmonella*:** Human pathogen that causes gastro-intestinal problems.

SBO: specified bovine offal

SCI: Sparks Companies, Inc.

Screw press: Machine used to separate fat from tankage continuously by applying the required pressure with a rotating screw.

Scrubber: Pollution control device for containing air exhausted from rendering plant with a water solution containing deodorizing chemicals for odor removal.

Sewage: Refuse liquids or waste matter carried off by sewers.

Sterilization: Sterilization is based on a statistical probability that the number of viable microorganisms will remain below an specified level after heating process (particularly temperature, time and pressure) and is dependent upon the overall heat transfer coefficient (conductive and convective) of cooking materials, which can determine the lethal effect of the heat.

Stick liquor or stick water: The viscous liquid left in the rendering tank after cooking process.

Tallow: The white nearly tasteless solid rendered fat of cattle and sheep which is used chiefly in soap, candles, and lubricants.

Tankage: Cooked material remaining after the liquid fat is drained and separated.

TDH: Texas Department of Health

Tricanter: A vessel used to separate three phases of small solid protein particle, water and fat solutions.

TSE: transmissible spongiform encephalopathy

UKDEFRA: United Kingdom Department for Environment, Food and Rural Affairs

US: United States

USDA: US Department of Agriculture

USEPA: US Environmental Protection Agency

Wet rendering: A method of batch rendering in which the raw material is subjected to a temperature of 140°C under high pressure generated either by injecting steam into the cooker, or by allowing the steam from moisture in the raw material to build up.

Yellow grease A or B; no 1, no 3 tallow: These result from the poorer pork and beef sources of raw material. Free fatty acid range up to 35%, and color can be as high as 37 FAC. (FAC is the abbreviation of the Fat Analysis Committee of the AOCS.) Often referred to as feed fats, they come from spent frying oils and animal fats. They may be animal or vegetable. A sample of fat is filtered then compared with standard color slides mounted on a circular aperture. FAC color standard runs from 1-45 using odd numbers divided into five series for grading:

1-9 = Light colored fats 11,11A, 11B, 11C =Very yellow fats,

13-19 = Dark, reddish fats. 21-29= Greenish fats 31-45= Very dark fats

The different series are somewhat independent so there is no orderly increase in the color from the lowest to the highest numbers, i.e., fats graded 21-29 may actually be lighter than those graded 13-19. The FAC method is used when fats are too dark or green to be read by the lovibond method.

Z value: The temperature increase required to reduce the thermal death time by a factor of 10 (or a one-log cycle

Section 1 – Key Content

This chapter provides a discussion of various aspects of carcass rendering, including effective parameters, raw materials, heat-energy, specifications, machinery, necessary equipment, cost analysis, and environmental impacts. This information has been adopted from Pelz (1980), Thiemann and Willinger (1980), Bisping et al. (1981), Hansen and Olgaard (1984), Clottey (1985), Machin et al. (1986), Kumar (1989), Ristic et al. (1993), Kaarstad (1995), Expert Group on Animal Feedingstuffs (1992), Prokop (1996), Haas et al. (1998), Turnbull (1998), United Kingdom Department for Environment, Food and Rural Affairs or UKDEFRA (2000), Mona Environmental Ltd. (2000), Ockerman and Hansen (2000), Texas Department of Health or TDH (2000), Food and Drug Administration or FDA (2001), Romans et al. (2001), Alberta Agriculture, Food and Rural Development or AAFRD (2002), Arnold (2002), Atlas-Stord (2003), Dormont (2002), Environment Protection Authority of Australia or EPAA (2002), UKDEFRA (2002), US Environmental Protection Agency or USEPA (2002), Giles (2002), Ravindran et al. (2002), Sander et al. (2002), Sparks Companies, Inc., or SCI (2002), Hamilton (2003), Kaye (2003), Pocket Information Manual (2003), Morley (2003), Pearl (2003), Provo City Corporation (2003), Scan American Corporation (2003), and The Dupps Company (2003).

1.1 – Definition and Principles

Rendering of animal mortalities involves conversion of carcasses into three end products—namely, carcass meal (proteinaceous solids), melted fat or tallow, and water—using mechanical processes (e.g., grinding, mixing, pressing, decanting and separating), thermal processes (e.g., cooking, evaporating, and drying), and sometimes chemical processes (e.g., solvent extraction). The main carcass rendering processes include size reduction followed by cooking and separation of fat, water, and protein materials using techniques such as screening, pressing, sequential centrifugation, solvent extraction, and drying. Resulting carcass meal can sometimes be used as an animal feed ingredient. If prohibited for animal feed use, or if produced from keratin materials of carcasses such as hooves and horns, the product will be classified as inedible and can be used as a fertilizer. Tallow can be used in livestock feed, production of fatty acids, or can be manufactured into soaps.

1.2 – Livestock Mortality and Biosecurity

Livestock mortality is a tremendous source of organic matter. A typical fresh carcass contains approximately 32% dry matter, of which 52% is protein, 41% is fat, and 6% is ash. Rendering offers several benefits to food animal and poultry production operations, including providing a source of protein for use in animal feed, and providing a hygienic means of disposing of fallen and condemned animals. The end products of rendering have economic value and can be stored for long periods of time. Using proper processing conditions, final products will be free of pathogenic bacteria and unpleasant odors.

In an outbreak of disease such as foot and mouth disease, transport and travel restrictions may make it impossible for rendering plants to obtain material from traditional sources within a quarantine area. Additionally, animals killed as a result of a natural disaster, such as a hurricane, might not be accessible before they decompose to the point that they can not be transported to a rendering facility and have to be disposed of on-site.

To overcome the impacts of catastrophic animal losses on public safety and the environment, some independent rendering plants should be sustainable and designated for rendering only species of animals which have the potential to produce end products contaminated with resistant prions believed to be responsible for transmissible spongiform encephalopathy (TSE) diseases, such as bovine spongiform encephalopathy (BSE; also known as mad cow disease), and the products from these facilities should be used only for amending agricultural soils (meat and bone meal or MBM) or as burning fuels (tallow).

1.3 – Capacity, Design, and Construction

While independent rendering plants in the United States (US) have an annual input capacity of about 20 billion pounds (10 million tons), the total weight of dead livestock in 2002 was less than 50% of this number (about 4.3 million tons). In order to justify costs and be economically feasible, a rendering plant must process at least 50-65 metric tons/day (60-70 tons/day), assuming 20 working hours per day. In the event of large-scale mortalities, rendering facilities may not be able to process all the animal mortalities, especially if disposal must be completed within 1-2 days. Providing facilities for temporary cold storage of carcasses, and increasing the capacities of small rendering plants are alternatives that should be studied in advance.

Rendering facilities should be constructed according to the minimum requirements of Health and Safety Code, §§144.051-144.055 of the Texas Department of Health (TDH) (2000). More clearly, construction must be appropriate for sanitary operations and environmental conditions; prevent the spread of disease-producing organisms, infectious or noxious materials and development of a malodorous condition or a nuisance; and provide sufficient space for placement of equipment, storage of carcasses, auxiliary materials, and finished products.

Plant structures and equipment should be designed and built in a manner that allows adequate cleaning, sanitation, and maintenance. Adulteration of raw materials should be prevented by proper equipment design, use of appropriate construction materials, and efficient processing operations. Appropriate odor control systems, including condensers, odor scrubbers, afterburners, and biofilters, should be employed.

1.4 – Handling and Storage

Animal mortalities should be collected and transferred in a hygienically safe manner according to the rules and regulations of TDH (2000). Because raw materials in an advanced stage of decay result in poor-quality end products, carcasses should be processed as soon as possible; if storage prior to rendering is necessary, carcasses should be refrigerated or otherwise preserved to retard decay. The cooking step of the rendering process kills most bacteria, but does not eliminate endotoxins produced by some bacteria during the decay of carcass tissue. These toxins can cause disease, and pet food manufacturers do not test their products for endotoxins.

1.5 – Processing and Management

The American rendering industry uses mainly continuous rendering processes, and continually attempts to improve the quality of final rendering products and to develop new markets. Further, the first reduced-temperature system, and later more advanced continuous systems, were designed and used in the US before their introduction into Europe. The maximum temperatures used in these processes varied between 124 and 154°C (255 to 309°F). The industry put forth considerable effort to preserve the nutritional quality of finished products by reducing the cooking temperatures used in rendering processes.

Batch cookers are not recommended for carcass rendering as they release odor and produce fat particles which tend to become airborne and are deposited on equipment and building surfaces within the plant. The contents and biological activities of lysine, methionine, and cystine (nutritional values) of meat meals produced by the conventional batch dry rendering method are lower than that of meat meals obtained by the semi-continuous wet rendering method because of protein degradation.

In dry high temperature rendering (HTR) processes, cookers operate at 120°C (250°F) and 2.8 bar for 45 min, or at 135°C (275°F) and 2 bar for 30 min, until the moisture content falls below 10%. While there is no free water in this method, the resulting meal is deep-fried in hot fat.

Low temperature rendering (LTR) operates in the temperature range of 70-100°C (158-212°F) with and without direct heating. While this process produces higher chemical oxygen demand (COD) loadings in wastewater, it has lower air pollutants (gases and odors), ash content in final meal, and an easier phase separation than HTR. The fat contents of meals from LTR processes are about 3-8%, and those from HTR processes are about 10-16%.

If LTR is selected to have less odors and obtain the final products with better color quality, nearly all tallow and more than 60% of the water from the minced raw materials should be recovered from a process at 95°C (203°F) for 3-7 minutes and by means of a pressing or centrifuging processes at (50-60℃ or 122-140°F) just above the melting point of the animal fat. The resultant solids should be sterilized and dried at temperatures ranging from 120 to 130°C (248 to 266°F).

LTR systems that incorporate both wet and dry rendering systems appear to be the method of choice. This process prevents amino acid destruction, maintains biological activities of lysine, methionine, and cystine in the protein component of the final meal, produces good-quality MBM (high content of amino acids, high digestibility, low amount of ash and 3-8% fat), and generates tallow with good color.

Contamination of finished products is undesirable. Salmonellae can be frequently isolated from samples of carcass-meal taken from rendering plants; Bisping et al. (1981) found salmonellae in 21.3% of carcass-meal samples. Despite the fact that salmonellae from rendered animal protein meals may not cause diseases in livestock/poultry and humans, it will provide much more confidence for the users if they are completely free of any salmonellae.

Carcass meal and MBM are the same as long as phosphorus content exceeds 4.4% and protein content is below 55%. MBM is an excellent source of calcium (7-10%), phosphorus (4.5-6%), and other minerals (K, Mg, Na, etc., ranges from 28-36%). As are other animal products, MBM is a good source of vitamin B-12 and has a good amino acid profile with high digestibility (81-87%).

1.6 – Cleaning and Sanitation

Discrete "clean" and "dirty" areas of a rendering plant are maintained and strictly separated. "Dirty" areas must be suitably prepared for disinfection of all equipment including transport vehicles, as well as collection and disposal of wastewater. Processing equipment is sanitized with live steam or suitable chemicals (such as perchloroethylene) that produce hygienically unobjectionable animal meal and fat. The sanitary condition of carcasses and resulting products is facilitated by an enclosed flow from receiving through packaging.

Effective disinfection processes are verified by the presence of only small numbers of gram-positive bacteria (like aerobic bacilli) within the facility, and by the absence of *Clostridium perfringens* spores in waste effluent.

Condenser units, which use cold water to liquefy all condensable materials (mainly steam and water-soluble odorous chemical compounds), are used to reduce the strongest odors which arise from cooking and, to some extent, drying processes. The cooling water removes up to 90% of odors, and recovers heat energy from the cooking steam thus reducing the temperature of the non-condensable substances to around 35-40℃ (95-104°F). Scrubber units for chemical absorption of non-condensable odorous gases (using hypochlorite, multi-stage acid and alkali units) and chlorination may be employed. Remaining odorous gases can be transferred to a biofilter bed constructed of materials such as concrete, blockwork, and earth, and layered with products such as compost, rice hulls, coarse gravel, sand, pinebark, and woodchips. Microorganisms in the bed break down organic and inorganic odors through aerobic microbial activity under damp conditions. Modern biofilter units (such as Monafil) provide odor removal efficiency of more than 95% for hydrogen sulfide (H_2S) and 100% for ammonium hydroxide (NH_4OH). Odor control equipment may incorporate monitoring devices and recorders to control key parameters.

All runoff from the rendering facility should be collected, directed away from production facilities, and finally directed to sanitary sewer systems or wastewater treatment plants.

1.7 – Energy Savings

Semi-continuous processes, incorporating both wet and dry rendering, use 40% less steam compared with dry rendering alone. Energy consumption in rendering plants can be reduced by concentrating the waste stream and recovering the soluble and insoluble materials as valuable products. Clean fuels, free of heavy metals and toxic wastes, should be used for all boilers, steam raising plants, and afterburners.

Energy for separation of nearly all fat and more than 60% of the water from carcasses can be conserved by means of a pressing process at low temperature (50-60°C or 122-140°F, just above the melting point of animal fat). This process reduces energy consumption from 75 kg oil/metric ton of raw material in the traditional rendering process, to an expected figure of approximately 35 kg oil/metric ton raw material, saving 60-70% of the energy without changing generating and heating equipment (e.g., boiler and cooker equipment).

The animal fat (tallow) produced by mortality rendering can be used as an alternative burner fuel. A mixture of chicken fat and beef tallow was blended with No. 2 fuel oil in a ratio of 33% chicken fat/beef tallow and 77% No. 2 fuel oil. The energy content of unblended animal biofuels was very consistent among the sources and averaged about 39,600 KJ/kg (16,900 Btu/lb). Blended fuels averaged nearly 43,250 KJ/kg (18,450 Btu/lb), and all were within 95% of the heating value of No. 2 fuel oil alone.

1.8 – Cost and Marketing

Over the last decade, the number of "independent" rendering plants has decreased, with an increasing trend towards "integrated" or "dependent" rendering plants (i.e., those that operate in conjunction with meat or poultry processing facilities). Out of 250 rendering plants operating in the US, only 150 are independent. While in 1995, production of MBM was roughly evenly split between integrated (livestock packer/renderers) and independent renderers, recent expert reports show that in the present situation, integrated operations produce at least 60% of all MBM, with independents accounting for the remaining 40% or less.

Current renderers' fees are estimated at $8.25 per head (average for both cattle and calves) if the final MBM product is used as an animal feed ingredient. If the use of MBM as a feed ingredient is prohibited (due to concerns regarding possible BSE contamination), it could increase renderers' collection fees to an average of over $24 per bovine.

According to the Sparks Companies, Inc. (SCI) (2002), independent renderers produced more than 433 million pounds of MBM from livestock mortalities, or approximately 6.5% of the 6.65 billion pounds of total MBM produced annually in the US (this total amount is in addition to the quantities of fats, tallow, and grease used in various feed and industrial sectors). The raw materials for these products comprised about 50% of all livestock mortalities.

Carcass meals are sold as open commodities in the market and can generate a competition with other sources of animal feed, thereby helping to stabilize animal feed prices. The percentage of feed mills using MBM declined from 75% in 1999 to 40% in 2002, and the market price for MBM dropped from about $300/metric ton in 1997 to almost $180/metric ton in 2003. The total quantity of MBM exported by the US increased from 400,000 metric tons in 1999 to about 600,000 metric tons in 2002 (Hamilton, 2003).

The quality of the final MBM produced from carcasses has a considerable effect on its international marketability. Besides BSE, *Salmonella* contamination may result in banned products. While export of MBM from some other countries to Japan has been significantly reduced in recent years because of potential for these contaminants, some countries like New Zealand made considerable progress in this trade. According to Arnold (2002), New Zealand MBM exports to Japan have attracted a premium payment over Australian product of between $15-$30/ton. Japanese buyers and end-users have come to accept MBM from New Zealand as being extremely low in *Salmonella* contamination and have accordingly paid a premium for this type of product. According to Arnold (2002), New Zealand exported 34,284 tons of MBM to Japan during 2000, representing 18.5% of the market share. During the first nine months of 2001, New Zealand exports to Japan had increased to 32.6% of the market share. In contrast, US MBM products represented 1.8% of the market share in 2000, and 3.2% of the market share during the first nine months of 2001.

1.9 – Disease Agent Considerations

The proper operation of rendering processes leads to production of safe and valuable end products. The heat treatment of rendering processes significantly increases the storage time of finished products by killing microorganisms present in the raw material, and removing moisture needed for microbial activity. Rendering outputs, such as carcass meal, should be free of pathogenic bacteria as the processing conditions are adequate to eliminate most bacterial pathogens. However, recontamination following processing can occur.

The emergence of BSE has been largely attributed to cattle being fed formulations that contained prion-infected MBM. As Dormont (2002) explained, TSE agents (also called prions) are generally regarded as being responsible for various fatal neurodegenerative diseases, including Creutzfeldt-Jakob disease in humans and BSE in cattle. According to UKDEFRA (2000), epidemiological work carried out in 1988 revealed that compounds of animal feeds containing infective MBM were the primary mechanism by which BSE was spread throughout the UK. Thus the rendering industry played a central role in the BSE story. Experts subsequently concluded that changes to rendering processes in the early 1980s might have led to the emergence of the disease.

Various policy decisions have been implemented to attempt to control the spread of BSE in the cattle population. Many countries have established rules and regulation for imported MBM. The recently identified cases of BSE in Japan have resulted in a temporary ban being imposed on the use of all MBM as an animal protein source (Arnold, 2002). FDA (2001) implemented a final rule that prohibits the use of most mammalian protein in feeds for ruminant animals. These limitations dramatically changed the logistical as well as the economical preconditions of the rendering industry.

According to UKDEFRA (2000), in 1994 the Spongiform Encephalopathy Advisory Committee stated that the minimum conditions necessary to inactivate the most heat-resistant forms of the scrapie agent were to autoclave at 136-138°C (277-280°F) at a pressure of ~2 bar (29.4 lb/in^2) for 18 minutes. The Committee noted that the BSE agent responded like scrapie in this respect. Ristic et al. (2001) reported that mad cow disease was due to prions which are more resistant than bacteria, and that the BSE epidemic may have been sparked by use of MBM produced from dead sheep, and processing of inedible by-products of slaughtered sheep by inadequate technological processes.

Section 2 – Background

The livestock and poultry industry has historically been one of the largest agricultural businesses in the United States (US). According to the US Department of Agriculture (USDA, 2003), from the nationwide 9.2 million dairy cows in 2002, nearly 170 billion pounds of milk was produced. SCI (2002) indicated that the market for US meat and meat-based products requires the annual slaughter of roughly 139 million head of cattle, calves, sheep, hogs and other livestock, as well as 36 billion pounds of poultry (broiler chickens, layer chickens and turkeys). Every year, millions of animals, representing billions of pounds of mortality, perish due to typical production death losses. For example, the average death rate of dairy cows is about 5% nationwide (Gerloff, 2003).

2.1 – History of Animal Mortality from Disease and Disasters

According to the USDA Economics and Statistics Systems (2002), more than 439 million poultry (excluding commercial broilers) were raised for commercial sale in the United States in 2002. Out of this production, about 52 million birds (almost 12% of the total production) died of various causes before they were marketable. SCI (2002) reported that ruminants (cattle, sheep, lamb, and goats) combine to account for about 22%, and swine 78%, of all mammalian livestock that die prior to slaughter each year. However, because they are considerably larger and heavier, cattle account for about 67% by weight of the total death loss each year.

Infectious and non-infectious diseases worldwide cause heavy losses of animal populations every year. Some of the worst catastrophic mortality losses resulting from various diseases in different countries during the last 10 years are summarized below.

- In 1993, an outbreak of Newcastle disease occurred on a Venezuela farm having nearly 100,000 chickens (Pakissan.com, 2001).
- In 1997 and in 2001, foot and mouth disease (FMD) outbreaks in Taiwan generated millions of dead swine, sheep, and cattle carcasses to be disposed of in a biosecure and time-sensitive manner (Wilson & Tsuzynski, 1997).
- In 1998, animal diseases took a heavy toll. Newcastle disease damaged three poultry farms in New South Wales (Province of Australia), and FMD damaged pig farms in Central Asia, Africa, South America, China, and Middle Eastern countries like Israel. In another case, Rift Valley fever led to the loss of 70% of the sheep and goat populations, and 20-30% of the cattle and camel populations in East and West Africa. During the same year, African swine fever broke out in Madagascar leading to the death of more than 107,000 pigs (Pakissan.com, 2001).
- In 2001, an outbreak of FMD in the United Kingdom resulted in the slaughter and disposal of over 6 million animals, including cattle, sheep, pigs, and goats (UKDEFRA, 2002). Approximately 4 million of these animals were culled for welfare reasons rather than for disease control purposes.
- An exotic Newcastle disease (END) outbreak in 2003 in Southern California resulted in the depopulation of nearly 4.5 million birds and is another example of a disease outbreak in poultry operations (Florida Department of Agriculture and Consumer Services, 2003).

Natural disasters have the potential to cause catastrophic animal mortalities that are just as devastating as infectious diseases. Mortality due to natural disasters can be attributed to a wide variety of events, such as floods, storms, lightning, heat extremes, fires, droughts, and earthquakes. Heat extremes, especially in unusually hot summers, have significant impact on increasing animal mortality. The following natural disasters caused massive animal mortalities.

- Floods that occurred in Texas in 1998 resulted in livestock losses estimated to be approximately $11 million over 20 counties (Ellis, 2001).
- In 1999 Hurricane Floyd in North Carolina resulted in estimated losses of livestock and poultry valued at approximately $13 million (North Carolina State Animal Recovery Team, NCSART, 2001). Losses included over 2 million chickens, 750,000 turkeys, 28,000 hogs, and over 1,100 cattle.
- During a period of intense heat in July 1995 in Iowa and Nebraska, the mortality of feedlot cattle increased tremendously. A total of 10,000 feedlot cattle perished, 3,750 within a single day. The estimated losses to livestock and poultry producers in central Iowa, respectively, were $28 million and $25 million (USDA, 2002).
- In 1997 the North Dakota Department of Agriculture disposed of approximately 11 million pounds of animals that perished during an April blizzard. More than 950 carcasses were removed from waterways, and a total of 13,700 carcasses were buried (Friez, D.C., 1997).

In each catastrophe, animal mortalities caused considerable economic loss to producers. In addition to economic consequences, catastrophic mortality losses may potentially impact public health or the environment.

2.2 – Historical Use of Rendering

The rendering process uses the dead cattle and other farm animal carcasses or their waste by-products. This process involves series of actions including crushing the raw material followed by direct or indirect heating, evaporation of the moisture and separation of the fat from the high-protein solids, pressing the greaves to remove the water, centrifugation of aqueous solution to remove the fat and protein materials, sometimes solvent extraction of protein parts to remove more tallow, drying the protein materials, and grinding them into meat and bone meal (MBM).

The production of tallow for candles and soap has occurred for centuries, demonstrating that the rendering process is not a new industry. However, it was only at the beginning of the 20th century that the conversion of animal slaughtering by-products to MBM for animal feed became important. It can be concluded that the rendering system emerged firstly for animal byproducts and secondly for carcass conversion.

In the 1980s, both tallow and MBM had good commercial values. It was the tallow which was the primary product of rendering. According to the UK Department for Environment, Food and Rural Affiars (UKDEFRA) (2000), the production and use of MBM steadily increased throughout the first half of the century and when national self-sufficiency became an important issue in the UK during the Second World War, regulations actually prescribed its use in animal feed. The production of MBM and tallow continued to increase after the war. UKDEFRA (2000) reported in 1985, roughly half of approximately 1.3 million tonnes or so of raw material processed annually was being dealt with in the 10% of plants that had a normal weekly capacity in excess of 1,000 tonnes. The capacity of the new, larger continuous rendering plants exceeded local supplies of raw materials. They had to look further a field, thus competing with other less efficient renderers, not only for customers, but also for this raw material. The number of rendering plants fell from about 120 in the 1960s, to around 100 in 1979 and roughly 70 in 1986. Many farms were closed, merged, or were taken over during these years. The concentration of the industry continued with further mergers. By 1991, the share of a single firm named PDM in the market had grown to 55% in Great Britain and 60% in England and Wales.

The UKDEFRA (2000) recognized that animal waste collection and rendering "constituted a vital public service as well as commercial activity," but made some recommendations intended to remedy the effect on competition of these firms' pricing policies. Further, carcass rendering offers several benefits to food animal production operations, including providing a feed source for livestock, and protecting herds from diseases resulting from fallen and condemned animals. Though this method of carcass disposal is environmentally sound and the recovered protein meal and fats can be used in animal and other industries, due to the resistance of the causative agent of bovine spongiform encephalopathy (BSE) (also known as mad cow disease) to rendering conditions, and the consequent potential health effects of feeding infective protein meal to susceptible animals, the demand for products from rendered animal carcasses has declined substantially.

2.3 – Objectives

The purpose of this report is to discuss various aspects of rendering as a mortality disposal option. This work is intended to provide information to those with planning and decision making responsibility to determine whether rendering is suitable to the circumstances at hand, and if so, to choose the most appropriate rendering process.

Section 3 – Principles of Operation

This section provides a discussion of various aspects of the rendering process as a carcass disposal mechanism.

3.1 – General Carcass Rendering Process

Definition

Rendering has historically been defined as separation of fat from animal tissues by the application of heat. Romans et al. (2001) indicated that rendering involves the heating or cooking of raw materials (with complex or simple mixtures of protein, minerals, and fatty substances) to liquefy fats and break down membranes or other structures that may hold fat. According to Kumar (1989), the goals of carcass rendering are elimination of water, separation of fat from other materials (mainly protein substances), sterilization of the final products, and production of MBM from a variety of condemned, fallen, culled, and experimental animals. Prokop (1996), UKDEFRA (2000), and Romans et al. (2001) defined rendering as a process of using high temperature and pressure to convert whole animal and poultry carcasses or their by-products with no or very low value to safe, nutritional, and economically valuable products. In fact, the highly perishable protein and fat materials comprising carcasses become a major problem and a liability if they are not converted, stabilized, or somehow processed during 24 hours following death.

Basic rendering processes

Generally rendering process is accomplished by receiving raw materials followed by removing undesirable parts, cutting, mixing, sometimes preheating, cooking, and separating fat and protein materials. The concentrated protein is then dried and ground. Additionally, refining of gases, odors, and wastewater (generated by cooking process) is necessary. Rendering processes may be categorized as either “edible” or “inedible.”

In “edible” rendering processes, carcass by-products such as fat trimmings are ground into small pieces, melted and disintegrated by cooking processes to release moisture and “edible” tallow or fat. The three end product portions (proteinaceous solids, melted fat, and water) are separated from each other by screening and sequential centrifugations. The proteinaceous solids are dried and may subsequently be used as an animal feed, water is discharged as sludge, and the edible fat is pumped to storage for refining. Figure 1 in Appendix A shows the flow diagram of fat materials in edible rendering.

Plants that employ “inedible” rendering processes convert the protein, fat, and keratin (hoof and horn) materials found in carcasses into tallow, carcass meal (used in livestock feed, soap, production of fatty acids, etc), and fertilizer, respectively. As was true for the edible process, raw materials in the first stage of an inedible process are dehydrated and cooked, and then the fat and protein substances are separated. The pre-cooking processes mainly include removal of skin and paunch and thorough washing of the entire carcass. The hide is not usually removed from hogs and small animals, but the hair of such animals is generally removed before washing and cleaning. The carcasses are crushed and transported to a weighing bin and then passed through metal and non-metal detectors. These devices in turn sort out nearly all of the magnetic and non-magnetic metal materials (tags, hardware, and boluses). Metals that may be associated with the carcasses are removed by strong magnets attached to conveyors.

The use of carcasses in advanced stages of decomposition is undesirable because hide removal and carcass cleaning is very difficult, and the fat and protein resulting from such carcasses is generally of low quality. In the event of a disaster situation, decayed carcasses without entrails along with dumped paunches should be segregated and processed separately.

Although edible and inedible rendering processes are generally similar, they differ in their raw materials, end products, and sometimes equipment. UKDEFRA (2002) stated that in batch rendering of inedible foodstuffs, multiple cookers are used. In inedible rendering systems the final solids, called "cracklings," are ground to produce protein meal. The fat is centrifuged or filtered to remove any remaining protein solids and is then stored in a tank.

According to the Expert Group on Animal Feedingstuffs (1992), the average particle size of material entering the cookers is 40 mm, the average cooking time is about 3 1/2 hours, and the maximum temperatures range from 120-135°C (248-275°F) under atmospheric pressure. This group also stated that some plants cook the materials under higher pressure and temperature (2 bar and 141°C [286°F]), but for a shorter time (e.g., 35 min). In some plants the load is discharged once the maximum temperature is reached; in others there may be a holding time of up to 20 minutes. On discharge, the free run fat is drained off and the residual "greaves" (a high-protein solid which is left from the cooking materials) are removed for pressing and/or centrifugation to extract more fat. Finally, the dried greaves are subsequently ground to produce MBM, or sold as greaves to other renderers for further processing. High-intensity odor emissions result from heated materials on the "percolating pan," and the screw press is either air-cooled in finned tube systems or water-cooled in shelled tube systems.

The resulting greaves and tallow products of rendering systems are impure and require further purification and refining processes. The tallow may contain water, and the greaves contain fat and water. To separate fat and water from greaves, solvent extraction and drying of solid proteins are used. According to UKDEFRA (2000), from the 1950s until the 1970s the preferred method of extracting tallow from greaves was solvent extraction. This extracted more tallow than other processes, so the resulting MBM contained less fat. During this time, the extra cost of solvent extraction was justified by the fact that the animal feed industry desired MBM with fat content of only 1 to 5%, and because tallow fetched a much higher price than MBM. However, this process subsequently fell out of favor for the following reasons (Arnold, 2002):

- The energy crisis in the 1970s dramatically raised the price of solvents;
- The price of tallow fell relative to MBM in the late 1970s, reducing the profit in producing more tallow and less MBM;
- Animal feed manufacturers began to produce higher-fat feeds (about 10 to 12% fat), and therefore no longer required the low-fat MBM produced by solvent extraction but preferred higher-fat MBM instead; and
- The use of solvents entailed an ongoing risk of fire and explosion.

Alternatives to refining by solvent extraction include a variety of methods, all of which are based on increasing the difference in specific gravity between the fat and suspended water and protein materials. Techniques to increase or pronounce the density differences between fat, protein materials, and water include the use of steam-jacketed, conical fat refining vessels along with adding brine solution and centrifugation. The fat and protein mixture is indirectly heated and boiled in a steam-jacketed vessel for about 15 minutes, and then pumped to another vessel. During the settling process, the heavy portion of the mixture (water and coagulated protein) settles to the bottom of the fat portion in the vessel. The proteinaceous matter and water are removed through a draw-off valve.

The fat obtained from the above process still contains impurities, primarily suspended proteinaceous substances. To separate these materials, Kumar (1989) recommended spraying saturated brine (around 20-25% salt content at the rate of 10% v/v of fat) on the fat surface and boiling the fat solution for 10 minutes. The main advantage of adding salt (brine) is the resulting breakdown of the water/fat emulsion with a corresponding increase in the difference in specific gravity between the fat and suspended matter. In this process most of the coagulated protein, along with the brine, will settle to the bottom, while clear fat floats to the top. The suspended matter is then easily removed through a draw-off valve. The remaining water and proteinaceous substances can be separated from the fat solution by high speed centrifugation and deodorization processes.

Factors affecting carcass rendering processes

Prokop (1996) stated that factors such as time, temperature, particle size, liquid level, and speed of the rotor in cylindrical tanks (defined as revolutions per minute or RPM) directly impact the quality and quantity of finished rendered products. Factors such as electrical loads in amperes for certain equipment, control valve settings, and equipment on/off status are considered indirect parameters. In modern rendering operations, computerized systems monitor and provide instantaneous indications of all of the above.

In order to separate carcass fat from the heavier materials (water and protein), it is necessary to use appropriate combinations of temperature, time, and air pressure, along with proper mixing of crushed raw materials. Proper temperature during the rendering process will increase the density differences between the heavy and light materials. After removing all the materials from the cooking vessel, the wet meat/bone material is dried, milled, and bagged. The cooking water contains some dissolved protein and fat, both of which are removed separately. The protein is added to the meat/bone meal before drying and the fat is directed to tallow stock.

Time and temperature

The time required to complete the rendering process depends greatly on the temperature and air pressure inside the system. As the air pressure and temperature increase, the time to complete the rendering process decreases. For example, the same material that that requires a process time of about 3.5 hours at 125°C (257°F) may only require 35 minutes under pressure (2 bar) at 141°C (286°F) (Expert Group on Animal Feedingstuffs, 1992, Annex 2.4). Furthermore, cooking time and temperature in turn depend on the type of rendering system used (wet or dry, batch or continuous), and on the particle size and chemical composition of raw materials. For instance, UKDEFRA (2000) reported that if the product was high in fat and low in moisture (as edible fat is), tallow in the material would melt out of the solid at around 45-50°C (113-122°F). Once the material reached 100°C (212°F), moisture would be driven off and the solid residue would cook very quickly, virtually frying in the hot tallow. On the other hand, some carcass by-product materials such as offal, which are higher in moisture and lower in fat, would take much longer to render at a higher temperature. As a matter of practicality, most renderers chose maximum temperatures below 140°C (284°F) and adjust processing times. At these temperatures vitamins and trace elements in the solids are not greatly affected, but solids are sufficiently processed to facilitate grinding. Renderers of low-quality material can afford to use higher temperatures.

Air pressure

Air pressure inside the rendering system has an important impact on the quality of outgoing products. According to Taylor (2000), conventional rendering processes do not inactivate prion proteins; but it can reduce their infectivity. He stated that complete inactivation will be achieved, when materials are cooked at 132°C (270°F) at approximately 3 bar (45 psi) for 4.5 hours. Shirley and Parsons (2000) studied the effects of rendering pressures of 0, 2, and 4 bar (0, 30 and 60 psi) on amino acid digestibility in MBM, and on the deactivation of the BSE agent within MBM. They concluded that increasing pressure during the rendering process, even for short time periods (i.e., 20 min), reduced the content of cysteine and lysine in MBM, and the true digestibility of these two amino acids (AA) was also significantly decreased. The digestibility of cysteine was observed to be 65, 50, and 15% at 0, 2, and 4 bar, respectively; the digestibility of lysine was observed to be 76, 68, and 41% at 0, 2, and 4 bar, respectively. While increasing rendering pressure and temperature in the cooking process reduces the potential BSE infectivity of MBM, it likely also decreases the nutritional value of MBM. Therefore, further research is warranted to identify new processing methods (such as applying high pressure without increasing temperature) that effectively eliminate prion infectivity while minimizing detrimental impacts on nutritional quality.

Clottey (1985) indicated that lowering the pressure at the end of the heating time, and simultaneously allowing the tank to cool for 40 to 45 min, will help to gravitate the heavier material to the bottom. Water will be collected above this in a middle layer, while fat rises to the top.

3.2 – Rendering System Options

This section discusses and compares various types of rendering systems.

Rendering systems

In spite of the variation in investment and energy costs, different rendering systems work well for small (poultry), medium (swine, sheep, calves), and large sized (cattle and horse) mortalities. This section outlines the four major rendering options (wet, dry, batch, and continuous) as well as recent combination techniques called wet pressing.

Wet rendering

In wet rendering systems, moisture is added to the raw materials during the cooking process. According to Kumar (1989), wet rendering is a process in which the raw material and added water are subjected to direct high steam pressure in a wet rendering vessel. A wet rendering process may be carried out in batch or continuous formats, and in horizontal or vertical vessels. Kumar (1989) stated that a cylindrical vessel with a semi-circular bottom fitted with a draw off valve can be used. In this system, a perforated metal plate is fitted at the junction of the bottom and sidewall of the vessel. This prevents solids from blocking the run-off valve. The vessel is also fitted with a manhole at the top for loading the offal or processed animal parts, and with a discharge door at the sidewall for removing the cooked materials. Two or three draw off cocks are also provided at the sidewall for removal of fat. The vessel has other fittings, such as a pressure gauge, steam supply valve, steam release valve, etc. Wet rendering vessels are available in capacities of 0.45-0.90 metric ton (0.5-1 ton). The manufacturers also indicate the maximum steam pressure with which the equipment may be safely and efficiently operated.

Clottey (1985) recommended a vertical or oblong-shaped cylinder with a cone-shaped base built of heavy steel and fitted with a steam-charging mechanism to provide high temperatures for cooking. Initially, the wet rendering tank is filled with water to about one-third of its capacity. The relatively heavier materials, like bones, feet, and heads, are put in next, with reduced sizes at the bottom of the tank. Softer organs, such as those of the viscera and carcass trimmings, are layered next. Finally, fat is placed on the top, allowing a headspace for the boiling action. In practice, the fill does not exceed three-quarters of the cylinder's volume. With the tank closed, steam is charged through the bottom directly into the tank. Clottey (1985) observed that this process was conducted at a pressure of about 2.72 bar (40 lb/in^2), a temperature of 135°C (275°F), and time of up to 5 hours. Under these conditions, the process was capable of breaking up and softening the tissues, releasing fat, and, importantly, destroying harmful microorganisms.

Injection of live (pressurized) steam into the raw material increases the rate of temperature increase inside the enclosed tank, and speeds up the process. However, it also causes overheating of nutrient materials. Romans et al. (2001) stated that accumulated water in this system, which needs extra energy to evaporate, may have unfavorable effects, such as the remaining material having a consistency similar to molasses. This phenomenon is called “stick” or “stick liquor.” This liquid is mixed with the tankage (precipitated solids) and dried. Clottey (1985) indicated that each batch should be analyzed to determine the nutrient composition, especially phosphorus and protein content, which are important criteria for grading and marketing. Horn and hoof tissues are prepared similarly to MBM, but this is done separately because they are inedible and intended to be used as fertilizers.

Although wet rendering can produce good-quality tallow, this system is no longer used because of its high energy consumption, loss of meal (up to 25% in wastewater), and adverse effects on fat quality (Ockerman & Hansen, 2000). It is also a labor-intensive process.

Dry rendering

Whereas the wet rendering method uses direct pressurized steam to cook carcasses along with grinding in large closed tanks, the relatively “newer” method of dry rendering cooks ground carcasses indirectly in their own fat while contained in a horizontal, steam-jacketed cylindrical vessel equipped with an agitator. In both methods, the final temperature of the cooker (120-135°C [250-275°F]) destroys harmful pathogens and produces usable end products such as meat, feather, bone, and blood meal that can be used in animal feeds (Franco & Swanson, 1996, and EPAA, 2002). Dry rendering can be accomplished in batch, semi continuous, and continuous systems.

In dry rendering systems, heat generated by steam condensation is applied to the jacket and agitator blades to ensure uniform heat distribution and shorten the time necessary for cooking the carcass materials. According to Kumar (1989), during the cooking time (which ranges from 45 minutes to 1.5

hours), the jacket pressure is normally maintained around 4.2 bar (60 lb/in^2), and the internal shell pressure around 2.8 bar (40 lb/in^2).

The indirect heat of the dry system converts the moisture in carcasses to steam; the resulting steam pressure inside the vessel, combined with continuous agitation, break down fat cells and disintegrate the material. The cooker is brought to a desirable steam pressure at which it is maintained for a period of time.

Through a sampling valve, cooked material is monitored periodically to determine when the cooking process is complete. The slight grittiness and fibrous nature of the cracklings provide indications of the progress of the cooking process (e.g., disappearance of fiber indicates over-cooking) (Kumar, 1989).

After cooking, steam generated inside the cooker is removed through a steam release valve (adjusted at specific pressure). Since there is no discharge of liquid stick in a dry rendering process, the remaining cooked product is dried inside the vessel, contributing to the higher yield of meat meal observed for dry rendering as compared to wet rendering processes.

Batch rendering

Both dry and wet rendering systems may be used in a batch configuration. The dry process will be considered first. In England about 20% of the available raw materials were consumed in batch rendering systems (Expert Group on Animal Feedingstuffs, 1992). According to Prokop (1996), UKDEFRA (2000), and EPAA (2002), "batch cookers" consist of large, horizontal, steam-jacketed, cylindrical vessels equipped with agitators or revolving beater shafts, which facilitate further break down of fatty tissues. In the first stage, the raw material from the receiving bin is conveyed to a crusher or similar device to reduce its size to pieces of 25-50 mm (1-2 in) for efficient cooking. Cookers are heated at normal atmospheric pressure to around 100°C (212°F) until the moisture is driven off through vents in the form of steam and the temperature rises to 121-135°C (250-275°F) depending on the type of raw materials. This high temperature breaks the cell structure of the residue and releases the fat as tallow. In terms of loading, some plants discharge raw materials to the batch cooker when the batch maximum temperature is reached; others utilize a holding time of up to 30 minutes. After the heating process, which normally takes up 2-3 hours, the tallow is decanted off and the solids are emptied from the cooker.

The cooked material is discharged into a separate container or a percolator drain pan, which allows the free-run fat to drain away from the protein solids (known as tankage or cracklings). Prokop (1996) and the US Environmental Protection Agency (USEPA) (2002) stated that the resulting insoluble protein (solid content), containing about 25% fat, is conveyed to a screw press and releases approximately 15% more fat, resulting in a final residual fat content of 10%. Figure 1 in Appendix B shows the material flow for a dry process in a batch configuration.

Another method of batch rendering is "wet rendering," in which the raw material is subjected to a temperature of 140°C under high pressure generated either by injecting steam into the cooker, or by allowing the steam from moisture in the raw material to build up. UKDEFRA (2000) reported that renderers often choose to first raise the temperature to the maximum and hold it for a while, and then slowly release the pressure, sending the temperature back to around 100°C (212°F). The extruded tallow can then be removed and purified by gravity or centrifugation to remove any water and particulate matter. The moist solids are then dried at this temperature for three to four hours. As an alternative, some renderers simply cook the raw material at an increasing temperature for two to three hours before reaching the maximum temperature, whereupon the material is removed (either immediately or after a specified holding time).

Protein solids containing residual fat are then conveyed to the pressers for additional separation of fat. Prokop (1996) stated that it is usual to screen and grind the protein material with a hammer mill to produce protein meal that passes through a number 12-mesh screen. The fine solid particles, which are discharged from the screw press along with fat, are usually removed either by centrifugation or filtration.

Water vapor is released by vacuum via an exhausted air vent. The USEPA (2002) reported that vapor emissions from the cooker pass through a condenser where the water vapor is condensed. Non-condensable compounds are emitted as volatile organic compounds.

Continuous rendering

Although a variety of rendering options have been designed and operated (from the early 1960s, by Baker Commodities in Los Angeles), most of them have a "continuous cooker" and use heating, separation, and cooling processes on a continuous flow basis. EPAA (2002) explained that in this system, all the rendering processes are done simultaneously and consecutively. Most continuous rendering systems require little to no manual operation, and, assuming a constant supply of raw material, finished products will be generated at a constant rate. In this system, more automated control is exercised over the crushing of big particles, uniform mixing of raw material, and the maintenance of required time and temperatures of the cooking processes. Batch and continuous rendering systems use indirect steam in jacketed vessels. Generally, continuous ones are equipped with automatic controls for both time and temperature. Continuous systems also generally offer greater flexibility, allowing a wider range of time and temperature combinations for cooking raw materials (UKDEFRA, 2000). Figure 2 in Appendix B shows that the flow diagram of a continuous dry rendering system is similar to batch rendering, but materials are added and product is removed in a continuous manner.

Press dewatering and wet pressing methods

Although under similar conditions, dry rendering systems use less energy than wet rendering systems, the energy conservation issue has forced renderers to seek new rendering processes that are even more energy efficient. A variety of methods have been suggested that use less heat while at the same time producing tallow and MBM of higher quality and quantity. In the press dewatering method suggested by Rendertech Limited (2002) the main processes are similar to continuous low temperature rendering (LTR) systems in that raw materials are heated until all the carcass fat is melted. After pressurizing the mixture with a double screw press, the solid protein and liquid portions are separated. The fat layer is removed by disc centrifuge, and the remaining liquid portion is evaporated. To produce the MBM, the thick liquid from the dehydrator is added to the solid protein left over on the press and the mixture is dried and sterilized.

Another method of conserving heat energy is the wet pressing method. In 1986, Kodfodfabrikken Ostjyden (KOFO) summarized the process, stating that offal and condemned animals are pre-broken (max. size 70 mm), transported to a weighing bin, and screened by metal and non-metal detectors, as well as a heavy duty electro magnet assembly specially designed and mounted on the entrance of the bin conveyor, to remove both magnetic and non-magnetic metal materials.

The raw material, free of metal, is hashed or chopped to a size of less than 19 mm and indirectly preheated with hot water to 60°C (140°F) in a coagulator. After passing a strainer screw with adjustable sized holes, it is condensed in a twin-screw press. This process divides the raw materials into two portions, a solid phase (press cake) containing 40-50% water and 4-7% crude fat on a dry matter basis, and a liquid phase containing fat, water, and some solids. The liquid phase is heated to 100°C (212°F) with live steam and passed through a 3-phase decanter (tricanter), which separates it into fat, stick water (the viscous liquid), and grax (suspended solid proteins).

The grax is returned to the coagulator, the fat is sent for refining and sterilization, and the stick water (containing 8% dry matter and 0.6% crude fat) is pumped into the 3-stage waste heat evaporator for concentration. This concentrate, containing 35% dry matter (with 8-9% fat in dry matter), is mixed into the press cake, which is dried in a plate contact drier indirectly heated by live steam. The meal leaves the drier at no less than 110°C (230°F) at which temperature sterilization is accomplished. The meal has a moisture content of 5-7% and a fat content of 7-8%. It is transported to milling by means of a pneumatic transport system. The drier gasses pass a scrubber where the particulates are removed from the vapors and a small proportion of the vapors are condensed. The scrubber liquid heats water (90°C [194°F]) for the coagulator via a heat exchanger. Figure 3 in Appendix B shows clearly the flow diagram for a wet pressing system and highlights the main differences as compared to the batch and continuous rendering systems.

Because lower temperatures are used in the dewatering and wet pressing methods, they are sometimes called LTR methods.

Comparison of different rendering processes

As mentioned earlier, the conditions of each system have a considerable effect on the materials and energy requirements and also on the properties of the final product.

Batch versus continuous systems

Batch and continuous rendering systems each have advantages and disadvantages. A batch rendering system cooks, pressurizes, and sterilizes in the same vessel, and separate cookers can be set aside for different materials (e.g., edible tallow, margarine tallow, and inedible tallow). Ockerman and Hansen (2000) stated the following major disadvantages of batch systems:

- Tallow is darker compared to that from LTR methods (dewatering and wet pressing).
- The high cooking and pressing temperature produces fines which pass into tallow and are lost in the effluent from the tallow-polishing centrifuges.
- Carcass material (especially viscera) must be cut and washed otherwise it generates a loss of fat and protein and adds water to the raw material.
- Since batch rendering processes are not contained in enclosed vessels, there is increased potential for re-contaminated of cooked products, and plant sanitation is more difficult.
- It is difficult to control the end point of the cooking process.
- There is a high consumption of steam if vent steam is not recovered as hot water.
- Finally, it is a labor-intensive process.

Continuous systems (single cooker) have the following advantages (Prokop, 1996) and disadvantages (Ockerman & Hansen, 2000).

Continuous system – advantages

- Continuous systems consist of a single cooker, whereas batch systems consist of multiple cookers (2 to 5 units).
- Continuous systems usually have a higher capacity than batch cooker systems.
- Continuous systems occupy considerably less space than batch cooker systems of equivalent capacity, thus saving construction costs.
- Single-cooker units are inherently more efficient than multiple-cooker units in terms of steam consumption. Thus, continuous systems achieve a significant savings in fuel usage by the boilers. Likewise, less electric power is consumed for agitation in the single continuous cooker units.
- They are labor-efficient.
- Continuous systems are more conducive to computerized control via centers located inside environmentally controlled rooms. Such control centers feature process control panels, which provide a schematic flow diagram of the entire process; indicator lights show whether individual equipment components are on or off. Process microcomputers control all start/stop operations in an interlocking sequence, adjust the speeds of the key equipment parts, and control various process elements to optimize plant operation.

Continuous system —disadvantages

- Continuous systems require greater initial capital investment.
- They cannot sterilize the product nor hydrolyze hair and wool by adding pressure along the cooking process.

These differences in rendering performance result in considerable differences in final products. Ristic et al. (1993) compared a conventional batch dry rendering method using screw press defatting to a semi-continuous wet rendering method using centrifugal defatting for processing inedible raw material (76.5% soft offal, 15% industrial bones, and 8.5% swine cadavers). He observed that the amount of amino acid destruction was higher, and biological activities of lysine, methionine, and cystine in the protein component of the final meal were lower with the conventional batch dry rendering method than with the semi-continuous wet rendering method. Thus, semi-continuous processes incorporating both wet and dry methods have been invented.

Although semi continuous rendering systems have high capital and repairs costs, they have been recommended by Ockerman and Hansen (2000) due to the following advantages:

- They produce tallow and meal of high quality.
- The meal fat is about 8%.
- Approximately 40% less steam is used compared with dry rendering.
- The process can be automated.

Low versus high temperature rendering

Cooking temperature (in batch or continuous systems) makes detectable and noticeable changes in the final rendering products. Taylor (1995) indicated that LTR, especially with direct heating (wet rendering), resulted in higher chemical oxygen demand (COD) loadings in wastewater, but lower odor production, when compared to high temperature rendering (HTR).

In traditional high-temperature dry rendering processes, water boils rapidly and evaporates after the raw material temperature in the cooker reaches 100°C (212°F). When the temperature rises to 110-130°C (230-266°F), there is no free water and the meal is deep-fried in hot fat. Due to the fact that the cooker contents (batch or continuous) are subjected to temperatures above 100°C (212°F) for relatively long periods, Ockerman and Hansen (2000) emphasized using only washed raw material for rendering to remove paunch contents and other "dirt." Otherwise, dirt color from the raw material becomes "fixed" in the tallow, and the tallow will be downgraded.

Since phase separation is carried out easily in LTR (70-100°C [158-212°F]), there is no need to wash raw materials because the color of paunch contents and other dirt do not become fixed in the tallow. As mentioned earlier, final meal products resulting from well-controlled LTR systems and post rendering processes will have low fat and moisture contents. Ockerman and Hansen (2000) reported the fat content of meals in HTR (usually batch dry-rendering) to be about 10-16%, and those of LTR to be about 3-8%.

3.3 – Design Parameters and Capacity of Carcass Rendering

As with any other industry, the concept of processing design in carcass rendering is to have suitable capacity and even flow of inputs and outputs while maintaining optimum quality. Proper design will lead to appropriate capacity, adjustable and meaningful production costs, and straightforward management and operation of the system. However, undersized or oversized capacities (due to improper design) may result in products that do not meet the required microbiological, nutritional, and physical characteristics. Improper design of machinery, process conditions, and plant layout may cause inadequate heating, incomplete destruction of pathogenic bacteria, overheating of raw materials, destruction of nutritional material, insufficient removal of unpleasant gases and odors, and finally production of wastewater with high biochemical oxygen demand (BOD), which may introduce environmental contamination. This section discusses effective design parameters, operating capacity, and their relation to different rendering systems.

Design parameters

Bone particle sizes and overall raw material throughput rate have substantial effects on the rendering process and inactivation of pathogens, particularly heat resistant microorganisms. Furthermore, the flow rate of material is affected by the dimensions and mixer revolutions of cookers. Manufacturing companies design various forms of milling, cooking, and drying machinery to meet the time and temperature requirements for sterilization, while at the same time preserving the nutritional quality of the final products.

It should be noted that most rendering methods, including wet, dry, high temperature, and low temperature (dewatering and wet pressing), can be designed and manufactured in a continuous manner. UKDEFRA (2000) explained that in a continuous rendering system, the workings of the heating stage varied according to plant design. Following are types of continuous cooking process, most of which were named after their first introducers.

- **Stork-Duke.** This system of rendering works on the principle of deep fat frying. Heat is applied indirectly via a steam jacket and a steam-heated tube rotor. The particle size of the raw material entering the cooker is 2.5–5.0 cm (1–2 in) and is held for at least 30 minutes at high temperatures ranging from 135 to 145°C (275 to 293°F). The protein material is then processed before being ground into MBM. Some sources indicate that 65 minutes is needed for the materials to pass from one end of the cooker to the other, however an accurate estimate it is difficult to determine because the residence time depends on the rate at which new material is fed into the system.

- **Stord Bartz.** Raw materials (particle size 2–5 cm or 0.8–2 in) are heated by a steam-heated disc rotor, which occupies the length of the rendering vessel. The average maximum temperature achieved is approximately 125°C (257°F) with an average residence time of between 22 and 35 minutes. Pressing and grinding of the end product (MBM) is similar to the procedure used in the Stork-Duke system. Most Stord Bartz driers operate in the range of 125 to 145°C (257 to 293°F), although some operate at 80°C (176°F).

- **Anderson Carver-Greenfield Finely.** Raw material (minced to less than 10 mm or 0.4 in) is first mixed with recycled, heated tallow to form a slurry. The mixture is then pumped through a system of tubular heat exchangers with vapor chambers under partial vacuum before being centrifuged and pressed into MBM. The described heat treatment involves a maximum process temperature of 125°C (257°F) with an average residence time of between 20 and 25 minutes.

- **Protec and Stord Bartz De-watering Process.** In this low temperature system, raw material is initially minced to a particle size of 10 mm (0.4 in) before being heated to 95°C (203°F) for 3–7 minutes. The liquid phases (fat and water) are removed by centrifuging or light pressing and further separated to recover the tallow. The resultant solids are dried at temperatures ranging from 120 to 130°C (248 to 266°F). An alternative process used at one facility employing a Protec low-temperature rendering system involves placing the residue inside a rotating barrel for about 25 minutes while treating with forced air that enters at 700–800°C (1292-1472°F) and exits at about 110°C (230°F). However, the actual temperature of the material inside the rotating barrel is unknown.

- **Dupps Continuous Rendering System or Equacooker.** This system is designed to operate in a manner similar to a batch cooker. While the layout, heating system, rotating shaft, material agitation, and conveying systems are similar to other continuous systems, the primary difference lies in an adjustable variable-speed drive of the feed screw. The discharge rate for the Equacooker is controlled by the speed or rotation of the control wheel. It employs buckets, similar to those used in a bucket elevator, to pick up the cooked material from the Equacooker and discharge it to the drainer.

According to UKDEFRA (2000), the American rendering industry uses mainly continuous rendering processes. The US rendering industry, as a net exporter of tallow and MBM, is continually attempting to improve the quality of final rendering products and to develop new markets. The first reduced temperature system (from Carver-Greenfield), and, later, more advanced continuous systems, were designed and used in the US before their introduction into Europe. The maximum temperatures used in these processes varied between 124 and 154°C (255 to 309°F). In the years leading up to 1986, the rendering industry put forth considerable efforts to preserve the nutritional quality of finished products by reducing the cooking temperatures used in rendering processes.

Drying systems

Recently The Dupps Company (2003) introduced the Quad-pass (dual-zone) drier (also called a four-pass rotary drier). Figure 1 in Appendix C provides a comparison of this new system with traditional three-pass drum driers. In traditional three-pass driers, material usually begins drying at high air velocity, with air velocity decreasing at each subsequent stage, ultimately slowing such that the material falls out. In this system particles are prone to accumulation, over-drying, volatilization, pyrolysis, and clogging. The manufacturer indicates that in the new four-pass rotary drier, the velocity of particles is slowest at the entrance of the drier and gets progressively faster in subsequent stages. This design allows moisture to be removed from each particle at its individual drying rate without overheating or volatilizing, regardless of particle size or moisture content.

Morley (2003) designed an airless drying system, which uses superheated steam at temperatures up to 450°C (841°F) to dry protein materials at atmospheric pressure. This design, which produces a faster drying rate than conventional air or contact driers, utilizes two separate closed loops of gas combustion and drying. The separation between the two loops occurs via a high efficiency heat exchanger. Figure 2 in Appendix C shows the combustion loop that produces heat energy from a two-megawatt gas burner, which heats up one side of the heat exchanger. The combustion loop recycles a high percentage of heat in order to maximize operating efficiencies. The drying loop re-circulates the superheated steam via a 37-kilowatt (kW) process fan. Superheated steam is conveyed via 700-milimeter ducting through a dust cyclone, process fan, and heat exchanger before entering a cascading rotary drying vessel measuring some 14.5 meters in length and 1.8 meters in diameter. Results of experimentation with this new system suggest that superheated steam dries at a faster rate while using less raw energy at temperatures above 210°C (410°F).

A central process logic controller (PLC) controls the devices of the two loops, including burner settings, fan speeds, combustion air, and exhausting air. The speed-controlled fan presents cooled steam from the preceding pass at 140°C (284°F) to the heat exchanger where it is reheated to a maximum of 450°C (840°F). From there it is introduced to a rotary cascading drum along with the moist material to be dried. To control the system, at any one time a dozen sensors monitor flows and temperatures and make subtle setting changes to the burner outlet, process fan speed, and feed augers to ensure that only the needed amount of heat energy is delivered to the drying vessel. Morley (2003) reported the following advantages for this new drier:

- The process does not require any form of biofiltration or odor control. Nitrogen oxide levels are markedly reduced.
- The system is constructed entirely of food-grade stainless steel, including all ducting, fans, cyclones, and valves, ensuring that the airless drier is easily cleaned.
- More steam leaves the drier on each pass than enters it due to the process of evaporating moisture during each pass. This is bled off before the heat exchanger and is presented to a condenser unit where the waste heat is converted into hot water that is reused within the plant.
- The overall efficiency of the drying loop reaches 85%, which contributes to impressive fuel conservation.
- The system allows for full recording, trending, and reporting of quality control information, and provides documentation that sterilization criteria have been reached.
- The design parameters suggest a 20% energy savings can be achieved, however, in reality a savings of approximately 35% is achievable based on similar throughputs of the conventional drying method. This is expected to increase with further refinements, including the utilization of waste heat from the combustion loop exhaust.
- Due to less contact of air with the materials being dried, the nutritional values of the resulting MBM are correspondingly higher than materials dried with conventional driers.

Many efforts have been directed at recovering heat energy in rendering systems. Atlas-Stord (2003) designed a new system of recovering waste heat from the dewatering process called the "Waste Heat Dewatering System." Figure 3 in Appendix C shows the flow process of this patented system. In this system, a twin screw press splits the preheated raw material into a solid and a liquid phase, with the liquid phase containing mainly water. Fat is concentrated in the waste heat evaporator, utilizing the energy content of the vapors from the continuous cooker. The pre-concentrated press water and the solids from the twin screw press are dried in the continuous dry rendering cooker. The final de-fatting of the solids takes place in the high pressure press. The authors indicate that a 50-60% reduction in steam/fuel demand compared with conventional batch systems can be achieved, and increases of up to 70% in capacity compared to existing continuous cooker/drier rendering plants may be realized.

Odor reduction

Considerable progress has been achieved in manufacturing very high efficiency odor neutralizing units. For example, Mona Environmental Ltd. (2000) built a biofilter pilot plant next to a rendering plant in Brittany, France to absorb and digest emissions produced by the cooking process. This plant had inlet concentrations of 400 mg H_2S/m^3 and 50 mg NH_4OH/m^3, and outlet concentrations of 20 mg H_2S/m^3 and 0 mg NH_4OH/m^3 (emission unit is defined by mg of odors such as H_2S and NH_4OH in 1 m^3 of gases leaving the cooking tank). In other words, the odor removal efficiency was 95% for H_2S and 100% for NH_4OH. Subsequently, a full scale system was installed to treat the total airflow of 60,000 m^3/hr, in which a removal efficiency of >99.5% was achieved for H_2S and 100% for NH_4OH.

Rendering capacity

Generally speaking, in most parts of Europe, as well as in the US, there is a trend towards fewer rendering plants of larger capacity. But recently, larger rendering capacities have resulted from the need for new technologies to meet environmental requirements. According to Asaj (1980), in Croatia the capacity of rendering plants was very low, with the average volume of material processed annually in the 7 existing plants estimated at roughly 57,000 tons. Due to expansion of the cattle-industry, two additional rendering plants were constructed to achieve a capacity of 100 metric tons (220,000 lb) per day. UKDEFRA (2000) reported that in 1991 in Holland, one company was processing all raw materials, mostly in two rendering plants. In Belgium, one plant processed 95% of raw material. In Denmark, there were four renderers, but one processed more than 80% of the raw material in four plants. On the other hand, in Germany, where federal authorities were directly or indirectly responsible for disposal of animal waste, there were about 42 public and private plants in operation. In Italy in 1995, there were 74 renderers (including those associated with slaughterhouses). They indicated that most European renderers transitioned from batch processes to continuous processing in order to meet pressure for hygienic products, decrease energy consumption, lower labor costs, and minimize environmental impacts. UKDEFRA (2000) reported that rendering in Northern European Countries (e.g., Austria, Denmark, Germany, Holland, Sweden, and Switzerland) required high-pressure cooking, and the new European Community (EC) regulations led to the installation of 200 high-pressure systems throughout the European Union (EU).

The US situation is different from that in Europe. In the past, most operations were "independent" rendering plants (which obtain their raw materials mainly from dead animals and are off-site or separate from the plant facility). However, over the years there has been an increasing trend towards "integrated" or "dependent" rendering plants (which operate in conjunction with meat and poultry processors). Of the estimated 250 plants operating in the US, approximately 150 are independent and approximately 100 are integrated facilities (UKDEFRA, 2000). Whereas in 1995, production of MBM was roughly evenly split between livestock packer/renderers and independents, recent expert reports show that in the present situation, the packer/renderers produce at least 60% of all MBM, with independents accounting for the remaining 40% or less (Giles, 2002).

In spite of the fact that the meal production of independent renderers has declined in recent years, they have a very good capacity to process dead animals. A UKDEFRA (2002) report indicates that the entire US rendering industry in 2002 produced about seven million tons of rendered products (MBM, lard, and tallow). According to SCI (2002), independent renderers produced more than 433 million pounds of MBM from livestock mortalities, or approximately 6.5% of the 6.65 billion pounds of total mammalian-based MBM produced annually in the US (this total amount is in addition to the quantities of fats, tallow, and grease used in various feed and industrial sectors). The livestock mortalities used for this product (433 million lbs) represent about 50% of all livestock mortalities.

As there is no published data on the rendering capacities of "integrated" rendering plants in the US, based on the above-mentioned data related to the year of 2002, the following calculation shows that independent renderers have enough potential to absorb and render all livestock mortalities.

- (100 dependent renderers)(2C) + (150 independent renderers)(C) = 7,000,000 tons (total production). To ensure a conservative estimate of the capacity (C) of independent renderers, the capacity of dependent renderers was assumed to be about two times that of independent renderers.
- Based on the above-mentioned equation, C (production capacity of each independent renderer) = 20,000 tons, and their total production capacity = (150 plants)(20,000 tons/plant) = 3,000,000 tons.
- The total production capacity of a rendering plant is approximately 30% of their input capacity, and based on this fact the independent rendering plants in the US have an input capacity of about 10,000,000 tons.
- Since the 433 million lbs of produced MBM were about 10% of the livestock mortalities as the raw materials, the total livestock mortalities were about 4.33 billion lbs, or 50% of the total mortalities in that year. Thus, the total weight of dead livestock was about 8.660 billion lbs (4.33 million tons).
- Comparison of the capacity of independent rendering plants and the total weight of dead livestock clearly shows that the independent plants have a good potential to convert all the farm animal mortalities into carcass meal and tallow.

Others (namely, Hamilton [2003]) report that the US rendering industry generates about 52 billion pounds (26 million tons) of rendered products annually. Of the raw materials used in this production, 40% is represented by animal mortalities made up of approximately 4 million cattle, 18 million pigs, and 100 million poultry. Keener et al. (2000) classified carcasses into four different weight groups of small (less than 23 kg [50 lb]; i.e., poultry), medium (23-114 kg [50-250 lb], or average of 70 kg [154 lb]; i.e. swine), large (114-227 kg [250-500 lb], or average of 170 kg [374 lb]) and very large or heavy carcasses (225- 500 kg [500-1100 lb], or an average of 362 kg [800 lb]). Using average weights of 600 lbs for cattle, 300 lbs for swine, and 4 lbs for poultry, the overall estimated weight of on-farm animal deaths will be as follows:

4×10^6 cattle x 600 lbs/cattle = 2.4 billion lbs

18×10^6 pigs x 300 lbs/pig = 5.4 billion lbs

100×10^6 poultry x 4 lbs/poultry = 400 million lbs

Total weight of dead livestock = 8.2 billion lbs (4.1 million tons)

This number is very close to the weight of dead farm animals calculated by MBM production in independent rendering plants. Figure 4 in Appendix C provides an overview of the relationship between the total animal mortalities and MBM production in 2002. The actual weight of mortalities used by renderers in 2002 was about 3.3 billion lbs. This number was about 40-50% of the total weight of dead carcasses or 8.3 billion lbs.

3.4 – Raw Materials, Energy, and Equipment Requirements

The microbiological, chemical, and physical characteristics of carcasses are important factors for making high quality rendered products. Some preparation processes, such as size reduction, pre-heating, and conveying, are essential for marketable rendering products.

Raw materials

Carcasses are composed of four broad components including water, fat, protein, and minerals. The European Commission (2003) reported that water, a major component of the live weight of the animal, varies between 70-80%, and for carcass byproducts is about 65%. Livestock mortality is a tremendous source of organic matter. A typical fresh carcass contains 32% dry matter, of which 52% is protein, 41% is fat, and 6% is ash. The carcasses of different animal species have slightly different compositions (see Table 1 in Appendix D). Fat content is quite different as well; the fat content of cattle and calves is about 10-12%, that of sheep is about 22%, and that of hogs is about 30%. These compositional differences result in different species having different optimal processing conditions. For example, under equal conditions, the wastewater generated by rendering hog carcasses may require more separation to remove all the fat as compared to wastewater generated by rendering cattle carcasses.

"Integrated" plants are generally located in conjunction with a slaughter operation and typically process only one type of raw material. Although the composition of raw material used in this type of operation is not completely homogeneous, it is somewhat consistent and raw materials are relatively fresh, therefore simplifying control of the processing conditions. In this system, the final human-grade, edible oil products known as tallow, lard, or edible grease are derived from the fatty tissues of cows and pigs.

Conversely, "independent" operations often process farm animal mortalities and a variety of other "raw by-products" that are not suitable for edible rendering. These raw materials are less homogeneous and therefore require more frequent changes in operating conditions within the system. Furthermore, these raw materials may harbor a potential public health hazard, and should preferably be sterilized before rendering. In addition to carcasses, the following could be used as raw materials for independent renderers, however the use of finished inedible products may be restricted in some circumstances (i.e., may not be used in some types of animal feed, etc.; Oosterom, 1985):

- Placenta
- Offal from hatcheries
- Inedible offal from slaughterhouses and poultry processing plants
- Intestinal contents, such as rumen ingesta
- Trimmings, fleshing, floor sweepings, sieve remains, and fat from wastewater produced in slaughterhouses and meat industries
- Sludge from slaughterhouse wastewater treatment plants
- Condemned fish and fish offal
- Leftover foods from restaurants, food industries, catering establishments, etc.
- Cadavers of pets, strays, and sport animals
- Cadavers of laboratory animals after completion of experiments
- Animals slaughtered for partial use: fur animals, sharks, shrimp, lobsters, frogs, crocodiles, etc.
- Remains from leather industries
- Remains of animal materials sent for examination to veterinary institutes, food laboratories, etc.

In July 1997 the US Food and Drug Administration (FDA) established a rule to prevent transmission of transmissible spongiform encephalopathy (TSE) agents in ruminant animals. According to FDA (2001), feeding ruminants with the meat meal resulted from rendering certain species of animals (mainly cattle, goats, sheep and farm-raised deer or elk) was prohibited. No restriction has been made on feeding ruminant animals with MBM produced by rendering non-ruminants such as poultry. The prions of TSEs are responsible for many fatal neurodegenerative diseases in humans and animals.

In addition to the 1997 ruminant-to-ruminant feed ban, other protective measures have been taken. These have included a ban on importation of ruminants and ruminant products from countries with BSE and measures to exclude potentially infective material from the human food supply. With the December 2003 discovery of BSE in Washington state, additional safeguards and surveillance activities are being implemented.

The European Commission (2003) defined the term MBM as a meal produced from red meat animals, but excludes meal produced from poultry. According to the Animal By-Products Regulations of Northern Ireland (2003), "MBM" or "mammalian MBM" refers to mammalian protein derived from the whole or part of any dead mammal by rendering (with the heat treatment at least 140°C for 30 minutes at 3 bar pressure) and "protein" means any proteinaceous material which is derived from a carcass (but does not include: milk or any milk product; dicalcium bone phosphate; dried plasma or any other blood product; gelatin; or amino acids produced from hides and skins). MBM in the US is defined as a multiple source of protein derived from the processing of animal carcasses (Zamzow, 2003). This material can include animals that are deceased from disease and even pet animals that have been euthanized. The material processed by carcass renderers may consist of the parts of permitted animals that are unsuitable for people to eat as a food, such as:

- offal that did not have a more valuable use, such as the bladder, diaphragm, udder, intestines, kidneys, spleen, blood, stomach, heart, liver, and lungs, which were only occasionally used for other purposes;
- the head, hooves, bones, and tails;
- edible fat; and
- waste from knacker's yards (entities who collect dead or diseased animals from farms in order to salvage any products of value and dispose of the remains, usually to a renderer), and from other animal by-product trades such as hunt kennels, maggot bait farms, tripe dressers, and tanners.

These materials could be subjected to further rapid deterioration or otherwise be contaminated by microbiological organisms, including those which may be pathogenic to humans. In order to protect human and animal health, as well as the environment, these materials should be properly collected and decontaminated as soon as possible after they become available. Decontamination of animal materials could be achieved by various means. For example, for destruction of anthrax spores, Turnbull (1998) recommended using formaldehyde, glutaraldehyde (at pH 8.0-8.5), hydrogen peroxide, and peracetic acid (for raw materials without blood such as hooves and bones). Although irradiation with gamma rays, use of particle bombardment, or fumigation with a gaseous disinfectant such as ethylene oxide has been recommended for decontamination of certain animal by-products (Turnbull, 1998), further research is needed to see the applicability of these methods for decontamination of animal mortalities.

Although the rendering process is capable of converting carcasses or their parts to dry meal, the quality of the carcass will affect the final product in terms of protein content and total bacterial counts. Clottey (1985) emphasized that only condemned material and parts of freshly dead animals can be included, but not material that is putrefied or in an advanced state of decomposition.

Storage of carcasses

When the quantity of carcasses received exceeds the processing capacity of a rendering plant, it is necessary to store the carcasses as a surplus of raw material. According to AAFRD (2002), carcasses requiring storage for more than 48 hours after death may be stored in one of the following ways:

- In an enclosed structure under refrigerated conditions (0-5°C or 32-41°F).
- Outside during winter months when the ambient temperatures is low enough to maintain the carcasses in a frozen state.
- In a freezer unit.

Some animal production operations use special low temperature storage bins, to refrigerate or freeze carcasses until they can be taken to a rendering facility. Using cold storage for carcasses not only reduces chemical and microbial activities and their associated odors, it also keeps them out of sight and prevents scavenging. Carcass storage areas should be located in areas that will minimize the spread of disease. It has been recommended separate entrances be provided to feedlots to prevent rendering trucks from entering the main feedlot areas.

Carcass storage areas and the surrounding vicinity should be thoroughly cleaned before and after use, and wastewater should be prevented from entering streams or other surface waters.

Electrical and heat energy

The most limiting factor in carcass rendering processes is the energy required for releasing fat, evaporating water, and more importantly, complete sterilization of raw materials. Due to the mixture of fat and water in the rendering process, the heat transfer coefficient varies, and therefore the required heat energy varies as well._According to Herbert and Norgate (1971), the heat transfer coefficients of rendering systems decline rapidly from 170 to 70 Btu/ft^{2}hF^o. They explained that as water is evaporated during the rendering process, a phase inversion occurs from a tallow-in-water dispersion initially present in the cooker, to a water-in-tallow dispersion. A minimum value is reached when all water droplets have disappeared and remaining water is present only as "bound water" in the protein particles. This idea became a base for transitioning from HTR to LTR systems, especially in batch rendering configurations which have high energy consumption and do not allow for secondary use of the energy in the exhaust steam from cookers.

KOFO (1986) outlined a concept of "wet pressing" based on the discovery that it is possible to separate nearly all fat, and more than 60% of the water, from the solids of raw materials by pressing at low temperature (50-60°C or 122-140°F, just above the melting point of the animal fat). This process optimized the energy necessary for sterilization and removal of water, thus reducing the energy consumption from 75 kg oil/metric ton raw materials in the traditional process, to approximately 35 kg oil/metric ton of raw material in the new process. As a further advantage, no organic solvents are needed for the process. Furthermore, as compared to HTR systems this system produces protein meal and tallow with higher quality and quantity. Energy consumption measurements demonstrated the following:

- 33.2 kg fuel oil used/metric ton of offal, corresponded to the use of 60.1 kg oil/metric ton of evaporated water.
- 69.1 kWh of energy/metric ton of offal, or 125 kWh/metric ton of evaporated water.

Fernando (1984) compared LTR and HTR systems and concluded that LTR systems required around 0.5 kg (1 lb) of steam per kg of raw material, whereas HTR systems required around 1.0 kg (2.2 lb) of steam per kg of raw material. That is, under equal conditions the consumption of steam in HTR is twice that of LTR systems.

Processing equipment

The machinery and equipment required depends on the specific rendering option, the input capacity, the degree of automation, and the extent of end product refining and storage. In batch systems, only minimal equipment is required (sometimes only one vessel). Flow (addition and removal) of materials is static. In a continuous system, materials flow in a steady stream, therefore pre- and post-rendering equipment is needed in addition to the main rendering unit.

Although traditional batch systems include a vessel in which most of the rendering process occurs, dry and continuous carcass rendering systems require auxiliary equipment, such as a pre-breaker, hasher and washer, metal detector, screw conveyor, fat refining system, and centrifugal extractor. Usually this equipment is installed along with the rendering cooker mainly for pre-rendering and post-rendering processes. Although optional for animal by-products (like offal), use of such pre-rendering equipment is necessary for rendering whole carcasses because of the size and nature of the materials.

In order to minimize processing time and allow use of the lowest possible sterilization temperature, carcass materials are crushed and mixed using equipment such as crushers, mixers, mills, screeners, decanter centrifuges, and millers. Of the equipment used on a continuous basis, size reducers, cookers, presses, evaporators, and centrifuges are notable. Surge bins, along with variable-speed drives between different units of operation, provide a relatively even flow and control of material through the system. Figure 1 in Appendix D provides a schematic diagram of the machinery and equipment used, along with material flow, in a continuous dry rendering process. More detailed information about the most common equipment used for different rendering processes follows.

Pre-rendering equipment

Before heat treatment, carcasses have to be broken down in a closed system into pieces not larger than 10 cm^3. This is accomplished using a "crusher" or pre-breaker to reduce carcasses into pieces of uniform size prior to passing through size reduction equipment and subsequently entering a continuous pre-heater or cooker/drier. A pre-breaker contains "anvils" in place of knives. In order to break large materials and move them through the bars, the anvils rotate between parallel bars at the bottom of the honor or pre-beaker. The capacity of size reducing equipment must be adequate to maintain a steady throughput of pre-ground material through the rendering plant.

Further size reduction is accomplished with rotating hammer devices called "hammer mills" or simply "grinders with rotating knives" that operate by impacting and pinching actions to force crushed materials through a retaining screen. As the rotor turns, hammer-heads swing and beat/drive the materials into a breaker plate and through a retention screen. Depending on the nature of raw materials, cutters or bars may be used instead of hammers.

Other pre-rendering equipment that may be used include hasher and washer units (hasher represents a French word for equipment that chops materials such as meat and potatoes into small pieces), metal detectors, and screw conveyors. The combined hasher and washer chops and washes carcass material, and, in some cases, soft tissue such as stomachs and intestines. A metal sorter detects and removes metal from crushed raw materials; ear tags, magnets, consumed metals, and other metal pieces are fairly common in livestock carcasses. Finally, a screw conveyor transports crushed raw material to the pre-cooker or cooker.

Cooking equipment

An integral part of any continuous rendering system (wet or dry) is the cooker, comprised of sections of pre-heater and heater. Cookers are constructed in a cylindrical form through which ground carcass material is conveyed by means of a rotor or agitator in the form of screw conveyer. For efficient heat energy use and transfer, most cylinders and agitators are steam heated. Various steam jacket designs have been used; for cylinders of considerable length the steam jacket can be divided into sections. Each section is equipped with devices for individual condensate discharge to regulate the steam supply and thus maintain the proper temperature for each section.

Various names such as "renderer," "rendering vessel," "rendering melter," or "rendering cooker" are given to the principal piece of equipment used in the rendering process. According to Kumar (1989), the conventional cooker is a horizontal steam jacketed vessel made up of two concentric cylindrical shells of milled steel (covered with end plates) and fitted with an agitator. The mixer is made of a shaft and attached solid or hollow blades. Along the horizontal central axis of the vessel, the shaft passes through the two end plates and is supported by heavy-duty bearings on either side. The blades are designed to continuously scrape the inner surface of the cooker, thus preventing scorching and overcooking. A manhole at the top of the cooker is used for maintenance and repairs. The vessel is equipped with an entrance gate for crushed raw material. Valve and discharge gates are fitted at one of the end plates. A suitable gear drive box and motor for the agitation are mounted on the other end plate of the vessel. Depending on the required rendering capacity, dry rendering cookers are manufactured in various sizes, but most are generally manufactured to withstand a working steam pressure of 7 bars or 100 psi (Kumar, 1989). In dry rendering systems (batch or continuous), steam is the main heating source which is entered in jacket layers, while in wet rendering water in form of steam or normal liquid is injected directly into the raw materials. Several factors, such as loading rate, temperature, pressure, and quantity of steam used, control the average cooking temperature and retention time of the materials inside the rendering tank.

Electrical instruments such as starters and reversing switches, as well as fittings such as pressure gauges (for the steam jacket and internal shell), safety valves, vapor line valves, steam condensate discharge valves, water jet condensers, etc. are provided at a convenient place for operation and monitoring.

Pressing units

Pressing units may be used to press the input materials going to the cooker, or the output products from the cooking process. Usually typical screw presses with one or two rotating elements operate in a continuous manner. The performance of single-screw presses is very similar to double-screw presses, with a reduction of volume as material moves down the screw (due to the change in pitch and diameter of flights).

Ockerman and Hansen (2000) reported that wet output material is fed into an inlet chute (a sloping channel) at the end of the press and fills the free space between the screw flights and the strainer plates. The materials are subjected to steadily increasing pressure that causes an efficient squeezing of the wet material. The liquid materials (mainly water and fat) escape through the perforated strainer plates around the screws and are colleted in a tray equipped with a discharge pipe. The solid or pressed, dewatered, and defatted material is discharged axially at the end of the press.

The characteristics of the material to be pressed have significant effects on the throughput and volume ratio of screw presses. Ockerman and Hansen (2000) indicated that for moist and soft materials, there is generally a quick initial compression followed by a more gradual compression rate during the subsequent pressing.

Evaporators

The liquid mixtures coming from the rendering process contain considerable water which can be removed economically using efficient evaporators. Water evaporation is an energy-intensive process; low-pressure evaporators are more efficient than open kettles or other systems operating at atmospheric pressure. At a pressure of 0.5 bar (almost 0.5 atmosphere) water boils at 81.5℃ (179℉); therefore, the use of low pressure evaporators can produce "waste" vapors that can be used as a heat source for the evaporators.

Increasing the efficiency of evaporators has been accomplished in several ways. One is by using the condensed live steam leaving the jacket of a cooker/drier as a heat source to drive the evaporator. Another technique is to use multiple-effect (stage) evaporators. Ockerman and Hansen (2000) reported that addition of every stage to the evaporator will nearly double the efficiency of evaporation, meaning twice as much liquid is evaporated per quantity of live steam or waste vapor consumed in the steam jacket. In a multiple-effect evaporator system, vapor from an effect is condensed in the steam jacket of a succeeding effect.

Increasing the heat transfer surface has been successfully practiced in modern evaporators. Instead of simple jacketing of the boiling chamber, vertical tube bundles can be used with the heating medium on the outside of the tubes and the product boiling on the inside. In the heat tubing evaporators, product is either moved downward through the tubes (falling film), or upward through the tubes (rising film). By feeding the evaporator with a thin film of product and at a proper flow rate, the overall heat resistance coefficient inside the tubes is minimized. This results in high heat transfer coefficients and allows a significant amount of water to be evaporated within a relatively small area of equipment.

Solid –liquid separators

Although tallow, water, and solid protein stay at three different levels in the rendering tank, each portion has considerable impurities of the other portions. Separation is achieved using both simple and sophisticated separation tools such as decanters, strainers, and centrifuges.

Ockerman and Hansen (2000) specified three purposes of decanters for clarification of rendered products, namely (1) primary clarification of tallow, (2) dewatering of coagulated blood solids, and (3) dewatering of solids from effluent. They recommended using decanters for removal of solids from slurry containing 30-40% solids. A drum rotating at 3,000-4,000 rpm separates the liquid phase, which remains close to the axis of rotation of the machine, from the solid content or heavier phase, which goes to the outside of the rotating drum, is transported along the shell to the conical section with the aid of a screw, and is discharged.

High speed separators, based on the application of centrifugal force, effectively separate tallow, water, and solid protein. Various types of centrifugal separators, such as decanters and disc-type high-speed separators are used in the rendering industry. Cracklings from the percolator are loaded into a perforated basket covered with a filter cloth and fitted inside a centrifugal fat extractor. As Kumar (1989) indicated, the centrifugal fat extractor (an ordinary centrifuge) runs at a high speed of 600 to 1,000 rpm, and provides for passing steam through the loaded cracklings to keep the fat in a molten state. When the centrifuge is in operation, it separates fat and moisture from the cracklings by centrifugal force, and the fat is collected in a tallow sump.

Today, high-speed disc centrifuges are commonly used as they are well suited to final clarification and purification of tallow. Separation takes place in the disc stack of the centrifuge. While the lighter phase, clarified and purified tallow, is discharged axially at the top of the centrifuge, the solids part accumulates in the widest part of the bowl and is discharged intermittently by opening a discharge slit (Fenton, 1984). In a relatively new type of decanting centrifuge, a screw rotates horizontally inside a drum and in the direction of the drum but at lower RPM (revolutions per minute). The solid protein, water, and liquid fat are discharged at the front, middle, and opposite end of the centrifuge from ports located close to axis of the rotation.

Driers

The solid protein materials leaving the rendering tank are the substances that contain the most moisture. That is, dry-rendering cookers are not capable of releasing the extra water of carcass meal, and there is, therefore, a need for subsequent driers.

Different drying equipment has been used to dehydrate these wet materials. The Dupps Company (2003) built an energy-efficient Ring Drier, which recovered the heat energy of exhausting air and dried product more efficiently than in conventional driers. According to Ockerman and Hansen (2000), a major advantage of the Ring Drier was recycling of 60% of the heated air back through the drier, which helped to make drying of a high-moisture substance, such as carcass protein or blood, economically feasible.

Odor control equipment

Odor control equipment systems include condensers, scrubbers, afterburners (incinerator), and bio-filters.

Condensers

Strong odors are generated during cooking, and, to some extent, drying processes, and are carried in the steam emitted by rendering plants. Condenser units function to wash the cooking steam with cold water and then liquefy all condensable materials (mainly steam- and water-soluble odorous chemical compounds). According to Fernando (1995), this process reduces the temperature of the non-condensable substances to around 35-40°C (95-104°F) and transfers the heat. The cooling water removes up to 90% of odors and recovers heat energy from the cooking steam. Figure 2 in Appendix D provides a schematic diagram of a condenser used for hot gases and steam coming from the rendering plant.

Scrubbers

Although condensing units absorb water soluble odors, they do not absorb chemical compounds. To address this problem, two chemical scrubbing systems have been used. The venturi-type scrubber is used for facilities generating low intensity odors, and the packed-bed type scrubber with various chemicals is used for facilities generating high intensity odors. Figures 3a and 3b in Appendix D provide schematic views of these two types of scrubbers. A condenser followed by a two-stage scrubbing unit can provide up to 99% odor reduction.

Depending on the chemical composition of odors produced, different chemical solutions can be used. According to Fernando (1995), for rendering plant applications, an acid pre-wash (using dilute sulphuric acid, pH 1.6) was used in the first-stage scrubber to prevent generation of odorous chlorinated compounds from forming ammonia and amines. Then, a second-stage used strong alkaline (pH 12-13) sodium hypochlorite with considerable excess of available chlorine. Alternatively, acidic sodium hypochlorite with pH 5.0 may be used in the first stage, and sodium hydrogen sulphite and sodium hydroxide in sequential order can be used in the second stage to remove aldehydes. Table 2 in Appendix D outlines combinations of chemicals for use in scrubbers.

Afterburners

An afterburner is used to burn the gases released from the exhaust of a scrubber. Afterburning parameters include the residence time and minimum burning temperature. According to Fernando (1995), the minimum requirements for complete burning are a residence time of 0.5 seconds and a temperature of 750°C. In order to calculate the burning residence time precisely, he used a temperature controller and a temperature recorder and considered a safety factor of 50% by increasing the volume of the afterburner and ensuring that the minimum temperature was achieved. The test on the composition of the gases released from the exhaust of the afterburner showed that it was completely free of hydrogen sulphide, mercaptans, and amines. Figure 4 in Appendix D shows the effect of residence time and temperature combinations.

Since this equipment requires a high burning temperature, fuel costs would be high unless the air is preheated by the use of the final exhaust gases. Hot water may be used elsewhere to conserve energy. Figure 5 in Appendix D shows the flow of gases in an afterburner system.

Bio-filters

A bio-filter is a system that treats odorous gases (including air) underground by passing them through a bed of organic material such as woodchips, bark, peat moss, rice hulls, compost, or a combination of these. Gases are broken down to non-odorous compounds by aerobic microbial activity under damp conditions (USEPA, 2002). The substrate is filled with stone (road metal or scoria) or soil and the organic material is placed on the top of the stones. Figure 6 in Appendix D demonstrates the arrangement of a typical bio-filter.

Parameters such as humidity, oxygen content, microbial load, distribution of gases through the bed, porous structure of the bed, drainage system under the bed, and temperature of the gases entering the bed have considerable effects on the efficiency of bio-filters. Fernando (1995) explained that the rate of gas passing through the bio-filters depends on the strength of the odorants in the gas and varies between 10 to 120 $m^3/h/m^2$ of the filter area, and it can be matched for different gases (mixtures of air and odors).

Complete process system

Manufacturers typically specialize in a certain type of equipment; therefore it is generally not possible to obtain all equipment necessary for a rendering operation from one manufacturer. Subsequently, most rendering operations employ machinery from several different manufacturers. A resulting disadvantage is the difficulty in harmonizing various machinery in one specific rendering plant.

To provide examples of the technical specifications of each group of equipment, a general inquiry for the equipment necessary for a complete carcass rendering plant was sent to different manufacturers. Based on quotations received from The Dupps Company (2003) and from Scan American Corporation (2003), the name and some general specifications of equipment needed for a continuous dry rendering processing line are presented in Appendix D as Table 3 and Table 4, respectively.

3.5 – Quality and Use of End Products

The quality and quantity of rendering end-products depends on the physicochemical and microbiological properties of the raw materials, the method of rendering, the pre-rendering and post-rendering processes used, and the operating conditions maintained within the system. In this section, the applications of use for carcass rendering end products, as well as their quality criteria, are discussed.

Carcass rendering end products and their applications

During the last 20 years the end-products of the rendering process, mainly MBM and tallow, have been widely used in the manufacture of a diverse range of animal feed, chemical, and industrial products. Currently, the end products of carcass rendering are used in four major sectors of the economy. The first and most important usage of these products is as an ingredient in feed formulations for livestock, poultry, and aquaculture production. Due to the high conversion efficiency of MBM and tallow, the production efficiency of livestock and poultry increases considerably with these ingredients, thereby making meat, milk, and egg products more affordable. Similarly, using these products as ingredients in pet food formulations helps sustain the health and extend the life of companion animals. In a second sector, extracted and refined animal fats create up to 3,000 modern industrial products that contain lipids and lipid derivatives (Pocket Information Manual, 2003). Some of the major industrial and agricultural applications for rendered products include the chemical industry, metallurgy, rubber, crop protection agents, and fertilizer formulations. The manufacture of soaps and personal care products represents the third key sector. In spite of progress in identifying new materials for use in the manufacture of products for the detergent and cosmetic industries, tallow is still the basic ingredient of laundry and other soaps. The world consumption of these products continues to grow. The last key application, which has generated some industrial interests, is the production of biofuels from animal fats.

While animal fats and proteins are constantly challenged by competing commodities, they play an important role in world trade. However, the continued identification of high-value uses for animal by-products is key to the stability of animal agriculture. Following is a more detailed discussion of the specific uses of MBM and tallow products.

Carcass meal

Carcass meal and MBM are very similar, although slightly different definitions apply. According to UKDEFRA (2000), the concentrated protein remaining after fat removal from the crackling (solid protein material) is called "meat meal." If bone is included as a raw material such that the phosphorus content of the protein product exceeds 4.4%, or if the crude protein content is below 55%, the product is called "meat and bone meal" or MBM. The protein product resulting from the processing of condemned whole carcasses is known as "carcass meal." Based on these definitions, carcass meal and MBM are essentially equivalent, as long as criteria for protein and phosphorus levels are met.

MBM is a good source of amino acids and is routinely used in formulating feeds for all classes of poultry, swine, many exotic animals, some species of fish, and pet foods. The FDA (2001) implemented the requirements and guidelines for the use of MBM and tallow in animal feed and pet foods. According to the feed rule, 21 CFR 589.2000, the feeding of MBM containing ruminant proteins back to ruminants has been prohibited.

Greaves may be used in fertilizer or animal feed, or may be processed further by pressing, centrifugation, or solvent extraction to remove more tallow. The residue can be ground to produce MBM and used largely in animal feed, including pet food. Sometimes tankage may be used in animal rations. In the early months of 1980, for the first time tankage was used in animal rations and animal feed (as a protein source) and MBM was used for fertilizer (UKDEFRA, 2000).

Edible and inedible tallow

Edible tallow and lard are the rendered fats of cattle and hog byproducts, respectively. They have approximate melting points of 40°C (104°F) and are used in the manufacture of many human foods, such as edible fats, jellies, and in baking (Ockerman & Hansen, 2000).

Inedible tallow or grease is the rendered fat of dead farm animals and is used in animal feed and pet food, as well as in pharmaceuticals, cosmetics, and in a range of industrial products (Ockerman & Hansen, 2000). Tallow is classified by grade depending on the concentration of free fatty acids (FFA), color, general appearance, moisture, and dirt content.

Inedible tallow and the fat remaining in carcass meal both have a tendency to become rancid, especially when stored for long periods under warm and humid conditions. Another disadvantage of storing carcass meal in unfavorable conditions is degradation of the fat-soluble vitamins A, D, and E. Additionally, if meal containing rancid fat is used in livestock rations, it may cause digestion disorders. By adding anti-oxidants to tallow or grease at the final stage of processing, rancidity is substantially impeded. Under the Food and Drug Act, the most common permissible anti-oxidants are butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA). According to Kumar (1989), addition of these materials in quantities of 100 g/ton of fat material helps to control rancidity. Based on this formula, it can also be added to carcass meal according to its fat content.

Finding new sources of energy, especially with diminishing reservoirs of fossil fuels in different parts of the world, is of significant interest. Due to decreasing markets for some types of carcass meal and tallow products as a result of concerns over the transmission of TSE agents (such as BSE), the possible use of fat and tallow products as direct or indirect sources of energy has been evaluated, with promising results. According to Pearl (2003), the University of Georgia, Engineering Outreach Service used chicken fat, beef tallow, and grease blended with No. 2 fuel oil as complete substitutes of fuel oil in the 45,000 kg/h (100,000 lb/h) boiler that provides steam for the Athens campus. All blends consisted of 33% fat or grease and 67% No. 2 fuel oil. The energy content of unblended animal biofuels was very consistent among the sources and averaged about 39,600 KJ/kg (16,900 Btu/lb). Blended fuels averaged nearly 43,250 KJ/kg (18,450 Btu/lb), and all were within 95% of the heating value of No. 2 fuel oil alone. A project test team inspected the interior of the boiler after three weeks of biofuel combustion, and observed that the water tube exterior surface and the furnace interior were nearly as clean as after firing natural gas, and substantially cleaner than following the use of fuel oil alone. Pearl (2003) indicated that the animal rendering industry now has sufficient data demonstrating that rendered animal fats can be used as alternative burner fuel. Environmental benefits will likely contribute to the growth of this market.

Quality criteria

The quality of the end products of rendering are affected by the physical, chemical, and microbiological conditions of raw materials, plant sanitation procedures, preparation processes (such as size reduction, pre-heating and pre-pressing), cooking and dewatering processes, and finally post rendering processes.

Various criteria have been established to define the quality of MBM and tallow, and they include different physical, chemical, and microbiological criteria such as nutrient content (mainly the contents of protein, fat, phosphorus, calcium, and other minerals such as sodium and potassium), microbial load, particle size distribution, texture, color, odor, and general appearance. While these criteria show the quality of rendering products properly, the most important physicochemical and nutritional quality indicators are the color of tallow, nutritional aspects, and digestibility of MBM.

Color

UKDEFRA (2000) indicated that the single most important factor in determining tallow grade is color. Tallow color is affected by raw material characteristics, including livestock breed, age, feeding formulation, health condition, and location. A green color of rendered fat is attributed to the presence of chlorophyll in the plant origin of feeding materials. Generally tallow color changes from white to yellow. Overheating the raw materials in dry rendering will give a reddish appearance to the tallow, which may be undesirable (Ockerman & Hansen, 2000).

High rendering temperatures (above 100°C [212°F]) can transfer and fix the "dirt" color of raw materials into the tallow, resulting in the tallow being downgraded. Ockerman and Hansen (2000) emphasized using only washed raw materials for rendering to remove paunch contents and other "dirt." In LTR (70-100°C; 158-212°F), there is no need to wash raw materials because the color of paunch contents and other dirt are not fixed in the tallow.

Tallow with good color is used for soap manufacture and for human consumption, while lower grades are used for animal feeds and fatty chemicals. Figure 1 in Appendix E shows the typical color of MBM and various tallow products.

Nutritional components

Table 1 in Appendix E shows the typical nutritional value of MBM. However, as is the case for other rendering end products such as tallow, the nutritional content of MBM is affected by the rendering method, heating process, type of cooking (direct or indirect; wet rendering or dry rendering), and by pre-rendering and post-rendering processes. The calcium/phosphorus ratio in MBM ranges from 2:1 to 2.2:1, with the actual content being about 9% calcium and 4.5% phosphorus (Table 1 Appendix E). The high phosphorus availability of MBM is one of its major nutritional advantages.

The optimum moisture content of MBM is 3-5%, with values lower than 3% indicating overcooking of MBM during the rendering process (Pocket Information Manual, 2003). However, moisture content is limited to a maximum of 10%. After centrifuging and pressing of MBM, fat content usually averages 8-12%. In addition to protein (amino acids) and phosphorus, MBM is an excellent source of calcium and some other minerals (K, Mg, Na, etc.). According to Machin et al. (1986), MBM normally has an ash content of 28 to 36%; calcium content of 7 to 10%, and phosphorus content of 4.5 to 6%. As is true for other animal-derived products, MBM is a good source of vitamin B-12 and has a good amino acid profile with a high "digestibility" (81-87%).

Fernando (1984) compared the quality and quantity of finished products from LTR and HTR systems. The experiments used raw materials composed of 60% water, 20% fat and 20% fat-free solids, a composition typical of animal carcasses. Table 2 in Appendix E summarizes the results of this study. Overall, the quantity and quality of finished products were higher with LTR than HTR systems. Furthermore, LTR systems required less capital, labor, repair, maintenance, and energy than HTR systems.

Digestibility and biological activities

Although the protein content (usually around 50%) of MBM is an important quality indicator and is the basis for selling this product as a feed ingredient, digestibility of the protein content (amino acids) is an essential factor in creating high quality feeds for poultry and swine. Apparent digestibility of amino acids, called "ileal" digestibility, is determined at the end of the small intestines (ileal refers to the ileum, the last division of the small intestine extending between the jejunum and large intestine) (Pocket Information Manual, 2003). According to this manual, MBM has a digestibility of 85% or higher. Some values of apparent ileal digestibility of rendered animal protein products are shown in Table 3 of Appendix E.

Ristic et al. (1993) employed the conventional batch dry rendering method with screw press defatting and the semi-continuous wet rendering method with centrifugal defatting for processing inedible raw material (76.5% soft offals, 15% industrial bones, and 8.5% swine cadavers). They observed that the contents and biological activities of lysine, methionine, and cystine (nutritional values) of meat meals produced by the conventional batch dry rendering method was lower than that of meat meals obtained by the semi-continuous wet rendering method.

Ash content significantly affects protein content and amino acid digestibility of the final MBM. Ravindran et al. (2002) studied the apparent ileal digestibility of amino acids in 19 MBM samples, obtained from commercial rendering plants processing 5-week-old broilers in New Zealand. They observed considerable variation among these samples in the contents of crude protein (38.5-67.2 g/100 g), ash (13.0-56.5 g/100 g), crude fat (4.3-15.3 g/100 g), and gross energy (9.4-22.3 MJ/kg). While amino acid concentrations and ileal digestibility of amino acids varied substantially, digestibility of amino acids, with the exception of aspartic acid, threonine, serine, tyrosine, histidine, and cystine, was negatively correlated with ash content (i.e., samples with higher ash levels had lower digestibility). Protein digestibility can be reduced in the final MBM if materials such as hooves, horns, hair, and raw feathers are used as raw materials (Pocket Information Manual, 2003).

3.6 – Cost Analysis of Carcass Rendering

As is the case for other carcass disposal methods, the costs of carcass rendering can be divided into operating (variable) and fixed costs of investment. Since the main investment for carcass rendering plants has been made by the industry, the main cost is variable cost. For any specific carcass rendering system, the cost should be analyzed and compared with other disposal methods. The most important factors involved in cost analysis of massive carcass rendering include collection, transportation, temporary storage fees, extra labor requirements, impact on the environment (sanitation for plant outdoor and indoor activities, odor control, and wastewater treatment), and sometimes additional facilities and equipment. These expenses primarily make the renderers' costs much higher than the cost of usual rendering.

Cost analysis

Given the fact that removing dead animals from production facilities would be the same for all disposal alternatives, usually the variable costs do not include labor or equipment for local mortality handling. However, SCI (2002) estimated the labor and equipment (rental or depreciation) costs, respectively, at $10 and $35/hour. Table 1 in Appendix F shows the cost of rendering (without collection and transportation cost of carcasses) is much less than other carcass disposal methods. The extra cost that renderers typically charge for collecting mortalities makes the operating and possible fixed costs of this system comparable with costs associated with most other methods.

Operating costs for different disposal techniques show significant variation across different mortality disposal methods. According to SCI (2000), if all mortalities were disposed of using only one method, the operating costs range from $58 million for incineration, to $194.4 million for rendering (if the resulting MBM from converting collected livestock are disposed in a landfill). This report indicated that current renderers' fees were estimated at $8.25 per head (average for both cattle and calves). However, assuming the sale of MBM produced from livestock mortalities were prohibited (due to the possible BSE contaminations), renderers' collection fees increase to an average of over $24 per bovine, an increase of almost 300% (see Table 1 in Appendix F). Although direct responsibility for the extra cost of rendering, including collection and transport of fallen animals, lies with livestock producers, this cost may eventually be incurred by society for controlling contamination sources and providing a pleasant environment.

Economic considerations

Table 2 in Appendix F shows consumption and export data for finished products produced by US rendering plants (primarily from carcasses) during 2001 and 2002. About 40% of the total MBM produced in US rendering plants was from carcasses. Close consideration of these data reveals the following points:

- Generally the conversion rate of raw material to dry meal is 3:1.
- More than 75% of the total fat produced in US rendering plants was inedible tallow and grease.
- Almost one third (33%) of the total inedible fat used for animal feed formulation was inedible tallow, increasing about 6% during the above-mentioned years.
- Export of inedible tallow increased almost 30%, suggesting good demand for inedible tallow in future years.
- Exported MBM increased 25%, which again suggests strong demand for this product in international markets.

Hamilton (2003) reported that the percentage of feed mills using meat & bone meal declined from 75% in 1999 to 40% in 2002, and the market price for MBM dropped from about $300/metric ton in 1997 to almost $180/metric ton in 2003. However, the total quantity of MBM exported by the US increased from 400,000 metric tons in 1999 to about 600,000 metric tons in 2002.

As long as the rendering industry can market valuable products from livestock mortalities (including protein based feed ingredients and various fats and greases), collection fees will likely remain relatively low. However, collection and disposal fees will be much higher if the final products can no longer be marketed. Having a commercial value for end products is crucial to the economic feasibility of carcass disposal by rendering. The US produces a little over 50% of the world's tallow and grease, and exports almost 40% of this (Giles, 2002). Additionally, more than half of the world's animal fat production (around 6.8 million tonnes) is produced in North America (Pocket Information Manual, 2003).

Rendering animal mortalities is advantageous not only to the environment, but also helps to stabilize the animal feed price in the market. Selling carcass meal on the open commodity market generates competition with other sources of animal feed, allowing animal operation units and ultimately customers to benefit by not paying higher prices for animal feed and meat products. Exporting rendered products promotes US export income and international activities. For example, the US exported 3,650 million pounds of fats and proteins to other countries during 1994, which yielded a favorable trade balance of payments of $639 million returned to the US (Prokop, 1996).

The quality of MBM produced from carcasses has a considerable effect on its international marketability. Issues related to TSE agents are of course critical, but even the presence of organisms such as *Salmonella* may limit the export potential of products to some countries. While the export of MBM from some countries to Japan has been significantly reduced in recent years because of potential for these contaminants, other countries such as New Zealand have made considerable progress in this trade. According to Arnold (2002), New Zealand MBM exports to Japan have attracted a premium payment over Australian product of $15-$30/ton. Japanese buyers and end-users have come to accept MBM from New Zealand as being extremely low in *Salmonella* contamination, and have accordingly paid a premium for this product. According to Table 3 in Appendix F, the market share percentage of MBM imported by Japan during the year 2000, compared to the first nine months of 2001, from New Zealand sources increased from 18.5% to 32.6%, and from US sources increased from 1.8% to 3.2%.

Section 4 – Disease Agent, Sterilization, and Environmental Considerations

Although rendering processes can eliminate many microorganisms from finished products, byproducts of the rendering process, such as odors, sludge, and wastewater, may present health and environmental problems if not treated properly. However, the potential for rapidly spreading diseases among livestock and people, and for contaminating the environment, arises if carcasses are not disposed of promptly and properly.

The following federal and state agencies have worked closely with the independent rendering plants and routinely inspect their facilities to provide proper collection and processing of fallen animals (Hamilton, 2003):

- Officers of the FDA inspect rendering facilities for compliance to BSE regulations.
- The USDA Animal and Plant Health Inspection Service (APHIS) inspects rendering plants for compliance to restrictions imposed by importing countries and issues export certificates for rendered products.
- State Feed Control Officials inspect and test rendered products for quality, adulteration, and compliance with feed safety policies.
- USEPA provides guidance and regulation for odor, sludge, and wastewater treatment.
- Additionally, voluntary internal control programs including good manufacturing practices (GMP) and hazard analysis critical control point (HACCP) systems are common among rendering plants.

Different parts of disease agents, their controlling methods and environmental impacts of carcass rendering process and related to topic of this section will be discussed.

4.1 – Disease Agents

Microorganisms

The proper operation of rendering processes leads to production of safe and valuable end products. The heat treatment of rendering processes significantly increases the storage time of finished products by killing microorganisms present in the raw material, and removing moisture needed for microbial activity.

Rendering outputs, such as carcass meal, should be free of pathogenic bacteria. Thiemann and Willinger (1980) reported that *Clostridium perfringens* is an indicator microorganism, which shows the sterilizing effect of rendering procedures. They reported that elimination of gram-negative bacteria and demonstration of only small numbers of gram-positive bacteria (like aerobic bacilli) in the rendering facility, and also absence of *Clostridium perfringens* spores in sewage of the contaminated side, are indicators of effective disinfection processes. Carcass meal, as well as waste products, may be contaminated with many pathogenic bacteria if inadequate processes are used. This contamination can be transferred to the environment. Bisping et al. (1981) found salmonellae in 21.3% of carcass-meal samples taken from rendering plants. He pointed out that the occurrence of salmonellae was due to recontamination after sterilization of the raw material. It should be noted that not all the *Salmonella* serovars or *Salmonella* species are pathogenic. The Pocket Information Manual (2003) reported that from 2,200 *Salmonella* serovars which may potentially produce disease, only about 10-15 serovars are routinely isolated in the majority of clinical salmonellosis in humans and livestock/poultry.

Resistant proteins (prions)

The emergence of BSE has been largely attributed to cattle being fed formulations that contained prion-infected MBM. As Dormont (2002) explained, TSE agents (also called prions), are generally regarded as being responsible for fatal neurodegenerative diseases in humans and animals. Creutzfeldt-Jakob is a disease of humans believed to be caused by prions. In animal populations, prions are thought to be responsible for scrapie in goats and sheep, BSE in cattle, feline spongiform encephalopathy, transmissible mink encephalopathy, and chronic wasting disease. According to UKDEFRA (2000), epidemiological work carried out in 1988 revealed that compounds of animal feeds containing infective MBM were the primary mechanism by which BSE was spread throughout the UK. Thus the rendering industry played a central role in the BSE story. Experts subsequently concluded that changes to rendering processes in the early 1980s might have led to the emergence of the disease.

The present epidemiological knowledge about BSE demonstrates why the BSE agent was able to survive the rendering processes that otherwise achieved microbial sterilization. For example, prion proteins are known to be quite heat resistant.

Various policy decisions have been implemented to attempt to control the spread of BSE in the cattle population. Many countries have established rules and regulation for imported MBM. The recently identified cases of BSE in Japan have resulted in a temporary ban being imposed on the use of all MBM as an animal protein source (Arnold, 2002).

Sander et al. (2002) reported that specific restrictions were placed on rendering sheep, goats, cattle, and farm-raised deer or elk in some areas of the US because of concern that TSE agents could be transmitted by the resulting meat meal. Poultry rendering is not subjected to new BSE regulations and it is a unique industrial section, which is typically supervised by specialized rendering firms. Poultry carcasses are generally not rendered with mammals, as the feathers require a higher heat process that damages other proteins.

According to UKDEFRA (2000), in 1994 the Spongiform Encephalopathy Advisory Committee stated that the minimum conditions necessary to inactivate the most heat-resistant forms of the scrapie agent were to autoclave at 136-138°C (277-280°F) at a pressure of ~2 bar (29.4 lb/in^2) for 18 minutes. The Committee noted that the BSE agent responded like scrapie in this respect. Ristic et al. (2001) reported that mad cow disease was due to prions which are more resistant than bacteria, and that the BSE epidemic may have been sparked by use of MBM produced from dead sheep, and processing of inedible by-products of slaughtered sheep by inadequate technological processes. They suggested that special attention should be paid when collecting and sorting these inedible raw materials and proposed a process, which includes high temperature, wet sterilization of chopped material (<40 mm) at 136°C (277°F) for 20 minutes at a pressure of 3.2 bar with constant control of critical control points in the process. Schreuder et al. (2001) used a pool of BSE infected brain stem material from the UK, and scrapie infected brain stem materials from Dutch sheep (as spike materials), at rendering plants with a hyperbaric system. They observed a reduction of about 2.2 log in the infectivity of BSE in the first round (with some residual infectivity detected) at a heating process of 20 minutes at 133°C (271°F), and in the second round in excess of 2.0 log (no residual infectivity detected).

According to Franco and Swanson (1996), while some European scientists believed this system inactivated the BSE agent, American scientists did not completely agree, and believed that using the specified high pressure and temperature in cooking processes would not completely inactivate the BSE agent, but simply reduce its infectivity. Heilemann (2002) reported that use of ruminant tissues with a high infectious potential with regard to BSE (specified risk material, or SRM) in the human and animal feed chains was eliminated. FDA (2001) implemented a final rule that prohibits the use of most mammalian protein in feeds for ruminant animals. These limitations dramatically changed the logistical as well as the economical preconditions of the rendering industry. He indicated that the basic treatment (pressure cooking) remained almost unchanged, but instead of physically recycling the products they are predominantly used as an energy source in industry.

4.2 – Controlling Methods

Use of raw materials with minimum microbial loads, combined with the use of GMPs, will facilitate control of disease agents. In this respect, appropriate sanitation and proper sterilization processes play a major role. Furthermore, GMPs are preventive practices that minimize product safety hazards by establishing basic controls and/or conditions favorable for producing a safe product.

Sterilization

The heat treatment of materials requires a sensitive balance. On one hand heat affects protein denaturation and/or enzyme inactivation of microorganisms, and therefore should be applied sufficiently to destroy certain pathogenic organisms. Conversely, many nutritional elements are sensitive to heating processes, and therefore heating should be minimized to limit significant effects on nutritional value or quality. The conditions necessary for sterilization depend on the total microbial load and on the heat tolerance of the target species, in addition to characteristics of the matrix being sterilized (i.e., moisture and fat content). Furthermore, there is a positive correlation between water level (related to water activity) and the efficiency of heat transfer to kill microorganisms. Other parameters, such as vessel size, particle size, and consistency of the material being processed, influence heat resistance.

Riedinger (1980) developed a mathematical model for computation of the sterilization process in rendering systems. Due to the similarity of the sterilization processes in canning and rendering, he used the F-value of the canning industry with heat resistance parameters "Z"= 10°C (50°F) and "D" = 10 sec as a guide. Based on the German Carcass Disposal Act requirements (temperature of 133°C or 271°F during 20 min after decomposition of the soft parts), Riedinger (1980) obtained a comparable sterilization time of roughly 300 min at 121°C for the test organism *Bacillus stearothermophilus* (a non-pathogenic organism that has been shown to be one of the most heat resistant strains of bacteria).

As Pearl (2001) indicated, for the raw materials used in the rendering industry the microorganisms of most concern are *Salmonella* sp., *Clostridium perfringens*, *Staphylococcus aureus*, *Listeria monocytogenes*, *Campylobacter* sp., and *Escherichia coli*, all of which have much lower Z values than *B. stearothermophilus*, and, therefore, a 12D process should be achieved in a shorter time. D is defined as the time in minutes required to destroy 90% (or a one-log cycle) of a population of cells at a given reference temperature. Therefore, a 12D process refers to the time required to achieve a 12 log reduction of the target organism (equivalent to reducing a population of organisms from 100,000,000,000 to 1) at a given reference temperature.

The temperature in a batch dry rendering process is a critical issue in terms of microbial inactivation. Because this process is carried out at atmospheric pressure, the temperature remains at 100°C (212°F) for the majority of the rendering process. After all free water is evaporated from the whole mass, the temperature gradually rises to approximately 120°C (248°F). In spite of this high temperature, the presence of fats serves to protect microorganisms by making fat layers around the cells, thereby increasing the cells heat resistance and protecting bacterial spores against thermal inactivation (Lowry et al., 1979; Pearl, 2001). Thus, sterilization requires a high heating time or a period of heating under pressure to inactivate bacterial spores, which may survive rendering conditions. Hansen and Olgaard (1984) used a pilot cooker and measured the sterility of MBM mixed with water or fat and inoculated with *Bacillus cereus* and *Clostridium perfringens*. They concluded that when the temperature during drying reached 110-120°C, the heat resistance of spores of both strains increased drastically, whereas the moisture content decreased and the rendering materials cooked in fat only. Lowry et al. (1979) determined bacilli and clostridia populations in rendered products obtained directly from three commercial cookers to be between 10^2 and 10^4 unit/g. In subsequent studies, artificial cultures of the heat resistant microorganism *Bacillus cereus* were added to the contents of a pilot-scale rendering plant (46% beef trimmings, 18% bone, and 30% water) to give an initial spore density of approximately 10^7 spores per g and a typical rendering cycle at atmospheric pressure was applied. Results indicated a sharp decline in the rate of spore death when the moisture content fell below 10%, and little decrease in spore numbers during the final 30 min of rendering, although the temperature rose from 105 to 130°C (221 to 266°F). In the final experiment, which was repeated with initial heating of the cooker's content to 120°C or 248°F for 15 min, the products were sterile. It can be concluded that when the moisture content is low, the materials must be heated under pressure to ensure that the spores are not covered in fat layers and thereby protected against thermal deactivation.

Hansen and Olgaard (1984) determined thermal death graphs for spores of *B. cereus* and *C. perfringens* by using the heat transmission data for bones to predict the decimal reductions of spores in the center of the largest pieces present during a given rendering process. They showed that primary dehydration of the raw materials for 45 min, followed by cooking at 125°C (257°F) for 15 min and final drying, ensured destruction of these bacteria even in the center of 70 mm (2.8 in) bone particles. A reasonable reduction of heat resistant clostridia spores was made when the same process was repeated with the particle size reduced to less than 40 mm (1.6 in). Hamilton (2003) explained that temperature and particle size of the material in heating processes are two critical points of HACCP programs associated with the destruction of viral and pathogenic bacteria present in animal mortalities and byproducts.

As previously stated, all species of salmonellae are readily killed by the thermal processes used in conventional rendering. However, contamination of final products can occur during post rendering processes such as handling, storage, and transportation, just as it can with any feed ingredient. The only method available to prevent salmonellae contamination of feeds or feed ingredients during these stages is using permitted chemical treatments.

It is important to distinguish between the two important terms of "sterilization" and "prion inactivation." Both terms usually refer, in legislation and elsewhere, to hygiene procedures designed to prevent microbiologically contaminated food being consumed by humans. As an example, according to UKDEFRA (2000), sterilization of meat materials requires that carcasses are:

- treated by boiling or by steaming under pressure until every piece of meat is cooked throughout;
- dry-rendered, digested, or solvent-processed into technical tallow, greaves, glues, feeding meals, or fertilizers; or
- subjected to some other process which results in all parts of the meat no longer having the appearance of raw meat and which inactivates all vegetative forms and spore formers of human pathogenic organisms in the meat.

Using this definition, the sterilization process would clearly not meet conditions necessary to inactivate prion agents, such as those of scrapie or BSE.

Sanitation and traceability

Sanitation guidelines have a significant effect on the quality of final products. In a study of three New Zealand rendering plants, Arnold (2002) reported that these plants, which produced over 55% of the country's MBM exports to Japan, did not record one positive test from equipment or the plant environment for the presence of *Salmonella* over a three year period.

Usually the source of contamination can be traced back to one or more particular areas within a rendering plant. One of these locations is the surge bin prior to the mill (Arnold, 2002). Various cleaning and sanitizing procedures can be adopted to reduce or eliminate microbial contamination from the plant environment, including regular cleaning to remove protein build-up, improving airflow, daily dosing with powder sanitizer, and fumigation processes. Key to producing rendered products of low microbial load is routine sanitation of the equipment and maintenance tools used on the processing lines and facilities. According to Turnbull (1998), a rendering plant should be divided into "dirty" and "clean" areas, with the dirty side suitably prepared for disinfection of all processing equipment including transport vehicles, collection and autoclaving of wastewater. Both before and after the cooking process, materials are conveyed in closed systems. Turnbull (1998) emphasized that the veterinary authorities should monitor the level of hygiene maintained in the clean side of the rendering plant at least twice yearly.

Studies have shown that steam treatment is likely to become a valuable and environmentally friendly method of sanitizing working surfaces and controlling hygienic problems, with the potential to replace chemical disinfectants to some extent. Haas et al. (1998) demonstrated that a steam cleaning device with a pressure of 5 bar (73.5 lb/in^2) and a temperature of 155°C (311°F) was effective at eliminating *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Candida albicans* along with viruses (ECBO- and Reo-virus) and *Ascaris suum* eggs on a variety of surfaces.

4.3 – Environmental Impacts and Preventive Treatments

Disposal of animal carcasses may generate different environmental and health hazards. Various agricultural agencies (AAFRD, 2002; Australian Veterinary Emergency Plan, Agricultural and Resource Management Council of Australia and New Zealand or AUSVETPLAN, 1996) indicated that improper carcass disposal processes might cause serious environmental and public health problems. These factors are summarized as follows:

- Odor nuisance, resulting from the anaerobic breakdown of proteins by bacteria, reduces the quality of life and decreases property values.
- Pathogens which may be present in decomposed material are capable of spreading diseases in soil, plants, and in animals and humans.
- Leaching of harmful nitrogen and sulfur compounds from carcasses to ground water.
- Attraction of insects and pests as potential vectors of harmful diseases for public health.

The most important byproducts of the carcass rendering process in terms of the potential to pollute air, ground water, and soil are odor and wastewater.

Odor

Because carcasses are typically not refrigerated for preservation prior to rendering, they begin to putrefy and give rise to a number of odorants. Due to this, rendering is often perceived by the public as an unpleasant or "smelly" industry. A significant environmental issue for the rendering industry is controlling various odors generated during pre-rendering, rendering, and post-rendering processes.

As discussed previously, in terms of odor emissions continuous systems have the advantage in that they are enclosed and therefore confine odors and fat particles within the equipment, whereas batch systems are open to the atmosphere during filling and discharge.

Only certain chemical compounds are responsible for odor constituents. The threshold levels at which humans can detect (smell) various odorants are shown in Table 1 of Appendix G (Fernando, 1995). A satisfactory odor abatement system in a rendering facility will reduce odorants to levels well below those given in this table. Fernando (1995) reported that amines, mercaptans, and sulphides are generally expected to be present in gases from rendering plants.

Regulatory authorities have specified methods for controlling odors from rendering plants. For example, the USEPA (2002) has established various regulations for different carcass rendering units. Following are recommended techniques for minimizing odor emissions.

- All emitted odors should be treated in condensing units followed by either chemical scrubbers or incinerators (afterburners) and/or biofilters for non-condensable odors.
- For chemical deodorization of rendering units, use of hypochlorite, multi-stage acid and alkali scrubbing followed by chlorination, and incineration of the final gases in boilers is recommended. Effective and reliable operation of chemical scrubbers and afterburners is essential.
- Odor control equipment should be fitted with monitoring devices and recorders to control key parameters.

- Good housekeeping is necessary to prevent odor development. Exposed raw materials will generate and develop odors.
- Procedures for monitoring odors, as well as investigating and resolving odor-related complaints, should be implemented.

As discussed earlier, condensers, scrubbers, afterburners, and bio-filters can be used in a combined system or individually to remove gaseous materials from the air emitted from rendering plants. Fernando (1995) reported that the cheapest to operate are bio-filters and scrubbers. Volatile gases can be burnt either in a boiler burner or an afterburner, both of which are equipped with heat recovery systems.

More than 20 years ago, different technologies were developed to eliminate odors that may transmit to neighbors. Pelz (1980) reported that in a European rendering plant built in Austria, carcasses, offal, and other animal materials were collected, transferred, and dumped in a hygienically safe manner into a receiving hopper and then transferred by screw conveyor to a crusher. Steam pressure pushed the material into a receptacle called "the gun," and from there it was conveyed to an extractor, which functioned as a sterilizer (30 min 134°C or 273°F), extractor, and drier. The wet extraction procedure used perchloroethylene and produced hygienically unobjectionable animal meal and fat. This method of deodorization created not only optimum working conditions in the plant, but also provided acceptable living conditions in the residential areas at a distance of some 400 m.

From the above discussion, it can be concluded that rendering processes can be carried out without being a public nuisance as long as "fresh" or "stabilized" raw materials are used and appropriate odor control devices are employed for plant emissions.

Wastewater

Historically, the main criteria for determining the acceptability of wastewater discharged from rendering facilities have been levels of BOD, suspended solids, and organic substances. However, available nutrients (nitrogen [N], phosphorus [P], and perhaps potassium [K]) within wastewater may play increasingly important roles (Taylor, 1995).

Microorganisms require ratios of carbon, nitrogen, and phosphorus (C:N:P) of approximately 100:6:1 to grow (Taylor, 1995). Bacteria in pond systems are unable to use high loadings of nitrogen and phosphorus that may be present in rendering wastewater. Treatment of wastewater to address these constituents, specifically phosphorus, is very important. Continued use of wastewater for irrigation tends to accumulate nitrogen and phosphorus in the soil. Since plants can only use a certain amount of these nutrients, USEPA now requires testing of soil to establish the nutrient status, and preparation of an annual "nutrient budget" showing the quantity of these materials that can be applied. If the available nutrients are greater than the amount required in the soil, nutrient contents should be reduced in refining treatment.

Mechanical aeration and oxidation of wastewater can reduce nitrogen, and to some extent phosphorus, contents. Addition of appropriate chemical flocculants, such as aluminum sulfate, to wastewater converts available phosphorus to insoluble phosphorus, which can be removed by settling processes. These chemical procedures will make rendering wastewater treatment more complex and more expensive.

In order to reduce the moisture content of carcasses and save energy in the cooker, receiving bins are generally perforated to allow water to drain off. While this procedure minimizes the energy required to evaporate excess water, it increases the microbial and chemical load of wastewater.

According to Fernando (1995), the quantity of wastewater produced in rendering plants is as follows:

1 ton of raw materials: 0.6-1 ton of wastewater

1 ton of raw materials: 0.5 ton evaporated water

Wastewater from draining in different sections: 0.1-0.5 ton

The volume of effluent and its organic materials vary from plant to plant depending on the raw material, washing process, rendering process, and plant management. The rendering operations are the major source of organic loading and they have the highest COD, 5-day BOD (BOD5), nitrogen, phosphorus, and sodium (Na) contents. Based on the Fernando (1995) report, following are typical ranges for each constituent:

BOD5 ....2,000-20,000 g/m^3

Suspended solids......3,000-30,000 g/m^3

Fat ....2,000-4,500 g/m^3

Protein ....1,000-15,000 g/m^3

Based on 200 metric tons of rendering effluent per day, about 6 tons per day of total solids (containing mainly protein and fat) or dried meal will be lost in the wastewater. By using different techniques such as evaporation, ultrafiltration, and combined chemical/physical treatment, most of the soluble and insoluble solid materials can be easily recovered. Fernando (1995) designed an air flotation system, which was based on mixing wastewater with a non-toxic natural coagulant combined with a polymer. The recovered sludge was thickened to 30% total solids using a decanter, mixed with decanted solids from the rendering process, and dehydrated in a drier. This technology not only increased final MBM yield, but also refined and treated the wastewater, resulting in lower concentrations of organic compounds.

O'Flynn (1999) mentioned that the discharged effluent of a rendering plant had a BOD level of 1,500-5,000 mg/l and an ammonia content of 250-750 mg/l, and that these levels should be reduced to 20 mg/l and 10 mg/l, respectively. He constructed an activated sludge plant with an anaerobic stage to provide a nitrification-denitrification process, and added chemicals to bind phosphate and allow its removal by post-precipitation.

Metzner and Temper (1990) showed that the wastewater from rendering plants can be used for anaerobic pretreatment to reduce COD levels. A fixed bed loop reactor was used to reduce the organic compounds of wastewater in a rendering plant. Since the main organic pollutants were volatile fatty acids, the treatment was carried out in a single-stage system. After 27 hours of anaerobic digestion, the COD concentration of wastewater was reduced to 75–80% of its original content of (8 kg/m^3).

In terms of plant and environmental sanitation, microbial contamination of wastewater is another important aspect to be considered. According to Zisch (1980), all wastewater from the unclean area of a carcass rendering plant should be sterilized, regardless of whether the sewage is discharged into the central purification plant. Another contamination source in animal rendering plants is sewage sludge produced at the end of the operation. Since the heating process converts soluble phosphorus to insoluble phosphorus, sludge contains most of the phosphorus. This sludge has a potential to become a source of soil and plant contamination if improperly disposed. One means of preventing such contamination, while at the same time properly utilizing nutrients, is to compost it with other carbon source materials. Paluszak et al. (2000) composted sewage sludge originating from animal rendering plants along with co-composting materials (such as wood chips, farmyard manure, and bark) soaked with a suspension of 20 ml *E. coli* (11.5 x 10^9 cfu/ml) and 20 ml group D Streptococci (7.5 x 10^9 cfu/ml) placed in the middle of each compost pile. The inactivation kinetics of the indicator organisms over a period of 24 weeks showed that the fastest reduction of the test organisms (0.3 log/week) was observed in the pile with sewage sludge and bark, in which a maximum temperature of >67°C (121°F) was recorded at the beginning of the composting process. After 13 weeks, the concentrations of D-Streptococci in all three clamps were within the international standard values for sanitized compost.

Because rendering plants are regulated by various governmental agencies and generally have good sanitation programs, the potential for spread of disease during the conversion process, and the potential for groundwater pollution from these plants, are relatively low compared to other carcass disposal methods. This is the main reason why many livestock producers and governmental agencies prefer rendering as an alternative to on-farm disposal methods.

Section 5 – Conclusions and Critical Research Needs

Since disposal of carcasses poses various biological and environmental problems, identifying and using safe and responsible methods is an important factor in maintaining the integrity of the livestock industry and producing safe animal protein, as well as maintaining a high level of public health and consumer confidence. Furthermore, selecting a proper disposal method in each situation is a must; and key factors include controlling the spread of disease and preventing environmental contamination. Following are the key conclusions of this report, and the identified critical research needs relative to rendering as an effective carcass disposal option.

5.1 – Conclusions

The most important, key items from the various sections of this report include the following:

- Renderers produce about 6.65 billion pounds of MBM. Independent renderers processed livestock mortalities and produced about 433 million pounds of MBM (around 6.5% of the total) and used raw materials representing about 50% of all livestock mortalities (SCI, 2002).
- The percentage of feed mills using meat & bone meal declined from 75% in 1999 to 40% in 2002 (Hamilton, 2003).
- The market price for MBM dropped from about $300/metric ton in 1997 to almost $180/metric ton in 2003 (Hamilton, 2003).
- The total quantity of MBM exported by the US increased from 400,000 metric tons in 1999 to about 600,000 metric tons in 2002 (Hamilton, 2003). Additionally, according to Arnold (2002), the market share percentage of MBM imported by Japan during the year 2000, compared to the first nine months of 2001, from New Zealand sources increased from 18.5% to 32.6%, and from US sources increased from 1.8% to 3.2%.
- Prions (or TSE agents) are believed to be responsible for fatal neurodegenerative diseases in humans and animals. US policies regarding TSE agents include (1) a ban on importation of ruminants and ruminant products from countries with BSE and (2) ruminant feeding restrictions to prevent the amplification and spread of the infective agent in domestic cattle (FDA, 2001).
- In order to justify costs and be economically feasible, a rendering plant must process at least 50-65 metric tons/day (60-70 tons/day), assuming 20 working hours per day.
- Most renderers (independent and dependent) use continuous dry rendering systems. Final MBM products are generally not completely free of salmonellae and have a fat content of about 12%. Generally the tallow produced by dependent renderers is lighter and has a higher grade than that produced by independent renderers.

5.2 – Critical Research Needs

Extensive research has been performed in the area of meat byproducts rendering, and a wealth of articles, books, and technical documents have been published or presented during the last 50 years. Additionally, many academic, governmental, state, and regional institutions and agencies worked and promoted this process and helped private sectors to produce various edible rendering products at the commercial level. The situation for "carcass rendering," which has stronger environmental and bio-security impacts, is quite different. Agricultural extension specialists and animal rendering scientists of academic institutions have made efforts to clarify the different aspects of this type of rendering. Although these efforts established rendering as a practical method of carcass disposal, the public health, animal health, and environmental hazards of "carcass rendering" have not been fully observed. To find adequate information, and to complete insufficient available data, intensive studies should be done on the following issues to determine scientific and practical answers for different aspects and challenges associated with carcass rendering:

- Develop robust sanitation, decontamination, and deodorization procedures for rendering operations. Biosecurity research should focus on the collection, transportation, storage, and processing of animal carcasses for rendering. Both waste products (odorous gases, sludge, and wastewater) and end products (meat-and-bone meal, tallow, and hides) should be free from pathogenic microorganisms, such as *Bacillus anthracis* and salmonellae, and harmful chemicals. Research would also focus on the possible combination of rendering with other methods of TSE inactivation.

- Consider how to improve rendering itself. In order to improve the quality of rendering products, research should focus on pre-rendering processes (e.g., carcass washing, grinding, and mixing), new rendering technologies (e.g., low-temperature rendering along with efficient wet pressing), and post-rendering processes (e.g., thermal centrifugation). By studying the physicochemical properties of carcass materials, valuable information might be gained and used to design improved rendering processes.
- Study how to improve rendering machinery and equipment to both comply with FDA requirements and produce top-quality products. The efficiency of some new equipment manufactured for different parts of animal byproduct rendering process should be studied, tested, and optimized for independent rendering plants.
- Investigate economic alternatives. The current economic value of rendered carcasses does not justify the cost of production, especially when protein product streams are unsuitable or disallowed for subsequent use in animal feed. Research should focus on (a) identifying means to reduce costs associated with rendering processes, (b) identifying new marketing and energy-use options for rendering products, and (c) identifying technologies that might be coupled with rendering to improve the utility of protein streams.
- Investigate temporary storage scenarios. In the case of high mortality losses, information will be needed regarding storage sites, time, and temperature and their appropriate relations to rendering.
- Evaluate means to treat waste products of rendering processes to reduce environmental impacts. Research should focus on advanced treatment systems for wastewater and exhaust odors to minimize any potential impacts to soil, ground water, vegetation, or air quality.
- Policy & regulatory considerations. Because biosecurity, traceability, and environmental protection methods for disposing of contaminated raw materials (or raw materials suspected of being contaminated) during an emergency are not available, uniform standards and methods for handling contaminated carcasses and animal byproducts are needed.

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Appendices

Appendix A

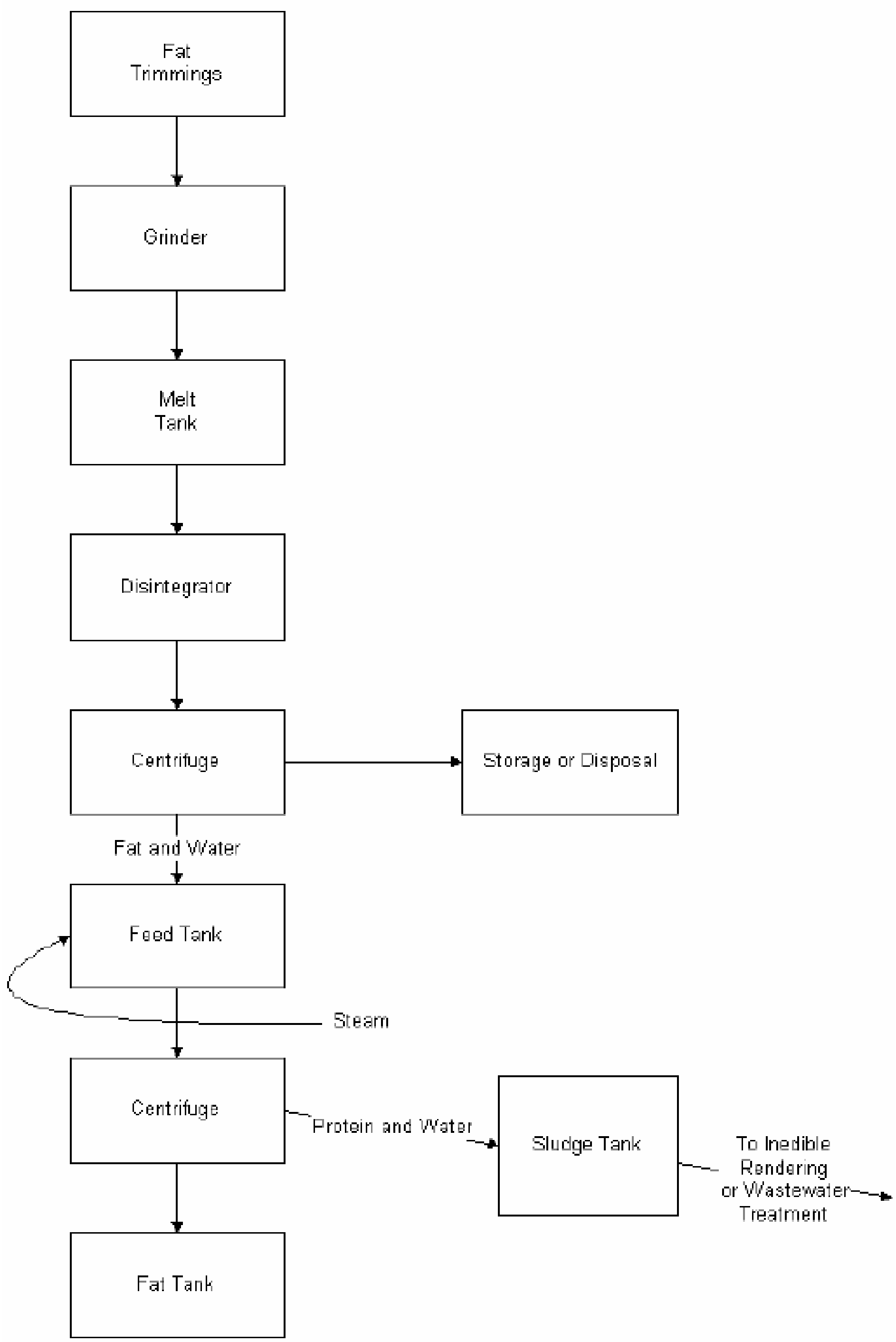

FIGURE 1. Flow diagram of an edible rendering process of fat trim.

Appendix B

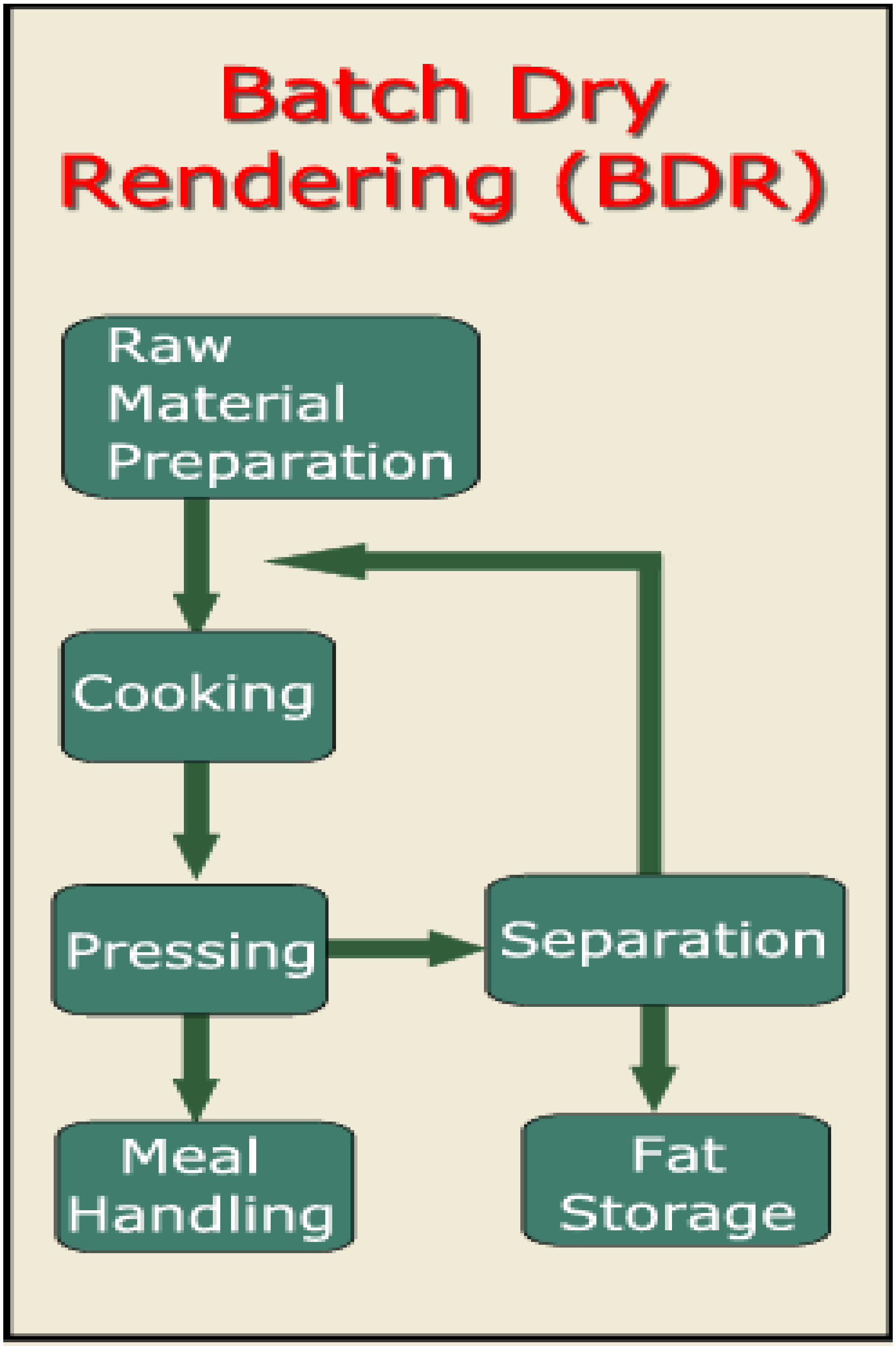

FIGURE 1. Flow diagram of batch dry rendering (Rendertech Limited, 2002).

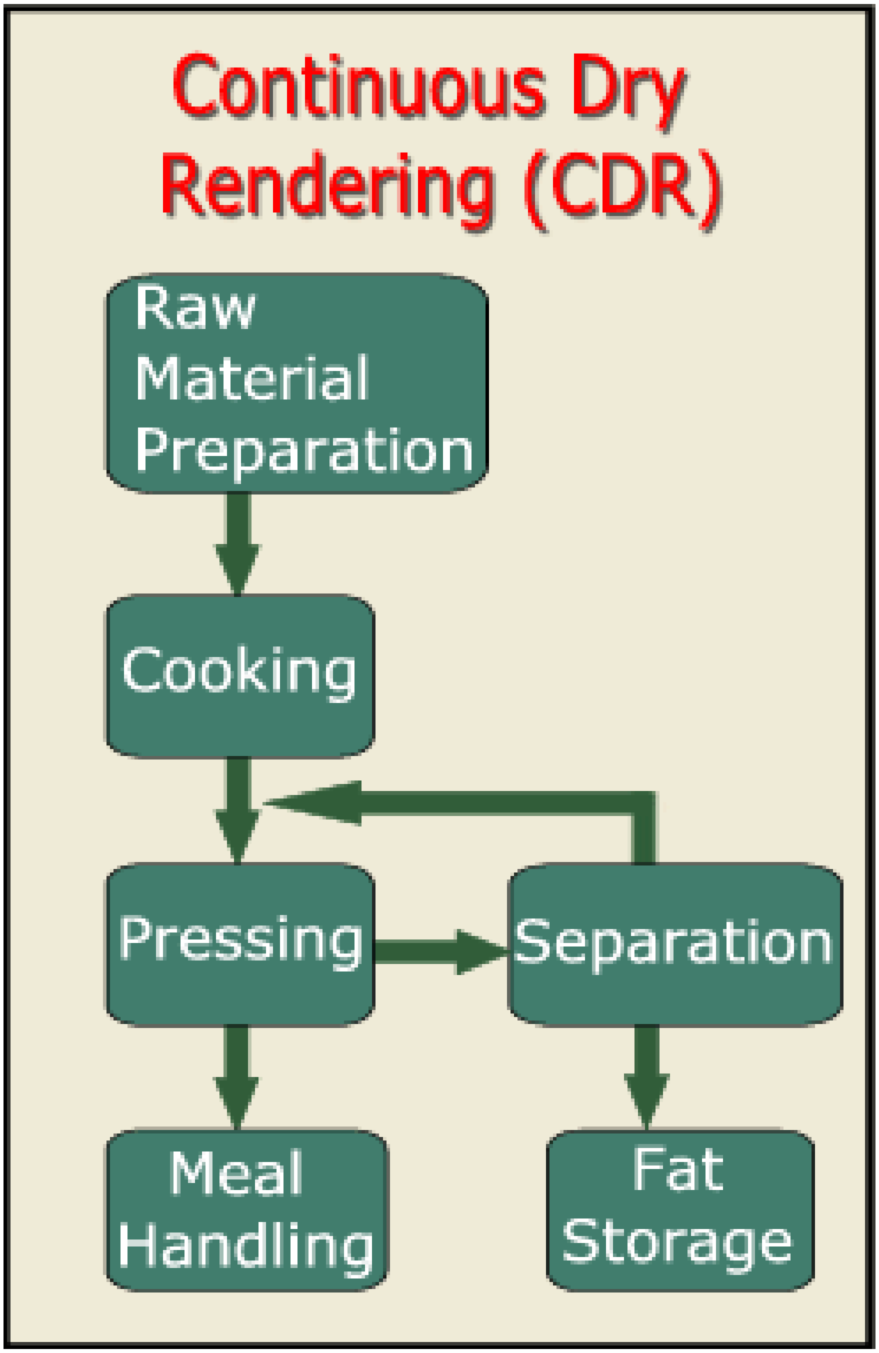

FIGURE 2. Flow diagram of continuous dry rendering (Rendertech Limited, 2002).

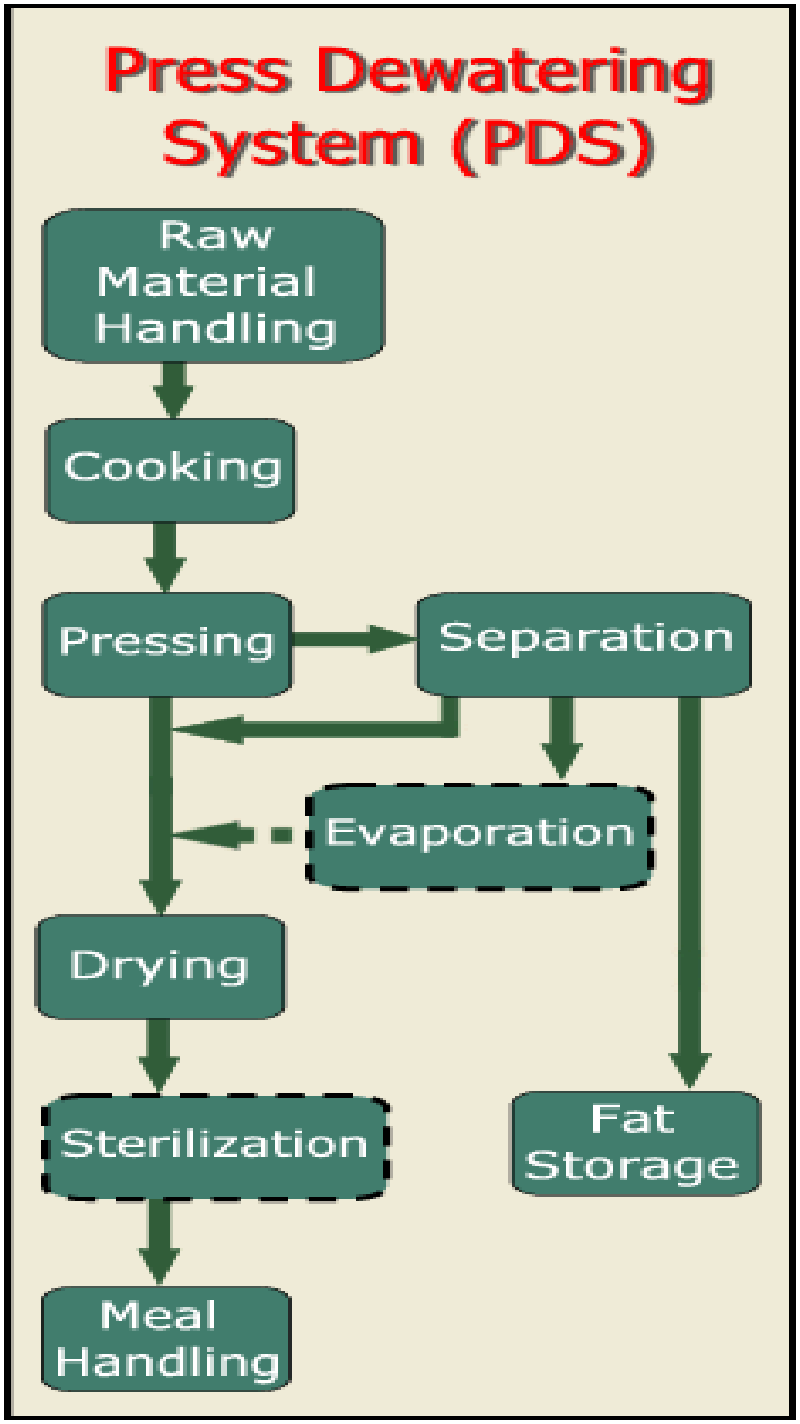

FIGURE 3. Flow diagram of press dewatering system (Rendertech Limited, 2002).

Appendix C

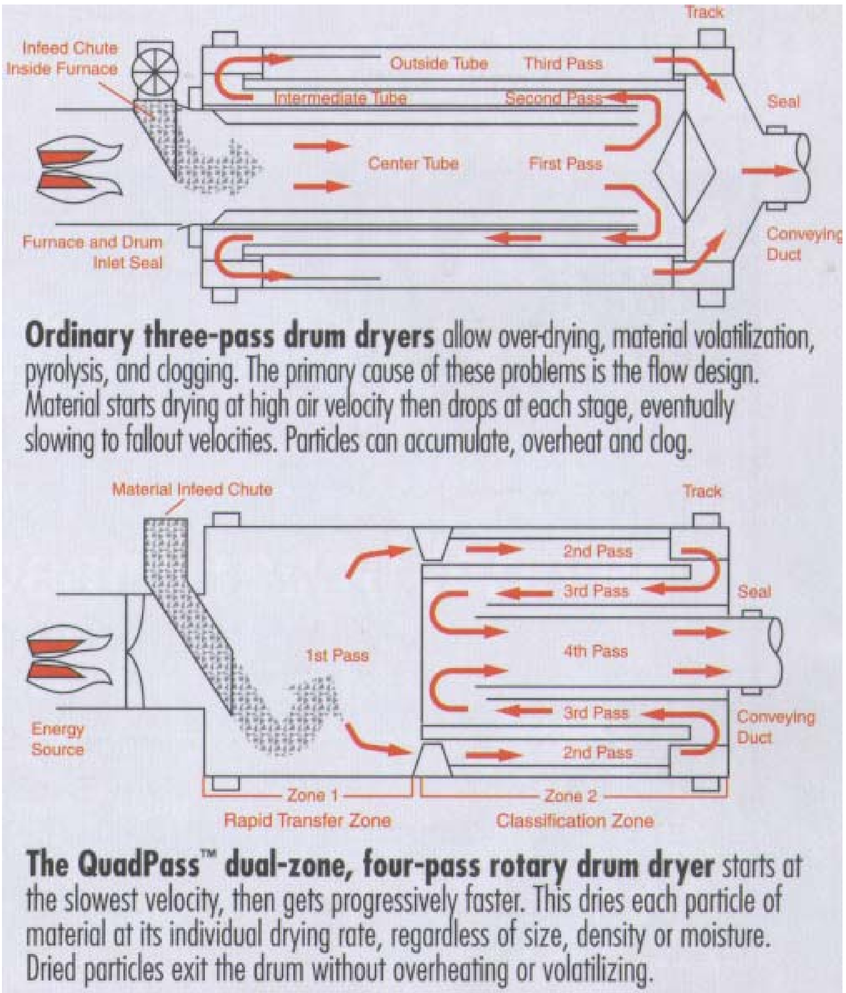

FIGURE 1. Comparison of the four-pass rotary drum drier and an ordinary three-pass drum drier used in animal rendering processes (The Dupps Company, 2003).

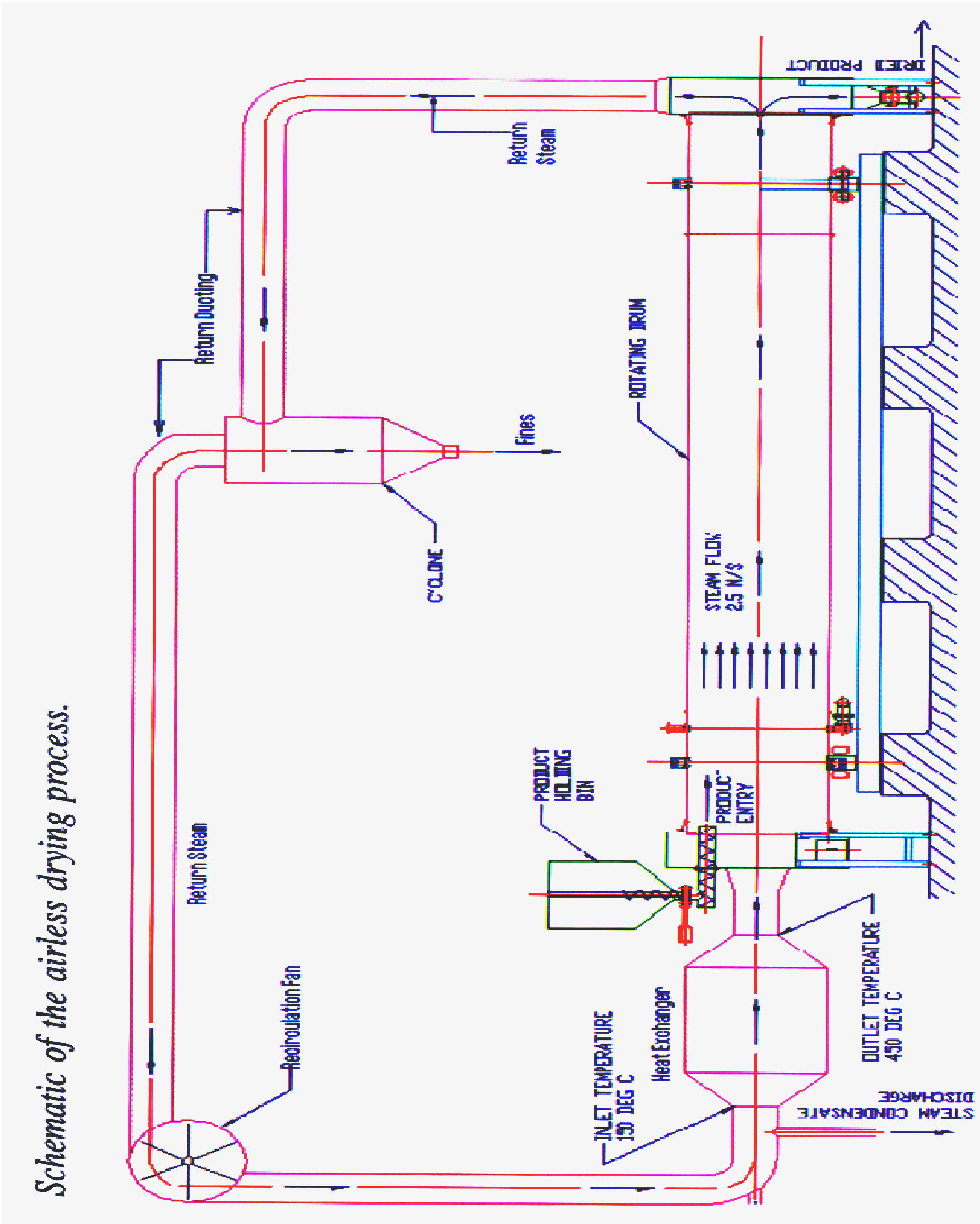

FIGURE 2. Schematic diagram of the heating and combustion loops of a new drier used for rendering processes (Morley, 2003).

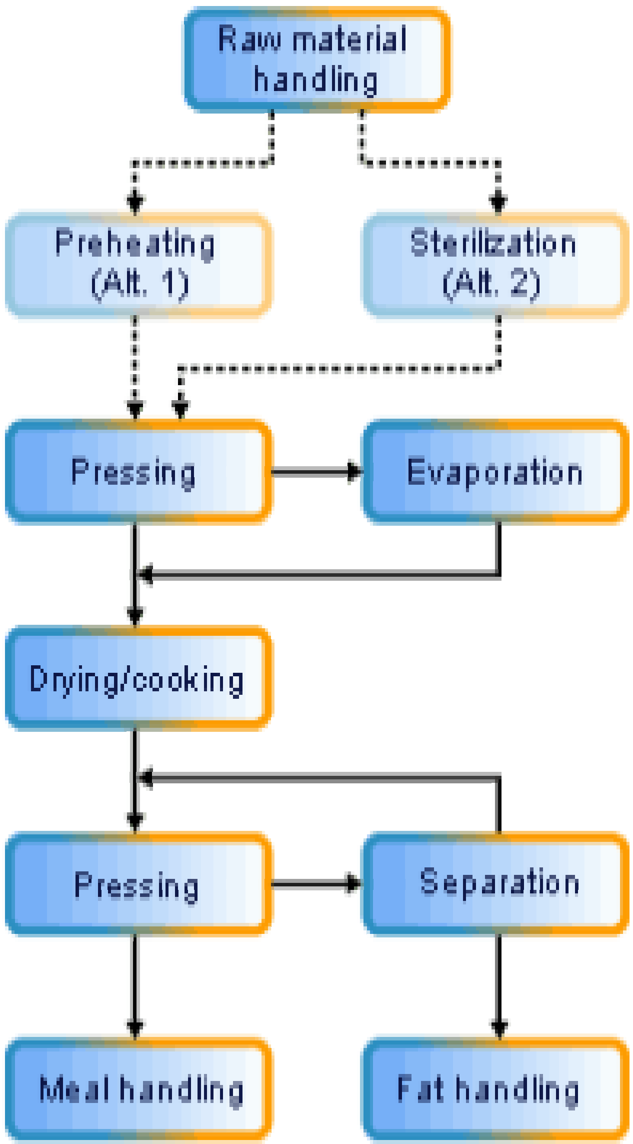

FIGURE 3. Flow process diagram of new continuous rendering systems with additional pressing and evaporation prior to the main cooking process (Atlas-Stord, 2003).

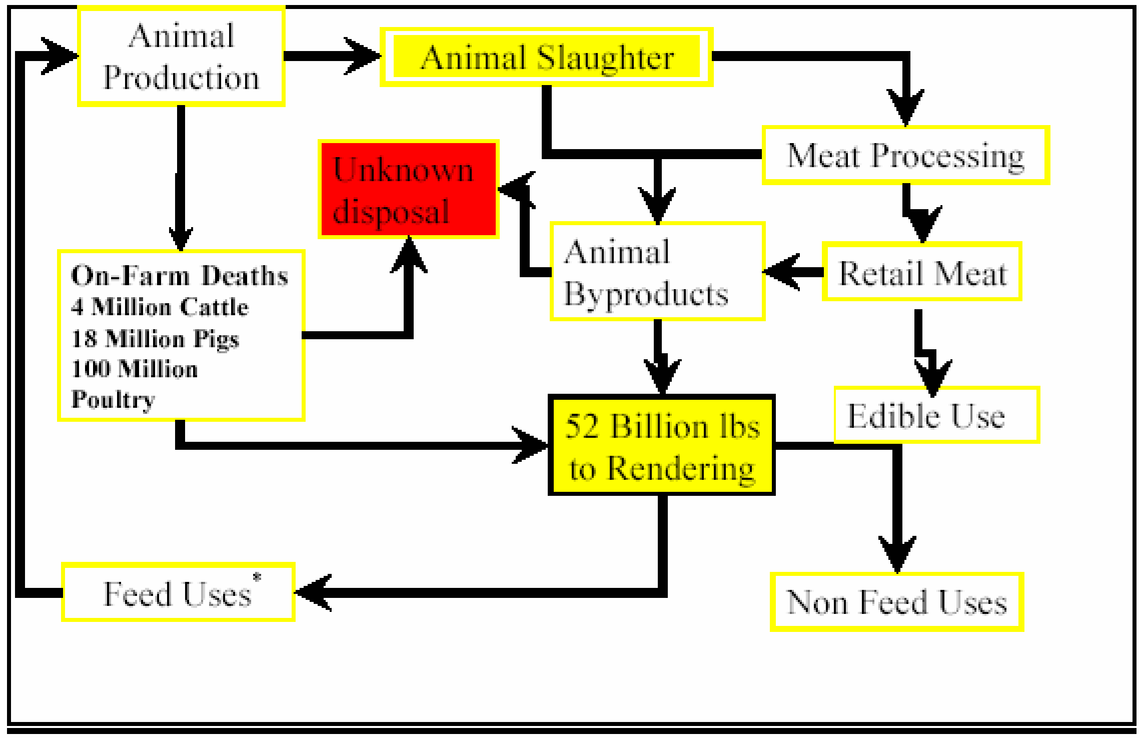

FIGURE 4. Estimated number of farm animal deaths, which provide about 40% of the raw materials needed for production of 52 billions pounds of rendering products (Hamilton, 2003).

TABLE 1. Annual animal byproducts and mortality, in 1,000 pounds (Hamilton, 2003).

Specie	Byproduct	Mortality	Total
Cattle	29,504,630	1,932,190	31,436,810
Swine	12,753,403	981,655	13,735,058
Sheep	297,213	64,106	361,319
Poultry	17,051,158	191,679	17,397,787
Total	59,606,403	3,324,570	62,930,974

Appendix D

TABLE 1. Composition of raw materials for inedible rendering (USEPA, 2002).

Source	Percent, by weight		
	Tallow/Grease	Protein Solids	Moisture
Packing house offal and bone	--	--	--
Steers	30-35	15-20	45-55
Cows	10-20	20-30	50-70
Calves	10-15	15-20	65-75
Sheep	25-30	20-25	45-55
Hogs	25-30	10-15	55-65
Poultry offal	10	25	65
Poultry feathers	None	33	67
Dead stock (whole animals)	--	--	--
Cattle	12	25	63
Calves	10	22	68
Sheep	22	25	53
Hogs	30	28	28
Butcher shop fat and bone	31	32	37
Blood	None	16-18	82-84
Restaurant grease	65	10	25

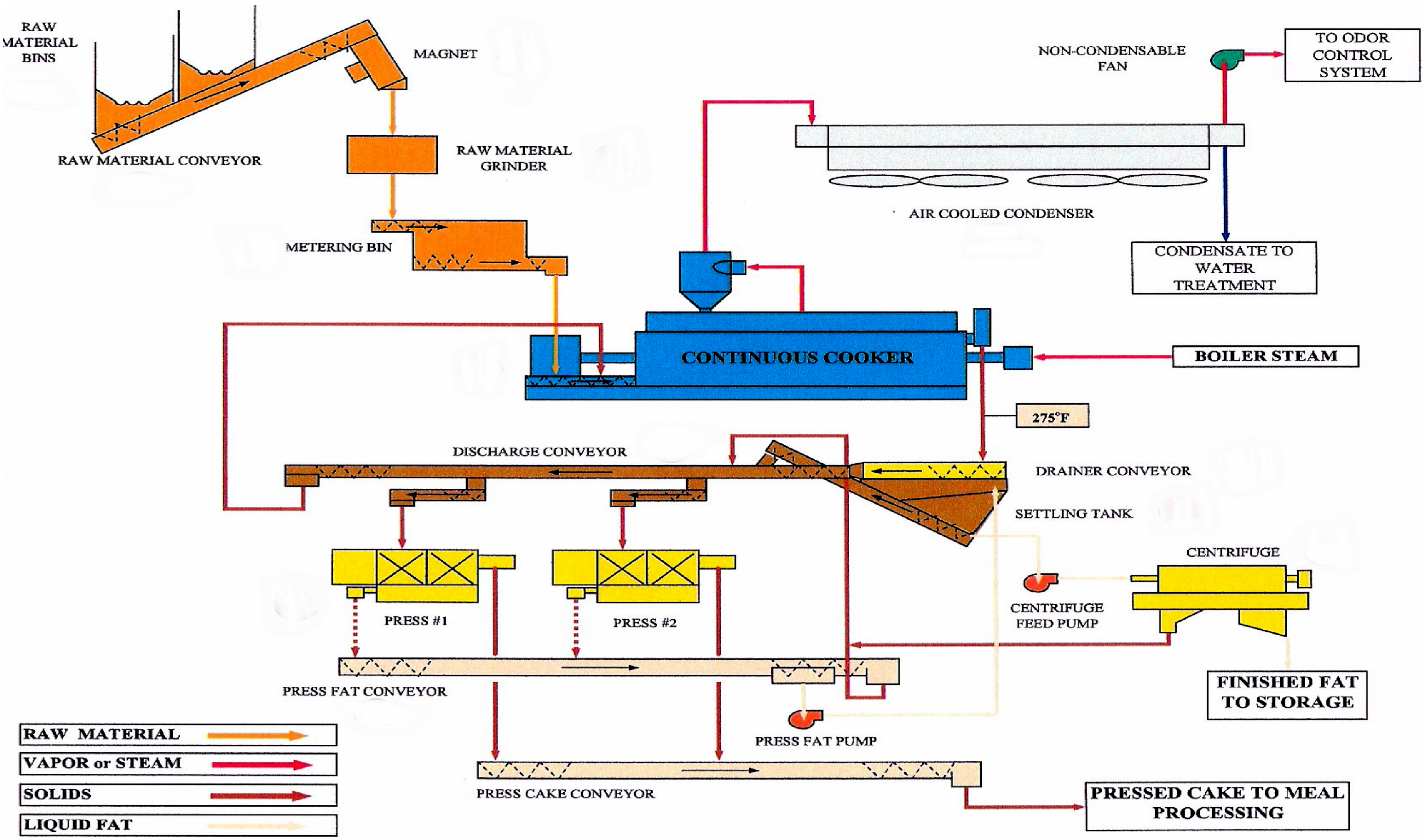

FIGURE 1. Schematic diagram of machinery, equipment, and material flow in a continuous dry rendering process (Hamilton, 2003).

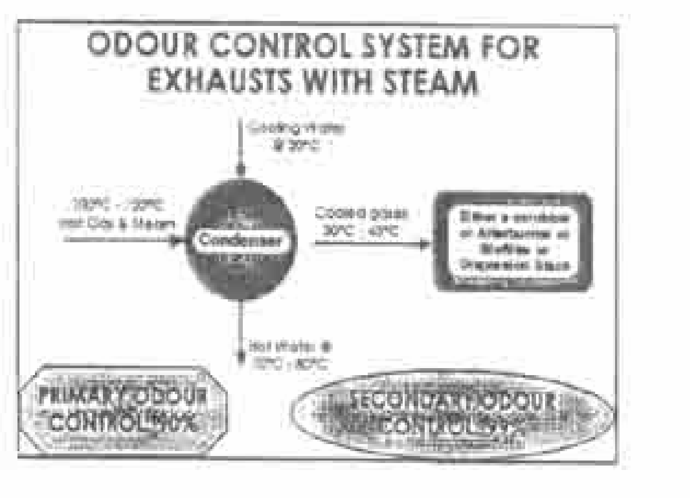

FIGURE 2. Schematic diagram of a typical condenser system used for condensation and odor control of exhausts vapors and gases of cooker with cooling water (Fernando, 1995).

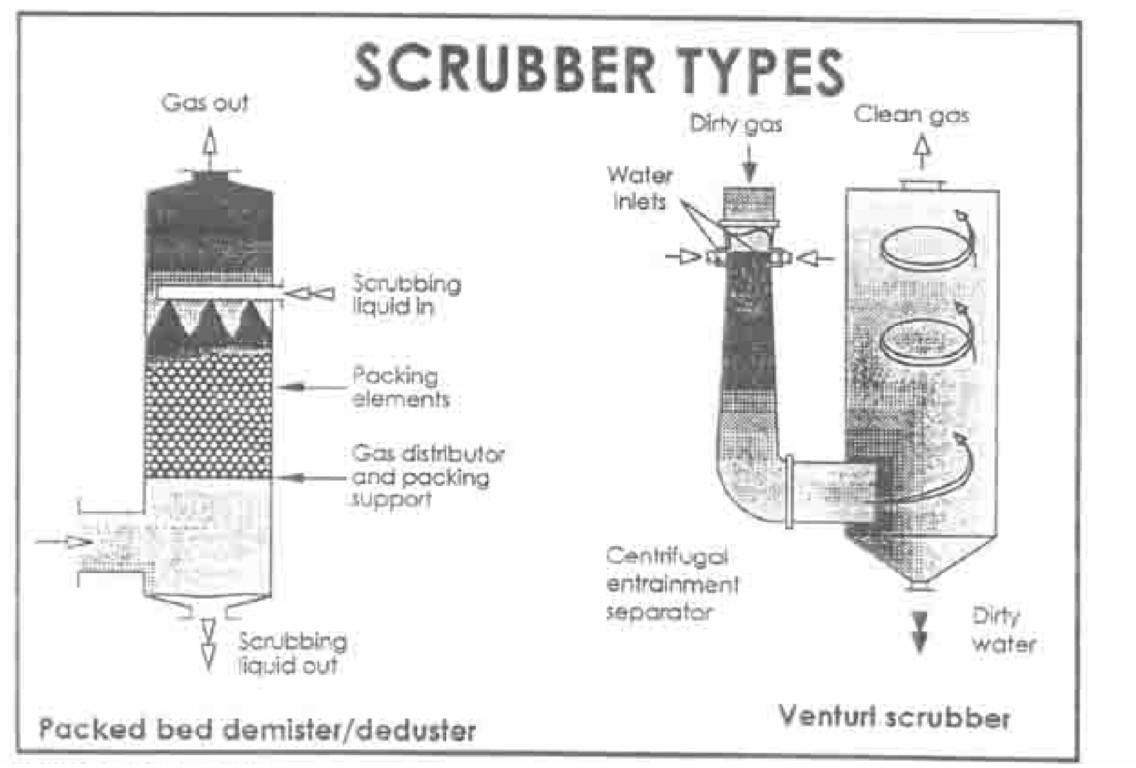

FIGURE 3a. Schematic diagram of two types of scrubbers used for chemical absorption of non-condensable gases leaving the condenser of rendering plants (Fernando, 1995).

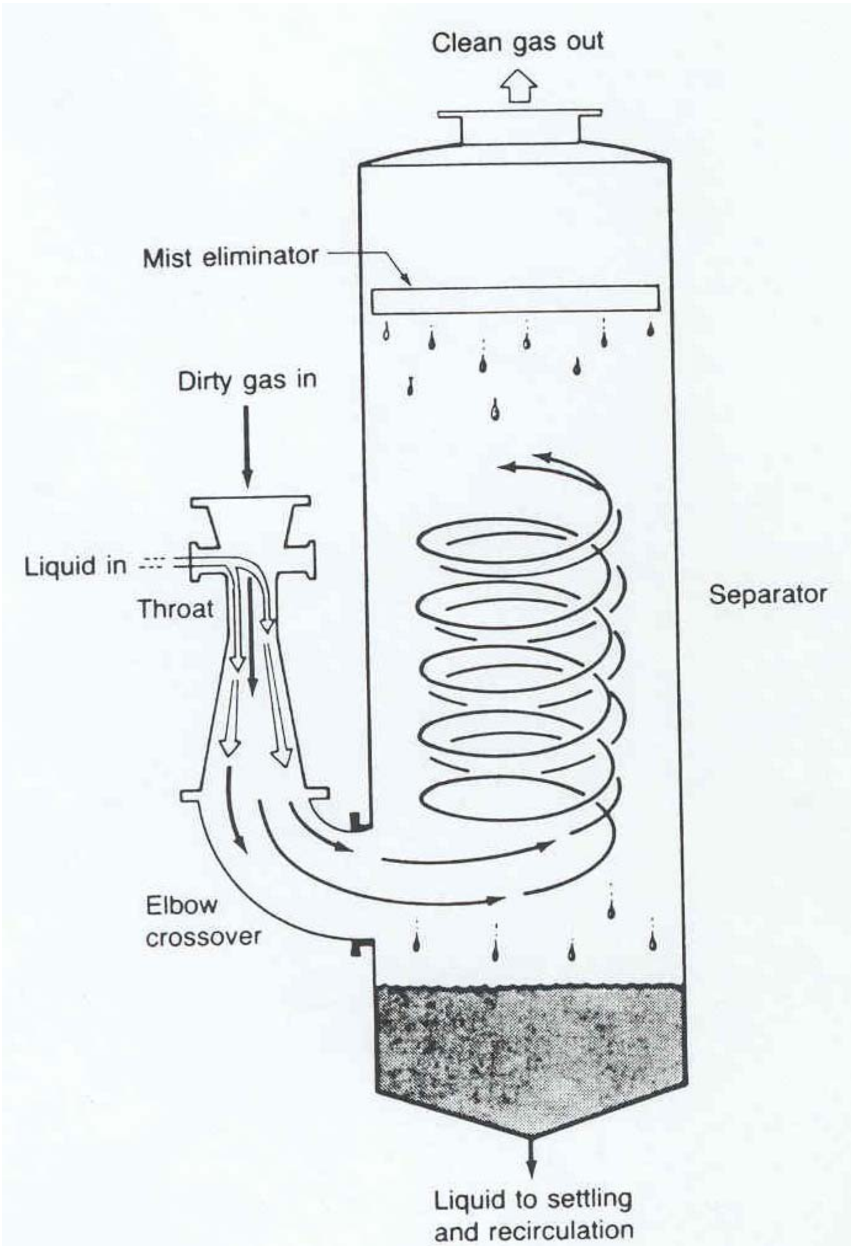

FIGURE 3b. Schematic diagram of an alternative venturi scrubber with a cyclone separator configuration (Cooper & Alley, 2002).

TABLE 2. Some results of packed tower experiments with various solutions (Fernando, 1995).

Odorant	Percentage of odorant removed in various solutions						
	Water	1% Sodium hypochlorite	3% Hydrogen peroxide	3% Potassium permanganate	5% Sodium Bisulphite	5% Hydrochloric Acid	5% Sodium Hydroxide
Valeraldehyde (aldehyde)	30	10	>90	30	>90	0	10-30
Trimethylamine (amine)	80-90	>90		>90		>90	0
Dipropyl Sulphide (sulphide)	0	>90	0	10-25	10	0	0
Butyric Acid (fatty Acid)							>90
Butanedione (ketone)							>90
Amyl alcohol (alcohol)	80-90	80	75	40-80	75	80	0-60
Heptadiene (unsaturated alkane)	0	20	0	25			

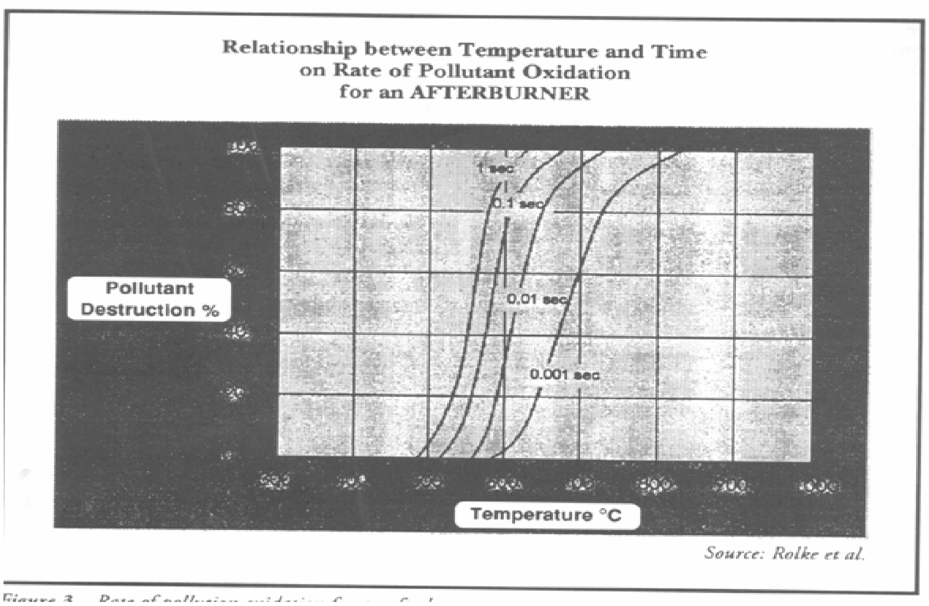

FIGURE 4. The relationship between temperature and time on the rate of complete oxidation of volatile gases in afterburners (Fernando, 1995).

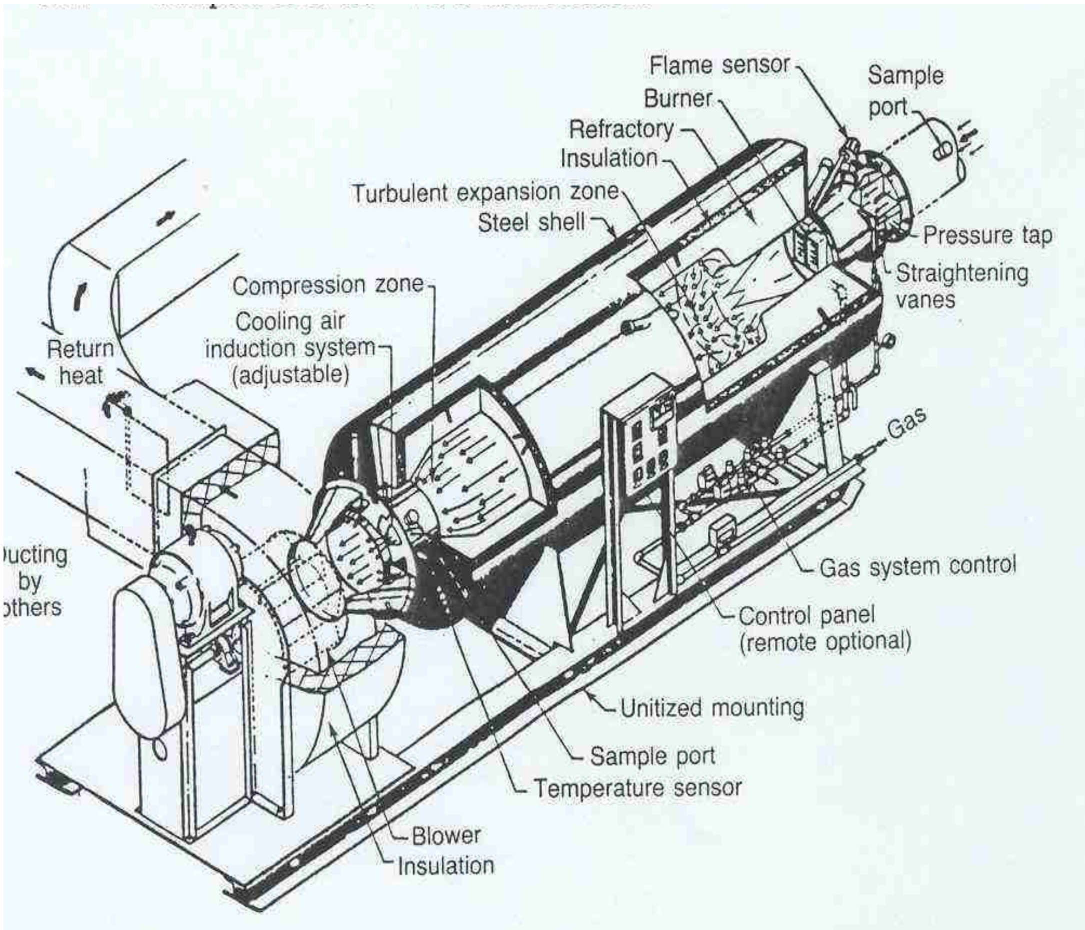

FIGURE 5. Sectional view of a direct-flame afterburner (Cooper & Alley, 2002).

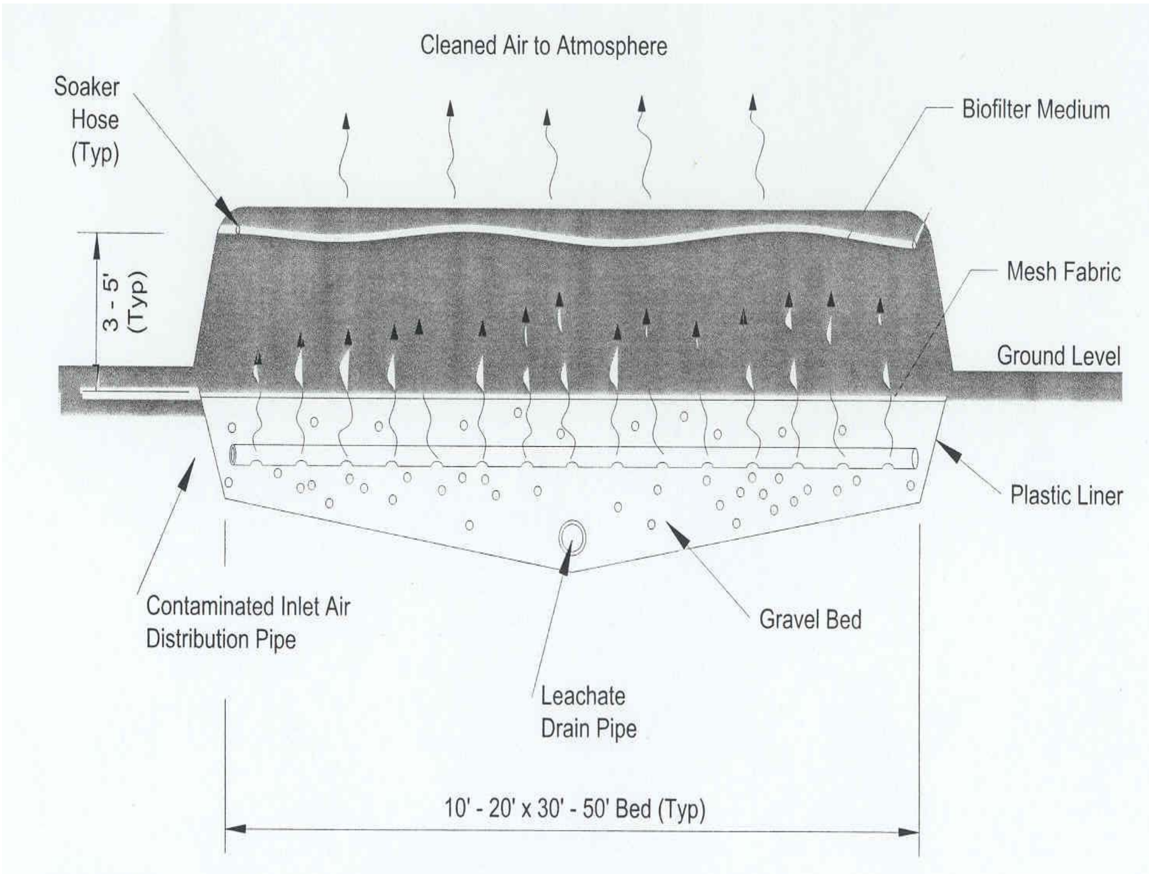

FIGURE 6. Cross section of a typical open-bed biofilter (Cooper & Alley, 2002).

TABLE 3. Quotation of The Dupps Company (2003) with the input capacity of approximately 80 metric tons/day (90 tons/day) assuming 20 working hr/day.

Item No.	Item Name	Quantity, HP	Description
RAW MATERIALS			
1	Raw materials storage bin	1; 7.5 HP	Type "A" raw material storage bin, approximately 70,000 pounds holding capacity
2	Raw material incline conveyor	1; H.P: 20	20" dia., type "D" screw conveyor.
3	Raw material storage sump pump	1; H.P: 0	Air operated, diaphragm type pump, for water removal at lower end of incline conveyor, complete with operating controls and valving
4	42" Electromagnet assembly	1; H.P: 7.5	Heavy duty electro magnet, specially designed for separation of ferrous metals from raw material, stepped face for trapping tramp metal, non-magnetic housing with hinged and latched access door, tramp metal receiver, rectifier to provide DC power and support staging
5	Prehogor feed conveyor	1; H.P: 20	20" dia., type "D" screw conveyor.
6	Prehogor - Model 180A-1	1; H.P: 150	Hard surfaced 1" rotor teeth and double row of replaceable 1" anvil teeth, heavy duty spherical roller bearings, flywheel and V-belt drive, up to 200 HP, 1750 RPM motor, 540 RPM rotor speed, drive guard, 1-1/2" thick steel plate housing with 25-3/4" x 36-3/8" charging opening, 22-3/4" x 36-3/4" discharge opening.
7	Prehogor staging and access platform	1; H.P: 0	Constructed of structural steel, included are: equipment supports, access platform, kickrails, handrails, and stairway that are required for the daily continuous operation of the system
8	Raw material metering bin	1; H.P: 5	A fully covered bin designed to control the raw material feed rate to a processing system and/or provide a surge of raw material ahead of the system. All reinforced carbon steel construction, variable pitch type bottom discharge screw(s) motor and drive. Access door for maintenance access and visual level checking
9	Raw material metering bin	1; H.P: 7.5	16" dia., type "B" screw conveyor
			TOTAL CONNECTED HORSEPOWER: 217.5
COOKING AND PRESSING			
10	Model NO. 70U Super cooker	1; H.P: 75	Steam heated shaft, un-jacketed shell.
11	Cooker upper level discharge gate	1; H.P: 0	Air operated slide gate designed for an upper level Cooker discharge
12	Cooker bottom discharge valve	1; H.P: 0	Air operated knife type gate valve, cast iron body, stainless steel seats, 500 degree F. "C" type packing, 4-way solenoid valve, all heavy construction. Designed for a bolted connection to the Cooker head plate
13	Control elevator	1; H.P: 10	Special slow speed elevator designed for metering applications such as Cooker discharge control, oil tight casing, heavy duty split type, positive discharge buckets mounted on a special 4"pitch chain, center of casing side discharge, bottom feed convey-or extended for bottom discharge of the Cooker and driven from the elevator tail shaft, motor, drive and mounting base
14	Drainer	1; H.P: 0	Special heavy duty screw with lifting paddles to turn the product for better drainage exposure, housed within a heavy carbon steel frame. Replaceable bottom drainage screens set in an adjustable frame to maintain a close tolerance between the screw and

			screen, latched aluminum side splash shields, bolted top cover with inspection openings, discharge box and support staging. Configured to mount on top of a sedimentor
15	Drainer discharge conveyor	1; H.P: 7.5	16" dia., type "B" screw conveyor
16	Sedimentor	1; H.P: 2	An enclosed tapered tank with an inclined bottom discharge screw, operating in a wrap-around type trough, sealed round sight glasses are mounted on the sides for viewing the tank contents, product and instrument connections, manually operated variable speed motor and drive. The top is configured for mounting the Drainer
17	Centrifuge feed pump	1; H.P: 3	Open impeller, centrifugal type, all carbon steel construction, mounted on a base and direct coupled to the motor
18	Centrifuge	1; H.P: 40	Keith 24 x 38 size, mild steel construction, solid bowl horizontal decanter type with a scroll that is hard surfaced on the outer-edge, vibro-isolators, 40 HP motor, v-belt drive, fluid coupling, appropriate safety guard(s), product and discharge chutes. Bearing oil recirculating and cooling system with a positive displacement type pump coupled to a 1.5 HP motor
19	Centrifuge support staging	1; H.P: 0	All welded construction, structural grade steel tubing, for mounting the Centrifuge approximately 4 feet high, adjustable legs and monorail type maintenance beam
20	Centrifuge discharge pump	1; H.P:5	Positive displacement type pump, all carbon steel construction, mounted on a base and direct coupled to the motor
21	Cooker priming pump	1; H.P:3	Consisting of a variable volume pump, mounted on a base and direct coupled to the motor
22	Pressor feed conveyor	1; H.P:2	9" dia., type "A" screw conveyor
23	Dupps 10-4 Pressor	1; H.P:200	Configured for 200 HP motor and drive, 12" dia. feed quill and feed assembly
24	Pressor cake discharge hood	1; H.P:0	1/8" thick stainless steel construction, directional flop-gate for two conveyor and floor discharge, vapor outlet with adjustable blast-gate
25	Hydraulic control console	1; H.P:2	Complete with hydraulic oil pump direct coupled to a 2 HP motor, pressure control valve, solenoid control valve, gauges, control relays and oil reservoir
26	Pressor pad access steps	1; H.P:0	Steps with hand-rails for access over discharge conveyors to the Pressor (s), all carbon steel construction.
27	Pressor ribbon recycle conveyor	1; H.P:3	9" dia., type "A" screw conveyor
28	Pressor fat pump	1; H.P:7.5	Style B, paddle type pump with a tapered feed screw, for handling large particle sizes, mounted on a base and direct coupled to a 7.5 HP., 1200 RPM motor. Configured for mounting to a screw conveyor screened drainage section
29	Pressor recycle cross conveyor	1; H.P:3	9" dia., type "B" screw conveyor
30	Pressor recycle conveyor	1; H.P:3	9" dia., type "A" screw conveyor
31	Pressor recycle incline conveyor	1; H.P:5	9" dia., type "B" screw conveyor
32	Pressor cake discharge conveyor	1; H.P:5	12" dia., type "A" screw conveyor
33	Vacuum protection of vapor lines	1; H.P:0	Consisting of a flanged rupture disc to be mounted directly on the vapor line

34	Plant process piping	1; H.P:0	All manually operated valves, special fittings, hoses, flexible hoses, expansion joints, etc., to interconnect the system process piping including steam and/or air product clean out blow lines
35	Special cooking controls	1; H.P:0	Part of "System Motor and Process Controls" listed below. a. Control Loop #1 - controls the discharge rate from the cooking unit. b. Control Loop #2 - controls the cooking unit discharge temperature by varying steam pressure. c. Control Loop #3 - controls the cooking unit level by varying the raw material feed rate to it. d. Control Loop #4 - Regulates the speed of the Non-Condensable Blower to maintain correct negative pressure in the cooking unit. TOTAL CONNECTED HORSEPOWER: 379.0
MEAL GRINDING			
36	Cake curing bin	1; H.P:5	All carbon steel construction except the top cover which is stainless steel, side wall and top reinforcing ribs, tapered bottom, 20"access door, heavy duty 12" variable pitch bottom discharge conveyor that extends at the discharge and drive ends in a U-shaped trough with angle type screw hold down when applicable and sealed 3/16" thick mild steel bolted covers. The bin is 8ft. wide x 10 ft. high x 17 ft. long, approximately 15 ton capacity, constant speed 5 HP motor and drive. 12" top leveling conveyor with extended U- shaped input trough, 3/16" thick mild steel bolted covers, constant speed 3 HP motor and drive
37	Vertical cake conveyor	1; H.P:7.5	12" diameter screw operating in a tubular housing, carbon steel construction except the top 2 ft. of the housing and the discharge chute which are #304 stainless steel, 3/8" thick sectional flighting continuously welded to a 4" #80 pipe, v-belt drive, 7.5 HP, 900 RPM motor
38	Grinder feed conveyor	1; H.P:3	9" dia., type "A" screw conveyor
39	Dupps meal grinder	1; H.P:150	Extra heavy carbon steel construction, replaceable alloy wear resistant cap and liners, 2 hard faced replaceable hammers attached to the rotor with heat treated bolts, split screens held in place with pivoting cradles that are secured by dual locking bolts, replaceable rotor shaft, heavy duty ball bearings, rotor shaft is direct coupled to the motor with a flexible type coupling,access doors permit screen and hammer changing without disturbing connecting chutes.
40	Grinder support structure	1; H.P:0	Constructed of structural steel, included are: equipment supports and access platform, kickrails, and stairway
41	Grinder discharge conveyor	1; H.P:3	9" dia., type "A" screw conveyor
42	Vibrating screen	1; H.P:3	40" X 84" size, all metal construction with aluminum screen deck and cover, automatic screen tensioning, cable suspension brackets, stainless steel bottom meal pan, nominal screening area 50.0 sq. ft., motor and drive.
43	Screen discharge conveyor	1; H.P:5	Tramco Bulk-Flow Heavy Duty Chain Conveyor. 1/4" thick AR carbon steel bottom and divider plates. 3/16" thick upper and lower side plates plus 3/16" thick cover. Carbon steel chain with carbon steel pins. Carbon steel support legs, 6" x 12" size. Carbon steel housing and cover. Teflon paddles.
44	Meal storage silo	1; H.P:10	A.O. Smith Permaglas Storage Silo , fused glass on carbon steel bolted panel construction, skirted shell, screened roof ventilators, roof opening cover plate, roof man way, slide inspection man

			way, sidewall accessory door, ladder and safety cage, flat profile roof with perimeter hand-rail
45	Silo discharge conveyor	1; H.P:7.5	Tramco Bulk-Flow Heavy Duty Chain Conveyor. 1/4" thick AR carbon steel bottom and divider plates. 3/16" thick upper and lower side plates plus 3/16" thick cover. Carbon steel chain with carbon steel pins. Carbon steel support legs, 10" x 15" size. Carbon steel housing and cover.
46	Truck-loading cross conveyor	1; H.P:5	16" dia., type "A" screw conveyor
47	Truck loading conveyor	1; H.P:7.5	16" dia., type "A" screw conveyor
			TOTAL CONNECTED HORSEPOWER: 209.5
MISCELLANEOUS EQUIPMENT			
48	Maintenance hoist #1	1; H.P:0	Pressor maintenance, one (1) ton capacity, low head room, trolley mounted, hand operated chain block.
49	Maintenance hoist #2	1; H.P:0	Centrifuge maintenance, 2 ton capacity, low head room, trolley mounted, hand operated chain block with a 20 ft. hook drop
50	Fat shipping pump	1; H.P:7.5	Centrifugal type pump, all carbon steel construction, direct coupled to the motor, mounting base, approximately 250 GPM capacities
51	Outside fat storage tank	2; H.P:0	10'-6" diameter tank of all carbon steel construction, 45 degree coned bottom, steam coils, covered top with 12" dia. top inspection opening with cover, 20" dia. Man way with hinged and bolted cover located in the cone, connecting pipe fittings for fat, steam, thermometer and overflow
52	Fat work tank	1	10'-0" diameter tank of all carbon steel construction, 45 degree coned bottom, support legs, steam coils, covered top with 12" dia. top inspection opening with cover, 20" dia. manway with hinged and bolted cover located in the cone, connecting pipe fittings for fat, steam, thermometer and overflow
53	Fat to storage pump	1; H.P:7.5	Centrifugal type pump, all carbon steel construction, direct coupled to the motor, mounting base, approximately 250 GPM capacities
54	Hot water pump	1; H.P:10	Centrifugal pump, double suction, ductile iron casing, bronze impeller, complete with motor, drive and mounting base
55	Hot water storage tank	1; H.P:0	32" 8" dia. X 16' nominal sidewall height factory coated bolted steel water tank, nominal level full capacity 100,000 US gallons, designed in accordance with AWWA D103-97 specifications, seismic zone 3,100 MPH wind load, 25 PSF live deck load and equipped as follows: ■ Anchoring stirrups with anchor bolts (if required). ■ Flat steel bottom. ■ 1:12 slope roof. ■ 24" X 46" flush type cleanout with two piece cover and handhole. ■ 20" dia. Center roof dome with screened ventilator. ■ 24" square hinged roof manway. ■ galvanized outside ladder with safety cage. ■ 8" overflow weir cone with external nozzle. ■ 6" inlet nozzle. ■ 8" outlet nozzle. ■ 1/2" thick fiber board furnished for placing between tank bottom and foundation ring wall.

			■ Level transmitter and high level alarm. Hardware: Galvanized bolts, nuts, washers and gasketing are standard. Plastic encapsulated head bolts for interior vertical and roof seams. Coating: Interior and both sides of bottom painted two coats Trico Bond thermoset corrosion resistant epoxy (5 mils average, DFT). Exterior epoxy primer with finish coat of baked on tan acrylic enamel (3 mils average, DFT) (color other than tan optional at an extra charge). Trico Bond epoxy is suitable for liquids with a pH range of 3 to 11.
56	Pressor maintenance impact wrench	1; H.P:0	1-1/2" drive, 90 psig @ approximately 137 cfm (25 HP air compressor minimum), 60Percent efficiency for 4,000 ft/lbs., torque, and maximum wrench torque is 10,000 ft/lbs
57	In-floor sump and pump	1; H.P:5	52" diameter x 72" deep tank with cover, configured for mounting the pump, access opening and ladder, coated for in-ground installation. Trash type open impeller pump direct coupled to the motor with a flexible type coupling, and is automatically actuated by a float operated switch. Pump capacity is 70 GPM; maximum particle handling size is 2-1/2" diameter
58	Mechanical catch basin	1; H.P:1	All carbon steel construction with mechanical skimmer for fat and sludge removal. Unit is equipped with screw conveyors to convey the reclaimed fat or sludge to either side of the unit. The conveyors are powered by the skimmer drive, motor and drive. The fat screw is fitted with a 1/2" pipe size rotary steam joint which requires 15 psig steams. Retention time is 40 minutes, water inlet and outlet nozzles are 6", speed of the drag chain is 3.25 FPM
59	Catch basin sludge conveyor	1; H.P:2	6" dia., type "A" screw conveyor
60	Pressurized condensate return system	1; H.P:20	The Mid-South Closed Loop System is a trapless condensate return system which is designed to return high pressure high temperature condensate directly to the boiler(s) or high pressure surge tank. Pumping the high pressure condensate directly to the boiler, ypassing the deaerator or feed tank, eliminates the loss of flash steam to atmosphere. Basic Features: ■ High efficiency, chemical duty motor. ■ Heavy duty process pumps, standard. ■ High temperature mechanical seal. ■ Condensate Receiver, ASME construction. ■ Level control with magnetic flag indicator. ■ Pneumatic actuated control valve. ■ Stainless steel control panel. ■ Stainless steel instrument panel. ■ Precision gauges, liquid filled. ■ Elevated Base for housekeeping. ■ Adjustable legs for leveling. ■ 2" calcium silicate insulation. ■ Stainless steel metal insulation jacketing TOTAL CONNECTED HORSEPOWER: 58
AIR POLLUTION & HOT WATER CONTROL			
61	Lot of condensable vapor piping	1; H.P:0	Stainless steel pipe, fittings, flanges and stiffener rings, to connect the Cooker exhaust vapors to the hot water condenser. Supports and hangers are carbon steel

62	Non-condensable blower	1; H.P:10	Type 304 stainless steel housing and impeller, 10 HP motor and drive, 3,423 RPM, 500 CFM at 24" static pressure
63	Lot of non-condensable vapor piping	1; H.P:0	Stainless steel pipe and fittings plus mild steel flow control slide gates to collect non-condensable vapors from the Condenser, Drainer, Centrifuge, Pressor and any other equipment requiring venting, into a common line which will terminate at a the input of the Non-condensable Control Equipment
64	Shell and tube hot water heat exchanger	1; H.P:0	1,700 sq. ft., all stainless steel construction. Vapor condensing is on the tube side and water is heated on the shell side
65	SCP Room air packed bed scrubber	1	For processing the room air within the processing area then exhausting it to the atmosphere. The following sub-systems are included: one (1) Packed Bed Scrubber, Interconnecting Ducting, and 110V Panel for automatic monitoring and control of chemical addition
66	SCP Two stage high intensity system	1	Equal Size Venturi/Packed Bed Scrubber for processing gases from selected equipment in the main processing area. The following sub-systems are included: one (1) Venturi Scrubber, one (1) Packed Bed Scrubber, Interconnecting Ducting, 110V Panel for automatic monitoring and control of the chemical addition
67	Grinder air cyclone separator	1	Fisher-Klosterman High Efficiency Cyclone Dust Collector to vent meal dust from the meal Grinder and discharge it into a meal conveyor
68	SCP Pre-incineration system	1	Designed to pre-treat high intensity odors as non-condensable gas or process gas prior to exhausting to the plants boiler for incineration
69	Scrubbing system ducting	1; H.P:0	The ducting required to interconnect the SCP air pollution control equipment. The ductwork to be constructed of 16 gauge 304 stainless steel with 304 stainless steel flanges and stiffeners. Straight runs will have one flange loose for field adjustment
70	SCP PVC Components	1; H.P:0	Pipe, fittings, valves, etc. for plumbing the SCP air pollution control system
			TOTAL CONNECTED HORSEPOWER: 279.5
SYSTEM ELECTRICAL CONTROL			
71	Motor control	1; H.P:0	Starter-breaker modules mounted and wired in an enclosure; 3-phase power wiring includes breaker to bus, breaker to starter and starter to terminal strip (size 1 and 2 starters). Motor control also includes AC frequency drives and soft starts mounted and wired (3-phase only) in an enclosure. Capacitors (for 50 HP and above), local disconnects (for all HPs), and Motor Control Electrical Engineering for all items above is also included
72	Process control - relay plant	H.P:0	Single phase control wiring for starter-breaker, AC frequency drive and soft start modules. Also includes mounting and wiring in an enclosure, items such as pushbuttons, relays, timers, motor load meters with CTs, recorders, and PID controllers. The process controls are mounted in a Panel Board or a Push Button Control Console. Includes all instrument and control items such as control valves, flow meters, and transmitters (level, pressure and temperature). Process Control Electrical Engineering is also included
SPECIAL SERVICES			
73	Engineering	1	Consisting of the basic items listed below, refer to Exhibit "B" for additional details.

			■ Layout of the above listed equipment within the Owners building. ■ Location of floor pits, building openings, access areas, and support staging. ■ Empty and operating equipment weights and their location to aid in the design of equipment support foundations. Actual foundation design is the responsibility of the Owner. ■ Wiring diagrams. ■ Size and locations of motors and control devices. ■ Schematic piping diagrams. ■ Advice as to utility requirements. ■ Provide technical information to assist the Owner or its agents, to remodel an existing building, with the special features required to house the equipment being furnished
74	System start up and operator training	1	Consisting of the basic items listed below, refer to Exhibit "B" for additional details. Provide the services of system start-up specialists to train the Owners personnel to operate and maintain the system. The training period will commence the day that raw material is initially processed and will consist of the following: ■ Maximum number of personnel ■ Maximum number of working hours per day per man ■ Maximum number of man-days including travel days without additional charges ■ Number of individual round trips to the job site ■ Per Diem and travel expenses for the above number of personnel. Any additional time required will be charged for according to the field service rates in effect at the time of service.
75	Installation	1	Consisting of the basic items listed below, refer to Exhibit "B" for additional details: ■ Rigging into place and interconnecting the equipment. ■ Piping - provide the labor and material to do the piping required to operate the equipment comprising the system, listed on Exhibit "A", within the processing area. ■ Electrical - provide the labor and material for the power and control wiring for all of the items listed on Exhibit "A". ■ Freight to the jobsite. ■ Insulation - of designated equipment and piping with a water-proof cover. ■ Paint - provide a shop coat of oxide primer. ■ Equipment Access - as required for the daily continuous operation of the equipment

TABLE 4. Quotation of Scan American Corporation (2003). Quantity & specifications of needed equipment for dry carcass rendering with feed capacity of 2,700 kg/head (6,000 lbs/head) and working 8 h/day.

Qty	Item	Description
RAW MATERIAL HANDLING		
1	Silo for dead carcasses and feathers	■ Each one with approximate volume of 15 m^3 and provided with one bottom screw conveyor (diameter 300 mm). ■ Each silo is manufactured in 5 mm mild steel plate and supported by frame. ■ The screw section of carcass silo is 6 mm with 10 mm wear plate and is driven by one gear motor 5.5 kW and chain drive. . ■ The base of the feather silo contains three screw conveyors. ■ Each screw has a diameter of 400 mm and is driven by one 5.5 kW gear motor.
1	Screw conveyor	Length= 9.5 m and diameter Ø400 mm
1	Screw conveyor	Two outlets each with Ø500 mm
2	Filling platform for dry-melter	■ With slide gate valve and electric motor ■ Manufactured in mild steel and includes handrail and steps.
1	Blood tank, 2,500 L with agitator	■ Manufactured in a form of cylindrical and vertical type. ■ All surfaces in contact with the product in stainless steel. ■ Supplied with a detachable top cover, partly hinged for inspection. ■ Side-mounted ladder gives access to this inspection. ■ Agitator with 1.5 kW motor. ■ The pump capacity is approximately 15 tons/hr with a motor of 2.2 kW (for pumping the raw blood from the blood tank to the dry rendering cooker, inclusive of pipes and flex hose).
1	Set of blood pipes NW50	
COOKING AND DRYING EQUIPMENT		
2	Dry melter type HM 5000	Assembled and delivered as a packaged unit mounted on a base frame. Volume: 5,000 l Inner shell: 25 mm (mild steel boiler plate DIN 17155) Steam jacket: 10 mm Charging dome: 20 mm Working pressure: Internal 5 bar, Jacket 10 bar, Agitator 10 bar Fittings: Steam inlet valve – manual, Sampling valve – manual, Pressure relief valve – safety, Vapor vent and by-pass valves – manual, Jacket pressure gauge, Internal pressure gauge, Internal vapor thermometer, Steam traps Drive: Shaft mounted gear box, V-belt drive, Hydraulic clutch, 37 kW squirrel cage motor Insulation: 50 mm rock-wool clad with stainless steel sheets
2	Pressure test certification (according to GOST rules)	
2	Automatic moisture control (with the following specifications)	■ Controls the instrument and stabilized DC supply unit for the measuring circuits. ■ The module accommodates two indicators for over set point and below set point. ■ One indicator for end point. ■ One reset button. ■ Selector for choosing different sensitivities.

		■ Characteristic with adjustable potentiometer. ■ Converter to be placed close to the moisture sensor. The box contains one set of electrical circuits. ■ Moisture sensor for mounting on the Dry Melter (special plug is standard on the dry melter0. ■ Power supply: 220 V AC +/- 10Percent, 50-60 cycles
1	Load cell system 4 x 10 ton	■ The 4 load cells system is placed between button frame and concrete foundation. ■ Four load cells with mountings. ■ Weight amplifier with autotara and two set points. ■ A terminal for recording instrument.
2	Terminal box and digital display	With front mounting in control panel
GREAVES HANDLING		
1	Collecting tank	■ With the capacity of approximately 8 m^3 . ■ Provided with two bottom screw conveyors, each with diameter 300 mm. ■ Manufactured in 5 mm mild steel plate with the screw section of 6 mm with 10 mm wear plate. ■ Each screw is driven by one gear motor 3 kW.
1	Screw conveyor Ø230 mm	■ Works with steam at pressure of 1 bar and its trough is made of 5 mm mild steel. ■ A 6 mm flight is welded on one center pipe 76 x 8 mm. This screw is driven by one gear motor 2.2 kW. The conveyor is steam heated on the trough and includes all valves and steam traps
1	Chute and magnet.	It is mounted with a permanent magnet to trap ferrous metal
1	Dosing screw conveyor Ø230 mm.	Its length is approximately 2 m and will be fitted with manual adjustable speed gear motor
1	Fat screw press (type HM1000).	It separates the fat solution from the protein materials. The fat content of the materials inside the press is approximately 10-14Percent (depending on raw material). It is constructed with a heavy-duty frame of all-welded construction. The shaft has sectional flights and steel cage with barrel bars and spacers. The press has a choke control unit and a conical choke to control the pressure in the cage. Its drive unit is integrated with planetary gearbox, v-belt system and electrical motor. Output meal capacity of screw press is about 700-800 kg/hr and total power consumption is about 37 kW
1	Cooling screw	Length = 8.2 m and Ø230 mm It is for cooling the meal prior to milling. It is equipped with a special cover with air inlet. The screw is complete with gear motor 3 kW. The cooling filter is for mounting on the screw conveyor. Capacity will be 1500-2000 m^3/hr
1	Milling plant (type 650/450)	This unit includes hammer mill with motor 45 kW, coupling and vibration dampers. It has supporting frame with platforms on both sides including handrail and staircase. It has a bag holder and underneath of its frame there is a collecting hopper mounted with spouts for direct bagging
1	Weighing scale	local supply
1	Bag closing machine	local supply
FAT HANDLING		
2	Balance tank	(V = 70 L). They equilibrate the fat flow from the screw press to settling/intermediate tank. The balance tanks are manufactured in mild steel plate with double bottom for steam heating and equipped with pump and motor. They are provided with automatic level controls. A pump which serves both

		tanks has a capacity of approximately 40 L/min and power of 1.1 kW.
2	Settling tank	(V =1000 L). They are manufactured in mild steel with outside steam spiral for heating, insulation and cover plate for same in stainless steel plate and equipped with all fixed accessories and fittings
CONDENSING EQUIPMENT		
1	Cyclone HM1000	It has a diameter of 1,000 mm and includes valve for discharging of the sludge and it is manufactured from stainless steel with captive loose flange connections
1	Air-cooled Condenser HM 3000 kg/hr	All materials in contact with vapor, condensate and/or non-condensable are stainless steel AISI 304. All other steel parts are hot dipped galvanized. The tube bundle consists of 4 rows of 32 mm stainless steel, finned tubes. The first pass is done in the 3 top rows. The second pass is in the bottom row in which the condensate is sub-cooled. Ambient air is blown through the tube bundle by 2 fans. Each fan is directly driven by a 15 Hp 11 kW, 480 rpm electric motor. To save energy, the cooling capacity can be automatically adjusted by switching the fans individually on or off. A temperature sensor in the condensate outlet controls the capacity adjustment.
1	Stainless Fan 500 m3/h.	It is manufactured in stainless steel, AISI 304 with a 250 mm VG, 1.1 kW motor and it is for non-condensable gases coming from the condenser
1	Frame for Fan	It is hot dipped galvanized
1	Set of blow off pipes with all fittings	It includes a blow-down pipe (from dry melters to the cyclone and further to the condenser and non-condensable gas fan – of stainless steel), a pipe for non-condensable gases (for interconnection of non-condensable gas fan and boiler – max 30 meters – of stainless steel).
VARIOUS ELECTRICAL DEVICES		
1	Electrical control panel.	It contains the following items: ■ Main switch ■ Motor contactors for all motors ■ Fuses ■ Start/stop buttons for all motors ■ Indication lamps for running machinery ■ Star delta starters for motors above 11 kW ■ Ammeters for motors above 11 kW ■ Terminal strips, etc. ■ Cabinets of mild steel – grey painted modules ■ Following IEC 439 and IEC 117-3
1	Electrical cables	They are necessary for connecting 2 x 5000 L dry melter
1	Distribution battery (with reduction unit, 10-1 bar)	It consists of a distribution battery with flange connection for live steam from the steam boiler, connection for live steam supply to the dry melters as well as a connection for reduction unit including stop valve, safety valve, pressure gauge and pressure pipe
1	Set of pipes with all fittings	It includes steam and condensate pipe (for inter-connection of boiler and distribution battery/reduction), a steam pipe (between dry melters, percolating tank, balance tanks, settling tanks and reduction unit – in mild steel), a steam condensate pipe (from dry melters, percolating tank, balance tanks, settling tanks, and reduction unit – in mild steel) and a fat pipe (between percolating tank, balance tanks and settling tanks). The pipes from the balance tank to the settling tank are supplied with electric heating cables.
STEAM BOILER PLANT		
1	Steam boiler with a steam capacity of 4000 kg/hr	This boiler has the following characteristics:

- Operating pressure 9 bar.
- 100 mm insulation.
- One ELCO oil burner light fuel.
- One electric and automatic control panel.
- Two feed water pump Grundfos including necessary valves.
- One feed water tank 2500 liter.
- Manufactured in mild steel (including steam heating).
- One water treatment plant with capacity of 3 m3/h, D= 4.5 m and H=4.5 m
- One dosing pump.
- One boiler test set.
- One steel chimney (10 m height).
- One blow down tank

COST

Price for Complete Plant: $1,065,200 USD

Includes Spare Parts for 2 years

Startup includes supervision, installation for 4 weeks, and start-up and training for 2 weeks

Appendix E

FIGURE 1. Typical appearance of meat and bone meal (MBM) and various tallow-products in jars (National Renderers Association, Inc., 2002).

TABLE 1. Typical analysis of meat and bone meal (Pocket Information Manual, 2003).

Constituent	Content
Protein	50% (or as specified)
Fat	10%
Fiber (max.)	3%
Calcium (max.)	8.8% (2.2 times actual phosphorus level
Phosphorus (min.)	4%
Moisture (max.)	10%
Pepsin indigestible residue (max.)	14%

TABLE 2. Comparison of yields obtained with traditional dry rendering (Fernando, 1984).

Yields	LTR	Dry Rendering
Fat (%)	99.5	95.0
Fat-free solids (%)	94.0	96.0
Fat in meal	8.0	12.0
Moisture in meal (%)	8.0	3.0
Tallow, metric ton[a]	4346.0	3909.0
Meal metric ton[a]	5371.0	5421.0

[a]To convert to US tons, multiply ton by 1.1.

TABLE 3. Amino acid digestibilities of rendered animal proteins (adapted from table citing various sources, available in Pocket Information Manual, 2003).

Amino Acid	Meat and Bone Meal		Whole Blood Plasma	Spray Dried Meal	Poultry By-product	
	Ileal	True			Ileal	True
Lysine	71	82	94	86	84	76
Tryptophan	57	-	92	92	74	-
Threonine	64	79	86	80	74	73
Methionine	84	87	84	63	-	88
Cystine	63	47	-	-	-	54
Isoleucine	68	89	67	83	79	67
Histidine	68	82	95	89	80	76
Arginine	80	86	90	86	87	82

Appendix F

TABLE 1. Estimated operating and total costs for various mortality disposal methods in the US (SCI, 2002). (Each estimate assumes all mortalities are disposed of by one method).

Species	Rendering[a] MBM Sold for Feed	Rendering[a] No MBM for Feed	Burial	Incineration	Composting
	Total (Sector-wide) Operating Costs ($ 1,000)				
Cattle and Calves	34,088	99,169	43,902	38,561	125,351
Weaned Hogs	48,020	79,061	51,450	16,906	58,018
Pre-weaned Hogs	5,533	7,786	8,300	1,226	4,209
Other	5,828	8,003	6,245	1,184	4,063
Total Operating Costs	$93,470	$194,470	$109,898	$57,879	$191,643
	Operating Costs, Dollars per Mortality ($/head)				
Cattle and Calves[b]	$8.25	$24.11	$10.63	$9.33	$30.34
Weaned Hogs	$7.00	$11.53	$12.45	$4.09	$14.04
Pre-weaned Hogs	$0.50	$0.70	$2.01	$0.30	$1.02
Other	$7.00	$9.61	$1.51	$0.29	$0.98
	Total (Sector-wide) Fixed Costs for Specialized Facilities ($ 1,000)				
Beef Cattle	N.A.	N.A	N.A	797,985	1,241,310
Dairy Cattle	N.A	N.A	N.A	333,630	518,980
Hogs	N.A	N.A	N.A	158,031	245,826
Other	N.A	N.A	N.A	90,000	140,000
Total Fixed Costs	N.A	N.A	N.A	$1,379,646	$2,146,116

[a]Assuming all dead stock were rendered.

[b]Under existing scenario, renderers are assumed to charge $10/mature cattle and $7/calf.

TABLE 2. US production, consumption, and export of rendered products 2001 & 2002 (adapted from US Census Bureau for Exports, 2003).

Category	2001 ('000 metric tons)	2002 ('000 metric tons)	Percent Change, 02/01
Production			
Inedible Tallow and Greases	3,116.2	3,272.6	5.0
Edible Tallow	836.9	892.7	6.7
Lard	182.9	175.1	-4.2
Total Fats	**4,135.9**	**4,340.4**	**4.9**
Meat Meal and Tankage MBM	2,508.7	2,514.2	0.2
Feather Meal	353.6	362.1	2.4
All Other Inedible Products	1,257.7	1,319.2	4.9
Total Rendered Products	**8,256.0**	**8,535.8**	**3.4**
Consumption			
Inedible Tallow for Feed Formulation	424.4	449.3	5.9
Grease for Feed Formulation	859.6	887.9	3.3
Inedible Tallow and Greases Used for Feed Formulation	**1,284.0**	**1,337.2**	**4.1**
Fatty Acids	**262.0**	**270**[a]	**3**
Soap	**136**[a]	**113.7**[a]	**-16.3**
Total Inedible Fat Used for Feed and Ind.	**1682**	**1720.9**	**2.3**
Edible Tallow For edible use	120.4	111.8	-7.2
Edible Tallow For inedible use	121.3	119.0	-1.9
Edible Tallow	**241.7**	**230.8**	**-4.5**
Lard For edible use	104.5	107.0	2.4
Lard For inedible use	31.5	30.6	-2.7
Lard	**136.0**	**137.1**	**0.8**
Subtotal	***2059.7***[b]	***2,088.8***[b]	***1.4***
Exports			
Inedible Tallow	605.4	779.4	28.8
Yellow Grease	184.3	287.5	56.0
Other Inedible Fats and Oils	190.3	206.7	8.6
Total Inedible Tallow and Grease	**980.0**	**1273.6**	**29.9**
Edible Tallow	165.3	209.3	26.6
Lard	46.8	38.1	-18.9
Total Fats	**1,192.1**	**1,521.0**	**27.6**
Meat and Bone Meal	451.6	564.8	25.1
Feather Meal	42.0	39.0	-7.5
Total Meals	**493.7**	**603.8**	**22.2**
Bone and Bone Products	**36.9**	**24.0**	**-35.0**
Total Exported Rendered Products	***1,722.7***	***2,148.8***	***24.7***

TABLE 3. Meat and bone meal (MBM) exports to Japan by different countries during 2000 and 2001 (Arnold, 2002).

	2000		2001 (9 Months Ending Sept -)	
	Metric Tons	Percent	Metric Tons	Percent
Australia	35,282	19.1	22,661	23.3
New Zealand	34,284	18.5	31,726	32.6
Italy	28,857	15.6	1,797	1.8
Denmark	25,768	13.9	4,554	4.7
Argentina	20,311	11.0	11,712	12.0
Uruguay	17,932	9.7	8,202	8.4
China	15,127	8.2	10,540	10.8
United States	3,489	1.9	3,164	3.2
South Korea	1,533	0.8	995	1.0
Hong Kong	1,144	0.6	765	0.8
Canada	944	0.5	638	0.7
India	108	0.1	85	0.1
Vietnam	105	0.1	-	-
Pakistan	66	0.0	43	0.0
Brazil	0	-	400	0.4
Mongolia	0	-	184	0.2
Total	**184,950**	**100.0**	**97,466**	**100.0**

Appendix G

TABLE 1. Odor threshold concentrations of selected compounds from a rendering plant (Fernando, 1995).

Compound	Chemical Formula	Odor Threshold (ppm by volume)
Acrolein	$CH_2.CH.CHO$	0.21
Butyric Acid	$CH_3CH_2CH_2CO_2H$	0.001
Ammonia	NH_3	46.8
Pyridine	C_5H_5N	0.021
Skatole	C_9H_8NH	0.220
Methyl Amine	CH_3NH_2	0.021
Dimethyl Amine	$(CH_3)_2N$	0.047
Trimethyl Amine	$(CH_3)_3N$	0.00021
Allyl Amine	$CH_2.CH.CH_2NH_2$	28
Ethyl Mercaptan	C_2H_5SH	0.001
Allyl Mercaptan	$CH_2.CH.CH_2SH$	0.016
Hydrogen Sulphide	H_2S	0.0047
Dimethyl Sulphide	CH_3SCH_3	0.0025
Dimethyl Disulphide	CH_3SSCH_3	0.0076
Dibutyl Sulphide	$(C_4H_9)_2S$	0.180

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

5

Lactic Acid Fermentation

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Table of Contents

Section 1 – Key Content

This chapter addresses lactic acid fermentation, a process that provides a way to store carcasses for at least 25 weeks and produce an end product that may be both pathogen-free and nutrient-rich. Lactic acid fermentation should be viewed as a means to preserve carcasses until they can be rendered. The low pH prevents undesirable degradation processes.

The process of lactic acid fermentation is simple and requires little equipment. Indeed, the process needs only a tank and a grinder. Fermentation is an anaerobic process that can proceed in any sized non-corrosive container provided it is sealed and vented for carbon dioxide release. During this process, carcasses can be decontaminated and there is a possibility of recycling the final products into feedstuff. Fermentation products can be stored until they are transported to a disposal site.

Carcasses are ground to fine particles, mixed with a fermentable carbohydrate source and culture innoculant, and then added to a fermentation container. Grinding aids in homogenizing the ingredients. For lactic acid fermentation, lactose, glucose, sucrose, whey, whey permeates, and molasses are all suitable carbohydrate sources. The carbohydrate source is fermented to lactic acid by *Lactobacillus acidophilus*.

Under optimal conditions, including a fermentation temperature of about 35°C (95°F), the pH of fresh carcasses is reduced to less than 4.5 within 2 days. Fermentation with *L. acidophilus* destroys many bacteria including *Salmonella* spp. There may be some microorganisms that can survive lactic acid fermentation, but these can be destroyed by heat treatment through rendering.

Biogenic amines produced during putrefaction are present in broiler carcasses. Tamim and Doerr (2000) argue that the presence of a single amine (tyramine) at a concentration above 550 ppm indicates a real risk of toxicity to animals being fed. This concentration is higher in the final product after rendering because the rendered product has less moisture than the fermentation broth. Thus, efforts should be made to reduce putrefaction. Properly prepared products will remain biologically stable until they are accepted for other processes such as rendering.

Taking into account the value of fermentation by-products, Crews et al. (1995) estimate the cost of fermention of poultry carcasses to be $68-171 per ton. Other calculations that exclude the value of fermentation by-products suggest the costs of fermentation of cattle carcasses to be about $650 per ton. The challenges with lactic acid fermentation are complete pathogen containment, fermentation tank contamination, and corrosion problems.

An intriguing idea is to plan for fermentation during the actual transportation of carcasses to the rendering sites; in such a scenario, railroad tank cars could be used for fermentation. This might prove useful, even in the case of an emergency carcass disposal situation. Fermentation could likely be carried out easily in these tank cars, perhaps in less time and with lower costs than other techniques requiring the actual construction of a fermentation tank. Of course, research is needed to ascertain the commercial feasibility of this idea.

Section 2 – Historical Use

In 1984, Dobbins of the University of Georgia proposed lactic acid fermentation as a biosecure method for recycling carcasses (Blake & Donald, 1992 and 1995a). At Auburn University in 1990, initial investigations into the fermentation of poultry carcasses were carried out with the goal of developing an on-farm fermentation system suitable for broiler production operations. In March 1992, the first disposal facility was constructed to demonstrate the feasibility of on-farm fermentation of poultry carcasses; the Agricultural Engineering Department at Auburn University designed the prototype.

Lactic acid fermentation is commonly referred to as pickling because microorganisms are inactivated and the decomposition process ceases when the pH is reduced to approximately 4.5 (Cai et al., 1994). Given its capacity to inactivate microorganisms and decompose biological material, lactic acid fermentation is used for decontamination and storage of carcasses in poultry production. Significantly, rendering companies will generally accept products produced by lactic acid fermentation (Damron, 2002). For poultry producers, the utilization of lactic fermentation to store carcasses reduces the cost of transportation to rendering facilities by 90%; it is much more expensive to pay renderers to pick up fresh carcasses (Blake & Donald, 1992 and 1995b).

Section 3 – Principles of Operation

3.1 – Introduction

For millennia, people have used lactic acid fermentation, which is a natural process, to preserve food and feeds (Campbell-Platt & Cook, 1995; Wood, 1985). Fermentation is an anaerobic process in which lactic acid bacteria transform sugar into lactic acid (see Figure 1). Lactic acid is a natural, low-pH, effective preservative. This process has been used by Blake and Donald (1995a) to manage poultry carcasses and by Kherrati et al. (1998) for slaughterhouse wastes.

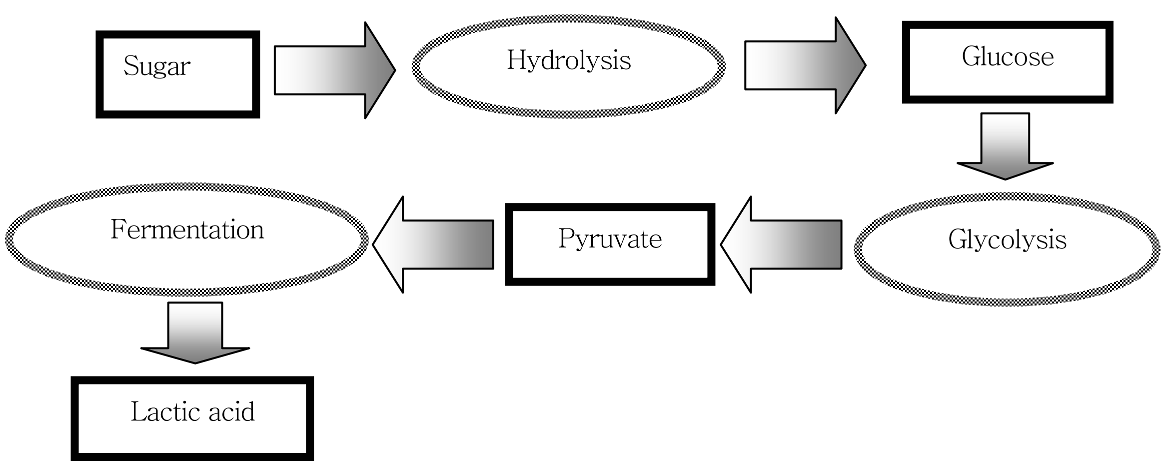

FIGURE 1. Lactic acid fermentation.

3.2 – Process Description

Carcasses are ground into smaller pieces to facilitate fermentation (Johnston et al., 1998). These smaller particles absorb lactic acid better than do whole carcasses. Furthermore, the mixture of ground carcasses permits better homogenization of the fermented material. The recommended particle size is 2.5 cm (1.0 inch) in diameter, or lower.

A fermentable carbohydrate source such as sucrose, molasses, whey, or ground corn is added to the ground carcasses. The ratio between fermentable carbohydrate and carcasses is 20:100 by weight (Blake & Donald, 1995a). The sugar is fermented to lactic acid by indigenous bacteria such as *Lactobacillus acidophilus*. This bacterial species is naturally present in the intestine of poultry; but for all animal species, including poultry, it is desirable to provide an additional inoculation of *Lactobacillus acidophilus* culture. The production of lactic acid creates acidification, which decreases the pH of the carcass material. Under optimal conditions, fermentation reduces the pH from 6.5 to 4.5 within 48 hours (Morrow & Ferket, 2002). This decrease in pH preserves the nutrients and permits the carcasses to be stored for several months before rendering or use for other purposes (Sander et al., 1995).

The ground carcasses are put in a nearly closed tank. Fermentation is a natural process that takes place in the absence of oxygen, but small amounts of oxygen are in fact helpful in starting the process. Fermentation is often conducted in a tank with a gate to vent the carbon dioxide produced.

3.3 – Process Requirements

Equipment

The process of lactic acid fermentation is simple and requires little equipment. Indeed, the process needs only a tank and a grinder. According to Tibbetts et al. (1987), the size of the container does not influence fermentation, but the use of a non-corrosive container is desirable to avoid corrosion. Fermentation tanks could be closed with a gate to vent the carbon dioxide produced, or have a small opening to allow carbon dioxide to flow out of the tank. The grinder used must be able to produce bits of carcasses sized 2.5 cm (1.0 inch) in diameter, or smaller. This size is recommended for better homogenization between different substances and better penetration of lactic acid into the carcass material.

Supplies and chemicals

Fresh carcasses contain few carbohydrate sources capable of being used by *Lactobacillus*. Consequently, a carbohydrate source such as sugar, whey, molasses, or ground corn should be added to the carcasses. Carbohydrates should be added in proportion to the carcass weight; for example, it is necessary to add 20 kg (44 lb) of molasses for every 100 kg (220 lb) of broiler carcasses (Blake & Donald, 1995a).

Unfortunately, sugar does not guarantee a good fermentation. It is also necessary to check two other factors—time of putrefaction and temperature of fermentation. After the death of an animal, putrefaction of tissue begins and produces some biogenic amines (see toxic risk below). The putrefaction process slows fermentation and may result in an end pH above 4.5. This is problematic because the fermentation process is imperfect above pH 4.5 and is good below pH 4.5. To avoid the complications arising from putrefaction, fermentation should be initiated promptly and an active inoculum of lactic acid cultures should be used.

According to Tamim and Doerr (2000), the temperature for fermentation should be above 30°C (86°F) to obtain a biologically safe final product with a pH of less than 4.5. If lactic acid fermentation incompletely acidifies the carcasses, a mineral or organic acid should be directly added.

Utility requirements

Utility requirements include water and electricity. After each use, the interior of the grinder and tank should be rinsed with water and disinfected. The grinder must be dismantled for complete washing and disinfection.

Construction and start-up time

The start-up time depends on the time required to transport all the equipment and supplies to the site. It is necessary to bring the equipment and material to the site before slaughter as the time lapse between slaughter and initiation of lactic fermentation should be minimized. Preparations prior to slaughter include the following:

1. The grinder and carbohydrate source can be easily moved on-site with trucks.
2. Fermentation can be carried out in several milk trucks, tank trailers, or railroad cars, which are easy to move and are generally resistant to corrosion (Hermel, 1992).
3. Lactic acid bacteria are procured and cultured to produce an inoculum, which is then added to the slurry of ground carcasses and carbohydrates.

Capacity

There is no maximum or minimum fermentation capacity, according to Tibbetts et al. (1987); the size of the fermentation container does not influence fermentation. Any closeable, corrosion-resistant container may be used for lactic acid fermentation.

The number of vessels (containers) required for a carcass disposal event can be calculated easily. The mass fraction of water should be at least 70% by weight for lactic acid fermentation. For 100 kg (220 lb) of carcasses, 20 kg (44 lb) of sugar is needed. If the carcass material is 70% water, the total dry mass is 50 kg (110 lb) and the total mass is 167 kg (367 lb) for a 70% moisture mixture. A reasonable tank volume is 200 liters, or 2 liters per kg of carcass. For 1000 animals and 500 kg (1100 lbs) live weight each, the required tank volume would be one million liters or 1,000 m^3 (35,315 ft^3). Eight railroad tank cars of 130 m^3 (4,590 ft^3) each could supply this fermentation volume. For tank trucks with a capacity of 20 m^3 (706 ft^3), 50 trucks would be needed.

3.4 – End Products

The aim of lactic fermentation is preservation and decontamination of the carcass material. Once carcass material is decontaminated, it can be sent to rendering plants. Other potential uses of fermented carcasses include mink and fox feed, aquaculture feeds, or other animal feeds. For example, up to 20% of fermented meat could be added to growing-finishing pigs' rations; this neither decreases nor increases the pigs' feed-to-gain ratios (Tibbetts et al., 1987). Most importantly, any use of fermentation end products must be considered carefully in order to avoid the transmission of pathogenic agents to other animals. Heat processes (cooking) can be used to ensure the destruction of any pathogens present.

3.5 – Economics

There are certain costs involved with the lactic fermentation process. The initial investment cost for setting up a tank is usually high. The net cost of fermentation, which includes variable costs and the value of by-products, is modest.

Taking into account the value of fermentation by-products, researchers have estimated the cost of fermention of poultry carcasses to be $68-171 per ton (Crews et al., 1995; Blake & Donald, 1995b).

The cost of molasses is about $40 per metric ton ($36 per US ton) and a polyethylene tank, which holds 500 gallons (1,890 liters) costs $640. For 1,000 animals with a weight of 500 kg (1100 lbs.) each, the costs would be as shown in Table 1.

The cost would be much less if one uses available mobile tanks, such as tank trucks or railroad tank cars, because fermentation could occur during transit and it would therefore not be necessary to purchase tanks.

TABLE 1. Estimated cost of lactic acid fermentation including the purchase cost of tanks.

Item	Cost / kg	Cost for 1000 cattle[a]
Tanks	$0.678	$339,000
Molasses	$0.008	$4,000
Expenses	$0.028	$14,000
Total cost	$0.714	$357,000

[a]The cattle are assumed to weigh 500 kg or 1100 lbs. each.

An estimation of the cost during an emergency is therefore $714 per metric ton of carcasses (~$650 per US ton). This price does not include the sale of by-products to rendering companies or resale of used equipment. The type of tank used for estimation is a 500-gallon (1.895 m^3) horizontal leg tank with an estimated cost of $640; an example tank is shown in Figure 2 below.

FIGURE 2. Type of tank used for estimation (United States Plastic Corporation, 2004).

Section 4 – Disease Agent Considerations

4.1 – Pathogen Containment

Lactobacillus acidophilus produces lactic acid and an antimicrobial agent called lactocidin, which has a broad antibacterial spectrum (Vincent et al., 1959; Coconnier et al., 1997). Together, low pH and temperature contribute to the destruction of bacterial pathogens and inactivation of viruses.

Bacteria

The survival period of *Salmonella* and its resistance to temperature is important while destroying bacteria (Shotts et al., 1984). Fermentation with *Lactobacillus acidophilus* destroys many bacteria such as *Salmonella typhimurium* within five days at 30°C (86°F) and 40°C (104°F). Significantly, citric, lactic, phosphoric, acetic, and propionic acid are all inhibitors of *Salmonella*. Table 2 shows the inhibition of the acids produced in the lactic acid fermentation compared to citric acid and phosphoric acid.

Most bacteria are destroyed within two days except the group E S*treptococcus,* which is similar to *Lactobacillus* (Dobbins, 1987). Germination of spores is also inhibited by low pH and lactic acid. Germination of *Bacillus subtilis* spores is strongly inhibited at pH 4.5 with 0.5 % lactic acid, as shown in Figure 3.

TABLE 2. Zone of inhibition of antimicrobial agents for *Salmonella* on petri dishes (Khan & Katamay, 1969).

	Concentration of antimicrobial agent				
	1%	3%	5%	7%	10%
Antimicrobial agents	Radius of zone of inhibition (millimeter)				
Acetic acid	18.3	24.6	28.7	32.3	35.7
Propionic acid	19.1	25.2	27.3	29.3	31.4
Lactic acid	15.4	19.6	21.9	23.7	26.1
Citric acid	15.3	19.4	21.8	23.3	25.8
Phosphoric acid	16.4	22.4	25.1	30.5	33.2

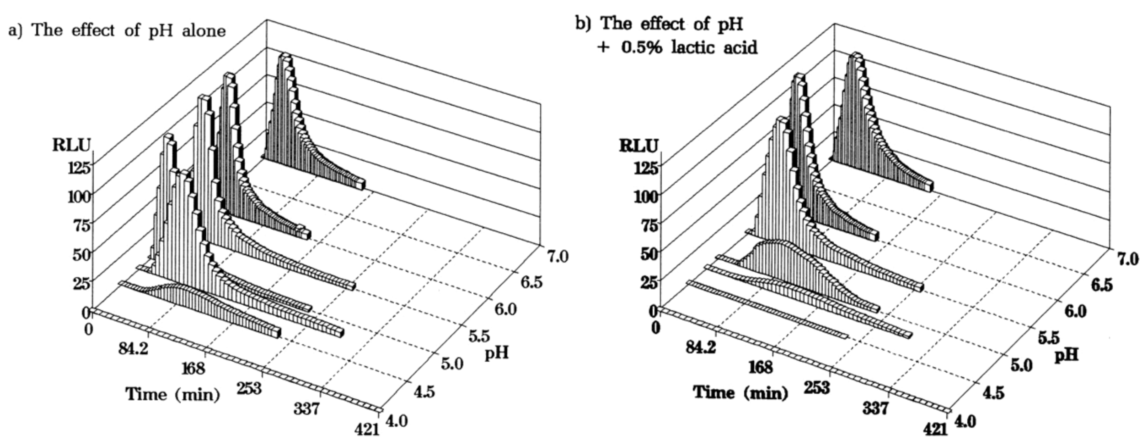

FIGURE 3. Effect of pH alone or with 0.5% lactic acid on the germination of *Bacillus subtilis* spores (Ciarciaglini et al., 2000).

Viruses

Both temperature and pH affect the viability of viruses. The adenovirus group (canine hepatitis), which is the most difficult virus to destroy, is destroyed within five days at 30°C (86°F) and 40°C (104°F). Viruses of the myxo virus group (e.g., Newcastle disease) are destroyed in just two days (Dobbins, 1987). However, Wooley et al. (1981) report that Newcastle disease and infectious canine hepatitis have survived for 96 hours at 30°C (86°F) in fermented, edible waste material. In the same study, pseudorabies virus and the viral agent of avian infectious bronchitis were inactivated in 24 hr at 30°C (86°F), measles virus and vesicular stomatitis virus in a few hours, and porcine picornavirus in 72 hours. Foot and mouth disease virus disassembles below pH 7, and rhinovirus loses its infectivity at about pH 5 (Twomey et al., 1995). Some viruses—like enterovirus, cardiovirus, and hepatovirus—are actually stable at pH 3 or lower, and poliovirus, an enterovirus, retains its infectivity even at pH 1.5 (Twomey et al., 1995). While acid-resistant, these viruses can be destroyed by heat. Thus mild heat treatment is needed to make sure that all viruses are destroyed.

4.2 – Risk of Contamination

There is a risk of toxic products that may be present following lactic acid fermentation and rendering. If the rendered product is used as an animal feed, it is important to realize that certain toxic agents can survive this treatment. If carcasses are sterilized after particle size reduction and prior to inoculation, the risk of contamination is reduced significantly.

4.3 – Toxic Risk

During the fermentation of broiler carcasses, certain amino acids have been shown to undergo decarboxylation and become biogenic amines (see Table 3). Necrotic cellular debris in the intestines of carcasses has been associated with biogenic amines in animal protein products. The level of biogenic amines depends on the state of decomposition of carcasses that are used in lactic acid fermentation.

TABLE 3. Common biogenic amines and their precursors (Tamim & Doerr, 2000).

Biogenic Amine	Amino Acid
Cadaverine	Lysine
Histamine	Histidine
Phenylethylamine	Phenylalanine
Putrescine	Arginine, Methionine
Spermine, Spermidine	Arginine, Methionine
Tryptamine	Tryptophan
Tyramine	Tryosine

Only spermidine and spermine are reduced during fermentation. All biogenic amines produced during putrefaction are present in broiler carcasses (Table 4), and Tamim and Doerr (2000) argue that the presence of a single amine (tyramine) at a concentration above 550 ppm indicates a real risk of toxicity to animals being fed. This concentration is higher in the final product after rendering because the rendered product has less moisture than the fermentation broth. Thus, efforts should be made to reduce putrefaction.

TABLE 4. Formation of biogenic amines during putrefaction and fermentation of broiler carcasses (Tamim & Doerr, 2000).

Amine	Putrefaction	Fermentation
Cadaverine	++[a]	++
Histamine	++	++
Phenylethylamine	++	++
Putrescine	++	++
Spermidine	++	--
Spermine	++	--
Tryptamine	++	++
Tyramine	++	++

[a]Key: (++) indicates produced; (--) indicates reduced.

Section 5 - Implications to the Environment

Lactic acid fermentation does not have any significant environmental effects if the products of fermentation are rendered and/or processed into marketable products. The process allows the carcasses to be stored until they can be processed.

Section 6 – Advantages and Disadvantages

The advantages and disadvantages associated with lactic acid fermentation are presented in Table 5.

TABLE 5. Advantages and disadvantages of lactic acid fermentation of carcasses.

Advantages	Disadvantages
Decontamination of carcasses	All pathogens are not destroyed
Possibility of recycling into a feedstuff	Risk of contamination
Possibility of storage	Problem of corrosion
Potentially mobile process	Need carbohydrate source and culture of *Lactobacillus acidophilus*

Section 7 – Critical Research Needs

1. Investigate combining lactic acid fermentation and transportation processes to minimize the risk of pathogen spread during transportation.

   One intriguing idea regarding lactic acid fermentation is to carry it out during transportation in railroad tank cars. These tank cars are available in almost all locations and can be made non-corrosive. The number of tank cars can vary based on the amount of carcasses involved. These tanks might prove particularly useful in emergency situations. The advantages of using these tanks include the following: they are available in large numbers, they can be reused with proper cleaning, and they take less time to assemble as compared to traditional equipment used currently in other processes.

2. Investigate additional treatments such as lactic acid addition, thermal processing, and radio frequency heating for their economic and technical feasibility and for their ability to kill pathogens in carcass material.

   Research should focus on other methods that might be used to kill pathogens in conjunction with lactic acid fermentation processes. Lactic acid fermentation will not destroy all pathogens. There may be some harmful microorganisms that require additional treatment for complete destruction/inactivation. Additional treatments such as lactic acid addition may be appropriate and should be investigated. Thermal processing may also be beneficial in some cases. There is a need to conduct experiments on the fate of pathogens in carcasses that are ground and subjected to lactic acid fermentation. For each pathogen, there is a need to know the pH level and lactic acid concentration that are sufficient to destroy it. If ground carcasses are fermented at ambient conditions, further research is needed to understand the effect of inoculum size and temperature on the competition of lactic acid fermentation with putrefaction.

Radio frequency heating is another process that may be used to kill pathogens (Wang et al., 2003). A thorough study is necessary to determine its economic and technical feasibility. It is now widely used in industrial applications and also for heating fruits, vegetables, and fish on a large scale. However non-uniform temperatures and difficulty in application of overpressure can be problems of concern in this process. Using this process, better quality end products can be obtained in a shorter time and with less energy. Radio frequency heating should be investigated for its economic and technical suitability for carcass disposal.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

6

Alkaline Hydrolysis

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Abbreviations

APHIS	USDA Animal and Plant Health Inspection Service
ARS	USDA Agricultural Research Service
BOD	biochemical oxygen demand
BSE	bovine spongiform encephalopathy
CWD	chronic wasting disease
DNA	deoxyribonucleic acid
psig	pounds per square inch, gauge
STAATT	State and Territorial Association on Alternative Treatment Technologies,
TSE	transmissible spongiform encephalopathy
US	United States
USDA	United States Department of Agriculture
WR^2	Waste Reduction by Waste Reduction, Inc.

Section 1 – Key Content

Alkaline hydrolysis represents a relatively new carcass disposal technology. It has been adapted for biological tissue disposal (e.g., in medical research institutions) as well as carcass disposal (e.g., in small and large managed culls of diseased animals). One company—Waste Reduction by Waste Reduction, Inc. (WR^2)—reports that it currently has 30 to 40 alkaline hydrolysis digestion units in operation in the United States (US), several of which are used to dispose of deer carcasses infected with chronic wasting disease (CWD) (Grady, 2004).

1.1 – Process Overview

Alkaline hydrolysis uses sodium hydroxide or potassium hydroxide to catalyze the hydrolysis of biological material (protein, nucleic acids, carbohydrates, lipids, etc.) into a sterile aqueous solution consisting of small peptides, amino acids, sugars, and soaps. Heat is also applied (150°C, or ~300°F) to significantly accelerate the process. The only solid byproducts of alkaline hydrolysis are the mineral constituents of the bones and teeth of vertebrates (WR^2, 2003). This undigested residue, which typically constitutes approximately two percent of the original weight and volume of carcass material, is sterile and easily crushed into a powder that may be used as a soil additive (WR^2, 2003).

Proteins—the major solid constituent of all animal cells and tissues—are degraded into salts of free amino acids. Some amino acids (e.g., arginine, asparagine, glutamine, and serine) are completely destroyed while others are racemized (i.e., structurally modified from a left-handed configuration to a mixture of left-handed and right-handed molecules). The temperature conditions and alkali concentrations of this process destroy the protein coats of viruses and the peptide bonds of prions (Taylor, 2001a). During alkaline hydrolysis, both lipids and nucleic acids are degraded.

Carbohydrates represent the cell and tissue constituents most slowly affected by alkaline hydrolysis. Both glycogen (in animals) and starch (in plants) are immediately solubilized; however, the actual breakdown of these polymers requires much longer treatment than is required for other polymers. Once broken down, the constituent monosaccharides (e.g., glucose, galactose, and mannose) are rapidly destroyed by the hot aqueous alkaline solution (WR^2, 2003). Significantly, large carbohydrate molecules such as cellulose are resistant to alkaline hydrolysis digestion. Items such as paper, string, undigested plant fibers, and wood shavings, although sterilized by the process, are not digestible by alkaline hydrolysis.

Alkaline hydrolysis is carried out in a tissue digester that consists of an insulated, steam-jacketed, stainless-steel pressure vessel with a lid that is manually or automatically clamped. The vessel contains a retainer basket for bone remnants and other materials (e.g., indigestible cellulose-based materials, latex, metal, etc.). The vessel is operated at up to 70 psig to achieve a processing temperature of 150°C (~300°F). According to WR^2, one individual can load and operate an alkaline hydrolysis unit. In addition to loading and operation, personnel resources must also be devoted to testing and monitoring of effluent (e.g., for temperature and pH) prior to release into the sanitary sewer system (Powers, 2003). Once loaded with carcasses, the system is activated by the push of a button and is thereafter computer-controlled. The weight of tissue in the vessel is determined by built-in load cells, a proportional amount of alkali and water is automatically added, and the vessel is sealed pressure-tight by way of an automatic valve. The contents are heated and continuously circulated by a fluid circulating system (WR^2, 2003).

The process releases no emissions into the atmosphere and results in only minor odor production. The end product is a sterile, coffee-colored, alkaline solution with a soap-like odor that can be released into a sanitary sewer in accordance with local and federal guidelines regarding pH and temperature (Kaye, 2003). This can require careful monitoring of temperature (to ensure release of the effluent at or above 190°C [374°F], a temperature below which the effluent solidifies), pH, and biochemical oxygen demand (BOD) (Powers, 2003).

The pH of undiluted hydrolyzate is normally between 10.3 and 11.5. For those sewer districts that have upper limits of pH 9 or 10, bubbling carbon dioxide into the hydrolyzate at the end of the digestion lowers the pH to the range of pH 8 or less (Kaye, 2003). As an example of the quantity of effluent generated by the process, WR^2 (2003) estimates that a unit of 4,000 lb capacity would generate approximately 1,250 gal (2,500 L) of undiluted hydrolyzate, and approximately 2,500 gal (9,466 L) of total effluent (including hydrolyzate, cooling water, rinse water, and coflush water).

The average BOD of undiluted hydrolyzate is approximately 70,000 mg/L. However, WR^2 indicates that in many instances the digester is located in a facility that releases in excess of 1,900,000 L (500,000 gal) per day, and, therefore, the added BOD is a fraction of the material being presented to the sewer district daily (Kaye, 2003). WR^2 also suggests that although the BOD is high, the carbon-containing molecules in the hydrolyzate have been broken down to single amino acids, small peptides, and fatty acids, all of which are nutrients for the microorganisms of sanitary treatment plants (Kaye, 2003). These aspects notwithstanding, disposal of effluent from alkaline hydrolysis units is a significant issue and must be so treated when considering this technology. In fact, some operators are contemplating alternative means of handling effluent, including solidification of effluent prior to disposal.

The total process time required for alkaline hydrolysis digestion of carcass material is three to eight hours, largely depending on the disease agent(s) of concern. For conventional (e.g., bacterial and viral) contaminated waste, four hours is sufficient. However, for material infected (or potentially infected) with a transmissible spongiform encephalopathy (TSE) agent, six hours is recommended (European Commission Scientific Steering Committee, 2002; European Commission Scientific Steering Committee, 2003). WR^2 notes that mobile-trailer units consisting of a digester vessel, boiler, and containment tank have a capacity of digesting 4,000 pounds of carcasses every 8 hours, or approximately 12,000 pounds (5,443 kg) in a 24-hour day. Others, however, note that loading and unloading of the digester can take time—as much as one hour in between processing cycles. Furthermore, temperature and pH monitoring of effluent takes time (Powers, 2003).

WR^2 estimates the cost of disposal of animal carcasses via alkaline hydrolysis at \$0.02 to \$0.03 per pound (\$40 to \$60/ton) of material (excluding capital and labor costs) (Wilson, 2003). Others have estimated the cost to be \$0.16 per pound (\$320/ton) including labor and sanitary sewer costs (Powers, 2003). WR^{2}'s mobile trailer unit capable of digesting 4,000 pounds of carcasses every 8 hours has a capital cost of approximately \$1.2 million (Wilson, 2003).

1.2 – Disease Agent Considerations

The alkaline hydrolysis process destroys all pathogens listed as index organisms by the State and Territorial Association on Alternative Treatment Technologies (STAATT I and STAATT II), which require a 6-log (99.9999%) reduction in vegetative agents and a 4-log (99.99%) reduction in spore-forming agents. Significantly, the alkaline hydrolysis process has been approved for the treatment of infectious waste in all states in which specific application for such approval has been made (Taylor, 2000; Taylor, 2001b).

The efficacy of alkaline hydrolysis was evaluated against pure cultures of selected infectious microorganisms during processing of animal carcasses in a digester at the Albany Medical College. The organisms tested included *Staphylococcus aureus, Mycobacterium fortuitum, Candida albicans, Bacillus subtilis, Pseudomonas aeruginosa, Aspergillus fumigatus, Mycobacterium bovis* BCG, MS-2 bacteriophage, and *Giardia muris.* Animal carcasses included pigs, sheep, rabbits, dogs, rats, mice, and guinea pigs. The tissue digester was operated at 110-120°C (230-248°F) and approximately 15 psig for 18 hours before the system was allowed to cool to 50°C (122°F), at which point samples were retrieved and submitted for microbial culture. The process completely destroyed all representative classes of potentially infectious agents as well as disposing of animal carcasses by solubilization and digestion (Kaye et al., 1998).

A study conducted at the Institute of Animal Health at the University of Edinburgh examined the capacity of alkaline hydrolysis to destroy bovine spongiform encephalopathy (BSE) prions grown in the brains of mice. Two mice heads were digested for three hours and one head for six hours. Samples of the hydrolyzate from each digestion were neutralized, diluted, and injected intracerebrally into naïve mice known to be susceptible to the effects of BSE. After two years, mice were sacrificed and their brains examined for signs of TSE. Evidence of TSE was found in the brains of some mice injected with hydrolyzate taken from three-hour-long digestions. Significantly, no evidence of TSE was found in the brains of mice injected with hydrolyzate from the six-hour-long digestion. The persistence of infectivity in the three-hour samples may have been due to the fact that material was introduced into the digestion vessel in a frozen state and was contained inside a polyethylene bag (i.e., the actual exposure of the prion-containing samples to the alkaline hydrolysis process may have been much less than 3 hours) (Taylor, 2001a). Based on these experiments, the European Commission Scientific Steering Committee has approved alkaline hydrolysis for TSE-infected material with the recommendation that TSE-infected material be digested for six hours (European Commission Scientific Steering Committee, 2002; European Commission Scientific Steering Committee, 2003). As a safety measure, one US-based facility disposing of CWD-infected carcasses uses an eight-hour-long digestion process to ensure destruction of any prion-contaminated material (Powers, 2003).

1.3 – Advantages & Disadvantages

Advantages of alkaline hydrolysis digestion of animal carcasses include the following:

- Combination of sterilization and digestion into one operation,
- Reduction of waste volume and weight by as much as 97 percent,
- Complete destruction of pathogens, including prions,
- Production of limited odor or public nuisances, and
- Elimination of radioactively contaminated tissues.

Disadvantages of alkaline hydrolysis process of animal carcass disposal include the following:

- At present, limited capacity for destruction of large volumes of carcasses in the US and
- Potential issues regarding disposal of effluent.

Section 2 – Historical Use

Alkaline hydrolysis technology has been and is currently being used in many institutions, laboratories, and animal disease diagnostic facilities to dispose of carcasses and other forms of biological waste. Table 1 below lists several sites where alkaline hydrolysis has been employed since 1993. Alkaline hydrolysis technology has not been adopted for large-scale, *catastrophic* carcass disposal events. Nevertheless, alkaline hydrolysis has been relied upon for carcass disposal related to small and large *managed* culls of animals infected with chronic wasting disease (CWD) and other transmissible spongiform encephalopathies (TSEs). One company—Waste Reduction by Waste Reduction, Inc. (WR^2)—reports that it currently has 30 to 40 alkaline hydrolysis digestion units in operation in the United States (US). Many of these units are used to dispose of CWD-infected deer carcasses (Grady, 2004).

TABLE 1. Biomedical research institutes, pharmaceutical companies, health care facilities, veterinary facilities, mortuaries, government agencies, and agricultural facilities that use alkaline hydrolysis processing for animal tissue disposal (Kaye, 2003).

Company	Installation Date	Use	Cycle Capacity	Operating Frequency
Albany Medical Center	Oct 1993	rodents, lagomorphs, sheep, pigs, goats	500 lbs.	1x/day
Allergan, Inc.	Jan 2001	rodents, lagomorphs	280 lbs.	1x/day
Biocon, Inc.	Oct 2002	rodents	~11 lbs.	2x/week
Colorado State University	Feb 2002	teaching hospital anatomic material and TSE-infected deer, elk, and sheep	2,000 lbs.	2x/day
Genentech, Inc.	Oct 2003	rodents, lagomorphs	280 lbs.	2x/week
Smithkline Beecham, Glaxo	Feb 1997	rodents, lagomorphs	600 lbs.	2x/week
Health Canada, Winnipeg	July 2000	rodents from TSE studies	30 lbs.	
Illinois Department of Agriculture	Feb 2003	livestock, roadkill, deer	2,000-3,000 lbs.	1x/day
Florida Division of Animal Industry	Mar 2003	necropsy tissue wastes	~11 lbs.	1x/day
Lexicon Genetics, Inc.	Jun 2002	rodents	80 lbs.	1x/day
Methodist Hospital	Mar 2001	pigs, sheep, human anatomic waste	280 lbs.	
Research Foundation for Mental Hygiene	Dec 2003	rodents from TSE studies	30 lbs.	3x/week
Sierra Biomedical, Inc.	May 2002	monkeys, bedding and food waste, animal waste	500 lbs.	1x/day
Immunex	Jun 2003	rodents, lagomorphs	80 lbs.	
South Dakota State University	Aug 2003	necropsy tissue wastes	~11 lbs.	1x/day
Humane Society of St. Joseph County, Inc.	Sep 2002	cats, dogs, euthanized animals	2,000-3,000 lbs.	1x/week
State University of New York, Binghamton	Jan 2002	rodents, lagomorphs, anatomic teaching wastes	80 lbs.	4x/week
Smithkline Beecham Pharmaceuticals, Rennes	Jul 1998	rodents (unit sold with plant when Glaxo divested SB labs)	80 lbs.	
Texas A&M Research Foundation	Aug 2002	livestock, horses	2,000-3,000 lbs.	1x/day
Tranxenogen, Inc.	Jul 2002	chicks	~11 lbs.	1x/day
Tulane University Medical Center	May 2003	monkeys	200 lbs.	1x/day
University of Florida	Apr 1998	horses, cattle, sheep, pigs, teaching hospital anatomic material	3,000 lbs.	1x/day
USDA-APHIS, Ames	Apr 2003	Belgian TSE-infected sheep, awaiting new building for reinstallation	7,000 lbs.	
USDA-ARS, Laramie	Jan 2000	being upgraded for new building	1,500 lbs.	
State of Wisconsin and USDA-APHIS	Nov 2003	undergoing acceptance tests, livestock, CWD-infected deer	4,000 lbs.	
WR2	(in stock)	demonstration unit for Europe, livestock, sheep, etc.	280 lbs.	
Seiko International-Obahiro University, University of Tokyo	Feb 2003	rodents from TSE studies	30 lbs.	
Institute for Animal Health, Edinburgh	Mar 2000	sheep heads doped with 301V BSE	30 lbs.	
Florida State Anatomical Board	Apr 1996	Human cadavers from medical education	1,000 lbs.	1x/day

Section 3 – Principles of Operation

3.1 – General Process Overview

A hydrolytic process

Hydrolysis is a process whereby chemical bonds are broken by the insertion of a water molecule. Hydrolysis can be catalyzed by enzymes, metal salts, acids, or bases. Alkaline hydrolysis relies upon bases—typically, water solutions of alkaline metal hydroxides such as sodium hydroxide or potassium hydroxide. Heat significantly accelerates hydrolytic processes; in this way, alkaline hydrolysis uses elevated temperatures (150°C, or ~300°F) to hasten the conversion of biological material (protein, nucleic acids, carbohydrates, lipids, etc.) into a sterile aqueous solution consisting of small peptides, amino acids, sugars, and soaps. The only solid byproducts of alkaline hydrolysis are the mineral constituents of the bones and teeth of vertebrates (WR^2, 2003).

Protein degradation

Alkaline hydrolysis ultimately leads to the degradation of proteins—the major solid constituent of all animal cells and tissues. Sodium or potassium salts of free amino acids are generated by the hydrolytic reaction, while oligopeptides (small chains of amino acids) are generated as reaction intermediates. Some amino acids (e.g., arginine, asparagine, glutamine, and serine) are completely destroyed while others are racemized (i.e., structurally modified from a left-handed configuration to a mixture of left-handed and right-handed molecules). Meanwhile, carbohydrate side chains are released from glycoproteins. The protein coats of viruses are destroyed and the peptide bonds of prions are broken courtesy of the temperature conditions and alkali concentrations used in the alkaline hydrolysis process (Taylor, 2001a).

Lipid degradation and the formation of "soaps"

Simple fats consist of three fatty acid chains bound through ester bonds to a molecule of glycerol. During alkaline hydrolysis, these ester bonds are hydrolyzed, yielding "soaps" (i.e., the sodium and potassium salts of fatty acids). Meanwhile, polyunsaturated fatty acids and carotenoids (pigments) undergo molecular rearrangements and are also destroyed by alkaline hydrolysis (WR^2, 2003).

Carbohydrate degradation

Carbohydrates are the cell and tissue constituents most slowly affected by alkaline hydrolysis. Both glycogen (the most common large polymer of glucose in animals) and starch (the most common large polymer of glucose in plants) are immediately solubilized. However, the actual breakdown of these polymers requires much longer treatment than is required for other polymers. Once broken down, the constituent monosaccharides (e.g., glucose, galactose, and mannose) are rapidly destroyed by the hot aqueous alkaline solution (WR^2, 2003).

Significantly, large carbohydrate molecules such as cellulose are resistant to alkaline hydrolysis digestion. Paper, string, undigested plant fibers and wood shavings are among the cellulose-based materials which may be associated with animal carcasses but which are not digestible by alkaline hydrolysis. However, these indigestible materials are completely sterilized by the alkaline hydrolysis process. They may be removed from the basket of the digester and disposed of as ordinary waste at a sanitary landfill.

Nucleic acid degradation

Nucleic acids (e.g., deoxyribonucleic acid, or DNA) are large, unbranched linear polymers held together by phosphodiester bonds. Like the ester bonds of lipids, nucleic acids' phosphodiester bonds are hydrolyzed by alkaline hydrolysis.

Undigested inorganic residue

Alkaline hydrolysis of animal tissues and carcasses yields an undigested residue—namely, the dry inorganic component of bones and teeth. This material typically constitutes approximately two percent of the original weight and volume of carcass material. It is sterile and easily crushed into a powder that may be used as a soil additive (WR^2, 2003).

3.2 – Operation, Resource, and Personnel Requirements

Alkaline hydrolysis is carried out in a tissue digester that consists of an insulated, steam-jacketed, stainless-steel pressure vessel with a lid that is manually or automatically clamped. An example digester is shown in Figure 1. The vessel contains a retainer basket for bone remnants and other materials (e.g., indigestible cellulose-based materials, latex, metal, etc.). The vessels are pressure-rated by the American Society of Mechanical Engineers to operate at 100 pounds per square inch, gauge (psig), but are operated at less than 70 psig to achieve a processing temperature of 150°C (~300°F).

FIGURE 1. Example alkaline hydrolysis tissue digester with 2,000 lb capacity (Powers, 2003).

According to WR^2, one individual can load and operate an alkaline hydrolysis unit. Once the digester vessel has been loaded with carcasses, the operating system is activated by the push of a button. The process is then computer-controlled. During the operation, a measured amount of alkali and water, proportional to the amount of tissue in the vessel, is automatically added. The concentration is calculated with tissue weight determined by built-in load cells. Water is added in an amount proportional to the tissue weight, and the vessel is sealed pressure-tight by way of an automatic valve. The contents are heated and continuously circulated. There are no moving parts inside the vessel; high-level agitation is provided in the fluid circulating system (WR^2, 2003). In addition to the requisite alkaline solutions and water, energy (for steam generation) and accommodation capacity (for emptying effluent) are necessary (Wilson, 2003).

In one facility, a necropsy technician who took an interest in alkaline hydrolysis technology has been sufficiently trained to operate the digestion unit. However, training other substitute personnel to operate the digestion unit would take considerable time. In addition to loading and operation, personnel resources must be devoted to testing and monitoring of effluent (e.g., for temperature and pH) prior to release into the sanitary sewer system (see related discussion in sections 3.5, 3.6, and 5) (Powers, 2003).

3.3 – Location Considerations

The largest alkaline hydrolysis unit currently available has a capacity of 10,000 pounds of biological material. The unit is eight feet in diameter and just over eight feet high. This unit requires a minimum room height of 24 feet; the actual footprint of the unit is 102 x 168 inches. Other digesters, with a capacity of 4,000 pounds, are mountable on mobile semi-trailers (Wilson, 2003).

As section 3.5 elaborates, alkaline hydrolysis units can give off a soapy odor. However, concerns about this odor are primarily limited to the period of time devoted to loading and unloading (Powers, 2003). Consequently, odor does not overly influence where digester units should or should not be placed.

3.4 – Time Considerations

The total process time required for alkaline hydrolysis digestion of carcass material is three to six hours (see related discussion in section 4). The precise processing time largely depends on the disease agent(s) of concern. For conventional (e.g., bacterial and viral) contaminated waste, three hours is sufficient. However, for TSE-infected (or potentially TSE-infected) material, six hours may be preferred.

WR^2 notes that mobile-trailer units consisting of a digester vessel, boiler, and containment tank have a capacity of digesting 4,000 pounds of carcasses every 8 hours, or approximately 12,000 pounds (5,443 kg) in a 24-hour day. Others, however, note that loading and unloading of the digester can take time—as much as one hour in between processing cycles. Furthermore, temperature and pH monitoring of effluent takes time (Powers, 2003).

3.5 – Disposal of Effluent

Alkaline hydrolysis results in a sterile, coffee-colored, alkaline solution with a soap-like odor. This solution can be released into a sanitary sewer in accordance with local and federal guidelines regarding pH and temperature (Kaye, 2003). In at least one facility, this has demanded careful monitoring of temperature (to ensure release of the effluent at or above 190°C (374°F), a temperature below which the effluent solidifies), pH, and biochemical oxygen demand (BOD) (Powers, 2003).

The pH of the undiluted hydrolyzate is essentially that of a solution of the sodium or potassium salts of the amino acids and small peptides remaining after digestion. This is normally between pH 10.3 and 11.5. For those sewer districts that have upper limits of pH 10 or even pH 9, bubbling carbon dioxide into the hydrolyzate at the end of the digestion lowers the pH to the range of pH 8 or less. The advantage of using carbon dioxide to adjust the pH is that it will not overcompensate and drive the hydrolyzate into the acid range (Kaye, 2003). The estimated quantity of effluent generated from the process is shown in Table 2.

The average BOD in the undiluted hydrolyzate is approximately 70,000 mg/L. While this is a high BOD, WR^2 notes that the largest digester has a total undiluted hydrolyzate volume of 9,100 liters (2,400 gal); and, again according to WR^2, in many instances, the digester is located in a facility that releases in excess of 1,900,000 L (500,000 gal) per day so that the added BOD is a fraction of the material being presented to the sewer district daily (Kaye, 2003).

TABLE 2. Approximate volume of hydrolysate and total effluent produced per cycle from the alkaline hydrolysis process (WR^2, 2003).

Unit Capacity (lb/kg)	Hydrolysate (undiluted effluent) produced per cycle (gal / L)[a]	Total effluent (hydrolysate, cooling water, rinse water, and coflush water) (gal / L)[a]
500 / 227	160 / 606	320 / 1,212
1,500 / 680	440 / 1,666	960 / 3,635
2,000 / 907	580 / 2,196	1,160 / 4,392
4,000 / 1,814	1,250 / 4,733	2,500 / 9,466
8,000 / 3,629	2,500 / 9,466	5,000 / 18,931
10,000 / 4,536	3,150 / 11,927	6,300 / 23,853

[a]Assumes unit loaded at full capacity. Hydrolysate produced is a function of the amount of tissue being processed. For example, processing at half capacity would generate half the amount of coflush water and cooling water. Cooling water (which is approximately 25% of total water used) can be saved in an optional tank to be reused as processing water for the next cycle.

WR^2 indicates that although the BOD is high in the hydrolyzate, the carbon-containing molecules have already been broken down from the large protein and fat molecules to single amino acids, small peptides, and fatty acids; all of these are nutrients for the microorganisms of sanitary treatment plants. In fact, reportedly some sewer districts prefer to receive the hydrolyzate at night to keep the bacteria active so they are ready to go to work when the bolus of waste arrives first thing the following morning (Kaye, 2003).

Despite this technical information and the fact that effluent exudes very little odor (Powers, 2003), disposal of effluent from alkaline hydrolysis units is a significant issue and must be so treated when considering this technology. In fact, some operators are contemplating alternative means of handling effluent, including solidification of effluent prior to disposal (Powers, 2003).

3.6 – Cost Considerations

WR[2] estimates the cost of disposal of animal carcasses via alkaline hydrolysis at $0.02 to $0.03 per pound of carcass material ($40 to $60/ton of carcass material) (excluding capital and labor costs) (Wilson, 2003). Others experienced with alkaline hydrolysis have estimated $0.16 per pound ($320/ton), a cost estimate that has been broken down in Table 3.

TABLE 3. Cost estimates for operation of an alkaline hydrolysis tissue digester with 2,000 lb capacity (Powers, 2003).

Item	Cost ($ per lb of carcass material processed)
Steam, water, electricity	$0.01/lb.
Chemicals (NaOH, KOH)	$0.02/lb.
Personnel (4 hours/day for 2 cycles)	$0.04/lb.
Sanitary sewer costs	$0.07/lb.
Maintenance & repair	$0.02/lb.
Total	**$0.16/lb.**

WR[2]'s mobile trailer unit consisting of a digestion vessel, boiler, and containment tank costs approximately $1.2 million. This unit would be capable of digesting 4,000 pounds of carcasses every 8 hours, or approximately 12,000 pounds (5,443 kg) in a 24 hour day (6 tons/day) (Wilson, 2003).

3.7 – Other Considerations

At present, research is being conducted on systems that would combine the alkaline hydrolysis process with a shredder-steam sterilizer technology. Such a system would theoretically allow processing of up to 25,000 to 30,000 pounds of animal carcasses per hour (12 to 15 tons/hr) for disposing of large volumes of biological waste (Kaye, 2003).

Section 4 – Disease Agent Considerations

4.1 – Conventional Disease Agents

The alkaline hydrolysis process destroys all pathogens listed as index organisms by the State and Territorial Association on Alternative Treatment Technologies (STAATT I and STAATT II). These reports call for a system to be able to prove efficacy in the destruction of infectious agents by producing a 6-log (99.9999%) reduction in vegetative infectious agents and a 4-log (99.99%) reduction in spore-forming agents. Significantly, the alkaline hydrolysis process has been approved for the treatment of infectious waste in all states in which specific application for such approval has been made (Taylor, 2000; Taylor, 2001b).

The efficacy of alkaline hydrolysis has been evaluated by testing for the destruction of samples of pure cultures of selected infectious microorganisms during processing of animal carcasses in a digester at the Albany Medical College. The organisms tested included *Staphylococcus aureus, Mycobacterium fortuitum, Candida albicans, Bacillus subtilis, Pseudomonas aeruginosa, Aspergillus fumigatus, Mycobacterium bovis* BCG, MS-2 bacteriophage, and *Giardia muris.* Animal carcasses included pigs, sheep, rabbits, dogs, rats, mice, and guinea pigs. The tissue digester was operated at 110-120°C (230-248°F) and approximately 15 psig for 18 hours before the system was allowed to cool to 50°C (122°F), at which point samples were retrieved and submitted for microbial culture. None of the samples obtained yielded indicator bacteria or fungi. Even *Giardia* cysts were completely destroyed; only small fragments of what appeared to be cyst wall material could be recognized with light microscopic examination. No plaque-forming units were detected with MS-2 bacteriophage after digestion. Furthermore, samples of the hydrolyzate did not yield growth on culture media. Animal carcasses were completely solubilized and digested, with only the inorganic components of the bones and teeth remaining after draining and rinsing of the digestion vessel. Alkaline hydrolysis completely destroyed all representative classes of potentially infectious agents as well as disposing of animal carcasses by solubilization and digestion (Kaye et al., 1998). The protein coats of viruses are destroyed and the peptide bonds of prions are broken under the extreme conditions of temperature and alkali concentration used in the alkaline hydrolysis process (Taylor, 2001a).

4.2 – TSE Disease Agents

A study, funded in 2000 by the United Kingdom Ministry of Agriculture, Fisheries and Food and carried out by Dr. Robert Somerville at the Institute of Animal Health at the University of Edinburgh, specifically examined the capacity of alkaline hydrolysis to destroy bovine spongiform encephalopathy (BSE) prions grown in the brains of mice. Two mice heads were digested for three hours and one head for six hours. Samples of the hydrolyzate from each digestion were neutralized, diluted, and injected intracerebrally into naïve mice known to be susceptible to the effects of BSE. The mice were kept for nearly two years, at which time they were sacrificed and their brains examined for signs of TSE. Evidence of TSE was found in the brains of 5 out of more than 200 mice; these five mice had been injected with hydrolyzate taken from three-hour-long digestions. Significantly, no evidence of TSE was found in the brains of mice injected with hydrolyzate from the six-hour-long digestion. The persistence of infectivity in the three-hour samples may have been due to the fact that material was introduced into the digestion vessel in a frozen state and was contained inside a polyethylene bag (i.e., the actual exposure of the prion-containing samples to the alkaline hydrolysis process may have been much less than 3 hours) (Taylor, 2001a). Based on these experiments, the European Commission Scientific Steering Committee has approved alkaline hydrolysis for TSE-infected material with the recommendation that TSE-infected material be digested for six hours (European Commission Scientific Steering Committee, 2002; European Commission Scientific Steering Committee, 2003). As a safety measure, one US-based facility disposing of CWD-infected carcasses uses an eight-hour-long digestion process to ensure destruction of any prion-contaminated material (Powers, 2003).

4.3 – Radioactivity

WR^2 reports that alkaline hydrolysis technology is effective in eliminating radioactively contaminated tissues.

Section 5 – Implications to the Environment

Alkaline hydrolysis releases no emissions into the atmosphere and results in only minor odor production. However, as alluded to in section 3.5, there are legitimate concerns about the temperature, pH, and BOD of the effluent produced by alkaline hydrolysis.

Section 6 – Advantages, Disadvantages, & Lessons Learned

6.1 – Advantages

Advantages of alkaline hydrolysis digestion of animal carcasses include the following:

- Combination of sterilization and digestion into one operation,
- Reduction of waste volume and weight by as much as 97 percent,
- Complete destruction of pathogens, including prions,
- Production of limited odor or public nuisances, and
- Elimination of radioactively contaminated tissues.

6.2 – Disadvantages

Disadvantages of alkaline hydrolysis process of animal carcass disposal include the following:

- At present, limited capacity for destruction of large volumes of carcasses in the US and
- Potential issues regarding disposal of effluent

6.3 – Lessons Learned

A common question facing animal disease regulators is whether to use alkaline-hydrolysis digestion or incineration to dispose of TSE-infected animals. While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs, fixed-facility incineration is also an effective means by which to dispose of TSE-infected material (see chapter regarding incineration). While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident recently in Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of CWD-infected deer and elk heads. Despite the need, officials in Larimer County, Colorado, have heeded local, anti-incinerator sentiments and, for the moment, have successfully blocked approval of the incinerator. Meanwhile, the alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003).

In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the Environmental Protection Agency whereby fixed-facility incineration might be more clearly endorsed as a technology for managing CWD-infected carcasses (O'Toole, 2003; Anonymous, 2003, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like this are needed to ensure adequate consideration of all available technologies by which to dispose of TSE-infected carcasses (Powers, 2003).

Section 7 – Critical Research Needs

1. Investigate environmentally suitable and publicly acceptable options for effluent disposal.
2. Investigate other uses for the alkaline hydrolysis effluent (e.g., as a form of fertilizer, as a nutrient

cocktail for improving sewage treatment plant performance, etc.)

3. Carry out engineering studies to ascertain how to use alkaline hydrolysis technology to accommodate large numbers of animal carcasses.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

7

Anaerobic Digestion

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Abbreviations

ANAMMOX	anaerobic ammonium oxidation
BSE	bovine spongiform encephalopathy
C/N ratio	carbon to nitrogen ratio
CWD	chronic wasting disease
END	exotic Newcastle disease
FMD	foot and mouth disease
GVRD	Greater Vancouver Regional District
HRT	hydraulic retention time
MPN	most probable number
OLR	organic loading rate
UASB	Upflow Anaerobic Sludge Blanket
UK	United Kingdom
US	United States
VS	volatile solids

Section 1 – Key Content

The management of dead animals has always been and continues to be a concern in animal production operations, slaughter plants, and other facilities that involve animals. In addition, episodes of exotic Newcastle disease (END) in the United States (US), bovine spongiform encephalopathy (BSE, or mad cow disease) in Europe and elsewhere, chronic wasting disease (CWD) in deer and elk in North America, and foot and mouth disease (FMD) in the United Kingdom (UK) have raised questions about how to provide proper, biosecure disposal of diseased animals. Carcass disposal is of concern in other situations—from major disease outbreaks among wildlife to road-kill and injured-animal events.

Proper disposal systems are especially important due to the potential for disease transfer to humans and other animals, and due to the risk of soil, air, and groundwater pollution. Anaerobic digestion represents one method for the disposal of carcasses. It can eliminate carcasses and, at the same time, produce energy; but in some cases it is necessary to conduct size-reduction and sterilization of carcasses on-site before applying anaerobic digestion technology. These preliminary measures prevent the risk of spreading the pathogen during transportation and reduce the number of digesters needed. Sometimes, if the quantity of carcasses is large, it may be necessary to distribute carcasses between several digesters and to transport them to different locations.

This chapter addresses the disposal of carcasses of animals such as cattle, swine, poultry, sheep, goats, fish, and wild birds using anaerobic digestion. This chapter considers anaerobic digestion's economic and environmental competitiveness as a carcass disposal option for either emergencies or routine daily mortalities. This process is suited for large-scale operations, reduces odor, and reduces pollution by greenhouse gases due to combustion of methane. The phases for carrying out these processes and their advantages are presented in detail in the following sections, along with the economics involved.

A simple anaerobic digester installation may cost less than $50 per kg of daily capacity ($22.73 per lb of daily capacity) and construction could be done in less than a month, whereas a permanent installation requires about six months to construct with costs of construction ranging from $70 to $90 per kg of fresh carcass daily capacity ($31.82 to $40.91 per lb of fresh carcass daily capacity). If utilization of the digester is temporary, it is not necessary to use special corrosion resistant equipment, but corrosion will become a problem if the installation is used for several years.

Pathogen containment is a high priority. Though anaerobic digestion is less expensive with mesophilic organisms at 35°C (95°F) than with thermophilic organisms at 55°C (131°F), a temperature of 55°C (131°F) is preferred as the additional heat destroys many pathogens. Many pathogens such as bacteria, viruses, helminthes, and protozoa are controlled at this temperature; however, it is advisable to use additional heat treatment at the end of the process to fully inactivate pathogenic agents capable of surviving in the digester (i.e., spore-formers). Even with an additional heat treatment, inactivation of prions would almost certainly not be achieved.

There are several environmental implications. Anaerobic digestion transforms waste into fertilizer, and from a public relations perspective people generally accept biodigesters. Other concerns include the recycling of nutrients.

Anaerobic digestion has been used for many years for processing a variety of wastes. Research has demonstrated that poultry carcasses can be processed using anaerobic digestion, and this technology has been used commercially. Carcasses have higher nitrogen content than most wastes, and the resulting high ammonia concentration can inhibit anaerobic digestion. This limits the loading rate for anaerobic digesters that are treating carcass wastes.

Anaerobic digestion is a technology worthy of future research. A new process called ANAMMOX—"anaerobic ammonium oxidation"—is proposed for nitrogen removal in waste treatment; this process should be further explored. There is also a need for research regarding how to optimally load carcasses into thermophilic digesters and thereby greatly reduce costs. Finally, there is a need to identify good criteria to measure pathogen reduction of anaerobic digestion processes.

Section 2 – Historical Use

Anaerobic digestion has been used for centuries. During the 10th century BC, bath water was heated by biogas in Assyria. In the 17th century, Jan Baptista Van Helmont learned that flammable gases could evolve from decaying organic matter, and in 1808 Sir Humphrey Davy determined that the anaerobic digestion of cattle manure produced methane. In 1859, a digestion plant was built at a leper colony in Bombay, India. By 1930, Buswell had identified anaerobic bacteria and the conditions that promote methane production (Biogas Works, 2003; Verma, 2002).

In the domain of anaerobic digestion, facilities built on farms for treatment of manure are perhaps the most common, and six to eight million families have used digesters to produce biogas for cooking and lighting with varying degrees of success. The process experienced a great growth in Europe after World War II because of the demand for energy. The facilities built had a large spectrum of usage in agriculture, industry and municipal waste management. Some facilities in Europe have been in operation for more than 20 years. Today, the technology of anaerobic digestion has been demonstrated and fully commercialized for the treatment of farm, industrial (food), and municipal wastes. There are some technical problems with high-solid concentrations, but several alternatives have been developed that operate with solid concentrations exceeding 30%.

Regarding its application to carcass disposal, anaerobic digestion has been investigated for poultry mortalities (Chen, 1999; Chen, 2000; Chen & Shyu, 1998; Chen & Wang, 1998; Mote & Estes, 1982; Collins et al., 2000). These investigators have demonstrated that poultry carcasses can be processed in anaerobic digesters that are being operated for other waste treatment purposes.

Section 3 – Principles of Operation

3.1 – Introduction

Disposal of carcasses infected, or potentially infected, with pathogenic agents is an important problem in animal production operations. It is necessary to find the best way to eliminate the carcasses without the risk of spreading pathogens. In an outbreak, the farmer may be confronted with a great quantity of carcasses that must be eliminated quickly and safely to prevent the spread of disease.

Anaerobic digestion, sometimes referred to as biomethanization and biodigestion, is one method for the disposal of carcasses. It can eliminate carcasses and produce energy at the same time, but in some cases it is necessary to reduce the size of the carcasses and sterilize them on-site before proceeding with anaerobic digestion. These preliminary measures prevent the risk of spreading pathogens during transportation to a digester and reduce the need for new digesters. If the quantity of carcasses is large, it may be necessary to distribute carcasses between several digesters and to transport them to different locations.

3.2 – General Process Description

Anaerobic digestion involves a transformation of organic matter by a mixed culture bacterial ecosystem without oxygen. It is a natural process that produces a gas principally composed of methane and carbon dioxide. Anaerobic digestion takes place in several steps as shown in Figure 1. Information used to construct Figure 1 was found on the website of Biological Sewage Treatment Tanks (2003) and in Erickson and Fung (1988).

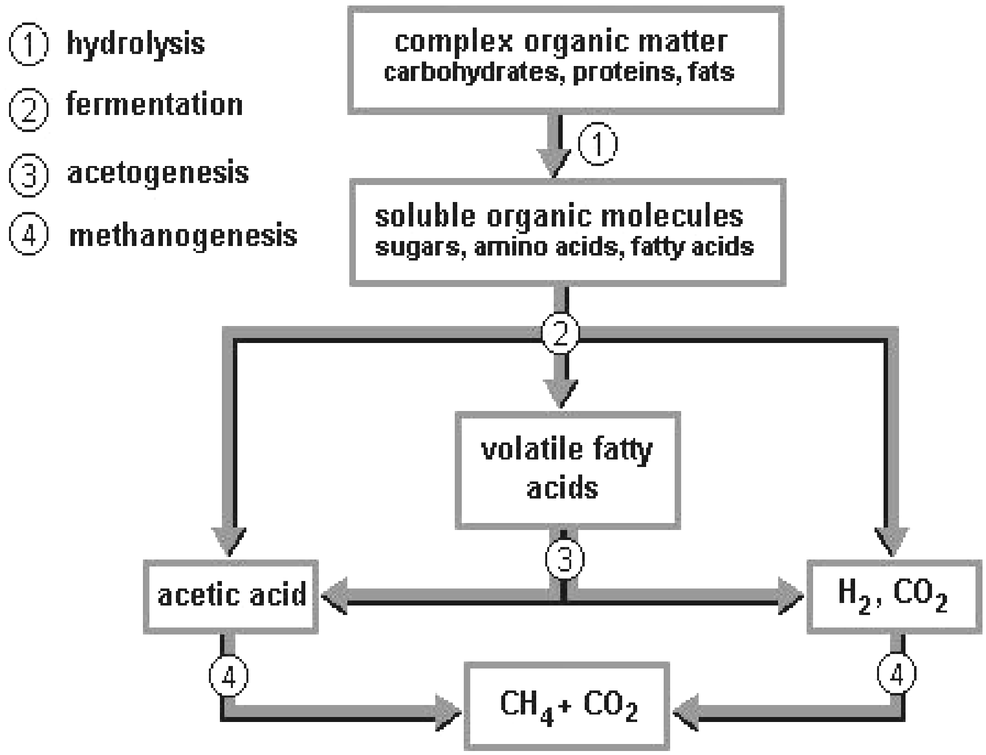


FIGURE 1. Anaerobic digestion pathway (Biological Sewage Treatment Tanks, 2003; Erickson & Fung, 1988).

The first step of anaerobic digestion is the hydrolysis of animal or plant matter. This step breaks down biopolymers and other organic material to usable-sized molecules:

Lipids → Fatty acids

Polysaccharides → Monosaccharides

Protein → Amino acids

Nucleic acids → Purines & Pyrimidines

The second step is the conversion, by acetogenic bacteria, of products of the first step to organic acids, carbon dioxide, and hydrogen. Acetogenic bacteria produce acetic acid; however other organic acids are also produced. The principal organic acids produced are acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH) and butyric acid ($CH_3CH_2CH_2COOH$). Ethanol (C_2H_5OH) and other products are also produced.

The final step is methanogenesis. Methane and carbon dioxide are produced from acetate, ethanol and other intermediates:

$$CH_3COOH \rightarrow CH_4 + CO_2$$

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

There are several groups of bacteria that perform each step; in total, dozens of different bacterial species are needed to completely degrade matter. The stability of the anaerobic process is very fragile. It is necessary to maintain a balance among the different microbial populations. Significantly, the biogas produced is a natural source of energy, which can be collected and used to generate heat or electricity. The advantage of this method is that it couples the treatment of the waste with energy production (methane).

3.3 – Process Requirements

Equipment

The equipment necessary to generate usable quantities of methane is not simple and requires substantial investment. One could build a digester that would be available for emergency use. This digester could be used to treat animal waste until it is needed for actual carcass disposal. The digestion tank (biodigester) is generally cylindrical for better mixing and the bottom is cone-shaped to facilitate sludge removal. The top can be fixed or floating. A floating top provides expandable gas storage with pressure control but is more expensive and difficult to manage. Most tanks are constructed with concrete and must be strong enough to resist the weight and pressures of the contained liquid. They are often situated at least partially below ground level for better support.

Mixing helps to achieve better distribution of heat and bacteria. Mixing can be accomplished by recirculating the gas collected from the top of the tank or by using mechanical mixers. The mixer is cheaper than recirculation of gas, but it is less efficient. An external heat exchanger or a heat-exchange coil may be necessary to maintain a good temperature in the digester. The heat-exchange coil is better than the external heat exchanger because of the corrosive nature of the liquid and also because the special, non-corrosive materials required in the external heat exchangers are expensive.

Pumps may be necessary to transfer the digester contents and sludge. The high solid content of the sludge requires special solid handling pumps. All piping must be of sufficient size to prevent clogging. To use the methane gas as an energy source requires some gas collection and pressure regulation equipment including the necessary safety devices to prevent explosions. A solid separator is necessary to remove the sludge; the sludge must be dewatered to convert it into useful biosolids. A grinder or other size-reduction equipment may be needed to reduce the size of the pieces of carcass before loading into the digester (Johnston et al., 1998), and a tank can be added to mix water and the solids before loading into the digester.

Supplies and chemicals

In the digester, the pH should be about 7 (between 6.8 and 7.5 is recommended). It may be necessary to use a base or buffer to maintain the pH in the biodigester. The volatile fatty acids and long-chain fatty acids produced by the degradation of fat are inhibitors of methanogenic activity because they decrease the pH. For example, calcium carbonate ($CaCO_3$) can be used as a buffer and calcium hydroxide ($Ca(OH)_2$) can be used to precipitate long-chain fatty acids that are toxic to methanogenic bacteria (Klein, 2002), but there exists a synergism between calcium (Ca^{2+}) and ammonium (NH_4^+). Indeed, potassium, magnesium and calcium increase the toxicity of ammonium more than sodium, which decreases the toxicity (Koster, 1989).

A reactor can be fed with sludge from another installation to provide an inoculation for the start up. According to Massé and Masse (2000), microorganisms in the sludge resulting from municipal wastewater treatment plants perform better than those in the sludge of milk processing plants for initiating anaerobic treatment of slaughterhouse wastewater in a sequencing batch reactor. This may be because the mixed culture from municipal wastewater treatment has the capability to biodegrade a wider range of compounds and wastes.

Utility requirements

The biodigester requires electricity and significant volumes of water. It uses electricity for pumping and mixing. Water requirements can be met by reusing/recycling the water, but water quality requirements of the digestion process must be considered. Moreover, methane may be needed as a fuel for the start-up of the digester before enough biogas is produced to supply the heat requirements of the digester.

Construction and start-up time

The period of construction depends on the time required to collect all material and equipment, as well as the complexity of the digester. Generally, the construction and installation of the equipment requires four to six months and one to three months are needed for the start-up of the digester. Because of this, carcasses may need to be fed to operating digesters in order to avoid delays associated with start-up.

Capacity

According to Salminen and Rintala (2002), the continuous process appeared to be stable with loadings of up to 0.8 kg volatile solids (VS) per m^3 each day and a hydraulic retention time (HRT) of 50 – 100 days at 31°C (87.8°F). According to Palmowski and Muller (2000), the VS of meat is 225.9 g/kg. To determine the size of digester, it is easier to use 3.6 kg of fresh meat/m^3day (see Appendix A).

Example:

> For 1,000 animals (cattle), each one has a weight of 700 kg (1540 lb) ⇒ 700,000 kg (1,540,000 lb) of beef.
>
> The size of the digester is about 195,000 m^3 with a loading of 0.8 kg VS/m^3d. With a digester volume of 195,000 m^3, the sterilized pieces of the 1,000 animals could be added in one day. In English units, 1,000 animals at 1,540 lbs per animal requires 6,883,000 ft^3 for a loading of 0.05 lb/ft^3 per day of VS.

3.4 – Size-Reduction and Preprocessing Requirement

It is necessary to reduce the size of the carcasses for better heat transfer before sterilization is attempted. If the carcasses are not reduced to a size of less than 5 cm (2.0 inches) in diameter, the heat transfer will take a longer time (Table 1), which of course is not desired. According to Gale (2002), the maximum particle size diameter in a biodigester is 5 cm (2.0 inches), which permits good heat transfer for sterilization of the carcasses and biodigestion.

TABLE 1. Estimated heat transfer times into spherical particles (Gale, 2002).

Particle diameter (cm)	Particle diameter (in)	Time for center to reach 90% of surface temperature (hr)
2	0.79	0.1
20	7.87	10
40	15.75	40

3.5 – Process Options

Dry or wet process

The amount of water or weight fraction of solids is an important factor in the construction of a biodigester. For a wet process, a pre-treatment of organic waste is necessary before loading the waste into the biodigester; conversely, in a dry process the pre-treatment is of less importance.

One-stage wet system

Technical process. The wet process works with a solid fraction between 10 to 15%. Therefore, dilution with water is necessary to obtain total solid contents less than 15%. In the digester, the sludge does not have homogenous consistency because heavy and light fractions form different layers and three phases are generally observed during the process. Bones and parts of the heavy fraction could damage the pump and the foam created by the light fraction could hamper the mixing. Inert solids such as sand must be periodically extracted (Vandeviviere et al., 2002) to assure good functioning of the biodigester. Some reactors use reinjection of product gas in the bottom of the tank to create a loop in the biodigester (Figure 2) and also to obtain better homogenization; other reactors use a simple mechanical mixing process.

This type of process has potential for short-circuiting, as shown in Figure 2. For most pathogens, it is necessary to pasteurize the waste beforehand, as anaerobic digestion of wastes may not be sufficient to control pathogens. The wet system needs equipment like pumps and piping as it involves a large volume of water; this increases the cost and requires additional treatment prior to discharge of the processed waste.

Biological process. Homogenization in the wet system helps to eliminate any special niches where pathogenic bacteria could survive. Ammonium is one of the inhibitors of biodegradation, and its concentration must be kept below 3 g/L (0.187 lb/ft^3). According to Vandeviviere et al. (2002), for certain substances with a carbon to nitrogen (C/N) ratio below 20 and biodegradable VS contents of 60%, the ammonium concentration cannot be brought below this level. Thus, it is beneficial to combine carcasses with other wastes to achieve a higher C/N ratio. The advantages and disadvantages of wet systems are summarized in Table 2.

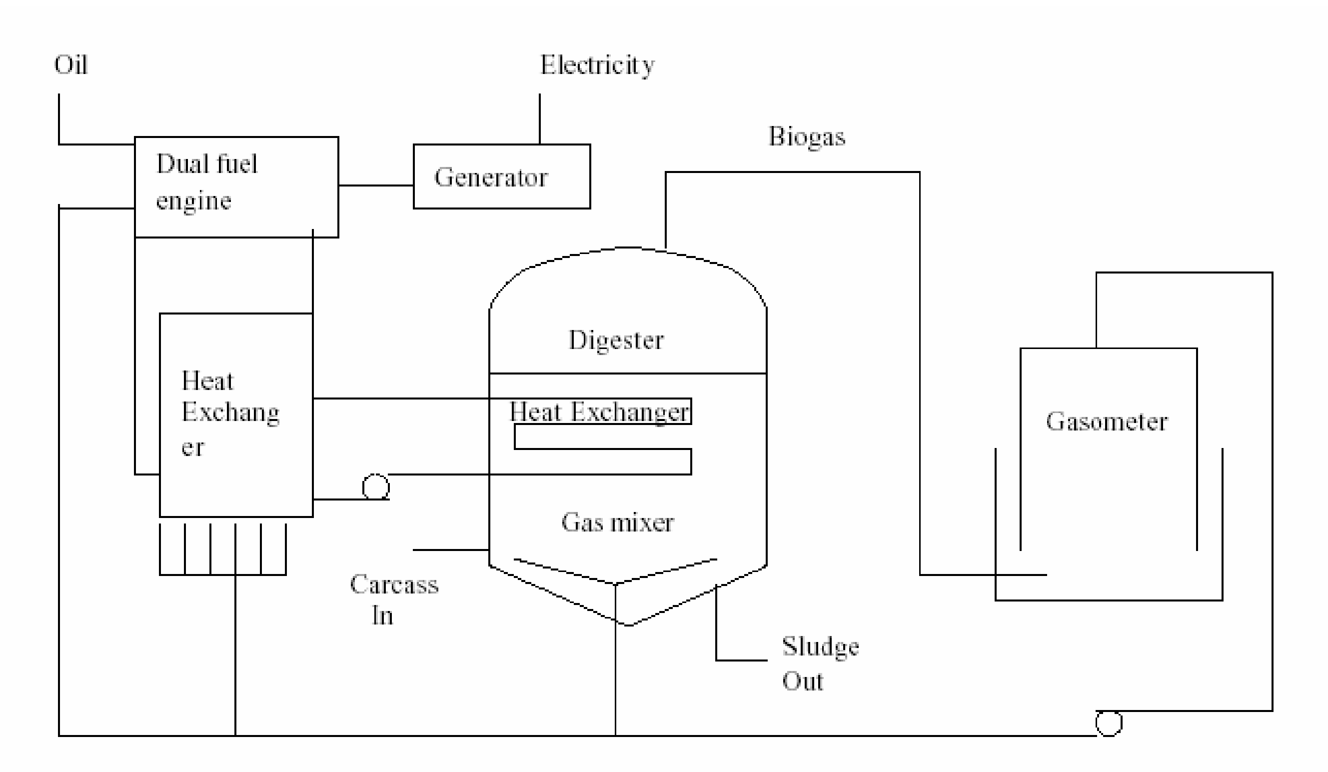


FIGURE 2. The flow diagram of a wet system (Verma, 2002).

TABLE 2. Advantages and disadvantages of a wet system (Vandeviviere et al., 2002).

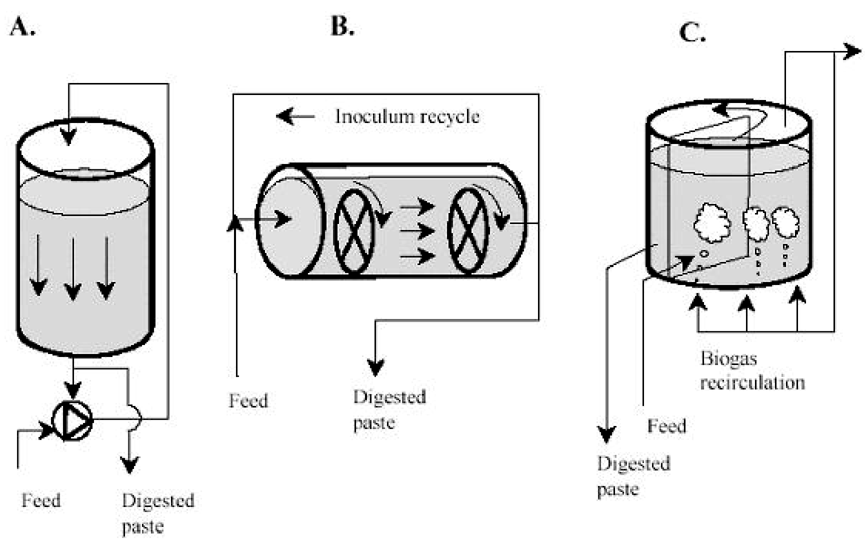
Criteria	Advantages	Disadvantages
Technical	▪ Inspired from known process ▪ Significant operating experience	▪ Short-circuiting reduces efficiency ▪ Sink and float phases (phase separation) ▪ Abrasion with sand
Biological	▪ Dilution of inhibitors with fresh water	▪ Particularly sensitive to shock loads as inhibitors spread immediately in reactor ▪ VS lost with inerts
Economical & Environmental	▪ Equipment to handle slurries is cheaper	▪ High consumption of water ▪ Higher energy consumption for heating large volume

One-stage dry system

Technical process. The dry system works well with solid contents from 20 to 40%. Substances with more than 40% solids must be diluted with fresh water. The dry system is more robust and flexible than the wet system in handling bits such as stone. Generally, the maximum size of particles is 4 cm (1.57 inches). However, mixing in a dry system is more difficult than in a wet system. Three types of homogenization exist in dry systems as shown in Figure 3 (Vandeviviere et al., 2002).

- In the first type, homogenization is achieved via recirculation of the wastes. Wastes are extracted from the bottom of the tank and injected at the top of the reactor for mixing with fresh wastes.
- The second type is the Kompogas process, which uses the same concept of recirculation except that the tank is horizontal and homogenization is aided by slowly rotating impellers inside the reactor.
- The third type is the Valorga system, which is different from the other processes. Here biogas is re-injected every 15 minutes into the bottom of the tank to provide mixing and homogenization.

Biological process. Inhibitors may be less problematic in a dry system than in a wet system. Table 3 lists the advantages and disadvantages of a dry system. The organic loading rate (OLR) mentioned in the table refers to the amount of manure (organic matter) added to the digester each day, divided by the size of the digester. The most common method of measuring organic matter is to use the parameter VS.



A. = Dranco design, **B.** = Kompogas design, **C.** = Valorga design

FIGURE 3. Different digester designs used in a dry system. (Vandeviviere et al., 2002).

TABLE 3. Advantages and disadvantages of a dry anaerobic digestion system (Vandeviviere et al., 2002).

Criteria	Advantages	Disadvantages
Technical	▪ No moving parts inside reactor ▪ Robust (inert materials need not be removed) ▪ No short-circuiting	▪ Wet wastes (<20% total solids) cannot be treated alone
Biological	▪ Less volatile solids loss in pre-treatment ▪ Larger organic loading rate (higher biomass) ▪ Limited dispersion of transient peak concentrations of inhibitors	▪ Little possibility to dilute inhibitors with fresh water
Economical & Environmental	▪ Cheaper pre-treatment and smaller reactors ▪ Complete hygienization ▪ Very small water usage ▪ Smaller heat requirement	▪ More robust and expensive handling equipment (compensated by smaller and simpler reactor)

Batch or continuous

Batch

This type of process may be best suited for carcass disposal events that occur sporadically and are not necessarily a regular phenomenon. In a batch digester, organic material is loaded in the digester and digested for the period of retention time. The retention time depends on temperature and other factors. Once digestion is complete, the effluent is removed and the process is restarted (Figure 4). Generally, it is necessary to have several digesters in a batch process to carry out alternate loading and emptying.

A batch digester is the easiest and cheapest to build. It is also more robust against an inhibitor than a continuous digester, but in a continuous system bacterial flora could become acclimated to the inhibitor by slowly increasing the concentration of the inhibitor. A batch digester produces less gas, has a lower loading rate, and carries a risk of explosion during emptying of the reactor (Vandeviviere et al., 2002).

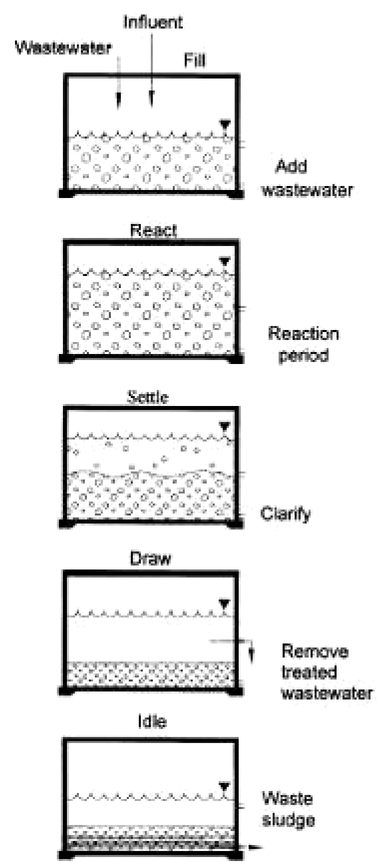


FIGURE 4. Operation of the anaerobic sequencing batch reactor (Massé & Masse, 2000).

In a batch system the contents are continuously mixed, which facilitates good distribution of the nutrients and bacteria. As shown in Figure 5, there exist three types of batch systems:

- Single stage.
- Sequential batch.
- Hybrid batch Upflow Anaerobic Sludge Blanket (UASB) digester.

The single-stage batch system mixes via a recirculation of sludge from the bottom to the top of the digester. The wastes are digested until production of the gas stops. The system is emptied and then loaded again.

The sequential batch system uses two or more reactors. The sludge from the first reactor, which contains a high level of organic acids, is injected into the second reactor. The leachate from the second reactor, after addition of a pH buffering agent, is injected into the first digester. The sludge from the second reactor contains little or no acid as a process called methanogenesis takes place in the second reactor. This type of flow system moves organisms and nutrients between reactors.

The third process is hybrid batch-UASB. It is very similar to the multistage system with two reactors. The system is composed of a simple batch reactor coupled with a UASB reactor. Methanogenesis takes place in the UASB reactor, and can treat liquid effluents with high levels of organic acids at high loading rates (Vandeviviere et al., 2002).

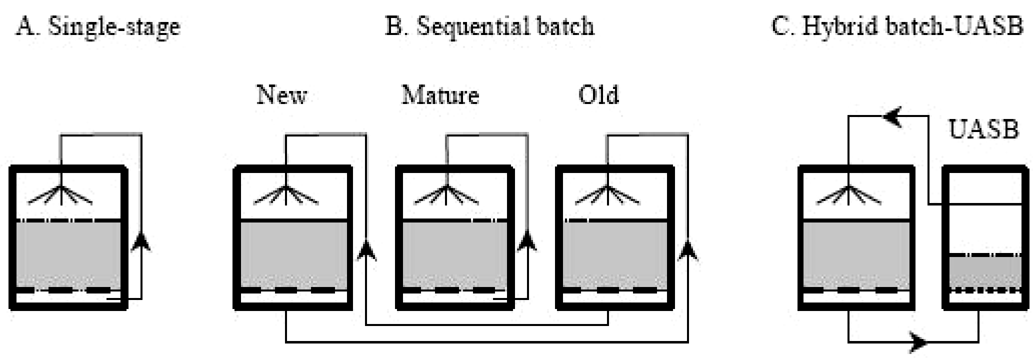


FIGURE 5. Different types of batch reactors (Vandeviviere et al., 2002).

Continuous

In a continuous digester, organic material is constantly or regularly fed into the digester. Generally, the material moves through the digester by pumping. Continuous digesters produce biogas without the interruption of loading the material and unloading the effluent. A continuous system may be better suited for large-scale operations, however the input should be continuous and of consistent composition; a drastic change of input material should be avoided, according to British BioGen (2003).

Mesophilic or thermophilic

The choice of temperature is important. Mesophilic organisms have optimal growth at 35°C (95°F) while thermophilic organisms grow best at 55°C (131°F). Based on the temperature chosen, the duration of the process and effectiveness in destroying pathogens will vary. In mesophilic digestion, the digester is heated to 35°C (95°F) and the typical time of retention in the digester is 15-30 days, whereas in thermophilic digestion the digester is heated to 55°C (131°F) and the time of retention is typically 12-14 days (Vandeviviere et al., 2002).

A mesophilic process tends to be more robust and tolerant to upsets than a thermophilic process, but the gas production is less and the end product may pose a greater pathogen risk if applied directly on fields, whereas a thermophilic digestion system offers higher methane production, faster throughput, and better pathogen and virus "kill." The greater stability of the mesophilic process makes it easier to control. Furthermore, a mesophilic treatment at 38°C (100.4°F) for 15 days reportedly destroys 99.9% of pathogens, while a thermophilic treatment at 55°C (131°F) destroys 99.999% (GVRD, 2000). From a biosecurity perspective, it is better to use a thermophilic process to destroy pathogens in the biodigester and produce a class A end product—that is, a product that could be applied to fields with a minimum risk.

The thermophilic digestion process needs more expensive technology, more energy to maintain its temperature, and a higher degree of operation and monitoring (Vandeviviere et al., 2002). Methanogens, bacteria that produce methane, are more sensitive to variations in temperature than are other bacteria. According to Gunnerson and Stuckey (1986), temperature variations as small as 2°C (3.6°F) can have adverse effects on mesophilic (~35°C or 95°F) digestion, and changes of 0.5°C (0.9°F) affect thermophilic (~55°C or 131°F) digestion.

Alternate processes and configurations

Costs and loading rates depend on the number of phases, as more phases require additional tanks and pumps. As the steps of anaerobic digestion have different optimal operating conditions, better results are obtained by separating the steps. Moreover, it is important that at least one of the phases is a thermophilic phase to destroy the pathogens when the carcasses are processed.

Schafer et al. (2003) have considered several alternate processes. The single digester is the easiest to construct, but a disadvantage of this process is that the feeding of waste has an adverse effect on methane production.

Two-phase digesters can have mesophilic operating conditions in one tank and thermophilic conditions in the other. The anaerobic degradation process starts with an acid phase, in which organic acids are produced (pH below 6), followed by a second phase in which methane gas is produced. There exist several possible combinations between acid-gas phases and mesophilic-thermophilic processes as shown in Figure 6.

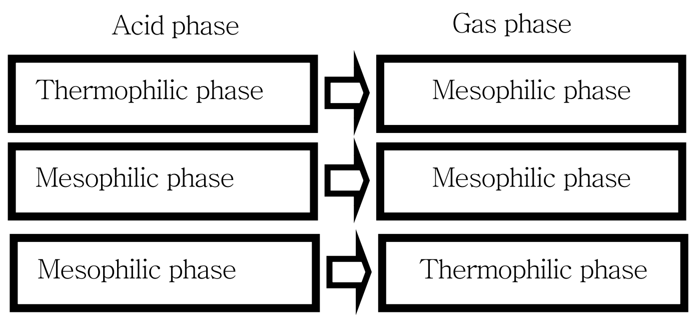


FIGURE 6. Combination of phases used in anaerobic digestion.

It is very important that at least one of the phases is thermophilic to maximize pathogen destruction. An acid-gas phase reduces foaming in the biodigester and increases the rate of matter reduction, but the sludge has high levels of ammonia and probably more hydrogen sulfide is produced during the acid phase (Schafer et al., 2003).

Moreover, thermophilic anaerobic digestion is more sensitive to high ammonium concentration than is mesophilic digestion. This is apparently due to the concentration of free ammonia at high temperatures, as demonstrated by Koster (1989). The balance between the molecular form and ionized form of ammonia depends on temperature. An increase in temperature favors the molecular form, but the molecular form is more toxic than the ionized form. The ammonium concentration is often high during the gas (methane production) phase.

3.6 – End Products

According to the Greater Vancouver Regional District (GVRD, 2000), decades of research on biosolids produced through anaerobic digestion have demonstrated that biosolids can be applied when EPA regulations regarding quality of biosolids and conditions of land application have been met.

Biosolids

After several appropriate treatments, sludge becomes a biosolid that may be used for land disposal. The first treatment of sludge involves thickening of the watery mass. During thickening, biodegradation continues and converts some of the sludge into biogas, which reduces a part of the solid concentration. Several processes are used for thickening; these include gravitation, flotation, and centrifugal concentration. Dewatering of sludge by filtration or centrifugation may follow thickening. Together, these treatments reduce disposal costs by reducing the quantity of biosolid. Furthermore, the water-eliminated liquor may be treated before discharge and used for agricultural purposes. With the addition of lime, chlorine, or heat, biosolids may be stabilized to reduce both odor and the number of pathogens present (Newton, 1985).

There are biosolid regulations designed to prevent the risk of pathogens. Only biosolids of class A and B may be applied to land, with class A biosolids being subject to more restriction than class B biosolids (GVRD, 2000). Regulation-compliant biosolids may be sold and used as soil amendments; unsafe biosolids should be destroyed, perhaps by incineration. When containment of a pathogen is of high priority, it is important to determine whether the pathogen is present in the anaerobic digester and/or the biosolids. If carcasses are sterilized following size reduction, the material delivered to the digesters should be free of pathogens; however, it is desirable to also check the digester broth for pathogens.

Class A standards for pathogen reduction require a fecal coliform density of less than 1,000 MPN (most probable number) per gram dry weight, or a *Salmonella* density of less than 3 MPN per 4 grams dry weight. These standards may be met by a specific time-temperature combination treatment (55°C [131°F] for 20 days).

Class B standards require the density of fecal coliforms to be less than two million per gram dry weight. Class B standards are met by mesophilic (38°C [100.4°F]) processing of the biosolids.

Liquor

Liquor produced from anaerobic digestion can be used as a liquid fertilizer because of its wide range of nutrients; however, if it has a low level of nutrients and a high level of water, it could simply be used in irrigation. According to British BioGen (2003), liquor can be used for "fertigation" (a combination of fertilizer and irrigation) on agricultural lands, but it cannot be used in greenhouses as it contains some particles that block feeder pipes. Sometimes, the liquor can be bottled and sold like fertilizer—but only if it is indeed safe.

Methane

Methane from anaerobic digestion can be used for the production of heat, which could be used to maintain a proper temperature in the digester or to heat a local farm or factory. Methane can also be used for the production of electricity. Such use of biogases reduces the consumption of fossil fuels and may reduce the cost of electricity at the particular digestion facility. If produced in sufficient quantities, methane-produced electricity can be sold to local energy distribution networks.

3.7 – Economics

Chen (1999 and 2000) and Chen and Shyu (1998) have used anaerobic digestion for disposal of poultry carcasses. According to Chen and Shyu (1998), the continuous process at 35°C (95°F) requires optimization to become competitive with other biological treatment processes used to destroy carcasses. Process optimization may allow a larger loading rate, which would reduce treatment costs. Anaerobic digestion at 35°C (95°F) is less expensive than at 55°C (131°F), but digestion at 55°C (131°F) is preferable as the additional heat destroys pathogens.

The cost of installation depends on the materials of construction. There are digesters composed of polyethylene that cost between \$7 per m^3 (in Vietnam) and \$30 per m^3 (in Colombia) (Bui Xuan An et al., 2003). These figures (\$7 per m^3 and \$30 per m^3) would correspond to \$2 per kg (\$0.90 per lb) and \$8.50 per kg (\$3.86 per lb) of carcass material, respectively. These polyethylene digesters have a low capacity (5-6 m^3), and it may not be possible to adapt them for disposal of carcasses. Appendix B provides examples of the determination of the cost of installation.

An anaerobic digester could be constructed by digging a simple trench covered with a liner. The broth contents should be covered to maintain anaerobic conditions. If utilization of the digester is temporary, it is not necessary to use special, corrosion-resistant equipment. Indeed, corrosion of a digester may become a problem only if an installation is used for several years. The cost of this simple type of installation is probably less than $50 per kg ($22.73 per lb) of daily capacity and the construction could be done in less than a month.

For a permanent installation, concrete construction of the digester takes about six months. Consequently, this type of installation requires construction well in advance of an emergency situation. It is important to choose a site that would minimize transport of carcasses from the point of origin to the digester. Since the occurrence of mortalities may be sporadic, it would be advantageous to use the digester for other substances like manure or municipal waste. Such utilization of the digester would allow more rapid recuperation of costs. The average price of construction is between $70 and $90 per kg ($31.82 and $40.91 per lb) of fresh carcass daily capacity (White and Van Horn, 1998; Boehnke et al., 2003) (see Appendix B).

Section 4 – Disease Agent Considerations

4.1 – Pathogen Containment

Pathogen containment must be a high priority in carcass management (European Commission, 2003). The list below is not exhaustive, but does provide a good representation of different pathogenic agents encountered in animal operations. While several authors agree that laboratory-grade pathogens are often less hardy than naturally-occurring strains (Couturier and Galtier, 2000), the results below are representative.

Bacteria

Results of laboratory studies on the destruction of bacteria at different temperatures are shown in Table 4.

All pathogenic bacteria listed are destroyed more rapidly at 53°C (127.4°F) than at 35°C (95°F); consequently, thermophilic digestion is advised. Some undesirable thermophilic bacteria can survive anaerobic digestion, however. For example, *Bacillus cereus* and *Bacillus anthracis* can survive temperatures of 53°C (127.4°F) and be transmitted by biosolid dust to infect the human eye. To prevent such risks from thermoresistant bacteria, it is important to add an additional heat treatment if such organisms are present.

TABLE 4. Results of laboratory studies on the destruction of bacteria at different temperatures (Couturier & Galtier, 2000; Gale, 2002).

Organism	T90[a] at 35°C or 95°F (days)	T90 at 53°C or 127°F (days)
Salmonella typhimurium	2.4	0.7
Salmonella Dublin	2.1	0.6
Escherichia coli	1.8	0.4
Erysipelothrix rhusiopathiae	1.8	1.2
Staphylococcus aureus	0.9	0.5
Mycobacterium paratuberculosis	6	0.7
Coliforms	3.1	-
D-streptococci	7.1	-
Streptococcus faecalis	2	1
Clostridium perfringens	No reduction	No reduction
Bacillus cereus	No reduction	No reduction

[a]T90 = the time in days necessary to destroy 90% of bacteria.

Viruses

Among viruses, the parvovirus is the most resistant. Therefore, some authors advise using parvovirus as a criterion for virus destruction. Unfortunately, parvovirus is not a good surrogate for animal viruses (Couturier & Galtier, 2000). Results of laboratory studies on the destruction of viruses at different temperatures are shown in Table 5.

TABLE 5. Results of laboratory studies on the destruction of viruses at different temperatures (Couturier & Galtier, 2000).

Organism	Inactivation time at 35°C (95°F)	Inactivation time at 55°C (131°F)
Porcine flu	>24h	1h
Parvovirus porcine	21 weeks	8 days
Bovine virus diarrhea	3h	5 minutes
Infectious bovine rhinotracheitis	24h	10 minutes
Aujesky's disease virus	5h	10 minutes
Classical swine fever virus	4h	Some seconds
Transmissible gastroenteritis virus (TGE virus)	24h	30 minutes

Helminthes

Helminthes include a vast number of worm species, most of which are parasitic. Worms are present in manure and some animals are affected by helminthes. Information on the inactivation of helminthes is provided in Table 6.

TABLE 6. Results of laboratory studies on the destruction of helminthes (worms) at different temperatures (Couturier & Galtier, 2000; Gale, 2002).

Organism	Inactivation time at 35°C (95°F)	Inactivation time at 53°C (127°F)
Egg of gastro-intestinal worms of bovine	2 days	1-4h
Egg of nodular worm of the pig	6-8 days	1-4h
Egg of Ascaris	21-35 days	20-50 minutes

Protozoa

According to the GVRD (2000, p. 10), "it is highly improbable that protozoan cysts could survive conditions capable of destroying helminth eggs."

4.2 – Risk of Contamination

If the end products of anaerobic digestion (biosolids) are applied to land without pathogens being sufficiently reduced, the pathogens may pose a risk of contamination. Human beings and animals can be contaminated after being exposed to variable quantities of pathogens, as shown in Table 7. The infective dose depends on the type of pathogen and health of the host. Indeed children, older people, and people with compromised immune system are at greatest risk.

TABLE 7. Minimal infective doses of pathogens (GVRD, 2000).

Organism	Minimal infective dose
Salmonella sp.	10^2 to 10^{10}
Shigella sp.	10 to 10^2
Escherichia coli	10^4 to 10^{10}
Giardia lamblia	1 cyst
Cryptosporidium parvum	10 cysts
Ascaris lumbricoides	1-10 eggs

Generally, sludge accumulates in the bottom of the digester. Consequently, all pathogen agents capable of surviving in the digester could still be found in the end product several months after the introduction of pathogens in contaminated carcasses.

Bovine spongiform encephalopathy (BSE), or "mad cow disease," can survive anaerobic digestion. This disease is due to a protein, called a prion, which causes a fatal degenerative disorder of the brain. Prions are highly resistant to many treatments; only two available technologies are reported to inactivate prions: incineration and alkaline hydrolysis (Jennette, 2002). *Bacillus cereus* and *Clostridium* can also survive thermophilic digestion (Couturier & Galtier, 2000) and should receive additional heat treatment.

As an alternative to thermal treatment of the end product, carcasses could be disinfected prior to loading into the digester. Such a pre-treatment may eliminate the need for post-processing disinfection, but it also might inhibit anaerobic digestion if it affects the bacterial flora of the digester. Human beings and animals can be exposed to risk of pathogens by several pathways. These different pathways can be by direct or indirect contact.

Direct contact

Direct contact occurs when a person or animal is directly in contact with the biosolid. Generally, this contact takes place at the digester or on the field where the biosolids have been applied recently or from the transport of dust. The field should be left free of cultivation or grazing during a specific period and its access should be limited. The survival time of different organisms in the soil depends on species and conditions as shown in Table 8.

TABLE 8. Estimated survival times of pathogens in soil and on plant surfaces (GVRD, 2000).

	Soil		Plants	
Pathogen	Absolute Maximum	Common Maximum	Absolute Maximum	Common Maximum
Bacteria	1 year	2 months	6 months	1 month
Viruses	1 year	3 months	2 months	1 month
Protozoan cysts	20 days	2 days	5 days	2 days
Helminth eggs	7 years	2 years	5 months	1 month

Jakubowski (1988), Sorber and Moore (1986), and Sobsey and Shields (1987) have investigated the fate of pathogens and viruses in soil. Knowledge of the survival time is useful to identify a specific period during which the field should not be accessed or used for cultivation or breeding.

Indirect contact

Indirect contact is more difficult to anticipate. It can be due to pathogens on crops grown on the field used for land application, or via use of water contaminated by runoff from land application. Organism movement depends on several factors including soil, rainfall, and sources of transport like birds, mice, or airborne dust. It is important to consider a buffer zone around a digester or field where biosolids are applied.

Personnel

Some workers are directly in contact with carcass digesters and sludge. There are two types of risk; the first is the toxic risk of gases such as hydrogen sulfide produced by biodigestion and the second is microbiological risk. Certain pathogens that affect animals could also affect human beings.

Section 5 – Implications to the Environment

There are several environmental advantages to anaerobic digestion. The process reduces greenhouse gas problems, decreases the consumption of fuel, and transforms waste into fertilizer. The consumption of water is a problem in dry areas; however, water from the process can be used for irrigation.

From a public relations perspective, people generally accept biodigesters. However, they should still be constructed far from residential areas for reasons of biosecurity and to minimize odor problems.

Section 6 – Advantages and Disadvantages

Anaerobic digestion offers both advantages and disadvantages, which are summarized in Table 9.

TABLE 9. Advantages and disadvantages of anaerobic digestion.

Advantages	Disadvantages
Couples the treatment of waste and production of energy	Cost of construction is expensive
Reduction of odors	Sludge disposal is a problem in some locations
Suited for large-scale operations	Larger than other installations such as lactic acid fermentation
Methane is used in place of fossil fuels	Difficulty of storage of gas (corrosive)
Reduces pollution by greenhouse gases by combusting methane	Significant consumption of water
Recycle effluent in fertilizer	Storage of fertilizer is difficult
Reduces chemical and biological oxygen demand, total solids and volatile solids of the carcass	Problem of management of the sludge
Destroys, or reduces to acceptable levels, coliform bacteria, pathogens, insect eggs and internal parasites	Does not destroy all pathogens: ▪ Prions (e.g., mad cow disease, chronic wasting disease) ▪ Thermo resistant bacteria (e.g., *Bacillus cereus*)

Section 7 – Critical Research Needs

Anaerobic digestion is well known for its application to the treatment of industrial, municipal, and agricultural waste. Nevertheless, it is rarely used for the disposal of carcasses. In fact, only a few studies are available about anaerobic digestion and carcass disposal. Areas of research regarding anaerobic digestion and carcass disposal are enumerated below.

1. Consider how to (and whether to) extend anaerobic digestion to large-animal carcass disposal.

Past research has demonstrated that poultry carcasses can be processed in anaerobic digesters. For larger animals, size reduction seems imperative. While it may be possible to load digesters with whole cattle, there are no data on either digester performance or pathogen management. Some research has been reported on the composting of large animals (Anonymous, 2003). Research is needed to develop the anaerobic digestion process if it is to be seriously considered. There are many manure management operations where manure is treated in an anaerobic digester that consists of a covered pond that may be lined. The wastes flow into the pond from the feeding area. Carcass mortalities could be flushed into the digester through the same inlet system; however, methods to feed carcass waste need to be investigated further.

2. Study how to eliminate ammonium during the process.

    Carcasses seem to have great methanogenic potential, but in reality deamination of protein generates a high concentration of ammonium, which inhibits methanogens. The maximum concentration of ammonium tolerated by methanogens after adaptation is about 1.5 to 3 g/l, and the free ammonia level must be kept below 80 mg/l (Gunnerson & Stuckey, 1986). This maximal concentration depends on several factors such as type of process and conditions required for digestion. Several means have been considered for solving this ammonium problem. A new process called "ANAMMOX" might be used to eliminate ammonium (Dongen, 2003). ANAMMOX, which stands for "anaerobic ammonium oxidation," is a new method of nitrogen-removal in wastewater treatment. The process is patented; licenses may be obtained from Paques B.V. (2003), which installed the first reactor in 2002. Research to develop this process for carcass disposal is needed. Blending carcasses with other wastes can also reduce the concentration of ammonia in the digester. If suitable wastes are available, the desired carbon to nitrogen (C/N) ratio can be obtained by blending. When carcasses are added to an operating digester, the total capacity of the digester and the C/N ratio should be considered. Research is needed to establish optimum loading for a thermophilic digester, and for a digester equipped with a system of ammonium removal. Indeed, the tank is the most expensive part of the biodigester and if the loading rate could be increased, the cost would greatly decrease.

3. Consider how to alleviate problems with fats in anaerobic digestion.

    Fats degrade to long-chain fatty acids, which inhibit methanogens.

4. Identify appropriate criteria to measure pathogen reduction.

    In US Environmental Protection Agency regulations, the criterion chosen is the reduction of fecal coliforms. Fecal coliforms are reduced at rates generally comparable to many pathogens. However, Couturier and Galtier (2000) note that the fecal Streptococci are a better indicator of pathogen destruction than fecal coliforms under thermophilic conditions. For carcass disposal, there is a need to measure pathogen reduction for the organism of concern (Burtscher & Wuertz, 2003).

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Appendices

Appendix A – Determination of Value 3.6 kg of Fresh Meat/m^3 (0.224 lb of Fresh Meat/ft^3)

According to Salminen and Rintala (2002), the process appeared stable with loadings of up to 0.8 kg VS/m^3.d and a HRT of 50–100 day at 31°C (87.8°F). Moreover according to Palmowski and Muller (2000) VS of the meat is 225.9 g/kg of fresh meat.

Calculation of loading: 0.8/0.2259 = 3.54 kg

The value given for 3.6 kg of fresh meat/m^3 (0.224 lb of fresh meat/ft^3) had been rounded up to consider the insoluble part of carcass like bone.

Example: For 1,000 beef cattle, each one has a weight of 700 kg ⇒ 700,000 kg of beef

> The size of digester is 197,667 m^3 with 3.54 kg/m^3.
>
> The size of digester is 194,444 m^3 with 3.6 kg/m^3.

Appendix B – Determination of Price of Installation

The price of concrete installation is extrapolated from the installation for manure. These two installations are equipped by:

Equipment	Farm 1 Cost[a]	Farm 2 Cost[b]
Mix tank	73,000	15,000
Manure storage	13,130	
Manure pump	9,800	7,000
Piping	520	475
Digester	132,000	68,178
Gas and water transmission	3,600	3,338
Engine generator and building	52,000	47,026
Solids separator	38,000	27,000
Solids storage building	38,000	37,000
Startup propane	5,700	4,416
Engineering	27,000	20,000
Expenses	4,000	4,000
Total Cost	$400,000	$320,000
Digester Size	1,325 m^3	1,210 m^3
Capacity (size * 3.6 kg/m^3)	4,770 kg	4,356 kg
Cost per kg of capacity	$84/kg ($38.18/lb)	$72/kg ($32.72/lb)

[a]Boehnke et al., 2003

[b]White and Van Horn, 1998

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

8

Non-Traditional & Novel Technologies

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Abbreviations

BSE	bovine spongiform encephalopathy
CAST	Council on Agriculture Science and Technology
CWD	chronic wasting disease
DEQ	Department of Environmental Quality
DHH	Department of Health and Hospitals
EPA	US Environmental Protection Agency
FDA	US Food and Drug Administration
HEPA	high efficiency particulate air
LSB	Livestock Sanitary Board
PRISM	Plasma Remediation of In-Situ Materials
ROI	Renewable Oil International
STI	Sterile Technology Industries
TDE	transmissible degenerative encephalopathy
UK	United Kingdom
US	United States
VOC	volatile organic compound
WR2®	Waste Reduction by Waste Reduction, Inc.

Section 1 – Key Content

This chapter summarizes novel or non-traditional methods that might be used to deal with large-scale animal mortalities that result from natural or man-made disasters. It also identifies specific methods that represent innovative approaches to disposing of animal carcasses. These carcass disposal methods include the following:

- Thermal depolymerization
- Plasma arc process
- Refeeding
- Napalm
- Ocean disposal
- Non-traditional rendering (including flash dehydration, fluidized-bed drying, and extrusion/expeller press)
- Novel pyrolysis technology (*ETL EnergyBeam™*)

A key conclusion of the chapter is that pre-processing of carcasses on-site increases biosecurity and will increase the number of process options available to utilize mortalities. Pre-processing methods examined in this chapter include the following:

- Freezing
- Grinding
- Fermentation
- STI Chem-Clav grinding and sterilization

1.1 – Pre-Processing

Several of the carcass disposal methods described in this chapter would benefit from, or require, on-farm pre-processing and transportation of carcasses to central facilities because of their complexity and cost. One possible solution for pre-processing and transporting carcasses involves a large portable grinder that could be taken to an affected farm to grind up to 15 tons of animal carcasses per hour. The processed material could be preserved with chemicals or heat and placed in heavy, sealed, plastic-lined roll-off containers. The containers could then be taken off-site to a central processing facility. Fermentation is yet another method of pre-processing mortalities on site which has been used in the poultry industry since the early 1980s. Carcasses are stored for at least 25 weeks. Fermentation is an anaerobic process that proceeds when ground carcasses are mixed with a fermentable carbohydrate source and culture inoculants and then added to a watertight fermentation vessel. Another approach, likely to be most suitable to normal day-to-day mortalities, is to place carcasses in a freezer until they can be taken to a central processing site. Freezing is currently being used by some large poultry and swine producers. Typically, a truck with a refrigeration unit is stored on site until it is full and then taken to a rendering operation. The refrigeration unit is operated via on-farm power when in a stationary position, and by the truck motor when in transit. This approach might not be feasible for large-scale die-offs or even for large carcasses unless they are first cut into smaller portions.

Any pre-processing option must minimize on-site contamination risks and maximize the options for disposing of, or eventually finding efficient uses for, the raw materials embodied in the carcass material. Transportation of pre-processed or frozen carcasses in sealed containers should minimize the risk of disease transmission during transit through populated or animal production areas.

Several options with limited throughput, such as rendering and incineration, could also benefit from the on-farm preprocessing and central processing strategy. This general approach is referred to here as a "de-centralized/centralized" model: de-centralized preprocessing to produce a stable organic feedstock that can be transported to a centrally-located facility in a controlled, orderly manner. Figure 1 shows a schematic of how the model might work for animal mortalities. Note that it may be necessary to process all manure from the production site as well as carcasses in the event of some types of communicable disease outbreaks. At other times, separated manure solids and other organic material could be transported and processed at the central plant if economical. Note also that processes suited for handling daily mortalities may or may not be appropriate for dealing with a mass die-off of animals or birds.

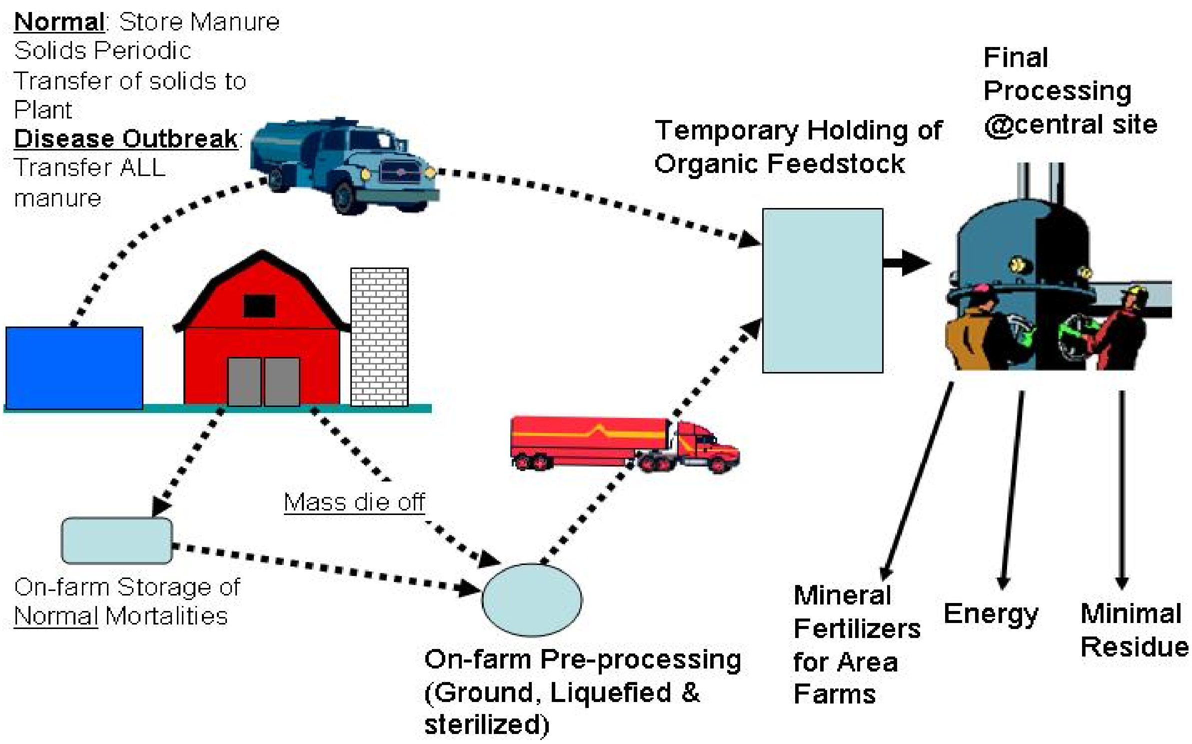

FIGURE 1. Model of decentralized collection and centralized processing. In the event of a mass die off due to communicable disease, it may be necessary to process all affected stored manure on the farm.

1.2 – Disposal Methods

There are several unconventional options for disposing of animal mortalities. Many of these would benefit from the de-centralized/centralized model discussed earlier.

Thermal depolymerization is an intriguing possibility for processing large-scale mortality events. This is a relatively new process that uses high heat and pressure to convert organic feedstock (e.g., pre-processed carcasses) into a type of fuel oil. The thermal depolymerization process has been studied by researchers at the University of Illinois and others. Since depolymerization disassembles materials at the molecular level, it may be effective at destroying pathogens, but this needs to be confirmed. While this alternative is still being evaluated in the laboratory, a large commercial-scale plant is being installed in Missouri to process organic byproducts from a poultry processing plant.

The **plasma arc process** relies on extremely hot plasma-arc torches to vitrify and gasify hazardous wastes, contaminated soils, or the contents of landfills. It can vitrify material in place with reduced costs and less chance of further contamination. The resulting rock-like substance is highly resistant to leaching. When treating landfill contents, it has reduced material volume by up to 90 percent. The process also generates fuel gases that can be collected and sold to help defray operational costs.

There are no references indicating that plasma arc processing has been used to dispose of livestock mortalities; however, it has several potentially useful characteristics from the standpoint of biosecurity that should be investigated. Specifically, it may be useful when coupled with burial systems because of the potential for treating the material in place. Plasma arc technology has been successfully used to process landfill waste, and there is no reason it should not be effective with mass burials of animal mortalities.

Refeeding of animal carcasses is already important in the poultry industry. There are currently a number of poultry producers using predators, particularly alligators, to consume mortalities.

There is typically very little processing involved in the refeeding process, with most carcasses being fed whole. Some poultry and/or alligator producers grind carcasses to create a liquefied feed that can be consumed by hatchling alligators.

While refeeding is an attractive option in areas where alligator farming is legal and practical, particularly in some southeastern states, many questions remain about the ability of such systems to accommodate the volume of mortalities associated with large-scale die-offs. Start-up costs and skill levels for workers on alligator farms can be high. Another concern relates to the potential for disease transmission through the predator herds.

Other non-traditional methods (including flash dehydration, ocean disposal, napalm, fluidized-bed drying and extrusion/expeller press) would require carcass handling and transportation to a processing site or the development of portable systems. Flash dehydration, fluidized-bed drying, or extrusion/expeller processing would result in a potentially useful by-product. Ocean disposal would not directly result in a beneficial or usable product; however, the addition of a protein source could positively impact aquatic life in the area over time.

Table 1 below summarizes the various innovative methods of handling animal mortalities discussed in this chapter.

TABLE 1. Overview of innovative options for processing or disposing of large-scale animal mortality events.

Technology/ Method	Applicable To: Non-Diseased Carcasses	Applicable To: Infectious Diseased Carcasses[a]	Requires Stabilization or Pre-Processing	Portable?	Centralized ?	Salvage Product(s)	Residue
Refeeding	✓	--[b]	✓	No	--	Nutrients	Bones
Thermal Depolymerization	✓	✓	--	Perhaps	Yes	Energy	Minerals
Plasma Arc Technology	✓	✓	✓	Yes	Yes	Energy	Vitrified material
On-Farm Autoclaving[c]	✓	✓	--	Yes	No	--	--
Napalm	✓	✓	--	Yes	--	--	Ash
Ocean Disposal	✓	--	--	No	--	--	None
Extrusion	✓	--	--	No	Yes	Energy	--
Novel Pyrolysis Technology (*ETL EnergyBeam™*)	✓	--	--	Perhaps	Yes	--	--

[a]Infectious diseases are handled in the most part by the various processes discussed here. Transmissible degenerative encephalopathy (TDE) and other prion-related agents need further study in all cases.

[b](--) indicates an unknown.

[c]Discussed later in chapter as STI Chem-Clav.

Section 2 – Pre-Processing (Pre-Disposal) Methods

2.1 – Freezing

Freezing was one of the first methods attempted to extend the storage time for poultry and swine mortalities, and is in use today at many larger operations. Freezing is a useful pre-processing option for small scale mortalities, however, the equipment and energy costs involved to handle a mass die off may not be readily available. Freezing was recently used in Wisconsin during a chronic wasting disease (CWD) eradication effort to store, prior to ultimate disposal, deer carcasses suspected of harboring CWD.

Cold storage was also used in the Netherlands during a 1997 outbreak of classical swine fever (hog cholera), providing the holding capacity to allow rendering facilities to process the majority of euthanized animals. By coupling temporary cold storage with means to slow animal production (breeding bans, slaughtering pigs at birth, restricting animal movements, etc.), disposal was accomplished almost entirely by the existing rendering capacity. On-site burial or open burning of carcasses was considered; however due to environmental concerns, cold storage with rendering was selected as the best disposal system (Lund, Kruger, & Weldon).

General process overview

Freezing is a relatively straightforward process and uses common refrigeration techniques to lower the body temperature of the carcass to the point where decomposition is retarded. The temperature required depends on the length of storage time required. For extended periods (weeks instead of days) or situations where the mortalities must be transported for several hours before reaching the central processing unit, the carcasses must be frozen.

Personnel requirements

Personnel requirements should be minimal, since the carcasses need only be loaded into the refrigeration unit, and later loaded into a vehicle for transport off farm to a central processing site.

Location considerations

Land area requirements should be minimal; however access to power will be essential.

Resource requirements

The primary resource requirement will be an uninterruptible supply of power.

Time considerations

The time required to lower carcass temperature below 40°F will depend largely on the capacity of the freezer and the weight of carcasses added at one time. Typically, a freezer or refrigerator will hold the mortalities at that temperature until a sufficient quantity has accumulated to warrant a trip to a rendering plant. Such on-farm equipment would likely be sized to handle normal mortalities and probably would not have sufficient capacity for a large die-off event of animals or birds.

Remediation requirements

Remediation requirements should be limited to any spillage that might occur when carcasses are loaded into the freezer unit, since the frozen carcasses would typically be taken to a central site for final processing.

Cost considerations

Morrow and Ferket (1993) reported that a large poultry producer using one-ton capacity freezers estimated a capital cost of $2,000 per freezer unit, and an electricity cost of $1.20/day or $0.01 per pound of carcasses, assuming $0.08 per kilowatt hour.

A broiler company in Florida developed special weather-proof units that could be moved with a forklift. The freezer unit that cooled the containers never leaves the farm. The loaded containers are either hauled away or emptied at the farm in order to transport the contents to a processing facility. Estimated total costs of using refrigeration in a 100,000-bird broiler operation were about $0.114 per pound (Damron, 2002).

Disease agent considerations

Freezing, especially for a short period, is not likely to significantly affect pathogen survival.

Implications to the environment

Freezing should have no direct negative effects on the environment, except indirectly when fuel is burned to generate the electricity needed to operate the units. Modern refrigeration units no longer use chemicals that could affect the ozone layer.

2.2 – Grinding

A possible solution for pre-processing and transporting carcasses involves a large portable grinder that can be taken to the farm. In order to be feasible for a large-scale mortality event involving mature cattle, very large equipment would be needed. The processed material could be preserved with chemicals or heat and placed in heavy, sealed, plastic-lined roll-off containers for transport off-site to a central processing facility (Morrow & Ferket, 2002).

General process overview

Grinding of carcasses will make most mortality processing systems more effective and more rapid by increasing the surface area where chemical and biological processes can occur. It is required as a component for fermentation of carcasses, which is a method of storing carcasses on farm for several months, until they can be transported to a central site for disposal. Carcasses are typically ground to 2.5 cm (1 inch) or less diameter, although no study could be found in the literature to indicate that this was optimum. Generally, a bulking agent would be needed to absorb the liquid released from carcasses during grinding.

Personnel requirements

Grinding is a mechanical process so a reasonable amount of labor will be required to maintain the equipment. However, grinding equipment should be very heavy duty, so most of the maintenance should be routine. There are a number of manufacturers that produce grinders capable of handling carcasses. One important requirement is that equipment be easily disassembled for cleaning and disinfecting. Two manufacturers that advertise their equipment as being suitable for grinding animal mortalities include the following:

Karl Schnell GmbH & Co.
Mühlstr. 30
D-73650 Winterbach
Tél + 49 (0)7181 / 962-0
Fax + 49 (0)7181 / 962-100
http://www.karlschnell.de/en/produktkategorien/crushers.htm

Supreme International
PO BOX 6450 STN MAIN
Wetaskiwin, Alberta, Canada
T9A 2G2
Phone: 780.352.6061
Fax: 780.352-6056
http://www.supremeinternational.com/

Location considerations

While grinding equipment will generate some noise while operating, it should not be a significant nuisance to the neighborhood. Access by trucks will be necessary to transport carcasses to and from the grinder. Power and water will be needed for stationary units.

Resource requirements

The fuel or energy and equipment requirements will depend on the size and number of carcasses to be ground. A machine for handling the daily mortality from a poultry operation would be considerably smaller than one needed to handle a large cattle feedlot. Also, a smaller grinder could presumably be utilized for mature cattle if the carcasses are cut into smaller portions before entering the grinder. A commercial-sized garbage grinder was used in a University of Minnesota study to process dead piglets. Large vertical tub grinders have also been used to handle entire mature cattle mortalities.

The bulking agent needed to absorb liquid could be cornstalks, straw, sawdust or similar material commonly available on farms. The amount and type of bulking agent used may also depend of the intended use of the ground carcasses. For example, material bound for use as alligator or pet food will require an agent that is digestible.

Time considerations

The time required to process a carcass will depend on the size of the equipment and the size of carcass. However, since there is no chemical or biological reaction time involved in this purely physical action, processing times should be relatively rapid. The largest commercially available portable equipment found appears to be able to handle approximately 15 tons per hour (perhaps over 150 mature cows/day).

Remediation requirements

The output materials generated should be a paste-like material that is essentially all redirected into another, final disposal or processing system.

Cost considerations

Foster (1999) estimated installation costs of $2,000 for a cutter and $6,000 for a grinder for pigs plus $5,000 in associated costs. A shelter to house the equipment plus utilities would increase this estimate. A portable unit should be more expensive because of the associated transport costs and portable power plant required. Also, the cost of the bulking agent is not included. Clearly, the size of carcass involved and the throughput needed will greatly affect cost and type of grinding equipment involved.

Disease agent considerations

Grinding, by itself, will not affect the potential for disease transmission. In fact, it could potentially increase transmission by increasing surface area of carcass tissue. Certainly, it would be wise to store and transport ground carcasses in sealed containers.

Implications to the environment

Grinding will speed biological decomposition of a carcass, so ground material should be used rapidly for additional processing/disposal, or a preservative may be warranted if the material will be stored. Grinding will also increase the potential for odor.

2.3 – Fermentation

General process overview

Fermentation is a process that can allow the on-farm storage of poultry carcasses for at least 25 weeks, and produces a "silage" end project that is nearly pathogen free. Fermentation of carcasses typically proceeds at near ambient temperatures in sealed containers that are vented for carbon dioxide. Carcasses are first ground to 1-inch diameter or smaller, mixed with a fermentable carbohydrate source and culture inoculant, and added to the fermentation container. The result is acidic silage that is stable for some time. A silage pH greater than the optimum pH of 4.3 to 4.5 can result in a secondary fermentation that spoils the silage (Morrow & Ferket, 1993).

Personnel requirements

Personnel requirements should be minimal with this process. The "recipe" for preparing the carcasses is easy to follow and simple to do.

Location considerations

The location chosen for the fermentation container should be near the source of the mortalities. Further, the grinding and mixing process must be designed so that any spills can be contained.

Resource requirements

Electricity must be available for the grinder. Water should be available for cleanup of the preparation area, and the fermentation vessel must be watertight. For lactic fermentation, lactose, glucose, sucrose, whey, whey permeate, condensed brewer's solubles, and molasses are all suitable as a fermentable carbohydrate source, although brewer's solubles works especially well.

Time considerations

Under optimal conditions, the pH of fresh carcasses can be reduced from 6.5 to less than 4.5 in 48 hours (Morrow & Ferket, 1993).

Remediation requirements

A properly prepared silage output from the fermentation process is semi-solid in nature, is stable for months, and can be accepted for rendering. Another potential use, according to Morrow and Ferket (1993), is refeeding to fur animals, ruminant animals, or aquaculture.

Cost considerations

Cost information could not be found in the literature reviewed.

Disease agent considerations

According to Morrow and Ferket (1993), the agent of Aujeszky's disease can survive for nine days at 50°C (122°F). Since mortality fermentation temperatures approximate ambient, this pathogen may survive in cold climates. The low pH of the anaerobic fermentation should kill most pathogens, however.

Implications to the environment

Fermentation should not pose a threat to the environment, as long as the fermentation container is watertight and as long as no spills occur while preparing materials for the fermentor or while removing material from it.

2.4 – Grinding/Sterilization by STI Chem-Clav®

Waste Reduction by Waste Reduction, Inc. (WR$^{2®}$) Companies, headquartered in Indianapolis, Indiana, currently markets a patented non-incineration technology for processing biological and biohazard waste materials called the STI Chem-Clav® (http://www.wr2.net/).

General process overview

The STI Chem-Clav® system has traditionally been used to process regulated medical wastes. The system incorporates negative air pressure and high efficiency particulate air (HEPA) filtration to prevent the escape of airborne pathogens while the waste is being shredded. Shredding maximizes surface area and subsequent exposure to steam. This process renders the waste, including sharps, "unrecognizable" and "unusable."

Process air passes through a HEPA filter chamber prior to exhausting to the atmosphere. A chemical disinfectant (sodium hypochlorite) acts as a deodorant for the waste stream.

Shredded waste enters the auger where low-pressure steam is applied through a system of injection ports (Figure 2). The time spent in this steam auger is approximately 60 minutes. Thermocouples maintain an operational temperature of 96°C to 116°C (205°F to 240°F). STI Chem-Clav® systems operate below the threshold temperature for volatilization of plastics to avoid volatile organic compound (VOC) emissions. Shredding increases surface to area exposure, allowing permeation of steam into the materials. A steam jacket raises the temperature of the shredded waste above 100°C (212°F) to dehydrate the waste.

Venting at the end of the auger creates a low pressure to remove and exhaust moisture. Dry, sterilized waste exits the system into a self-contained/roll-off type container and is typically transported to a sanitary landfill as municipal waste.

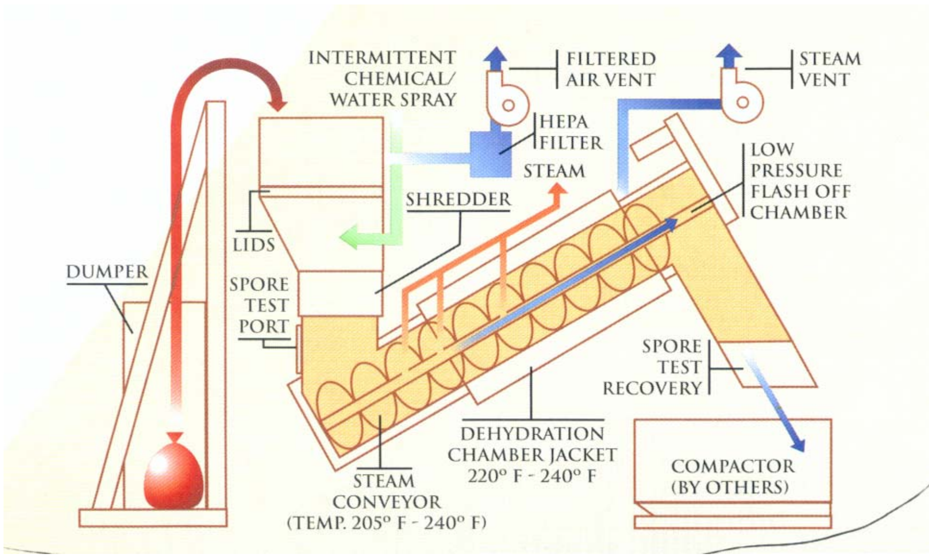

FIGURE 2. STI Chem-Clav® Steam Sterilization Systems (by Sterile Technology Industries, Inc.) has been used to render medical waste sterile into unrecognizable and unusable waste material (http://www.wr2.net).

Personnel requirements

The STI Chem-Clav® system would require trained operators to operate the processing equipment and skilled labor to operate the trucks and material handling equipment.

The STI Chem-Clav® system is available from Sterile Technology Industries, Inc. (STI), a wholly-owned subsidiary of $WR^{2®}$ which is headquartered in Indianapolis, Indiana. $WR^{2®}$ also markets alkaline hydrolysis systems.

Sterile Technology Industries, Inc.
5725 W Minnesota St.
Indianapolis, IN 46241
Phone: 317-484-4200 Fax: 317-484-4201
E-mail: chemclav@aol.com

Location considerations

The STI Chem-Clav® system can be designed as a stationary or portable unit. It can be transported on a flatbed semi trailer to a site. An area capable of supporting large trucks and material handling equipment would be necessary.

Resource requirements

A mobile STI Chem-Clav® unit would require a fuel source such as propane and an electrical hook-up to power the system. In lieu of electrical power, the unit could be hydraulically driven with a diesel engine and hydraulic pump. Material handling equipment such as front-end loaders and leak-proof trucks to transport processed material would also be required.

Time considerations

According to $WR^{2®}$, the STI Chem-Clav® process could be made mobile and optimized for rapid processing, achieving a throughput rate of up to 13,608 kg (30,000 lbs.) per hour (approximately 20 large animals per hour) (J. Wilson, 2003). These units can be built to order and would need to be constructed in advance of a disaster.

Remediation requirements

In situations where the system can neutralize the disease agents involved, or in the case of a natural disaster, the resulting material could be rendered, used in a composting system, deposited in a landfill, put in cold storage for further processing, or utilized in an energy recovery system such as a fixed hearth plasma arc furnace or a thermal depolymerization oil recovery system. Prior planning for the recovery of animal or plant nutrients or energy could reduce the effects on the environment and provide a more useful output.

Cost considerations

The cost of a mobile STI Chem-Clav® as described is estimated to be approximately $150,000. This does not include a semi tractor or fuel supply trucks. The addition of a disinfectant into the screw processing mechanism would also add to the cost. If the system were used on a daily basis for processing other wastes (food scraps, medical, etc.), the cost of processing would be decreased; however the normal flow of feedstock would need to be diverted or stored in the event of a large mortality event.

Disease agent considerations

The STI Chem Clav technology appears most promising for non-disease related mortalities and animal disease outbreaks involving bacteria or virus-contaminated animals that can be neutralized by steam sterilization or the addition of an alkaline material. TDE agents (prions) would not be neutralized by steam sterilization, and the efficacy of the addition of an alkaline material would need to be examined.

Implications to the environment

In situations where disease agents can be neutralized by this process, the resulting material could be used in a composting system, deposited in a landfill or utilized in an energy recovery system such as a fixed hearth plasma arc furnace or a thermal depolymerization oil recovery system. Prior planning for the recovery of plant nutrients or energy could reduce the effects on the environment.

Advantages and disadvantages

One advantage of this system is its portability. Another advantage, in situations where TDE agents are not a concern, is the ability to process solids and liquids with the same machinery. Waste milk, manure, feed, or even some structural materials could be processed for further disposal.

Disadvantages include the inability to neutralize TDE agents and a high initial cost.

Section 3 – Non-Traditional and Novel Disposal Methods

A variety of traditional carcass disposal methods are used to address daily mortalities in animal production operations. The non-traditional or novel methods outlined in this report could potentially be adapted for daily mortalities, catastrophic losses, or both. This report addresses various mortality causes, including typical production losses, natural disasters, and disease outbreaks of either natural or deliberate (i.e., bioterrorism) origin.

The selection and implementation of mass carcass disposal strategies should be considered within a decision-making process that is part of a national and/or state level contingency plan. The goals and objectives of a contingency plan should endeavor to:

1. minimize the number of animals to be slaughtered in the case of disease or injury;
2. minimize disruption of farming activities and food production;
3. minimize potential damage to the environment;
4. minimize damage to the economy;
5. contain and eradicate infectious disease outbreaks;

6. provide a safe, rapid attainment of disease-free status;
7. maximize use of existing infrastructure;
8. minimize cost to the taxpayer;
9. protect public health and safety; and
10. retain the confidence and support of the public.

Within the contingency plan, the decision-making process should allow for flexibility to utilize disposal methods based on the nature of the problem. Natural disasters may allow more options versus a situation involving infectious diseases that might limit transportation options or require the neutralization of pathogens. In disaster circumstances, or other instances that do not involve an infectious agent, transportation and collection may be suitable if the situation can be handled in a reasonable timeframe. Strong consideration should be given to the general approach of treating mortalities as an organic feedstock having value as opposed to a waste suitable only for disposal.

3.1 – Thermal Depolymerization

Thermal depolymerization, developed by Paul Baskis in the 1980s to reduce complex organic materials to light crude oil, is a promising method of processing waste organic materials, including animal mortalities. The process has been described as follows:

> It mimics the natural geological processes thought to be involved in the production of fossil fuels. Under pressure and heat, long chain polymers of hydrogen, oxygen, and carbon decompose into short-chain petroleum hydrocarbons. Many methods to create hydrocarbons use a lot of energy to remove water from the materials. This method instead requires water, as the water both improves the heating process and supplies hydrogen and oxygen for the chemical reactions.
>
> (Anonymous)

According to Lemley (2003), a thermal depolymerization plant is being constructed at the ConAgra Foods Turkey plant in Carthage, Missouri, to digest 200 tons of turkey processing waste per day. ConAgra previously trucked feathers and other waste to a rendering facility where it was processed into animal feed, fertilizer, and other chemical products. Recent outbreaks of TDE diseases, such as bovine spongiform encephalopathy (BSE or "mad cow disease"), have raised concerns about feeding rendered materials back to animals. This practice is illegal for all livestock in Europe and, since 1997, it has been illegal in the United States (US) to feed rendered mammalian products to ruminants. Since depolymerization disassembles materials at the molecular level, in theory it should be effective at destroying most pathogens. However, it is unclear from the literature if prions are destroyed by thermal depolymerization. The effectiveness of this process on pathogen destruction warrants further examination.

According to Lemley (2003), the ConAgra plant will convert turkey offal—guts, skin, bones, fat, blood, and feathers—into a variety of products. During the first-stage heat-and-pressure reaction, fats, proteins, and carbohydrates will be broken down into carboxylic oil. The second-stage reaction will strip off carboxyl groups (a carbon atom, two oxygen atoms, and a hydrogen atom) from the fatty acids and break the remaining hydrocarbon chains into smaller fragments to produce light oil which can be used as-is, or refined into lighter fuels such as naphtha, gasoline, and kerosene. The process is also expected to yield fertilizer-grade minerals derived mostly from bones and carbon solids.

The Missouri plant expects to produce 10 tons of combustible gas and 21,000 gallons of water per day; the water will be discharged into a municipal sewage system. The plant should generate 11 tons of minerals and 600 barrels of oil, with approximately the same specifications as #2 heating oil. The plant's designers intend to produce oil at $15 per barrel and eventually drop the cost of production to $10 by fine-tuning plant operations; $10 per barrel approximates current prices for crude oil.

Figure 3 depicts the thermal depolymerization process. The current status of the ConAgra plant is unclear. The company building the plant indicated that it would be operational in late 2002, but as of December 2003 no update on the operational status has been provided. The operational date may be affected by expected incentives in the US energy bill, which is still stalled in Congress.

Thermal depolymerization and pyrolysis will be discussed together, but it must be noted that the condition of feestock required and the type of bio-fuel produced are quite different.

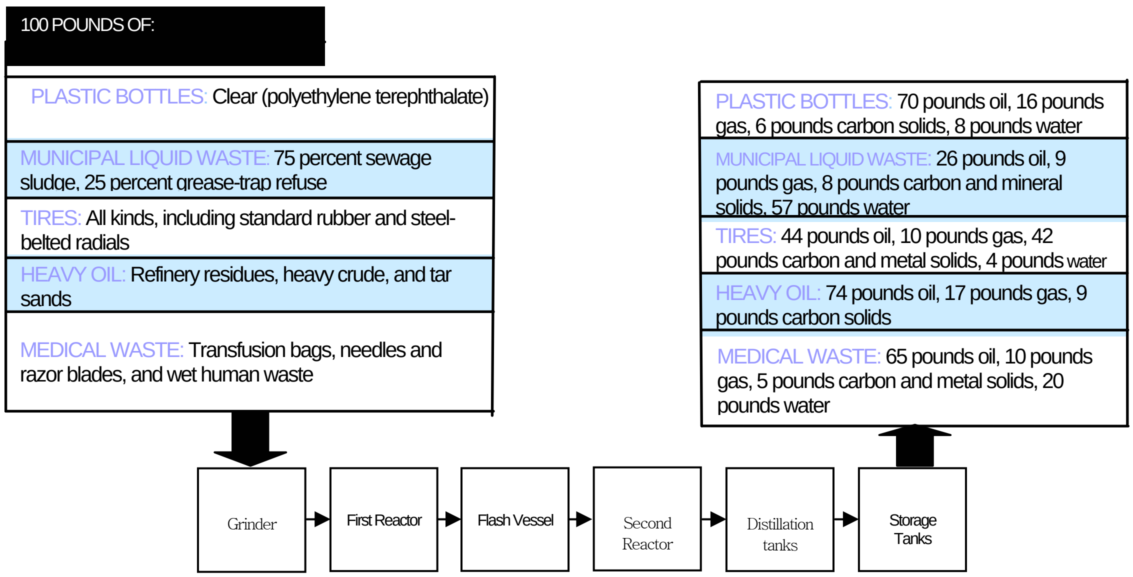

FIGURE 3. Potential outputs from thermal depolymerization of various wastes (Lemley, 2003).

General process overview

Thermal depolymerization works in principle by heating organic matter under pressure in very controlled conditions with the addition of carbon monoxide and steam to produce useful organic products such as bio-fuel. The process was described in more detail in the following way:

> The feedstock material is first ground into smaller particles, and mixed with water if it is especially dry. It is then fed into a reaction chamber where it is heated to around 250°C and subjected to 600 psi for approximately 15 minutes, after which the pressure is rapidly released to boil off most of the water. The result is a mix of crude hydrocarbons and solid minerals, which are separated out. The hydrocarbons are sent to a second-stage reactor where they are heated to 500°C, further breaking down the longer chains, and the resulting petroleum is then distilled in a manner similar to conventional oil refining.
>
> (Anonymous)

Personnel requirements

These are complex processes and the labor requirements can be expected to be at a relatively high skill level.

The following companies are developing thermal depolymerization or pyrolysis facilities.

Changing World Technologies
460 Hempstead Avenue
West Hempstead, NY 11552
http://www.changingworldtech.com/indusfr.htm
Phone: (516) 536-7258

Renewable Oil International LLC
3115 Northington Court
PO Box 26
Florence, AL 35630
http://www.renewableoil.com
Phone: (256) 740-5634

Renewable Oil International LLC (ROI) uses an approach similar to thermal depolymerization called pyrolysis. Pyrolysis is done at a higher temperature than thermal depolymerization, but uses a considerably dryer feedstock and does not take place in the presence of water.

Location characteristics

The usual restrictions placed on a similar type of plant should apply. For example, the plant should be centrally located to the sources of material to be used as feedstock and near a refinery that can process the bio-oil produced. All-weather roads and ready access to the area's highway system are essential. Since there would be the possibility of an inadvertent spill of a water contaminant or odor release, the plant location should be somewhat isolated from waterways and heavily populated areas. Space requirements should be largely determined by the scale of the plant.

Resource requirements

Thermal depolymerization is a complex process involving very robust vessels, valving, pumps, and other fittings capable of handing high pressures and high temperatures, so the equipment requirements can be expected to be extensive. Also, carcasses would need to be ground into a paste or small particles before being added to the thermal depolymerization process.

Once started, the process appears to be energy self-sufficient. Working with turkey offal as the feedstock, Changing World Technologies reports that its process has energy efficiencies of approximately 85%; in other words, the energy required to process materials could be supplied by using 15% of the energy output. Higher efficiencies may be possible with drier and more carbon-rich inputs (feedstock) such as waste plastic. Laboratory studies at the University of Illinois by Zhang, Riskowski, and Funk (1999) have also indicated a positive energy flow in laboratory studies of thermal depolymerization of animal wastes. In these studies, carbon monoxide was added to improve the quality and yield of bio-fuel produced. The pyrolysis process can utilize considerably dryer feestock.

Time considerations

On-farm pre-processing and transport in sealed plastic containers should allow a large plant to keep up with emergencies. To be able to sustain a large central processing facility so that it is available if needed in an emergency, it would be necessary for the facility to operate on a routine basis with other feedstock whose flow could be suspended in times of emergencies such that priority could be given to processing carcasses.

The Changing World Technologies website indicates that plants smaller than the 200 ton/day unit in Missouri are possible, but they are focusing on larger plants at the present time.

ROI has had a five metric ton/day (dry ton) pilot plant operating with poultry litter as a feedstock since spring 2003, and is developing plans for a very large stationary system (Badger, 2003).

Remediation requirements

Site remediation should not be an issue with thermal depolymerization or pyrolysis because of the points discussed under "Implications to the environment" below. Thermal decomposition produces a light oil product that can be used as a raw material to produce other petroleum-based products, including fuels. The minerals produced should be useable for crop fertilization. ROI indicates an energy content of 80,000 BTU per gallon of bio-oil (Badger, 2003) (http://www.renewableoil.com).

Cost considerations

ROI estimates a capital cost of $3 million for a 120 ton/day operation using a 2.5-MW gas turbine to generate electricity. The ConAgra plant in Missouri has not released its costs at this time.

Disease agent considerations

With on-farm preprocessing and transport in sealed containers, biosecurity issues on-farm, and during the transport between the farm and plant, should be minimized. It is not known at this time if prions can survive the thermal depolymerization or pyrolysis processes; however, other pathogens should be killed. This is an issue that needs to be verified.

Implications to the environment

Environmental implications should be minimal; site residues from the thermal depolymerization and pyrolysis processes are inert. The materials are held in sealed containers before and during processing, and emissions to the environment should be contained.

Advantages and disadvantages

The advantages of thermal depolymerization and pyrolysis include production of a reusable energy source, production of more energy than is consumed, and the potential to be centrally placed in rural areas with plentiful organic residues in order to continuously operate and produce energy. Disadvantages of the process include the requirement that carcasses be preprocessed before they can be added to the reactors, and the lack of existing operational facilities. While cost data are lacking at present, costs are expected to be too high to justify the construction and operation of facilities for mortality disposal alone. Possibly a portable "mini-reactor" could be developed for the purpose of on-site processing in the event of catastrophic mortality losses. ROI is currently developing a mobile pyrolysis unit which is expected to yield oil from organic matter feedstock.

Other

Start-up of the ConAgra thermal depolymerization plant appears to be behind schedule (it was originally to begin operation in April 2003) so problems may have been encountered during construction or during startup. The Changing World Technologies website on April 2, 2003, indicated the plant would be operational in a few weeks, but the website did not indicate that it was operating as of December, 2003. Its current status is unknown, but it may be waiting on potential cost share working in the US energy bill pending in the US Senate.

As this is a relatively new process in the initial stages of commercialization, it is likely that many improvements will be made in the future if it continues to appear to be effective and economical. As with any new process, there will likely be opportunities to reduce complexities and cost to improve performance over time. The portable thermal depolymerization process being developed by ROI, assuming it has adequate throughput, could be of interest to the poultry and animal production industry. The residue material remaining after the thermal depolymerization process is complete should be minimal. It is largely inorganic inert material and could be used as an agricultural soil amendment or placed in a landfill.

3.2 – Plasma Arc Process

The production of plasma results from the ionization of matter by modifying the temperature and electrical characteristics of a substance. Ionization of a gas produces free electrons and ions among the gas atoms, and will respond to magnetic fields allowing control of the plasma. Plasma is a gas that has been ionized by the electric arc of a plasma torch and can therefore respond to electrical and magnetic fields. Almost any type of gas (oxygen, nitrogen, carbon monoxide, air, etc.) in a wide range of pressures (vacuum to 20 atmospheres) can be used to produce plasma. The origins of industrial uses of plasma can be found in the development of tungsten inert gas welding by defense industries in 1941, when a better method of welding steel was required. Plasma technology was further developed for use in cutting metals and for cleansing material surfaces during manufacturing processes (Anonymous, 1999).

Plasma arc torches operate over a wide range of temperatures, from 1500°C to over 7000°C, approximately 1000°C hotter than the surface of the sun. The plasma torch and copper electrodes are water-cooled and the average life of the electrodes ranges from 200 to 500 hours of operation. Electrical requirements are met with a DC power supply unit, and commercial units are available in power levels ranging from about 100 KW to 10 MW capacities (Division of Construction Engineering and Management, 2000).

The plasma arc process is a potential solution to a variety of pollution problems. Utilization of the plasma arc process to dispose of wastes has been conducted in both mobile and fixed facility forms. The mobile form, Plasma Remediation of In-Situ Materials (PRISM), has been studied in-depth at the Georgia Tech Plasma Applications Research Facility. The PRISM process relies on extremely hot plasma arc torches to vitrify or gasify hazardous wastes, contaminated soils, or the contents of landfills via vertical boreholes. Since materials do not have to be excavated or otherwise handled, PRISM can vitrify the material with reduced costs and less chance of further contamination. The resulting rock-like substance is highly resistant to leaching (Johnson; Mayne, Burns, & Circeo, 2000; Solena Group, 1997).

Fixed-facility configurations (fixed hearth plasma arc units) have been used in Honolulu, HI, France, and Japan as commercial tools in the waste disposal sector, as well as in other industries such as steelmaking, and precious metal recovery. Research programs for the study of the basic science of plasma heating, as well as for development and implementation of models and prototypes for different applications, are being conducted in the US, Japan, Canada, Russia, France, and Switzerland (Beck, R.W. Inc., 2003; Anonymous, 2003a).

Fixed hearth plasma arc units in operation for the disposal of waste organics start at 400 kg (880 lb) per day. The Solena Group and Westinghouse have installed over 40 plasma arc waste disposal facilities around the world. Examples of fixed hearth plasma furnace throughput capacity for steel processing is 40 tons of loose cast iron borings scrap steel per hour at a General Motors plant in Defiance, Ohio, and 60 tons per hour at a Geneva Steel plant in Utah. The plant in Ohio began daily production in 1989 utilizing a 1.5MW Westinghouse MARC-11 plasma torch (Solena Group; Gary, Fry, Chaput, Darr, & Dighe, 1998). Fixed hearth plasma arc technology has been implemented by the Mixed Waste Integrated Program through the Department of Energy in cooperation with several national laboratories and corporations

Several disposal projects have utilized fixed hearth plasma arc technologies to incinerate hazardous wastes while capturing waste gases for energy production (Department of Energy, 1994). A pilot project headed by Westinghouse to process harbor sediment in New York/New Jersey is underway to process 76,000 m^3 (100,000 yd^3) per year with 380,000 m^3 (497,000 yd^3) per year planned in a full scale facility (Westinghouse; McLaughlin, Dighe, Keairns, & Ulerich).

A municipal waste processing facility in Lubsko, Poland is using plasma pyrolysis to produce a high energy synthetic gas composed of 80% hydrogen and carbon monoxide. Steam is injected into the reaction chamber resulting in gasification in a few seconds. Without oxygen, no fumes, ashes, dioxins, or furans are formed (Solena Group, 1997).

General process overview

PRISM is a process that relies on extremely hot plasma arc torches to vitrify or gasify hazardous wastes and contaminated soils such as the contents of landfills (Circeo & Martin, 2001; Circeo, 2003). A plasma arc torch can be lowered to any depth via a borehole to melt contaminated materials into a type of magma which cools into vitrified material. Subsequently, the plasma torch is slowly raised and operated at progressively higher levels to thermally convert a mass of soil into a vertical column of vitrified and remediated material called slag (see Figure 4). This slag can be left in place on the landfill to seal the site, more garbage can be piled on top, or the vitrified material can be removed and used as gravel in roadway projects, molded into products like bricks, or used as concrete aggregate.

The gases released through combustion reactions or devolatilization can move freely to the surface through a subsidence zone and into an open pipe for treatment (Figure 4). Water, CO_2, and air are the predominant gases released during processing. At sites containing significant organic matter, H_2 and CO also may also be produced. Thus, secondary combustion of these gases would be required within the remediation process (Johnson; Gibbs, 1993; Anonymous, 1995b; Malloy, 1995; Wright, 1995).

At present, no references could be found to indicate that plasma arc technology has been used to process livestock mortalities. However, it has several features that may prove useful for this purpose (e.g., may have potential in the in situ remediation of large mortality burial sites).

If a fixed hearth plasma arc facility, analogous to the centralized plant described in the centralized/decentralized model, could be used to convert other organic wastes to generate energy on a continuing basis, perhaps the infrastructure and capacity would then be available to handle carcass disposal emergencies.

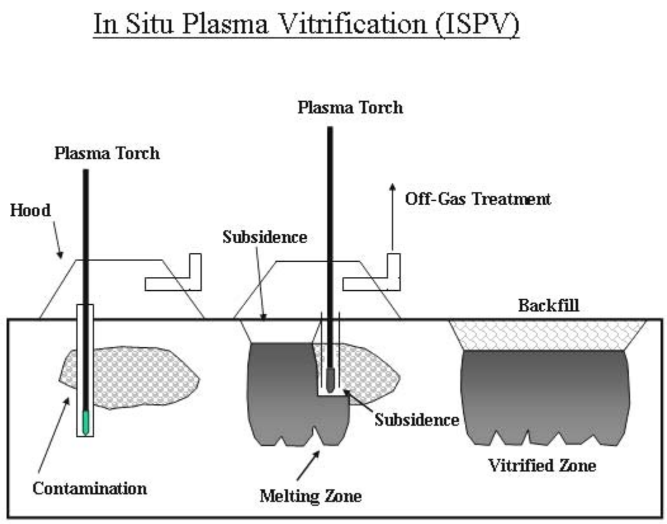

FIGURE 4. Use of in situ plasma arc to remediate landfill (adapted from Circeo & Martin, 2001).

Personnel requirements

This is a complex process and the labor requirements can be expected to be at a relatively high skill level for the operation of the plant.

The following vendors provide various forms of waste disposal utilizing plasma arc technology:

- Pulsed Energy Plasma, http://hometown.aol.com/hypercom59/
- Global Plasma Systems, Solena Group, http://users.erols.com/gpsys/index.html
- Westinghouse Plasma Corporation, http://www.westinghouse-plasma.com/
- Geoplasma, LLC, http://maven.gtri.gatech.edu/geoplasma/about.html
- Earthfirst Technologies, http://www.earthfirsttech.com/home.shtml
- Phoenix Solutions Company & Plasma Energy Corporation, http://www.phoenixsolutionsco.com/main/index.php
- Integrated Environmental Technologies, LLC, http://www.inentec.com/
- RCL Plasma, Inc., http://www.rcl-plasma.com/

Location considerations

A study of existing installations should provide a guide for the required foot print of a plasma arc facility. In agriculture, processing might be related to burial sites used for mortalities. Site selection criteria should be the same as any other industrial plant in the case of a fixed facility location. Issues such as all weather roads, access by heavy trucks, and access to utilities would need to be considered.

The usual restrictions placed on a similar type of plant should apply for a stationary plant. For example, the plant should be centrally located to the sources of material to be used as feedstock and near a facility that could utilize the combustible gas and waste heat produced. All-weather roads and ready access to the area's highway system are essential. Since there would be the possibility of an inadvertent spill of a water contaminant or odor release, the plant location should be somewhat isolated from waterways and heavily populated areas. Space requirements should be largely determined by the scale of the plant.

Resource requirements

Fixed hearth (stationary) plasma arc systems are specifically designed to process waste streams such as metals, plastic, or liquid organic wastes. Carcasses would require pre-processing and transportation in order to be introduced into a stationary furnace. A plasma arc system is a complex process involving very robust vessels, valves, pumps, and other fittings capable of handing high pressures and high temperatures, so the equipment requirements can be expected to be extensive.

The recent development of a portable plasma arc system for the purpose of destroying specific PCB containing material offers the opportunity for a mobile response. Site requirements are AC power, a water supply, and a sanitary sewer or water containment lagoon (Westinghouse). Portable preprocessing or grinding and portable plasma arc processing may be a combination of techniques that could provide a certain destruction of TDE-contaminated animals, but this needs to be verified.

In situ processing would not require pre-processing. A portable plasma arc torch, equipment to bore into a burial site, and gas collection equipment would be required to process in situ.

A DC power supply is required to power the plasma torch with electrical requirements ranging from about 100 KW to 10 MW. Energy to power boring machines to recover gas equipment is necessary for portable processing systems. Based on the size of the torch, varying amounts of cooling water are required. To utilize the methane or combustible gas generated, some form of portable gas-powered electrical generator is required. Systems utilizing gas turbine powered generators would not require large amounts of cooling water (Anonymous, 1995a).

Time considerations

The disposal of carcass material would need to be considered in the design and construction of a stationary fixed hearth plasma facility, as it may not be possible to retrofit existing facilities to accept carcass material. On-farm pre-processing and transport in sealed plastic containers should allow a large plant to keep up with emergencies. To be able to sustain a large central processing facility so that it is available if needed, it will be necessary to be able to operate the plant on a routine basis with other feedstock whose flow can be suspended in times of emergencies. In situ plasma arc processing could be accomplished with truck mounted portable units. In situ units might be available from commercial vendors involved in landfill remediation in the future.

Remediation requirements

When treating a landfill, PRISM can reduce the volume of the material by up to 90 percent. The process generates fuel gases that can be collected and sold or used on site with portable generators to produce electricity to help defray operational costs. Energy production techniques would be similar to those currently utilized at landfills (US EPA, Office of Air and Radiation, 1999). The process also results in a material similar to obsidian that is highly resistant to leaching, durable, and strong (US EPA, 2002; Advanced Technology Research).

Specific requirements for site remediation are not established for processing in situ, buried carcasses.

The utilization of stationary fixed hearth plasma arc furnaces would require planning for secure transportation and decontamination of the transport vehicles. In situ plasma arc vitrification of buried carcasses several months after burial would entail security for the site prior to vitrification. Any material removed when boring access holes would need to be treated appropriately.

Costs considerations

Plasma arc in situ vitrification of large volume carcass burial sites should be technically feasible. Although the economics are still in question, the costs involved in processing landfills should provide some insight. D. Wilson (2003) estimated the cost to treat buried carcasses in situ to be approximately $60 per ton.

Disease agent considerations

It is not known at this time if prions can survive the plasma arc process; however, other pathogens should be killed. This is an issue that needs to be verified. With on-farm preprocessing and transport in sealed containers, biosecurity issues on-farm, and during transport between the farm and plant, should be minimized.

Implications to the environment

The vitrified material produced in situ could become a water impermeable layer that may change ground water flow and drainage at a site where buried or composted carcasses have been processed with the plasma arc technology. The location and information about a site should be recorded at the time of processing and shared with future land owners. The methane generated from the plasma arc process and/or the carbon dioxide from utilizing the methane as power generation could pose risks to local air quality if not captured.

Environmental implications should be minimal; any remaining residues from the fixed hearth plasma arc process are inert. Material is held in sealed containers before and during processing so emissions to the environment should be contained.

Advantages and disadvantages

Advantages of the plasma arc process include the ability to effectively treat most waste materials, production of a reusable energy source, production of more energy than is consumed, and, in the case of a fixed hearth system, the potential to be centrally placed in rural areas with plentiful organic residues in order to continuously operate and produce energy. The PRISM system could also be used to remediate burial pits or trenches which hold animal or bird carcasses.

Disadvantages of the process include the limited number of operating facilities, the requirement that carcasses be preprocessed before disposal, and potentially high costs. While cost data are lacking at present, the cost will likely be too high to justify construction and operation of facilities for mortality disposal alone. Possibly portable publicly owned and operated “mini-reactors” could be developed for the purpose of on-site processing in the event of large die offs. An agricultural waste remediation system has been proposed, and the control mechanism patented by Pulsed Energy Plasma (Anonymous, 2003b; Arnold, 2001).

3.3 – Refeeding (Primarily to Alligators)

The use of whole or cut up raw carcasses as a feed for another species of animal (refeeding) is an alternative technique for salvaging value from either a continuous, non-emergency flow of mortalities or potentially from a large-scale die-off. Historically, carcasses have been rendered and the resulting products, such as meat and bone meal, have been fed back to the same or different species.

General process overview

Direct feeding of raw carcasses has been proposed and/or practiced within the following systems: hunt kennels in the United Kingdom, fur animal operations in parts of the northern US, and alligator production operations in a number of US states. In the US, the most common example of carcass refeeding is poultry mortalities fed to alligators being raised in commercial confined feeding operations primarily in the Southeast. However, refeeding could apply to a range of commercial livestock. Swine carcasses and fish farm mortalities have also been used for alligator feed.

According to Valentine (2003), European farmers are banned from burying or burning animal carcasses after May 1, 2003, by the European Union. Thereafter, the only lawful methods of dead livestock disposal will be rendering, incineration, or refeeding at hunt kennels.

Farmers in the United Kingdom (UK) are being urged by the British Government to join a subscription scheme that will pay for the collection and disposal of fallen stock, with small holdings paying £50 a year, medium-sized farms paying £100, and large units paying £200. Until this program becomes operational, hunt kennels have offered to help farmers deal with fallen stock during that period and beyond. According to Valentine (2003), a spokesman for the Countryside Alliance stated that hunt kennels could provide an indispensable service to farmers and that the Masters of Foxhounds Association has been working with the government to address the situation. Hunt kennels disposed of 366,000 head of fallen stock in 2000, and that rate is likely to increase following the May 1, 2003 deadline. So far, 146 hunt kennels had offered to help with the surplus.

Non-rendered animal mortalities can be used as feed for fur animals in Minnesota, but restrictions include the following (Minnesota Board of Animal Health, 2003):

- A permit and veterinary inspection is required. Carcasses, facilities, and equipment must meet Board of Animal Health specifications for fur farm consumption,
- Fur farms must keep the farm in a sanitary condition,
- Permits allow feeding only to fur-bearing animals that do not re-enter the food chain, and
- The owner of the fur farm assumes the risk of any disease or condition in the carcass that could be detrimental to the fur animals.

According to the National Contract Poultry Growers Association (National Contract Growers Association), alligator farming has become a spin-off of Georgia's booming $2.1 billion-a-year poultry industry. Such operations have become a viable option for disposing of the hundreds of thousands of chickens that die before they reach the processing plant.

A farmer with 350,000 chickens can expect to lose about 21,000, or 6 percent, of the flock each year under normal conditions. A poultry farmer who opened one of the Georgia's newest alligator farms reported that the farm's 6500 alligators devoured about 2,000 pounds of dead chickens per day. Mortalities from the operation's 20 chicken houses are ground into a white paste prior to feeding to the alligators. There are now ten farmers in Georgia who are exploring the synergies of raising chickens and alligators.

Research in Florida, where dead swine were fed to pond-raised alligators, demonstrated a faster rate of gain as compared to alligators fed a diet of meat and fish by-products (Walker, Lane, & Jennings, 1992). One problem with this disposal system is that alligators become less active during cool winter months and are not as effective at disposing of carcasses during this time. The estimated feed-to gain ratio was 4.5 kg (9.9 lbs.) of dry matter intake per kg (2.2 lbs.) of weight gain (Walker, Lane, Jennings, Myer, & Brendemuhl, 1994).

There are restrictions on refeeding in some jurisdictions. In Louisiana, for instance, poultry mortalities cannot be fed to hogs or alligators unless the carcasses are first cooked or rendered (Louisiana State University Ag Center Research and Extension, 2003). A complaint to the Livestock Sanitary Board (LSB), the Department of Health and Hospitals (DHH), or the Department of Environmental Quality (DEQ) concerning noncompliance with these regulations can result in inspections and penalties.

A potential complication in alligator operations is West Nile virus. The virus was found in farm-raised Florida alligators in late 2002, the first time the potentially deadly virus had been observed in the North American species (Bruno, 2002). It is believed that alligators, which serve as an amplification host for the virus, spread the disease among themselves through water in their holding tanks (Bruno, 2003).

According to the Council on Agriculture Science and Technology (CAST), the US Food & Drug Administration (FDA) is currently drafting regulations that will expand its current ban against the use of brains and spinal tissue in cattle feed to include feed for dogs, cats, pigs, and poultry. These new regulations will probably require companies that slaughter "downer" livestock to dispose of the brain and spinal cord before mixing feed and pet food (CAST, 2003). With the recent discovery in the US of an animal with mad cow disease, these regulations may reduce refeeding of carcasses in the US.

Personnel requirements

Collection of carcasses from a large animal production operation is a routine procedure, as is feeding of predator animals in a production setting. No additional personnel requirements are anticipated unless special processing of the mortalities prior to feeding is required.

Location considerations

Carcass collection and feeding should normally be performed on a regular basis (daily) and should happen in rapid succession, minimizing the need for stockpiling space.

Most current examples of refeeding in the US involve poultry producers, primarily in the Southeast. Some producers are co-locating poultry and alligator production facilities in order to take advantage of the carcass disposal opportunity afforded through predator consumption and the low-cost source of nutrition for the predator species.

Alligator production in the US is concentrated in the South and Southeast, in Alabama, Florida, Georgia, Louisiana, Mississippi, and Texas (Masser, 1993). In 2001, the state of South Carolina established a three-year pilot program to determine the feasibility of alligator farming for disposal of poultry mortalities.

Louisiana leads the nation in alligator production, generating over $11 million in revenue annually with about 167,000 farm-raised animals marketed annually and more than 500,000 animals in captivity (Roberts, 2001). North Carolina's only alligator farm aids in the disposal of poultry mortalities (Price, 2003). The 4,500-animal herd consumes 2,000 pounds of carcasses per day.

Alligator production is not limited to the Southeast. Animals are being grown in Idaho where dead stock are used as feed at trout farms. Researchers in Iowa are also investigating the possibility of alligator farms to assist in the disposal of dead pigs from swine operations (Clayton, 2002).

Resource requirements

Carcass grinding equipment would be required for those operations that pre-process mortalities into a paste prior to feeding. Some operators grind poultry carcasses prior to feeding to create a paste that permits hatchling alligators to feed on the mortalities (Hammond, 2001). Equipment needs for grinding depend on carcass size. Experimental work has revealed the challenges of grinding the carcasses of mature animals, even poultry (Clanton, Johnston, & Robinson, 1999).

Cooking or rendering equipment would be necessary in those states that require such processing prior to refeeding.

Time considerations

Capacity is related to the alligator herd size and age distribution of the alligator herd. Growth to market size takes 36 to 42 months. Alligators consume approximately 30 pounds of meat during the first year of growth, 125 pounds of meat in the second year, and 250 pounds the third year (Lane & Ruppert, 1987). Adult alligators in a breeding herd will consume approximately 400 pounds of meat per year (Lane & King, 1989).

Since alligators are cold blooded reptiles, they become inactive in cold weather. Therefore, the capacity of alligator herds to consume animal mortalities is affected by the weather.

Additional information is required to properly gauge the ability of existing predator herds to consume large additional inflows of protein that would be available in the case of a large-scale die-off of animals. Carcasses from a natural disaster would need to be pre-processed to inhibit decomposition and stored in sealed containers or frozen until consumption.

Remediation requirements

The output materials generated are alligators, along with excrement and wastewater from the growing operation. The harvested alligators provide hides, heads, and meat to markets in the US and Europe.

Site remediation concerns with regard to the excrement and wastewater are unknown at this time, but would likely involve dilution and land application of spent water.

Cost considerations

Startup costs for an alligator farm can be substantial. Alligator farms in Florida have an average herd size of approximately 3,200 animals (Clayton, 2002). Some operations, even in the Southeast, raise alligators indoors in temperature-regulated facilities. Alligator waste must be filtered from the water in which they are kept, secure fencing must be provided (Sewell, 1999), and permits acquired (where necessary).

A sizable investment—at least $250,000—is required to start an alligator farm. If an alligator hide has not been marred by scratches or bite marks, it may bring $75 in Italy or other markets where alligator hides are used for belts, purses, and shoes. The meat may bring an additional $20 regionally (Sack, 2000).

Disease agent considerations

There is potential for pathogens present in carcasses fed to alligators to be transmitted via the excrement of the alligators. Rodents and birds could also transport pathogens present in carcasses awaiting consumption by predator species if the animals are kept in the open. Biosecurity concerns should be minimal if refeeding is limited to mortalities from natural disasters or noninfectious diseases. Mortalities resulting from infectious diseases or large scale mortality events will likely require other methods.

Implications to the environment

There is potential for pathogens present in carcasses fed to alligators to be transmitted via the excrement of the alligators. Rodents and birds could also transport pathogens present in carcasses awaiting consumption by predator species, particularly if the predators are raised in uncovered enclosures. The refeeding of diseased carcasses should be avoided.

Advantages and disadvantages

Refeeding is a low-technology solution to mortality management. If mortalities are generated near existing herds of predator species such as alligators, refeeding is also a low-cost option for mortality management. Difficulty in timely processing of large scale mortality events would be a disadvantage of refeeding. Carcasses must be incorporated into the diet of predator herds. If pre-processing is used to stabilize carcasses prior to refeeding, modifications may be required to maintain palatability.

3.4 – Napalm

Developed by US scientists during World War II for use in flame throwers and other weapons, napalm is a mixture of gasoline, benzene, and a thickening agent. For most people, napalm conjures up images of warfare, destruction, and horrific human casualties. However, napalm has been used in a variety of peace-time applications, including the break up of oil spills and the destruction of anthrax-infected cattle carcasses in the US.

In 1999, more than 2,271 L (600 gal) of napalm and 181 kg (400 lbs) of explosives were used to destroy a beached cargo vessel carrying nearly 1.5 mil L (400,000 gal) of fuel in an attempt to save Oregon's beaches. The Nevada Department of Agriculture at Reno and the Louisiana State Veterinary Service at Baton Rouge have some experience in peace-time uses of napalm to dispose of animal mortalities (Anonymous, 2001; Southwest Division Naval Engineering Facilities Command).

Anonymous (2001) reported that this highly flammable fuel-based material could be an effective way of speeding up the disposal of thousands of animals slaughtered in the 2001 foot-and-mouth disease crisis in the UK. UK Environment Minister Michael Meacher stated that there are environmental arguments in favor of using the chemical because it was fast and did not produce pollutants (Anonymous, 2001).

Environmental groups and health authorities raised concerns about the toxic effects of pyres that consisted of wooden railway sleepers, coal, and old tires as fuel, releasing cancer-causing dioxins into the air. According to one source, napalm could be an option:

> It sounds ideal: it's very hot, it burns quickly, and it coats the carcasses in a gel while they burn. And it's a lot cheaper than building a pyre. Napalm can reportedly dispose of carcasses in 60 minutes, whereas pyres take up to three days. Napalm also is easier to control and burns slower than gasoline—about 1,000°C (1,832°F) compared to 675°C (1,247°F) for thickened gasoline, ensuring the required destruction of infected carcasses.
>
> (Anonymous, 2001)

Because of the chemical's devastating wartime history and public perception, however, a spokesman for the Department of the Environment, Transport and the Regions in the UK said the use of napalm for handling mortalities was unlikely.

General process overview

Experiments in 2000 by Ron Anderson of the Nevada Department of Agriculture demonstrated that napalm could be sprayed over carcasses and set alight with a Terra Torch. The resulting fire consumed animal carcasses in about 60 minutes (Anonymous, 2001; Anderson, 2004; Firecon, 2002; Jones, 2004).

Napalm could also be combined with other technologies if at some point rapid burning of residues, stored carcasses, or composting operations was deemed necessary. However, Gary Ford of Air Burners, LLC indicated that their company had tried adding diesel fuel and gelled fuel to one of their air curtain incinerators, and the result was increased smoke emission and the explosion potential of the fuel without enhancement of the burning process. Napalm, being a gelled fuel, may not be compatible with air curtain incinerator technology (Ford, 2003).

Personnel requirements

The personnel requirements are poorly understood for this purpose. The level of training required to use napalm effectively is very high from a safety standpoint, but the process should be fairly straight forward (Anderson, 2004).

At present, the only source found in the US for the powdered aluminum soap is:

Fire-Trol Holdings, LLC
2620 North 37th Drive
Phoenix, Arizona 85009
firetrol@firetrolholdings.com

The powder aluminum octoate based gelling agents used in the burning of forestry slash, and even in the cleaning up of oil spills at sea, are manufactured by:

H.L. Blachford Ltd.
977 Lucien L'Allier
Montreal, QC H3G 2C3 , Canada
Tel: (514) 938-9775 ; Fax: (514) 938-8595
http://www.blachford.ca/

The Terra Torch system used by the US Forest Service for controlled burns in forest and grasslands is available from:

Firecon, Inc.
PO Box 657
Ontario, OR 97914
Tel: 541.889.8630, Fax: 541.889.8654
firecon@fmtc.com.

Location considerations

The area required for disposal using napalm disposal should be free of combustible materials and be large enough so that the carcasses are one layer deep. The site selection criteria used should be essentially the same as for pyres.

Resource requirements

The jellied gasoline or napalm of WWII was composed of gasoline mixed with aluminum soap powder derived from napthene and palmitate to produce a sticky, brown syrup that burned slower than gasoline. Napalm-B (super napalm or NP2) is safer than the napalm used in WWII. Current variations of napalm can be formulated by mixing aluminum soap powder polystyrene and benzene with gasoline or diesel fuel to solidify these fuels into a flammable but not explosive material that can be ignited in a controlled manner.

Previous delivery systems used by the military utilized handheld tanks with a pressurized flammable gas such as butane to propel the napalm to a target. Larger systems utilized a bronze rotary pump or a piston pump to pressurize the napalm. Ignition was accomplished with a battery-powered igniter. Napalm can be transported in steel or aluminum tanks. No pre-processing should be required and the fuel can be mixed just prior to use (Anderson, 2004; Jones, 2004).

The recommended fuel mixture for incinerating an adult cow is a mixture an aluminum soap powder in a 70/30 mixture of regular diesel fuel and regular leaded gasoline. If constant agitation is not provided, the powder may settle resulting in a very strong gel being formed on the bottom of the tank. Mixing should be maintained until the gel reaches the minimum viscosity required. Mixing time varies with fuel temperatures, e.g. with 70 percent diesel/30 percent gas the mixing times would be 29 minutes at 10°C (50°F) and 18 minutes at 21°C (70°F). The recommended amount of powder is 0.45 kg (1 lb) per 75.7 L (20 gal) of fuel. It takes 2.2 kg (4.8 lbs) of powder when using a 208 L (55 gallon) tank. The fuel must be secured and managed to ensure worker and animal safety to prevent direct exposure and/or fire. The fuel should be stored away from flammables (Jones, 2004).

In situations requiring continuous operation, two Terra Torch Model 2400 units with 240-gal tanks, a 50 ft fuel fill hose for transferring fuel from one unit to the other, and the terra torch gun with 25 ft of hose could be used. One unit could serve as a support unit, mixing and transferring, while the other continuously fired (Firecon, 2002; Jones, 2004).

Time considerations

The amount of construction or response time required for the use of napalm should be minimal if the delivery units or torches are available.

Remediation requirements

Site remediation should be similar to pyre or trench burning methods. No reports as to the amount of ash or residues were found in the literature. Napalm was used to decontaminate the surrounding soil after carcass disposal in Nevada, and potentially could be used to "sanitize" a site after other types of remediation were used (Anderson, 2004).

Cost considerations

Estimated costs of using napalm for carcass disposal are $25 to $30 per animal, but would depend on the cost and temperature of available fuel and on the size of animal. The price of aluminum soap powder varies from $4.60 to $5.30 per pound. The disposal of large numbers of carcasses may be more efficient than dealing with small disposal situations (Anderson, 2004).

The delivery equipment outlined above for continuous operation (large Model 2400 Batch Mixer/Terra Torch with 240 gallon (skid mount) tank, a 50 ft fuel fill hose, Terra Torch Gun, and 25 ft hose) costs approximately $14,700 (Firecon, 2002; Jones, 2004).

Disease agent considerations

Biosecurity issues are largely unknown at this time; however, it is thought that the high temperatures generated by napalm should destroy most pathogens. The fate of prions is unknown and would need to be determined if the use of napalm were to become more common.

Implications to the environment

If handled improperly, napalm fuel could contaminate soil or groundwater, just as other petroleum-derived products can. Smoke and particulates resulting from carcass burning could affect air quality, and ash remaining after burning could be a potential groundwater contaminant. Substituting kerosene for diesel fuel in the mixture may reduce the black smoke (Anderson, 2004). No studies of the environmental effects of napalm could be found in the literature reviewed. Transportation of napalm on public roads may be of concern to public safety agencies and would need to be addressed.

Advantages and disadvantages

Napalm is easy to manufacture, burns at higher temperatures than fuels such as gasoline, and destroys carcasses more quickly than with conventional pyres. The logistics of mixing, delivery, and storage of napalm for carcass disposal pose the greatest challenge. Guidelines for the selection of materials, transport, and implementation would need to be developed.

Concerns include smoke and particulates that could affect air quality. Ash remaining after burning could be a water quality concern. Worker safety and the potential fire hazard posed by storing, handling and using napalm must also be considered. Constraints on the use of napalm are poorly understood at this time, but should be limited only by the availability of napalm and its application equipment and by the space available at the disposal site.

3.5 – Ocean Disposal

Ocean disposal of carcasses was proposed after Hurricane Andrew swept through North Carolina recently. The North Carolina Department of Agriculture reported that the US Environmental Protection Agency (EPA) did not have regulations governing the disposal of animal carcasses beyond territorial limits (D. Wilson, 2003). The Coast Guard states the method can be used as long as there is no floating debris. The EPA has assessed the types and origins of floatable debris and has limited the disposal of animal carcasses related to specific medical research (US EPA, 2002). The disposal of animal carcasses near land can promote the presence of scavengers that can interfere with human activities. Open disposal of large quantities of animal processing waste could result in dead zones in the ocean, and has prompted some animal processors to look for other methods of managing animal remains (Iwamoto, 2003).

General process overview

Carcasses would be loaded onto open barges or into containers, floated beyond territorial limits, and emptied overboard. Eliminating all floating debris may require some sort of packaging or pre-processing.

Personnel requirements

Personnel needs have not been determined, but could be substantial if it only occurs due to a one-time mortality event.

Location considerations

Areas proximal to ports and a designated handling area would need to be identified. Transfer sites at ports that do not disrupt other commerce would need to be identified.

Resource requirements

Barge operators could supply equipment for water transportation. Land transportation schemes would also need to be developed for safe movement of animals to seaports.

Transportation and decontamination would be required for each vessel and truck. Enclosed, secure transportation to prevent contamination or access by sea birds would be required. Carcasses may need to be ground in order to prevent floating.

Time considerations

Capacity constraints are unknown, but should be dependent on the acceptance rate of aquatic life in the region of interest.

Remediation requirements

Potential site remediation would include decontamination of equipment used to transport mortalities.

Cost considerations

One source has estimated the cost of ocean disposal at $1 per ton (D. Wilson, 2003). However, no indication was provided as to whether this estimate included shipping terminal fees and all related transportation costs.

Disease agent considerations

Ocean dumped carcasses should probably exclude disease-related mortalities, especially if the mortalities are from commercial aquaculture operations.

Implications to the environment

The mortalities should provide a protein and energy source for aquatic life in the area.

Specific environmental impacts are not fully defined, but will likely be minimized if steps are taken to ensure there is no floating debris resulting from disposal. Secure transport and temporary storage must be provided.

In addition, nutrient loading limits at the ocean disposal sites need to be defined to reduce potentially negative environmental impacts.

Advantages and disadvantages

Ocean disposal provides a means to rapidly dispose of carcasses from a large die-off with no noticeable residues. It also holds the potential of adding needed protein to the ocean food chain, assuming the transport container is punctured before disposal. There is, however, the potential to overload a disposal area. Effective transport distances are not clear. Carcasses must be handled twice. Carcasses should be in sealed containers during transport and storage prior to disposal. It is unclear at this time if disease could re-enter the domestic bird or animal production system through birds or harvested fish.

Concerns over floating debris and determinations of the maximum acceptable nutrient loading for areas of intent in the ocean need to be dealt with. Utilizing inert, disposable containers that will not float should be explored. Roll off dumpsters with sealed plastic liners could be used for transportation from a farm site. The dumpster could be loaded onto a barge and taken to the disposal site off-shore. The question of whether a loaded sealed liner of carcasses would sink or float without modification would need to be explored.

3.6 – Non-Traditional Rendering

Instead of using conventional rendering procedures, ground non-disease related mortalities can be converted into a feedstuff by fluidized-bed drying, flash dehydration, or extrusion. These technologies were studied at North Carolina State University's Animal and Poultry Waste Management Center and could emerge as economical and environmentally-sound alternatives to conventional rendering of dead pigs. The following provides an overview of the "flash dehydration" process:

> In fluidized-bed drying or flash dehydration, the material flows along a channel of super-heated air. Flash dehydration can be used to dry many types of wet wastes, but it is most applicable for drying animal by-products and offal. Depending on the moisture and fat contents, ground swine mortality carcasses must be blended with an organic carrier to facilitate the flash dehydration process.
>
> (Nesbitt, 2002)

Extrusion and expeller press processing was studied by Middleton, Nesbitt, Boyd, and Ferket (2002) who reported that the processes have been used for a number of years in the soybean industry to fractionate oil from soybean meal, resulting in two high-value products. They evaluated the feasibility of the technology for swine and poultry carcasses.

Middleton et al. (2002) used flash dehydration followed by extrusion and the expeller press extraction of fats and oils. The compositions and material handling characteristics of all resulting products (meals and oils) were studied and their value in broiler diets was determined by least-cost linear programming. A financial *pro forma* for a model county-based cooperative facility employing these technologies was developed.

> It has been used to process human foods for more than 50 years, producing 13 billion pounds of product with a market value of $8 billion annually. If extrusion is used to process carcasses it will most likely be done centrally because of capital costs. However, if it can also be used on site to extrude full-fat soybeans and creep feed, individual farms may be able to justify the cost.
>
> (Middleton et al., 2002)

Morrow and Ferket (2001 & 2002) go on to explain the principles involved in extrusion as follows. They report that finely-ground, high-moisture material is mixed with an organic carrier to a moisture content of about 30% and then subjected to processing by friction heat, shear, and pressure within the dry extruder barrel. In the extruder barrel, a screw (or screws) forces the material through a series of flanged steam locks where temperatures range from 115-1,550°C (239–2,822°F) and pressures of 20-40 atmospheres develop within 30 seconds. The sudden decrease in pressure as the product leaves the extruder causes it to expand and lose 12-15% of its moisture. The food industry mostly uses single screw dry extruders because they are about 50% less expensive, in terms of capital and operating expense. However, double-screw systems can better cope with the high moisture ingredients and therefore may be more appropriate for dead pig disposal.

Personnel requirements

This is a complex process and the labor requirements can be expected to be at a relatively high skill level.

Location considerations

Due to the size of current equipment and the supporting infrastructure, fluidized-bed drying, flash dehydration, and extrusion are not transportable. A fixed processing site with good truck access would be required and carcasses would be transported to the facility.

Resource requirements

Current equipment can evaporate 500 gal of water per hour, using approximately 1300 BTUs per pound of water evaporated. In drying dead pigs, higher efficiencies have been documented, perhaps because the equipment burns some of the more volatile fats in the pigs (Nesbitt, 2002).

Time considerations

These units are built to order and would need to be constructed in advance of a disaster and operate on a daily basis, processing feedstock, to be economical and viable.

Remediation requirements

The high temperatures and short dwell times of flash dehydration cause little damage to protein quality, resulting in superior protein digestibility. If sterilization of the product is required, the meal can be dehydrated to about 10% moisture and subjected to extrusion processing (Nesbitt, 2002).

In situations where this system can neutralize disease agents or in the case of a natural disaster, the resulting material could be used as a protein source, rendered, used in a composting system, deposited in a landfill, put in cold storage for further processing, or utilized an energy recovery system such as in a fixed hearth plasma arc furnace or a thermal depolymerization oil recovery system. Prior planning for the recovery of animal or plant nutrients or energy could reduce costs as well as the effects on the environment and provide a useable output.

Cost considerations

While the operational costs of using flash dehydration followed by extrusion to recycle carcasses appear to be economically sustainable, the process is unlikely to attract outside investors since the time to recover capital expenditures ranged from 11.41 to 48 years. The addition of the expeller press technology could be expected to increase the capital costs and reduce the annual profits for the plant even further. Extrusion is not a new technique, having been used in the food industry for some time.

The cost to dehydrate turkey mortalities to 20% moisture is about $27 per 907 kg (1 ton) of final product, and $40 per 907 kg (1 ton) if followed by extrusion. These estimates assume $1.10 per 3.8 L (1 gal) for fuel, $0.12 per kWh, and $0.75 per 907 kg (1 ton) for maintenance (Nesbitt, 2002).

Disease agent considerations

Bacteria, molds, and viruses are readily inactivated by extrusion (Morrow & Ferket, 2001). No reference to survival of prions during the extrusion process could be found in the literature.

Implications to the environment

In the situation where a disease agent can be neutralized by this process, the resulting material could be used in a composting system, deposited in a landfill or utilized an energy recovery system such as in a fixed hearth plasma arc furnace or a thermal depolymerization oil recovery system. The recovery of plant nutrients or energy would reduce costs and the effects on the environment.

Advantages and disadvantages

One advantage of this system, in situations where TDEs are not a concern, is that it offers the ability to process solids and liquids with the same machinery. Manure solids, or contaminated feed could also be processed for further disposal.

Disadvantages are its lack of portability, high initial cost, and the need to transport feedstock to a central processing site unless a unit is located on a farm where it is used for processing soybean meal or other feed products. Another disadvantage of this system may be its inability to neutralize TDE agents.

3.7 – Novel Pyrolysis Technology (*ETL EnergyBeam™*)

Energystics Technologies, Ltd. has developed a novel pyrolysis technology, called *ETL EnergyBeam™*, that uses a proprietary technology to concentrate and direct electromagnetic waves at solid, liquid, or gaseous targets (Sheperak, 2004). Rather than converting electrical energy to thermal energy in a conductive medium, this technology directly couples electromagnetic energy with a target material to produce heat. The target absorbs energy, generating temperatures that exceed the melting or vaporization points of the target materials. These temperatures provide the ability to disassociate strong molecular bonds in hazardous materials. Because the technology does not utilize a conductive medium, only a relatively small energy input is required (e.g., requires 400 Watts to vaporize/sublime pure tungsten rods at 3,370°C [6,098°F], compared with a home hair dryer which uses 1,200 Watts to heat air). Advantages of the technology reportedly include instantaneous, controllable heating, a lack of hydrocarbon pollutants or harmful emissions, and reduced energy requirements. Additionally, the technology is reportedly scalable and lends itself to continuous operation and automation. However, the technology has yet to be tested on actual intact carcasses.

Studies at the University of Toledo demonstrated the feasibility of the system for destroying polychlorinated biphenyls, with temperatures outside the coupling zone observed to be in excess of 1,690°C (3,074°F) (Sheperak, 2004). Therefore, the system generates temperatures believed to be adequate for destruction of pathogens, including prions. As a demonstration of the application for animal tissue, a 20-gram sample of beef tissue was pyrolized, resulting in complete dematerialization of the tissue and no visible residues or smoke (Figure 5).

Because the technology is scalable, a system could reportedly distribute energy to carcasses through a unique nozzle design within a pyrolysis chamber. The developers believe carcasses could be efficiently introduced into a unit and any remaining sediment could be removed from the bottom of the unit after pyrolization. Based upon existing empirical data, the developers anticipate that the unit will efficiently eliminate carcasses as well as any hazardous chemical or biological materials (Sheperak, 2004).

An alternative use of the technology is as an "afterburner" for stack gases of existing incinerators to provide additional assurance of destruction of hydrocarbons and pathogens. This application could reduce the capital expense associated with retrofitting existing incineration units to meet more stringent EPA emission requirements.

FIGURE 5. Pyrolysis of a 20-gram sample of beef tissue using the *ETL EnergyBeam™* (purple/white area) technology (Sheperak, 2004).

Section 4 – A Proposed Model Integrated Disposal System

This report concludes that pre-processing of carcasses on-site decreases biosecurity concerns and increases the number of process options available to utilize mortalities, especially in cases where large scale disposal of carcasses is necessary. If biosecurity can be maintained, processing carcasses on-site would allow neutralization of most pathogens and transportation to a central location where further processing could occur. Figure 6 shows animal production concentrations in Indiana, and demonstrates the potential central location of processing plants, based on transportation times. Figure 6 shows GIS coverage that includes confined feeding operations, cities, and roads in Indiana. Concentrations of animals in certain parts of the state would suggest that two locations—Fort Wayne and Columbus, for instance—would be ideal spots for central processing facilities should large-scale mortality events affect the state. Each of these cities is located in the midst of significant concentrations of livestock. A similar process can be used in other states to avoid moving mortalities across state lines.

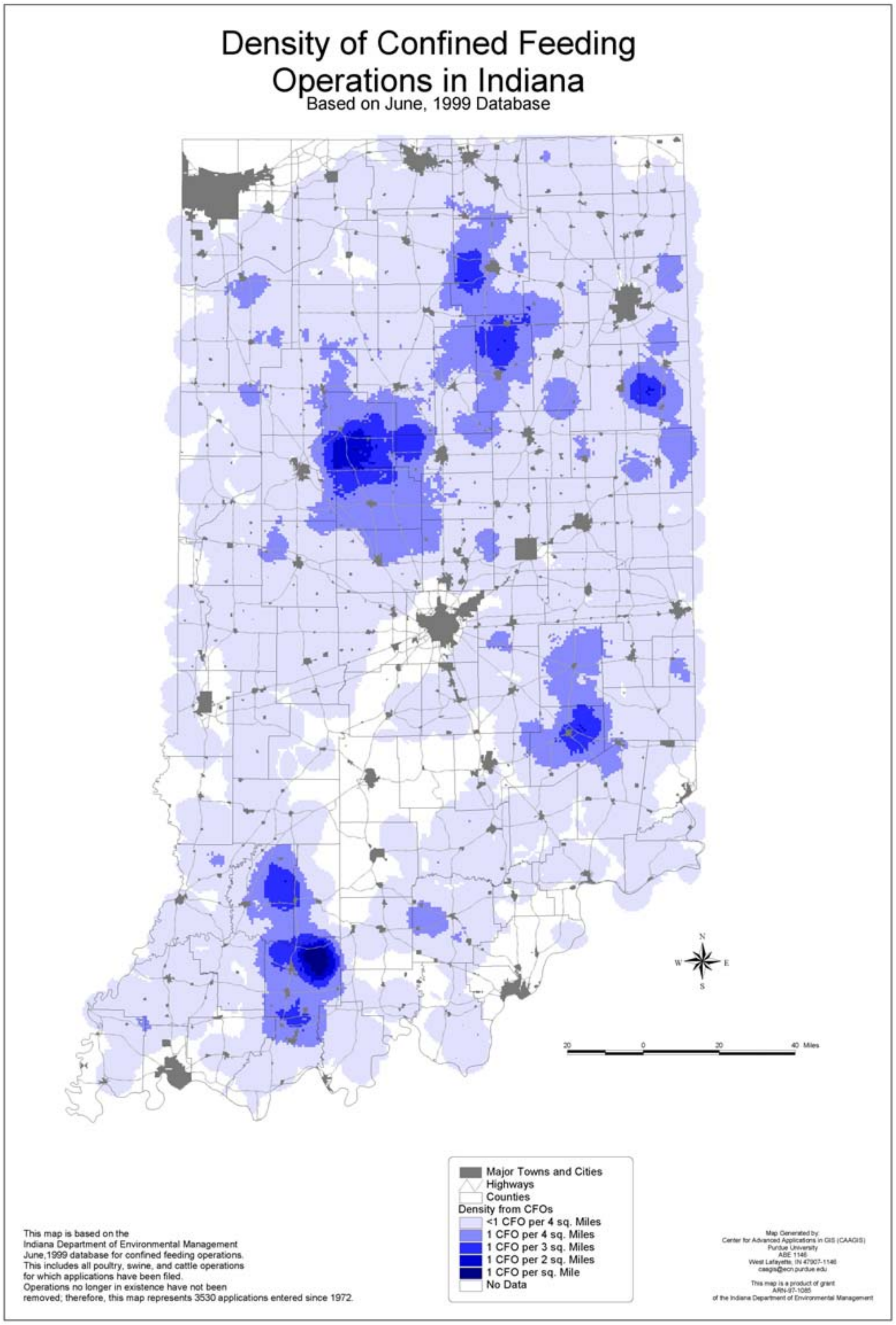

FIGURE 6. Map of Indiana, showing concentration of confined feeding operations (map obtained by the authors).

4.1 – Example: Grinder-Dumpster System for Pre-Processing and Stabilization of Mortalities

The following system represents a variation of the WR$^{2®}$ STI Chem-Clav process, extended to include sealed, secure transport of pre-processed carcasses.

System components

The following system components have been compiled from Stikeleather and McKeithan (1996).

1. Power plant installed in separate containment pan to retain oil or fuel spills
2. Hydraulic pump to drive sheep's foot rollers, shredders, and/or grinder
3. Hydraulic drive for covered variable speed control – reversible feed of sheep's foot rollers and/or grinder
4. Screw grinder from US Patent 5,547,420 – modified to handle bone fragments of full size bovine
5. Hydrogel or quicklime to mix with ground carcasses to aid in flow characteristics and act as a carrier for disinfectant
6. Large peristaltic pump or screw conveyor if needed to move material (pre-processed carcasses in hydrogel) to final processing or to transport trucks
7. Complete skid system suitable for transport on a flatbed semi-trailer with a containment pan to retain waste liquids for disposal
8. Transport system to be comprised of vacuum tanker or plastic lined roll-off dumpsters

System specifications

1. Desirable processing speed – at least 20 bovine carcasses per hour
2. Volume above sheep's foot rollers = 2 x maximum size bovine to allow for 1 animal to be dropped into the hopper and let the doors close above it
3. End panels of upper – removable for roller removal and cleaning
4. Upper hopper with spring loaded or hydraulically controlled doors that close after an animal is loaded
5. Standard 55' flatbed trailer for transport of roll-off container to central processing
6. Vinyl liners (for roll-off containers) – 10 mil form-fitted bag – from Packaging Research and Design Corp. 800-833-9364

Size	Price
20 yd^3 (15.3 m^3)	$23.00
30 yd^3 (22.9 m^3)	$29.34
40 yd^3 (30.6 m^3)	$32.49
19,000 currently in stock	

7. Utilize Milwaukee® Heat gun or equivalent– seal & tarp or 3M Spray Adhesive

Comment on specification #6 (vinyl liners):

a) Crushed contaminated concrete has been loaded into 10 mil liner, sealed and hauled without damaging the liner

b) Similar liners have also been used at the Hanford, WA nuclear site for the demolition process for contaminated soil

c) Roll off containers easy to fit with liners because of their standard sizing. It is more difficult to fit a semi trailer however.

d) Another alternative source for liners:

Extra Packaging Corp. 888-353-9732

This product is composed of a flat sheet (not fitted for the roll-off container) from Mexico.

The system described above could prepare carcasses for transport to a central processing facility. More expensive and more complex processing options would be available under this decentralized-centralized approach if the processing option chosen is also able to continue operating with other feedstock during times when carcasses are not available, as shown in Figure 7. Thermal depolymerization and plasma arc appear to hold the most promise in this regard since they utilize not only mortalities but also other organic matter to produce energy. Both processes are relatively new and require additional research, but both should have potential in agricultural areas where large amounts of organic feedstock are available for the production of petroleum-like products.

Specifically, the following model is proposed here, as shown in Figure 7:

On-site Pre-processing: Grinding of the carcasses into a paste at the animal production site.

Transportation: Loading the mortality paste produced into sealed roll-off containers and transport to a centralized plant.

Central Processing: Utilization of the mortality paste as a feedstock in a centrally-located, continuously-operated plant that is capable of converting organic matter into oil and methane.

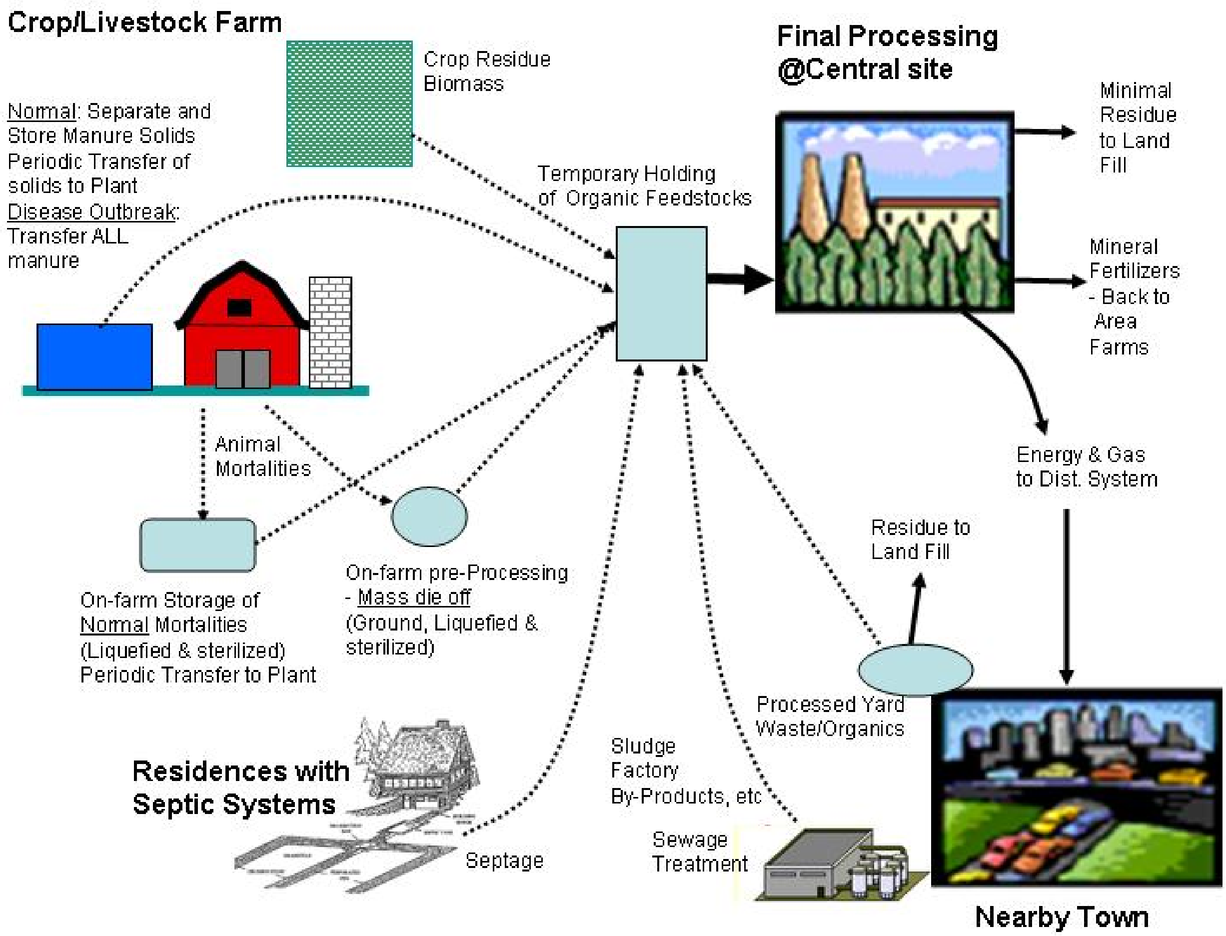

FIGURE 7. Schematic of area-wide comprehensive rural organic processing system. In this scenario, carcass composting becomes only a part of the feedstock.

Section 5 – Critical Research Needs

Much is known about carcass disposal systems; however, many knowledge gaps remain. The list below shows the critical research needs that remain:

1. Investigate the capacity and biosecurity of existing refeeding (e.g., alligator refeeding) operations to accommodate large-volume, temporary input from large-scale mortality incidents.
2. Identify cost information and feasibility of alternative methods of on-farm processing of large and small animal die-off events.
3. Study the feasibility of transporting and storing partially stabilized, pre-processed carcasses.
4. Identify the likelihood of pathogen survival under each of the processing systems.
5. Identify cost information and feasibility of processing ground mortalities using centralized versus mobile plants that employ thermal depolymerization and plasma arc technologies.
6. Investigate the economic sustainability and technical feasibility of centralized plants that would play a role in processing carcasses from rural areas.

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Introduction to Part 2 – Cross-Cutting & Policy Issues

A number of issues beyond the carcass disposal technologies themselves require appropriate consideration; in order to make sound decisions, decision-makers must balance the scientific, economic, and social issues at stake. Part 2 of this report therefore examines carcass disposal from the perspective of a host of cross-cutting issues: economic and costs considerations, historical documentation, regulatory issues and cooperation, public relations efforts, physical security of carcass disposal sites, evaluation of environmental impacts, geographic information systems (GIS) technology, decontamination of sites and carcasses, and transportation.

As this introduction sets forth, there are numerous issues that will impact large-scale carcass disposal decisions. For any policy designed to provide decision-making guidance, it is necessary to identify the numerous factors that must be considered. Historical documentation of events related to large-scale carcass disposal will prove invaluable to decision-makers facing this dilemma. The selection of the appropriate technology must incorporate the scientific basis for the technology along with the associated needs of security, transportation, location, and decontamination. An understanding of the regulatory factors, the importance of agencies and other entities to work together, and the consideration of public opinion are all key to successfully handling a carcass disposal emergency. Decision-makers must understand the associated economic costs as well as the environmental and societal impacts.

To convey the relevance of these cross-cutting issues, this introduction considers four episodes of historical carcass disposal experience, and then extracts from these episodes preliminary lessons regarding each cross-cutting issue. Subsequent chapters (chapters 9-17) follow and, issue-by-issue, provide more analysis.

Historical Experience

United Kingdom – foot and mouth disease

In 2001, the United Kingdom (UK) experienced an outbreak of foot and mouth disease (FMD), which has, to date, provided the best "lesson in history" on large-scale carcass disposal. The UK government faced the challenge of disposing of a large number of carcasses with limited disposal resources in a tight time frame. In June 2002, the National Audit Office (NAO) published a summary on the 2001 outbreak of FMD. The NAO report summarizes the governmental issues related to the disease outbreak, including carcass disposal. The 2001 epidemic lasted 32 weeks, impacted 44 counties, invaded over 2,000 premises, and impacted the sheep, swine, and cattle industries. During the height of the outbreak, an average of 100,000 animals were slaughtered and disposed of each day in a large and complex operation. In total, more than six million animals were slaughtered over the course of the outbreak for both disease-control and welfare reasons (NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002). In the areas where less infection occurred, authorities were able to keep up with the disposal needs. However, in the worst-hit areas, there were long delays in the slaughter and disposal of infected and exposed animals. The existing contingency plan simply did not allow for sufficient handling of a situation of that scale (NAO, 2002; Hickman & Hughes, 2002).

In the UK, the Department for Environment, Food and Rural Affairs (DEFRA, formerly the Ministry of Agriculture, Fisheries and Foods) maintained lead responsibility for the FMD outbreak and disposal of all animals. DEFRA's organizational structure in regards to Animal Health is comprised of a policy-making wing and an operational wing, the State Veterinary Service. A variety of other departments and agencies also participated in managing the outbreak and producers, contractors, and other stakeholders assisted as well (NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

DEFRA's veterinary officers initially directed the disposal operations. About a month after the outbreak was detected, it was determined that the State Veterinary Service could not handle all aspects of the epidemic and additional organizational structures were created. Broadening the cooperative structure gave state veterinarians more time for veterinary work, especially for slaughter and disposal management. Increasing the role of other agencies and departments took time, but other government entities, local agencies, voluntary organizations, and other stakeholders made critical contributions to stopping the spread of FMD. The military was not immediately involved but within a month began to play a key role in the slaughter, transportation, and disposal of animals (NAO, 2002).

Timely slaughter is critical to disease control. While rapid disposal of infected and exposed carcasses may not be crucial in controlling the spread of some diseases, it can be if it holds up the slaughter process (NAO, 2002).

The magnitude of the FMD epidemic made carcass disposal a serious problem. In addition, the massive scale of disposal required by destroying livestock on both infected and "exposed" farms led to problems in disease control, communication, and public perception (Cumbria Foot and Mouth Disease Inquiry Panel, 2002). By mid-April, a backlog of 200,000 carcasses awaiting disposal existed. During the first seven weeks of the epidemic, it was commonplace for dead animals to remain on the ground awaiting disposal for four days or more. The scale of the epidemic combined with resource shortages in both animal health officers and leak-proof transport for off-farm disposal contributed to the problem. The risk of disease spread resulting from off-farm disposal and the need for "robust biosecurity protocols" to minimize virus spread during transport and subsequent disposal was of major concern. The shortage of environmentally suitable and safe disposal sites also led to the delay (NAO, 2002; Hickman & Hughes, 2002).

The legal and environmental framework for disposal of carcasses and animal by-products had changed significantly since the UK's previous outbreak in 1967-68. Plans recognized that disposal methods needed to meet these environmental constraints and be acceptable to the UK Environment Agency and local authorities. Slaughter at a location close to the infected premises was critical to slowing the spread of the disease. At that time, on-farm burial was initially considered the preferred method followed by on-farm burning. However, on-farm disposal proved to be impractical because of environmental constraints and high water tables. In mid-March 2001, the Environment Agency began conducting rapid (within 3 hours) groundwater site assessments and advised on appropriate disposal. The Environment Agency also approved a disposal hierarchy for different species and age of stock. In addition, the Department of Public Health issued guides on how the risks to public health could be minimized. The stakeholders then agreed on a disposal hierarchy that attempted to protect public health, safeguard the environment and ensure FMD disease control. Cost was a material but much less important factor. This new focus on environment and public health was substantially different from the initial approach based on animal health risks and logistics (NAO, 2002; Hickman & Hughes, 2002).

Rendering and fixed-facility incineration were preferred, but the necessary resources were not immediately available and UK officials soon learned that the capacity would only cover a portion of the disposal needs. Disposal in commercial landfills was seen as the next best environmental solution, but legal, commercial, and local community problems limited landfill use. With these limitations in mind, pyre burning was the actual initial method used but was subsequently discontinued following increasing public, scientific, and political concerns. Mass burial and on-farm burial were last on the preferred method list due to the complicating matter of bovine spongiform encephalopathy (BSE) and the risk posed to groundwater (Hickman & Hughes, 2002). The hierarchy and case-specific circumstances determined the methods utilized. Decisions were impacted by the availability of nearby rendering capacity, the relative risks of transporting carcasses, and suitability of sites for burial and burning. Even with the new hierarchy in place, burial and burning remained common choices because of the need to slaughter expeditiously and limit transportation of carcasses. Overall, burning was the most common method of carcass disposal (29%), followed by rendering (28%), landfill (22%) and burial (18%) (NAO, 2002; Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

TABLE 1. UK 2001 FMD outbreak – approved disposal routes for different species and age of stock (NAO, 2002).

Preferred Method of Disposal	Permitted Animals
Rendering	All
High-temperature Incineration	All
Landfill, on approved sites	Sheep, pigs of any age & cattle younger than 5 (due to BSE concerns)
Burning	All (with a limit of 1,000 cattle per pyre)
Mass Burial or approved on-farm Burial	Sheep, pigs of any age & cattle younger than 5 (due to BSE concerns)

Huge logistical problems developed in the disposal of millions of slaughtered animals. DEFRA cited problems with all disposal methods. Rendering was unavailable until rendering plants complied with necessary biosecurity protocols and transportation vehicles were adequately sealed. In March 2001, protocols for biosecurity of rendering plants and vehicles were approved. However, until late in the epidemic, the rendering plants could not handle the necessary capacity. High-temperature incineration was also difficult to utilize because the facilities were committed to the disposal of BSE-affected cattle. Air-curtain incinerators were used on occasion. Landfill operators and local communities were resistant to the use of landfills for disposal because they were often located near large population centers. While 111 suitable facilities were identified, only 29 were utilized. Over 950 locations were used for burning with most located on-farms. However, the use of mass pyres generated a negative response from the media and devastated the tourism industry. These mass burnings ended in two months because of public opposition. Mass burial was the selected alternative when carcasses began to pile up. However, public protests and technical problems—such as seepage of carcass liquid—resulted when 1.3 million carcasses were disposed of in mass burial sites. Regardless of public concerns, the efforts of DEFRA, the Environment Agency, the military, and others helped eliminate the backlog of carcasses (NAO, 2002).

Carcass disposal was a highly controversial issue. Public backlash, especially in response to burning and mass burial, was significant and long-term economic impacts remain in question. DEFRA's Contingency Plan for future FMD outbreaks is to use commercial incineration for the first few cases, followed by rendering and then commercial landfills. The plan would include agreements ensuring minimum rendering capacity and use of national landfill sites. DEFRA also stated that it is unlikely that pyre burning or mass burial would be used again (NAO, 2002). Burning of carcasses on open pyres was an enormous task requiring substantial materials and generating significant amounts of ash for disposal. These pyres were viewed unfavorably by local residents and producers. The images of burning carcasses were broadcast via television around the world and likely contributed to the wider economic damage, especially to the tourism industry. Local residents disliked mass burial as well. The general public reacted most positively to the rendering alternative (Rossides, 2002). At the beginning of the outbreak, the priority was to eradicate the disease. While the Department realized cost control was important, it was also clear that all steps to stop the disease needed to be taken regardless of expense (Hickman & Hughes, 2002).

NAO offered multiple recommendations for future contingency plans. One example of their recommendations is to develop a clear chain of command with defined responsibilities, roles, reporting lines, and accountabilities. They also recommended researching the effectiveness and efficiency of disposal methods of slaughtered animals and continually inspecting and monitoring the environmental impacts of disposal sites (NAO, 2002).

In response to the Government-commissioned inquiries, the UK Government notes the need for multiple strategies for different disease situations. The Government is committed to reviewing preventive culling and vaccination policies. The Government also noted that the disposal hierarchy in its current contingency plan differs from the hierarchy agreed upon during the actual FMD outbreak by the Environment Agency and Department of Health. The new plan states that first preference will be commercial incineration followed by rendering and disposal in licensed landfills. Mass burn pyres are not advised and on-farm burial will only be used if demand exceeds capacity of the preferred options (Anonymous, 2002).

Further review of the environmental impact by the Environment Agency found 212 reported water pollution incidents, mostly minor, and only 24% were related to carcass disposal. None of the pollution problems were on-going problems in private or public water supplies. Additional monitoring has not shown any ongoing air quality deterioration, and concentrations of dioxins in soil samples near pyres are the same as before the outbreak (UK Environment Agency, 2002).

Taiwan – foot and mouth disease

In 1997, Taiwan experienced an outbreak of FMD that resulted in slaughter and disposal of about five million animals. Carcass disposal methods included burying, rendering, and incineration/burning. With the disposal choice very dependent on farm locations, burial in landfills (80% of carcasses) was the most common method. Swine producers were allowed to send hogs to nearby rendering plants. High water tables and complex environmental regulations complicated disposal. In areas where water resources were endangered, incineration (with portable incinerators or open burning) was the only approved method. Army personnel completed the majority of the disposal work. At the peak of the crisis, disposal capacity reached 200,000 pigs per day. The eradication campaign lagged well behind the identification of potential FMD cases, causing many farms to wait from one to four weeks before animals could be slaughtered. The delay was blamed on lack of manpower and equipment, and large-scale death loss experience combined with the difficulty of disposal. The manpower shortage was alleviated with military assistance. The disposal method selected was dependent on the availability of landfill sites, level of the water table, proximity to residences, availability of equipment and other environmental factors. Major issues related to carcass disposal included the number of animals involved, biosecurity concerns over movement of infected and exposed animals, people and equipment, environmental concerns, and extreme psychological distress and anxiety felt by emergency workers (Ekboir, 1999; Ellis, 2001; Yang et al., 1999).

United States – natural disasters

Two natural disasters, floods in Texas in 1998 and Hurricane Floyd in North Carolina in 1999, have provided similar yet smaller-scale carcass disposal experience. Dr. Dee Ellis of the Texas Animal Health Commission reviewed these two disasters, collected data, and performed numerous personal interviews (Ellis, 2001). His findings are summarized below.

In October 1998, torrential rains in south central Texas resulted in the flooding of the San Marcos, Guadalupe, San Antonio, and Colorado River Basins. Over 23,000 cattle were drowned or lost in addition to hundreds of swine, sheep, and horses. The Texas Animal Health Commission (TAHC) worked with state emergency personnel from the Governor's Division of Emergency Management, the Texas Department of Transportation, and the Texas Forest Service to manage the disposal of animal carcasses. Local emergency response personnel played integral roles in the actual disposal process. Most animal carcasses were buried (where found if possible) or burned in air-curtain incinerators. Two air-curtain incinerators were utilized. One difficulty that arose was finding a burn site that was not located on saturated ground. Some carcasses were inaccessible and began to decompose before actual disposal could take place. According to Ellis, the main carcass disposal issues were (1) lack of prior delineation or responsibilities between agencies, (2) non-existent carcass disposal plans and pre-selected disposal sites, (3) a short window of time to complete disposal, (4) minimal pre-disaster involvement between animal health and local emergency officials, and (5) inaccessibility of some carcasses (Ellis, 2001).

In September 1999, Hurricane Floyd devastated North Carolina. The hurricane, combined with prior heavy rains, resulted in the worst floods in state history. Animal loss was estimated at 28,000 swine, 2.8 million poultry, and 600 cattle. Disposal of dead animals was coordinated by the North Carolina Department of Agriculture. Costs were partially subsidized at a cost of $5 million by the USDA's Emergency Watershed Protection program. The North Carolina State Veterinarian coordinated disposal to ensure safety for both human health and the environment. Major problems related to carcass disposal included contamination of drinking water sources, fly control, odor control, zoonotic disease introduction, and removal and transport of carcasses. These problems were compounded in the cases of highly concentrated swine and poultry losses on heavily flooded property. The order of preference for disposal in North Carolina is rendering, burial, composting, and incineration. However, rendering capacity was so limited that it was not a viable option. Burial was the most widely used option and was utilized for 80% of the swine, 99% of the poultry, and 35% of the cattle. Incineration was used for the remainder of the carcasses. Most burial took place on the land of the livestock producers. They were offered a financial incentive to bury on their own land in order to minimize transport of carcasses. However, this process led to additional environmental concerns as producers often buried carcasses in saturated ground that allowed carcass runoff to leach back into ground water or local water resources. This threat caught the attention of both environmental watch groups and the national media, resulting in a study group that created a multi-agency approach and animal burial guidelines for future use. Ellis noted the major issues in North Carolina to be (1) high number of dead swine located near populated areas, (2) environmental threats to groundwater and water resources, (3) interagency jurisdictional conflicts, (4) lack of well-developed carcass disposal plans, and (5) minimal involvement of animal health officials with the state emergency management system (Ellis, 2001).

United States – chronic wasting disease

In February 2002, chronic wasting disease (CWD) was identified in whitetail deer in southwest Wisconsin. CWD is a transmissible spongiform encephalopathy (TSE). In order to control the disease, a 360-square-mile disease eradication zone and surrounding management zone were developed. All deer within the eradication zone were designated for elimination, and deer in the surrounding area were designated to be reduced. Many of the deer were destroyed by citizen-hunters, who were not permitted to use the deer for venison. Disposal methods were selected that do not endanger animal or human health or environmental quality. Selected methods had to be able to handle a large number of carcasses and comply with regulations. Cost was also a consideration, and it is anticipated that disposal costs will be one of the most significant expenses of the CWD control program. The four preferred methods used were landfilling, rendering, incineration, and chemical digestion (alkaline hydrolysis) (Wisconsin Department of Natural Resources, 2002).

Lessons Learned Regarding Cross-Cutting and Policy Issues

The historical experiences related to large-scale carcass disposal have provided "lessons" from which the livestock industry and regulatory agencies can learn. Many of these lessons are discussed in terms of the cross-cutting and policy issues addressed in subsequent chapters:

- **Economic & Cost Considerations.** Any large-scale animal death loss will present significant economic costs. The disposal of large numbers of carcasses will be expensive and fixed and variable costs will vary with the choice of disposal method. In addition, each method used will result in indirect costs on the environment, local economies, producers, and the livestock industry. Decision-makers need to better understand the economic impact of various disposal technologies. Broader policy considerations involving carcass disposal and a large-scale animal disaster need to be identified and discussed as well. Chapter 9 discusses these issues.
- **Historical Documentation.** An important resource for the development of a carcass disposal plan is historical documentation from previous large-scale animal death losses. However, serious deficiencies exist in historical documentation of past events and significant variances occur among agencies relative to

planning, experience, and preparation for a catastrophic event. Chapter 10 examines the state of historical documentation of past carcass disposal events within the United States and explores the potential for developing a Historic Incidents Database and Archive (HIDA).

- **Regulatory Issues and Cooperation.** Previous experiences dictate that strong interagency relations and communications are critical to effectively dealing with a large-scale animal disaster. Federal, state, and county regulations related to carcass disposal may be unclear or perhaps in conflict with one another. Interagency issues may result in additional problems or the extension of the disaster. Steps must be taken to identify interagency relationship problems and develop a plan for dealing with large-scale carcass disposal. Chapter 11 identifies opportunities for agency coordination and plan development.

- **Public Relations Efforts.** A disaster-related animal death loss will cause significant public concern. Historical experience shows that the disposal of carcasses creates public dismay and apprehension. To facilitate positive public perception, decision-makers handling massive livestock mortality and carcass disposal must have access to expert public-information professionals and agree to make communicating with the public a top priority. Chapter 12 provides guidance to public information professionals, subject matter experts, and disposal managers to understand the role and importance of communicating with the public about large-scale carcass disposal.

- **Physical Security of Carcass Disposal Sites.** History suggests a need for security systems during carcass disposal operations. Examples of security threats related to carcass disposal include potential equipment theft, angry and discontented livestock owners and citizens, and unintentional animal or human activity. The most important aspect of security is keeping the disease from spreading from the site to other areas. A well-designed security system would control these issues. Chapter 13 identifies potential threats, security technology, and potential security designs.

- **Evaluating Environmental Impacts.** Carcass disposal events can result in detrimental effects on the environment. The specific impacts vary by carcass disposal technology, site specific properties of the location, weather, the type and number of carcasses, and other factors. To accurately determine the impacts of a specific carcass disposal event on the environment, environmental monitoring will be necessary. Chapter 14 provides an overview of monitoring that may be necessary or desirable to quantify environmental impacts for a carcass disposal event, and introduces models that may be useful in this regard.

- **Geographic Information Systems (GIS) Technology.** GIS technology should play a significant role in the management of mapped or spatial data prior to, during, and after carcass disposal events. At the simplest level, GIS can provide maps while, at the more complex level, can serve as a decision support capability. Chapter 15 contains an overview of GIS and how it has been used in recent livestock disease and carcass disposal efforts.

- **Decontamination of Sites & Carcasses.** Regardless of the carcass disposal method utilized, concern must be given to contain the disease and limit any potential disease spread. Decontamination will prove to be vital in this endeavor. The first, and most important, step in the process of decontamination is the identification of the disease agent present and assessment of the situation. Those involved must understand how the causative agent works and exactly how it spreads. Chapter 16 identifies various infectious agents, groups of disinfectants, and decontamination procedures.

- **Transportation.** The disposal of carcasses following a large-animal disease event will likely require transportation to an off-site disposal location. The transportation of large numbers of diseased animals or carcasses requires significant planning and preparation in order to prevent further dissemination of the disease. Chapter 17 focuses on critical issues related to transportation during a carcass-disposal event.

Chapters 9-17 serve as an overview of these cross-cutting and policy issues by highlighting critical information, summarizing available background material, offering recommendations to decision-makers, and identifying critical research needs.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

9

Economic & Cost Considerations

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Abbreviations

AI	avian influenza
APHIS	USDA Animal and Plant Health Inspection Service
BSE	bovine spongiform encephalopathy
CWD	chronic wasting disease
DEFRA	UK Department of Environment, Food and Rural Affairs
END	exotic Newcastle disease
FMD	foot and mouth disease
LWDS	livestock welfare disposal scheme
ROI	Renewable Oil International LLC
UK	United Kingdom
USDA	United States Department of Agriculture
$WR^{2®}$	Waste Reduction by Waste Reduction Inc.

Section 1 – Key Content

A complete and multidimensional strategy is necessary when planning for the disposal of livestock and poultry in the event of high death losses resulting from an intentional bioterrorism attack on agriculture, an accidental introduction of dangerous pathogens, or a natural disaster. A critically important part of that strategy is the ability to dispose of large numbers of animal carcasses in a cost effective and socially and environmentally effective manner.

While many technologies exist, the "best" method for carcass disposal remains an issue of uncertainty and matter of circumstance. Contingency plans must consider the economic costs and the availability of resources for the actual disposal, as well as numerous related costs. A complete cost-benefit analysis of alternative methods of disposal for various situations is a necessity to determine the "best" alternative.

This chapter (1) highlights previous carcass disposal experiences and costs, (2) summarizes costs and economic factors related to disposal technologies, (3) presents broad regulatory and policy issues related to carcass disposal, and (4) identifies future research needs.

In 2001, the United Kingdom experienced an outbreak of foot and mouth disease (FMD), which has, to date, provided the best "lesson in history" on large-scale carcass disposal. The Government faced the challenge of disposing of approximately six million carcasses with limited disposal resources in a tight time frame. The large scale of the epidemic made carcass disposal a serious problem. Total expenditures by the Government were estimated to be over £2.8 billion, with over £1 billion related to direct costs of control measures. This included £252 million for haulage and disposal.

During the 1997 FMD outbreak in Taiwan, approximately five million carcasses required disposal. The costs born by the government associated with the epidemic were estimated at $187.5 million, with expenses for carcass disposal of approximately $24.6 million.

In order to understand the economic issues related to carcass disposal, it is critical to understand the cost data available. An effective control strategy will not only limit disease spread but will keep direct and indirect costs low. There is relatively little data on the costs of carcass disposal, and consistency regarding both direct and indirect costs is lacking.

Various direct and indirect costs need to be identified, including those related to direct disposal, transportation, facilities and equipment, energy requirements, environmental impact, and social costs. Major economic factors and implications also need to be identified and the different disposal options need to be compared and contrasted. In this chapter, examples of direct costs are identified and potential indirect costs are discussed relative to each technology. Most existing data applies only to small-scale disposals, and few reliable cost estimates exist for large-scale disposal. In the case of a foreign animal disease outbreak or natural disaster, total actual costs are difficult to estimate. In addition, little to no attention has been paid to indirect costs of these technologies in previous research. The impact on the environment, land values, public opinion, and general economic factors must be evaluated and quantified as well. This type of economic analysis is critical to any decision-making process. Figure 1 summarizes the technology costs found in the literature.

In order to determine the optimal investment in disposal technology and capacity, the cost-benefit ratio of alternative methods for carcass disposal needs to be analyzed. Economics cannot and should not be the sole factor in a decision-making process, but economics should be part of the equation. Economically attractive disposal methods may not meet regulatory requirements; the most cost-effective method may be prohibited by local, state, or federal regulations. Additional efforts are necessary to assess state-by-state regulations, investigate opportunities for individual states and the federal government to work together, have disposal plans in place before an emergency, and delineate clear decision-making responsibilities. Balancing economic considerations with regulatory requirements is necessary to determine the best options for carcass disposal. Furthermore, in order to minimize direct costs, contracts with technology providers should be negotiated in advance.

Improvement of the decision-making process related to large-scale carcass disposal is the ultimate goal. Further review and response to the research needs noted in this chapter will provide regulators and policymakers with the necessary information to make decisions. These results, combined with increased research from the scientific community on each disposal technology, will help government and industry be better prepared for any large-scale carcass disposal event.

Section 2 – Background

2.1 – Overview

Animal agriculture's changing structure to higher production concentration increases the industry's vulnerability to high death losses due to disease or disaster. One infected animal introduced into a concentrated animal facility can affect thousands of animals in a short time period resulting in a potentially devastating economic impact on producers as well as local, state, and national economies. However, concentration also allows a planned defense with a strategy for dealing with such events to be focused on limited geographic areas.

A complete and multidimensional policy strategy is necessary when planning for the disposal of livestock and poultry in the event of high death losses resulting from an intentional bioterrorism attack on agriculture, an accidental introduction of dangerous pathogens, or a natural disaster. A critically important part of that strategy is the ability to dispose of large numbers of animal carcasses in a cost effective and socially and environmentally effective manner (Adams, 1999; Casagrande, 2002; Deen, 1999).

Historical carcass disposal events indicate that a multitude of issues must be considered when determining the appropriate process for disposing of infected and exposed carcasses. In order to develop a decision-making framework, policy makers must balance the scientific, economic, and social ramifications of disposal technologies.

The greatest logistical problem in any large-scale animal death loss is carcass disposal. While many technologies exist, the "best" method for carcass disposal remains an issue of uncertainty and matter of circumstance. Contingency plans must consider the economic costs and the availability of resources for the actual disposal, as well as the numerous related costs. A complete cost-benefit analysis of alternative methods of disposal for various situations is a necessity to determine the "best" alternative (Ekboir, 1999).

Timely disposal may be difficult with a large-scale death loss or depopulation requirement. Resources may not be available for the actual disposal or the numerous related costs. In the United Kingdom (UK) foot and mouth disease (FMD) outbreak, contingency planning should have considered several additional issues, including the logistical problems related to the location of disposal facilities, size and species of animals, and access to farms. Or, the UK could have planned to vaccinate animals to postpone slaughter or freeze carcasses to pace the disposal (Anderson, 2002).

To understand the dilemma, consider the development of an action plan for fighting FMD in the state of California. The California Department of Food and Agriculture action plan states that all precautions should be taken to prevent disease spread and to comply with environmental regulations during disposal of infected and exposed animals. While the state allows the Governor to overrule environmental regulations in the case of an emergency, uncertainty over the long term environmental impacts and public concern will likely delay even proven disposal methods.

The greatest logistical problem defined in the California research is the disposal of carcasses. The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) currently identifies burial as the preferred method of disposal when practical, and considers burning as the alternative. However, burial would require the digging of miles of trench pits that could not be disturbed for years. This alone imposes a major future cost on producers. Carcass burning would require more wood or other fuel than is readily available in a timely manner. The ability to use an air-curtain would be limited to equipment availability and would likely increase disposal time. Landfill usage would be limited because of the need to mix with waste in a fixed portion and the cost imposed on the local communities of filling the landfill. Limited disposal ability and capacity will impact the spread of disease (Ekboir, 1999).

This chapter (1) highlights previous carcass disposal experiences and costs, (2) summarizes costs and economic factors related to disposal technologies, (3) presents broad regulatory and policy issues related to carcass disposal, and (4) identifies future research needs.

2.2 – Historical Experience

United Kingdom – foot and mouth disease

In 2001, the UK experienced an outbreak of FMD, which has, to date, provided the best "lesson in history" on large-scale carcass disposal. The Government faced the challenge of disposing approximately six million carcasses with limited disposal resources in a tight time frame. The large scale of the epidemic made carcass disposal a serious problem. While the UK Department for Environment, Food and Rural Affairs (DEFRA) realized cost control was important, it was also clear that all steps to stop the disease needed to be taken regardless of expense (Hickman & Hughes, 2002). Although some costs are clearly defined, economic impacts on farmers, small businesses, and the tourism industry are more difficult to define.

In Table 1, direct and indirect costs are identified in many areas of disease control (farmer compensation, vaccination, cleaning and disinfecting, staff time, et cetera), including costs resulting from the slaughter and disposal of livestock, either to control the disease or deal with animal welfare (Anderson, 2002).

One portion of these costs were part of the Livestock Welfare Disposal Scheme (LWDS), a voluntary program for farmers to dispose of animals that were not directly affected by FMD but could not be moved to alternative accommodations or markets. The Rural Payments Agency paid farmers £205 million for the slaughter of two million animals from 18,000 farms. The cost to run the program was £164 million, including operating costs, disposal charges, slaughter fees, transportation of animals, and administration (NAO, 2002). The FMD Inquiry commissioned by the House of Commons lists specific costs expended by the Government as noted in Table 1. Total expenditures by the Government were estimated to be over £2.8 billion, with over £1 billion related to direct costs of control measures. This included £252 million for haulage and disposal (Anderson, 2002; NAO, 2002).

In addition to the LWDS, the disposal of infected and exposed carcasses was significant. Goods and services were purchased from a range of private and public sector businesses, including transportation and construction services, materials required to burn pyres, and slaughter services. Landfill operators received substantial sums for receiving slaughtered animals and landowners were paid several million pounds for allowing their land to be used as mass burial sites. DEFRA was forced to pay premium fees to get the work done in the necessary time frame. For example, in order to build the burial pits, crews worked 24 hours a day, seven days a week and were paid substantial amounts of overtime, nighttime, and weekend wages. Similar construction would have taken two years if tight deadlines did not exist. Because many small local firms were fearful of becoming involved with the crisis, there existed shortages of goods and services and, thus, increased costs. Work with infected carcasses was also considered hazardous causing contracting firms to charge premium rates. DEFRA purchased coal and wooden railway sleepers needed for pyres at prices five to ten times higher than normal.

TABLE 1. Expenditures by the Government during the 2001 outbreak of FMD in the UK (Anderson, 2002; NAO, 2002).

Activity	Actual Expenditures to 24 May 2002 (£ million)
Payments to farmers	
Compensation paid to farmers for animals culled and items seized or destroyed	1,130
Payments to farmers for animals slaughtered for welfare reasons (Livestock welfare disposal scheme - £205.4 million; Light lambs scheme - £5.3 million)	211
Total payments to farmers	**1,341**
Direct costs of measures to deal with the epidemic	
Haulage, disposal, and additional building work	252
Cleansing and disinfection	295
Extra human resource costs	217
Administration of the Livestock Welfare Disposal Scheme including operating costs, disposal charges, and slaughter fees	164
Payments to other Government departments, local authorities, agencies and others	73
Miscellaneous, including serology, slaughterers, valuers, equipment and vaccine	68
Claims against the Department	5
Total direct costs of measures to deal with the epidemic	**1,074**
Other Costs	
Cost of government departments' staff time	100
Support measures for businesses affected by the outbreak (includes EU funds)	282
Total other costs	**382**
TOTAL COSTS	**2,797**

Substantial costs were also incurred in protecting the environment and public health from carcass disposal risks; this included costs related to preparing safe locations and transporting to these locations. Construction costs for burial pits, for example, were substantial with DEFRA acquiring land for seven mass burial pits. These pits had to be designed from scratch to be environmentally acceptable and required heavy investment to stop the release of leachate (animal body fluids) into watercourses, protect surface water, and allow for disposal of contaminants. The total cost of the pits alone was £79 million of the disposal costs (included in Table 1), not including restoration, monitoring, and maintenance. In one case, after the site had been partially filled, it was found to be unacceptable. The 18,000 carcasses buried were exhumed and burned at a cost of over £2 million (NAO, 2002).

High temperature incineration was very costly at over £500 per ton. Dealing with the ash from incineration and mass pyres was expensive because of the difficulties in disposal. In dealing with all expenses, DEFRA often found itself in a weak position for negotiating contracts and fee rates. This position forced the department to pay higher prices for almost all goods and services. Purchase controls were also considered weak. Because purchases were often made quickly, DEFRA did not benefit from bulk or surplus purchase prices. Normal procedures for authorization of department expenses were by-passed and contracts were not awarded in a competitive method. Many contracts, amounting to millions of pounds, were agreed to in a few hours instead of the normal period of several weeks. The procurement of supplies and services was highly expensive and the Government did not have a strong negotiating position. The rates charged by contractors for labor, materials, and services varied greatly from one to another. Landfill owners were paid large sums, as were private landowners whose land was used for disposal. By April 2001, DEFRA began to impose some cost controls but was still limited in their ability to truly be cost effective and efficient (NAO, 2002; de Klerk, 2002).

Taiwan – foot and mouth disease

During the 1997 FMD outbreak in Taiwan, approximately five million carcasses required disposal. The costs born by the government associated with the epidemic were estimated at $187.5 million, with expenses for carcass disposal of approximately $24.6 million.

Eighty percent of the carcasses were buried, 15% were rendered and 5% were incinerated or burned in open fields. A comparative cost analysis showed that burying was the least expensive and easiest form of disposal, with 32.5% of total disposal costs covering 80% of the carcasses. Rendering was more costly, with only 15% of the carcasses being rendered for 26.1% of the costs. The most expensive method was burning or incineration with 41.4% of disposal expenses being used to dispose of 5% of the carcasses. In addition to direct costs, the Taiwanese swine industry faced an estimated loss of $1.6 billion as a result of production and export loss. Related industries such as feed mills, pharmaceutical companies, equipment manufacturers, meat packers, auction markets, and the transportation industry all suffered economic losses.

The use of mass vaccination could impact disposal costs, by either delaying the urgency related to large-scale disposal efforts or by reducing the number of animals in need of disposal. Additional analysis implies mass vaccination was the cheapest way to eliminate the spread of the disease and future consideration should be given to cost-benefit analysis of vaccination and limited depopulation versus total depopulation (Ekboir, 1999; Ellis, 2001).

Virginia - avian influenza

Two major outbreaks of avian influenza (AI) have impacted Rockingham County, VA over the last 20 years. In 1984, over 5,700 tons of poultry carcasses required disposal and another 16,900 tons were disposed of in 2002. On-site burial accounted for 87.5% of the carcasses in 1984, with the remaining carcasses being disposed of in landfills. On-site burial cost and landfill costs were $25 per ton for a total of $142,000. In that outbreak, 1.4 million birds were destroyed at a total economic cost of $40 million, and disposal costs accounted for less than 0.5% of total costs (Brglez, 2003).

Carcasses take up to six months to decompose when composted, and can take several years to totally decompose in landfills or on-site burial pits. An example of this occurred in Virginia when a school was built on a 1984 burial site and people were shocked to find the carcasses in near complete condition with little decomposition. This caused a change in state law requiring landowners to agree to record carcass burial on their property deed if they are applying for an on-site burial permit (Brglez, 2003).

In the 2002 Virginia outbreak, landfills accounted for 85% of the carcasses disposed. Two primary landfill sites were used and over 64% of total tonnage was shipped over 160 miles to these landfill sites. The cost to dispose in the landfill was only $45 per ton but over $1 million in transportation in specially prepared trucks was necessary. In one case, the waste management plant associated with a landfill could not handle the ammonia leachate produced (Brglez, 2003).

Four incinerators were used late in the process due to slow negotiations. For 29 days, 76 tons per day were disposed through the incinerators. The total cost of disposing of 3,023 tons was $317,616 at a rate of approximately $105 per ton, including transportation. Transporting the carcasses to the quarry where the incinerators were located cost $267,908 for truck rental and mileage. Other costs included the rental of incinerators and labor totaling $810,389, rent screener and screening of ashes totaling $75,283, removing ashes and delivering as fertilizer totaling $173,466, and wood fuel costs of $477 per ton. This was an expensive process, and created a negative externality in the resulting stench (Brglez, 2003).

Section 3 – Direct and Indirect Costs

In order to understand the economic issues related to carcass disposal, it is critical to understand the cost data available. An effective control strategy will not only limit disease spread but will keep direct and indirect costs low. There is relatively little data on the costs of carcass disposal and consistency regarding both direct and indirect costs is lacking. The available data are primarily related to routine disposal and not disposal in an emergency situation. Costs can be divided into the following categories: (1) direct costs, including fixed costs and variable (operating) costs, and (2) indirect costs.

In order to analyze the economic implications of the different disposal options, various direct and indirect costs need to be identified, including those related to direct disposal, transportation, facilities and equipment, energy requirements, environmental impact, and social costs. Major economic factors and implications also need to be identified and the different disposal options need to be compared and contrasted. In the following section, examples of direct costs are identified and potential indirect costs are discussed relative to each technology. However, most existing data applies only to small-scale disposals and does not attempt to quantify indirect costs.

3.1 – Burial

The two most common forms of burial are disposal pits and trench burial. Both can be used for daily mortality needs, but trench burial is the most likely process used when there is large-scale death loss (Wineland et al., 1997). Few direct cost estimates exist and decision makers usually assume burial is a low-cost option. Most direct cost estimates available are relative to the use of disposal pits for normal mortality use, and the costs in a large-scale disaster situation would differ significantly.

Direct costs

Routine disposal

Burial requires significant labor and equipment, and actual costs are dependent on the availability and accessibility of these two factors. A number of studies have identified costs related to routine disposal efforts. These studies may provide insight into the cost factors in large-scale disposal estimates.

In a study by University of Nebraska researchers to be discussed repeatedly in this section, costs were estimated for the disposal of normal death loss on a hog farm. Nebraska regulations state that burial must occur within 36 hours of death and carcasses must be buried at least 4 feet deep. They also recommend that trenches should be immediately closed, making it a difficult option for routine disposal purposes. Therefore, they paid relatively less attention to burial costs in their research. They did estimate a basic budget that included building one trench to hold one year's death loss of 40,000 lbs. Digging the pit and fencing the area would cost approximately $600. Additional labor costs based on 135 hours for transporting animals to the burial site and covering the carcasses appropriately were included. Estimated costs totaled $3,878 per year, resulting in estimates of $0.097 per pound of mortality ($193.90 per ton) (Henry et al., 2001).

Researchers at the University of Alabama investigated routine poultry carcass disposal. The poultry industry as a whole generates 800 tons of carcasses weekly, thus economically efficient disposal methods are important in daily routines. Disposal pits designed for everyday use are a potential solution for both large and small producers. The cost of the pits varies widely depending on materials used and size of pit. Routine mortality disposal costs were estimated for a flock size of 100,000. Estimates included initial investment costs ($4,500), annual variable costs ($1,378), and annual fixed costs ($829) totaling $2,207, resulting in a cost per hundredweight of $3.68, or cost per ton of

$73.60. For a flock of 200,000 birds, the cost per ton would be reduced to $62.40 (Crews et al., 1995).

Sparks Companies, Inc. (2002) estimated costs of on-farm burial of daily mortalities. They assumed each mortality was buried individually, all environmental safeguard procedures were followed, on-farm burial was feasible, and the only direct costs associated with burial were labor (estimated at $10/hr) and machinery (rental or depreciation estimated at $35/hr). These costs resulted in per mortality costs of $15 per head for cattle over 500 lbs. and $7.50 per head for calves and hogs. These estimates are likely not representative of the costs that may be incurred during a catastrophic mortality loss, since multiple mortalities would be buried together, rather than individually as estimated here. Furthermore, actual hourly rates for labor and equipment may be significantly different during an emergency than estimated here.

A survey of Iowa Pork Producers Association members was conducted in March 2001 to determine the disposal methods used for daily mortalities, as well as associated costs (Schwager et al., 2001). The authors defined the total estimated cost for disposal by burial (including labor, machinery, contractors, and land) as a function of operation size, rather than as a function of the number of mortalities disposed. They estimated that the total cost for burial was approximately $198 per 100 head marketed. A report on various carcass disposal options available in Colorado identified the cost of renting excavation equipment as $50-75/hr (Talley, 2001).

The New South Wales Department of Agriculture Resources states that on-site burial may be the only economic choice because the costs of transport may be expensive relative to the value of the stock. They estimate on-farm disposal can cost A$1-2 per head if machinery is hired (Burton, 1999).

Emergency disposal

Little information exists regarding the costs associated with carcass burial during emergency situations. During the 1984 AI outbreak in Virginia, a total of 5,700 tons of poultry carcasses (about 1.4 million birds) were disposed. Approximately 85% of this total (about 4,845 tons) was disposed by trench burial at an estimated cost of approximately $25 per ton (Brglez, 2003).

The 2001 UK FMD outbreak provides emergency disposal cost examples for mass burial sites. The costs of mass burial sites included purchase and/or rental; construction, operation, and maintenance; and long-term restoration and maintenance. Based on the estimated number of carcasses buried at each site, the approximate cost per carcass has been estimated in Chapter 1 (Burial) of this report. The approximated cost per carcass ranged from £20.41 at the Birkshaw Forest mass burial site to £337.77 at the Tow Law site, with an average cost of £90.26 for the 1,262,000 carcasses buried in five mass burial sites. Although cost per ton would be a more preferred basis for comparison, for all sites except Throckmorton it was not possible to determine this value because few reports provided either the total weight of carcasses buried at each site, or the number of carcasses by species at each site (although reportedly the majority of carcasses were sheep). For the Throckmorton site, based on an estimated total weight buried in the site of 13,572 tons (see Table 12 in Chapter 1), the cost of using this site on a per ton basis is estimated to be £1,665 per ton (NAO, 2002).

Indirect costs

Burial as a method of carcass disposal can result in a variety of indirect costs including environmental costs and impact on land values. The major environmental impact is ground and surface water contamination, particularly in areas with light soil and a high water table. Body fluids and high-concentrate ammonium leachate could pollute the groundwater. Most degradation would occur within 5 to 10 years but leachate could be released for 20 years or more. Calculating values aligned with indirect costs is challenging because individual producers may not have knowledge of or may choose to ignore approved procedures, leading to additional environmental costs.

Predators could also be a problem by spreading the disease or causing an unsightly disturbance if they are uncovering the carcasses. Such disturbances or other unpleasing circumstances may also create negative public reactions. In addition, if anaerobic digestion occurs the hydrogen sulfide created can exceed safe human levels. It is also possible that acid-forming bacteria may exist and decomposition-inhibiting fermentation may occur. Burial on private land can also impact future land use and land values, especially if legislation requires that carcass burial be listed on the property deed. Mass burial offers similar environmental risks at a higher level of significance (Harman, 2001; Morrow & Ferket, 1993; Sparks Companies, Inc., 2002; Wineland et al., 1997).

3.2 – Landfills

The use of public landfills is another potential disposal alternative requiring the cooperation of operators, transportation to the disposal location, and regulatory compliance.

Direct costs

The fee charged by a landfill for accepting waste is typically based on either weight or volume, and may vary with the type of waste deposited. Even though many state regulations allow landfill use for carcass disposal, many municipal authorities refuse carcasses. Many can charge $10-30 per ton, which some have viewed as cost prohibitive (Morrow & Ferket, 1993).

For landfill disposal of small numbers of animal carcasses—such as companion animal remains, carcasses resulting from hunting activities (such as deer or elk), or small numbers of daily mortalities from livestock production facilities—fees may be based either on weight or on the number of carcasses. Fees at three landfills in Colorado were reportedly $10 per animal, $160 per ton, and $7.80 per cubic yard, respectively (Talley, 2001). As of 2003, fees for carcass disposal in Riverside County, California consist of a $20 flat fee for quantities less than 1,000 lbs, and $40 per ton for quantities greater than 1,000 lbs. These fees are slightly higher than those charged at the same facility for general municipal solid waste because animal carcasses are classified as "hard-to-handle" waste as they require immediate burial (immediate cover) (Riverside County Waste Management Department). Landfill costs for disposing of animal byproducts in European countries range from 30 to 80 Euros per ton of material (Commission of the European Communities, 2001).

Following confirmation of two cases of chronic wasting disease (CWD) in South Dakota, the City Council of Sioux Falls established disposal fees for deer and elk carcasses at the city landfill. A mono-fill area (mono-fill indicating waste of only one type) designed to accommodate 10,000 deer carcasses was developed in an unused expansion of the landfill at a reported cost of about $50,000. Fees of $50 per ton were established for deer or elk carcasses originating within the state, and $500 per ton for carcasses originating outside the state. However, private individuals are exempt from the ordinance and may dispose of up to 10 carcasses without charge (Tucker, 2002).

In situations involving significant volumes of carcass material (e.g., an animal disease outbreak), fees would most likely be based on weight (i.e., per ton of carcass material). Costs associated with transportation of carcass material from the site of the outbreak to the landfill must also be considered. In instances where this distance is great, transportation costs can be significant. During the 2002 outbreak of AI in Virginia, tipping fees were approximately $45 per ton for disposing of poultry carcasses at landfills. However, significant additional cost was incurred due to lengthy transportation distance (Brglez, 2003). During the 2002 outbreak of exotic Newcastle disease (END) in southern California, tipping fees were approximately $40 per ton for disposing of poultry waste at landfills (Hickman, 2003).

Indirect costs

Disposal in landfills requires additional daily management leading to increased management costs. The use of a landfill for carcass disposal is likely to impact the location's ability to handle other waste disposal needs creating an opportunity cost. In addition, if landfills are used, the county may be financially impacted if landfill capacity is reduced prematurely. Environmental costs also exist with landfill usage. Disposal of carcasses in landfills can generate very high organic loads and other pollutants for up to 20 years. The odors are also considered a public problem. Landfills offer similar concerns as burial regarding groundwater contamination and predators. If a landfill usage is mandated at a higher level of government, the cost of public perception and poor cooperation could be large as well (Morrow & Ferket, 1993).

3.3 – Incineration/Burning

There are three common forms of incineration: open burning (e.g., pyre burning), air-curtain incineration, and fixed-facility incineration. In the Incineration Chapter of this report (Chapter 2), "intervals of approximation" have been used to describe the costs for each incineration technology. These intervals are listed as $196 to $723 per ton for open burning, $98 to $2000 per ton for fixed-facility incineration, and $143 to $506 for air-curtain incineration. Specific cost examples are provided in this section.

Direct costs

Open burning

An open air pyre requires fuel, which may include coal, timber, pallets, straw, or diesel fuel. While this may seem clear, specific cost data is limited. Cooper et al. estimate open-air pyre burning of cattle carcasses to cost $196 per ton of cattle carcasses (Cooper et al., 2003). During the UK 2001 FMD outbreak, there were concerns about the on-farm burial of pyre-ash. Therefore, pyre-ash was disposed of at landfills at a cost of approximately £317 per ton, or $527 per ton (Anderson, 2002).

Fixed-facility incineration

The most significant costs related to fixed-facility incineration are the fixed-costs associated with construction of the incineration facility and purchase of incineration equipment. These are the most extensive costs for both individual producers and governments preparing for large-scale mortality capability (Harman, 2001). A 500-pound incinerator costs $3,000 and will last for approximately four years (Sander et al., 2002).

Researchers at the University of Nebraska have estimated disposal costs on an annual basis for a pork production system with average annual mortality loss of 40,000 pounds per year. The costs do not include labor or loader use for removing dead animals from the farm, because they assumed no change between alternatives. They calculated fixed costs to include depreciation, interest on the undepreciated balance, repairs, property taxes, and insurance. The incinerator used had a 500 pound capacity and along with a fuel tank and fuel lines costs $3,642. The rate of incineration was estimated to be 78 pounds per hour with diesel fuel consumption of 1 gallon per hour priced at $1.10 per gallon. The incinerator was calculated to last ten years or 5,000 hours. Interest rates were calculated at 10% and annual repairs were calculated as 3% of original cost. This study assumed the incinerator would be taken to the production unit so transportation costs were not relevant. Labor for operation was set at 10 minutes per day. An incinerator with an afterburner may be necessary to reduce emissions and would increase investment costs by $1,000 and increase fuel consumption to 1.35 gallons per hour. The study estimated costs for both types of incineration as depicted in Table 2 (Henry et al., 2001).

TABLE 2. Cost estimates for on-farm incineration of daily mortalities (Henry et al., 2001).

	Incineration without afterburner	Incineration with afterburner
Disposal equipment	Incinerator and fuel tank	Incinerator and fuel tank
Capital investment	$3,642.00	$4,642.00
Labor hours per year	60.7	60.7
Budgeted annual costs	$710.19	$905.19
Fixed costs – disposal equipment		
Machinery operating costs	$572.00	$1,341.44
Labor	$667.33	$667.33
Annual cost per year	**$1,949.52**	**$2,913.96**
Annual cost per pound	**$0.049**	**$0.073**
Annual cost per ton	**$97.48**	**$145.70**

In Alabama, poultry producers utilize incineration when burial is ruled out due to environmental concerns. An incineration unit with gas or oil burners is required, and producers need a concrete slab and shelter to house the unit. Additional cost considerations are fuel costs and burn rate. Initial investment costs are $2,000 at a minimum with annual variable costs of $4,833 and annual fixed costs of $522. These equate to total net costs of $5,355 and a cost per hundredweight of $8.92, resulting in a per ton cost of $178.40 (Crews et al., 1995). In a similar study in Alabama, costs are estimated at approximately $3.50 per 100 pounds or $70 per ton of carcasses assuming fuel costs at $0.61 per pound (Crews et al., 1995).

In a study at the University of Tennessee, the use of incineration for poultry mortality management was studied. Variability in fuel prices will impact the cost of incinerator operation. If propane costs are estimated at $0.75 per gallon, the cost to burn 100 pounds of poultry broiler carcasses will average $4 per 100 pounds ($80 per ton). The amount of fuel needed is impacted by the size of birds and their body fat percentage. The researchers also noted that while incineration is an effective technique, producers should have an alternative plan for handling catastrophic bird loss (Burns, 2002).

The Georgia Department of Agriculture reports that the cost of incinerating 450 tons of dead chickens after tornadoes struck Mitchell County in 2001 was $300 per ton or outsourced for $1600 per ton.

The Incineration Chapter of this report (Chapter 2) indicates that larger, fixed-facility incineration has been approximated by Waste Reduction Inc. at $460-$2,000 per ton of carcass material in the US. This interval captures a forecasted during-emergency price of $1,531 per ton (Western Australia Department of Agriculture, 2002).

Air-curtain incineration

Cost information for air-curtain incineration depends on species type, fuel costs, and ash disposal. The largest single expense related to air-curtain incineration is the expense of the air-curtain incinerator, either by purchase or rental. In a test operation in Texas held by the USDA and Texas Animal Health, a trench burner was leased from Air Burners, LLC for 3 days for $7,500 including transportation to the site and operators. The test operation disposed of 504 head of swine carcasses weighing 91,600 pounds. In this same case, fire wood was used as the fuel and with delivery cost nearly $4,000. Another large expense was the transportation of swine to the location costing over $4,500. All costs noted are listed in Table 3. The project investigators did not include the time of any animal health or emergency professionals nor did they attempt to account for any indirect costs (Ford, 1994). Jordan (2003) and Brglez (2003) estimated per ton incineration costs for poultry to be $143 and $477, respectively.

TABLE 3. Air-curtain incineration project cost based on 91,600 lbs of swine carcasses (Ford, 1994).

USDA/TAHC Incineration Project Cost	
Site and Equipment Preparation	$1,700
Site Rental (by contract)	$650
Air-curtain Incinerator	$7,500
Diesel Fuel	$300
Protective Wear	$2,400
Lumber and Plywood	$135
Firewood and Delivery	$3,960
Truck Rental	$250
Animal Transportation	$4,640
Modification of Chute/Knock Box	$1,285
Miscellaneous Supplies	$225
TOTAL	**$23,045**
Cost Per Ton	**$503**

Indirect costs

The negative impacts of burning include pollution of the environment and release of noxious gases and compounds, including dioxins, which affect the health and well being of the population. Dioxins have been identified as a possible cancer-causing agent and the opportunity exists for uptake by plants or animals and thus for the contamination of the food chain. Public perceptions of pyres combined with emissions of dioxins and the health effects from smoke inhalation are additional negative externalities. Mass slaughter of animals and the large "funeral" pyres in the UK horrified the public, and these televised images contributed to greater economic damage, specifically tourist activity (Franco, 2002; Hickman & Hughes, 2002; Hutton, 2002; National Farmers Union, 2002; Serecon Management Consulting, Inc., 2002). The Canadian Animal Health Coalition concurs that scenes of piles of dead animal burning in farmer's fields would not help the values in Canada's brand in the international market place (Serecon Management Consulting, Inc., 2002).

While incineration is biologically safe, produces little waste, and does not create water pollution concerns, the primary concern is emission of particulates generated during burning. Indirect environmental costs include the impact of emit particles and other products of combustion on air, liquid leakage on soil and water, and the remaining ash that needs disposed. The concern of disease spread through the air is also a concern. The air quality risk will be higher if the process is not properly managed. Smoke and odor are both a concern to neighbors and the general public. Other issues for cost consideration include worker safety precautions, management expenses, and burn permits. The cost of maintaining on-farm incineration permits has escalated as has the inspection and regulatory costs for large incinerators for medical or hazardous waste disposal (Harman, 2001; Morrow & Ferket, 1993; Sparks Companies, Inc., 2002; Winchell, 2001; Wineland et al., 1997). Available estimates do not take into account regulatory-compliance costs as well as public-perception problems, which in the UK during 2001 were tremendous for the tourism industry.

3.4 – Composting

Composting has captured the attention of producers as a means of disposal because they are already familiar with the practice in manure management. It has moved from a novel, experimental idea to a viable, common practice in more industries than just that of poultry (Rynk, 2003). Three types of composting deserve consideration: bin, windrow, and enclosed composting. For individual livestock producers, decisions regarding an appropriate carcass composting system will depend not only on the recurring expenses associated with the method, but also on the initial investment required for construction of the system (bin or windrow) and required agricultural machinery and equipment.

Direct costs

The most important factors involved in cost analysis of carcass composting processes have been described by Mescher (2000) and are ordered in importance as volume and weight of mortality, frequency of mortality occurrence, labor requirements, accessibility and timeliness, impact on the environment, required facilities and equipment (new and existing) and their useful life expectancy. The major rendering costs are construction, equipment, and labor needs. Plentiful carbon sources must also be readily available. Carcass composting has some economic advantages, such as long-life of the facility or pad, minimal cost of depreciation after start-up, similar labor requirements, inexpensive and readily accessible carbon sources in most livestock production areas, and, finally, no need for new equipment (Mescher, 2000).

Bin composting

In the University of Nebraska study, two types of composting units were used for average annual cost estimates. Both structures included concrete floors and bin walls with the higher investment option also including a roof, higher sidewalls, a storage bin for carbon source, and a concrete apron in front of the facility. The estimated construction cost of the high investment version was $15,200 with the low investment version costing $7,850. The lifetime of both was estimated to be 15 years. Researchers estimated that 80 cubic yards of sawdust would be needed at a cost of $4/cubic yard. A skid steer loader would be utilized at $10/hour for transporting dead animals, moving sawdust, and loading materials on the manure spreader. Labor was measured for daily loading of sawdust and animals, moving materials from primary to secondary bins and moving materials to a recycling bin and spreading the remainder. Labor costs for the low investment option are slightly higher, because the carbon source material is not stored in the compost bins and must be moved into the bin (Henry et al., 2001). Estimates do not include indirect costs nor do they show the economic benefit of the final product.

TABLE 4. Estimated costs for bin composting of 20 tons annual routine daily mortalities (Henry et al., 2001).

	Composting High Investment	Composting Low Investment
Disposal equipment	Compost bins and buildings	Compost bins
Capital investment	$15,200.00	$7,850.00
Other equipment needed	Skid steer loader, tractor, manure spreader	Skid steer loader, tractor, manure spreader
Labor hours per year	115	125.9
Budgeted annual costs	$2,305.33	$1,190.58
Fixed Costs – Disposal Equipment		
Machinery costs	$382.19	$447.39
Fixed	$254.79	$298.26
Operating	$320.00	$320.00
Other Operating costs		
Labor	$1,265.15	$1,384.68
Annual Cost	**$4,527.47**	**$3,640.92**
Annual cost per pound	**$0.113**	**$0.091**
Annual cost per ton	**~$226**	**~$182**

In the Alabama poultry study, researchers estimated costs for large-bin and small-bin composting. Poultry producers have readily accepted composting as a means of disposal and over 800 have purchased freestanding composters. The large-bin composting method requires two covered bins with concrete foundations. The initial investment cost is $7,500 and annual variable costs of $3,281 and annual fixed costs of $1,658. The total cost is $4,939, but the value of the by-product for fertilizer use is $2,010 resulting in an annual net cost of $2,929 and cost per hundredweight of $4.88 or $97.60 per ton (Crews et al., 1995).

Sparks Companies, Inc. (2002) estimated the overall cost of small-bin composting carcasses of different species. Their report indicated the total annual costs of composting incurred by the livestock sector to be $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses.

Windrow composting

Kube (2002) used a windrow system and composted cattle carcasses with the three different methods, each with 1,000 lb carcasses. The first method was conventional composting (no grinding), the second was grinding carcasses after composting, and the last was grinding carcass before composting. The cost analysis of this experiment indicated that, depending on the option selected for carcass composting, the total estimated cost ranged from $50 to $104 per ton of carcasses. While carcass grinding before composting increased the operation cost by about $6/head, it reduced the time, area and management cost needed for composting in comparison with conventional windrow system. Furthermore, he estimated the value of finished compost at a rate of $10-$30 per carcass or $5-$15 per ton and estimated the net cost per carcass to be approximately $5 to $42. In this estimate, no value was assigned to the organic matter of the compost.

Enclosed composting

An enclosed or in-vessel system of composting organics using aerated synthetic tubes called Ag-Bags has been available commercially for the past 10 years. The system consists of a plastic tube 10 ft in diameter and up to 200 ft long. These tubes are equipped with an air distribution system connected to a blower. Raw materials are loaded into the tube with a feed hopper. Tubes used for medium or large intact carcasses are opened at the seam prior to loading raw materials and then sealed for forced air distribution during composting. APHIS used Ag-Bag to compost over 100,000 birds infected with AI depopulated from poultry houses in West Virginia. The structural equipment costs are estimated at $130,000 with additional equipment operating costs of $6-10 per ton (Mickel, 2003). These costs do not include the necessary carbon source expense or labor expense estimates. Virginia AI Ag-Bag composting costs were reported by Brglez at $60 per ton with service from an outside agency (Brglez, 2003).

Indirect costs

The value of the by-product would offset a portion of the estimated costs. No permits would be necessary for composting and it could serve as a temporary step as the virus is destroyed quickly and could be moved and disposed of elsewhere permanently (Brglez, 2003). Odors can be of concern if improperly managed. Risks to water sources do occur if composting is poorly located or managed. Opportunity costs could also exist if the use of the land is impacted while composting is taking place. Keeping the carcasses in public view could also be a public relation problem. In a large-scale outbreak, more compost may be created than can be used, and, therefore, another disposal problem will exist in the long-term. A problem also exists with the attraction of disease vectors such as flies, mosquitoes, rats, and wildlife. Additional record keeping and management time is also necessary (Franco, 2002; Sparks Companies, Inc., 2002).

3.5 – Rendering

Renderers have historically played a critical role in disposal of animal carcasses, accounting for approximately 50% of all routine livestock mortalities and representing the preferred method of disposal. Renderers typically charge modest fees to collect mortalities but they are able to keep the costs low as they profit from the sale of meat and bone meal. However, the role the rendering industry is changing significantly. The risk of bovine spongiform encephalopathy (BSE) has prompted the US and other countries to create safeguards to protect the livestock industry resulting in tight restrictions and bans on rendering livestock carcasses. Changes in regulations are likely to result in large increases in renderer fees to make up for the profit loss associated with the reduction of the meat and bone meal (MBM) market (Sparks Companies, Inc., 2002).

Therefore, the rendering industry has experienced general consolidation in recent years, resulting in higher fees and discontinued service in some areas. There are fewer rendering plants located at a greater distance from the livestock farms that traditionally depended on them to process mortalities. Farms used to be paid by the rendering plants for the mortalities, but renderers no longer find it profitable to pay for the carcasses. Instead, producers are required to pay for the same service. Depressed world market prices for fats, protein and hides, combined with the elimination of use of animal proteins in ruminant feeds are forcing many renderers to leave the industry or significantly increase their fees. Additional regulations that limit the use of rendering will have an increasingly significant impact. Therefore, use of rendering for even daily carcass disposal has become a more significant problem (Rynk, 2003; Doyle & Groves, 1993; Henry et al., 2001; Morrow & Ferket, 1993; Peck, 2002).

The most important factors involved in cost analysis of massive carcass rendering include collection, transportation, temporary storage fees, extra labor requirements, impact on the environment (sanitation for plant outdoor and indoor activities, odor control, and waste water treatment), sometimes additional facilities and equipment. These expenses primarily make the renderers' costs much higher than the cost of usual rendering.

Direct costs

In a University of Nebraska study, cost estimates for routine rendering to accommodate annual mortality of 40,000 lbs were budgeted at four pickup loads a week at a cost of $25 per load. The cost of creating a holding pen away from the production facility and away from public view is estimated to be $300. Labor costs include transporting to and from the holding pen at an average of 70 minutes per week. The values included in the following table refer to the four pickup loads per week and results in a cost per pound of mortality of $0.163. The estimates for one, two, three, five or six load would be $0.066, $0.098,

$0.131, $0.196, and $0.228 per pound of animal mortality, respectively. When calculated per ton, costs range from $132 to $456 per ton (Henry et al., 2001).

TABLE 5. Estimated rendering costs to dispose of 20 tons annual mortality (Henry et al., 2001).

	Rendering (4 pickups per week)
Disposal equipment	Screen storage area
Capital investment	$300.00
Other equipment needed	Skid steer loader
Labor hours per year	60.7
Budgeted annual costs	$51.00
Fixed Costs – Disposal Equipment	
Machinery costs	$364.00
Fixed	$242.67
Operating	$5,200.00
Labor	$667.33
Total annual cost	**$6,525.00**
Annual cost per pound	**$0.163**
Annual cost per ton	**~$326**

Sparks Company, Inc (2002) estimated the labor and equipment (rental or depreciation) costs, respectively, at $10 and $35/hour. As long as the rendering industry can market valuable products from livestock mortalities (including protein based feed ingredients and various fats and greases), collection fees will likely remain relatively low. However, collection and disposal fees will be much higher if the final products can no longer be marketed. Having a commercial value for end products is key to the economic feasibility of carcass disposal by rendering.

For rendering, theoretical estimates were based on a plant owner agreeing to a fee of $80 per ton with one cooker solely dedicated to diseased carcasses as a biosecurity measure. If all tonnage were taken to this plant in 2002 scenario, the total government cost would have been $2,820,206 including the disposal of the rendered product at a landfill resulting in a per ton cost of approximately $167. If the rendered product could be used as a fuel source, the total cost would be $1,565,006 or $93 per ton, and, if the product could be used in feed to local trout farms, the final cost would be $662,606 or $39 per ton (Brglez, 2003).

Indirect costs

Currently in the US, rendering cannot be used for any carcasses that could be infected with a TSE. Therefore, rendering does create an indirect cost related to lack of biosecurity and the risk of disease spread when carcasses are moved to the rendering plant and in the impact on the future use of the rendering plant (Winchell, 2001; Wineland et al., 1997). The environmental costs are minimal if the plants are well managed and control measures are followed (Harman, 2001).

Rendering animal mortalities is advantageous not only to the environment, but also helps to stabilize the animal feed price in the market. Selling carcass meal on the open commodity market will generate a competition with other sources of animal feed, allowing animal operation units and ultimately customers to benefit by not paying higher prices for animal feed and meat products.

Exporting the carcass rendering end products promotes US export income and international activities. For example, US exported 3,650 million lb of fats and proteins to other countries during 1994, which yielded a favorable trade balance of payments of $639 million returned to the US (Prokop, 1996). This export figure is particularly important in view of the shared rendering industry for future marketing of US fats and protein materials and their impacts on the country's economy.

3.6 – Lactic Acid Fermentation

Fermentation was studied in the Alabama poultry study based on 30 tons annual death loss. To practice this method, the producer must purchase a grinder and multiple fiberglass holding tanks. All equipment should be housed in an open shed of approximately 150 square feet. The initial investment cost is, therefore, fairly expensive at $8,200. Annual total costs of $4,052 include variable costs of $2,862 and fixed costs of $1,190.

The value from by-products totals $1,320, resulting in annual net costs of $2,732 and per hundredweight costs of $4.55 or $91 per ton. Other estimates range from $68 to $171 per ton. On-farm fermentation results in reduced transportation costs and safer transport with the fermented product (Crews et al., 1995). Fermentation can hold carcasses for over 25 weeks and the resulting product could be used as fur animal or aquaculture feeds. Acid preservation costs are estimated at $0.10 per pound and could be a fairly low cost alternative (Morrow & Ferket, 1993).

The Lactic Acid Fermentation chapter of the CDWG estimated the costs in an emergency to be about $650 per ton. Their example was based on the disposal of 1000 head of cattle weighing approximately 1100 lbs. This price does not include the sale of by-products to rendering companies or resale of used equipment.

3.7 – Alkaline Hydrolysis

A mobile tissue digester as supplied by Waste Reduction by Waste Reduction Inc. (WR2®) is a specially designed mobile unit for carcass disposal. The units have a 4000 pound capacity and can dispose of that amount in less than 3 hours. For the 2002 Virginia AI outbreak, Brglez estimated that twelve digestors would have been needed operating for 24 hours with one operator per location regardless of the number of units. Each unit is priced at $1 million. The digesters handle 15 tons per day and would have required operation for the full 90 days at a cost of $97 per ton or $1,636,567. Disposal of effluent may also have been necessary if it is not possible to use it as fertilizer (Brglez, 2003).

The cost of operation of these units is low compared to some other means of carcass disposal. Estimated cost of disposal of animal carcasses with the unit operating at maximum capacity and efficiency is $0.02 to $0.03 per pound or $40 – 60 per ton. Estimated cost of the mobile trailer unit with vessel, boiler and containment tank included is approximately $1.2 million. This unit would have capacity of digesting 4,000 pounds of carcasses every 8 hours or approximately 12,000 pounds in a 24 hour day (Wilson, 2003). Others experienced with alkaline hydrolysis have estimated $0.16 per pound ($320 per ton) including costs for power, chemical inputs, personnel, sanitary sewer expenses, and maintenance and repair (Powers, 2003).

3.8 – Anaerobic Digestion

Direct costs

Anaerobic digestion costs were estimated by Chen on a system with one upflow anaerobic sludge blanket and five leachbeds. He estimated the costs for a poultry farm with 10,000 birds at $105-118 dollars per 10,000 kilograms live weight production. Capital costs made up 41% of the costs and economies of scale existed with decreasing costs as farm size increased. With 100,000 bird operations, costs were estimated at $28 dollars per 10,000 kilograms live weight production. Based on Chen's assumption of an 8% mortality rate, the costs per ton of mortality range from $109 -123 per ton for a 10,000 bird operation to $29 per ton for a 100,000 bird operation. Calculating the potential benefits available from the sale of methane could improve the economic impact (Chen, 2000). Scale-up consideration and a costing analysis showed that thermal inactivation was likely to be more suitable and considerably less expensive (Turner et al., 2000).

The various alternatives for construction materials and installation methods will impact the cost of the chosen system. If utilization of the digester is temporary, the construction materials will be less expensive, estimated at less than $50 per kg of daily capacity ($22.73 per lb of daily capacity) and the construction could be done in less than a month. For a permanent installation, concrete construction of the digester takes about six months and would cost between $70 and $90 per kg of fresh carcass daily capacity ($31.82 and $40.91 per lb of fresh carcass daily capacity). Consequently, this type of installation requires construction well in advance of an emergency situation. It would be logical to use the digester for other substances like manure or municipal waste to help alleviate the expense (White & Van Horn, 1998; Boehnke et al., 2003).

3.9 – Novel Technologies

Refrigeration/Freezing

Alabama researchers studied costs related to refrigeration/freezing. The initial purchase cost of a large-capacity freezer combined with on-going electrical costs makes this a very expensive option. Initial costs are estimated at $14,500 with annual variable costs of $5,378 and annual fixed costs of $2,670. The value of the by-products is $1,200 and if combined with total costs of $8,048, results in an annual net cost of $6,848 or $11.41 per hundredweight or $228 per ton (Crews et al., 1995). Freezing has been utilized in the poultry industry. Freezers that hold one ton of carcasses are available for around $2000 and require electricity at approximately $1.20 per day or $0.01 per pound ($20 per ton) (Morrow & Ferket, 1993). A broiler company in Florida developed special weather-proof units that could be moved with a forklift. The freezer unit that cooled the containers never leaves the farm. The loaded containers are either hauled away or emptied at the farm in order to transport the contents to a processing facility (Damron, 2002).

Grinding

Foster (1999) estimated installation costs of $2,000 for a cutter and $6,000 for a grinder for pigs plus $5,000 in associated costs. A shelter to house the equipment plus utilities would increase this estimate. A portable unit should be more expensive because of the associated transport costs and portable power plant required. Also, the cost of the bulking agent is not included. Clearly, the size of carcass involved and the throughput needed will greatly affect cost and type of grinding equipment involved.

Grinding/Sterilization by STI Chem-Clav®

WR2® Companies, headquartered in Indianapolis, Indiana, currently market a patented non-incineration technology for processing biological and biohazard waste materials called the STI Chem-Clav® (http://www.wr2.net/). The cost of a mobile STI Chem-Clav® as described is estimated to be approximately $150,000. This does not include a semi tractor or fuel supply trucks. The addition of a disinfectant into the screw processing mechanism would also add to the cost. If the system were used on a daily basis for processing other wastes (food scraps, medical, etc.), the cost of processing would be decreased; however, the normal flow of feedstock would need to be diverted or stored in the event of a large mortality event.

Ocean disposal

Ocean disposal is a low cost option where available, estimated at approximately $1 per ton. Costs are primarily due to biosecure transportation to the location by truck and then barge rates of $2000/day and tug rates of $2500/day. There would also be a minimal cost for weighting the carcasses to sink. Indirect costs of ocean disposal are minimal. The most significant environmental risk is that of transportation risk. The actual disposal itself is environmentally friendly and is beneficial to marine life. However, appropriate public relations efforts would be necessary in order to avoid significant public disapproval (Wilson, 2003).

Plasma arc

Plasma vitrification generates heat in an efficient and cost effective method. Brglez estimated that four plasma arc torches would have been needed to assist with the Virginia AI outbreak. The units cost $2 million each and the gas collection hoods cost $500,000. Five people would be needed to operate and maintain the torches. The operation costs were estimated to be $120 per ton and the cost of digging the pit was $30 per ton. The total cost for 240 tons of carcasses was $36,000 per day and the total cost for the 2002 AI outbreak disposing of 16,500 tons was $2,475,000 resulting in a per ton cost of $150. There is no odor, little to no environmental risk, it is considered very biosecure (Brglez, 2003). At the North Carolina Disposal Conference, costs were estimated costs to be $60 per ton to treat in situ (i.e., buried) carcasses (Wilson, 2003).

Thermal depolymerization

Renewable Oil International LLC (ROI) uses an approach similar to thermal depolymerization called pyrolysis. Pyrolysis is done at a higher temperature than thermal depolymerization, but uses a considerably dryer feedstock and does not take place in the presence of water. ROI estimates a capital cost of $3 million for a 120 ton per day and a 2.5 MW gas turbine to generate electricity including the cost of feedstock.

Refeeding (primarily to alligators)

Startup costs for an alligator farm can be substantial at approximately $250,000. Some operations, even in the Southeast, raise alligators indoors in temperature-regulated facilities. Alligator waste must be filtered from the water in which they are kept, secure fencing must be provided (Sewell, 1999), and permits acquired (where necessary). Alligator farms in Florida have an average herd size of approximately 3,200 animals (Clayton, 2002). A Mitchell County, Florida farm of 6,500 alligators devoured more than a ton of dead chickens per day.

Napalm

Estimated costs of using napalm for carcass disposal are $25 to $30 per animal but will depend on the cost and temperature of available fuel and on the size of animal. The price of aluminum soap powder varies from $4.60 to $5.30 per pound. The disposal of large number of carcasses may be more efficient than dealing with small disposal situation.

Non-traditional rendering

While the operational costs of using flash dehydration followed by extrusion to recycle mortality carcasses and/or spent laying fowl appear to be economically sustainable, the process is unlikely to attract outside investors since the time to recover capital expenditures ranged from 11.41 to 48 years. The addition of the expeller press technology could be expected to increase the capital costs and reduce the annual profits for the plant even further. Extrusion is not a new technique, having been used in the food industry for some time.

The cost to dehydrate turkey mortalities to 20% moisture is about $27 per ton of final product and $40 per ton if followed by extrusion (Nesbitt, 2002). The use of extrusion methods has high capital costs, but it is possible that farmers could use the extruders for other purposes in creating feeds (Morrow & Ferket, 1993).

3.10 – Cost Comparisons

Foreign animal diseases and the efforts to control them are costly. Disposal methods and other means of disease eradication will have high short-term costs. However, failure to employ an effective strategy will lead to enormous long-term costs. Selection of appropriate strategies should consider both the short and long term costs (Nelson, 1999).

Previous comparative studies

Based on AI outbreaks in Virginia, Brglez compared methods of disposal in the case of a catastrophic avian influenza outbreak. Each method was evaluated on its capacity to dispose of 188 tons of diseased poultry carcasses per day for 90 days. Actual costs of the disposal methods used were compared with hypothetical cost estimates.

Brglez found rendering as the method of choice. The other methods considered included on-site burial, landfill burial, composting, incineration, alkaline hydrolysis, and “in-situ” plasma vitrification. The variables of disposal cost estimated were transportation, labor, materials, land-use fees, and equipment usage. The value of potentially saleable products was also considered. All methods were considered to meet the needs of stopping the spread of pathogens. It was important for the method to be cost effective and quickly accessible. Environmental concerns can be managed with burial, landfill, and incineration management techniques. The objective of the study was to determine the cost, environmental impacts, public perception impact, and complexity of each method.

Brglez examined each method by weighing the four factors on a point scale with good=1, average=2, and poor=3. Any decision making tool needs to consider all factors. The recommended choice in his final analysis was rendering (Brglez, 2003).

TABLE 6. Summary of comparative analysis (Brglez, 2003).

Method	Cost	Environment	Perception	Complexity	Total Score
On-site burial	2	2	3	1	8
Landfills	3	2	2	1	8
Incineration	3	2	3	3	11
Composting	1	1	1	3	6
Rendering	1	1	2	1	5
Alkaline Hydrolysis	3	2	2	2	9
In-situ plasma Vitrification	3	1	2	1	7

Dan Wilson of the North Carolina Department of Agriculture gathered data from a variety of vendors and presented a simple cost comparison at the Midwest Regional Carcass Disposal Conference held in Kansas City, Missouri on August 18-19, 2003. His data appears in Table 7 (Wilson, 2003).

TABLE 7. Estimated cost per ton and technology capacity for various carcass disposal methods (Wilson, 2003).

	Cost	Capacity
Rendering	$86	35-40 ton/hour
Burial	$30-60	10 ton/hour
Composting	$40-60	Equipment Limit
Air-curtain incineration	$30-200	5-6 ton/hour
Landfill	$40-100	Transport Limit
Alkaline hydrolysis	$45-260	4 Hours/Cycle
Plasma	$60	.25 to 7.5 tons/hr
Ocean disposal	$1	Transport Limit

A 2002 study commissioned by the National Renderer's Association and conducted by the Sparks Company investigated methods of disposal for livestock and their potential costs. The evaluation was completed to look specifically at the economic impact of regulations on rendering as an alternative for daily mortality disposal because of the related risks to BSE. Their estimates were based on 2000 annual mortality rates in the US of 3 billion pounds of livestock and 346 million pounds of poultry (Sparks Companies, Inc., 2002). These estimates are calculated at a per ton rate that do not include capital costs for specialized facilities (Table 8).

Renderers typically charge modest fees, but still prove to be highly cost effective because of the operating and fixed costs associated with other methods. However, if regulations keep renderers from selling their by-product their fees will likely increase significantly. The viability of disposal options for producers will depend on logistics, mortality quantity, facility locations, soil type, topography, labor availability, and equipment accessibility. Estimated costs will be driven by producers' attitudes toward the environment, management preferences, and government regulations. Results indicated rendering is a top preference assuming current rendering rates. If rendering prices increase, producers will likely choose other methods and, depending on method choice, could increase costs on society through environmental degradation, groundwater pollution, or spreading of disease. Furthermore, if the costs of "approved" methods increase, the use of "unapproved" methods may increase as well leading to greater environmental risks. Methods with high capital investment costs will be challenging for small producers especially. Therefore, any regulations impacting disposal methods need to carefully analyze all the benefits and costs of any proposed change (Sparks Companies, Inc., 2002).

TABLE 8. Cost estimates for methods of mortality disposal (Sparks Companies, Inc., 2002).

Species	Rendering: MBM sold for feed	Rendering: MBM not sold	Burial	Incineration	Composting
Total (Sector-Wide) Operating Costs ($1,000)					
Cattle and calves	34,088	99,619	43,902	38,561	125,351
Weaned Hogs	48,020	79,061	51,450	16,906	58,018
Pre-weaned Hogs	5,533	7,786	8,300	1,226	4,209
Other	5,828	8,003	6,245	1,184	4,063
Total Operating Costs	$93,470	$194,470	$109,898	$57,879	$191,643
Cost per ton ($)	$55	$116	$66	$35	$115
Operating Costs, Dollars per Mortality ($/head)					
Cattle and calves	$8.25	$24.11	$10.63	$9.33	$30.34
Weaned Hogs	$7.00	$11.53	$12.45	$4.09	$14.04
Pre-weaned Hogs	$0.50	$0.70	$2.01	$0.30	$1.02
Other	$7.00	$9.61	$1.51	$0.29	$0.98
Total (sector-Wide) Fixed Costs for Specialized Facilities ($1,000)					
Beef Cattle				797,985	1,241,310
Dairy Cattle				333,630	518,980
Hogs				158,031	245,826
Other				90,000	140,000
Total Fixed Costs				$1,379,646	$2,146,116

In a study completed at Iowa State University, data was analyzed from pork producers on the disposal methods used, satisfaction with method and costs associated with each method, including capital investment, labor, and operating costs. Incineration requires the highest capital investment while burial requires the lowest investment. However, this investment level changes if feasible burial land is not available. Composting does require an initial capital investment, but often an existing facility was converted to a composting bin. Burial had the highest labor costs, and rendering required the least labor as renderers picked up the dead stock. Depending on the labor available to the producer, it became a critical factor in method selection. Since composting is a fairly new method for these producers, labor costs are high but are likely to decline over time. Due to equipment costs, total operating costs were the highest for burial followed by composting. If the producer already owns the necessary equipment, these costs would be relatively lower. When calculated for 100 head, rendering was the least costly. When satisfaction is considered, rendering and burial are the least satisfactory; meanwhile composting, a more expensive alternative, had the highest satisfactory level (Schwager et al., 2001).

While rendering is a common current option, regulatory changes in the ability of renderers to use dead animal by-products may increase the cost to producers for rendering services. This will in turn deter rendering and result in an increase of on-farm disposal. Small producers are more likely to change activities than large producers, yet small producers may spend just as much in appropriately disposing of their death loss on their own property (Food and Drug Administration, 1997).

In the University of Nebraska study which estimates cost for routine disposal, incineration at $0.049 per pound ($98 per ton) is the lowest cost alternative followed by the incinerator with afterburner at $0.073 ($146 per ton). Low investment composting comes next at $0.091 ($182), followed by burial at $0.097 per pound ($194). (Researchers do not consider burial as a viable option). High investment composting is next at $0.113 ($226) and rendering is the most expensive at $0.163 per pound ($326) (with four loads per week) (Henry et al., 2001).

Alabama researchers found small-bin composting to be the most efficient method at a cost of $3.50 per hundredweight ($70 per ton). The size of the production unit has an impact on the identification of the most economic method. Three size operations were compared: operations with 40,000, 100,000 and 200,000 chickens. Large-bin composting showed economies of scale when comparing a farm of 40,000 to 200,000 with a reduction in net costs of 53%. Increasing flock size reduced net costs of fermentation by 60%. Burial pits were the least responsive with the operation size increase showing a reduction of only 26% while small-bin composting costs were reduced by 26% and incineration costs declined 30%. Refrigeration costs only decreased by 11% (Crews et al., 1995).

Incineration and composting of poultry (broilers, broiler breeders, and commercial layers) were compared by researchers at North Carolina State University. Cost analysis is based on fuel consumption, composter capacity needs, and labor requirements. Analysis was based on 100,000 head of broilers, layers and broiler breeders. The capital investment for incineration of layers and broiler breeders was $2500 and $1400 for their composting. The additional cost to incinerate layers was $1730 and to compost was $2237. For broiler breeders, the cost to incinerate was $1612 and to compost was $1976.50. Broilers are more expensive to dispose because they are larger. The capital investment for incineration was $3500 and $3750 for composting. The fixed and variable costs of incineration were $4003.50 and $4093 for composting (Wineland et al., 1997).

The Canadian Plan Service compared methods of disposal of poultry mortalities. They considered regulation compliance, reliability, biosecurity level and economic factors, such as amount or carcasses, capital costs, equipment availability, and labor costs. They considered four methods: incineration, rendering, composting, and farm burial. Catastrophic losses would require alternative plans be in place as no single method could likely handle the disposal needs. Incineration costs will vary depending on the types of poultry to be destroyed and the most significant cost is capital expense followed by fuel costs. Delivery to a rendering plant for the producer is the easiest, lowest cost method but is dependent on a rendering plant being nearby. Composting costs include the building of the compost bin, material, labor, and the positive value of the fertilizer. Burial on-farm was the most common, but the least recommended. But, it may be necessary in the case of a catastrophic death loss (Winchell, 2001).

Cost models

In a study by the University of California Agricultural Issues Center, the total estimated cost of a FMD outbreak (direct, indirect and induced costs) is estimated in a two-component model: an epidemiologic module that simulates a FMD outbreak in the South Valley and an economic module that estimates the economic impact. The economic model has three parts: (1) calculating the direct cost of depopulation, cleaning and disinfection, and quarantine enforcement; (2) using an input-output model of the California economy to estimate direct, indirect and induced losses; and (3) estimating the losses caused by trade reduction. The first component includes only cattle and swine. Carcass disposal costs are included in a summed depopulation cost with compensation payments and euthanasia costs. Depopulation cost per individual animal is estimated and multiplied by the expected loss from the first module. The model assumes all disposal occurs through burning and burial. Recommendations from the study not only state that depopulation costs would exceed the financial resources available but also includes the following statement: "Depopulation and carcass disposal would face serious difficulties – timely availability of sufficient human, physical and financial resources, availability of burning materials, lack of knowledge of the cost imposed on different social groups by alternative carcass disposal methods, environmental and legal issues, etc" (Ekboir, 1999).

Summary of technology costs

While numerous cost examples are available in the literature and have been highlighted in this chapter as well as in the disposal technology chapters, few reliable cost estimates exist for large-scale disposal. In the case of a foreign animal disease outbreak or natural disaster, total actual costs are unknown. Both operating and variable costs are simply approximates developed from a small number of experiences and routine disposal estimates. In addition, little to no attention has been paid to indirect costs of these technologies. The impact on the environment, land values, public opinion, and general economic factors must be evaluated as well. This type of economic analysis is critical to any decision making process.

The numbers available do provide the opportunity to compare expected fixed and variable costs per ton of carcasses; however, these comparisons should be considered with caution because 1) these estimates are the result of an extensive literature review which utilized numerous different sources; 2) the data available from these various sources are based on a variety of assumptions, including differing circumstances, cause of death, scale of disposal efforts, species, dates, and geographical locations; and 3) these various sources do not consistently incorporate capital, transportation, labor or input costs into the estimates. Despite these limitations, the following table summarizes the cost information identified in the literature. Because of the minimal cost data available on novel technologies, these innovations are not included in the table.

For each technology, Figure 1 provides summarizes the available cost data. The table included highlights the following information: (1) the range of cost estimates cited in previous studies and experiences; (2) comparative representation of cost indicators for capital, transport, labor and input costs ($ – low, $$ – intermediate, $$$ – high, $$$$-very high); (3) comparative representation of indirect cost indicators, including environment/public health and public perception; (4) an example of other indirect cost considerations; and (5) an indication of the existence of valuable or beneficial by-products. The chart reflects the high and low cost estimates as well as the most likely representative estimate. The representative estimate was derived by analyzing the data and weighting the average costs found in the literature.

Technology	Range of cost estimates per ton of carcass material disposed[a]	Direct Cost Indicators: Initial Capital[b]	Direct Cost Indicators: Transportation[c]	Direct Cost Indicators: Labor	Direct Cost Indicators: Inputs	Indirect Cost Indicators: Environment /Public Health	Indirect Cost Indicators: Public Perception	Indirect Cost Indicators: Other cost considerations	Creates valuable or beneficial by-products
Burial (on- and off-site)	$15-200	$	$	$$$	$	$$$	$$$$	Land use and values Predator activity	
Landfill usage	$10-500	$$	$$$	$	$	$$	$$$	Municipal costs Management costs	
Open burning	$200-725	$	$	$$$	$$$$	$$$	$$$$	Disposal of ash Permit Fees	
Fixed-facility incineration	$35-2000	$$	$$$	$$	$$	$$	$$$	Disposal of ash Permit Fees	
Air-curtain incineration	$140-510	$$	$$	$$	$$$	$$	$$$	Disposal of ash Permit Fees	
Bin- and in-vessel composting	$6-230	$$	$	$$$	$$$	$	$$	Land use Time efficiency	√
Windrow composting	$10-105	$	$	$$$	$$$	$	$$	Land use Time efficiency Predator activity	√
Rendering	$40-460	$$	$$$	$	$$	$	$$	Biosecurity risk	√
Fermentation	$65-650	$$$$	$	$$	$$	$	$	Time efficiency	√
Anaerobic digestion	$25-125	$$$$	$	$$	$$	$	$	Time efficiency	√
Alkaline hydrolysis	$40-320	$$$	$$	$	$$	$	$	Disposal of effluent	

[a] These estimates are the result of an extensive literature review which utilized numerous sources. The data available is based on a variety of assumptions, including differing circumstances, cause of death, scale of disposal efforts, species, dates, and geographical locations. In addition, different cost estimates do not consistently incorporate capital, transportation, labor or input costs.
[b] Includes capital costs directly associated with carcass disposal only.
[c] Transportation costs depends on the location of the technology. These indicators assume minimal transportation for more likely available technologies.

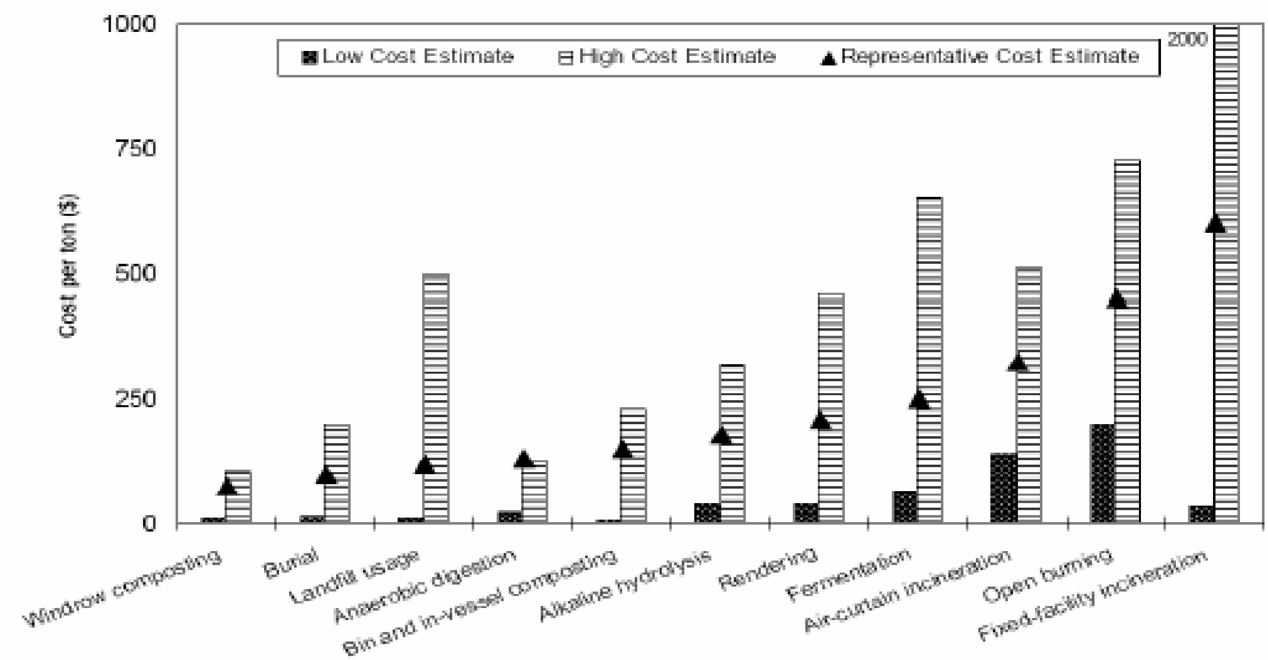

FIGURE 1. Summary of technology costs.

3.11 – Agreements and Contracts

In order to have efficient and immediate action in the case of an outbreak of a foreign animal disease and to reduce the uncertainties, agreements must already be in place with all parties involved and as many decisions as possible should be made prior to the outbreak. Agreements should be in contracts. Contracts should be in place to allow for the increase of expert staff and resources so situations will be controllable. It is easier to negotiate prices with service providers during a disease-free time period. Contracts should be negotiated with providers responsible for laboratories, rendering plants, slaughterhouses, cold storage plants, incinerators, disinfection companies, equipment suppliers, employment agencies, large machinery owners and operators, shower trucks, livestock haulers, communication systems, accommodation suppliers, and others. Any required licenses should be confirmed at this time as well. In order to ensure proper use of public funds when commercial operators are involved, sound management with consistent and sound financial control is necessary. Government agencies should utilize and delegate to specialists available in the private sector to deal with a large animal death loss (de Klerk, 2002; National Farmers Union, 2002).

During the 2001 outbreak of FMD in the UK, organization and management of contracts and the increasing number of contractors created serious challenges in disposal operations. Material for pyres became difficult to obtain, and rapid price inflation existed on fuel sources. Poor quality coal made achieving combustion difficult and a lack of available manual labor caused efforts to be less efficient than in the 1967 outbreak (Scudamore et al., 2002).

The disposal of thousands of animal carcasses in North Carolina in the wake of Hurricane Floyd resulted in additional provisions regarding carcass handling. In the County Plan recommended by the North Carolina State Animal Response Team, the Mortality Management Section coordinators, Drs. Jim Kittrell and Dan Wilson, identify the need to prearrange contracts for resources to handle dead animal removal, burial and disposal. Under the State Plan, it is recommended to work out financing so counties can arrange local contracts with understanding of reimbursement. An important consideration in any contract is how the contracted work is to be measured and compensated. In developing such contracts, consideration should be given to how the animal will be handled and the condition of the carcass. Both parties of the designated contract, the payee and payer, must be able to accurately and consistently measure and count the unit (Ellis, 2001; Kittrell & Wilson, 2002).

Section 4 - Policy Considerations

There are numerous factors that will impact large-scale carcass disposal decisions. It is necessary to identify the factors that must be considered. One of the first factors to be highlighted is the cause of death. If death is due to a contagious disease, then finding a biosecure solution is critical. Biosecurity concerns outweigh nearly all other concerns when a highly contagious disease is involved. In those cases, public exposure must be limited, transportation should be minimized and performed in a manner that will ensure containment of the infectious agent, and biosecurity measures must be the priority. If, instead, deaths are due to a natural disaster, then emphasis should be placed on an environmentally friendly solution. Each method has a different impact on the environment and creates different lasting impacts. The USDA Veterinary Services agency provides a list of environmental decisions to be made, and encourages decision makers to consider impacts on groundwater, wildlife, air quality, surface water, climate, public health, solid waste, cultural resources, utilities and vegetation. It is critical that greater consistencies exist in state regulations and the mechanisms to waive those regulations.

The scale (numbers of carcasses) and scope (species) of the death loss are also important factors. Certain technologies can handle only limited numbers and may not be efficient enough in the case of a major emergency. Some disposal methods are more acceptable with cattle than poultry and vice versa. Logistical issues regarding location of the carcasses, spread of the animal deaths, and proximity to facilities and resources (e.g., fuel) becomes of critical consideration as well. The best solution for one state may differ from another because of the location of large animal numbers and the distance to major population centers. Public health must always be considered as the over-riding factor in determining the most appropriate method of disposal (Ellis, 2001, p. 35). One factor often not discussed in the decision process is the economic impact of the disposal method and the direct and indirect costs, including those related to direct disposal, transportation, facilities and equipment, energy requirements, environmental impact and social costs.

Any final regulatory policy that provides emergency response personnel and animal health officials decision-making guidelines must include consideration of:

- Cause of death loss
- Diseases involved
- Scale of death loss
- Site and facility availability
- Fuel and resources
- Water table and resources
- Transportation options
- Distance to disposal sites
- Costs and economic impacts
- Proximity to population centers
- Public health
- Species involved
- Public perception
- Environmental life cycles
- Soil types.

Any animal health plan must include at least these points for consideration when determining the appropriate disposal technology. Any plan should include multiple methods of disposal and steps need to be taken prior to an emergency to prepare for the usage of multiple disposal methods (Ekboir, 1999; Harman, 2001). If plans are based solely on what is cheap and fast, poor decisions may be made. For example, in Alberta, "Dr. Gerald Ollis noted that burying carcasses is the cheapest disposal method because rendering and incinerating can cost several times more than an animal is worth" (Teel, 2003).

Animal health officials are examining pre-emptive slaughter strategies across the country. In Kansas, as an example, the regulation that all animals within a 1.5-mile radius should be destroyed is being questioned. Feed yard concentration may impact such regulations. If an animal in a feed yard is infected, it may not be necessary to destroy animals more than ½ a mile away if there are no cattle immediately surrounding the feedlot. There may be no way for the disease to be carried from one lot to another and the hot, dry climate of Western Kansas does not lend to easy survival of FMD (Bickel, 2003).

The impact on the environment will be greatly impacted by any change in rural economy and agricultural policy regarding large animal death loss and specifically carcass disposal. Water, air, soils and biodiversity should all be considered. Recent outbreaks have proven that limited time to select burial or burning locations, rapid authorization of disposal permits, communication difficulties between agencies, and public contentions all were directly related to environmental concerns (Harman, 2001). The impact on public health as a result of environmental impacts as well as other physical and psychological issues is also a concern.

Another issue to be discussed is the need for interagency cooperation and clearly defined responsibilities amongst those agencies. State interagency coordination is fundamental to being prepared to handle an animal health emergency (Ekboir, 1999). These issues need to be addressed between local, state, and federal governments as well as between agencies at any government level. Jurisdictional conflicts exist and must be resolved prior to the onset of an emergency situation. Few states have comprehensive disposal plans in place although such plans are critical to making efficient and effective decisions in the face of both small- and large-scale death losses. Therefore, there is a critical need to further review and recommend policy and regulation guidelines (Ellis, 2001). In the US every state has regulations regarding the disposal of dead animals; therefore, each state must approve the disposal method before it is used (Morrow & Ferket, 1993).

An issue that needs further policy consideration is the combination of vaccination and slaughter to control disease. In some countries, where FMD stamping-out is feasible, compete slaughter is the most cost effective alternative, but, in other countries, vaccination may be more cost effective. Introduction of a foreign animal disease will elicit a rapid attempt to control and eradiate the disease (including carcass disposal), and the short-term economic damage may be greater than the cost of the disease itself. Regardless of the costs, the control mechanisms are necessary as the long-term economic impact of the disease becoming endemic would be greater than the control and eradiation costs (Wheelis et al., 2002).

Rushton et al. developed a decision analysis structure to assist policy makers in the selection of control and eradication strategies. They utilized epidemiology, rural economy, export issues, and livestock systems in a matrix together with epidemiological and economic models to determine costs of different strategies. They estimated and compared four strategies: complete stamping out, stamping out with vaccination and slaughter of vaccinates, stamping out combined with vaccination, and vaccination alone. The results indicate that slaughtering infected and suspected animals and vaccinating contiguous flocks/herds is the most cost effective strategy. Methods of disposal of those slaughtered are not clarified. Using decision analysis and a more flexible approach could help reduce cost, maintain producer and public support, and confine and shorten the epidemic (Rushton et al., 2002).

The issue of producer compensation is also important and has significant policy implications. Most states have policies in place regarding this issue. Consider, for example, the wording in Kansas statute 47-626: "The cost of all animal euthanasia and disposal of animal carcasses will be paid by the State of Kansas" (Kansas Animal Health Department, 2002). However, a great deal more thought must be given to when and how producers will be compensated for death loss and disposal costs.

Section 5 – Critical Research Needs

In the event of a large-scale animal health emergency, the slaughter and disposal of infected and exposed animals is an instrumental part of controlling and eradicating the disease. Available technologies offer multiple options for disposal, including rendering, burial, incineration/burning, composting, alkaline hydrolysis, and other emerging concepts. Selection of an appropriate technology, or combination of technologies, will depend on a number of factors, including cause of death, availability of necessary technology and resources, public health, environmental concerns, public perception, transportation needs, location, climate, regulatory issues and economic considerations.

At times, location and technology availability may give producers and animal health officials little to no choice regarding the disposal technology used. Public health should always be a priority if an infective disease agent is involved. In the case of no threat to public health, biosecurity risks related to the livestock industry are of paramount concern. Short-term and long-term impact on the environment should also play a key role in the technology selection process. Economic considerations, including but not limited to direct cost of the disposal methods, must also be a part of the decision making process.

Economic analysis must go beyond the direct costs of disposal (e.g., technology, equipment, transportation, storage, site acquisition, fuel, facilities, and labor) and must include other economic estimates, such as the impact on the environment, tourism, future land values, and other social costs.

The method of carcass disposal used can impose heavy costs on society. Some methods could result in costs incurred not solely by producers, but by society as a whole through environmental degradation, elimination of tourism opportunities, or the spreading of disease. The impact on the environment of certain disposal methods could be unrecoverable. Burial of carcasses will likely cause land used for pits to be lost for production for several years, therefore affecting producers future economic well-being. Tourism can be greatly affected simply by carcass disposal images portrayed to the public. If landfills are used, the county may be financially impacted if landfill capacity is reduced prematurely. Estimating this impact requires an in-depth examination of future land use.

In order to determine the optimal investment in disposal technology and capacity, the cost-benefit ratio of alternative methods for carcass disposal needs to be analyzed. Joint programs between states and/or the federal government to invest in disposal equipment should be evaluated as a possibility. The costs to producers, processors and local communities for each disposal method should be carefully considered. Regulations requiring contingency plans for rapid depopulation of livestock premises should be considered.

For example, in a qualitative disposal risk assessment completed by the UK Department of Health, the chemical and biological sources of greatest concern were combustion gases, air-borne particles, bacteria spread through water, water-borne protozoa and BSE from cattle. The Department of Health assessed rendering, incineration, licensed landfill usage, pyre burning, and on-farm burial for their ability to minimize the previously listed hazards. They noted the importance of following prescribed guidelines in all technologies and found rendering to be the best choice. It was also noted that potential risks to pubic health if disposal is delayed might be greater than risks associated with alternative disposal methods. While a qualitative approach allows for numerous issues to be discussed, no quantitative impact on public health was examined nor was it determined how these issues might formally become part of decision making processes.

Economics cannot and should not be the sole factor in a decision-making process, but economics should be part of the equation. Economically attractive disposal methods may not meet regulatory requirements; the most cost-effective method may be prohibited by local, state, or federal regulations. Additional efforts are necessary to assess state-by-state regulations, investigate opportunities for individual states and the federal government to work together, have disposal plans in place before an emergency, and delineate clear decision-making responsibilities. For example, in order to minimize direct costs, contracts with technology providers should be negotiated in advance. It must be clear who takes on this responsibility. Balancing economic considerations with regulatory requirements is necessary to determine the best options for carcass disposal.

In consideration of further research, the following issues should be addressed:

- Identify direct costs of each disposal technology in the case of large-scale, emergency disposal. Cost estimation models need to include equipment, transportation, training, site acquisition, fuel, facilities, labor, storage, and other direct disposal costs.
- Estimate costs to regulatory agencies of preparing, training, and organizing staff for each disposal technology. This should include an analysis of different levels of preparedness compared to the costs of the outbreak (i.e., the cost of preparedness at level A would be X and the costs of the outbreak given this level of preparedness would be Y).
- Identify a method to estimate direct environmental costs with each technology, including impact on air, water, soil, wildlife, climate, and vegetation and estimate such costs. The method of carcass disposal used can impose heavy costs on society, including environmental degradation. Therefore, estimating the economic impact beyond direct disposal costs is critical to any complete economic analysis. Previous economic work related to similar industries (e.g., waste disposal) could be used in creating economic models.
- Estimate other indirect costs and economic impacts of large-scale disposal efforts on national economies, particular sectors, and society as a whole (including production,

processing, public health, and tourism). Examples of factors to be considered include the impacts of different disposal technologies on land-values, tourism, consumer consumption of animal agriculture products, and the public health costs of stress on producers and emergency workers.

- Develop a cost-benefit analysis model incorporating control, preparation, and direct and indirect costs of disposal technologies.
- Consider the role of the public sector in providing compensation for carcass disposal and minimizing direct and indirect costs to producers (this would include the estimation of recovery costs). This includes estimating the economic impact on different sectors, including producers, local communities, and government. Investment partnerships in technology and training should also be evaluated.
- Consider the role that cost factors should play in government regulation and how economic criteria and biological criteria should be balanced in a decision-making framework. Improvement of the decision making process related to large-scale carcass disposal is the ultimate goal.
- In addition to further defining policy regarding carcass disposal, consideration should be given to vaccination, euthanasia, and animal welfare policies. The depopulation of animals for disease control or animal welfare purposes is a complex issue and deserves significant investigation. Future research should investigate various technologies and kill policies, along with their relationship to animal welfare and behavior, transportation, disposal, economic impact, environmental effect, public relations, public health, and related industries. The following research issues need to be addressed:
    - Identify current policies and regulations related to depopulation and euthanasia at local, state and federal levels.
    - Examine the technologies available for the euthanasia of animals for disease control or animal welfare purposes.
    - Examine current emergency vaccination policies and their relationship to the destruction of animals for animal disease control and welfare purposes.
    - Investigate the impact of different euthanasia technologies on animal welfare and animal behavior.
    - Identify the primary issues related to the use of these technologies and their relationship to transportation and movement, disposal, economic impact, environmental effect, public relations, public health, and related industries.
    - Investigate the impact of certain mass destruction methods, laws and policies on animal producers or caretakers.

Improvement of the decision making process related to large-scale carcass disposal is the ultimate goal. Further review and response to the research questions noted would provide regulators and policymakers with the necessary information to make decisions. These results, combined with increased research from the scientific community on each disposal technology, will help government and industry be better prepared for any large-scale carcass disposal event.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

10

Historical Documentation

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Abbreviations

APHIS USDA Animal and Plant Health Inspection Service
CDWG carcass disposal working group
DOE US Department of Energy
DEP Pennsylvania Department of Environmental Protection
END exotic Newcastle disease
FMD foot and mouth disease
HIDA Historic Incidents Database and Archive
HPAI highly pathogenic avian influenza
LPAI low pathogenic avian influenza
NPAI nonpathogenic avian influenza
USDA United States Department of Agriculture

Section 1 – Key Content

The objectives of this research were to examine the state of historical documentation relative to past carcass disposal events within the United States, and explore the potential for developing a Historic Incidents Database and Archive (HIDA). Based on research into past incidents of catastrophic losses of livestock and their associated large-scale disposal efforts, deficiencies were observed to exist in historical documentation, with significant variances occurring among states relative to planning, experience, and preparation for a catastrophic event. There was also an evident problem in sharing information, expertise, and experiences among the states in regard to handling a catastrophic carcass disposal event.

Research indicated that California, Georgia, Indiana, Maryland, North Carolina, North Dakota, Pennsylvania, and Texas have accumulated a great deal of experience and expertise in catastrophic animal disposal incidents. The most frequent causes of carcass disposal events included avian influenza, pseudorabies, and natural disasters. The states of Florida, Hawaii, Idaho, Iowa, Maine, Michigan, Missouri, Oregon, and Washington have had experience with relatively small carcass disposal incidents due to avian influenza, accidents, or natural disasters. Other states have indicated they have had no recent experience with large-scale carcass disposal operations but have provided information on their states' carcass disposal regulations. All the officials contacted in the course of this research expressed enthusiasm for opportunities to communicate and exchange information, experience, and expertise on carcass disposal with officials in other states.

During the course of this research it became evident that US officials concerned with managing a catastrophic animal disposal incident could benefit from a rigorous historical program. A historical team dedicated to issues of agricultural biosecurity and carcass disposal could provide officials on both the state and federal level with information that would be invaluable for emergency planning and incident management. A historical program for agricultural biosecurity and carcass disposal would also help to assure both the media and the general public that the carcass disposal methods used in dealing with any future catastrophe are both necessary and effective. A well-documented history of both past and emerging catastrophic carcass disposal incidents would also provide additional credibility to emergency management officials when dealing with governors, state legislatures, and the US Congress.

Although documentation of past large-scale animal disposal events is limited, a number of incidents were investigated that yield important lessons for emergency management officials concerned about the possibility of a catastrophic event (see Section 3). While the lessons from these experiences should serve as guides for other states and localities preparing for a catastrophic event, dissemination of these lessons is hampered by the almost total absence of historical records documenting catastrophic animal disposal events. Large-scale animal disposal events caused by natural disasters or epidemics are certainly nothing new, and states and localities have encountered these problems in the past; however, interviews and correspondence with officials from various states confirm that state agencies dealing with this problem generally have no institutional memory. The documents that do exist provide only rudimentary data, and states often purge what are deemed as inconsequential records at five- or ten-year intervals. As a result, detailed information about carcass disposal incidents that occurred more than ten years ago can be very difficult, if not impossible, to obtain.

As a consequence of the generally inadequate historical documentation of animal disposal events, a majority of the information that can be gleaned about past events has to be obtained from interviews of the persons involved in such events. Although information obtained from interviews can certainly be useful and the knowledge and experience of those involved in past events is worthy of documentation and distribution, oral history can have significant shortcomings. Human memory can be problematic and hard facts concerning numbers of livestock lost, economic losses, disposal expenses, and the exact location of disposal sites can be difficult or even impossible to obtain. In addition, the death, retirement, or career changes of those individuals with the most knowledge of past incidents means that the ability to learn lessons from past incidents dissipates with each passing year. The absence of any institutional memory or written history of past incidents robs current government officials of a useful pool of knowledge concerning how best to handle any future large-scale animal disposal emergency.

Another major deficiency lies in communicating and distributing current information concerning carcass disposal technologies, planning, problem solving, and historic incidents. It appears that the various states and localities operate as independent islands with each one attempting to plan and prepare for potential emergencies as if in a vacuum. Communication is lacking among officials in various state agencies involved in regulating or directing animal disposal projects, academics involved in the study of carcass disposal, and the various federal agencies that might provide assistance. Consequently, evaluation of opportunities and means to facilitate communication between state and federal officials, producers, and academics is warranted. Possible means include virtual forums—or other electronic formats—that could provide an inexpensive and effective channel to share past experiences and problems and to distribute information on carcass disposal technologies, emergency planning, laws and regulations, logistics, and a variety of other relevant topics. Information from these forums could then be captured for further development. Many officials attending an August 2003 Midwest Regional Carcass Disposal Conference expressed great interest and enthusiasm for opportunities to increase communication with outside experts or other experienced individuals.

Section 2 – Historical Studies

The September 11th attacks in Washington, DC, New York, and Pennsylvania offer dramatic examples of "asymmetric warfare." Small groups of highly organized and highly motivated irregulars can move undetected in American society and, with minimal resources, execute attacks that simultaneously inflict enormous loss of human life and billons of dollars worth of economic damage. Given the open nature of American society, targets for terrorist cells are abundant. Possibly one of the United States' most vulnerable targets is its food supply system. An attack by terrorist cells deliberately infecting American livestock with highly pathogenic agents could threaten the food supply and impose significant economic losses on producers. The vulnerability of the nation's food supply to terrorist attack or even accidental infection is greatly magnified by the fact that current livestock operations concentrate very large numbers of cattle, chickens, turkeys, and swine in feedlots or confinement systems. The rapid transit of livestock to slaughter facilities simply magnifies an already enormous vulnerability. The accidental infection of livestock in the United Kingdom with foot and mouth disease (FMD) in 2001, and the highly problematic containment and disposal effort that followed, provides an example of the enormous economic damage that can be inflicted by highly contagious diseases regardless of whether livestock are deliberately or accidentally infected.

In preparing for the possibility of a terrorist attack on the US food supply or even the possibility of the US food supply becoming accidentally contaminated by some infectious agent, state, local, and federal agricultural officials can realize some important returns on a modest historical/scientific research effort in past large-scale animal disposal incidents. The historical programs of the US armed forces and the US Department of Energy (DOE) offer excellent examples of the usefulness of historical studies for the successful execution of their particular mission as well as effective models that officials concerned with agricultural biosecurity can imitate. The US Armed Forces devote significant resources to documenting and analyzing past operations, campaigns and conflicts as well as preserving historically important materials for future research. For example, the US Army has highly trained civilian command historians who actively document the activities of each US Army command. The US Army Center of Military

History, which is staffed by active duty personnel and highly trained civilian historians, documents and writes a variety of campaign studies and analyses and researches, composes, and publishes the US Army's official histories. The US Army also utilizes Military History Detachments, small units of active duty soldiers who enter combat zones and theaters of active military operations. These soldier-historians conduct subject, after-action, and exit interviews of commanders and troops, photograph and film combat operations, and document all aspects of military operations that can be used to compile important "lessons learned," campaign analysis, and official histories (Gough, 1996; Wright, 1985, pp. 3-6).

The US DOE, like the US Armed Forces, also realized the benefit of a vigorous historical research program. In the aftermath of the nuclear reactor accident at Three Mile Island, Pennsylvania, in March 1979, the DOE discovered it possessed no systematic institutional memory concerning nuclear accidents whether civilian or military. There existed a good deal of information concerning laboratory mishaps, reactor accidents, military "broken-arrows," and other nuclear incidents, but the data, while voluminous, was uncollated, non-uniform, unverified, incomplete, inaccessible, contradictory and, frequently, self-serving. In addition, the historical information was not centralized, but rather was scattered among headquarters and field offices, laboratory archives, military commands, and contractor records. Much of the data was security classified. Consequently, the DOE had great difficulty in providing Congress, the White House, cooperating federal agencies, state and local officials, and the press accurate and reliable historical information concerning the department's experience in dealing with nuclear accidents.

In addition to writing the report of the DOE's response to Three Mile Island (*Crisis Contained: The Department of Energy at Three Mile Island*), the History Division, under the leadership of Chief Historian Jack M. Holl, was tasked to develop a centralized, comprehensive nuclear incidents database and archives for the DOE. The nuclear incidents database would contain standardized information on all nuclear and non-nuclear reactor accidents; nuclear mishaps at all DOE laboratories and contractor facilities; military "broken-arrows" and nuclear incidents in the armed forces; and unauthorized, illegal, criminal, and terrorist use of nuclear materials or devices. The computerized nuclear incidents database would be supplemented by an archive of reports, hearings, investigations, articles, books, press releases, newspaper and video coverage, and other printed, pictorial, and evidentiary material pertinent to the database. The nuclear incidents database, while centralized in the DOE History Division, was designed to be searchable from the field.

The nuclear incidents database and archives provided the DOE an invaluable management tool and public relations asset. Public policy rests to some degree on the assessment and understanding of historical precedent. DOE officials in command of accurate and pertinent data stand on firm historical ground in developing and promulgating national policy relative to nuclear accidents and terrorism. In concert with providing the department a useable institutional memory, the History Division also augmented the nuclear incidents database with a "current history project" which actively collected data and records of current nuclear incidents worldwide to the extent that the information was available. Thus the nuclear incidents database and archives was kept up-to-date with a proactive, ongoing data collection and analysis project (Holl, 2004).

Section 3 – Historical Experiences

The objectives of this research included examining historical incidents of catastrophic losses of livestock and their associated large-scale disposal efforts, and designing and populating a Historic Incidents Database and Archive (HIDA). This database is intended to become a searchable, Web-based database documenting past incidents of catastrophic livestock losses and their associated disposal efforts.

HIDA will also store bibliographic material, images and files related to carcass disposal, and historic carcass disposal events. The various fields that HIDA will feature are outlined in Appendix A. Progress in building the first version of a HIDA is well advanced, as is the identification of historic events to populate this database.

3.1 – Survey Methods

Research into the history and magnitude of past large-scale carcass disposal incidents within the United States was initially conducted using traditional, library-based research with the intent of developing bibliographies of materials concerning catastrophic animal disposal efforts. Although some useful materials were obtained through library research, it was discovered that catastrophic animal disposal incidents are largely undocumented. Some library resources offer journalistic reports that indicate the approximate scope of agricultural losses due to natural disaster or disease but do not provide any significant details on carcass disposal efforts, numbers of various species lost, economic losses sustained, disposal methods and protocols used, disposal effort expenses, or long-term problems associated with a massive disposal operation (i.e. environmental impacts). Needless to say, these sources are inadequate for the purposes of fully developing the HIDA.

Given the dearth of detailed historic information relative to carcass disposal events, efforts were then turned to contacting all state departments of agriculture to request information on past carcass disposal incidents within their states, the availability of documentation regarding past incidents, current regulations concerning animal disposal, and current planning. Requests were mailed to all fifty states, and the quality and quantity of responses varied. The responses received are summarized in the following paragraphs. Responses were followed up with additional telephone calls, e-mails, and the dispatch of a carcass disposal questionnaire (see appendix B) about the specific incidents that were reported.

Correspondence with and telephone interviews of various state officials who responded to the mailing yielded some interesting information regarding past carcass disposal efforts that should be of great interest to all involved with the Carcass Disposal Working Group (CDWG) project. In addition, correspondence and interviews with respondents revealed that state records of carcass disposal events are at best fragmentary and incomplete. A great deal of information had to be obtained from correspondence and interviews of persons with firsthand knowledge of these events.

3.2 – Preliminary Survey Results

Of the states that responded to the inquiries, some have accumulated a great deal of knowledge and experience in handling catastrophic animal losses due to both natural disaster and disease. California, Georgia, Maryland, North Carolina, North Dakota, Pennsylvania, and Texas North Carolina, Texas, California, North Dakota, Pennsylvania, Georgia, Maryland and Indiana appear to have accumulated the most experience in dealing with catastrophic losses of animals and their disposal. The incidents these states handled offer the richest areas for the study of past catastrophes and important lessons in planning for future events.

A number of other states revealed they had accumulated some experience with relatively modest animal disposal incidents. Other states indicated they had no experience with such catastrophes but did provide information on their state regulations governing animal disposal or potential problems should an animal catastrophe occur within their state.

North Carolina

North Carolina's experience in disposing of approximately 3 million animals as a result of Hurricane Floyd in 1999 makes it one of the nation's leaders in handling carcass disposal in the wake of a catastrophe. The vast majority of the animals lost in Hurricane Floyd were poultry and therefore North Carolina officials were not faced with the disposal of hundreds of thousands of large animals, nor a massive disposal effort made more complex by protocols necessary for the containment and eradication of an epidemic. However, the destruction left in the wake of Hurricane Floyd did create an enormous carcass disposal incident. Flooding led to the loss of 752,970 turkeys, 2,107,857 chickens, 21,474 swine, 619 cattle, 125 goats, 23 horses, and 10,000 cases of eggs. The disposal effort was also inhibited by impaired transportation and widespread electrical power outages. As a result of the power failures, rendering facilities were not able to operate. North Carolina law requires rendering, burial, or incineration of carcasses, but given the emergency the North Carolina State Veterinarian authorized the composting of avian carcasses in open areas. The compost piles were required to have a bed of hay or plastic and the carcasses were required to be covered with bulking material and covered by plastic sheeting and located at least 300 feet from flowing streams, bodies of water, or wells. Any runoff from the compost sites was to be controlled by berms and all the location of all the compost piles were to be reported to the State of North Carolina.

Air curtain incineration was used to dispose of cattle, swine, and some poultry carcasses, but this technology was utilized under less than ideal conditions. Obtaining dry wood for fuel and the abundance of waterlogged carcasses inhibited the efficiency of this disposal technology. The advanced state of decay of some carcasses also inhibited efficient incineration.

North Carolina also utilized burial as a carcass disposal technology but this option was also problematic. North Carolina statutes require carcasses to be buried at least 3 feet below the ground surface and at least 300 feet from a flowing stream, well, or body of water. Severe flooding limited access to potential burial sites and the rapid decomposition of carcasses created difficulties in handling and transport.

In reviewing and evaluating the carcass disposal effort in the wake of Hurricane Floyd, North Carolina officials were able to discern a number of important lessons. The first is that the most effective way to handle any disaster situation is to let local officials be in charge of their own disaster relief efforts. Local officials know the local population and the disposition and location of local resources better than anyone on the state or federal level. North Carolina also determined that any delay can be extraordinarily costly and it is best to have contracts in place long before a disaster strikes. Extended contact and coordination between state, local, and federal officials before an urgent animal disposal event emerges also facilitates the disposal effort (Kirkland, 2003).

North Carolina's experience and use of a variety of disposal technologies, planning, and "lessons learned" from Hurricane Floyd offer an outstanding template for other states and localities concerned with the possibility of catastrophic animal losses.

California

The poultry industry in southern California recently experienced an outbreak of exotic Newcastle disease (END) that resulted in the destruction of 3.6 million birds. END was first discovered in October 2002 and infected the first commercial egg farm by November 2002. By January the disease had spread throughout Riverside County, California, and infected 21 commercial flocks and 899 backyard flocks. State and local officials quarantined over 18,340 premises in an effort to check the disease and discovered that 920 of the quarantined premises had been infected. California's disposal effort was made more complicated by a fire that destroyed a local rendering facility. As a result all the birds were disposed of via landfill. Birds were euthanized using carbon dioxide gas then loaded into sealed trucks wrapped in thick-ply plastic for transport to Riverside County landfills. Decontamination of the vehicles occurred on site as well as at the landfill (Hickman, 2003a; Hickman 2003b; Riverside County Waste Management Department, 2003).

The END incident in California is well documented but, at time of publication, minimal detailed information from the University of California Extension Service is publicly available.

North Dakota

A severe winter and a major flood in the winter/spring of 1996 and 1997 destroyed approximately 110,000 cattle in North Dakota. In North Dakota's case only 14,000 animal carcasses were actually documented as buried. Although local authorities and producers buried many carcasses, in some cases burial or other means of disposal was not possible due to the carcasses being inaccessible and subsequently in an advanced stage of decay. The North Dakota carcass disposal effort provides excellent opportunities for further study. Obviously logistical problems, planning, and limited state resources all played a part and these aspects warrant deeper examination (Carlson, 2003; North Dakota Department of Agriculture).

Texas

Texas Floods in 1998 provided carcass disposal experience. Dee Ellis of the Texas Animal Health Commission reviewed the disasters, collected data and performed numerous personal interviews.

In October 1998, torrential downpours in south central Texas resulted in the flooding of the San Marcos, Guadalupe, San Antonio, and Colorado River Basins. Over 23,000 cattle were drowned or lost, in addition to hundreds of swine, sheep, and horses. The Texas Animal Health Commission (TAHC) worked with state emergency personnel from the Governor's Division of Emergency Management, the Texas Department of Transportation, and the Texas Forest Service to manage the disposal of animal carcasses. Local emergency response personnel played integral roles in the actual disposal process. Most animal carcasses were buried (where found if possible) or burned in air curtain incinerators. Two air curtain incinerators were utilized. One difficulty that arose was finding a burn site selection that was not located on saturated ground. Some carcasses were inaccessible and began to decompose before actual disposal could take place. According to Ellis, the main carcass disposal issues were 1) lack of prior delineation or responsibilities between agencies, 2) non-existent carcass disposal plans and pre-selected disposal sites, 3) a short window of time to complete disposal, 4) minimal pre-disaster involvement between animal health and local emergency officials, and 5) and inaccessibility of some carcasses (Ellis, 2001).

Pennsylvania

The State of Pennsylvania has been extremely cooperative and has shared a great deal of information on their large-scale animal disposal incidents. Pennsylvania officials have dealt with two outbreaks of low pathogenic avian influenza, one incident of highly pathogenic avian influenza, and one outbreak of pseudorabies.

In 1983-84 Pennsylvania was forced to deal with an outbreak of highly pathogenic avian influenza (HPAI) that required the destruction and disposal of more than 16,000,000 birds and cost more than $70 million. A 1997-98 outbreak of low pathogenic avian influenza (LPAI) resulted in the destruction and disposal of 1,565,000 birds and another outbreak of LPAI in 2001 required the state to dispose of 170,500 birds. The 1997-98 LPAI incident indemnity and carcass disposal cost $2,000,000 while the 2001 LPAI incident indemnity and disposal cost $150,000. In all three incidents the Pennsylvania Department of Agriculture officials used a combination of disposal technologies that included burial, composing, and landfill in order to accommodate the disposal of such large numbers of birds. Burial of birds on site created a number of problems. First, some carcasses were pushed to the surface due to decomposition gasses and inadequate soil coverage. Soil subsidence of the burial pits was also a problem. In addition, burial of enormous numbers of chickens created a perception problem about the possibility of groundwater contamination. Despite the fact frequent testing revealed no groundwater contamination has occurred, the concerns of those who live in the vicinity of the burial pits persist.

In-house composting is perhaps Pennsylvania's preferred carcass disposal technology though this option, in Pennsylvania's experience, also presents some problems. The first problem is an economic one due to the fact that there is an inconvenience cost associated with keeping the farm under quarantine but not in production as well as concerns about the biosecurity of this procedure for the disposal of diseased carcasses. Composting was also found to be impractical for the disposal of layer flocks due to the layout of the poultry houses.

Landfill disposal, in Pennsylvania's experience, also presented a number of concerns and was, at times, problematic. The landfill option poses biosecurity concerns surrounding the transport of carcasses, as well as additional labor in lining trucks with thick plastic and sanitizing vehicles at both the farm and landfill. The limited hours of operation for landfills also made the timing of flock depopulation and transport to the landfill a constant challenge. Finally, the use of landfills for the disposal of diseased animals also required clearances from the Pennsylvania Department of Environmental Protection (DEP).

Incineration of the diseased poultry was never considered and Pennsylvania has never attempted air curtain incineration. In the incidents listed above, the Pennsylvania DEP provided follow-up monitoring of all burial and landfill sites. No complications or significant problems have yet been encountered.

In 2002 Pennsylvania faced a pseudorabies outbreak that required the disposal of 15,000 hogs within a six-day period. The majority of the infected hogs were initially scheduled to go to rendering facilities. At the last moment this disposal option could not be utilized due to the fact that Pennsylvania rendering facilities refused to handle diseased animals and had a processing rate that was too slow to accommodate the needs of the carcass disposal team. Instead the Pennsylvania carcass disposal team decided to dispose of the hogs via landfills and a small percentage of the hogs were buried on site.

In managing the Pennsylvania pseudorabies incident the carcass disposal team developed very efficient means of handling the large number of infected animals. The swine were loaded into refrigerated trucks (reefers) and euthanized using carbon dioxide gas for 12-18 minute cycles. This resulted in 100% mortality. Captive bolt guns were available as a backup but were rarely used. Carcasses were unloaded from the refrigerated truck using a skid-steer payloader operating from two flatbed trailers parked adjacent to one another. The only bottleneck in the carcass disposal system was created by the time required to unload the reefers. Pennsylvania received expert advice and assistance in the euthanasia operation from a US Department of Agriculture (USDA) team under the direction of Dr. Frank Wilson.

Once the swine were euthanized, the carcasses were loaded onto dump trucks and hauled to area landfills. On the second to the last day of the disposal operation two truckloads of carcasses, approximately 80,000 pounds, arrived at the local landfill a few minutes after closing and were refused entry and permission to park overnight on the landfill premises so as to facilitate the prompt unloading of the trucks the following day. As a result of this development the carcass disposal team recalled the trucks to the farm so that the carcasses could be buried on site. A bulldozer operator was located and a pit was excavated. The Pennsylvania DEP supervised the burial. The DEP provided follow-up monitoring of both the landfill and burial site and has reported no complications from the disposal technologies utilized (Knepley, 2003; Pennsylvania Department of Agriculture).

Georgia

Dr. Nelwyn Stone, a veterinarian with the Georgia Department of Agriculture, provided information on four catastrophic carcass disposal incidents that occurred in Georgia. The first occurred in 1994 when Hurricane Alberto hit Georgia. Forty counties in Georgia were affected and hundreds of thousands of livestock perished. Many of the carcasses washed into rivers and were eventually swept out to sea. The destruction of so much livestock and the resulting flooding led to significant public health problems for human beings. Hardest hit was Dougherty County where all the livestock in a feeding operation drowned. The county sewer system flooded and the well around the feeding operation became contaminated with coliform bacteria and high nitrate levels from animal waste and decomposing carcasses. As a result, local residents in Dougherty County were compelled to boil their drinking water for several years following Hurricane Alberto.

Hurricane Alberto also hit Macon County, Georgia, very hard and necessitated the burial of 100,000 birds. The Georgia Department of Agriculture, Department of Transportation, and the Georgia National Guard assisted in the burial of the birds on site.

The problems Georgia encountered in the wake of Hurricane Alberto led to the adoption in 1995 of the Emergency Support Function Plan 14 which attempted to better coordinate state resources to train personnel and plan, respond, and mitigate animal health emergencies caused by disease or natural disaster.

In 1999 tornadoes struck Mitchell County in Southwest Georgia and destroyed 3 farms resulting in 900 tons of dead chickens. The Georgia

Department of Agriculture incinerated the carcasses and then buried the ashes on site. In 2001 tornadoes again struck the same farms and resulted in 450 tons of dead chickens. Incineration of the carcasses and burial of the ashes on site was again used to dispose of the chickens. Dr. Stone indicated that, as a result of the emergency management system now in place in Georgia, the disposal of the chicken carcasses in these operations cost $300,000 or about 15 cents per pound. Outsourced bids for carcass disposal in these operations ran to $1.5 million or approximately 80 cents per pound.

In 2002 Georgia also dealt with a relatively rare man-made carcass disposal incident. In Wayne and Pierce County, Georgia, the operator of a poultry layer farm abandoned 1,171,000 chickens with no food. Consequently many thousands of chickens died of starvation. Of the 1,171,000 that the State of Georgia discovered on the farm, 705,000 were determined to be in good enough condition to sell to other companies. Georgia had to bury 103,000 on site, render 233,000, dispose of 90,000 in landfills, and sent the remaining 40,000 to slaughter.

At the time of this report, Dr. Stone is continuing to gather information for the CDWG and has indicated that he and his colleagues in the Georgia Department of Agriculture are enthusiastic about participating in any carcass disposal forum that might be created (Stone, 2003).

Maryland

Maryland's documented experience with large-scale carcass disposal involves the loss of poultry to nonpathogenic avian influenza (NPAI) and natural disaster. In November 1993 Maryland Department of Agriculture officials mandated the destruction of 18,000 game birds (pheasants, chuckers, quail, mallards, and turkeys) due to NPAI. Maryland opted to destroy the carcasses via burial and incineration. The birds were euthanized with firearms or carbon dioxide gas. Maryland officials indicated that during this incident the appropriate knowledge and equipment for gassing the birds was deficient and constituted a deficiency in their planning. The burial sites were not recorded nor were they subject to long-term monitoring.

In 2001 the Maryland Department of Agriculture was again faced with a large-scale disposal effort, this time emanating from the collapse of a poultry house after a very heavy snow. Approximately 10,000 birds were either killed in the collapse or had to be euthanized with carbon dioxide gas.

Unfortunately, Maryland does not keep records of their carcass disposal efforts; however, according to Dr. J. Casper, DVM, the Maryland Department of Agriculture's emergency planning has improved substantially as a result of these incidents (Casper, 2003a; Casper 2003b).

Indiana

Correspondence with Dr. John A. Johnston, DVM, and Director of the Swine Health Division of the Indiana State Board of Animal Health revealed that Indiana had a relatively recent experience in a large-scale animal disposal event. Between February 15, 1999, and May 15, 2000, the Indiana Board of Animal Health in cooperation with producers and USDA Animal and Plant Health Inspection Service (APHIS) participated in the Accelerated Pseudorabies Eradication Program. This program depopulated over 100 swine herds (244,822 animals) infected with the pseudorabies virus.

Indiana's experience is interesting in that the nature of the emergency did not mandate the immediate destruction and disposal of the animals. As a result the disposal operation could be well managed and planned. The number of carcasses at no time overwhelmed Indiana's ability to process and dispose of them rapidly. In addition, Indiana's experience also required a large-scale euthanasia program.

In disposing of the carcasses the Indiana and USDA/APHIS authorities opted to use rendering. Dr. Johnson indicated that in future emergencies caused by a foreign animal disease, Indiana probably will not be able to rely on rendering as a disposal technology.

Indiana arranged to conduct the euthanasia process using the facilities of a recently closed meat packing plant. Appropriate modifications were made to the stockyard facilities, namely the construction of special chutes, an electrical shock system and a conveyor system to move the deceased animals to semi-trailers for transport to the rendering facilities.

Most pigs were destroyed using electrical shock. Smaller pigs were destroyed with carbon dioxide gas and nursing pigs were euthanized with lethal injections. Trucks hauling live pigs to the euthanasia facilities and trucks hauling carcasses to the rendering plant were washed and disinfected before being allowed to return to the farms. During the 15-month operation 25 trucking companies and six rendering companies were employed.

Dr. Johnston also indicated that Indiana permits carcass disposal via rendering, composting, incineration, and burial. On-site burial is permitted in a pit at least 4 feet deep. Animals must also be covered by at least 4 feet of earth. Disposal via landfill is permitted only if state and local regulations do not prohibit it. Landfill operators in Indiana are by no means required to accept carcasses (Johnston, 2003; Wilson, 2003).

Michigan

Michigan, according to Dr. Joan Arnoldi, the Michigan State Veterinarian, has had the rare experience of dealing with a catastrophic carcass disposal incident caused by a feed mixing accident that occurred in the fall of 1973. In this incident animals were poisoned as a result of a chemical called "Firemaster" or polybrominated biphenyls being mixed into livestock and poultry feed rather than "Nutrimaster." The incident affected 557 premises and caused the death of approximately 30,000 animals of various species.

In dealing with this disaster the State of Michigan elected to bury the carcasses in remote locations near Kalkaska and Oscoda, Michigan. The Kalkaska pit consisted of trenches 12 feet deep in sandy soil and was approximately 80-90 feet above the water table. The pit had a bentonite cover over the trenches and monitoring wells. The Kalkaska trenches accommodated 22,691 cattle, 3,707 swine, 1,371 sheep, 573 poultry, 2 goats, 2 horses, and 32 rabbits.

The Oscoda pit was built with the same dimensions and boasted 20-foot-thick clay walls. The Oscoda pit accommodated 921 cattle and 1,789 barrels of carcasses. Monitoring wells at both sites have revealed only slightly higher level of nutrients from the decomposition of the animal carcasses. Dr. Arnoldi indicated that the incident cost over $40 million for indemnity, labor, equipment, lawsuits, and other legal matters (Arnoldi, 2003).

Idaho

Idaho officials have reported their only catastrophic carcass disposal event occurred in 1976 when the Teton Dam broke and resulted in the deaths of more than 5,000 cattle. Idaho's carcass disposal effort offers a rare case of a problematic disposal effort. Idaho elected to bury the animals, but too many cattle were placed in the pits. Despite being covered with 3 feet of earth, gasses associated with carcass decomposition pushed many carcasses to the surface. The pits had to be recovered with earth each week for six weeks before the problem subsided.

In addition to the experience associated with the Teton Dam incident, the Idaho Department of Agriculture indicated that in any future large-scale animal disposal event, landfills might not be a viable option due to public pressure and reluctant county commissioners. Idaho did provide a copy of their newest animal disposal regulations, which were implemented in March 2002. Idaho regulations permit rendering, composting, landfill, and digestion.

Idaho regulations mandate that burial can be utilized as long as the carcasses are covered by at least 3 feet of earth, and the pit is located at least 300 feet from public or private water supply, 300 feet from residences, 50 feet from property lines, 100 feet from roadways, and 200 feet from lakes or streams. Burial sites are also not permitted in areas subject to flooding or with a high water table.

Incineration is permitted only in an approved incineration facility or with a mobile air curtain incinerator approved by the State of Idaho. Open burning of animal carcasses is not allowed except as authorized by the State of Idaho.

Idaho also permits the open decomposition of animals that die from causes other than contagious disease if the carcass is located 1,320 feet from public and private water supplies, springs, streams, lakes, or sinkholes. The carcass must also be 1,320 feet from roadways and residences.

Idaho regulations also have dead animal emergency provisions that permit extraordinary disposal measures in the event of contagious disease or the sudden loss of a sizable number of animals. In the event of such an emergency Idaho regulations permit open burning, pit burning, burning with accelerants, pyre burning, air curtain incineration, mass burial, and natural decomposition (Simunich, 2003; Idaho Administrative Code).

Maine

Maine has had some limited experience with carcass disposal. In February 2002 low pathogenic avian influenza was detected by producer of ducks, geese, quail, and pheasant. The farm was quarantined and approximately 5,000 birds were euthanized with carbon dioxide gas. Burial was an unsuitable alternative given the frozen ground and characteristics of Maine's terrain. Instead, all 5,000 birds were composed on site with excellent results. The producers were also paid the market value of the 5,000 birds to compensate for their losses (Rourque, 2003; Associated Press, 2002a; Associated Press, 2002b).

Iowa

Contact was established with personnel from the Iowa Department of Natural Resources at the Midwest Regional Carcass Disposal Conference at Kansas City. Kathryne Clark provided some information on the disposal of 60 cattle carcasses killed by a fire in the early summer of 2003. Half of the carcasses were disposed of via landfill and the remaining 30 were rendered (Clark, 2003).

Alison Manz provided some details of a much larger carcass disposal incident occurring the summer of 2003. As a result of a lightning strike that simultaneously shut down the ventilation system and sparked the fire of a large hog confinement building, approximately 800 hogs were lost. Because the source of the fire was not immediately known, the disposal of the carcasses could not proceed until the completion of the Fire Marshal's investigation. Several days passed and given the summer heat the carcasses were in an advanced state of decay. The Department of Natural Resources decided to bury the carcasses and constructed a burial pit on top of a ridge on the producer's farm. Monitoring wells were also constructed around the pits so any contamination resulting from the burial pits could be quickly detected. Ms. Manz indicated that although composting of the carcasses might have been the best disposal option, the Iowa Department of Natural Resources is ambivalent about using or encouraging the use of this technology because of doubts that producers will do it properly (Manz, 2003).

Florida

Florida's acting State Veterinarian, Dr. William C. Jeter, indicated that he had no recollection of any large-scale animal disposal incident within Florida. Dr. Jeter indicated that small-scale carcass disposal incidents occurred within the Florida poultry industry when birds were killed as a result of heat or flooding. In these circumstances local county officials and producers dispose of the carcasses via on site burial (Jeter, 2003).

Hawaii

The State Veterinarian of Hawaii, Dr. Jim Fobboli, indicated that Hawaii has no experience in performing mass animal depopulations. The largest incident to date is the disposal of 167 head of swine that was disposed of via landfill. Dr. Fobboli did not indicate the reason for the depopulation. According to Dr. Fobboli, Hawaii has no laws or regulations that specifically address carcass disposal (Fobboli, 2003).

Illinois

Dr. Colleen O'Keefe, DVM, of the Illinois Department of Agriculture, reported that Illinois has not had a disaster that resulted in a large-scale animal disposal problem. Dr. O'Keefe indicated that Illinois did have experience with several incidents of large-scale animal deaths that were resolved by a combination of on-site burial and rendering (O'Keefe, 2003).

Arizona

Arizona indicated it had no information on large-scale disposal incidents occurring within its borders. Dr. Rick Willer, the Arizona State Veterinarian, indicated that the State of Arizona is currently addressing an antiquated law that mandates disposal of dead livestock by rendering if the carcass is removed from a premise. Dr. Willer indicated that only one rendering plant exists in Arizona and does not serve most of the rural areas of the state. Price gouging has occurred and the state legislature has revised the law to allow for the disposal of dead livestock at licensed landfills unless the State Veterinarian determines a disease risk warrants an alternative means of disposal (Willer, 2003).

Arkansas

Dr. Jack Gibson, director of the Arkansas Livestock and Poultry Commission, provided a copy of Arkansas regulations, dated June 17, 1993, concerning the disposal of large animal carcasses. According to these regulations Arkansas permits rendering, burial, incineration, extrusion, cooking of carcasses for swine food, and composting unless the State Veterinarian mandates a specific manner of disposal. Rendering in Arkansas is permitted if the carcass is transported to rendering facilities in a sealed, leak-proof vehicle. Burial is permitted if a site is at least 100 yards from a well and situated where streams cannot be contaminated. Carcasses infected with anthrax are, according to Arkansas regulations, to be covered with 1 inch of lime and all carcasses are to be covered with at least 2 feet of earth. All animals that expire as a result of anthrax must be buried on site. The disposal of any carcass via a landfill is not permitted. According to Arkansas regulations carcasses may be cooked for swine food if the internal temperature reaches 212° F for 30 minutes. This method of carcass disposal is only permissible with a federal permit issued by USDA-APHIS. Curiously, Arkansas regulations mandate that carcasses can only be composted if the carcasses or portions of carcasses are no heavier than 60 lbs. The only regulation concerning incineration is that the carcasses must be reduced to ash. No detailed information on large-scale animal disposal incidents within Arkansas was available(Gibson, 2003).

Missouri

Missouri reported some limited experiences with carcass disposal disasters. Correspondence with Jack Sifford of the Animal Health Division of the Missouri Department of Agriculture indicated that Missouri has had a few useful experiences in large-scale carcass disposal and revealed some potential difficulties should any future disaster affect Missouri. All of Missouri's experiences, to Mr. Sifford's knowledge, involve the loss of animals due to natural disaster, accident, or neglect. Mr. Sifford did not have any knowledge of any incident during his 15-year tenure with the Missouri Department of Agriculture resulting from a highly pathogenic disease.

In 2001 the curtains of a hog confinement operation failed to operate and killed 290 hogs. The majority of the carcasses were disposed of via rendering while 70 carcasses were composted on site.

An accident involving the collapse of poultry houses resulting in the death of 40,000 birds created another large-scale carcass disposal incident. In this case the producers relied on their own rendering facility to dispose of all the carcasses.

A case of criminal neglect resulted in the death of 80 head of cattle in 2001. The cattle died from a combination of pneumonia and poor nutrition. The State of Missouri arranged to excavate three burial pits on site and buried all the carcasses.

An accidental poisoning left 25 cattle dead in southeast Missouri 2001. Problematic conditions surrounded this particular incident since landfills in that area of Missouri would not accept carcasses, no incinerators existed, and burial was not permitted due to a high water table. Composting was also ruled out as an impractical method given the number of cattle involved. Due to the extenuating circumstances surrounding the incident the state permitted the owner to build pyres, burn the carcasses, and then bury the ashes.

In discussing Missouri's experience with large-scale animal disposal, Mr. Sifford indicated that future events would be more problematic given the fact that rendering companies stopped making free on-farm pickups of fresh deaths. In addition, Mr. Sifford indicated that Missouri's carcass disposal laws are poorly written and create many problems for those in charge of enforcing the statutes (Sifford, 2003).

Oregon

Rodger Huffman, administrator for Animal Health and Identification, Oregon Department of Agriculture, indicated that Oregon has had two incidents involving large-scale carcass disposal in the past ten years. In each case the animals were euthanized and transported to landfills for disposal. Mr. Huffman indicated that in 1999 Oregon passed a law that gives the Oregon Department of Agriculture broad powers to deal with an animal health emergency. Under this statute the diseased or deceased animals will be disposed of on site and either burned or buried (Huffman, 2003).

Washington

The State of Washington indicated that they have had large-scale carcass disposal incidents but due to the fact that the incidents occurred more than ten years ago, the records associated with these incidents have been destroyed. Dr. Kathleen Connell, DVM, did provide a copy of Washington's regulations regarding animal disposal. These regulations indicate that burial and incineration are the only approved means of animal disposal (Connell, 2003; Washington Administrative Code).

3.3 – Preliminary Survey Conclusions

While the lessons from these experiences should serve as guides for other states and localities preparing for a catastrophic event, dissemination of these lessons is hampered by the almost total absence of historical records documenting catastrophic animal disposal events. Large-scale animal disposal events caused by natural disasters or epidemics are certainly nothing new, and states and localities have encountered these problems in the past; however, interviews and correspondence with officials from various states confirm that state agencies dealing with this problem generally have no institutional memory. The documents that do exist provide only rudimentary data, and states often purge what are deemed as inconsequential records at five- or ten-year intervals. As a result, detailed information about carcass disposal incidents that occurred more than ten years ago can be very difficult, if not impossible, to obtain.

As a consequence of the generally inadequate historical documentation of animal disposal events, a majority of the information that can be gleaned about past events has to be obtained from interviews of the persons involved in such events. Although information obtained from interviews can certainly be useful and the knowledge and experience of those involved in past events is worthy of documentation and distribution, oral history can have significant shortcomings. Human memory can be problematic and hard facts concerning numbers of livestock lost, economic losses, disposal expenses, and the exact location of burial sites can be difficult or even impossible to obtain. In addition, the death, retirement, or career changes of those individuals with the most knowledge of past incidents means that the ability to learn lessons from past incidents dissipates with each passing year. The absence of any institutional memory or written history of past incidents robs current government officials of a useful pool of knowledge concerning how best to handle any future large-scale animal disposal emergency.

Another major deficiency lies in communicating and distributing current information concerning carcass disposal technologies, planning, problem solving, and historic incidents. It appears that the various states and localities operate as independent islands with each one attempting to plan and prepare for potential emergencies as if in a vacuum. Communication is lacking among officials in various state agencies involved in regulating or directing animal disposal projects, academics involved in the study of carcass disposal, and the various federal agencies that might provide assistance. Consequently, evaluation of opportunities and means to facilitate communication between state and federal officials, producers, and academics is warranted. Possible means include virtual forums -- or other electronic formats -- that could provide an inexpensive and effective channel to share past experiences and problems and to distribute information on carcass disposal technologies, emergency planning, laws and regulations, logistics, and a variety of other relevant topics. Information from these forums could then be captured for further development. Many officials attending the August 2003 Midwest Regional Carcass Disposal Conference expressed great interest and enthusiasm for opportunities to increase communication with outside experts or other experienced individuals.

Section 4 – Critical Research Needs

- Rectify the general inadequacy of documentation regarding historical, large-scale animal disposal incidents and the lack of institutional memory. The development of a pool of historical knowledge of past incidents will offer useful lessons to current officials and credibility to those handling an urgent animal disposal incident. Development of a HIDA and documentation of past incidents may require significant travel and a significant number of interviews.
- Conduct follow-up research on past animal disposal incidents in the areas of policy, planning, lessons learned, and the scientific evaluation of past disposal methods.
- Compile and review states' emergency plans for a catastrophic animal disposal effort. Copies of plans have been requested, although not yet provided. It is suspected that emergency planning is deficient or in some cases nonexistent.
- Explore opportunities and means to facilitate communication among academic, state, and federal authorities and producers concerning all aspects of carcass disposal. Conferences, virtual forums, and electronic formats are all possibilities that merit exploration.
- Create Web-based tools that would include a HIDA as well as planning, policy, and communications advice. Although it is a daunting task, it is indeed possible, based on exploratory development of a HIDA, that a central, Web-based archive of incidents and bibliographic sources could be developed to facilitate planning, policy development, and communication among all interested parties. Such a database would be central to capturing the history and important lessons learned from past events and would serve as a repository for bibliographic material on carcass disposal issues.

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Appendices

Appendix A – HIDA Fields

1. Cause of animal disposal event: (disease/natural disaster/accident/criminal act)
2. Location: state/province
3. Date of incident:
4. If disease-related, the pathway or suspected pathway of the pathogen
5. If a criminal act or accident, the method of destroying or infecting the animals
6. Total number of animals disposed
7. Number of animals disposed by species
8. Method of destruction of animals
9. Numbers euthanized (welfare killings)
10. Method(s) of carcass disposal
11. Economic losses inflicted on producers
12. Costs of disposal effort
13. Detailed incident summary. This summary will include available geographic information, images, spreadsheets, problems encountered, lessons learned, bibliographic information, and contact information for those officials providing the information to the History Task Group.

Appendix B – CDWG Historical Incidents Questionnaire

Name: ______________________

Agency: ______________________

Address: ______________________

Telephone: ______________________

Fax: ______________________

E-mail: ______________________

1. What caused the carcass disposal incident?
    a. Natural disaster
    b. Disease
    c. Criminal act
    d. Accident
2. Date of incident:
3. If the incident was caused by a disease, what type of disease was it?
4. If the incident was caused by a disease, what was the pathway or suspected pathway of the infectious agent?
5. If the incident was caused by a natural disaster, what type of disaster was it?
    a. tornado
    b. hurricane
    c. flood
    d. blizzard
    e. other _________
6. If the incident was caused by a criminal act or accident, what was the method used to destroy the animals?
7. How many carcasses had to be disposed?

a. cattle __________

b. chickens __________

c. turkeys __________

d. swine __________

e. sheep/goats __________

f. deer __________

g. other __________

8. Which method(s) of disposal were used? If multiple methods were used please give estimates of number disposed with each method.

   a. burial __________

   b. incineration __________

   c. composting __________

   d. landfill __________

   e. alkaline hydrolysis __________

   f. rendering __________

9. If burial was a method of disposal, were the graves marked or recorded and were they monitored for possible contamination? YES/NO

10. If yes, where are the graves located?

11. Are you aware if any follow-up investigation that has been done as to the effectiveness of the burial (i.e., the extent to which the animals have decomposed, etc.).

12. Did any animals have to be euthanized? YES/NO

    If yes please indicate the method(s) used and approximate numbers euthanized with each method.

    a. firearm __________

    b. lethal injection __________

    c. electrocution __________

    d. carbon dioxide __________

    e. blunt trauma __________

13. Approximately how large were the economic losses sustained by livestock owners?

14. What were the approximate costs of the disposal effort?

15. What agencies (federal/state/local) or producers were involved in the disposal effort?

16. What sort of planning was done prior to the incident?

17. What deficiencies in planning were apparent during the incident?

18. What lessons were derived from the incident?

19. Does your state/company maintain records of catastrophic carcass disposal incidents? YES/NO

20. If yes, where are these records located?

21. Would your state be willing to provide copies of incident records to Kansas State University so they can be archived in Kansas State University's Hale Library? (Doing so would be extraordinarily helpful to others involved in carcass disposal research.)

22. Are there any other persons you know (state government employees, producers, or private industry) with intimate knowledge of this incident? If so would you please provide their contact information?

23. Is there any other information about this incident you would like to provide that has not been covered by the questions above? If so please provide your comments in the space below:

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

August 2004

Chapter 11

Regulatory Issues & Cooperation

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Table of Contents

Abbreviations

BOAH	Indiana Board of Animal Health
CEMP	comprehensive emergency management plan
DAD	dead animal disease
DHS	Department of Homeland Security
FDA	Food and Drug Administration
FMD	foot and mouth disease
ICS	Incident Command System
IDEM	Indiana Department of Environmental Management
ISDH	Indiana State Department of Health
MOA	memorandum of agreement
MOU	memorandum of understanding
NIMS	National Incident Management System
SEMA	State Emergency Management System
SOP	standard operating procedure
USDA	United States Department of Agriculture

Section 1 – Key Content

Not all potential problems can be anticipated and addressed in advance of a major biosecurity event, but two overall actions which might prevent a large-scale animal disaster from taking larger tolls are education and facilitation.

Factors related to education include:

- Better understanding of the Incident Command System (ICS) by agricultural industry leaders and participants.
- Better understanding of the ICS, standard operating procedures (SOPs), and agriculture by county governments and agricultural groups.
- Better understanding of agriculture by the emergency management and county government systems.
- Better understanding of agricultural disaster response by state and local agencies (public health, legal, etc.).

A primary factor related to facilitation includes:

- Encouragement of periodic (annual or semi-annual) meetings at the state level to discuss specific operational, legal, and future research needs in the area of animal disaster management.

In Indiana, for example, two specific actions will enhance the response efforts during a major disaster. First, acting agencies need to know they are part of the Comprehensive Emergency Management Plan (CEMP). Second, more people within agencies should have a comprehensive awareness and understanding of all others involved, in addition to understanding their own agency's SOPs. In order to enhance the functionality of the CEMP, the State Emergency Management Agency (SEMA) also incorporates the use of the ICS during the management of a disaster. At the time of writing, Indiana's SEMA was just learning how the ICS will evolve to the National Incident Management System (NIMS). In 2003, US President George W. Bush issued directives which provide the Secretary of Homeland Security with the responsibility to manage major domestic incidents by establishing a single, comprehensive national incident management system. The introduction of the NIMS will not change the recommendations of this document, but rather enhance the possibilities of these recommendations being implemented. The key is how thoroughly the NIMS is utilized from federal to state to local agencies.

An idealistic approach to a disaster would be to know, in detail, what needs to be done, what protocols need to be enacted, and who is going to take the lead. However, no real-life disaster plays out as a textbook example. General disaster plans are created with a number of annexes and SOPs attributed to specific situations. Regardless of the tragedy or the number of agencies involved, there are several areas that should be addressed to achieve a higher level of preparedness and response:

- An interagency working group should be created that meets periodically (e.g., at least two times a year) and consists of at least the state environmental, animal health, public health, contract service, emergency management, extension service, transportation, and wildlife agencies.
- An analysis should be conducted of the agencies' (state and county) awareness level of the functionality of the CEMP and its components, as well as the overall functions of the ICS. Have enough agencies been included? Are there enough training opportunities for agency employees? Do the involved agencies have a well-established representation of their SOPs within the annexes of the CEMP?
- A training program should be established that:
  - Requires ICS training for all agencies involved in the CEMP—state and county level. The training should include enough people from various agencies to ensure a widespread understanding of the ICS and various agencies' roles.
  - Establishes programs at the county level to bridge the gap between the legal system and agricultural issues in a biosecurity event.

Results of a roundtable discussion demonstrated that (1) more could be known about how critically involved agencies will react to a large-scale animal carcass disposal situation, and (2) in an environment of short-staffing and high workloads, agency personnel will likely not place a high priority on planning for theoretical animal carcass disposal issues.

Therefore, to facilitate planning efforts and provide structure for interagency discussions and exercises, research into (and summarization of) the actual laws, regulations, guidelines, and SOPs of key agencies is warranted on a state-by-state basis.

This research is critical to the development of comprehensive plans for state and county governments to more easily identify their roles. These could be used in training programs for state and local agencies to develop pertinent SOPs and memorandums of agreement.

Section 2 – Agency Involvement in Emergency Response

The history of massive animal carcass disposal disasters in the US and other countries indicates many interagency issues and possible sub-disasters for those agencies if steps are not taken ahead of time to anticipate problems. For example, the foot and mouth disease (FMD) outbreak in Great Britain in 2001 showed how a lack of cooperation between jurisdictions and local and national agencies resulted in:

- Extended disease control issues.
- Loss of human lives (suicides).
- Complete change of a national agency. (The UK's Ministry of Agriculture, Fisheries and Food became the Department for Environment Food and Rural Affairs.)

While not all potential problems can be anticipated and addressed in advance, two of the actions that might prevent a disaster from taking larger tolls are education and facilitation.

Factors related to education include:

- Better understanding of the Incident Command System (ICS) by agricultural industry leaders and participants. Note: The ICS will probably evolve into the National Incident Management System (NIMS) in 2004. But until NIMS is adopted nationwide by state emergency management agencies, this report uses the term ICS. The NIMS movement will use the same basic concepts as ICS. NIMS uses multiagency oversight that President George W. Bush provided with the unified Department of Homeland Security (DHS). The movement from ICS to NIMS will enhance the recommendations of this report.
- Better understanding of the ICS, standard operating procedures (SOPs), and agriculture by county governments and agricultural groups.
- Better understanding of agriculture by the emergency management and county government systems.
- Better understanding of agricultural disaster response by state and local agencies (public health, legal, etc.).

A primary factor related to facilitation:

- Encouragement of periodic (annual or semi-annual) meetings at the state level to discuss specific operational, legal, and future research needs in the area of animal disaster management.

2.1 – Overview of the Problem

When a disaster strikes, a number of agencies respond, depending on the type of disaster and its magnitude. When multiple-agency involvement becomes a factor, the efficiency of interagency relations and communications are important. Such coordination is a key component of a successful outcome. Several questions -- What works?, How does it work?, and What should be implemented? – are important when examining ways to strengthen the existing infrastructure of state disaster responding agencies.

In the event of a major disaster, proactive interagency coordination will aid in the response efforts, whereas the lack of coordination will hinder the progress of necessary actions. Specifically, steps taken within agencies to provide SOPs that enhance an agency's response, as well as interagency response, are critical to successful outcomes.

2.2 – Background in Emergency Response – Indiana Example

In December 2001, the Indiana State Emergency Management Agency (SEMA) put into effect a revised version of the Comprehensive Emergency Management Plan (CEMP). The CEMP is a checklist requiring all state agencies to develop and implement SOPs and standard operating guides. Its function is to outline expected protocol for disasters most likely to affect Indiana, designate the primary coordinating agency for a given disaster, and determine the supporting role of other agencies (SEMA, 2001).

In Indiana, two actions will enhance the response efforts during a major disaster. First, acting agencies need to know they are part of the CEMP plan. Second, more people within agencies should have a comprehensive awareness and understanding of all others involved, in addition to understanding their own agency's SOPs. In order to enhance the functionality of the CEMP, SEMA also incorporates the use of the ICS during the management of a disaster.

The ICS is a standardized response management system. As an "all hazard – all risk" approach to managing crisis response operations as well as non-crisis events, this system is organizationally flexible and capable of expanding and contracting to accommodate responses or events of varying size or complexity (NOAA).

The ICS has four functional areas:

- Operations.

  This area includes all activities directed toward reducing the immediate hazard, controlling the situation, and restoring normal operations.

- Planning.

  This area includes the collection, evaluation, dissemination, and use of information relative to the development of the incident and the status of resources, and creation of an action plan.

- Logistics.

  This area provides all support needs, orders all resources from off-incident locations; and provides facilities, transportation, supplies, equipment maintenance, meals, communications, and medical services.

- Finance.

  This area tracks all incident costs and evaluates the financial considerations of the incident (Merlin, 1999).

In order to pull all elements of disaster management together, SEMA takes a top-down approach. A general response plan is developed for disasters most likely to take place in Indiana. For each plan, a number of specific disaster situations are addressed. To deal with these particulars, annexes are created. Certain instances require the elaboration of annexes or the narrowing of specific responsibilities to agencies or organizations. At this point, an SOP is created for more finite guidance to the annex. Overall, the ICS provides a flexible structure to deal with changing disaster scenarios and the various annexes/SOPs that apply.

NOTE: At the time of writing, Indiana's SEMA was just learning how the ICS will evolve to the NIMS. In 2003, US President George W. Bush issued directives which provide the DHS Secretary with the responsibility to manage major domestic incidents by establishing a single, comprehensive national incident management system. The introduction of the NIMS will not change the recommendations of this document, but rather enhance the possibilities of these recommendations being implemented. The key is how thoroughly the NIMS is utilized from federal to state to local agencies (White House, 2003).

2.3 – Methods and Process

The initial step in considering interagency coordination was to design a high-magnitude disaster on paper (Appendix A) that would demand the involvement of a number of agencies from a variety of areas. The scenario used in this project was called Dead Animal Disease (DAD). The intention was to create a situation which placed the audience at a specific point – two weeks into an unknown animal disease with an anticipation of a massive carcass disposal – that would present a number of unanswered questions.

The second step was to organize a roundtable discussion that would provide the agencies with an opportunity to come together as a group and discuss the expected roles and responsibilities of each agency during the hypothetical disaster. The following agencies participated in the project:

- County-Level Board of Health
- Indiana Board of Animal Health (BOAH)
- Indiana Counter-Terrorism and Security Council
- Indiana Department of Environmental Management (IDEM)
- Indiana Department of Natural Resources
- Indiana Office of the Commissioner of Agriculture
- Indiana State Chemist Office
- Indiana State Department of Health (ISDH)
- Indiana SEMA
- Indiana Public Health Association
- Purdue Animal Disease Diagnostic Lab
- Purdue University Cooperative Extension Service
- US Attorney General's Office
- US Department of Agriculture (USDA) Farm Service Agency

Each participant was provided the scenario in advance. In addition, they were asked to answer a list of questions (Appendix B) regarding their roles and actions for the CEMP at two weeks into the disaster. These answers were collected, organized into one document, and mailed to everyone for their review prior to the discussion.

The individuals who participated (Appendix C) in the discussion were directors from various areas of their respective agencies, including administration, communications, and operations. All participants were chosen based on the leadership role they would play the moment their agency became involved in the response efforts.

At the onset of the roundtable discussion (Appendix D), individuals were allowed the opportunity to share additional information in regard to their previous responses. At this point, many questions were raised as to who would be responsible for what and how it would be accomplished.

As the discussion continued, the group was asked to consider the areas of cooperation among responding agencies, as well as future actions that should be considered in order to improve interagency coordination.

All participants provided valuable information in regard to their agency's roles and responsibilities during the course of the hypothetical animal disaster. Much information was provided for consideration, identification, and, in some cases, realization for the first time by others involved. For the most part, concentration fell on three main areas: response, communication, and education. The following are a number of comments and questions that were discussed as a group:

Response

- While BOAH and SEMA know who is in charge, do a critical number of other agencies know who is in charge?
- Who should formulate and make a public announcement at the appropriate time?
- What is the level of public health significance of an agricultural event?
- What audiences are affected? They have a right to know what is taking place, and in the event of quarantine, they will demand freedom of movement and commerce.
- Would initial actions and decisions be committee-based?

- How will staffing needs be fully met?
- At what time is it appropriate for an agency to begin responding?
- Should the subject matter expert and the jurisdictional authority be the same person?
- What are the legal and jurisdictional issues? What do you legally have the right to do?
- SEMA will prepare and distribute situational reports of other agencies as a way of sharing information.
- Planning for too narrow of a perspective puts preplanning resources in the wrong place. It would be impossible to have a specific plan for every incident; sometimes what status quo has to be enough.
- Perhaps the memorandums of agreement (MOAs) take precedence; overall, it is the continuity of government to show the agreement of function and cooperation.
- Considering the cooperative agreements as well as identifying possible cooperative research that exists—in many ways, this is already being done with carcass disposal in regard to land layout and site identification.

Communication

- Animals and animal by-products leaving Indiana will be considered tainted. We must communicate to the public the real health risks and actions taking place to remove the risks and restore a healthy food supply.
- Communication is the key factor throughout the entire situation—a communication center has to be up and ready, first and foremost.
- When something is unknown (e.g. DAD), offering a timeline for identification could be nearly impossible.
- The sharing of information from one level to the next should be kept consistent among multiple agencies.

Education

- Appropriate agencies with proven records should be utilized for public education.
- Educational efforts are key to the cooperation of the affected public during necessary response efforts. Examples include: educating people who could be inhibitors to the eradication of the disaster at hand, informing people of the possible threats they could create by moving their animals, and educating people on the safety of the environment around infected areas/farms (i.e. water/fish from nearby streams).
- Leaders/figures who need to be key players in developing plans and communications should be better educated in the decision-making process.
- The Food & Drug Administration (FDA), USDA, and Cooperative Extension Service are in prime positions to serve as resources of information and education.
- Every county should have emergency response training in place.
- All agencies can learn from past events: Ralstonia solanacearium, race 3 biovar 2 – disease of geraniums (2003), Monkey Pox (2003), and FMD (Britain, 2001). In the Ralstonia situation, USDA needed a quicker confirmation and action plan that was communicated clearly to all involved agencies. In the Monkey Pox situation, the communications from the Department of Health were not activated quickly enough because they assumed it was not human health-related and the FMD issues were explored at the beginning of this document. But all three situations provided insights and learning opportunities as to how agencies would act (or not act) at the finding of an outbreak.

Recommendations

- Strengthened cooperation is needed not only between government agencies but also with industry and the organizations representing the public.
- Take advantage of resources available for use where needed in the response to a disaster (i.e.

superior FDA and Environmental Protection Agency labs).

- Providing reassurance to all those concerned could mean taking actions that are not necessary for the event, but necessary for public easement. Actions which deal with perceived issues as well as real issues and communicating that message are necessary to reassure the public.

2.4 – Strategies to Deal with Issues

The hypothetical event (DAD) was directly animal-related, which automatically placed BOAH as the lead agency. However, as events unfolded, other areas of expertise were in demand. Because the agent causing the animals' sickness and subsequent death was unknown, the testing capabilities of the Purdue Animal Disease Diagnostic Lab were required. In addition, because approximately 37,000 animal carcasses required handling and disposal, the resources of contracted companies and agencies, such as the IDEM, were required.

Oftentimes, certain assistance was necessary due to events that take place indirectly to the overall disaster. The ISDH should be called upon for three initial reasons:

- The agent/disease was unknown, raising the question of whether or not it was zoonotic, which presents the consideration of how it could affect humans.
- A massive carcass disposal issue was ensuing, which inevitably creates a human health and safety issue.
- Such a large disaster would find its way to the media outlets, causing a possible public perception of fear and concern about such things as the food and water supply. (NOTE: as identified in past exercises, additional agencies are brought into the mix at the request of the lead state agency or at the recommendation of SEMA based on past experience.)

After examining the collected information and considering the open-ended questions posed to agencies at the two-week point in the animal disaster scenario, the next step was to consider what currently works in the state of Indiana. Relationships between agencies with well-defined responsibilities work well during a disaster. For instance, in the case of a known animal disease outbreak, BOAH and SEMA establish a teamed response with the necessary chain-of-command organization quickly in place through the common practice of the ICS.

In the instance of the animal disaster scenario used in this project, BOAH and SEMA would be the initial organizers. As the events of a disaster continue to unfold, more responding agencies are required to become an integral part of the ICS. However, some key agencies may not have a good understanding of how this system functions. As a result, the organization of the four functioning ICS areas (operations, planning, logistics, and finance) potentially could be slowed.

State agencies are working parts of the emergency response system, but those at the local level are involved as well. In the DAD disaster scenario, the incident was contained within a 25-mile radius of the Indianapolis airport. As a result, county law enforcement and emergency personnel were involved from the beginning and/or as events unfolded. Such involvement demonstrated an overlapping of MOAs of the local or county agencies with the functionality of the CEMP at the state level. This will result in local action versus state action. For example, as the number of dead animals increases, carcass disposal issues will need to be addressed, which would result in possible local jurisdictional conflicts and authority issues between county and state agencies. In addition, county governments may not have a good understanding of ICS and agriculture's specific needs.

2.5 – Outcomes

An idealistic approach to a disaster would be to know, in detail, what needs to be done, what protocols need to be enacted, and who is going to take the lead. However, no real-life disaster plays out as a textbook example. General disaster plans are created with a number of annexes and SOPs attributed to specific situations. Regardless of the tragedy or the number of agencies involved, there are several areas that should be addressed to achieve a higher level of preparedness and response:

- An interagency working group should be created that meets periodically (e.g., at least two times a year) and consists of at least the state environmental, animal health, public health, contract service, emergency management, extension service, transportation, and wildlife agencies.
- An analysis should be conducted of the agencies' (state and county) awareness level of the functionality of the CEMP and its components, as well as the overall functions of the ICS. Have enough agencies been included? Are there enough training opportunities for agency employees? Do the involved agencies have a well-established representation of their SOPs within the annexes of the CEMP?
- A training program should be established that:
    - Requires ICS training for all agencies involved in the CEMP – state and county level. The training should include enough people from various agencies to ensure a widespread understanding of the ICS and various agencies' roles.
    - Establishes programs at the county level to bridge the gap between the legal system and agricultural issues in a biosecurity event.

Section 3 – Reflections and Project Barriers

The assessment of interagency communication began with an attempt to consider the relationships that should exist across platforms for a most-effective response to a high-magnitude disaster. Therefore, the creation of a situational disaster requiring agencies to approach the problem from opposite directions was necessary. Through examination of possible required resources, a list of potential participants was created. However, as was expected, it wasn't until the roundtable discussion took place that missing entities were identified. In hindsight, valuable information from individuals at the local and federal levels was lacking.

Once information was collected and organized from all participants, it became evident that the problem may not entirely exist with interagency communications but, rather, with the total understanding of the ICS. Therefore, a stronger emphasis was placed on training rather than communication during the development of possible solutions.

If this project were repeated, the focal point in its creation would move from the quality of communication taking place between agencies during a disaster to the comprehensive training provided within agencies on how the ICS needs to function to be successful. If all involved individuals and their respective agencies are fully aware of how their role will develop in a disaster, then necessary communication will begin to improve. Once that is established, areas still lacking in interagency communication should be addressed.

Section 4 – Critical Research Needs

This study shows that more could be known about how key agencies will react to a massive animal carcass disposal situation. While facilitation of this process will help agencies discuss their respective issues, some issues will not be addressed by agencies due to prioritization and current workloads. In other words, many agency professionals will not feel the need to put a high priority on animal carcass disposal issues. They will not be inclined to dedicate staff time to a theoretical issue when they have enough real issues to deal with at the present.

Research into (and summarization of) the laws, regulations, guidelines, and SOPs of key state agencies involved in responding to catastrophic carcass disposal events is needed.

In conjunction with the Carcass Disposal Working Group project, within the state of Indiana a roundtable discussion was organized to provide an opportunity for representatives from state agencies involved in responding to a foreign animal disease outbreak to come together to discuss the expected roles and responsibilities of each agency during a hypothetical disaster. Results of this roundtable discussion demonstrated that (1) more could be known about how critically involved agencies will react to a massive animal carcass disposal situation, and (2) in an environment of short-staffing and high workloads, agency personnel will likely not place a high priority on planning for theoretical animal carcass disposal issues.

Therefore, to facilitate planning efforts and provide structure for interagency discussions and exercises, research into (and summarization of) the actual laws, regulations, guidelines, and standard operating procedures of key agencies is warranted on a state-by-state basis.

This research is critical to the development of comprehensive plans for state and county governments to more easily identify their roles. These could be used in training programs for state and local agencies to develop pertinent SOPs and MOAs.

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Appendices

Appendix A – Indiana Biosecurity & Public Health Roundtable, Situational Setup

What:

A breakout of Dead Animal Disease (DAD) – this is an unknown disease. At two weeks into the disaster, affected animals include cows, pigs, and chickens. Symptoms include internal bleeding and massive respiratory problems. The incubation period appears to be five to seven days with death occurring three days later. The spread appears to be rapid. Confidence is high that it does not affect humans, but such a concern is not 100 percent ruled out.

Where:

A total of seven farms within a 25-mile radius of the Indianapolis Airport are reporting the disease.

When:

The first reports are from a dairy farm (A) and poultry farm (B) on July 16. The other five farms report symptoms four days later on July 20.

Details:

Farm A: 1,000 dairy cows

Farm B: 16,000 chickens

Farm C: 12,000 swine

Farm D: 500 beef cattle

Farm E: 5,000 swine

Farm F: 1,500 dairy cows

Farm G: 1,000 beef cattle

Total Number of Animals: 37,000

By July 17, an unknown disease, which is being referred to as DAD, is identified within the confines of farms A and B; 675 cows and 7,350 chickens are showing symptoms for the mysterious disease. Two days before the confirmation (July 15) a feed truck had made rounds to these two farms, as well as ten others. By July 20, five of the ten are reporting symptoms. On the same day, ten percent of the infected animals on farms A and B have died. On July 21, the truck is quarantined.

On July 18, concerned neighbors near farms A and B report to the Dawson County Sheriff that a white sedan was seen near the farms' premises. Both accounts verify that the sedan had rental plates and was carrying three or four people. To date, there is no evidence of this vehicle, or others, being on all seven farms.

All farms ship to markets:

- Farms A (milk daily), D (2x/yr), E (1x/week), G (2x/yr) – state shipping
- Farms C (1x/week), F (milk daily) – interstate shipping
- Farm B (eggs daily) – international shipping

Those affected:

1. The infected farms are experiencing catastrophic losses. At minimum, 37,000 animals will have to be dealt with for mass carcass disposal.
2. Surrounding land and uninfected farms that are located in the established quarantined perimeter (a three-mile radius) around each infected farm. Such quarantine would institute a complete halt to all business which concerns movement outside of the property.
3. People/public could be affected in four ways:
   a. Those in quarantined zone could be deemed immobile for an enforced amount of time.
   b. Massive carcass disposal issue = public health issue.
   c. Public perception and concerns – a poor understanding of DAD and a fear of the safety of associated animal products bought from grocery store shelves or supplied to school lunch programs.

i. One problem is that DAD is so closely timed with SARS. Some feel strongly it could affect humans. Therefore, the public fear level is increased.

d. Possibility still exists that disease is zoonotic.

4. The national dairy, pork, poultry, and beef markets experience a devastating drop in prices and trade capabilities.
5. Already, scores of national reporters are camped out on the west side of Indianapolis and are demanding information.

Questions/assumptions/scenario changes:

1. Can all shipped meat, milk, eggs, and live animals from infected farms be tracked?
2. Characteristics of this disease: What is the rate of spread? How long is the incubation period? What are the potential vectors? Can it be spread by contact, air, or other animals?
3. What are the appropriate biosecurity procedures that the animal care specialists must take to safeguard themselves and unaffected animals?
4. Will other species, such as wildlife, have to be examined or destroyed because of this outbreak? If so, how will this hinder personnel and the logistics of controlling the situation?
5. Possible assumption: DAD is a genetically modified organism.
6. Possible assumption: It is suggested that the disease was spread into confinement buildings through an aerosol sprayed into the air intake. This makes the disease deadly at those operations. But, because of modern confinement and current biosecurity habits, the disease does not seem to be spreading as fast as it could.
7. Scenario change: The county sheriff, in cooperation with a local citizen, finds a suspect container with trace amounts of an unknown substance that is currently being investigated. This container was found in a ditch just outside the city limits of the Dawson County Seat.

Appendix B – Indiana Biosecurity & Public Health Roundtable, Questions Posed to Participants

The accompanying Dead Animal Disease (DAD) scenario explains a hypothetical outbreak of an unidentified disease that is suspected to be genetically altered. Please refer to this scenario as you answer the following questions (*if your answers require more space, please use the back of this page or attach additional pages, if necessary*):

1. The state of Indiana has a Comprehensive Emergency Management Plan. Is your agency represented in that plan? ___ Yes ___ No ___ Don't know.
2. This plan calls for standard operation procedures (SOPs) with guides and plans to support it. In reference to the DAD scenario, does your agency have SOPs that apply? ___ Yes ___ No ___ Don't know.
3. Considering those SOPs and the DAD scenario, at two weeks into the disaster:
   a. What protocols would have been completed by your agency?
   b. What continuing steps would you expect your agency to take?
4. For the DAD scenario, what Memorandums of Agreement (MOAs) or Memorandums of Understanding (MOUs) do you think are already in place to aid in interactions with other agencies?
5. For the DAD scenario, what MOAs or MOUs do you think need to be in place in the future to aid in interactions with other agencies?
6. What problems do you feel will surface if a disaster of this nature and magnitude appear in Indiana?

Appendix C – Indiana Biosecurity & Public Health Roundtable, Participants

Organization	Participant
Animal Disease Diagnostic Lab	Leon Thacker, Director
Counter-Terrorism and Security Council	Clifford Ong, Director
Farm Service Agency	Steve Brown, Program Specialist
Indiana Board of Animal Health	Marianne Ashe, DVM, Director of Emergency Planning Denise Derrer, Public Information Director
Indiana Dept. of Environmental Mgmt.	Cheryl Reed, Asst. Commissioner for Public Policy & Planning Dan Hottle Max Michael
Indiana Dept. of Natural Resources	Russ Grunden
Indiana State Chemist Office	Allen Hanks, State Chemist
Indiana State Department of Health	James Howell, DVM, MPH, Veterinary Epidemiologist Kathy Weaver, Director, Office of Policy and GRC Coordinator, BT Education and Training
Ofc. of the Commissioner of Ag.	DeeDee Sigler, Communications Director
Purdue University Extension Service	Steve Cain, Disaster Communication Specialist
State Emergency Management Agency	Bob Demuth, Emergency Operations Center
Indiana Public Health Association	Jerry King, Executive Director
US Attorney General's Office	Jack Osborne, Joint Chairs & Task Force
County-Level Board of Health	Linda Chezem, JD, Chair

Appendix D – Indiana Biosecurity & Public Health Roundtable, Agenda

Agenda	
Date	July 30, 2003
Location	Hamilton County Extension Office, Noblesville, Indiana
Schedule	
8:45 to 9:00	Refreshments
9:00 to 9:20	Introductory comments and introduction
9:20 to 9:30	Review scenario
9:30 to 10:00	Review responses from pre-questionnaire
10:00 to 10:15	Break
10:15 to 12:00	Areas of Cooperation Future Actions
12:00 noon	Adjourn

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

August 2004

Chapter

12

Public Relations Efforts

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Abbreviations

APHIS	USDA Animal and Plant Health Inspection Service
CDWG	carcass disposal working group
DEFRA	UK Department for Environment, Food and Rural Affairs
QRT	quick response team
UK	United Kingdom
USDA	United States Department of Agriculture

Section 1 – Key Content

To assure positive public perception, decision-makers handling large-scale livestock mortality and carcass disposal events must have access to expert public information professionals and must agree to make communicating with the public a top priority. Before a disposal method is chosen, the incident commander and public information leader should consider potential public perception.

If the disposal of large numbers of animal carcasses is necessary, it can be safely assumed a disaster has occurred. Whether by natural or human means, the public most likely will be aware of the circumstances and will notice efforts to dispose of carcasses. All methods of disposal deserve consideration. No method of disposal should be ruled out in advance, because circumstances can change and locales may have conditions that favor one type of disposal over another.

It is incumbent on decision-makers to communicate quickly and often with the public via a capable public information officer. Depending on the type of disaster that caused the loss of livestock, the general public itself may already be suffering from a high-stress situation (if there has been a devastating hurricane, for example, or an act of terrorism).

While one agency will lead the effort, numerous other state and federal agencies, as well as private entities, should be involved. Unified communication amongst the public information staffs of all involved parties is vital to shape positive public perception.

As reported after the foot and mouth disease outbreak in the United Kingdom (UK) (Parker, 2002), "Communications were extremely difficult both to and from DEFRA [Department of Environmental, Food, and Rural Affairs] during this period and this led to a complete loss of confidence from the public, local authorities and partners involved." Parker (2002) also reported "poor communications led to confusion and the perception that there was little control." Thus the most important factor is to communicate well with the public initially, throughout, and beyond the episode.

The strategy for effective communication involves two time frames: Issue Management in the short-term, and Issue Education in the long-term. These two efforts must be pursued simultaneously in three areas: factual information collection, communications techniques, and resource allocation.

This chapter provides guidance to public information professionals and helps subject matter experts and disposal managers understand the role and importance of communicating with the public about large-scale carcass disposal.

Section 2 – Issue Management (Short-term)

2.1 – Definition

Issue management involves the early recognition of signals from a sensitive public and an analysis of the likely effects on all stakeholders involved (Epprecht, 2000).

2.2 – General Considerations

Issue management (short-term) involves informing the public about various issues within the overall incident. As with most large-scale livestock operations, it is recommended that those involved should "determine what concerns exist and quickly address them. Perceptions, true or not, must be recognized (Davison, 2001)." These concerns should be the focus of a public information team.

Prior to the beginning of disposal, the public information team should begin providing facts to the public via the media. This team should include at least one public information officer from each of the agencies/entities involved in the disposal effort with one member of the team designated as leader.

Facts must be quickly gathered, appropriate communications techniques employed, and ample resources allocated to ensure that public information begins in a positive vein. To do this, the lead public information officer should have a direct link to the incident commander.

The Alberta Agriculture, Food & Rural Development department has identified four communication principles for community acceptance (Davison, 2001). These principles can be directly applied to a large-scale carcass disposal effort. The principles state:

- The public should have a say in projects that are perceived to affect their lives. Proponents should genuinely listen to and act upon public input. They should deal seriously with perceptions and fears.
- Livestock producers should seek approvals supported by the community at large. This ensures long-term decisions will not have to be revisited.
- Proponents should seek out concerns, comments, and ideas from all those potentially affected. Decision makers should take advice from the community in determining how citizens provide their input.
- Decision makers should share all relevant information with all interested parties in a timely manner. They should inform them how their input affects the project through all phases (Davison, 2001).

A public information team can guide an incident commander through these principles.

Recognize that not all groups will want to resolve any controversies that develop. However, the agencies/entities involved will be viewed more positively if they lead an effort to deliver to the public credible, unbiased facts based on scientific data generated in the Carcass Disposal Working Group (CDWG) project or other research efforts.

Throughout the time of issue management, the public information team also should take care to maintain the perception that the various agencies and entities working on carcass disposal are unified in the effort. One of the problems in the foot and mouth incident in the UK was the "perception that there was a great deal of tension between the State Veterinary Service and Department of Environmental, Food, and Rural Affairs officials and that communication internally left people feeling frustrated" (Parker, 2002).

2.3 – Information Collection

The CDWG project summary documents are an excellent starting point for unbiased data. The public information team should have a copy of this document and future documents to expeditiously examine and continually use throughout the incident.

Additional facts tied to specific issues will be needed throughout the event. These might include the demographics and geography of the region where disposal is to occur, for example. The more facts that are immediately available, the better the public information team can gauge potential controversies. The public information team should continually identify and assess controversies within the overall incident.

2.4 – Communications Strategies

Public relations experts call it "full and fast disclosure." Agencies and businesses that have successfully dealt with negative events know it is perhaps the single-most important technique for instilling positive public perception.

The communications team should be assembled at the first rumblings of a possible carcass disposal event. The team should quickly develop recommendations for the incident managers and take immediate action to communicate to the public and to the entire disposal team, as deemed necessary, using materials previously developed and any others that become necessary. As soon as possible after the event is identified—no more than one hour from the beginning of the episode—the team should prepare and present the facts to the news media.

The various issues and target audiences can be derived through the use of the four communications principles for community acceptance discussed in Section 2.2.

Key experts for each issue should be identified as potential spokespersons on various topics. A list of decision makers and key experts, and the role of each agency assembled for the disposal, should be provided to the public information team for use with the media. The lead public information team member should assume the spokesperson role when carcass disposal decision makers are unavailable, verifying all information through the local incident commander prior to release.

All involved should be upfront and avoid being placed in a defensive position. A "good neighbor" policy suggested for swine facilities states that decision makers should "listen to and acknowledge the concerns of neighbors, be active in the local community, and maintain an attractive farm" (Heber and Jones, 1999). This "good neighbor" policy can be applied in a carcass disposal event and presented to the news media and in public meetings with residents near the disposal site.

If a decision is made but later has to be changed, the news media should be informed of the reasons. Broken promises and poor management are said to have destroyed public perception at the Widdrington burial site in the UK's foot and mouth disease episode (Parker, 2002). On the other hand, public perception about pyre burning and the impact it was having on the UK image abroad led to the cessation of that practice (Trevelyan et al., 2002).

Materials presented to the media and public will differ for each issue and for each targeted audience but may include Web sites, printed materials, videos, flyers, or other such communications vehicles. Opinion-editorial pieces written for local, regional, or national newspapers may be considered as well. Depending on the carcass disposal location, it may seem more efficient to use only the large urban media and wire services, but local media near the incident location must not be neglected.

The carcass disposal team should be prepared to facilitate conflict resolution, preferably with a trained mediator. If efforts have been made to work with opposition groups but resolution is not possible, the public information team should have a plan with materials (such as briefing sheets) to assure a clear statement of the views, perceptions, and reasons for decisions made by the incident commander.

2.5 – Resource Allocation

The lead agency's resources should be integrated with those of other agencies/entities participating in carcass disposal. Much of the public information work can be done in-kind or through cost-effective materials such as Web-based (print on demand) items.

A multidisciplinary team of public information specialists from the various agencies will work jointly on this issue, and their expenses for on-site issue management should be covered. Equipment can be pooled, but a need may develop for specialized equipment (satellite telephones, for example, if cellular capabilities are not available) to be made available to the public information staff when possible.

Funds also should be allocated to establish and maintain a news media headquarters for the duration of the disposal effort. This will help manage the news distribution and logistics.

Likewise, funds may be necessary to collect additional facts, retrieve information, and gather newspaper and broadcast clips about the event.

2.6 – Measuring Success

A system should be initiated by the first news release to facilitate and monitor clips that appear in the news media—both newspapers and broadcast. This should be done throughout the event. The clips should be organized in a database with such parameters as the name of the media, print or air date, reporter's name, city/state of news media, person quoted, etc. The monitoring of clips also is useful for correcting misstatements that appear in news media reports.

The public information team also should conduct a post-event critique of the public information effort.

Section 3 – Issue Education (Long-term)

3.1 – Definition

While issue management involves the early recognition of signals from a sensitive public, issue education is the continued, long-term monitoring and information conveyance to targeted audiences.

3.2 – General Considerations

How long is long-term? In some cases, this educational effort may need to continue months or even years after the last carcass is disposed. In fact, just when it is felt that the information flow can slow, that may be the time to increase the public relations effort.

The public may be interested in knowing how a region was or may be impacted due to the method of disposal chosen. And even though this information may have been provided to the best of the disposal team's ability at the time of disposal, new people may move into an area, people who were children at the time will become adults interested in the event, and new uses for the land may renew an interest in the facts pertaining to the massive carcass disposal effort.

Because of the importance for long-term education, the agency must determine at an early stage in carcass disposal what role it desires to play over time. This will set the pace for all educational activities.

Does the agency want to continue to assist and respond to traditional clientele exclusively? If so, are there new ways to assist those groups in a changing society that may perceive carcass disposal differently than in the past? Does the agency want to seek out new clientele and commit itself to developing new resources for those groups? Does the agency seek unquestioned credibility with all groups? The answers to these questions are the basis from which educational efforts will spring.

Note that issue education does not wait until the last carcass is disposed to begin. Issue education should be parallel to issue management/short-term efforts and continue beyond as needed. In fact, an ideal situation would be to start issue education long before there ever is a need for disposal of massive livestock mortalities.

Many of the same public information team who work on issue management will be a part of issue education due to the expertise they develop from having worked on a carcass disposal incident. But additional team members such as subject matter specialists should be included to develop education materials and campaigns.

3.3 – Information Collection

Just as the CDWG project summary documents are an excellent starting point for unbiased data in the issues management phase, so will they be invaluable for issue education. The public information issue education team should have a copy of this document and future documents to expeditiously examine and continually use throughout the incident.

Additional facts tied to specific issues will be needed throughout the event. These might include the demographics and geography of the region where disposal is to occur, for example. The more facts that are immediately available, the better the public information available.

Facts that are presented to the public must be well organized and easy to obtain.

Ongoing dialogue with key groups, such as a fact-finding mission, may be crucial for molding and maintaining public perception following an incident. Although the public initially accepted a burial site in Widdrington in the UK's foot and mouth episode of 2001, the perception later changed to extremely negative due to poor management and broken promises (Parker, 2002).

The issue education team should identify groups with whom they should maintain contact so that facts will continue to be readily available. A list of key contacts and public information persons for each of those groups should be maintained.

It may be useful for the public relations team to meet periodically in an attempt to predict future potential issues, discuss possible areas of concern, and identify experts who can address emerging issues regarding carcass disposal.

3.4 – Communications Strategies

It should be a high priority to strive for public confidence in leadership by remaining involved and providing information as long as there is a need. Communication with the public through every possible means and as frequently as the situation merits is a necessity. A designated spokesperson may be necessary for this to free incident managers to make decisions, but the two must work closely together.

For related issues that do not fall under the purview of the agencies/entities, public information offices may facilitate collaboration with the proper state or federal agencies to make sure the issue is addressed for the public.

In addition to ongoing communication through the news media, outreach programs that involve the community should be initiated. Additional outlets for information dissemination, such as law enforcement agencies, should be incorporated into communication efforts. Educational products aimed at points of interest gleaned from dialogue with all sides of the issue should be created and utilized.

All educational products should state the role of the various agencies involved.

Volunteer programs made up of local people trained on carcass disposal issues may be most useful in long-term education. Having a well-known local or "everyday" person (perhaps a mayor or a producer) teach about an issue may produce more positive results in public perception than having an agency official. Success stories should be identified and highlighted. Give examples of previous incidents that used particular methods, such as the burning of carcasses in the aftermath of Hurricane Floyd in North Carolina (Jordan 2003). Similarly, any criticisms or negative situations that surfaced in issue management or short-term efforts should be addressed in this phase. Often, a well-maintained, thorough, and frequently updated Web site can effectively manage massive public inquiries in the long-term. It should have all news generated by the public information team during the event plus any other related or ongoing information as it becomes available. It also should be interactive with contact e-mail addresses available.

3.5 – Resource Allocation

Consideration should be given to partnerships for the allocation of funds to enable the long-term issue education plan. Resources need to be allocated to facilitate internal communication at the same level as what is being done externally. Cooperative programs with other universities, agencies and interest groups should be developed, if appropriate, to jointly review and develop responses for the long-term strategy.

Resources also may be needed to continue some of the issue management efforts, such as monitoring news media clips. Response teams should be established with individuals designated for interviews about educational efforts.

3.6 – Measuring Success

Depending on how long issue education is needed, the type of materials may need to change over time. With the first materials produced, a survey measurement tool, including demographic content, should be included so the targeted audience can be identified and feedback can be provided as to its usefulness. Post-event critique of the public information effort should be conducted.

Section 4 – Public Relations Checklist

4.1 – Issue Management (Short-term)

The following "Animal Health Crisis Media Response Plan, Step by Step," adapted for use in a massive carcass disposal effort, was developed by a team of public information officers from various Texas agencies planning for an animal health crisis (Mayes, et al., 2001) and is a good guideline for issue management. It is strongly recommended that a Quick Response Team (QRT) be designated prior to any need. Having a team in place will enable the collection of contact information for key people in each state who could be called on to assist.

Animal health crisis media response plan, step by step

The lead time between the trigger event and the need to alert news media will be short -- perhaps only hours -- requiring rapid decisions and movement of people and resources. This makes having a well-thought-out media response plan critical.

Prior to the trigger event, the following items should be prepared and ready for use:

- ■ Shell of news release announcing necessity of carcass disposal method(s).
- ■ Web site for news media and general public on carcass disposal. Listings on site should include:
  - Key fact sheets on carcass disposal methods.
  - Names of experts who can speak about carcass disposal (and associated issues) in various regions, with their contact info and mug shots.
  - Links to sites with information about the cause of massive livestock mortality.
  - Streaming video about carcass disposal for general public.
  - Downloadable radio public service announcements in English, Spanish, and French.
  - High-resolution photos of carcass disposal methods.
  - Maps of recent outbreaks.
- ■ Develop rules of engagement, including press protocols for covering this story, and include an editor's note with initial release.
- ■ Compile who's who of key players in carcass disposal leadership team, including photos, titles, and a brief description of each person's responsibility and role in crisis.
- ■ Intranet Web site, protected by password, for communications use by carcass disposal leadership team, veterinarians in field and other agency/industry professionals working on problem.
- ■ Designation of a hotline number for news media to call for additional information. (Should be included in initial press release).

First trigger event

Notification of an event has caused massive livestock mortality.

The USDA Animal and Plant Health Inspection Service (APHIS) sends e-mail advisory to designated "tree" of public information officers at the appropriate agencies such as state departments of agriculture, parks and wildlife, public safety, health, mental health-mental retardation, criminal justice, natural resources, governor's office, land grant university agriculture agencies, and associated agriculture and industry leaders.

Hours 1-2

- ■ Tree representatives or alternates notify APHIS by phone that message has been received and they are ready to implement response plan.
- ■ APHIS sets up conference call to brief the public information officers on what has transpired.

- Complete news release and clear with carcass disposal team leadership. Translate release into Spanish; have Spanish-language capability for revised release based on existing facts.
- QRT is activated and readied to travel to site of carcass disposal. Members should be prepared for a stay of three days at least, with a second team ready to rotate. QRT lead member calls department of public safety to learn if mobile media command post is activated. QRT leaves for carcass disposal site. Travel by car if at all possible so equipment can be carried more easily. Items QRT should take to location:
  - Cell phones
  - Laptop computers with Internet connections
  - Portable printer with extra cartridge and paper
  - Printed handouts of key carcass disposal fact sheets
  - Tape recorders for interviews and tapes
  - Video camera with protective shell for shooting pool video footage
  - Nametags for press credentials
  - Extra electrical cords and surge protectors
  - Pens and notepads
  - Fax cover sheets
  - Log sheets to record actions taken (news releases, faxes sent and received, phone calls, media contacts, etc.)

Hours 2-4 (or as soon as possible thereafter)

- QRT works with carcass disposal leadership to help determine appropriate site for setting up field headquarters and handling press briefings.
- One public information officer goes to the main command post in order to coordinate media/information with communicators at field locations.

Second trigger event:

Confirmation of the method of carcass disposal to be used.

- Initial news release announcing carcass disposal finding sent via e-mail and fax to media. (This list should be developed prior to an event and maintained by the APHIS public information office.)
- QRT works with carcass disposal leadership team to complete communications site plans.
- Issues that must be determined on site include:
  - How lines of communication will be established between QRT members and key people working on carcass disposal.
  - If bioterrorism is suspected, who will be investigating on site.
  - Media access to perimeter of premises where carcass disposal is ongoing.
  - Identity of affected people (owners of the livestock) and media access to them.
  - Identification and prepping of key spokespersons on site.
  - Drafting of key talking points/messages for spokesperson to use during briefing.
  - Scheduling of first news briefing and deciding schedule for those that follow.
  - Determine whether news conferences via Web cast/teleconference are feasible from site.
- A phone bank should be activated to field media calls around the clock, at least during first two days. Advanced actions needed include:
  - Determine how logistically the phone bank can happen, and whether phones can be rolled to various agencies to provide staffing relief.
  - Determine minimum staffing of phone bank and consider how to keep all coordinated and on message.
  - Develop briefing book that has key message points and facts. Provide updates through e-mail and intranet Web site. Provide someone who can converse in Spanish on phones.
  - One approach to 24/7 phone staffing issue may be to shuffle clusters of media calls to a

phone bridge (up to 24 parties), where an expert or public information officer could field multiple questions from media without tying up phone lines with individual callers.

- Investigate whether experts could be made available via Internet on Web, with reporters asking questions live via e-mail.

That evening or next morning

- Conduct initial press briefing on site.
- Coordinate this with any statement governor or high-ranking federal official may be planning to make on the carcass disposal crisis.
- Generate maps showing location of carcass disposal.
- Monitor written and broadcast news reports, in order to correct false or misleading information generated by news coverage.
- Post the first digital and video images of scene on carcass disposal news Web site, as gathered and transmitted by QRT.

Section 5 – Critical Research Needs

Many communications tools for responding to catastrophic carcass disposal events could be prepared in advance. Doing so would relieve pressure and help steer public perception to positive acceptance if an event causes the need for mass carcass disposal. A team of communicators should work with experts who have completed this work on various methods of carcass disposal to develop materials for each disposal method that include, but are not limited to:

- Fact sheets briefly detailing how the method is done and the reasons for using that method.
- Video segments (on CD, DVD, VHS, and streaming Web) briefly detailing how the method is done and the reasons for using that method.
- Expert lists with contact information for those who can discuss the method. Include all contact information and a mug shot. Include experts who can talk about bioterrorism in general.
- High resolution photos of carcass disposal methods being properly performed.
- List of key players in carcass disposal leadership team, complete with photo, title, and brief description of each person's responsibility.
- Easy-to-follow guidelines on managing conflict and conducting public meetings for use by communicators who would be called to handle carcass disposal information and public relations.

In addition to these materials for each disposal method, the following communications tools could be developed:

- Web site to serve as clearinghouse for information with the media and general public as the target audience. Most of the above items could be available on this site, which also would have links to other pertinent sites.
- Intranet Web site, password protected, for communications use by disposal leadership teams, veterinarians in the field, and other agency/industry professionals working on the problem.
- Enhance clipping capabilities to enable public relations officials to gather, track, and assemble print and broadcast news stories about the event.

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Carcass Disposal: A Comprehensive Review

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USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

13

Physical Security of Carcass Disposal Sites

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Abbreviations

A	active (Table 2)
C	covert (Table 2)
CCTV	closed-circuit television
CDC	Center for Disease Control and Prevention (Table 1)
FAA	Federal Aviation Administration (Table 1)
IR	infrared
L	line (Table 2)
LOS	line of sight (as in line-of-sight sensors) (Table 2)
NAR	nuisance alarm rate
NAR (OR)	nuisance alarm rate of the OR combination
P	passive (Table 2)
P_D	probability of detection
P_D (AND)	detection probability of the AND combination
PIR	passive infrared
PPS	physical protection system (Figure 1)
TF	terrain-following (as in terrain-following sensor) (Table 2)
USDA	United States Department of Agriculture
V	visible (Table 2)
VMD	video motion detectors
VOL	volumetric (Table 2)

Section 1 – Key Content

1.1 – Overview

Serious issues mandate the need for a security system during carcass disposal operations. Relatively high-value equipment may be used in the operation that would be vulnerable to theft. Angry and discontented livestock owners who believe the destruction of their animals is unnecessary could put the operators of the system at risk. Unauthorized, graphic photographs or descriptions of the operation could also impact the effort through negative publicity. Most important is that the disease could be spread from the site to other areas. A well-designed security system would control these issues.

The type of security required for carcass disposal operations is obviously not the same as that required for a bank, a nuclear weapon facility, or an infrastructure system; however, an understanding of basic security concepts and design methodology is required for the development of any security system. This basic understanding underlies the design of a system that meets the desired performance objectives. A carcass disposal security system will need to be designed and implemented within a large number of very serious constraints such as time (for design) and cost (of operation). Applying proven physical security design concepts will assure that the best system possible is designed and operated within these real-world constraints.

When designing the carcass disposal security system, clear objectives regarding the actions and outcomes the system is trying to prevent are a necessity. Regardless of the performance goals, all effective security systems must include the elements of detection, assessment, communication, and response.

Three types of adversaries are considered when designing a physical protection system: outsiders, insiders, and outsiders in collusion with insiders. These adversaries can use tactics of force, stealth, or deceit in achieving their goals.

The security system requirements for a carcass disposal system also carry unique characteristics. However, in each case a threat analysis is needed to answer the following questions:

- Who is the threat?
- What are the motivations?
- What are the capabilities?

Before any type of security system can be designed, it is necessary to define the goals of the security system as well as the threats that could disrupt the achievement of these goals.

1.2 – Performance Goals

There will likely be two main components in any large-scale carcass disposal operation. The first component will be the site(s) where processing and disposal operations occur. The second component is the transportation link. In some cases a third component, a regional quarantine boundary, could be considered. For each of these components, a brief description of the action or situation that needs to be prevented provides the basis for the performance goals of an ideal system.

Appropriate security must be provided for these fixed-site operations for all credible threat scenarios. Some unique challenges are presented for mobile operations quickly moving from location to location, but all fixed-site operations share common vulnerabilities that could result in actions that disrupt the controlled disposal of carcasses. At any given fixed disposal site, a range of actions could engage the security system.

This is not to suggest all or even any of these actions *would* occur, only that they *could* occur. It is also important to realize that given the real-world constraints, no security system can be completely effective against all potential actions. In actually designing the system, the designer and analyst must select those actions considered to be the most important and credible and design the system to be most effective against these actions.

The performance goals for the ideal fixed-site security system would be to prevent the following events:

- Interruption of operations.
- Destruction/sabotage of equipment.
- Equipment theft.
- Intimidation of operating personnel.
- Spread of contamination.
- Unauthorized access.

The performance goals for the ideal transportation-link security system would be to prevent the following events:

- Interrupted transfer of people, equipment, and materials (including carcasses).
- Spread of contamination.
- Equipment theft or sabotage.

The performance goal for a regional security system would be to:

- Prevent the unauthorized movement of animals, materials, products, and people across the defined boundary of the region.

Additional performance goals may be determined in collaboration with carcass disposal operations stakeholders.

1.3 – Design Considerations

The design considerations for the ideal security system include (but are not limited to):

- Disposal technology.
- Disposal rationale.
- Prescribed haul routes.
- Disposal system administration.
- Staffing.
- Funding.
- Training.
- Advanced planning and preparation.
- Operational period.
- Geography.

Additional design considerations may be determined in collaboration with carcass disposal operations stakeholders.

1.4 – Threat Analysis

The threat may be very different in cases where there is a natural disaster as opposed to a disease outbreak. In the natural disaster situation the animals will already be dead and there is no question about the need for disposal. In the disease outbreak situation, however, there may be the slaughter of both diseased and healthy, or apparently-healthy, animals. Decisions about the number of animals that need to be destroyed and the geographic area where the animals will be destroyed could become quite controversial.

The threat spectrum for the carcass disposal operations security system design is likely to include two types of threats:

- Malevolent threats (adversaries who intend to produce, create, or otherwise cause unwanted events).
- Nonmalevolent threats (adversaries who unintentionally produce, create, or cause unwanted events).

Carcass disposal operations are unusual in that some of the nonmalevolent adversaries posing a threat to the operations are nonhuman. For example, animals, groundwater, and wind can all spread contamination. The ideal physical security system would prevent these nonhuman adversaries from completing such actions.

Threat analysis for the ideal fixed-site security system would include the following adversaries:

- Intentional malevolent threats, including:
    - Animal owners.
    - Animal rights activists.
    - Site workers/visitors/animals.
    - Unauthorized media.
    - Disgruntled employees.
- Nonmalevolent threats, including:

- Inadvertent intruders
- Curious individuals
- Unintentional insiders
- Animals and other forces of nature

Additional adversaries may be identified in collaboration with carcass disposal operations stakeholders.

1.5 – Security Technology

There are many security technologies available to support the success of designed physical protection systems. Before security technologies can be applied to a carcass disposal operation, the performance goals of the system must be defined, the design considerations must be characterized, and the threat must be analyzed. Only then can a security system be designed to address the needs of the particular problem.

It is possible to expect that sensors, specifically exterior intrusion detection sensors, are likely to be a part of a physical protections system designed to provide security for a carcass disposal operation. For this reason, a technical description of the capabilities of these sensors is provided in Section 7.

1.6 – Recommendations

Several general recommendations for designing an effective security system for carcass disposal operations are provided. The general recommendations include:

- Plan ahead.
- Include local law enforcement in planning.
- Focus on low-cost, rapidly deployable technologies.
- Provide pre-event training.
- Coordinate efforts.
- Understand the legal issues.
- Integrate security plans with biosecurity protocols and procedures

Additional specific requirements and recommendations need to be developed in collaboration with carcass disposal operations stakeholders.

1.7 – Critical Research Needs

In collaboration with owners, operators, and other stakeholders in carcass disposal operations, security designers must develop the performance goals and design constraints for the security system. A thorough threat analysis will be necessary to identify potential adversaries and credible threat scenarios. This information is required before the system can be designed. Design iterations are to be expected, not only because the facility characteristics change (changes in one part of the system may necessitate changes in other parts), but also because the threat analysis may change.

Section 2 – Introduction

Why is there any need to provide security for dead animals? This is probably the first reaction to the suggestion that a security system is needed for carcass disposal operations. At best, the idea of a security system appears odd. However, there are serious issues to be addressed by a security system. Relatively high-value equipment may be used in the operation that would be vulnerable to theft. Angry and discontented livestock owners who believe that the destruction of their animals is unnecessary could put the operators of the system at risk. Unauthorized, graphic photographs of the operation could also impact the effort through negative publicity. Most important is that disease could be spread from the site to other areas. A well-designed security system would control these issues.

The primary purpose of this effort is to identify the main issues associated with physical security of carcass disposal and to describe how an appropriate system might be developed. The effort discusses the expectations for the system, describes how a system might be designed, identifies important design consideration, reviews technology needs, and identifies operation issues.

The following sections describe general principles associated with the design of security systems (Section 3), the performance goals of a security system for carcass disposal operations (Section 4), the design considerations – many of which are currently unknown – for this effort (Section 5), the approach for analyzing the threat (Section 6), and a review of the sensor technologies that can be brought to bear upon the security issues attending carcass disposal (Section 7). Recommendations for the successful performance of this task are presented (Section 8) and, finally, critical research needs (Section 9) are identified.

Section 3 – Physical Security System Concepts and Design Methodology

3.1 – Design Methodology

This section focuses on the general concepts and methodology required for the design of a physical security system. The type of security required for carcass disposal operations is obviously not the same as that required for a bank, a nuclear weapon facility, or an infrastructure system; however, an understanding of basic security concepts and design methodology is required for the development of any security system. This basic understanding underlies the design of a system that meets the desired performance objectives. As discussed below, a carcass disposal security system will need to be designed and implemented within a large number of very serious constraints such as time (for design) and cost (of operation). Applying proven physical security design concepts will assure that the best system possible is designed and operated within these real-world constraints.

Most physical security systems focus on preventing one of two types of actions: theft or sabotage. For example, a bank is primarily concerned with the theft of money. An adversary comes into the bank, takes the money, and must leave the premises with the money to be successful. In a case of sabotage, the adversary needs only to gain access to the facility and complete a destructive act. For example, an activist may wish to halt the production of some product. To be successful, the adversary gains access to the facility or production line in order to destroy or disrupt the production. In an extreme example, the adversary would not even need to gain physical access to the facility but could use standoff weapons such as rocket-propelled grenades to disrupt the operation. Security systems to prevent theft and security systems to prevent sabotage are thus very different. Security systems can also be designed to prevent other types of undesired actions, such as kidnapping, violence against persons, misuse of the facility, or disclosure of information. When designing the carcass disposal security system, clear objectives regarding the actions and outcomes the system is trying to prevent are a necessity. Regardless of the performance goals, all effective security systems must include the elements of detection, assessment, communication, and response.

Three types of adversaries are considered when designing a physical protection system: outsiders, insiders, and outsiders in collusion with insiders.

These adversaries can use tactics of force, stealth, or deceit in achieving their goals. Adversaries can have a variety of different motivations. These motivations may be ideological, economic, or personal. The capabilities of the adversaries can also vary widely. An adversary could be an unarmed individual or a heavily armed paramilitary force. The adversary's level of dedication will also vary. At one end of the spectrum is the common vandal, who will run away at the first sign of detection; at the other end of the adversary spectrum is the highly dedicated extremist willing to die for a cause.

These factors must be considered in designing the physical protection system. Adversary characteristics are obviously very different when considering the design of a nuclear weapons physical protection system versus a home alarm system. The security system requirements for a carcass disposal system also carry unique characteristics. However, in each case a threat analysis is needed to answer the questions:

- Who is the threat?
- What are the motivations?
- What are the capabilities?

Thus we see that before any type of security system can be designed, it is necessary to define the goals of the security system as well as the threats that could disrupt the achievement of these goals. In the case of carcass disposal, these performance goals and adversaries may be different from those associated with typical physical security systems.

To assure that the system achieves the desired goals, a cyclical design process (see Figure 1) is used. The cycle begins with defining the system requirements followed by a proposed design concept. The effectiveness of the system in meeting the performance goals is then analyzed. The results of the analysis answer the question, "Does the physical protection system meet protection performance goals?" If the system does not meet the stated goals, it must be redesigned. The next design phase attempts to improve weaknesses that have been identified in the system. The design and analysis cycle is closed by analysis of the redesigned system. The cycle is repeated until an effective design is achieved.

In designing the optimal system a wide variety of real-world constraints must be considered. Such constraints may include:

- Budget for design, construction, and operation.
- Time available for design and implementation.
- Expected system lifetime.
- Ability to perform maintenance.
- Power and utility availability.
- Personnel training.
- Operational personnel qualifications (e.g., military professionals, day laborers).

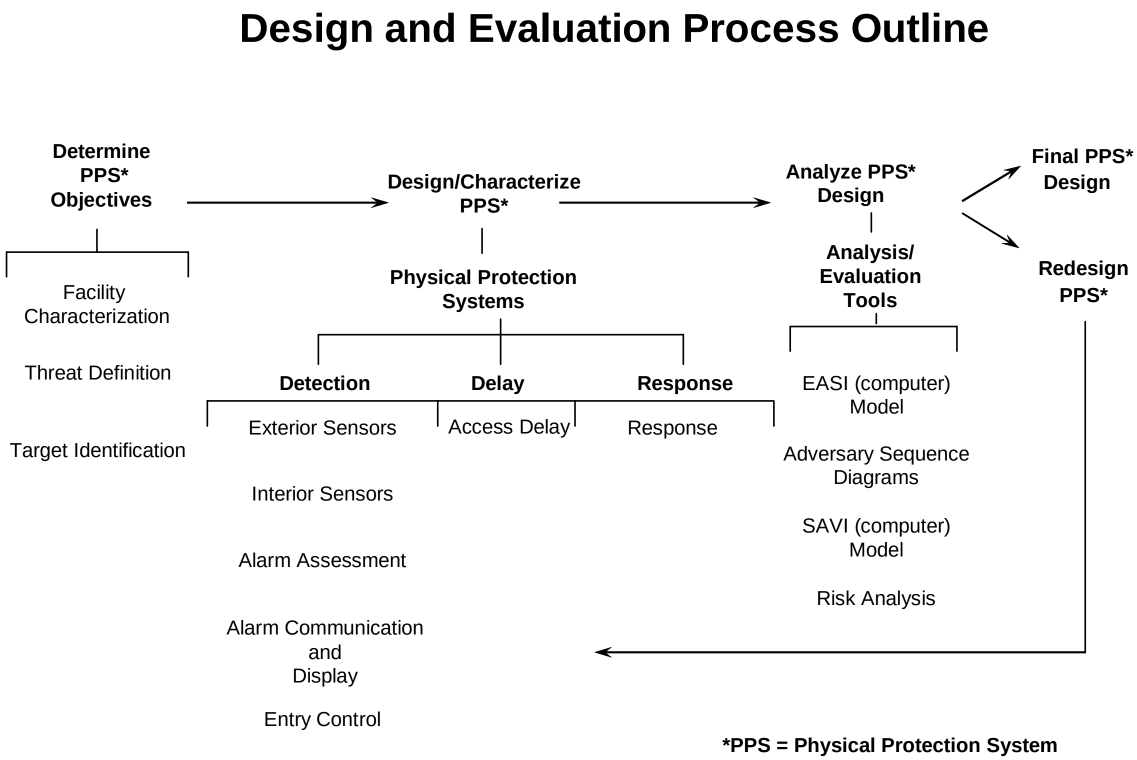


FIGURE 1. The design and evaluation process for physical security systems.

These and other considerations must be factored in when designing the system. Because resources are finite, the design must be optimized to meet the performance goals as successfully as possible within the specified limitations or constraints. Therefore, the iterative design process must factor in all real-world considerations to achieve the optimal design that meets the budget and operational constraints unique to the carcass disposal situation.

A balanced approach that does not allocate all resources to one aspect of the problem while ignoring another is also required. For example, it would be a waste of resources to build a very sturdy, heavily locked gate when it is possible to cut a barbed wire fence and simply drive around the gate. (See Figure 2 for another inappropriate application of security measures.) Once the system is in place, performance metrics are needed to help assess the effectiveness of the system.

In the final analysis, any security system provided for carcass disposal will need to be very low cost, simple to install, easy to maintain, and easy to operate. The reality is that there will be a very limited budget and the system will probably only need to operate for a limited period of time. The following sections focus on understanding the problem and defining the needs and constraints of the system.

FIGURE 2. Clear zone with multiple sensors – part of a robust security system that is not appropriate for the carcass disposal operations problem.

3.2 – Design Application

This section provides a simplified hypothetical example of how the security design process might be applied to a carcass disposal operation.

Information needs

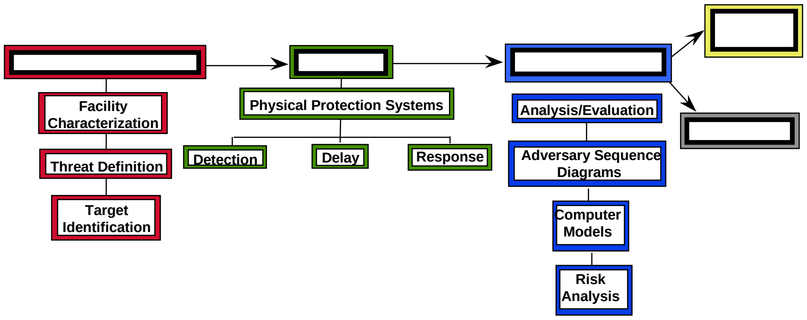
Table 1, compiled by Kimberly Asbury of the Intrusion Detection Department at Sandia National Laboratories, provides an outline of the design requirements of a physical protection system in the first column, and credible responses to those information needs are posited in the second column. The second column also contains the preliminary component modeling for a physical protection system to meet the security requirements of the hypothetical carcass disposal site.

Design options

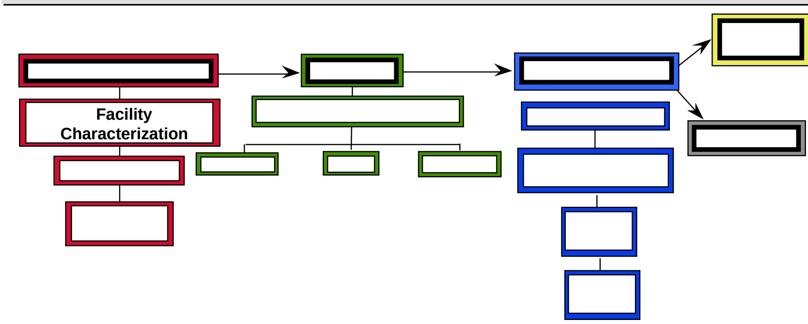
Based on the hypothetical information in the second column of Table 1, a preliminary physical protection system can be designed. Two potential design options were developed as examples. One option is a high-end security system and the other is both less effective and less expensive.

TABLE 1. Model application of the physical security design process for a hypothetical carcass disposal operation.

Information Needs	Site Data (Hypothetical)



Facility Characterization (describe the facility)

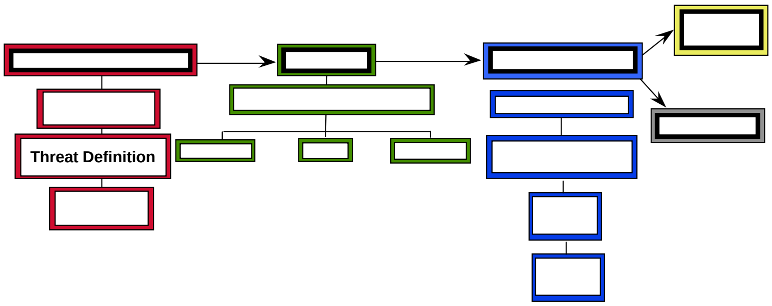


Physical Conditions	
Topography	Relatively flat even terrain (farming, agricultural lands)
Vegetation	Grasslands and low-density forests
Wildlife	Scavenger animals (coyotes, raccoons, birds, etc.)
Background noise	■ Major highways ■ Railway ■ Small aircraft (crop dusters)
Climate & weather	■ Blizzards, hail, thunderstorms, and tornadoes ■ Temp range from 24oF winters – 90oF summers ■ High humidity
Site boundary	■ Property fencing ■ Naturally occurring boundaries (i.e., river, stream, ditch)
Traffic	■ Heavy equipment (i.e., backhoes, tractors) ■ Semi trucks ■ Trains ■ Personal vehicles
Number, location, and types of buildings in the complex; also, room locations within buildings	Generally low in number, single room, prefabricated, easily mobile ■ Carcass disposal area requirements (will vary depending upon technique used for disposal) ■ Test facility and offices (modular, butler buildings, tents) ■ Ranchers'/farmers' homes, stables, barns, sheds

Access points	■ Pre-existing doors and tent openings ■ Traffic access points into the perimeter
Existing physical protection features	■ Local law enforcement ■ Pre-existing locks on windows and doors of buildings ■ Tent closures
Infrastructure Details	
Heating	Standard design for most buildings
Ventilation & air-conditioning systems	Standard design for most buildings
Communication paths and type (fiber optic, telephone, computer networks, etc.)	■ Cellular ■ Radio
Construction materials of walls and ceilings	■ Fabric walls and roofs for tents ■ Metal 2-x-2 walls and roof for modular units
Power distribution system	■ Generators ■ Hardened lines
Environmentally controlled areas of the facility	Test labs will be environmentally controlled ■ Independent power and ventilation system
Locations of hazardous materials	Type, quantity, and location will depend upon carcass disposal technique ■ Type: Gas (carbon dioxide) and injectibles ■ Fragmentation bullets and captive bolt pistols used in euthanizing the affected animals
Exterior areas	Carcass disposal and storage areas
Facility Goals and Objectives	
Goal	Eradicate and effectively contain the pathogen while minimizing incidents during transport and disposal of carcasses
Processes that support this goal	Enforceable documented regulations (decontamination protocols, safety and security plans)
Operating conditions (work hours, emergency operations, etc.)	Employee schedules, emergency operations, etc.
Types and numbers of employees	■ Shift work ■ Skill set
Support functions	■ Law enforcement ■ Regulatory/federal agencies (USDA, CDC, etc.) ■ Medical ■ Transportation contractors
Facility Policies and Procedures	
Pre-existing documented policies and procedures	
Regulatory Requirements	
Pre-existing requirements imposed by regulatory agencies (e.g., FAA, local law enforcement, emergency response units, etc.)	
Legal Issues	
Safety Considerations	

Effectiveness of current system in normal and abnormal conditions (e.g., fire or flood)

Threat Definition (describe the adversary)



Type and Motivation

Malevolent

(deliberate acts that result in the spread of contamination or the disruption of the facility)

- Farmers/ranchers – Owners of the animals to be destroyed could be severely impacted financially
- Extremists (animal rights activists) – Due to the large number of animals to be destroyed there may be protests
- Local stakeholders – These individuals may not want contaminated animals being disposed of in their landfills
- Disgruntled employees – A worker who disagrees with the new work constraints or the act of disposing of such a large number of animals
- Unauthorized media – Journalists trying to get photographs or a story without undergoing the appropriate approval process

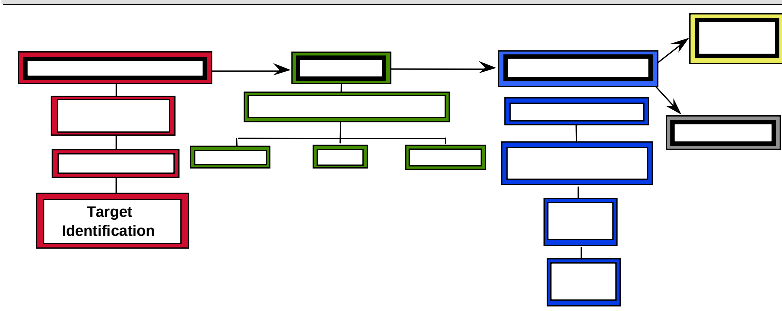
Potential Goals Based Upon Targets

Tactics, Numbers, and Capabilities

Malevolent

- Sabotage, theft
- Low skills
- Single to multiple individuals
- Firearms and explosives
- Vehicles and heavy equipment
- Medical supplies

Target Identification (determine & asses the targets)

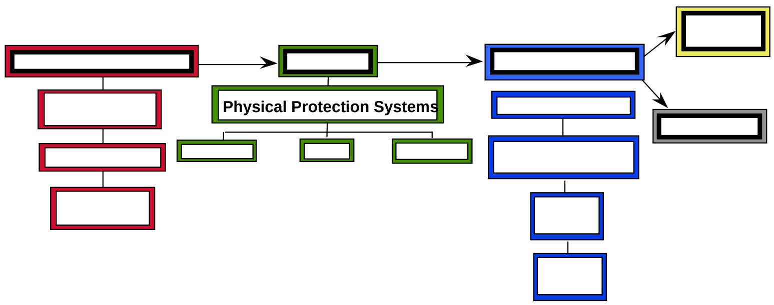


Undesirable Consequences

- Spread of the pathogen
- Interruption of the transfer of people, equipment, and materials (including carcasses)
- Equipment theft or sabotage

Select Technique for Target Identification	What systems/processes in operation if targeted would result in the undesirable consequences

Identify Targets	■ Carcasses ■ Carcass storage/disposal facilities ■ Test labs ■ Vehicles used to transport materials, people, equipment ■ Equipment/machinery essential to operations
Physical Protection System (design a physical protection system that incorporates detection, delay, and response)	



Detection	
P_d Probability of Detection	■ A lower P_d (.70 or higher) can be tolerated due to the realistic threat level being low ■ Adversaries to be detected are humans walking, running, crawling, and climbing; vehicles breaching the perimeter; and scavenger animals
P_a Probability of Alarm (P_d * Probability of Communication)	■ The $P_{a\ will}$ be fairly high due to the response force being onsite local law enforcement
Exterior Sensors	■ The exterior perimeter costs will be the dominant consideration; however, the materials are reusable ■ Entrance – The entrance to the area can be monitored by local law enforcement ■ Outer fence will be an electric net that will keep out scavenger animals as well as reduce nuisance alarms on the inner fence ■ Portable barricades mounted with chain-link fencing and fence-disturbance sensors will be used around the protected area. This will keep out scavenger animals, delay vehicles, and provide delay for alarm assessment
Interior Sensors	Not discussed in this process; however, cost-effective sensors with low nuisance and false alarm rates (such as balanced magnetic switches) should be used
Alarm Assessment	■ Portable halogen lighting ■ Camera images displayed on-site to response personnel ■ A lower resolution black-and-white camera may be used if this video is used for detection and classification rather than prosecution ■ Digital video recorder for storage as well as to provide pre-alarm assessment
Alarm Communication and Display	Local alarm annunciation
Entry Control	Entry control will be performed by law enforcement
Delay	
Delay	■ Jersey barriers at entrance to create a serpentine approach

	to slow down vehicles ■ Jersey barriers around perimeter to stop or slow vehicles ■ Locked gate at entrance ■ Locked gate to the carcass disposal areas and building areas ■ Fences to delay an adversary long enough to ensure good assessment
Response	
Interruption & Neutralization	■ On-site local law enforcement ■ Other response forces used for backup

The following example physical protection designs are based on the hypothetical information presented in Table 1. They are presented for illustrative purposes only.

Design 1: higher-cost option

This perimeter intrusion detection system is capable of detecting a human attempting to cut or climb the inner perimeter fence, protecting against scavenger animals, and protecting against vehicles attempting to ram the perimeter. This system will not protect against birds. Figure 3 shows the layout for Design Option 1.

Design specifications

This example physical protection system was designed for a 1320-foot rectangular perimeter.

Perimeter

Outer fence. This fence is made from low-cost 3.5-foot-high electric netting. The purposes of this fence are to keep out the ground scavenger animals as well as reduce the number of nuisance alarms on the protected areas fence sensor.

Inner fence. This fence is made from off-the-shelf interlocking 32-inch-high barriers with mounted 5-foot-high 9-gauge rolled chain link. Mounted to the fence is a coaxial fence disturbance sensor. The purposes of this fence are to protect the perimeter from vehicle penetration, detect the adversary, and provide the delay required for alarm assessment.

Fence sensor. Coaxial cable sensors provide the desired portability, as maintenance is easier than with fiber disturbance sensors.

Perimeter lighting. Portable halogen work lights mounted on a tripod are recommended to illuminate the area for camera assessment. These are available from home improvement stores at a low cost; another alternative is to rent them for the duration of the operation.

Cameras. One camera per zone is recommended. The cameras should be mounted beneath the lighting to avoid blooming as well as at a slight downward angle to avoid sun glare.

Assessment trailer

This example includes a very simple alarm assessment system that can be used in a field setting.

Alarm control and display. A simple alarm annunciator can be used to detect the relay closures of the sensor. The annunciator can use a horn to alert staff and message LEDs to indicate the different zones of the fence.

Monitor. A low-cost black-and-white monitor with a switcher can be used to view the different cameras and zones.

Cost breakdown for design 1

Costs are presented per-foot using a 1320-foot perimeter, and do not include labor and maintenance.

Item	$/foot
Electric net	$1.06
Barriers	$31.22
Chain link fence (uninstalled)	$2.01
Fence disturbance sensor	$10.00
Assessment (camera, switcher, monitor)	$4.42
Annunciator	$0.12
Lighting	Varies
TOTAL (excluding lighting)	**$48.83**

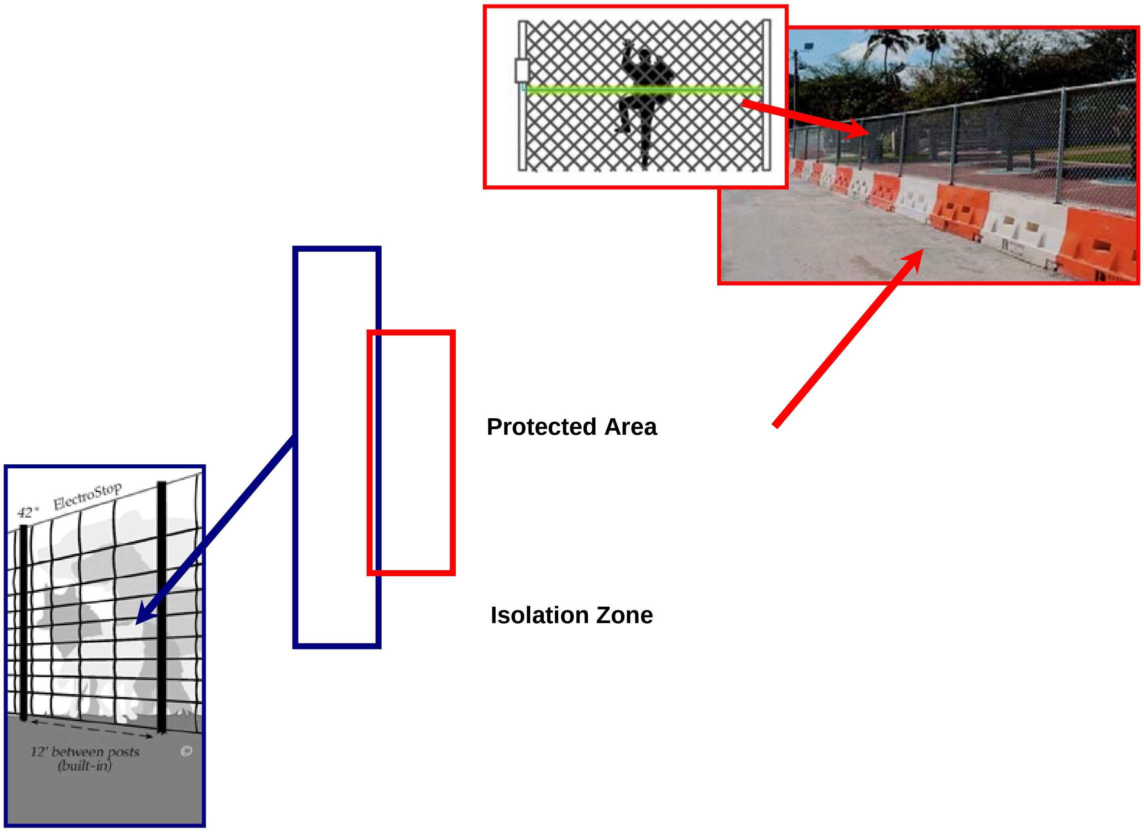


FIGURE 3. Design Option 1 layout diagram.

Design 2: lower-cost option

This perimeter intrusion detection system is capable both of protecting against a person crossing the zone by walking, running, rolling, or crawling and protecting against scavenger animals. This system will not protect against birds. Because it uses exterior passive infrared sensors, this design may have a significantly higher nuisance alarm rate than the higher-cost option. Figure 4 shows the layout for Design Option 2.

Design specifications

This example physical protection system was also designed for a 1320-foot rectangular perimeter.

Perimeter

Perimeter fence. This fence is made from a low-cost 3.5-foot-high electric netting. The purposes of this fence are to keep out the ground scavenger animals as well as reduce the number of nuisance alarms on the protected area passive infrared fence sensors.

This design option does not protect against vehicles and does not offer any delay or detection on the fence line.

Sensors. Exterior passive infrared will be used within the perimeter in order to detect scavenger animals and humans. This type of sensor may have high nuisance alarm rate in some locations.

Perimeter lighting. As in Design 1, portable halogen work lights mounted on a tripod are recommended to illuminate the area for camera assessment. These are available from home improvement stores at a low cost; another alternative is to rent them for the duration of the operation.

Cameras. As in Design 1, one camera per zone is recommended.

Assessment trailer

As in Design 1, this example includes a very simple alarm assessment system that can be used in a field setting.

Alarm control and display. As in Design 1, a simple alarm annunciator can be used to detect the relay closures of the sensor. The annunciator can use a horn to alert staff and message LEDs to indicate the different zones of the fence.

Monitor. As in Design 1, a low-cost black-and-white monitor with a switcher can be used to view the different cameras and zones.

Cost breakdown for design 2

Costs are presented per-foot using a 1320-foot perimeter.

Item	$/foot
Electric net	$1.06
Exterior passive infrared sensor	$31.22
Assessment (camera, switcher, monitor)	$4.42
Annunciator	$0.12
Lighting	Varies
TOTAL (excluding lighting)	**$10.85**

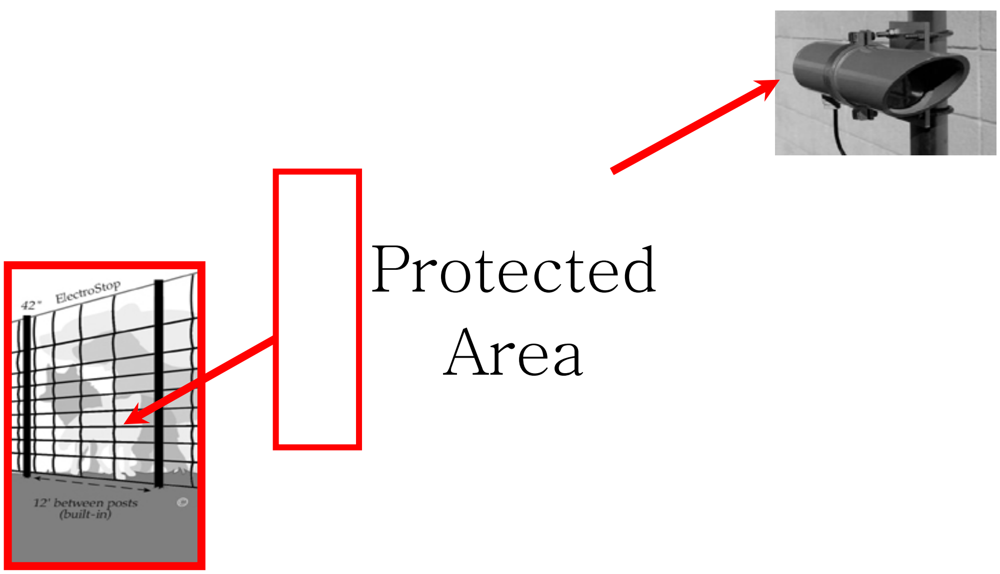


FIGURE 4. Design Option 2 layout diagram.

Section 4 – Performance Goals

This analysis assumes that large numbers of animals are involved and that the processing operation will require weeks or even months. Small-scale disposal activities, such as those associated with normal production losses, are not considered here. These types of operations do not require any formal review of security beyond what is normally provided for farm or processing operations. Similarly small-scale disposal operations necessitated by a local problem (such as a fire or small flood) do not need security planning other than that required as part of normal operational practices. In these cases, normal industrial security practices, such as locking or disabling heavy equipment, is probably adequate.

However, large-scale carcass disposal, with the possibility of pathogen movement, the use of large amounts of heavy equipment, and the potential to generate anger and discontent over decisions made by policy makers, creates a unique security situation.

There will most likely be two main components in any large-scale carcass disposal operation. The first component will be the site(s) where processing and disposal operations occur. The second component is the transportation link. In some cases a third component, a regional quarantine boundary, could be considered. For each of these components, a brief description of the action or situation that needs to be prevented provides the basis for the performance goals of an ideal system.

4.1 – Fixed-Site Processing and Disposal Operations

Processing (grinding, chopping, etc.) and disposal could occur at a regional location where live animals are brought for slaughter, processing, and disposal, or where dead animals are brought for processing and disposal. It is possible that slaughter and some preprocessing will be performed at multiple locations and the carcasses then transported to the regional center. It is even possible that mobile systems will be utilized. In this case, operations would be established for a short period of time at one location (such as a feedlot) and then moved to another location.

In all these scenarios, appropriate security must be provided for these fixed-site operations. Some unique challenges are presented for mobile operations that are quickly moved from location to location, but all fixed-site operations share common vulnerabilities that could result in actions that disrupt the controlled disposal of carcasses. At any given fixed disposal site, a range of actions could be encountered by the system. Each of these actions is discussed below.

This is not to suggest all or even any of these actions *would* occur, only that they *could* occur. It is also important to realize that given the real-world constraints, no security system can be completely effective against all potential actions. In actually designing the system, the designer and analyst must select those actions considered to be the most important and credible and design the system to be most effective against these actions.

Interruption of operations

A goal of some adversaries may be to interrupt operations. Individual or group motivations could range from objections to the destruction of animals to environmental concerns about the disposal process to opposition to the proximity of the operations to individual's properties. Some examples of how the operations could be interrupted are described in the following paragraphs.

Site blockade

Adversaries could attempt to block access to the sites where disposal operations are occurring. This could take the form of individuals blocking roadways, vehicles and equipment blocking site entrances, or even picket lines. In these situations, trucks carrying animals, operational personnel, or support equipment could be prevented from entering the site.

Prevention of access to animals

Adversaries may inhibit access to their farms, facilities, and operations to prevent the removal of animals or prohibit their destruction on site. These actions could delay or prevent the destruction of animals.

Disruption of support utilities

Adversaries cutting the power lines could interrupt disposal operations reliant on off-site power. Similarly, gas and water services supplied through off-site pipelines could be interrupted.

Intimidation of workers

Workers could fail to report to work if they feel threatened in the local community.

Destruction or sabotage of equipment

Most disposal options require the use of heavy equipment. Much of this heavy equipment could be easily sabotaged. Animal-handling equipment could include loaders, backhoes, tractors, and trucks. Disposal equipment may include incinerators, grinders, and composting materials. There are three obvious ways such equipment could be sabotaged:

- Mechanical sabotage.

  Sabotage can include actions typically thought of as vandalism, such as breaking critical mechanical components with crowbars or baseball bats.

- Fire.

  Arson could be used to destroy individual pieces of equipment or entire carcass disposal facilities, such as rendering plants.

- Fuel contamination.

  Equipment fuel tanks, on-site storage tanks, or even fuel supply trucks could all be contaminated to prevent operation of the equipment.

Equipment theft

This is one of the most likely security concerns at a carcass disposal operation due to the relatively high-value heavy equipment used at the site. These pieces of equipment are attractive because of their value and versatility of use. Equipment theft is the most common industrial concern.

Intimidation of operating personnel

Because of anger about the destruction of apparently healthy animals, there could be threats of violence or actual assaults against operating personnel.

Contamination spread

Strictly speaking, industrial hygiene or biosecurity, defined as the precautions taken to contain pathogens, may not be considered a security issue. However, the goals of biosecurity and physical security are so closely aligned that the distinction seems artificial (although some protection measures are implemented solely for biosecurity or physical security). Any designed security system must be required to prevent the spread of pathogens from the site. This goal is relevant whether animals are being destroyed because of a disease outbreak or because of a natural disaster. In the case of a natural disaster, rotting carcasses will harbor diseases that require containment. An unusual aspect of preventing the removal of pathogens from the site to be considered is that the threat is not just realized through human adversaries. Pathogens could be removed from the site via a number of different pathways: air/wind, animals (birds, mammals, insects), groundwater, equipment movement, or human activity (workers, visitors, intruders).

Unauthorized access

Individuals may try to enter the site because of malicious intent, curiosity, or even by accident. Because the site will contain heavy equipment and perhaps other dangerous processing machinery, the site is hazardous for visitors. Thus the ideal security system will prevent unauthorized access to the site for innocent visitors as well as malevolent adversaries.

The performance goals for the ideal fixed-site security system would be to prevent the following events:

- Interruption of operations.
- Destruction/sabotage of equipment.
- Equipment theft.
- Intimidation of operating personnel.
- Spread of contamination.
- Unauthorized access.

Additional performance goals may be determined in collaboration with carcass disposal operations stakeholders.

4.2 – Transportation Links

In any sizeable carcass disposal operation, transportation links will be a part of the process. At a minimum, there will be delivery of equipment and consumables to the site. It is possible that live or dead animals will be collected throughout an area and then transported to the disposal site. At any given fixed disposal site, a range of actions encountered by the transportation link could disrupt controlled carcass disposal operations.

Interrupted transfer of people, equipment, or material

Adversaries could block transportation routes to prevent delivery of disposal operations supplies, such as fuel or equipment, or drivers could be prevented access to animals to be removed.

Spread of contamination

Vehicles may be moving in and out of contaminated areas. Because of this there may be an unintentional spread of contamination from the disposal site or the vehicles. In addition, live or dead animals may be transported which could also cause the spread of contamination.

Equipment theft or sabotage

As with fixed-site operations, equipment could be stolen or sabotaged at the transportation links.

The performance goals for the ideal transportation-link security system would be to prevent the following events:

- Interrupted transfer of people, equipment, and materials (including carcasses).
- Spread of contamination.
- Equipment theft or sabotage.

Additional performance goals may be determined in collaboration with carcass disposal operations stakeholders.

4.3 – Regional Boundary Security

In the case of the outbreak of a disease, officials may make the decision to quarantine an entire area or region. This quarantine could require the cessation of movement of certain types of animals. It could also restrict the shipment of certain products or, in some cases, even individuals, such as agricultural workers. Although issues associated with regional security are beyond the scope of this study, the main issues should be considered, as there may be an impact on the design of the physical protection system for carcass disposal. It is imperative that plans are in place and agencies have coordinated plans prior to an outbreak.

Large resources are required for regional boundary security systems, which will undoubtedly be beyond the capabilities of local jurisdictions. State or even federal support, such as the National Guard, will be required to support the manpower requirements of these operations. These operations could require stopping and searching large numbers of vehicles. The transport of animals, individuals, equipment, and products would all be affected. All modes of travel (roads, rail, river or coast, air) into and out of the area would be monitored.

As the number of checkpoints increases, personnel requirements rapidly become unmanageable. To help minimize the resource requirements, natural choke points should be identified for the region. For example, inspections could be set up at a few river bridges rather than along all roads. In addition, there may be the need to perform some type of patrols or spot-checking along the quarantine boundary.

Training will be required for the individuals involved in these operations. Legal issues associated with searches must be carefully addressed.

The performance goal for a regional security system would be to prevent the unauthorized movement of animals, materials, products, and people across the defined boundary of the region.

Additional performance goals may be determined in collaboration with carcass disposal operations stakeholders.

Section 5 – Design Considerations

This section briefly describes some elements that affect the design and operation of the security system.

5.1 – Disposal Technology

The type of technology chosen for the carcass disposal will have tremendous implications for the design of the security system. For example, if the entire operation is contained in enclosed buildings the security system can focus on the doors and other penetrations of the building. However, if equipment and operations are mobile and moved from farm to farm, then portable, rapidly deployable equipment will be required.

5.2 – Disposal Rationale

If disposal operations are occurring because of an outbreak of a contagious pathogen such as foot-and-mouth disease, the security system will need to consider biosecurity practices and assure the security system is complementary. If, however, disposal is occurring because of a noninfectious agent such as bovine spongiform encephalitis (BSE), security may focus more on the protection of the assets used in the disposal operation. In the BSE case, strict security and biosecurity measures would not be required for the transport of live animals or carcasses.

5.3 – Prescribed Haul Routes

There may be reluctance in a community to have trucks carrying dead animals or potentially infected animals through certain areas or on certain roads. The local population may have health concerns or there may be concern about transportation adjacent to areas where animals have not been affected by a disease outbreak. There may even be concerns about tourism, so that transportation is prohibited through tourist areas. Prescribed haul routes have been required in previous carcass disposal situations. Because of concerns about deviations, the local population may request some type of monitoring and enforcement of the agreed-upon haul routes.

5.4 – Disposal System Administration

Depending upon the reason for the disposal operation and its size, the entire operation could be administered by local, state, or even federal entities. These different levels of administration will have direct implications for how a security system can be designed and implemented. If the disposal operation is managed at the local level using local resources, funding and flexibility in system design may be very limited. In this case, existing law enforcement resources may provide security for the site. As administration goes to higher levels, more resources and funding may be brought to bear on the problem, thus allowing higher utilization of technologies.

5.5 – Staffing

Local law enforcement professionals, contracted security professionals, or the National Guard could operate the security system. Each of these operators will offer different design implications. Decisions about staffing will affect how the security system is designed. If the National Guard provides continuous patrols of a perimeter, the need for technological solutions will likely be reduced.

5.6 – Funding

System design and operation will always be limited by funding. In considering the design of the system, however, economic trade-offs will need to be made. For example, utilizing technology can sometimes offset manpower costs.

5.7 – Training

The possibility of training individuals in the use of the security system before an incident occurs versus training only after the disposal operations have begun should be considered. If training can only occur after the onset of an incident, a technically and procedurally simple security system is required.

5.8 – Advanced Planning and Preparation

If relevant agencies are able to plan for potential carcass disposal events, there will be more opportunities to control the costs associated with security. If, however, design only occurs at the inception of an event, high-cost, manpower-intensive solutions will probably be implemented. Advanced planning can lead to agreements on who will be providing security and how it will be implemented. There may even be opportunities to purchase needed technologies prior to an event or to identify resources already available in the area that could be applied. If planning occurs before an event, agreements can be developed between jurisdictions for sharing or loaning equipment.

5.9 – Operational Period

This analysis assumes that the carcass disposal operations will be occurring for at least a few weeks. If the disposal operation is very short-term, there will be little motivation to invest in security technologies. However, as the length of time increases for the disposal operation, there is increasing motivation to decrease labor costs through the application of technology. It should also be noted that the nature of the threat might change over time.

5.10 – Geography

Natural barriers can play a role in the security system. As an example, an open-pit mine was used as the base of carcass disposal operations in North Carolina. The vertical sides of the mine provided a natural deterrent for human intrusion into the site. Other geographic features can either assist or impede the security system. Flat treeless areas provide a good location for ease of assessment. Heavily forested areas make patrol and monitoring of a perimeter difficult.

To identify the design considerations applicable to a specific carcass disposal operation, the characteristics of the operation must be determined. The design considerations for the ideal security system include (but are not limited to):

- Disposal technology.
- Disposal rationale.
- Prescribed haul routes.
- Disposal system administration.
- Staffing.
- Funding.
- Training.
- Advanced planning and preparation.
- Operational period.
- Geography.

Additional design considerations may be determined in collaboration with carcass disposal operations stakeholders.

Section 6 – Threat Analysis

Carcass disposal security systems will probably not be facing a large paramilitary force armed with automatic weapons and explosives. The threat will be very different in cases where there is a natural disaster as opposed to a disease outbreak. In the natural disaster situation, the animals will already be dead and there is no question about the need for disposal. In the disease outbreak situation, however, the slaughter of diseased and healthy or apparently healthy animals may be required. Decisions about the number of animals to be destroyed and the geographic limits of the area in which animals will be destroyed could become quite controversial. There are several categories of people who may be impacted by the carcass disposal operation. The following discussion illustrates the spectrum of threats that the security system could be expected to address.

6.1 – Intentional Malevolent Threats

Animal owners

Individuals could be severely impacted economically if their animals are destroyed. Some breeding animals could be quite valuable. These individuals could potentially be armed and may not appear rational.

It should be noted that in previous animal destruction situations there have been concerns regarding farmers "cheating" the system. Farmers will bring in animals for destruction and receive compensation for their destruction. The farmers then instead of taking the animals to be destroyed will surreptitiously remove the animals and then bring them back again and receive compensation a second time.

Animal rights activists

Because thousands or even millions of animals may be destroyed, there may be some form of protest from animal rights activists.

Local stakeholders

People may not want thousands of dead animals disposed of in their local landfills or processed in their backyards.

Unauthorized media

Journalists trying to obtain information or photographs of the operation without proper approval to be on the site create a nuisance problem, at the least.

Disgruntled employees

As with any work environment, there is a possibility for individual workers to be a threat. Adversaries who represent malevolent threats may engage in such activities as:

- Civil disobedience, such as protests or blockade.
- Vandalism.
- Verbal or physical intimidation of workers.
- Armed or unarmed assault against workers.
- Theft.

Such activities can result in the spread of contamination or the disruption of operations.

6.2 – Unintentional Nonmalevolent Threats

Human and animal movements can result in the inadvertent transfer of pathogens. The activities of these unwitting adversaries can result in the spread of contamination or the disruption of operations similar to the impact of the intentional activities of the malevolent adversary.

Inadvertent intruders

Disposal sites could be quite large. It is possible that individuals could unknowingly enter the site while hiking or hunting, for example.

Curious individuals

In previous carcass disposal operations, curious onlookers have been a significant issue. These onlookers have lined the road to the disposal site. This can potentially impede access and create a dangerous situation.

Unintentional insider (site workers/visitors)

Site workers or approved visitors may accidentally remove contamination from the site by not following decontamination protocols.

Animals

It may be considered the role of the security system to help prevent animals from entering and exiting the site and transporting pathogens off site (Figure 5).

FIGURE 5. Prairie dogs are a threat to spread contamination.

Section 7 – Security Technology

There are many security technologies available to support the success of designed physical protection systems. Before security technologies can be applied to a carcass disposal operation, the performance goals of the system must be defined, the design considerations must be characterized, and the threat must be analyzed. Only then can a security system be designed to address the needs of the particular problem.

It is possible to expect that sensors, specifically exterior intrusion detection sensors, are likely to be a part of a physical protections system designed to provide security for a carcass disposal operation. For this reason, a technical description of the capabilities of these sensors is provided below.

7.1 – Exterior Intrusion Detection Sensors

The integration of individual sensors into a perimeter sensor system must consider specific design goals, the effects of physical and environmental conditions, and the interaction of the perimeter system with a balanced and integrated physical protection system. Sensor performance is described by the following characteristics: probability of detection (P_D), nuisance alarm rate (NAR), and vulnerability to defeat.

The methods of classification of exterior sensors include passive or active, covert or visible, line of sight or terrain-following, volumetric or line detection, and application (buried-line, fence-associated, or freestanding). This section presents several examples of sensors in each application category. An effective perimeter sensor system provides a continuous line of detection using multiple lines of complementary sensors located in an isolated clear zone. Topography, vegetation, wildlife, background noise, climate, weather, soil conditions, and pavement all affect the performance of exterior sensors. The designer of the perimeter sensor system must also consider its interaction with the video assessment system and the access delay system.

Introduction

Overview

Intrusion detection systems consist of exterior and interior intrusion sensors, video alarm assessment, entry control, and alarm communication systems all working together. Exterior sensors are those used in an outdoor environment, and interior sensors are those used inside buildings.

Intrusion detection definition

Intrusion detection is defined as the detection of a person or vehicle attempting to gain unauthorized entry into an area that is being protected. The intrusion detection boundary is ideally a sphere enclosing the item being protected so that all intrusions, whether by surface, air, underwater, or underground, are detected. The development of intrusion detection technology has emphasized detection on or slightly above the ground surface with increasing emphasis being placed on airborne intrusion. Ground-level perimeter intrusion detection systems are relevant to detection systems for carcass disposal.

Performance characteristics

Fundamentals of intrusion sensor performance

Intrusion sensor performance is described by three fundamental characteristics:

- Probability of detection (P_D).
- Nuisance alarm rate (NAR).
- Vulnerability to defeat.

An understanding of these characteristics is essential for designing and operating an effective intrusion sensor system.

Probability of detection (P_D)

Ideal sensors have 100% success. For the ideal sensor, the probability of detection (P_D) of an intrusion is one (1.0). That is, it has a 100% P_D. However, no sensor is ideal, and the P_D is, therefore, always less than 1.0. The way that P_D is calculated does not allow a P_D of 1. Even with thousands of tests, the P_D only approaches 1. The P_D depends primarily upon:

- Target to be detected.
- Sensor hardware design.
- Installation conditions.
- Sensitivity adjustment.
- Weather conditions.
- Condition of the equipment.

All of the above conditions can vary; thus despite the claims of some sensor manufacturers, a specific P_D cannot be assigned to one component or set of sensor hardware. For a P_D value to be meaningful, the conditions of the test must be carefully explained.

Nuisance alarm rate (NAR)

Description. A nuisance alarm is any alarm that is not caused by an intrusion. In an ideal sensor system, the NAR would be zero (0.0). However, in the real world, all sensors interact with their environment and they cannot discriminate between intrusions and other events in their detection zone. Alarm assessment systems are needed because not all sensor alarms are caused by intrusions.

Sources of nuisance alarms. Usually nuisance alarms are further classified by source. Both natural and industrial environments can cause nuisance alarms. Common sources of natural nuisance alarms are vegetation (trees and weeds), wildlife (animals and birds), and weather conditions (wind, rain, snow, fog, lightning). Industrial sources of noise include ground vibration, debris moved by wind, and electromagnetic interference.

False alarms. False alarms are those nuisance alarms generated by the equipment itself, whether by poor design, inadequate maintenance, or component failure. Different types of intrusion sensors have different sensitivities to these nuisance or false alarm sources, as is discussed in detail later.

Vulnerability to defeat

Sensor defeat methods. An ideal sensor could not be defeated; however, all existing sensors can be defeated by a knowledgeable adversary with the proper tools and enough time. The objective of the physical protection system designer is to make the system very difficult to defeat. The two general ways to defeat the system are:

- Bypass. Because all intrusion sensors have a finite detection zone, any sensor can be defeated by going around its detection volume.
- Spoof. Spoofing is any technique that allows the target to pass through the sensor's normal detection zone without generating an alarm. Different types of sensors and sensor models have different vulnerabilities to defeat.

Sensor classification

In this discussion, five methods of classification are used:

- Passive or active.
- Covert or visible.
- Line of sight or terrain-following.
- Volumetric or line detection.
- Application.

Passive or active

Passive sensors detect energy. Passive sensors detect some type of energy that is emitted by the target of interest or detect the change of some natural field of energy caused by the target. Examples of the former are mechanical energy from a human walking on the soil or climbing on a fence. An example of the latter is a change in the local magnetic field caused by the presence of a metal.

Active sensors transmit energy. Active sensors transmit some type of energy and detect a change in the received energy created by the presence or motion of the target.

Advantages and disadvantages. The distinction of passive or active has a practical importance. The presence or location of a passive sensor is more difficult to determine than that of an active sensor, which puts the intruder at a disadvantage. Active sensors may be less affected by environmental conditions than passive sensors, because they are transmitting signals selected to be compatible with those conditions. Because of this, an active sensor typically may have fewer nuisance alarms than a passive sensor in the same environment.

Covert or visible

Comparison of sensor types. *Covert sensors* are hidden from view, such as buried in the ground. Covert sensors may have signal emanations that can be detected using electronic equipment. Covert sensors are more difficult for an intruder to detect and locate (than visible sensors), and thus they can be more effective. Also, they do not disturb the appearance of the environment.

Visible sensors are in plain view of an intruder, such as attached to a fence or mounted on another support structure. Visible sensors may deter the intruder from acting. They are typically simpler to install and easier to repair than covert ones.

Line of sight or terrain-following

Line of sight sensors require specific site preparation. Line of sight sensors perform acceptably only when installed with a clear line of sight in the detection space. This usually means a clear line of sight between the transmitter and receiver for active sensors. These sensors normally require a flat ground surface, or at least a clear line of sight from each point on the ground surface to both the transmitter and receiver. The use of line of sight sensors on sites without a flat terrain requires expensive site preparation to achieve acceptable performance.

Terrain-following sensors. Terrain-following sensors detect equally well on flat and irregular terrain. The transducer elements and the radiated field follow the terrain and result in uniform detection throughout the detection zone. Some terrain-following sensors may require some leveling between fence posts to maintain a high P_D.

Volumetric or line detection

Factors that affect volumetric detection. Volumetric sensors detect intrusion in a volume of space. An alarm is generated when an intruder enters the detection volume. The detection volume is generally not visible and is difficult for the intruder to precisely identify. The detection volume characteristics are based upon frequency, antenna properties, and other factors. Other factors, such as cable spacing, mounting height, sensitivity, and alignment, can make the exact detection volume difficult for an intruder to determine.

Line detection detects at a specific point. Line detection sensors detect along a line. For example, sensors that detect fence motion are mounted directly on the fence. The fence becomes a line of detection, since an intruder will not be detected while approaching the fence; detection occurs only if the intruder moves the fence fabric where the sensor is attached. The detection zone of a line detection sensor is usually easy to identify.

Application

Modes of sensors: buried line, fence, and freestanding. In this classification method, the sensors are grouped by mode of application in the physical detection space. These modes are:

- Buried line. The sensor is in the form of a line buried in the ground.
- Fence-associated. The sensor either is mounted on a fence or forms a sensor fence.
- Freestanding. The sensor is being neither buried nor associated with a fence, but mounted on a support in free space.

Sensor technology

In this discussion, sensors are grouped by their modes of application. Table 2 summarizes exterior intrusion sensor technologies according to the different sensor classification schemes.

TABLE 2. Types of perimeter sensors.

	Passive (P) or Active (A) Detection	Covert (C) or Visible (V)	Line of Sight (LOS) or Terrain-Following (TF)	Volumetric (VOL) or Line (L)
Buried Line				
Seismic Pressure	P	C	TF	L
Magnetic Field	P	C	TF	VOL
Ported Coax	A	C	TF	VOL
Fiber-Optic Cables	P	C	TF	L
Fence-Associated				
Fence Disturbance	P	V	TF	L
Sensor Fence	P	V	TF	L
Electric Field	A	V	TF	VOL
Freestanding				
Active Infrared	A	V	LOS	VOL
Passive Infrared	P	V	LOS	VOL
Bistatic Microwave	A	V	LOS	VOL
Dual Technology	A	V	LOS	VOL
Video Motion	P	C	LOS	VOL

Buried-line sensors

Types of buried line sensors

Types of buried-line sensors that depend on different sensing phenomena include:

- Pressure or seismic sensors.
- Magnetic field sensors.
- Ported coaxial cable sensor.
- Fiber-optic sensors.

Pressure or seismic

Description and applications. Pressure or seismic sensors are passive, covert, terrain-following sensors that are buried in the ground. They respond to disturbances of the soil caused by an intruder walking, running, jumping, or crawling on the ground. Pressure sensors are generally sensitive to lower frequency pressure waves in the soil, and seismic sensors are sensitive to higher frequency vibration of the soil.

Pressure sensor technology. A typical pressure sensor consists of a reinforced hose filled with a pressurized liquid and connected to a pressure transducer. A balanced pressure system consists of two such hoses connected to a transducer to permit differential sensing and to reduce nuisance alarms from seismic sources located far away.

Seismic sensor technology. A typical seismic sensor consists of a string of geophones. A geophone consists of a conducting coil and a permanent magnet. Either the coil or the magnet is fixed in position, and the other is free to vibrate during a seismic disturbance; in both cases an electrical current is generated in the coil. Alternating the polarity of the coils in the geophone string can reduce far-field effects in seismic sensors.

Sensitivity and burial depth. The sensitivity of this type of sensor is very dependent on the type of soil in which it is buried. The best burial depth is also dependent on the soil. The trade-off is high P_D with narrow detection width at a shallow depth versus lower P_D with wider detection width at a greater depth. A test conducted on site with short test sections of the sensor buried at different depths is recommended to determine the optimum depth. A typical detection width for walking intruders is in the range of 1– 2 m.

Effects of winter weather. Pressure and seismic sensors tend to lose sensitivity in frozen soil. Thus, at sites where the soil freezes in winter, either reduced winter sensitivity must be accepted, or a semiannual adjustment to pressure and seismic sensors must be made to obtain equivalent sensitivity throughout the year.

Nuisance alarms for seismic sensors. Many sources of seismic noise may affect these sensors and cause nuisance alarms. The primary natural source of nuisance alarms is wind energy that is transmitted into the ground by fences, poles, and trees. Seismic sources made by man include vehicular traffic (cars, trucks, trains) and heavy industrial machinery.

Defeat methods. Because these sensors are passive and buried, movement above the ground is not detected. If the location of the buried-line sensor is known, an adversary may defeat this sensor by forming a low bridge over the transducer line.

Magnetic field

Detect vehicles and intruders with metal weapons. Magnetic field sensors are passive, covert, terrain-following sensors that are buried in the ground. They respond to a change in the local magnetic field caused by the movement of nearby metallic material. Thus magnetic field sensors are effective for detecting vehicles or intruders with weapons.

Technology description, nuisance alarms, defeat method. This type of sensor consists of a series of wire loops or coils buried in the ground. Movement of metallic material near the loop or coil changes the local magnetic field and induces a current. Magnetic field sensors can be susceptible to local electromagnetic disturbances such as lightning. Intruders who are not wearing or carrying any metal may be able to defeat this type of sensor.

Ported coaxial cables

Description. Ported coaxial cable sensors are active, covert, terrain-following sensors that are buried in the ground. They are also known as leaky coax or radiating cable sensors. This type of sensor responds to motion of a material with a high dielectric constant or high conductivity near the cables. These materials include both the human body and metal vehicles.

__Technology.__ The name of this sensor is derived from the construction of the transducer cable. The outer conductor of this coaxial cable does not provide complete shielding for the center conductor; thus some of the radiated signal leaks through the ports of the outer conductor. The detection volume of ported coax sensors extends significantly above the ground: about 0.5 to 1.0 m above the surface and about 1 to 2 m wider than the cable separation. The sensitivity of this type of sensor in frozen soil actually increases slightly relative to thawed conditions. This is because some of the field energy is absorbed by conductive soil, and the conductivity of frozen ground is less than that of thawed ground.

__Installation.__ Some ported coaxial cables use a foil shield with a slot instead of actual ports. A semiconductive inner jacket allows the combination of the two cables into a single outer jacket. This allows the sensor to be installed more easily because only a single trench is required and cable spacing is no longer an issue. The disadvantage is that the detection volume is slightly smaller than for a dual cable system with wider cable spacing.

__Nuisance alarms.__ Metal or water in the ported coax detection zone can cause two types of sensor problems. Moving metal objects and moving water are large targets for ported coax sensors and, thus, are a major potential source of nuisance alarms. Both flowing water and standing water contribute to this problem. The second problem is that fixed metal objects and standing water distort the radiated field, possibly to the extent of creating insensitive areas with no detection. Nearby metal objects or utility lines should be excluded from the detection volume. This includes above ground fences and poles and underground water lines and electrical cables.

Fiber-optic cables

__Description.__ Optical fibers are long, hair-like strands of transparent glass or plastic. Fiber optics is the class of optical technology that uses these transparent fibers to guide light from one end to the other. A fiber-optic cable consists of an inner core of pure material and a cladding material that is usually the same material as the core with additional "doping" material added. Because the cladding is designed to have a different refraction of light, the light ray is bent back towards the center of the core. Thus the fiber becomes a "light pipe" (Figure 6). A fiber can either be multi-mode or single-mode depending upon the thickness of the core of the fiber. Single-mode fibers are so thin that only a single light path is possible through the core.

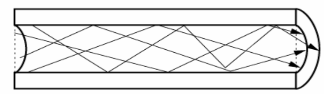


FIGURE 6. Optical fiber guides light.

__Fiber-optic cable technology.__ A fiber optic cable does not have to be straight because the characteristics of the fiber allow light to remain in the core. The light diffraction (speckle) pattern and the light intensity at the end of the multi-mode fiber is a function of the shape of the fiber over its entire length. Even the slightest change in the shape of the fiber can be sensed using sophisticated sensors and computer signal processing at the far end (100 meters or more). A single mode fiber can also be used as a sensor by splitting the light source and sending it both directions around a loop. If the fiber is disturbed, the two light sources come back in a different phase. The change in phasing relates to the amount of disturbance. Thus a single strand of fiber optic cable, buried in the ground at the depth of a few centimeters, can very effectively give an alarm when an intruder steps on the ground above the fiber. To ensure that an intruder steps above the fiber, it is usually woven into a grid and buried just beneath the surface. Fiber-optic cables are also commonly used as fence disturbance sensors.

Fence-associated sensors

General types

Three types of intrusion sensors either mount on or attach to a fence or form a fence using the transducer material:

- Fence disturbance sensors.
- Sensor fences.
- Electric field or capacitance sensors.

Fence disturbance sensors

Description. Fence disturbance sensors are passive, visible, terrain-following sensors designed for installation on a security fence, typically constructed with chain-link mesh. These sensors are considered terrain-following because the chain-link mesh is supported every 3 m with a galvanized steel post, thus the fence itself is terrain-following.

Mechanical disturbances. Fence disturbance sensors respond to mechanical disturbances of the fence. They are intended to detect primarily an intruder who climbs on or cuts through the fence fabric. Several kinds of transducers are used to detect the movement or vibration of the fence. These include switches, electromechanical transducers, fiber-optic cables, and strain-sensitive cables.

Nuisance alarms. Fence disturbance sensors respond to all mechanical disturbances of the fence, not just intruders. Common disturbances include strong winds, debris blown by wind, rain driven by wind, hail, and seismic activity from nearby traffic and machinery. Good fence construction, specifically rigid fence posts and tight fence fabric, is important to minimize nuisance alarms.

Defeat methods. Digging under the fence or bridging over the fence without touching the fence can defeat fence disturbance sensors. Digging can be deterred by putting concrete under the fence. The bottom edge of the fabric can also be placed in the concrete, although this may be undesirable for corrosive environments where the fabric must be replaced frequently.

Sensor fences

Description. Sensor fences are passive, visible, terrain-following sensors that make use of the transducer elements to form a fence itself. These sensor fences are designed primarily to detect climbing or cutting on the fence. Sensor fences tend to be much less susceptible to nuisance alarms than fence disturbance sensors. However, because sensor fences also have a plane of detection that is well defined, they are vulnerable to the same defeat methods as fence disturbance sensors.

Taut wire sensor fences. Taut wire sensor fences consist of many parallel, horizontal wires with high tensile strength that are connected under tension to transducers near the midpoint of the wire span. These transducers detect deflection of the wires caused by an intruder cutting the wires, climbing on the wires to get over the fence, or separating the wires to climb through the fence. The wire is typically barbed wire, and the transducers are mechanical switches, strain gages, or piezoelectric elements. Taut wire sensor fences can either be mounted on an existing set of fence posts or installed on an independent row of posts.

Fiber-optic, mesh fences. Fiber optics can be woven into a mesh that can be installed on a fence to create a sensor fence. These mesh fences usually use some type of continuity detection to determine when an intruder has cut through the fence. The upper portion of the fence is usually configured mechanically in such a manner that the fiber is crimped when an intruder attempts to climb over the fence. The crimp of the fiber reduces the amount of light passed through the fiber causing an alarm.

Electric field or capacitance

Description. Electric field or capacitance sensors are active, visible, terrain-following sensors that are designed to detect a change in capacitive coupling among a set of wires attached to, but electrically isolated from, a fence.

Sensitivity and nuisance alarms. The sensitivity of some electric field sensors can be adjusted to extend up to 1 m beyond the wire or plane of wires. A high sensitivity typically has a trade-off of more nuisance alarms. Electric field and capacitance sensors may be susceptible to lightning, rain, fence motion, and small animals. Ice storms may cause substantial breakage and damage to the wires and the standoff insulators. Good electrical grounding of electric field sensors is important to reduce nuisance alarms. Other metal objects (such as the chain-link fence) in the sensor field must also be well grounded; poor or intermittent grounds will cause nuisance alarms.

Defeat methods. Because the detection volume extends beyond the fence plane, electric field sensors are more difficult than other fence-associated sensors to defeat by digging under or bridging over the fence.

Performance. Electric field or capacitance sensors can be mounted on their own set of posts. This results in two areas of improved performance: a wider detection volume for the sensitive electric field sensor, and a lower NAR by eliminating extraneous motion from the chain-link fence. For the freestanding version of electric field sensors, some electronic signal processing techniques employ additional wires in the horizontal plane to reduce the effects of distant lightning and alarms due to small animals.

Freestanding sensors

General types

The types of freestanding sensors currently used for exterior intrusion detection are:

- Active infrared (IR).
- Passive infrared (PIR).
- Bistatic microwave.
- Video motion detection sensors.

Active infrared (IR)

Characteristics of exterior IR sensors. The IR sensors used for exterior intrusion detection are active, visible, line of sight, and freestanding sensors.

How IR sensors work. An IR beam is transmitted from an IR light-emitting diode through a collimating lens. This beam is received at the other end of the detection zone by a collecting lens that focuses the energy onto a photodiode. The IR sensor detects the loss of the received IR energy when an opaque object blocks the beam. These sensors operate at a wavelength of about 0.9 microns, which is not visible to the human eye.

Although single-beam IR sensors are available, multiple-beam sensors are normally used for high-level security applications because a single IR beam is too easy to defeat or bypass. A multiple-beam IR sensor system typically consists of two vertical arrays of IR transmitter and receiver modules. The specific number and configuration of modules depends on the manufacturer. Thus the IR sensor creates an IR fence of multiple beams but detects a single beam break. Multiple beam sensors usually incorporate some type of logic that will detect if an intruder attempts to capture a receiver with an IR source.

Nuisance alarms. Conditions that reduce atmospheric visibility have the potential to block the IR beams and cause nuisance alarms. If the visibility between the two arrays is less than the distance between the two arrays, the system will probably produce a nuisance alarm. These conditions sometimes exist in fog, snow, and dust storms.

Defeat methods. The detection volume cross section of a multiple-beam IR sensor is typically 5 cm wide and 2 m high; thus IR sensors have a narrow plane of detection similar in dimensions to fence sensors. IR sensors are considered line of sight sensors and require a flat ground surface, because the IR beam travels in a straight line. A convex ground surface will block the beam, and a concave surface will permit passing under the beam without detection. Digging under the bottom beam is possible unless a concrete sill or paved surface has been installed.

Passive infrared (PIR)

How PIR sensors work. Humans emit energy because of the warmth of their body. On the average, each active human emits the equivalent energy of a 50-watt lightbulb, and PIR detectors sense the presence of this energy and cause an alarm to be generated. For years, this technology was only usable in an interior application because the changes in heat emitted by the ground as clouds passed overhead caused too many false alarms. Current models, however, as shown in Figure 7, compare the received thermal energy from two curtain-shaped sensing patterns. A human moving into one area and then the other would cause an imbalance. Weather changes should affect both areas equally and would not cause an alarm.

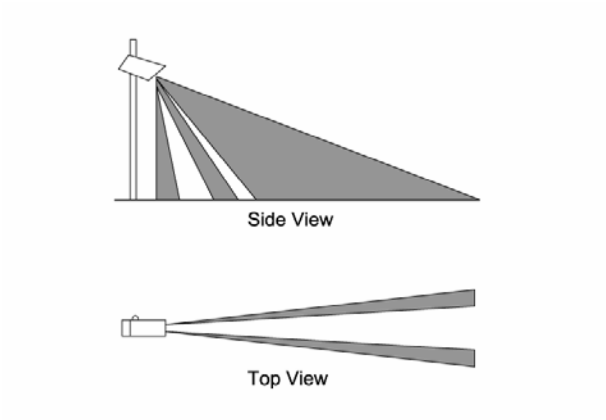


FIGURE 7. PIR sensor.

__Nuisance alarms and detection ranges.__ The PIR sensors should be mounted such that the motion of the intruder will most likely be across the line of sight, because that is the most sensitive direction. Blowing debris, animals, and birds could cause nuisance alarms. The PIR detector is most sensitive when the background is at a much different temperature than an intruder. Detection ranges can exceed 100 m. Because these are optical devices, the only way to limit the maximum range is to aim the detector at a solid object, such as the ground, at the end of the desired detection zone.

Bistatic microwave

__Description.__ Bistatic microwave sensors are active, visible, line of sight, freestanding sensors. Typically, two identical microwave antennas are installed at opposite ends of the detection zone. One is connected to a microwave transmitter that operates near 10 GHz or 24 GHz. The other is connected to a microwave receiver that detects the received microwave energy. This energy is the vector sum of the direct beam between the antennas and the microwave signals reflected from the ground surface and other objects in the transmitted beam.

Microwave sensors respond to changes in the vector sum caused by objects moving in that portion of the transmitted beam that is within the viewing field of the receiver. This vector sum may actually increase or decrease, as the reflected signal may add in phase or out of phase.

__How microwave sensors work.__ Bistatic microwave sensors are often installed to detect a human crawling or rolling on the ground across the microwave beam, keeping the body parallel to the beam. From this aspect the human body presents the smallest effective object to the bistatic microwave sensor. This has the following important consequences for the installation of microwave sensors:

- *The ground surface must be flat* so that the object is not shadowed from the microwave beam, precluding detection. The surface flatness specification for this case is +0, –15 cm. Even with this flatness, crawlers may not be detected if the distance between antennas is much greater than 120 m.
- *A zone of no detection exists* in the first few meters in front of the antennas. This distance from the antennae to the point of first crawler detection is called the "offset distance." Because of this offset distance, long perimeters where microwave sensors are configured to achieve a continuous line of detection require that the antennas overlap one another, rather than being adjacent to each other. An offset of 10 m is typically assumed for design purposes, thus adjacent sectors must overlap twice the offset distance of 20 m.

__Detection volume.__ The detection volume for bistatic microwave sensors varies with the manufacturer's antenna design but is large compared to most other intrusion sensors. The largest detection cross section is at midrange between the two antennas and is approximately 4 m wide and 3 m high.

__Nuisance alarms.__ Microwave sensors tolerate a wide range of environmental conditions without producing nuisance alarms. However, nuisance alarms can be produced by the following conditions:

- A nearby parallel *chain-link fence with loose mesh that flexes in the wind* will appear to the sensor as a large moving target.
- *Surface water from rain or melting snow* appears to the microwave sensor as a moving reflector; therefore, the flat plane required for crawler detection should have a cross slope for water drainage.

- *Heavy blowing snow* may produce nuisance alarms. Snow accumulation will reduce the P_D, especially for the crawler, and complete burial of the antenna in snow will produce a constant alarm. The water content of the snow increases. Snow effects: dry light snow has less effect than heavy wet snow.

Defeat methods. Defeats by bridging or digging under are not simple due to the extent of the detection volume. More sophisticated defeat methods involve the use of secondary transmitters.

Monostatic microwave detectors. Monostatic microwave detectors are also available. In this configuration, the transmitter and receiver are in the same unit. Radio frequency energy is pulsed from the transmitter and the receiver looks for a change in the reflected energy. Motion by an intruder causes the reflected energy to change, causing an alarm. These sensors are "range-gated" meaning that the site can set the range beyond which motion can occur without an alarm. Monostatic microwave sensors have similar characteristics to bistatic sensors, although they are more affected by cross fences than parallel fences, and they are susceptible to re-aiming.

Dual technology sensors

Combine sensors to reduce nuisance alarms. In an effort to reduce nuisance alarms, dual technology sensors are becoming more popular for security use. An example of dual technology would be to place both a PIR and a monostatic microwave in the same housing. The device would not give an alarm until both sensors alarmed, thus avoiding common nuisance alarms from each of the technologies and only alarming on an actual intruder. In this mode, the sensitivity of each sensor could be set very high without the associated nuisance alarms.

The P_D of these dual-technology sensors is lower than some of the other sensors since an intruder must only defeat one of the two sensors to bypass the detector.

Video motion detection

Description. Video motion detectors (VMDs) are passive, covert, line of sight sensors that process the video signal from closed-circuit television (CCTV) cameras. These cameras are generally installed on towers to view the scene of interest and may be jointly used for detection, surveillance, and alarm assessment. Lighting is required for continuous 24-hour operation.

How VMDs work. VMDs sense a change in the video signal level for some defined portion of the viewed scene. Depending on the application, this portion may be a large rectangle, a set of discrete points, or a rectangular grid. Detection of human body movement is reliable except during conditions of reduced visibility, such as fog, snow, and heavy rain.

Nuisance alarms. Potential sources of nuisance alarms for VMDs used outdoors include:

- Apparent scene motion due to unstable camera mounts.
- Changes in scene illumination caused by such things as cloud shadows, shiny reflectors, and vehicle headlights.
- Moving objects in the scene such as birds, animals, blowing debris, and precipitation on or near the camera.

Defeat tactics. Defeat tactics include taking advantage of poor visibility conditions and camouflaging the target into the background.

Perimeter sensor systems

Integrating sensors into a system

This section discusses the integration of individual sensors into a perimeter sensor system and considers the interaction of the perimeter system or subsystem with a balanced integrated physical protection system. Before the detailed design and implementation of a perimeter sensor system are considered, some basic design philosophy and concepts for perimeter sensor systems should be understood.

Design concepts and goals

Continuous line of detection

By definition, a perimeter is a closed line around some area that needs protection. A design goal is to have uniform detection around the entire length of the perimeter. This requires that sensors form a continuous line of detection around the perimeter. In practice, this means configuring the sensor hardware, so that the detection zone from one perimeter sector overlaps with the detection zones for the two adjacent sectors. Also, in areas where the primary sensor cannot be deployed properly, such as a gate, an alternate sensor is used to cover that gap.

Protection-in-depth

As applied to perimeter sensor systems, the concept of protection-in-depth means the use of multiple lines of detection. A minimum of two continuous lines of detection is used in high security systems. Many perimeter sensor systems have been installed with three sensor lines, and a few have four. For example, a perimeter sensor system might include a buried-line sensor, a fence-associated sensor, and a freestanding sensor. Multiple sensor lines provide duplicated detection, increased reliability and, in case of hardware failure, will provide fail-safe security. In this scheme, any single sensor can fail without jeopardizing the overall security of the facility being protected.

Complementary sensors

Significantly better performance by the perimeter sensor system can be achieved by selecting different and complementary types of sensors for the multiple lines of detection. Complementary sensors enhance the overall system performance, expressed in terms of the three fundamental sensor characteristics: P_D, nuisance alarm rate, and vulnerability to defeat.

This implies that no two sensor lines will use the same technology. This design philosophy results in detection of a wider spectrum of targets, allows operation of at least one sensor line during any conceivable environmental disturbance, and increases the difficulty of the task for the covert intruder attempting to defeat the system.

Priority schemes

Processing nuisance alarms. One disadvantage of multiple sensor lines is that more nuisance alarms will have to be processed. System effectiveness has not been increased if the system operator is overwhelmed with nuisance alarms because the P_D decreases as the time to assess alarms increases. The assessment subsystem should aid the operator in evaluating alarm information.

Using computer software to prioritize alarms. A recommended method for handling alarms requires the system operator to assess all alarms with the aid of a computer that establishes the time order of assessment for multiple simultaneous alarms. The computer sets a priority for each alarm based on the probability that an alarm event corresponds to a real intrusion. The alarms are displayed to the operator in order of decreasing priority; all alarms are eventually assessed. The alarm priority is established typically by taking into account the following:

- Number of sensors in alarm in a given sector.
- Time between alarms in the sector.
- Order in which the alarms occur in relation to the physical configuration of the sensors.
- Alarms in the two adjacent sectors.

Combination of sensors

Strive to improve detection and reduce nuisance alarms. It is desirable that a sensor or sensor system have a high P_D for all expected types of intrusion and a low NAR for all expected environmental conditions.

No single exterior sensor presently available meets both of these criteria. All are limited in their detection capabilities and all have high NARs under certain environmental conditions.

Basic techniques

The two basic techniques for combining sensors are:

- OR combinations.
- AND combinations.

OR combination. A system can consist of two or more sensors with their outputs combined by an OR gate so that an alarm would be generated when any sensor is activated. This combination is useful for sensors that make up for the deficiencies of each other, and each sensor is intended to detect particular types of intrusions. Thus sensors that detect aboveground, overhead, and tunneling intrusions should be combined by an OR gate. The NAR of the OR combination (NAR (OR)) will be the sum of the NAR of each sensor.

AND combination. The NAR can be significantly reduced by combining sensors with an AND gate if the nuisance alarms of the sensors are not correlated. A seismic sensor and an electric field sensor do not give correlated alarms, for example, because they respond to different things. If both are activated at about the same time, it is probable that they have detected an intrusion.

Since a single intrusion attempt will not activate two or more sensors simultaneously, a system can be designed to generate an alarm if two or more sensors are all activated within a preselected time interval. A long time interval is desirable to assure detection of intruders moving slowly, but if the interval is too long, the NAR may not be reduced enough. By installing sensors so they cover the same general area, thereby providing redundant coverage, the time interval can be kept small.

AND combination and vulnerability to defeat. Detection probability of the AND combination (P_D(AND)) will be lower than the detection probability of each sensor. If an intruder can successfully defeat one sensor then the entire combination is defeated and will not alarm. To assure a reasonable detection probability for the system, the detection probability of the individual sensors must be high. AND combinations are seldom used in the exterior environment at high security facilities because of the vulnerability to defeat.

Clear zone

Definition and purpose. Two parallel fences extending the entire length of the perimeter usually define a clear zone. The fences are intended to keep people, animals, and vehicles out of the detection zone. The area between the fences is usually cleared of all aboveground structures, including overhead utility lines, and vegetation is also removed. After the zone between the fences is cleared, only the detection and assessment hardware and associated power and data lines are installed in the area.

The purpose of the clear zone is to improve performance of the perimeter sensor system by increasing detection probability, reducing nuisance alarms, and preventing defeat.

The clear zone also promotes good visual assessment of the causes of sensor alarms. A perimeter intrusion detection system performs better when it is located in an isolated clear zone.

Sensor configuration

Combine sensors to improve coverage. The configuration of the multiple sensors within the clear zone also affects the system performance. Overlapping the detection volumes of two different sensors within each sector enhances performance by creating a larger overall detection volume. As a result, defeat of the sensor pair is less probable because a larger volume must be bypassed or two different technologies must be defeated simultaneously. A third sensor can even further enhance performance, not by overlapping with the first two, but by forming a separate line of detection. Physically separate lines of detection can reveal information useful for determining alarm priority during multiple simultaneous alarms. In particular, the order of alarms in a sector (or adjacent sectors) may correspond to the logical sequence for an intrusion.

Site-specific system

Each site is unique. Each site requiring physical protection has a unique combination of configuration and physical environment. A physical protection system designed for one site cannot be transferred to another.

Factors that help determine which sensors will be appropriate. The following factors generally help determine the appropriate set of sensors:

- *The physical environment* will influence the selection of types of sensors for perimeter sensor systems.
- *The natural and industrial environments* provide the nuisance alarm sources for the specific site.
- *The topography of the perimeter* determines the shapes and sizes of the space available for detection, specifically the clear zone width and the existence of flat or irregular terrain.

Although the understanding of the interaction between intrusion sensors and the environment has increased significantly in recent years, it is still advisable to set up a demonstration sector on site using the possible sensors before making a commitment to a complete system. This test sector located on site is intended to confirm sensor selection and to help refine the final system design.

Tamper indication

Features of tamper indication. The hardware and system design should incorporate features that detect or indicate tampering, as follows:

- Sensor electronics and junction box enclosures should have tamper switches that alarm if opened.
- Aboveground power and signal cables should be installed inside metal conduit.
- Alarm communication lines should use some type of line supervision that detects lines that have been cut, disconnected, short-circuited, or bypassed.
- To reduce vulnerability to defeat, place bistatic sensors so that an intruder must be in or pass through the detection volume to approach the receiver.

Self-test

Manual and remote testing capabilities. To verify normal operation of a perimeter sensor system, its ability to detect must be tested regularly. Although manual testing is recommended, manpower requirements are usually restrictive. A capability for remote testing of trigger signals can be provided and initiated by the alarm communication and control system. Typically this is just a switch closure or opening. In an automatic remote test procedure, the central computer control system generates at a random time a test trigger to a given sensor. The sensor must then respond with an alarm. The control system determines if an alarm occurred within a specified time and if it cleared within another specified time. Failure to pass the test indicates a hardware failure or tampering and produces an alarm message.

Pattern recognition

Computers can analyze pattern signals. Computers can receive signals from sensors and analyze the signal pattern, looking for patterns that are characteristic of an intruder. Using neural network or artificial intelligence software, the computers can learn the intruder signal patterns and then avoid nuisance alarms. Any sensor or combination of sensors that return a signal other than just "off" or "on" can have their signal analyzed by a computer and it can very reliably sense whether or not an intruder is present. One concern with these types of sensors is how the pattern recognition system is trained. It may be possible to over-train a system to reduce nuisance alarms at the expense of missing real intrusions. Another concern is that the intruder may be able to simulate a signal that the system rejects as a nuisance alarm in order to defeat the system.

Effects of physical and environmental conditions

The physical and environmental conditions that can affect exterior detection systems include:

- Topography.
- Vegetation.
- Wildlife.
- Background noise.
- Climate and weather.
- Soil and pavement.

These conditions are different at every site.

Topography. Topographic features such as gullies, slopes, lakes, rivers, and swamps must be considered when designing an exterior detection system. Grading may be required to reduce hills and slopes. Draining may also be required to reduce water flow through gullies and ditches to prevent seismic disturbances caused by running water. The perimeter system should avoid lakes, rivers, and swamps, since there are few commercial sensors suitable for use in water.

Vegetation. Sensor performance can be affected by vegetation in two ways: underground and aboveground. Motion of trees or plants caused by wind may be transmitted to their root systems and cause a seismic sensor to generate a nuisance alarm. Aboveground, an intruder can use large plants and trees as cover. If vegetation is a problem, mowing, removal, soil sterilization, or surfacing should be used to control it.

Wildlife. In some locations, wildlife may cause problems. Large animals may damage equipment by collision and burrowing animals may eat through cable insulation material. Small animals, birds, and insects also cause nuisance alarms that may be difficult to assess. Dual chain-link fences and chemical controls may be used to control wildlife; however, local regulations should be observed with regard to poisons and repellents. Removing vegetation from fence lines has been found to discourage some smaller animals.

Background noise. A site survey along with information obtained from utility companies and plant-engineering organizations on site may reveal many sources of background noise. These sources may include wind, traffic, electromagnetic interference, and seismic sources:

1. *Wind*. These disturbances are caused by the transfer of energy to the ground by trees, power and light poles, fences, etc. High winds and windblown debris can also cause nuisance alarms from sensors mounted on fences by disturbing the fence.
2. *Traffic* from nearby roadways, railways, and airports creates nuisance alarms from seismic sensors. Roads should be kept smooth and the speed limit at a minimum to reduce the nuisance alarm rate. Seismic sensors are not practical near heavy air or railway traffic, because this type of traffic causes seismic disturbances even at long distances.
3. Examples of sources of *electromagnetic interference* include lightning, radio transmitters, welding, and electrical transients. Shielding of the sources or the sensors can reduce nuisance alarms.

Climate and weather. Specific data about the climate and the weather conditions should be obtained for the site. Information such as frequency, velocity, accumulation, and duration should be obtained about hail, electrical storms, rainfall, and wind. Mean minimum and maximum temperatures should also be noted as well as other weather and environmental conditions.

Because exterior sensors are installed outdoors, they are exposed to electrical storms at most sites. Lightning can easily disable, damage, or destroy the sensitive electronics used in sensor equipment. There are three primary precautions for reducing lightning damage. First, all signal cables should be shielded, either by the internal cable construction or by using metal conduit. Second, a good ground system is required. This means eliminating ground loops and using grounds at a single point. Third, passive transient suppression devices can be installed at the ends of the cables. Fiber-optic transmission cables are not affected by lightning and have thus become very popular for transmitting signals long distances outside a building.

Soil and pavement. Soil and pavement conditions can affect the operation of buried seismic sensors. The seismic conductivity of the medium is the determining factor. It should be high enough to make seismic sensors effective, but not so high that it causes nuisance alarms. Wet soil tends to have exceptionally good seismic conduction. However, wet soil tends to respond strongly to distant sources of seismic activity and thus cause excessive nuisance alarms. Buried systems of seismic magnetic sensors and seismic sensors may have to be embedded in or installed under areas paved with concrete or asphalt. The sensitivity of a sensor embedded in the pavement is increased if the sensor is adequately coupled to the medium. If the sensor is not adequately coupled to the medium, its sensitivity may be much lower than when it is installed in soil or buried under the pavement.

Integration with video assessment system

Compatibility

Many perimeter security systems use a CCTV system to perform alarm assessment. For both the sensor and video systems to perform well, care must be taken to ensure that the designs of the two systems or subsystems are compatible.

Clear zone

One consideration is the width of the clear zone. Sensor engineers desire a wide area for installing their sensors to reduce nuisance alarms. Video engineers desire a narrow area to assess so that they can achieve better resolution from the cameras. A compromise clear zone width is in the range of 10 to 15 m.

Location of camera towers

Another trade-off is the location of the camera tower within the clear zone. The camera must be positioned to view the entire area being assessed. The sensors must be placed far enough away from the camera towers to prevent distortion of the detection volume and nuisance alarms. Frequently the camera towers are located 1 to 2 m inside the outer fence of the clear zone.

Integration with barrier delay system

Delay time allows video assessment

Balanced integrated physical protection systems usually incorporate some type of barrier or access denial systems to provide delay time for video assessment of the alarm source and for the response force to respond to an intrusion. In many cases, this includes some type of barrier installed at the perimeter; however, the barrier should not degrade the performance of the sensors.

Barrier placement

Perimeter barriers are usually installed on or near the inner clear zone fence so that an intruder cannot tamper with or defeat the barrier without first passing through the detection zone. This placement is important to ensure that the response action is initiated before the delay occurs. Barriers should not distort the sensors' detection volume, cause nuisance alarms, or obscure part of the cameras' view.

Summary

Exterior intrusion detection sensors have been discussed in terms of application, P_D, nuisance alarm rate, and vulnerability to defeat. The designer integrating individual sensors into a perimeter sensor system must consider specific design goals, the effects of physical and environmental conditions, and the interaction of the perimeter system with a balanced and integrated physical protection system.

Section 8 – Recommendations

The following recommendations should be included in the design of a security system for a carcass disposal operation.

- **Plan ahead!** Before there is an incident, each level of jurisdiction should plan for the security system. Planning before an event will save costs during an event. Without advance planning the only immediate options are to fail to provide security (which may result in unacceptable health, financial, political, and other risks) or to incur very high labor costs. Advanced planning will help control the costs of security as well as provide a higher level of security.
- **Include local law enforcement in planning.** Local law enforcement should be included in the development of plans because they may be involved in implementation or other coordination with the carcass disposal operators.
- **Focus on low-cost, rapidly deployable technologies**.
- **Provide pre-event training.** All entities involved in security operations should train together. Training materials can be developed before an event so that they can be rapidly deployed to enforcement officials after an incident occurs.
- **Coordinate efforts.** Before an event, all relevant enforcement agencies should have plans for how to coordinate.
- **Understand the legal issues.** An understanding of the legal issues and the legal authorities of those involved in security should be in place prior to an event. There may be complex legal issues associated with seizing private property and implementing disposal operations on privately owned land.

- **Integrate security plans with biosecurity.** A well-designed and implemented security plan will help to assure the biosecurity of the site. An adequate security plan will help to ensure that biosecurity protocols are being followed and decontamination procedures are not bypassed.

Section 9 – Critical Research Needs

- Develop practical, prototypic security plans and then test them at actual large-scale feedlots (e.g., in southwest Kansas).
- Develop actual security plans for various jurisdiction levels. Before there is an incident, each level of jurisdiction should plan for the security system. Planning before an event will save costs during an event. Advanced planning will help control the costs of security as well as provide a higher level of security.
- Conduct activities that include local law enforcement in planning. Local law enforcement should be included in the development of plans because they may be involved in implementation or other coordination with the carcass disposal operators.
- Investigate and identify low-cost, rapidly deployable technologies.
- Develop pre-event training materials. All entities involved in security operations should train together. Training materials can be developed before an event so that they can be rapidly deployed to enforcement officials after an incident occurs.
- Summarize legal issues in carcass disposal site security. An understanding of the legal issues and the legal authorities of those involved in security should be in place prior to an event. There may be complex legal issues associated with seizing private property and implementing disposal operations on privately owned land.
- Integrate security plans with biosecurity. A well-designed and implemented security plan will help to assure the biosecurity of the site. An adequate security plan will help to ensure that biosecurity protocols are being followed and decontamination procedures are not bypassed.

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
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Carcass Disposal Working Group

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Chapter 14

Evaluating Environmental Impacts

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Selected Abbreviations

3MRA	multimedia, multi-pathway, multi-receptor exposure and risk assessment model
ADMS	atmospheric dispersion modeling system
AGNPS	agricultural nonpoint source
ALOHA	areal locations of hazardous atmospheres
AMC	antecedent moisture condition
ANSWERS	aerial nonpoint source watershed environment response simulation
ARS	USDA Agricultural Research Service
BOD	biochemical oxygen demand
CN	curve number
CTSCREEN	complex terrain screening model
DRAINMOD	a field-scale water management simulation model

DRASTIC	a standardized system for evaluation of groundwater pollution potential using hydrogeologic settings
ERS	Economic Research Service
EPA	Environmental Protection Agency
EPIC	erosion-productivity impact calculator
EUTROMOD	a watershed-scale nutrient loading and lake response model
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FMD	foot and mouth disease
GIS	geographic information system
GLEAMS	a model to simulate the effects of different agricultural management systems on water quality
HEC	
HELP	standard model for landfill design
HSPF	
INPUFF	intergrated PUFF
K	soil erodibility screening model
L-THIA	long-term hydrological impact assessment
MULTIMED	multimedia exposure assessment model
NAPRA	national agricultural pesticide risk analysis
NEH-4	USDA SCS National Engineering Handbook
NFF	national flood frequency
NH4-N	ammonia-nitrogen
NPS	non-point source
NRCS	Natural Resources Conservation Service
OBODM	open burn/open detonation dispersion model
QUAL2E	enhanced stream water quality model
PRZM3	predicts pesticide transport and transformation
REM	register of ecological models
RUSLE/RUSLE2	revisions to the universal soil loss equation
RWEQ	revised wind erosion equation
SCS	Soil Conservation Service
SEDSPEC	sediment and erosion control planning, design and specification information and guidance tool
SWAT	soil and water assessment tools
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
USLE	universal soil loss equation
USDA	United States Department of Agriculture
USGS	US Geological Service
VPM	virus protection model
WEPP	water erosion prediction project
WEPS	wind erosion prediction system
WMS	watershed modeling system

Section 1 – Key Content

Carcass disposal events can result in detrimental effects on the environment. The specific impacts vary by carcass disposal technology, site-specific properties of the location, weather, type and number of carcasses, and other factors. To accurately determine the impacts of a specific carcass disposal event on the environment, environmental monitoring will be necessary. This chapter provides an overview of the monitoring that may be necessary or desirable to quantify environmental impacts for a carcass disposal event.

Environmental models can be helpful in addressing environmental concerns associated with carcass disposal, and can be used at various stages, including:

1. **Prescreening.** Sites can be prescreened using environmental models to identify locations that might be investigated further in the event of an actual disposal event. The models would likely be used with geographic information systems (GIS) to create maps of potentially suitable sites for each carcass disposal technology.
2. **Screening.** In the event of a carcass disposal incident, environmental models might be used to further screen sites and disposal technologies being considered. Such models would require more site-specific data than those used for prescreening.
3. **Real-time environmental assessment.** Models might be used to predict the environmental impact of carcass disposal at a particular location for the observed conditions (site and weather) during a carcass disposal event. These predictions would be helpful for real-time management decision-making, and would provide estimates of environmental impact.
4. **Post-disposal assessment.** Once a carcass disposal event is over, the activities at the location may continue to impact the environment. A combination of monitoring and modeling may be useful to assess the likely impacts.

Some of the most promising environmental models that might be used for the various tasks described above have been reviewed and summarized in this chapter. Models were reviewed for water (surface and ground), soil erosion, soil quality, and air. Brief summaries of the models are included.

Section 2 – Environmental Monitoring to Assess Impacts of Carcass Disposal

In the case of a natural disaster or foreign animal disease outbreak, significant numbers of animal carcasses may need to be buried or disposed of using a variety of methods or technologies. Carcass disposal methods such as burial, incineration, composting, and others could result in significant impacts on human health, water supplies, air quality, soil, and the food chain, which would need to be scientifically monitored and assessed.

Protecting public health and preventing or minimizing the possible impacts of contamination with proper environmental monitoring before and after carcass disposal is a necessity. Sampling frequency and volume should be determined based on a standard sampling method to prevent human-induced errors and provide true characteristics and variability of the pollutant(s) from carcass disposal areas. Depending on carcass types and disposal methods, various sampling protocols may be applicable before, during, and after disposal.

Important elements of an environmental monitoring program include sample locations, minimum number of sampling points, frequency of sampling, baseline data prior to disposal, equipment, and pollutant types.

Laboratories capable of providing appropriate detection limits and analyses for each pollutant should be carefully selected as a part of the monitoring program.

The environmental impacts of carcass disposal are not well documented (Freedman and Fleming, 2003; Glanville, 2000). The United Kingdom Environment Agency (2001) indicated that any environmental impacts of carcass disposal in the UK following the 2001 disposal events were short-term and localized and much smaller than the day-to-day impacts of current farming practices. However, the literature available and past experiences with burial of wastes indicate carcass disposal by burial will likely require the most extensive environmental monitoring of the carcass disposal technologies considered in this document. Literature describing the potential environmental impacts of carcass disposal technologies is briefly discussed in the paragraphs that follow.

Glanville (2000) reported on the impact of livestock burial on shallow groundwater quality, noting that proper disposal of livestock mortalities can be more difficult than manure management, because animal carcasses are not easily stored for long periods of time and cannot be spread on cropland. In order to study the characteristic types, concentrations, and duration of release of contaminants from on-farm burial, the Iowa Department of Natural Resources funded two case studies.

The first case study examined two 1.8 m deep pits containing 28,400 kg of turkey carcasses that had been buried one year prior to the initiation of the study. The site was located in poorly drained soil with moderately slow permeability with a seasonal high water at depths of 0.3 to 0.9 m. Twelve monitoring wells were used to identify contaminant movement and background water quality with samples collected monthly for a period of 15 months, and again at 20 months and 40 months.

In the second case study, two 1.2 m deep trenches were spaced 2.4 m apart in well-drained, moderately permeable soil. The seasonal high water table was at a depth greater than 1.8 m. Each trench was loaded with six 11.3-13.6 kg swine carcasses spaced evenly along the trench bottom. The mass of carcasses in each trench was considered a reasonable loading rate according to Iowa rules. One of the trenches was lined with PVC sheeting and 10 cm of pea gravel. A PVC pipe was buried vertically at one end of the trench and equipped with a sump pump so that monthly samples of leachate could be obtained. The leachate was analyzed to examine the mass, concentration, and duration of decay products. Eight monitoring wells were placed around the trenches to monitor groundwater.

In these case studies, elevated levels of biochemical oxygen demand (BOD), ammonia-nitrogen (NH4-N), total dissolved solids (TDS), and chloride were commonly found within or very near the burial trenches. Although chloride concentrations were generally lower than the other contaminants, elevated chloride levels are generally the best indicator of burial-related groundwater contamination. Glanville (2000) concluded that localized contamination may persist for a decade or more in wet soil with a high seasonal water table and low groundwater flow velocity. Even in lightly loaded burial trenches constructed in well-drained soil, complete decay may take two years or more. Neither of these experiments showed burial-related contamination more than a meter or two from the pits. In cases where groundwater velocities are higher, however, or where vertical groundwater movement occurs, leachate from burial sites may pose a higher contamination risk to groundwater.

Ritter et al. (1988) examined the impact of dead bird disposal on groundwater quality by monitoring groundwater quality around six disposal pits in Delaware. Open-bottomed pits were used for day-to-day mortality disposal. These pits are not identical to burial pits, though there are similarities. Most of these pits were located in sandy soils with high seasonal water tables. Therefore, the potential for pollution of groundwater is high with this method of disposal. After selecting the sites, two to three monitoring wells were placed around each pit to a depth of 4.5 m. Ammonia concentrations were high in two of the wells, with three of the disposal pits causing an increase in ammonia concentrations in the groundwater. Total dissolved solids concentrations were high in all monitoring wells for most dates. Bacterial contamination of groundwater by the disposal pits was low.

Ritter and Chirnside (1995) examined the impact of dead bird disposal pits on groundwater quality on the Delmarva Peninsula in Delaware. They reported these additional discoveries:

- Nitrogen is a greater problem than bacterial contamination.
- Serious contamination may occur if large numbers of birds are added to the pit.
- Abandoned disposal pits should be pumped out and filled with soil to minimize their impact on groundwater quality.
- Subsurface disposal of dead birds should be regulated.
- Only certain types of disposal pits (i.e. concrete tanks) should be allowed.
- Permits should be issued for disposal sites meeting minimum standards (i.e. dealing with soil type, water table depth, etc.).

At the time of UK foot and mouth disease (FMD) outbreaks in 2001, on-farm burial and on-farm burning were initially the primary means of carcass disposal. However, concerns for potential groundwater contamination by on-farm burial and local community health concerns due to smoke and emissions from on-farm burning were raised (Scudamore et al., 2002). Thus, mass burial and on-farm burning are now ranked at the bottom of options in the disposal hierarchy within the UK (Scudamore et al., 2002).

The State of Wisconsin Department of Natural Resources (2002) analyzed the threat of carcass disposal of deer with chronic wasting disease. They concluded that disposal of these carcasses in municipal solid waste landfills would provide adequate levels of protection to reduce the spread of chronic wasting disease, protect the environment, and protect human health.

The environment may also be impacted in unanticipated ways due to reductions in farm incomes associated with carcass disposal events (The Productive Commission, 2002). A reduction in farm income may indirectly impact the environment, because farmers may be unwilling to spend money on soil conservation or general environmental preservation due to increased financial pressure. Quantification of the environmental impacts in such cases through monitoring would not likely be feasible due to the highly diffuse nature of such impacts and the time scales over which they would occur. In such cases, models may be helpful in estimating the possible environmental impacts.

2.1 – Monitoring of Water Supplies

Burial

Burial of carcasses is likely to have the greatest impact on water quality of the carcass disposal techniques discussed. When the carcasses are buried and undergo decomposition processes, nutrients, pathogens, and other materials may be released into the environment. These substances may be degraded, transformed, lost to air, or immobilized, posing no environmental impacts. However, some may contaminate the soil, surface water, and groundwater bodies (Freedman and Fleming, 2003). Elevated levels of BOD, NH4-N, TDS, and chloride have been found within or very near carcass burial trenches (Glanville, 2000). Elevated chloride levels are generally the best indicator of burial-related groundwater contamination (Glanville, 2000). According to the UK Environment Agency (UK Environment Agency, 2001), 212 surface and groundwater pollution incidents were reported, although minor, as a result of carcass disposal during the 2001 carcass disposal events in the UK Of these incidents, 24% were due to leachates from carcass disposal pits. This was largely because the carcasses were initially buried close to a water table, since the environmental impacts of carcass burial were not high priority concerns when selecting disposal sites.

Improper management of carcass burial sites can result in both surface water and groundwater contamination. For example, the soil cover on burial sites may have to be replenished every few weeks, because settling in the cover can cause surface runoff to flow into the site. The best soil type for covering carcass burial pits to reduce groundwater contamination is a fine-grained, heavy soil like clay.

However, clay soils increase direct runoff, possibly resulting in surface water contamination.

When carcasses are buried in pits, leachate is generated by water and other liquid percolating or passing through the carcasses, as well as the liquids released by the decaying carcasses. Leachate is contaminated water containing a number of dissolved and suspended materials Leachate from carcass disposal pits is often highly contaminated and should not be directly discharged into surface water bodies or groundwater. Scudamore et al. (2002) indicated that during the large carcass disposal effort in the UK in 2001, there were initially no proven designs for mass burial sites. However, the design and engineering features of the burial sites underwent a significant transformation during the disposal period. Initially the burial pits were large holes in the ground, but later locations were engineered with increasingly sophisticated liners and leachate collection systems to minimize risks to groundwater (Scudamore et al., 2002).

Leachate quality varies depending on the composition of materials buried, elapsed time after carcass disposal, ambient temperature, available moisture, and available oxygen. Leachate quantity varies depending on precipitation, groundwater intrusion, moisture content of waste, and final cover design. Monitoring of the quantity and quality of leachate over time (daily, seasonal, and long-term) is important (Bagchi, 1994).

Leachate quality should be assessed at an early stage to identify if the waste is hazardous, to choose a pit design, o design or gain access to a suitable leachate treatment plant, and to develop a list of analytes for the groundwater monitoring program. Leachate quality can be measured using laboratory tests, such as a water leach test, standard leach test, toxicity characteristic leaching procedure (TCLP) test, and the synthetic precipitation leachate procedure. The condition of the leachate can be judged based on the concentration of contaminants, and decisions made regarding whether further action is necessary (Bagchi, 1994).

Chloride, ammonium, nitrate, conductivity, total coliforms, and *E. coli* should be monitored in potentially contaminated water supplies. Although not definitively conclusive, increases in these contaminates may indicate leachate contamination. Other possible sources, such as manure storage and spreading, should also be investigated. Thus further monitoring may be needed to confirm sources of contamination (United Kingdom Department of Health, 2003).

An elevated concentration of nitrate in groundwater is of significant concern, because nitrates can potentially be harmful to infants if found in drinking water. Proper management of a leachate plume from carcass disposal pits is important. If the site is chemically treated to kill viruses, additional monitoring may be required to check whether the processes involved meet regulatory standards (United Kingdom Department of Health, 2003).

The concentration of pollutants generated in the first year following waste disposal by burial may be less than those in the subsequent years, and concentrations of all pollutants do not peak at the same time. While this is generally true for municipal wastes, this may not be true for carcass burial. Therefore, both short-term and long-term monitoring is necessary to identify the possible risks due to the higher concentrations of pollutants. Environmental risk assessments should be performed for all burial sites to minimize the risk to the environment, which consider local topography, soil, water, geological, and aquifer features.

Trucks and equipment used for excavation or other disposal operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

To detect possible environmental contamination from carcass burial sites, the following factors need to be monitored:

- Leachate head within the pit.
- Head in the dewatering system, if installed.
- Leakage through the bottom of a burial pit or landfill.
- Head and quality of leachate in the collection tank.
- Stability of the final cover.

- Groundwater around the site.
- Gas in the soil and the atmosphere around the carcass disposal pit.
- Soil quality at or near the carcass disposal site.

All of these factors will vary with time, and monitoring over time is needed to ensure carcass burial sites are performing as designed.

It may take dozens of years for carcasses to decompose, thus short-term and long-term effects of carcass disposal on the environment should be considered. Retrospective assessments are also necessary to ensure sampling locations adequately depict the environmental impact of the carcass disposal event. If carcass disposal locations cause public complaint, additional monitoring may be warranted. Following closure of carcass burial sites, the owner/operator should conduct post-closure care for a period of time. Post-closure care consists of maintaining the integrity of the final cover and groundwater, gas, and leachate collection and monitoring systems (Bagchi, 1994).

In the case of carcass burial, the migration of gas, leachate, and chemicals which may have been used for decontamination should be monitored; remedial actions are easier and less expensive when only limited areas are contaminated. It is necessary to determine if the leachate and gas from the burial sites meet regulatory standards.

Incineration

In the case of incineration, heavy metals from the contaminants in coal or fuel sources can reach water supplies and change the taste and smell of the water. If water sample data contain statistically higher levels of contaminants compared with the background data, and water supplies are considered to be at risk to the contamination, routine monitoring is necessary as is monitoring for potential impacts on public health. Generally, incineration of carcasses will not produce significant surface water and groundwater concerns.

Again, trucks and equipment used in incineration operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

Alkaline hydrolysis

The impacts of alkaline hydrolysis carcass disposal efforts on water should be negligible if conducted properly. The most likely impacts on water quality would likely be due to runoff from the site that might carry sediments and materials washed off equipment. If the digestate produced by alkaline hydrolysis is land applied, it may be desirable to monitor water quality (surface water and shallow groundwater) for these fields. However, if the digestate is applied at rates that are agronomically safe with respect to nutrients and trace metals, the environmental impacts should be minimal.

Trucks and equipment used in alkaline hydrolysis operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

Composting

The impacts of carcass composting efforts on water should be negligible if conducted properly. To relieve public concern, limited groundwater and surface water runoff sampling near sites that are composting large masses of carcasses could be done. Application of the finished compost to land at agronomic rates should pose minimal threats to surface water and groundwater.

Once again, trucks and equipment used in composting operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

2.2 – Monitoring of Air Quality and Soil Quality

Burial

While groundwater contamination may take time to occur and appear, air pollution from burial sites can cause immediate and direct impact. When carcasses are buried, anaerobic decomposition of organic materials will result in gases, such as methane, carbon dioxide, carbon monoxide, nitrogen oxides, sulphur dioxide, hydrogen chloride, hydrogen fluoride, and methane. These gases could potentially be very toxic and could violate air quality standards. For example, methane, a greenhouse gas, is potentially explosive. The diffuse gases from carcass burial sites should be monitored on a routine basis to check the potential hazard to workers and people living around the sites.

Venting of gas may be necessary if the pressure of gas generated from biodegradation or other physical/chemical processes in carcass burial sites may be high enough to rupture the disposal site cover. Thus monitoring of gas pressure is also suggested. Gas diffused through the cover can stress and potentially kill vegetation, resulting in increased erosion of the final cover. A routine monitoring program should be implemented to ensure the concentration of explosive gases from the carcass burial sites does not exceed regulatory standards in the area.

Like leachate, the quality and quantity of gas from the carcass burial sites varies with time. The quantity of gas generated depends on waste volume and time; sampling time and frequency are important as well. Spatially and temporarily unbiased sampling is needed for correct assessment.

Incineration

In the case of incineration, the prevailing wind direction should be monitored at the time of incineration to prevent unnecessary smoke and objectionable odors reaching sensitive areas. Hickman and Hughes (2002) indicated that according to the UK Department of Health, large pyres need to be built at least 3 km away from local communities and more heavily populated areas. During the FMD outbreak in the UK in 2001, pollutants from pyres were measured at various distances from the pyres with a variety of percentages of time downwind. The pollutant levels in these cases were either lower than air quality standards or within urban background levels (UK Department of Health, 2001).

Since a significant amount of fuel is often needed for complete incineration, the environmental impacts of using these fuels should be monitored and evaluated. Dioxins from pyre smoke can accumulate in soil and vegetation, ultimately entering the food chain through animal grazing. Monitoring of dioxins and dioxin-like polychlorinated biphenyls should therefore be conducted in soil, vegetation, eggs, milk, lamb, chicken, and other animal products to check whether foods produced close to these areas have higher concentration of these contaminants. Following the FMD outbreak in the UK in 2001, levels of dioxins in soil, vegetation, and food were mostly within the expected range or similar to levels at control farms (UK Department of Health, 2001). Hickman and Hughes (2002) indicated that there have been no confirmed reports of dioxins and dioxin-like products reaching the human food chain from carcass disposal activities.

One of the critical air quality pollutants from pyres is often sulphur dioxide, so use of coal with low sulphur content is highly recommended to reduce the sulphur dioxide level. In addition to sulphur, combustion products such as nitrogen oxides, particulate matter, carbon monoxide, dioxin, and polycyclic aromatic hydrocarbons should be monitored. After incineration of carcasses, ash should not be left unattended. Strong wind and heavy rainfall can cause the ash to contaminate a large area quickly, and the ash can also leach into the soil causing further contamination in surrounding areas.

It is noteworthy that the concentrations at monitoring locations selected in previous studies with carcass disposal by incineration may not represent the higher pollutant concentrations closer to the pyres, which could cause adverse impacts on human health. Fine particles carried through the air from carcass disposal sites could cause inflammation and deterioration in the heart and lungs. Carbon monoxide can lead to a significant reduction in the supply of oxygen to the heart. Air pollution can cause eye irritation and coughing, and breathing difficulties, especially for elderly people.

Concerns have been raised about the potential for diseases to be transmitted in the smoke and particles that move off site as a result of incineration of diseased carcasses. The FMD virus can be spread by the wind as well as by the movement of infected animals and aerogenous transmission to susceptible animals (Donaldson and Alexandersen, 2002). Although the wind spread of the FMD virus is not that common, its impacts on downwind areas can be very rapid and extensive, and become uncontrollable, once spread by the wind. Hickman and Hughes (2002), however, indicate that there is no evidence of the FMD virus being transmitted to humans or into the human food chain as a result of the incineration of diseased livestock in the UK

Alkaline hydrolysis

The use of alkaline hydrolysis for carcass disposal is unlikely to negatively impact air quality. Therefore, air quality monitoring would not likely be necessary. However, the spread of disease by wind from carcasses that are stockpiled at the site or that are being placed in the digester may be a concern.

Composting

The use of composting for carcass disposal is unlikely to negatively impact air quality. Therefore, air quality monitoring would not likely be necessary. However, the spread of disease by wind from carcasses that are stockpiled at the site or that are being placed in the compost material may be a concern.

Section 3 – Environmental Models for Carcass Disposal Impact Evaluation

3.1 – Introduction

Natural disasters or disease outbreaks can result in an unexpected large number of dead livestock and present a challenge in the disposal of carcasses. Catastrophic livestock deaths could also be the result of intentional attacks or introductions of disease. Quick and efficient responses are required to deal with carcass disposal. Since September 11, homeland security and public protection from biological attacks such as anthrax have become a more serious concern. The livestock industry, a significant portion of the agricultural sector in the United States, provides numerous products highly related to public health.

Animal disasters may engender massive carcass disposal or destruction of livestock. Carcass disposal should be handled correctly and quickly to minimize environmental impacts on surface water, groundwater, soil, and air. Although some situations may allow for carcasses to be safely disposed of on site, other situations may require off-site disposal. Carcass disposal and treatment sites are environmentally vulnerable due to potentially enormous numbers of dead animal bodies with associated liquids and organic material that should be isolated from the environment. The presence of pathogens in the carcasses can present even greater environmental risks.

Depending on the disposal method, water resources are often the most vulnerable aspect of the environment. Disposal sites may be located near streams, lakes, and ponds, and groundwater is likely to be present beneath sites. Water bodies can be contaminated from carcass disposal and serve as a route or delivery medium for waterborne pathogens and liquids from carcasses (Freedman and Fleming, 2003). The potential environmental impact of carcass disposal should be evaluated prior to disposal in order to minimize effects on water resources. In addition, evaluation should continue after disposal to detect any potential problems before they occur.

Soil is also vulnerable to contamination from massive carcass disposal, especially from burial. Burial methods usually expose the soil to chemical and biological interactions with carcasses. Around and under the burial site, soil may potentially be exposed to high nutrient levels, including phosphorus and nitrogen, from animal decomposition. Leachate from carcasses may also contain biological agents. Other carcass disposal technologies may also contaminate soil through contact of soil with ash and by-products, disinfectant materials, fuel sources, and other materials used by the disposal technology. Hence, the impact of the disposal technology on soil should be evaluated during site selection, operation, and post-closure. Air can also be negatively impacted by carcass disposal. Some disposal technologies potentially impact air to a much larger degree than others. For instance, open burning of carcasses can potentially have severe consequences on air quality. Air pollution can cause eye irritation, coughing, and breathing difficulties.

This section describes models that can potentially be used to assess the environmental sensitivity of surface water, groundwater, erosion/sedimentation, soil quality, and air models at or near possible carcass disposal locations. In the case of a carcass disposal event, these models can be used to screen sites during planning, evaluate potential sites during site selection, and estimate the environmental impact during and following the emergency. Itemized model information is provided in the sections that follow. The models are described in terms of category, model name, evaluation stage, specified use, model overview, applicable scale, computer system requirements, cost, model inputs, model outputs, selected references, and model Web site. The models in the list were chosen based on information gathered through the Internet, journals, and reports. Many additional models are available, so those identified as potentially most appropriate for carcass disposal issues are discussed.

3.2 – Surface Water and Groundwater Models

Various hydrologic models simulating surface water, groundwater, nutrients, and pathogen movement can play a significant role in evaluating the impact of carcass disposal. These models can be used for screening, pre-disposal site selection, real-time evaluation of possible environmental impact, and post-disposal evaluation of sites. Realistically, environmental impacts cannot be entirely avoided in large-scale carcass disposal, but they can be minimized by using appropriate tools, including hydrologic models, to improve decision making. Hydrologic models operated with readily available data from each step can provide information to assist with decision making.

Impacts on surface water and groundwater due to carcass disposal differ for each carcass disposal method. The impacts on surface water and groundwater will also be site-specific for a given carcass disposal technology. In the case of burial, the selected disposal site may be modified prior to disposal to provide more appropriate land surface conditions for slope, aspect, and roughness, potentially reducing the potential impact on water resources. After disposal, water contamination possibilities increase from decomposition of the carcasses.

Impact evaluation on surface water from carcass disposal includes several issues, such as peak runoff (storm flow), long-term runoff, and stream flow. Surface water quality issues also arise with carcass disposal. Carcasses may release materials that reach water, potentially increasing waterborne pathogens, nutrients, and oxygen consumption.

To evaluate the hydrologic impacts from carcass disposal, the following analysis steps are suggested: screening to identify potential carcass disposal sites for various carcass disposal technologies, more detailed pre-disposal assessment of sites, real-time assessment of sites during carcass disposal and post-disposal site assessment. Complex physical models typically require intensive and wide ranges of data and data preparation, so such models may be too difficult to run for large areas and in the event of a carcass disposal emergency. Therefore, choosing a hydrologic model for a carcass disposal impact evaluation for any stage of carcass disposal analysis is critical to support decision making.

Role of surface water and groundwater models

Through model application, the impact of carcass disposal on water bodies can be identified.

Fundamental questions for water body management typically include "how" and "what if" questions. For example, if a watershed is a carcass disposal site or will be altered by carcass disposal processes, then a question may be "how" the carcass disposal will affect hydrologic conditions and water quality. To answer such a question, hydrologic models are commonly used to evaluate the impact of changes.

The hydrologic models overviewed have varying capabilities as described in the further detail associated with each model. Collectively, they can simulate surface water, groundwater, nutrient movement, and pathogen movement, and may play a significant role in evaluating the impact of carcass disposal. A search of the literature did not identify any example applications of these or other hydrologic models to carcass disposal efforts, and thus the following paragraphs provide brief descriptions of how the hydrologic models have generally been used. This should be helpful for assessing the potential application of these models in carcass disposal events.

The United States Department of Agriculture (USDA) Soil Conservation Service (SCS) Curve Number (CN) Method (USDA SCS, 1986) is one of most popular direct runoff (surface runoff – excludes base flow and other forms of flow in streams) estimation methods and has been incorporated in numerous hydrologic models as a key element. SWAT (Soil and Water Assessment Tools), L-THIA (Long-Term Hydrological Impact Assessment), AGNPS (Agricultural Non-Point Source), SEDSPEC (Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool), and the HEC series of models use the SCS CN method to estimate direct runoff. The SCS CN Method can be used for run off estimation from small areas and watersheds and thus can provide estimates of amounts of water that might runoff an area being used for carcass disposal or that might run on to such an area from the upstream or upslope area.

Since the 1990s, GIS tools have been commonly used with hydrologic and water quality models. SWAT (Arnold et al., 1998) has been integrated with the US Environmental Protection Agency's (EPA) Better Assessment Science Integrating point and Non-point Sources (BASINS, http://www.epa.gov/waterscience/basins/) effort to provide an analysis capability to meet the needs of pollution control agencies. BASINS integrates a GIS, national watershed and meteorological data, and state-of-the-art environmental assessment and modeling tools, with SWAT as a key hydrologic and non-point source pollution model. SWAT also has a broad application spectrum with ability to estimate daily stream flow, non-point source pollution loading and Total Maximum Daily Load (TMDL) levels.

There are several models that can be operated through the Internet thus reducing the level of expertise required to use the models. The Internet-based models include L-THIA, WWW NAPRA (National Agricultural Pesticide Risk Analysis) and SEDSPEC. Among them, L-THIA developed by Harbor (1994) is a screening stage model for NPS and direct runoff estimation. L-THIA uses the SCS CN method as its main core to simulate runoff based on long-term daily rainfall values, land use, and soil information. Its effectiveness as a long-term land use change analysis tool has been demonstrated by several studies (Leitch and Harbor, 1999; 2000; Grove et al., 2001). Muthukrishnan et al. (2002) used the L-THIA model to study the hydrologic impacts of land use changes using time series analysis for watersheds in northeastern Ohio, and the results were found to be very useful to the community and the watershed planners in planning for future land use zoning and development, and minimizing the impacts associated with land use conversion. Models such as L-THIA and SEDSPEC could potentially be used to quickly analyze sites being considered for carcass disposal to understand the potential for runoff from the sites.

The WWW NAPRA (Lim and Engel, 1999) model, also Internet-based, uses the GLEAMS model to simulate field scale non-point source pollution loading and fate. SEDSPEC (Tang et al., 2002) is also an Internet-based model that was developed to support peak runoff, sediment, and erosion control efforts when there are needs to design runoff, erosion, and sediment control structures. SEDSPEC might be useful for quickly assessing whether runoff and erosion control structures (vegetated and lined channels, water diversion structures, culverts, etc) are required at a carcass disposal site and providing a preliminary design for such structures.

The AGNPS model is widely used to estimate runoff and non-point source pollution loadings. Recently, AGNPS was restructured as an annualized continuous-simulation version of the model, AnnAGNPS, to provide operational flexibility. Since AGNPS was introduced, a large number of research results have been published, especially in integrating it with GIS and for agricultural watershed management. Mitchell et al. (1993) applied AGNPS to agricultural small watershed to identify areas contributing disproportionate amounts of runoff and pollutants. Such areas can then be targeted with best management practices to reduce such impacts. In carcass disposal efforts, the local watershed in which the carcass disposal location is located could be analyzed to determine the potential impact of the carcass disposal location in contributing runoff and pollutants to local streams or other waterbodies.

The DRAINMOD model may be useful in understanding shallow groundwater impacts of carcass disposal efforts. McCarthy and Skaggs (1991) applied DRAINMOD to predict drainage rates for changing boundary conditions, and Madramootoo (1990) assessed drainage benefits on a heavy clay soil in Quebec, Canada. The installation of subsurface drainage near carcass disposal sites may be desirable to prevent high water tables from interacting with the disposal site. DRAINMOD is capable of such analysis.

Model classification

Surface water and groundwater models were categorized by evaluation stage for screening, pre-disposal site selection, site analysis during a disposal emergency, and post-disposal analysis. The models were classified into these categories largely based on their complexity, data requirements, and operational requirements.

Screening and pre-disposal evaluation models

Models that evaluate hydrologic and water quality impacts of carcass disposal vary from simple empirical methods to complex physical models in terms of data requirements and model components. Screening models can be applied before or during disposal site selection to identify potentially suitable sites. Such applications require comparably simple data and are relatively easy to use. These models are recommended for preliminary site screening use, and for use in situations of limited resources (time, cost, and human resources). More detailed information is located in Appendix A. For this stage, three models were identified and are listed below:

- SEDSPEC: Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (estimates peak runoff and erosion).
- L-THIA, WWW LTHIA, GIS L-THIA: Long-Term Hydrological Impact Assessment (estimates average annual runoff and nonpoint source pollution).
- DRASTIC: A standardized system for evaluation of groundwater pollution potential using hydrogeologic settings (estimates groundwater vulnerability to pollutants).

Real-time and post-disposal evaluation models

For real-time and post-carcass disposal evaluation, more intensive environmental evaluation using models that have more scientific consideration and better representation of hydrologic components is desirable. Models for these uses typically require significantly greater data, time, and human resources than screening stage models. More detailed information is located in Appendix A. The models recommended in this category are listed below:

- SCS Curve Number Method.
- ANSWERS (ANSWERS-2000): Aerial Nonpoint Source Watershed Environment Response Simulation.
- AGNPS, AnnAGNPS: Agricultural Non-Point Source (AGNPS) model.
- DRAINMOD: A field-scale water management simulation model.
- EUTROMOD: A watershed-scale nutrient loading and lake response model.
- GLEAMS: A model to simulate the effects of different agricultural management systems on the water quality.
- NAPRA WWW: Web-based National Agriculture Pesticide Risk Analysis model.
- SWAT: Soil and Water Assessment Tool.

- WMS: Watershed Modeling System.
- WEPP: Water Erosion Prediction Project.
- EPIC: The Erosion-Productivity Impact Calculator.
- QUAL2E: The Enhanced Stream Water Quality Model, recommended only for post-disposal evaluation because the model requires observed data for calibration.

3.3 – Sediment and soil transport

Significant soil disturbance at disposal sites is a likely result of many carcass disposal technologies. In most instances, burial would result in significant soil disturbances. However, incineration, composting, and alkaline hydrolysis may result in disturbances due to operation of heavy machinery and trucks. Soil disturbances typically increase the potential for erosion, and soil eroding from these sites may carry contaminants resulting in severe off-site impacts. After the closure of carcass burial sites, the gas diffused through the cover of the site can stress vegetation, potentially increasing soil erosion. The impacts of carcass disposal methods on soil erosion should be considered and minimized to avoid possible off-site contamination by pathogens and other contaminants attached to sediment.

Role of sediment and soil transport models

Computer models can be used to identify possible locations for carcass disposal, minimizing the soil erosion and soil quality degradation. These models can be used to simulate the impacts of land disturbance by the carcass disposal methods on soil erosion. Since soil erosion is also related to water movement, combined hydrologic and soil erosion models can be used for this purpose. To simulate the movement of soil particles and associated contaminants by wind, wind erosion models are also discussed.

A search of the literature did not identify any example applications of erosion models to carcass disposal efforts, and thus the following paragraphs provide brief descriptions of how some erosion models have generally been used. This should be helpful for assessing the potential application of these models in carcass disposal events.

The Water Erosion Prediction Project (WEPP) model estimates runoff and soil erosion from small watershed or field areas. Cochrane and Flanagan (1999) applied WEPP to assess water erosion in small watersheds using GIS and digital elevation models. Vining et al. (2001) applied WEPP to a watershed in Michigan to solve a water quality problem, and Laflen et al. (2001) utilized WEPP at construction sites to understand the erosion impact from unprotected soils. WEPP could be useful in assessing the potential magnitude of soil losses from carcass disposal sites and from such sites once they are "closed."

RUSLE2 (Foster et al., 2001) and RUSLE (Renard et al., 1991) are revisions of the USLE (Universal Soil Loss Equation). The USLE is the most widely used erosion model and is often embedded in other soil erosion models to estimate annual soil loss yield and erosion. Among the abundant applications of USLE, Toy et al. (1999) used RUSLE to estimate soil loss from mining, construction, and reclamation lands during periods when the soil was disturbed. Hession and Shanholtz (1988) used GIS with the USLE to compute sediment loading to streams. The USLE estimated values matched the measured values reasonably well (R2 = 0.88) for the small watersheds studied. Simanton et al. (1980) applied the USLE to four watersheds and found USLE estimated soil losses matched reasonably for two watersheds having no gullies or significant alluvial channels. Note the USLE does not estimate gully erosion, rather it provides a method for quick estimation of rill and inter-rill erosion.

Model classification

Erosion models ranging from simple screening models to complex models, which can be used to assess the impacts of carcass disposal methods on the soil erosion and sediment yield, are introduced below.

Screening models

Many water and wind erosion models can be used for the evaluation of carcass disposal sites. However, these models are complex and are difficult to operate without erosion modeling knowledge. These screening models can be used as guidance to choose a potential location for carcass disposal. Additional descriptions of these can be found in Appendix B. The erosion screening models include:

- K: Soil Erodibility.
- RWEQ: The Revised Wind Erosion Equation.
- WEPS: Wind Erosion Prediction System.
- USLE: Universal Soil Loss Equation.

Pre-disposal, real-time, and post-disposal evaluation models

The water and wind erosion models listed below can be used for pre-disposal site assessment, real-time assessment of erosion, and post-disposal evaluation. These models provide more detailed soil erosion and sediment yield results than the screening models, although input data required for these models are sometimes not readily available. Some of the following models predict the results on a daily time step, which is potentially desirable for real-time assessment and post-disposal evaluation. Additional information is located in Appendix B. These models are:

- RUSLE: Revised Universal Soil Loss Equation.
- WEPP: The Water Erosion Prediction Project.
- AGNPS: Agricultural Non-Point Source Pollution Model.
- ANSWERS: Areal Nonpoint Source Watershed Environmental Response Simulation.
- SWAT: Soil and Water Assessment Tool.
- WEPS: Wind Erosion Prediction System.

3.4 – Soil Quality and Ecology (Biological Transport)

As stated previously, significant soil disturbance at disposal sites is a likely result of many carcass disposal technologies. In particular, burial of carcasses, or ash and residue from burning or chemical digestion, can create what are, in effect, mini-landfills which may require careful design and long-term monitoring. The rationale for this comparison stems from the large volumes of leachate produced by burial of carcasses, the concentration of metals or pathogens possible from burial of ash and incineration, or biological digestion remnants.

For example, a pit intended to contain 100 carcasses at 1,000 pounds mass per carcass may not be designed to effectively handle the hundreds of liters of leachate from the decomposing carcasses. Leachate may contain biological agents or mineral constituents undesirable in underlying aquifers. Leachate will be present even if a clay cap is placed over the pit, arising from fluids in the carcasses. Technology for determining hazards represented by this leachate and for controlling, preventing, or monitoring this leachate exists and can be implemented with proper planning.

The pits intended to contain ash and residue from the burning or chemical digestion of carcasses can also suffer from poor design. The range of possible construction criteria goes from wet, aerobic composting-type pits to covered, anaerobic landfill-type excavations. The specific design style should be determined in advance for the local or regional conditions. High-water tables, shallow drinking aquifers, rocky or sandy soils, and proximity of water bodies are examples of factors that should be included in the design stage, preferably in advance of an emergency.

Role of multimedia models in soil quality

These factors suggest that using computer models intended to design and monitor landfill construction may be useful in creating a standard design for a disposal site for burying carcasses, incineration remains, or chemical digestion products. Appropriate models individually or in aggregate should account for the water balance leaving the site and carrying with it chemical and biological constituents.

Model classification

As with other technologies, models range from simple and basic to those with very detailed inputs and complex functions. This document describes models based on i) pre-implementation regional screening and risk management or ii) design standards for disposal and post-implementation monitoring.

Regional screening and pre-disposal evaluation and risk assessment

Models that can account for leachate creation and motion on a regional scale include generalizations of local physical characteristics or boundary conditions. These models can result in outputs that can be generalized across a region and can describe exposure to leached contaminants in terms of risk to the population or food chain.

Models in this section involve physical soil parameters, weather parameters, chemical constants, and time steps; and they are referred to as "multimedia" models. Several such models are available for use in risk assessment of exposure to chemicals moving off site from surface impoundments, landfills, land application units, and waste piles. Some are available as open source programs and also as enhanced versions from commercial distributors. Examples of both are included. The principal models used are discussed below. Detailed descriptions of these can be found in Appendix C.

Regional screening and risk assessment

The models most suitable for prescreening of sites, including at regional scales, include:

- PRZM3.
- MULTIMED 2.0.
- 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment Model.
- MMSOILS.

Site design and monitoring

Several multimedia models are available for use in designing landfills, sludge disposal sites, manure waste lagoons, and similar features that need to account for the precise motion of water, chemicals, and biological agents through both constructed and natural features. The standard model for landfill design (HELP) is available as an open source program and also in enhanced versions from commercial distributors. Examples of both are included. Detailed descriptions of these can be found in the Appendix. The principal models that might be considered are listed below:

- HELP.
- Visual HELP.
- BIOF&T-3D.
- 3DFATMIC.
- MIGRATEv9.

3.5 –Air

The impacts of carcass disposal methods—such as burial, incineration, and composting—on air quality should be assessed to control and monitor the possible hazard to the local public. Gases generated from carcass burial could be toxic and could violate air quality standards. In the case of incineration, dioxins may be generated and travel off site with pyre smoke.

Role of air models

Computer models can be used to simulate the movement of odor, toxic gases, particulate matter, and airborne pathogens. These computer models can be used to identify the potential location for carcass disposal while minimizing off-site impacts of airborne pollutants. These simulations can be used to assess the impact of a disposal site on air quality during disposal and after a site is closed.

A search of the literature did not identify any example applications of air quality models to carcass disposal efforts. However, concerns have been raised about the potential for diseases to be transmitted in the smoke and particles that move off site as a result of incineration of diseased carcasses. The FMD virus can be spread by the wind as well as by the movement of infected animals and aerogenous transmission to susceptible animals (Donaldson and Alexandersen, 2002). A computer model called the Virus Production Model (VPM) was developed and integrated into a GIS system to simulate the airborne spread of viruses (Sorensen et al., 2000; Sorensen et al., 2001). The model generates airborne plumes that can assist decision-making processes and help in deploying personnel to contain the disease (Sorensen et al., 2001). However, the model does not consider the incineration of diseased animals but assumes live animals. The following paragraph provides a brief description of how some air quality models have generally been used. This should be helpful for assessing the potential application of such models in carcass disposal events

SCREEN3 is the model currently used by US EPA for regulatory screening of new air permit applications and new source review screening. It estimates the worst-case scenario ambient impacts from point, volume, and area sources of pollutants by incorporating general meteorological conditions. USEPA uses this model as a conservative first-run screening tool, followed by more refined modeling in areas determined by SCREEN3 to be of potential concern (US EPA, 1995). Such a model might be used for screening locations and carcass disposal situations. Those locations and situations that appear to raise potential air quality concerns could be modeled further with more complex models.

Model classification

Models ranging from simple screening models to complex that can be used to assess the impacts of carcass disposal methods on air quality are introduced in the following sections.

Screening models

Two air dispersion models were identified for potential use as screening tools. These screening models can be used to simulate/assess the immediate impacts of carcass disposal on air quality in the vicinity of the carcass disposal site. More detailed information is provided in Appendix D.

- SCREEN3
- CTSCREEN: Complex Terrain Screening Model.

Pre-disposal, real-time, and post-disposal evaluation models

Different computer models are needed to simulate the dispersion of pollutants from the different carcass disposal methods, such as burial and incineration. The air dispersion models, capable of simulating dispersion from open burning, point, line, and area sources, can be used for the evaluation of sites prior to disposal, during disposal and post-disposal. These complex computer models predict the peak concentration and time-averaged concentration of air pollutants. These models can predict the source contribution and plume characteristics at sampling locations for every hour, day, and year. More detailed information is provided in Appendix D.

- Open Burn/Open Detonation Dispersion Model (OBODM).
- Atmospheric Dispersion Modeling System (ADMS).
- Areal Locations of Hazardous Atmospheres (ALOHA).
- Integrated PUFF (INPUFF).

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Appendices

Appendix A – Surface water and groundwater models list

A1. SCS Curve Number Method

A2. ANSWERS (ANSWERS-2000)

A3. AGNPS, AnnAGNPS

A4. DRAINMOD

A5. EUTROMOD

A6. GLEAMS

A7. SEDSPEC

A8. L-THIA, WWW-LTHIA, GIS-L-THIA

A9. NAPRA WWW

A10. SWAT

A11. QUAL2E

A12. WMS

A13. DRASTIC

A14. WEPP

A15. EPIC

A16. MODFLOW

No. A1: SCS Curve Number Method

Category: Surface water/Groundwater/Air/Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water (peak runoff estimation)

Model Name: NRCS Curve Number Method

Overview

The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions, results in the equation found in Section 4 of the US Department of Agriculture Soil and Conservation Service *National Engineering Handbook* (NEH-4), where curve number (CN) represents a convenient representation of the potential maximum soil retention.

Although usually considered to be a model for predicting surface runoff, "direct flow" (Q) also includes subsurface flow or interflow. The method was developed to predict the initial or "quick" response of a watershed outlet to a storm event. In the case of tile-drained watersheds, total outlet response may be the sum of base flow or water flowing directly in through the sides and bottom of the ditch or stream channel, flow entering the ditch via field tile systems, and surface runoff. Quick response may be predominantly tile-flow, with any surface runoff being passed to the low-lying areas of the watershed to exit as base flow or tile flow. Conceptually, the SCS method could be applicable to such watersheds with possible modification of the following:

a) Curve number (CN) value used to estimate potential maximum soil retention (S). Values are tabulated in Chapter 9 of NEH-4 for various land covers and soil textures. These values were developed from annual flood rainfall-runoff data from the literature for a variety of watersheds generally less than one square mile in area.

b) Fraction of potential maximum retention (S) associated with initial abstractions (Ia). Initial abstractions are water losses (such as plant interception, infiltration, and surface storage) which occur prior to runoff and are thus subtracted from the total rainfall available for either soil retention or quick response. The standard assumption is that $Ia = 0.2S$. The "0.2" was based on watershed measurements with a large degree of variability and other researchers have reported using values ranging from 0.0 to 0.3. The original estimates of Ia were determined by subtracting rain that fell prior to the beginning of watershed outlet response from the total rainfall. Several sources of error associated with these estimates are listed in NEH-4, including the likelihood that some of the abstracted rainfall does eventually appear at the outlet. In the case of tile-drained watersheds, there is a greater chance that some of this rainfall could contribute to quick response.

c) Accounting for watershed wetness prior to the storm event of interest (antecedent moisture condition, AMC). Curve number can be adjusted to estimate less runoff under dry conditions and more runoff under wet conditions. Table 4.2 of NEH-4 provides guidance for this adjustment based on the amount of rainfall over the previous five days. The appropriateness of this guidance is likely to depend on location and size of the watershed. The table was eliminated from the 1993 edition of NEH-4.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial, Public domain, N/A

Input Data: Land use, Hydrologic soil group, Rainfall

Output Results: Direct Runoff

Selected References:

US Department of Agriculture, Soil Conservation Service. (1971). *National Engineering Handbook. Section 4. Hydrology*. Washington, DC: US Department of Agriculture.

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No. A2: ANSWERS

Category: Surface Water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water - Storm water, Nonpoint source pollution and sediment loading

Model Name: ANSWERS (ANSWERS-2000)

Overview

Beasley and Huggins (1980) developed the original ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) model in the late 1970s. ANSWERS-2000 is a distributed parameter, physically-based, continuous simulation, farm or watershed scale, upland planning model developed for evaluating the effectiveness of agricultural and urban BMPs in reducing sediment and nutrient delivery to streams in surface runoff and leaching of nitrogen through the root zone. The model is intended for use by planners on ungaged watersheds where data for model calibration is not available. The model divides the area simulated into a uniform grid of square (1 hectare or smaller), within which all properties (surface and subsurface soil properties, vegetation, surface condition, crop management, and climate) are assumed homogeneous. The model uses breakpoint precipitation data and simulates hydrologic processes with a 30-second time step during runoff events and with a daily time step between runoff events. The model simulates interception; surface retention/detention; infiltration; percolation; sediment detachment and transport of mixed particle size classes; crop growth; plant uptake of nutrients; N and P dynamics in the soil; nitrate leaching; and losses of nitrate, ammonium, total Kjeldahl nitrogen, and P in surface runoff as affected by soil, nutrient, cover and hydrologic conditions. The model has an ArcInfo based user interface that facilitates data file creation and manipulation. The model is in the public domain and is available via ftp (Dillaha et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: UNIX, Windows

Cost: Public domain

Input Data: Land use, Topographic data, Soil, Storm rainfall

Output Results: Storm runoff, Nonpoint source pollution loading, Sediment loading

Selected References:

Beasley, D.B., Huggins, L.F., & Monke, E.J. (1980). ANSWERS: A model for watershed planning. *Transactions of the ASAE, 23* (4), 938-944.

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ANSWERS-2000. http://dillaha.bse.vt.edu/answers/index.htm, ftp://dillaha.ageng.vt.edu/pub/models/answers

No. A3: AGNPS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Storm runoff, Annual loading of nonpoint source pollution, Sediment loading, Pesticide

Model Name: AGNPS, AnnAGNPS

Overview

The single event Agricultural Non-Point Source (AGNPS) model was developed in the early 1980s by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Natural Resource Conservation Service (NRCS). The model was developed to analyze and provide estimates of runoff water quality resulting from single storm events from agricultural watersheds ranging in size from a few hectares to 20,000 ha. Because of its ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

AGNPS is a single-event model. Early in its development, this was recognized as a serious model limitation. In the early 1990s, a cooperative team of ARS and NRCS scientists was formed to develop an annualized continuous-simulation version of the model, AnnAGNPS. Coordination of the effort was originally supervised by the ARS, North Central Soil Conservation Laboratory in Morris, Minnesota, and later was transferred to the NRCS, National Water and Climate Center, Water Science and Technology Team in Beltsville, Maryland. Research and development leadership was assumed by the ARS, National Sedimentation Laboratory in Oxford, Mississippi. NRCS in Beltsville provides technology transfer support for AnnAGNPS.

AnnAGNPS is the pollutant loading component for a suite of models referred to as AGNPS 2001. AGNPS 2001 is a tool for use in evaluating the effect of management decisions impacting a watershed system. AGNPS 2001 includes GIS routines for developing model input and analysis of model output, a synthetic weather generator (GEM), AnnAGNPS for pollutant loading, in-stream modeling routines, and routines to examine salmon development. The tool automates many of the input data preparation steps needed for use with large watershed systems (Bosch et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: UNIX, DOS, Windows

Cost: Commercial or Public domain

Input Data:

- Climate: precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed
- Land characterization data: soil characterization, curve number, RUSLE parameters, and watershed drainage characterization

- Field operation data: tillage, planting, harvest, rotation, chemical operations, and irrigation schedules
- Feedlot operations: daily manure production rates, times of manure removal, and residual amount from previous operations.
- Output Results: storm runoff, nonpoint source pollution loading, sediment loading, pesticide

Selected References:

Bosch, D., Theurer, F., Bingner, R., Felton, G., & Chaubey, I. (2001). Evaluation of the AnnAGNPS Water Quality Model, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398. Southern Association of Agricultural Experiment Station Directors, 45-54.

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USDA-ARS. National Sedimentation Laboratory. http://dillaha.bse.vt.edu/answers/index.htm

No. A4: DRAINMOD

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface and subsurface water flow simulation

Model Name: DRAINMOD

Overview

DRAINMOD is a field-scale water management simulation model. The model simulates surface and subsurface water flows in response to water management systems in soils with high water tables. Surface and subsurface drainage improvements along with controlled drainage and subirrigation can be considered by DRAINMOD. Simulations of 20 years or more enable system comparisons over a range of weather scenarios. The model was developed by Skaggs (1980a) and has been updated a number of times to extend the model's capabilities (Skaggs et al., 1988; Workman et al., 1994; Fernandez et al., 1998).

DRAINMOD simulates the effects of various water management systems on water tables by performing a one-dimensional water balance at the midpoint between parallel drains. The drains can be either subsurface tiles or open ditches. The water management systems can include combinations of surface drainage, subsurface drainage, controlled drainage, and subirrigation. The water balance includes routines to simulate surface and subsurface drainage, infiltration, and evapotranspiration (Parsons et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial or Public domain

Input Data: Field observations, NRCS soils databases, Long-term weather records

Output Results: Runoff, Infiltration, Evapotranspiration, Depth to the water table, Drainage volume, Number of work days based on soil air volume, Drought and wet stresses

Selected References:

Fernandez, G.P., Chescheir, G.W., & Skaggs, R.W. (1998, March). DRAINMOD 5.0: A windows version that considers crop yield, nitrogen and salinity. In Brown, L. C. (Eds.), *Drainage in the 21st Century: Food Production and the*

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Skaggs, R.W. (1980b). *DRAINMOD: Reference Report - Methods for Design and Evaluation of Drainage-Water Management Systems for Soils with High Water Tables*. Fort Worth, TX: USDA-SCS.

Skaggs, R.W., Parsons, J.E., & Konyha, K.D. (1988). DRAINMOD version 4.0 — An overview. *Proceedings of the American Society of Agricultural Engineers,* Paper No. 88-2563. St. Joseph, MI: ASAE.

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No. A5: EUTROMOD

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Watershed-scale nutrient loading and lake response

Model Name: EUTROMOD

Overview

EUTROMOD is a watershed-scale nutrient loading and lake response model. The model provides information concerning the appropriate mix of point source discharges, land use, and land management controls that result in acceptable lake water quality. EUTROMOD is intended for predicting lakewide average conditions for the growing season as a function of annual nutrient loadings. Therefore, short-term conditions (e.g., weekly or monthly), spatially-local water quality (e.g., concentrations in embayments), and dynamic response (e.g., continuous changes over time) cannot be predicted.

The model was developed by Ken Reckhow of Duke University (Reckhow et al., 1992) as a simple, spreadsheet-based collection of models with built-in uncertainty analysis. Although several updates are currently in development, this paper focuses on Version 3.0 which is actively supported and available from the North American Lake Management Society for a fee. Annual runoff, erosion, and nutrient (nitrogen and phosphorus) loadings are simulated with a simple, lumped watershed modeling procedure. Lake response is predicted by a set of nonlinear regression equations from multi-lake regional data sets in terms of lake nutrient levels, chlorophyll *a*, Secchi Disk depth, and a trophic state (Hession et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Cost: Commercial or Public domain

Input Data:

- Precipitation: annual mean, coefficient of variation
- Precipitation nutrients: phosphorus, nitrogen
- Erosion factors: runoff coefficient, rainfall erosivity, soil erodibility, topographic factor, cropping factor, practice factor, area per land use
- Phosphorus loading factors: dissolved, sediment attached, phosphorus enrichment ratio, ENP ratio
- Nitrogen loading factors: dissolved, sediment attached, nitrogen enrichment ratio, ENN ratio, trapping factors
- Septic system information: number of people, phosphorus load, nitrogen load, phosphorus soil retention, nitrogen soil retention
- Point source information: waste flow, phosphorus concentration, nitrogen concentration
- Lake: surface area, mean depth, lake evaporation

Output Results: Average annual surface water runoff, Annual soil loss, Nutrient loading, Lake nutrient concentrations, Chlorophyll *a* concentrations, Trophic state index

Selected References:

Reckhow, K.H., Coffey, S., Henning, M.H., Smith, K., & Banting, R. (1992). *EUTROMOD: technical guidance and spreadsheet models for nutrient loading and lake eutrophication*. Draft report. Durham, NC: School of the Environment, Duke University.

Hession, W.C., Storm, D.E., Burks, S.L., Smolen, M.D., Lakshminarayanan, R., & Haan, C.T. (1995). Using EUTROMOD with a GIS for establishing total maximum daily loads to Wister Lake, Oklahoma, In K. Steele (Eds.), *Impact of Animal Waste on the Land-Water Interface*, 215-222. Boca Raton, FL: Lewis Publ.

Hession, W.C., McBride, M., Parsons, J.E., & Reckhow, K.H. (2001). Evaluation of the Water Quality Model EUTROMOD, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 63-68. Southern Association of Agricultural Experiment Station Directors.

No. A6: GLEAMS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water and Groundwater

Model Name: GLEAMS

Overview

The GLEAMS model is a computer program used to simulate water quality events on an agricultural field. GLEAMS has been used in the US and internationally to evaluate the hydrologic and water quality response of many different scenarios considering different cropping systems, wetland conditions, subsurface drained fields, agricultural and municipal waste applications, nutrient and pesticide applications, and different tillage systems. It has been used both as a research model and as a management model, depending upon the user's desire. (Shirmohammadi et al., 2001)

In order to simulate the many events occurring on a field, the model is divided into three separate submodels, or parameter files. These submodels include hydrology, erosion/sediment yield, and chemical transport. The chemical transport submodel is further subdivided into nutrient and pesticide components so that one, or both, may be simulated as desired by the user. The parameter files contain variables which are entered by the user in order to best simulate the management events occurring on the particular field of study. The hydrology component simulates runoff due to daily rainfall using a modification of the SCS curve number method. Hydrologic computations are determined using a daily time step (Shirmohammadi et al., 2001).

A modification of the Universal Soil Loss Equation (USLE) is used to estimate inter-rill and rill detachments, and a modification of Yalin's equation is used to estimate the sediment transport capacity. Different topographic configurations and surface flow processes may be selected to properly assess the sediment detachment and deposition on the land surface. The chemistry component of the GLEAMS is divided to pesticide and nutrient submodels. The user may select to run any or all of the specified components during each simulation (Shirmohammadi et al., 2001).

The pesticide component of the GLEAMS incorporates the surface pesticide response of CREAMS with a vertical flux component to route pesticides into, within, and through the root zone. Characteristics of pesticide adsorption to soil organic carbon are used to partition compounds between solution and soil fractions for simulating extraction into runoff, sediment, and percolation losses. Pesticide dissipation in soil and on foliage is treated as a first-order process with a different apparent half-life for each. (Shirmohammadi et al., 2001).

The nutrient component of the GLEAMS is a complex submodel and considers both nitrogen and phosphorus cycles. The nitrogen component includes: mineralization, immobilization, denitrification, ammonia volatilization, nitrogen fixation by legumes, crop N uptake, and losses of N in runoff, sediment, and percolation below the root zone. It also considers fertilizer and animal waste application. The phosphorus component includes: mineralization, immobilization, crop uptake, losses to surface runoff, sediment, and leaching, and it also includes fertilizer and animal waste application. Tillage algorithms are included in the model to account for the incorporation of crop residue, fertilizer and animal waste (Shirmohammadi et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial or Public domain

Input Data: Precipitation, Soil characteristics, Land use, Pesticide, Nutrients, Cultivation

Output Results: Water, Sediment, Nutrient, and Pesticide movement on surface and through the root zone

Selected References:

Knisel, W. G., Leonard, R. A., & Davis, F. M. (1989, July). Agricultural management alternatives: GLEAMS model simulations. *Proceedings of the 1989 Summer Computer Simulation Conference*, 701-706. Austin, TX: Society for Computer Simulation.

Shirmohammadi, A., Knisel, W. G., Bergström, L. F., Bengtson, R., Ward, A., Reyes, M., Manguerra, H., & King, K. (2001). GLEAMS Model, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 69-82. Southern Association of Agricultural Experiment Station Directors.

Southeast Watershed Research Laboratory. http://dino.wiz.uni-kassel.de/model_db/mdb/gleams.html

No. A7: SEDSPEC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation and conservation structures design

Model Name: SEDSPEC

Overview

SEDSPEC, Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool, is an expert system which will assist users in analyzing runoff and erosion problems on their sites. The analysis will provide information about different types of runoff and erosion control structures. Also, SEDSPEC will provide customized drawings of the structures, and there is a limited amount of interaction which allows users to determine what size structure fits their needs.

SEDSPEC designs and recommends many structures. The following lists provide some basic information and maintenance concerns for each structure. The reason SEDSPEC does not design every structure on the list is that many structures require no design, and a few structures are too complicated to design over the Web.

SEDSPEC designs the following structures: Concrete-lined channel, culvert, grass-lined channel, level terrace, low-water crossing, open channel, riprap-lined channel, runoff diversion, sediment basin, and storm water detention basin.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Web browser, Internet connection

Cost: Commercial or Public domain

Input Data: Land use, hydrologic soil group, area, location information

Output Results: Peak runoff, conservation structures dimension recommended

Selected References:

Tang, Z., Choi, J.Y., Sullivan, K., Lim, K.J., Engel, B.A. (2002). A Web-based DSS for watershed sediment and erosion control. *Proceedings of the American Society of Agricultural Engineers*, Chicago, IL, Paper. No. 023038, St. Joseph, Michigan: ASAE.

Purdue Research Foundation. (1994). http://pasture.ecn.purdue.edu/~sedspec

No. A8: L-THIA

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Long-term daily direct runoff estimation

Model Name: L-THIA, WWW LTHIA, GIS L-THIA

Overview

Community planners, developers, and citizens of a community should be aware of the long-term impacts of land use change on their environmental resources. L-THIA, Long-Term Hydrologic Impact Assessment, is designed to help these people to quantify the impact of land use change on the quantity and quality of their water. This tool uses the land use and a soil characteristic from the user along with thirty years of precipitation data to determine the average impact that a particular land use change or set of changes will have on both the annual runoff and the average amount of several non-point source pollutants. For those unfamiliar with the hydrologic (water-related) impacts of land use change, this tool and the supporting documents will hopefully give the user enough information to start asking questions about land use changes in their area.

There are two input screens for L-THIA; both are available from the side bar to the left. For those new to L-THIA and land use planning, Basic Input is a good place to start. There are eight choices for land use types which most land uses fall into. For those familiar with land use planning terms or who need to describe a custom land use, Detailed Input gives more land use options. The fourteen choices for land uses includes six lot sizes for residential housing and an option to define a custom land use. After using the Basic Input for a few analyses, a user would be able to use the Detailed Input.

Additional information about long-term impacts of land use change and L-THIA can be found in the Documentation section (click on the words in the navigation bar to the left). Along with background information about L-THIA there is information on how to interpret your results and what you can do to minimize the impacts of land use change.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Internet connection and Web browser

Cost: Commercial or Public domain

Input Data: Land use, Hydrologic soil group, Area, Location (state, county name)

Output Results: Daily direct runoff, Nonpoint source pollution

Selected References:

Harbor, J. (1994). A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff, Groundwater Recharge, and Wetland Hydrology. *Journal of the American Planning Association, 60* (1), 95-108.

Lim, K.J., Engel, B.A., Kim, Y., Bhaduri, B., & Harbor. J. (1999). Development of L-THIA/NPS GIS System and Web-Based L-THIA System. *Proceedings of the American Society of Agricultural Engineers*, St. Joseph, MI, Paper No. 992009, St. Joseph, MI: ASAE.

Pandey, S., Gunn, R., Lim, K.J., Engel, B.A., & Harbor, J. (2000). Developing Web-based Tool to Assess Long-term Hydrologic Impacts of Land use Change: Information Technology Issues and a Case Study. *Journal of Urban and Regional Information System Association (URISA), 12* (4), 5-17.

Pandey, S., Harbor, J., & Engel, B. (2001). *Internet Based Geographic Information Systems and Decision Support Tools*. Rak Rigde, IL: Urban and Regional Information Systems Association.

Purdue Research Foundation. (1994). www.ecn.purdue.edu/runoff

No. A9: NAPRA WWW

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Field scale pesticide and nutrient movement

Model Name: NAPRA WWW

Overview

NAPRA WWW provides a basis from which decisions on crop management practices can be made based on potential pesticide loss to the environment. The NAPRA tool recognizes that yearly variations in climate prevent the prediction of "typical" values of pesticide loss, and it therefore provides probabilities that can be used to make informed decisions to enhance farmer profitability while protecting the environment.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Internet connection and Web browser

Cost: Commercial or Public domain

Input Data: Land use, Hydrologic soil group, Area, Location (state, county name), Pesticide, Rainfall, Management data

Output Results: Water, Sediment, Nutrient, and Pesticide movement on surface and through the root zone

Selected References:

Knisel, W.G., Leonard, R.A., & Davis, F.M. (1994). *Groundwater Loading Effects of Agricultural Management systems. Version 2.10*. Tifton, GA: USDA-ARS. Southeast Watershed Research Laboratory.

Lim, K.J., & Engel, B.A. (2003). Extension and enhancement of national agricultural pesticide risk analysis (NAPRA) WWW decision support system to include nutrients, *Computers and Electronics in Agriculture, 38* (3), 227-236.

Manguerra, H.B., & Engel, B.A. (1997). Java-based Internet/WWW front-end for an integrated hydrologic and pesticide risk assessment model. *Proceedings of the American Society of Agricultural Engineers,* Minneapolis, MN.

Purdue Research Foundation. (1994). http://pasture.ecn.purdue.edu/~napra

No. A10: SWAT

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Daily stream flow, Pesticide, Nutrient loading

Model Name: SWAT

Overview

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data.

SWAT is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single-event flood routing (Neitsch et al., 2002).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Windows, UNIX, ArcView

Cost: Commercial or Public domain

Input Data: Daily rainfall, Geospatial data (DEM, Soil), Pesiticide, Nutrient

Output Results: Daily streamflow, Evapotranspiration, Pesticide, Nutrient

Selected References:

Neitsch S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., King, K. W. (2002). *Soil and Water Assessment Tool Theoretical Documentation 2000*. Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

Srinivasan, R., Ramanarayanan, T. S., Arnold, T. G., & Bednarz, S. T. (1998). Large Area Hydrologic Modeling and Assessment - Part II: Model Application. *Journal of the American Water Resources Association, 34* (1), 91-101.

Soil and Water Assessment Tool. http://www.brc.tamus.edu/swat/

No. A11: QUAL2E

Category: Surface Water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: River water quality modeling

Model Name: QUAL2E

Overview

The Enhanced Stream Water Quality Model (QUAL2E) is a comprehensive and versatile one-dimensional stream water quality model. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration, and their effects on the dissolved oxygen balance. In addition, the computer program includes a heat balance for the computation of temperature and mass balances for conservative minerals, coliform bacteria, and non-conservative constituents such as radioactive substances. (F. Birgand, 2001)

The model is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. QUAL2E has been explicitly developed for steady flow and steady wasteload conditions and is therefore a “steady state model” although temperature and algae functions can vary on a diurnal basis. Although the core of the model has not changed since 1987, there have been some modifications on the interfaces and other associated tools to assist the users, and the evaluation will discuss all the available versions of QUAL2E.

The conceptual representation of a stream used in the QUAL2E formulation is a stream reach that has been divided into a number of subreaches or computational elements equivalent to finite difference elements. For each computational element, a hydrologic balance in terms of flow, a heat balance in terms of temperature, and a materials balance in terms of concentration is written. Both advective and dispersive transports are considered in the materials balance. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations and it specifically uses a special steady-state implementation of an implicit backward difference numerical scheme which gives the model an unconditional stability.

Applicable Scale: River

Cost: Commercial or Public domain

Input Data: Values and ranges for rates and constants are provided by the user’s manual

Output Results:

QUAL2E produces three types of tables -- hydraulics, reaction coefficient, and water quality -- in the output file. The outputs can be easily imported into other application such as spreadsheets for analysis. The Windows™ based version (US EPA, 1995) includes some graphic analysis of the model results. State variables can be plotted at defined distances along the reaches. In addition, the user can input field observations for dissolved oxygen with minimum, average, and maximum values. The model uses those values to plot the observed data versus the estimated ones. In case of dynamic simulations, the model produces temperature and algae values on the defined time step (F. Birgand, 2001).

Selected References:

Birgand, F. (2001). Evaluation of QUAL2E, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 99-106. Southern Association of Agricultural Experiment Station Directors.

US EPA. (1995). *QUAL2E Windows interface user's guide*. (US EPA Publication No. EAP/823/B/95/003). United States Environmental Protection Agency

Environmental Protection Agency. http://www.epa.gov/OST/BASINS/bsnsdocs.html.

No. A12: WMS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation, Surface runoff

Model Name: WMS (Watershed Modeling System)

Overview

WMS, the Watershed Modeling System, is an integrated system for watershed modeling rather than a hydrologic model. WMS is a comprehensive hydrologic modeling environment. WMS provides tools for all phases of watershed modeling including automated watershed and sub-basin delineation, geometric parameter computation, hydrologic parameter computation (CN, time of concentration, rainfall depth, etc.) and result visualization. WMS provides complete support of the industry-standard US Army Corps of Engineers HEC-1 and HEC-HMS, US Soil Conservation Service TR-20 and TR-55, and Rational Method Equation hydrologic routing programs. Also supported the National Flood Frequency (NFF) model, which was developed by the US Geologiocal Service (USGS) in cooperation with the Federal Highway Administration (FHWA) and the Federal Emergency Management Agency (FEMA). In addition, support for the EPA/USGS hydrologic water quality HSPF model is also provided (http://www.scisoftware.com/products/wms_details/wms_details.html).

This system can be used to evaluate not only hydrologic impact from carcass disposal, but also flood feasibility analysis around carcass disposal sites, because this system includes more than four different hydrologic models. One great benefit of using this system is that it has well-developed user interface and results visualization.

Applicable Scale: Field and Watershed

Computer System Requirements: Windows

Cost: Commercial or Public domain

Input Data: Input parameters vary depending on the model. Details are provided by the user's manual.

Output Results: Output parameters vary depending on the model. Details are provided by the user's manual.

Selected References:

http://www.scisoftware.com/products/wms_details/wms_details.html.

No. A13: DRASTIC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Groundwater

Model Name: DRASTIC

Overview

DRASTIC is a groundwater quality model for evaluating the pollution potential of large areas using the hydrogeologic settings of the region (Aller et al., 1985, Aller et al., 1987, Deichert et al., 1992). This model was developed by the EPA in the 1980s. DRASTIC includes various hydrogeologic settings which influence the pollution potential of a region. A hydrogeologic setting is defined as a mappable unit with common hydrogeologic characteristics. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative groundwater vulnerability to contamination. The hydrogeologic settings which make up the acronym DRASTIC are:

[D] Depth to Water Table: Shallow water tables pose a greater chance for the contaminant to reach the groundwater surface as opposed to deep water tables.

[R] Recharge (Net): Net recharge is the amount of water per unit area of the soil that percolates to the aquifer. This is the principal vehicle that transports the contaminant to the groundwater. The more the recharge, the greater the chances of the contaminant to be transported to the groundwater table.

[A] Aquifer Media: The material of the aquifer determines the mobility of the contaminant through it. An increase in the time of travel of the pollutant through the aquifer results in more attenuation of the contaminant.

[S] Soil Media: Soil media is the uppermost portion of the unsaturated/vadose zone characterized by significant biological activity. This, along with the aquifer media, will determine the amount of percolating water that reaches the groundwater surface. Soils with clays and silts have larger water holding capacity and thus increase the travel time of the contaminant through the root zone.

[T] Topography (Slope): The higher the slope, the lower the pollution potential due to higher runoff and erosion rates. These include the pollutants that infiltrate into the soil.

[I] Impact of Vadose Zone: The unsaturated zone above the water table is referred to as the vadose zone. The texture of the vadose zone determines how long the contaminant will travel through it. The layer that most restricts the flow of water will be used.

[C] Conductivity (Hydraulic): Hydraulic conductivity of the soil media determines the amount of water percolating to the groundwater through the aquifer. For highly permeable soils, the pollutant travel time is decreased within the aquifer.

Applicable Scale: Watershed and Regional

Computer System Requirements: DOS and UNIX

Cost: Commercial or Public domain

Input Data: Climate, Precipitation, Soil characteristics

Output Results: Soil moisture, Groundwater quality items

Selected References:

Aller, L., Bennett, T., Lehr, J.H., & Petty, R.J. (1985). *DRASTIC: A Standardized System for Evaluation Groundwater Pollution Potential Using Hydrogeologic Settings*. (US EPA Publication No. EPA/600/2-85/0108). Robert S. Kerr Environmental Research Laboratory.

Purdue University. http://pasture.ecn.purdue.edu/~caagis/tgis/cases/gwq/drastic.html

No. A14: WEPP

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation

Model Name: WEPP

Overview

The WEPP, Water Erosion Predict Project, erosion model is a continuous simulation computer program which predicts soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flow in small channels, and sediment deposition in impoundments. In addition to the erosion components, it also includes a climate component which uses a stochastic generator to provide daily weather information, a hydrology component which is based on a modified Green-Ampt infiltration equation and solutions of the kinematic wave equations, a daily water balance component, a plant growth and residue decomposition component, and an irrigation component. The WEPP model computes spatial and temporal distributions of soil loss and deposition, and provides explicit estimates of when and where in a watershed or on a hill slope that erosion is occurring so that conservation measures can be selected to most effectively control soil loss and sediment yield (Flanagan and Nearing, 1995).

The WEPP now has several different versions for a user's convenience. The WEPP supports a web browser interface (http://octagon.nserl.purdue.edu/weppV1/), and runs on ArcView desktop GIS environment (http://www.geog.buffalo.edu/~rensch/geowepp/).

Applicable Scale: Field, Hill slope and Watershed

Computer System Requirements: DOS, UNIX, and Windows

Cost: Commercial or Public domain

Input Data: Input parameters vary depending on the model. Details are provided by the user's manual.

Output Results: Output parameters vary depending on the model. Details are provided by the user's manual.

Selected References:

Flanagan, D.C., & Nearing, M.A. (1995). *USDA-Water Erosion Prediction Project (WEPP)-Technical Documentation*. (NSERL Report No. 10). West Lafayette, Indiana: National Soil Erosion Research Laboratory, USDA-ARS-MWA.

Purdue University. http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html

No. A15: EPIC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Nonpoint source estimation

Model Name: EPIC

Overview

In the early 1980s teams of USDA Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) scientists developed EPIC, Erosion-Productivity Impact Calculator, to quantify the costs of soil erosion and benefits of soil erosion research and control in the United States. Led by Dr. Jimmy Williams, ARS scientists were responsible for model development. SCS and ERS staff collaborated on model development and took leading roles in soil and weather database development, validation, and creating interfaces with economic models. EPIC is designed to be:

1. Capable of simulating the relevant biophysical processes simultaneously, as well as realistically, using readily available inputs and, where possible, accepted Methodologies.
2. Capable of simulating cropping systems for hundreds of years because erosion can be a relatively slow process.
3. Applicable to a wide range of soils, climates, and crops.
4. Efficient, convenient to use, and capable of simulating the particular effects of management on soil erosion and productivity in specific environments.

The model uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, pesticide and nutrient movement with water and sediment, and field-scale costs and returns.

(http://www.brc.tamus.edu/epic/introduction/index.html)

Applicable Scale: Field

Computer System Requirements: DOS or Windows

Cost: Commercial or Public domain

Input Data: Climate data, Precipitation, Soil characteristics, Land use

Output Results: Runoff, Soil moisture, Evapotranspiration

Selected References:

http://www.brc.tamus.edu/epic/documentation/index.html.

http://www.brc.tamus.edu/epic/introduction/index.html.

No. A16: MODFLOW

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: 3-Dimensional groundwater flow simulation using finite-difference scheme

Model Name: MODFLOW

Overview

MODFLOW, "a three-dimensional finite-difference groundwater flow model" by Michael G. McDonald and Arlen W. Harbaugh, is the most widely used groundwater model in the world. MODFLOW is the name that has been given the USGS Modular Three-Dimensional Groundwater Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation, and mine dewatering. Groundwater flow within the aquifer is simulated in MODFLOW using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, aerial recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated. (http://www.modflow.com/modflow/modflow.html).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

UNIX-based computers and DOS-based 386 or greater computers having a math coprocessor and 4 MB of memory. For more enhanced version with graphical user interface, refer to the Web site, http://www.modflow.com/modflow/modflow.html.

Cost: Public domain

Input Data:

A large amount of information and a complete description of the flow system is required to make the most efficient use of MODFLOW. In situations where only rough estimates of the flow system are needed, the input requirements of MODFLOW may not justify its use. To use MODFLOW, the region to be simulated must be divided into cells with a rectilinear grid resulting in layers, rows, and columns. Files must then be prepared that contain hydraulic parameters (hydraulic conductivity, transmissivity, specific yield, etc.), boundary conditions (location of impermeable boundaries and constant heads), and stresses (pumping wells, recharge from precipitation, rivers, drains, etc.) (http://www.modflow.com/modflow/modflow.html).

Output Results:

MODFLOW can result for groundwater flow for confined, unconfined, or a combination of both aquifers, flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds. Primary output is head, which can be written to the listing file or into a separate file. Other output includes the complete listing of all input data, drawdown, and budget data. Budget data are printed as a summary in the listing file, and detailed budget data for all model cells can be written into a separate file.

Selected References:

Anderman, E.R., & Hill, M.C. (2001). MODFLOW-2000, the US Geological Survey modular ground-water model - documentation of the ADVective-transport observation (ADV2) package, version 2. (US Geological Survey Open-File Report 01-54), US Geological Survey.

Harbaugh, A.W., Banta, E.R., Hill, M.C., & McDonald, M.G. (2000). MODFLOW-2000, the US Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process. (US Geological Survey Open-File Report 00-92), US Geological Survey.

Harbaugh, A.W., & McDonald, M.G. (1996). User's documentation for MODFLOW-96, an update to the US Geological Survey modular finite-difference ground-water flow model. (US Geological Survey Open-File Report 96-485), US Geological Survey.

http://water.usgs.gov/nrp/gwsoftware/modflow.html

http://www.modflow.com/modflow/modflow.html

Appendix B – Sediment and soil transport models list

B1. USLE

B2. RUSLE

B3. Soil Erodibility (K)

B4. WEPP

B5. AGNPS

B6. ANSWERS

B7. SWAT

B8. RWEQ

B9. WEPS

No. B1: USLE

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Screening

Model Name: Universal Soil Loss Equation (USLE)

Overview

The Universal Soil Loss Equation (USLE), developed by W. Wischmeier and D. Smith, has been the most widely used soil loss equation. It estimates the annual soil loss potential by sheet and rill erosion. It cannot be used to estimate the soil erosion for a single storm event or for a certain period of time. The USLE estimates annual soil erosion based on six factors, such as R, K, L, S, C, and P factors. It can be used to find the least soil erosion impact areas for a carcass disposal site.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data:

R = Rainfall-runoff erosivity factor (isoerodent map is available)

K = Soil erodibility factor (available in STATSGO soil database)

L = Slope length factor (can be derived from DEM)

S = Slope steepness factor (can be derived from DEM)

C = Covert-management factor (can be obtained from literature)

P = Support practice factor (can be obtained from literature)

Output Results: Annual average soil loss per unit area (tons/acre/year)

Selected References:

Wischmeier, W.H., & Smith, D.D. (1978). *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*. USDA Agric. Handbook No. 537, 85p.

http://topsoil.nserl.purdue.edu/usle/

No. B2: RUSLE

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Estimate water erosion potential

Model Name: Revised Universal Soil Loss Equation (RUSLE)

Overview

The Revised Universal Soil Loss Equation (RUSLE) is a widely and easily used computer program to estimate soil erosion rates – especially rill and inter-rill erosion – caused by rainfall and overland flow. It is an index-based method to compute the soil erosion in mass per unit area. The RUSLE can be used to develop conservation plants to control erosion. It can be applied to disturbed lands, landfills, construction sites, reclaimed lands, and land disposal of waste. The RUSLE can be used to evaluate the impacts of soil disturbance due to burial or burn by modifying K, LS, and/or? C input parameter values.

Applicable Scale: Field scale

Computer System Requirements: DOS, Windows

Cost: Public domain

Input Data:

R = Rainfall-runoff erosivity factor (Isoerodent map is available)

K = Soil erodibility factor (available in STATSGO soil database)

L = Slope length factor (can be derived from DEM)

S = Slope steepness factor (can be derived from DEM)

C = Covert-management factor (can be obtained from literature/RUSLE)

P = Support practice factor (can be obtained from literature/RUSLE)

Output Results: Annual average soil loss per unit area (tons/acre/year)

Selected References:

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE).* USDA Agric. Handbook No. 703.

http://www.sedlab.olemiss.edu/rusle/

No. B3: Soil Erodibility (K)

Category: Soil erosion

Evaluation State: Screening

Specified Use: Estimate water erosion potential

Model Name: Soil Erodibility (K)

Overview

The soil erodibility (K) represents: (1) susceptibility of soil or surface material to erosion, (2) transportability of the sediment, and (3) the amount and rate of runoff given a particular rainfall input. Fine-textured soils, such as clay, have low K values because of higher resistance to detachment. Coarse-textured soils, such as sandy soil, also have low K value because of high infiltration though these soils are easily detached. Medium-textured soils, such as a silt loam, have moderate K values because of moderate susceptibility to particle detachment and moderate runoff. The soil erodibility can be used as a guidance to choose a potential location for carcass disposal.

Applicable Scale: Field scale

Computer System Requirements: DOS (Using RUSLE K Module)

Cost: Public domain

Input Data: Values of K for undisturbed soils should be selected from soil-survey information published by the NRCS. Values of K for disturbed soils should be computed using the soil-erodibility nomograph.

Output Results: Soil erodibility value between 0 to 1. (Higher K value indicates higher soil erodibility and lower K value indicates lower soil erodibility.)

Selected References:

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE).* USDA Agric. Handbook No. 703.

http://www.sedlab.olemiss.edu/rusle/

No. B4: WEPP

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Estimates soil erosion and sediment yield by water

Model Name: The Water Erosion Prediction Project (WEPP)

Overview

A continuous simulation model used to predict soil erosion for conservation planning and assessment of environmental impacts. This model updates the soil and crop conditions that affect soil erosion. When rainfall occurs, the plant and soil characteristics are used to determine if surface runoff will occur. If predicted, then it computes estimated sheet and rill detachment and deposition, and channel detachment and deposition. It can be used for pre- and post-evaluation of carcass disposal.

Applicable Scale: Hill slope or Field-sized watershed

Computer System Requirements: MS DOS or Windows

Cost: Public domain

Input Data: Climate from either simulated or measured data, Crop and tillage, Rill/inter-rill erodibility, Texture, Organic matter, Rocks. Over 200 input parameters.

Output Results: Daily runoff volumes and peak runoff, plant-canopy, biomass, residue cover, roots, buried residue, soil detachment along hill slope and channel, deposition, sediment yield, soil water by layer, snow melt/frost lenses, and sediment size distribution.

Selected References:

Flanagan, D.C., & Nearing, M.A. (1995). *USDA-Water Erosion Prediction Project (WEPP)-Technical Documentation.* (NSERL Report No. 10). West Lafayette, Indiana: National Soil Erosion Research Laboratory, USDA-ARS-MWA.

http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html

No. B5: AGNPS

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates sediment yield for a basin from a single storm event

Model Name: Agricultural Non-Point Source Pollution Model (AGNPS)

Overview

AGNPS is a tool for use in evaluating the effect of management decisions impacting a watershed system. The capabilities of RUSLE were incorporated into AGNPS. This provides a watershed scale aspect to conservation planning. With the routing capability in this model, it allows modeling of the sediment yield changes at the downstream areas before and after soil disturbance due to carcass disposal methods.

Applicable Scale: Watershed scale

Computer System Requirements: UNIX/Windows

Cost: Public Ddomain

Input Data: SCS Curve Number, land slope, slope shape factor, field slope length, channel sideslope, Manning's roughness, soil erodibility factor, cover and management factor, support practice factor, surface condition constant, aspect (direction to drainage), soil texture, fertilization level, fertilization availability factor, point source indicator, gully source level, impoundment factor, channel indicator.

Output Results: Watershed description, area, characteristic storm precipitation, storm energy-intensity (EI) value, runoff volume, peak runoff rate, fraction of runoff generated within the cell, sediment yield and concentration, sediment particle distribution, upload erosion, channel erosion, amount of deposition, sediment generated within the cell, enrichment ratio, delivery ratio.

Selected References:

Young, R.A., Bosch, D.D., & Anderson, W.P. (1987). *AGNPS, Agricultural Non-Point Source Pollution Model; A Large Watershed Analysis Tool.* Report 35. Washington, DC: USDA.

http://www.sedlab.olemiss.edu/agnps.html

No. B6: ANSWERS

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates sediment loading

Model Name: Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)

Overview

ANSWERS is a distributed parameter, physically-based, continuous simulation, farm or watershed scale, upland planning model developed for evaluating the effectiveness of agricultural and urban BMPs in reducing sediment and nutrient delivery to streams in surface runoff and leaching of nitrogen through the root zone. It allows modeling of sediment yield changes at the downstream areas before and after soil disturbance due to carcass disposal methods.

Applicable Scale: Field and Watershed scale

Computer System Requirements: UNIX/Windows

Cost: Public domain

Input Data: Land use, Topographical data, Soil, Storm rainfall

Output Results: Storm runoff, Pollutant loading, Sediment loading

Selected References:

Beasley, B.B., Huggins, L.F., & Monke, E.J. (1980). ANSWERS: A Model for Watershed Planning. *Transactions of the ASAE*, *23* (4), 938-944.

http://dillaha.bse.vt.edu/answers/index.htm

No. B7: SWAT

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates soil erosion and sediment loading

Model Name: Soil and Water Assessment Tool (SWAT)

Overview

SWAT is a watershed scale, continuous daily time step model to predict the impacts of different agricultural management systems on hydrology, sediment, pesticides, and nutrients in large complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT simulates the crop growth, pesticide and nutrient cycles, and water and sediment movements on a daily time step.

Applicable Scale: Watershed scale

Computer System Requirements: UNIX, Windows

Cost: Public domain

Input Data: Soil, Land use, DEM, Weather data, Pesticide and nutrient application data, Tillage, Cropping

Output Results: Hydrology, sediment, Pesticide, and Nutrient

Selected References:

Neitsch S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., & King, K.W. (2002). *Soil and Water Assessment Tool Theoretical Documentation 2000*. Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

http://www.brc.tamus.edu/swat

No. B8: RWEQ

Category: Soil erosion

Evaluation State: Screening

Specified Use: Calculates average annual soil loss by wind

Model Name: The Revised Wind Erosion Equation (RWEQ)

Overview

The RWEQ model predicts the soil loss between the soil surface and a height of two meters due to wind erosion with information on weather, soils, plants, and land management. It estimates annual or period of wind erosion based on a single event wind erosion model. It can be applied to simulate the movement of airborne pathogen - some pathogens may be easily attached to the fine soil particle - due to wind erosion after carcass disposal on the ground.

Applicable Scale: Field

Computer System Requirements: DOS

Cost: Public domain

Input Data: Monthly weather data, soil and field data, cropping system, tillage and operation dates, wind barrier description, irrigation information.

Output Results: Total erosion by periods in either tabular format or graphical format.

Selected References:

Fryrear, D.W., Saleh, A., Bilbro, J.D., Schomberg, H.M., Stout, J.E., & Zobeck, T.M. (1998). *Revised Wind Erosion Equation.* Agricultural Research Service, Southern Plains Area Cropping Systems Research Laboratory. Wind Erosion and Water Conservation Research Unit. US Department of Agriculture. Technical Bulletin No. 1. June, 1998.

http://www.csrl.ars.usda.gov/wewc/rweq/rweq.htm

No. B9: WEPS

Category: Soil erosion

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: Estimate wind erosion potential

Model Name: Wind Erosion Prediction System (WEPS)

Overview

A process-based, continuous, daily time step model that simulates weather, field conditions, and erosion. It is capable of simulating spatial and temporal variability of field conditions and soil loss/deposition within a field. WEPS can simulate complex field shapes, barriers not on the field boundaries, and complex topographies. It can simulate not only the basic wind erosion processes, but also the processes that modify a soil's susceptibility to wind erosion. It can be applied to simulate the movement of airborne pathogen - some pathogens may be easily attached to the fine soil particle - due to wind erosion after carcass disposal on the ground.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data: Climate statistics, parameters for management such as tillage tool parameters, soil data, crop growth and decomposition parameters. Model input data source: Climate database, SCS soils database.

Output Results: Average soil loss and deposition (including asuspension, saltation, and surface creep components), water balance, and crop biomass.

Selected References:

Hagen, L.J., Wagner, L.E., & Tatarko, J. (1996). *Wind Erosion Prediction System (WEPS) Technical Documentation.* Beta Release 95-08. http://www.weru.ksu.edu/weps/docs/weps_tech.pdf

http://www.weru.ksu.edu/weps.html

Glossary

- Rill erosion: Rill erosion is the removal of soil by concentrated water running through little streamlets, or headcuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills will become wider and deeper.
- Inter-rill erosion: The removal of a fairly uniform layer of soil on a multitude of relatively small areas by splash due to raindrop impact and by sheet flow.
- Overland flow: Overland flow is water that runs across the land after rainfall, either before it enters a watercourse or after it overflows from river banks as flood water.
- Sediment yield: The amount of sediment moved out of the watershed in a given time.
- Enrichment ratio: The ratio of a compound's concentration in the eroded soil to the noneroded soil.
- Delivery ratio: The ratio of the sediment yield to the gross erosion per unit area above a measuring point.

Appendix C – Soil Quality and Ecology Models List

C1. PRZM3

C2. MULTIMED 2.0

C3. 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment Model

C4. MMSOILS

C5. HELP v.3

C6. Visual HELP

C7. BIOF&T – 3D

C8. 3DFATMIC

C9. MIGRATEv9

No. C1: PRZM3

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening

Specified Use: PRZM3 is the most recent version of a modeling system that links two subordinate models--PRZM and VADOFT--in order to predict pesticide transport and transformation down through the crop root and unsaturated zone. Source: Register of Ecological Models

Model Name: PRZM3

Overview

PRZM is a one-dimensional, finite-difference model that accounts for pesticide and nitrogen fate in the crop root zone. PRZM-3 includes modeling capabilities for such phenomena as soil temperature simulation, volatilization, and vapor phase transport in soils, irrigation simulation, microbial transformation, and a method of characteristics (MOC) algorithm to eliminate numerical dispersion. PRZM is capable of simulating transport and transformation of the parent compound and as many as two daughter species.

VADOFT is a one-dimensional, finite-element code that solves the Richard's equation for flow in the unsaturated zone. The user may make use of constitutive relationships between pressure, water content, and hydraulic conductivity to solve the flow equations. VADOFT may also simulate the fate of two parent and two daughter products. The PRZM and VADOFT codes are linked together with the aid of a flexible execution supervisor that allows the user to build loading models that are tailored to site-specific situations. In order to perform probability-based exposure assessments, the code is also equipped with a Monte Carlo pre- and post-processor.

The PRZM3 model system with documentation is available for microcomputer (DOS) systems. Enhancements to Release 3.0 include algorithms that enable modeling of nitrogen cycle soil kinetic processes with the ability to track nitrogen discharges from a septic tank into the soil environment and movement to groundwater. Additional enhancements enable better simulation of physiochemical processes, increased flexibility in representing agronomic practices, and improved post-processing and data interpretation aids. Source: http://www.epa.gov/ceampubl/gwater/przm3/

Applicable Scale: Regional to site

Computer System Requirements: 32-bit MS-DOS

Cost: Public domain (DOS version)

Input Data: Exhaustive set of physical data on chemical and field soil characteristics and weather data for local region.

Output Results: Predicts pesticide and daughter product concentrations; can be run for daily, monthly or annual output. Model allows dynamic simulations including pulse loads, peak events, and time-varying emission or concentration profiles in layered soils.

Selected References:

Register of Ecological Models. PRZM3 Review by Carsel, R. F., Smith, C. N., Mulkey, L. A., & Dean,

J. D. from World Wide Web: http://lupo.wiz.uni-kassel.de/model_db/mdb/przm3.html.

http://www.epa.gov/ceampubl/gwater/przm3/

No. C2: MULTIMED 2.0

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal evaluation

Specified Use: Exposure assessment

Model Name: MULTIMED 2.0

Overview

The Multimedia Exposure Assessment Model (MULTIMED) simulates the movement of contaminants leaching from a waste disposal facility for exposure assessment. The model consists of modules which predict concentrations at a receptor produced by transport in soil subsurface, surface air, or air. Separate interactive pre- (PREMED) and post-processing (POSTMED) programs allow user to create and edit input and plot model output.

Flow and transport through the unsaturated zone and transport in saturated zone can be considered. A one-dimensional, semi-analytical module simulates flow in the unsaturated zone. The output from this module, water saturation as a function of depth, is used as input to the unsaturated zone transport module. The latter simulates transient, one-dimensional (vertical) transport in the unsaturated zone using either an analytical model that includes the effects of longitudinal dispersion, linear adsorption, and first-order decay or a numerical model that includes the effects of longitudinal dispersion, non-linear adsorption, first-order decay, time variable infiltration rates, and arbitrary initial conditions of chemical concentration in the unsaturated zone.

The unsaturated zone transport module calculates steady-state or transient contaminant concentrations. Output from both unsaturated zone modules is used to couple the unsaturated zone transport module with the steady-state or transient, semi-analytical saturated zone transport module. The latter includes one-dimensional uniform flow, three-dimensional dispersion, linear adsorption, first-order decay, and dilution due to direct infiltration into the groundwater plume.

The fate of contaminants in the various media depends on the chemical properties of the contaminants as well as a number of media- and environment-specific parameters. The uncertainty in these parameters can be quantified in MULTIMED using the Monte Carlo simulation technique. Source: EPA documentation,

(http://www.epa.gov/ceampubl/mmedia/multim2/ABSTRACT.TXT)

Applicable Scale: Regional to site

Computer System Requirements: DOS

Cost: Public domain

Input Data: The operation of each module requires specific input, which is organized into data groups. The General Data Group, which is required for all simulations, contains flags and data which describe the scenario being modeled. The input parameters needed for the Saturated Zone Transport Model are arranged in three additional data groups: the Chemical Data Group, the Source Data Group, and the Aquifer Data Group. Use of the Unsaturated Zone Modules requires input found in the above data groups, as well as data from the Unsaturated Zone Flow Data Group and the Unsaturated Zone Transport Data Group.

Output Results: The POSTMED postprocessor can be used to generate three types of plots: concentration vs. time at a groundwater receptor, cumulative frequency, and frequency or probability density. The cumulative frequency and frequency plots are related to model parameters that are randomly varied within the context of a Monte Carlo simulation. Source: The Register of Ecological Models (REM.) REM is a cooperative service of the University of Kassel and the GSF - National Research Center for Environment and Health. http://lupo.wiz.uni-kassel.de/model_db/mdb/multimed.html by Tobias Gabele.

Selected References:

Salhotra, A.M., Mineart, P., Sharp-Hansen, S., Allison, T., Johns, R., & Mills, W.B. (1995). *Multimedia*

Exposure Assessment Model (MULTIMED 2.0) for Evaluating the Land Disposal of Wastes-- Model Theory. Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

Sharp-Hansen, S., Travers, C., Hummel, P., Allison, T., Johns, R., & Mills, W.B. (1995). *A Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model (MULTIMED 2.0).* Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

US EPA. (1995). *Revised Verification Testing of the Enhancements, MULTIMED Model (2.0).* Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

http://www.epa.gov/ceampubl/mmedia/multim2/index.htm

No. C3: 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: Exposure and risk assessment: The Vadose Zone and Aquifer Modules simulate the subsurface movement of contaminants in leachate from surface impoundments, landfills, land application units (LAUs), and waste piles through the soil to downgradient drinking water wells and waterbodies.

Model Name: 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (Vadose Zone and aquifer modules)

Overview

The Vadose Zone and Aquifer Modules simulate the fate and transport of dissolved contaminants from a point of release at the base of a waste management unit (WMU), through the underlying soil, and through a surficial aquifer (or groundwater source). Module outputs include groundwater contaminant concentrations in wells, which are used by the Human Exposure Module to estimate exposures through drinking water and showering, and by the Farm Food Chain Module to estimate contaminant concentrations in beef and milk from farm well use; and contaminant fluxes into waterbodies, which are used by the Surface Water Module, along with contaminant fluxes from atmospheric deposition and overland flow, to estimate contaminant concentrations in streams, lakes, and wetlands.

The Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (3MRA) technology provides the ability to conduct screening-level risk-based assessment of potential human and ecological health risks resulting from long term (chronic) exposure to HWIR chemicals released from land-based WMUs containing currently listed waste streams. The 3MRA system consists of a series of components within a system framework. The new modeling system, dubbed 3MRA technology, is envisioned as the foundation for eventually integrating other regulatory support decision tool needs anticipated in the future.

The HWIR assessment is a screening-level risk-based assessment of potential human and ecological health risks resulting from long-term (chronic) exposure to HWIR chemicals released from land-based waste management units (WMUs) containing currently 'listed' waste streams. The assessment of potential human and ecological health risks is site-based and include, for each site statistically sampled from a national database of WMUs, the simultaneous release of chemicals from the WMU to each environmental medium, the fate and transport of the chemical through a multimedia environment, and the receptor-specific exposures that result. The assessment includes an estimation of the potential exposures, per exposure pathway/receptor, and an estimation of the resulting carcinogenic and non-carcinogenic health effects. The end point of the assessment is the establishment of chemical-specific exit levels representing threshold waste concentrations below which the associated waste stream is not considered hazardous and therefore does not require Subtitle C type disposal. The exit levels are applicable to all waste streams and all locations, i.e., nationally. Source: EPA model documentation.

Applicable Scale: Regional to site

Computer System Requirements: Windows 98, NT, 2000, XP

Cost: Public domain

Input Data: Physical site databases and chemical properties databases. Physical properties such as infiltration rate, chemical flux, and soil properties such as Koc.

Output Results: The Vadose Zone and Aquifer Modules perform the following functions:

1. Model vadose zone flow and transport. The one-dimensional (1-D) Vadose Zone Module simulates infiltration and dissolved contaminant transport, by advection and dispersion, leaching from the bottom of a WMU through the soil above the water table (i.e., the vadose zone) to estimate the contaminant and water flux to the underlying groundwater.

2. Model groundwater flow and transport. The pseudo-3-D Aquifer Module simulates groundwater flow and contaminant transport, by advection and dispersion, from the base of the vadose zone to estimate contaminant concentrations in drinking water wells and contaminant discharge fluxes to intercepted waterbodies.

3. Model subsurface chemical reactions. Both the Vadose Zone and Aquifer Modules simulate sorption to soil or aquifer materials and biological and chemical degradation, which can reduce contaminant concentrations as they move through soil and groundwater. In cases where degradation of a contaminant yields other contaminants that are of concern, the modules can account for the formation and transport of up to six different daughter and granddaughter degradation products. For metals, the modules use sorption isotherms that allow adjustment of sorption behavior to account for varying metal concentrations and geochemical conditions. Source : http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/sab03/vol1/1_09_vadose.pdf

The assessment of potential human and ecological health risks is site-based and include, for each site statistically sampled from a national database of WMUs, the simultaneous release of chemicals from the WMU to each environmental medium, the fate and transport of the chemical through a multimedia environment, and the receptor-specific exposures that result. The assessment includes an estimation of the potential exposures, per exposure pathway/receptor, and an estimation of the resulting carcinogenic and non-carcinogenic health effects. The end point of the assessment is the establishment of chemical-specific exit levels representing threshold waste concentrations below which the associated waste stream is not considered hazardous and therefore does not require Subtitle C type disposal. The exit levels are applicable to all waste streams and all locations, i.e., nationally. Source: EPA model documentation.

Selected References:

US EPA. (1999). The Vadose and Saturated Zone Modules. Extracted from EPACMTP for HWIR99. Office of Solid Waste, Washington, DC.

http://www.epa.gov/athens/research/projects/3mra/index.html

No. C4: MMSOILS

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening and Risk assessment

Specified Use: "The methodology consists of a multimedia model that addresses the transport of a chemical in groundwater, surface water, soil erosion, the atmosphere, and accumulation in the food chain. The methodology can be used to provide an estimate of health risks for a specific site. Since the uncertainty of the estimated risk may be quite large (depending on the site characteristics and available data), MMSOILS addresses these uncertainties via Monte Carlo analysis. Source: http://www.epa.gov/ceampubl/mmedia/mmsoils/ABSTRACT.TXT

Model Name: MMSOILS

Overview

The Multimedia Contaminant Fate, Transport, and Exposure Model (MMSOILS) estimates the human exposure and health risk associated with releases of contamination from hazardous waste sites. The methodology consists of a multimedia model that addresses the transport of a chemical in groundwater, surface water, soil erosion, the atmosphere, and accumulation in the food chain. The human exposure pathways considered in the methodology include: soil ingestion, air inhalation of volatiles and particulates, dermal contact, ingestion of drinking water, consumption of fish, consumption of plants grown in contaminated soil, and consumption of animals grazing on contaminated pasture. For multimedia exposures, the methodology provides estimates of human exposure through individual pathways and combined exposure through all pathways considered. The risk associated with the total exposure dose is calculated based on chemical-specific toxicity data.

The methodology is intended for use as a screening tool. It is critical that the results are interpreted in the appropriate framework. The intended use of the exposure assessment tool is for screening and relative comparison of different waste sites, remediation activities, and hazard evaluation. The methodology can be used to provide an estimate of health risks for a specific site. Since the uncertainty of the estimated risk may be quite large (depending on the site characteristics and available data), MMSOILS addresses these uncertainties via Monte Carlo analysis. Source: http://www.epa.gov/ceampubl/mmedia/mmsoils/index.htm

Applicable Scale: Regional to site

Computer System Requirements: DOS

Cost: Public Ddomain

Input Data: Modeling incorporates information on cover soils, waste cells, lateral drain layers, low permeability barrier soils, synthetic geomembrane liners, and weather.

Output Results: Results are expressed as daily, monthly, annual, and long-term water budgets.

Selected References:

http://www.epa.gov/ceampubl/mmedia/mmsoils/index.htm

No. C5: HELP v.3

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: The HELP model is a quasi-two-dimensional, deterministic, water-routing model for determining water balances for municipal landfills, RCRA and CERCLA facilities, and other land disposal systems, including disposal of dredged material.

Model Name: HELP v.3 (Hydrologic Evaluation of Landfill Performance)

Overview

The Hydrologic Evaluation of Landfill Performance (HELP) model was developed to help hazardous waste landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model accepts weather, soil, and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. Results are expressed as daily, monthly, annual, and long-term average water budgets.

Version 3 of the HELP model has been greatly enhanced beyond versions 1 and 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste material, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computations of leachate recirculation and groundwater drainage into the landfill have been added. HELP Version 3 also accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears, and seaming flaws) and by vapor diffusion through the liner. The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. Source: (international groundwater modeling center, Review Authors: R. Lee Payton (Univ. Of Missouri-Columbia) and Paul Schroeder (US Army Corps of Engineers) http--typhoon.mines.edu-software-igwmcsoft-help.htm

A Spanish version is available from the US Army Corps of Engineers at the Web site below.

Applicable Scale: Site design

Computer System Requirements: MS-DOS

Cost: Public domain

Input Data: Weather, soil, and design data.

Output Results: Detailed water balance for comparison of design alternatives.

Selected References:

http://www.wes.army.mil/el/elmodels/helpinfo.html.

http://www.wes.army.mil/el/elmodels/index.html.

No. C6: Visual HELP

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use:

- Simulate multiple landfill profiles to find the most suitable design.
- Evaluate leachate mounding or leakage problems with current landfills.
- Determine the effectiveness of landfill caps for reducing leachate mounding.
- Design and optimize leachate collection systems.

Model Name: Visual HELP

Overview

This is one of several commercialized versions of the HELP model. This example provides a "hydrological modeling environment available for designing landfills, predicting leachate mounding and evaluating potential leachate contamination. Visual HELP combines the latest version of the HELP model (v.3.07) with an easy-to-use interface and powerful graphical features for designing the model and evaluating the modeling results. This latest version of the HELP model addresses many of the limitations and bugs of earlier versions and also includes several new analysis features.

Visual HELP's user-friendly interface and flexible data handling procedures provide you with convenient access to both the basic and advanced features of the HELP model. This completely-integrated HELP modeling environment allows the user to:

- Graphically create several profiles representing different parts of a landfill,
- Automatically generate statistically-reliable weather data (or create your own),
- Run complex model simulations,
- Visualize full-color, high-resolution results, and
- Prepare graphical and document materials for your report.

Visual HELP has also proven to be an extremely valuable tool for accurately predicting seasonal groundwater recharge for periods of up to 100 years for use in MODFLOW models. This seasonal recharge data has proven to significantly influence the vertical migration of contaminants through the unsaturated zone. Source: Scientific Software Group.

Applicable Scale: Site design

Computer System Requirements: Windows 95/98/2000/NT

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data: Weather, soil, and design data.

Output Results: Detailed water balance for comparison of design alternatives.

Selected References:

Source: Scientific Software Group.

No. C7: BIOF&T – 3D

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Model Name: BIOF&T -3D

Overview

BIOF&T -3D models flow and transport in the saturated and unsaturated zones in two or three dimensions in heterogeneous, anisotropic porous media, or fractured media. Package will model convection, dispersion, diffusion, adsorption, desorption, and microbial processes based on oxygen limited, anaerobic, first order, or Monod type biodegradation kinetics. Includes anaerobic or first order sequential degradation involving multiple daughter species. Source: http://www.hydrology-software.com/issubsrf.htm

Applicable Scale: Site

Computer System Requirements: Microsoft Windows ™

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data:

- Mesh discretization data.
- Initial conditions for flow: water.
- Boundary conditions for flow: specified head boundaries, flux boundaries, and sources and sinks.
- Soil hydraulic properties: van Genuchten parameters, hydraulic conductivity distribution and porosity.
- Initial conditions for transport: species concentration.
- Boundary conditions for transport: specified concentration boundary, specified mass flux, and spatial distribution of contaminant loading.
- Dispersivities.
- Mass transfer rate coefficient between oil and water phase.
- Distribution coefficient.
- Bulk density.
- Diffusion coefficient for species.
- Biodegradation parameters for each species.
- Fraction of the mobile phase.

Output Results:

Flow

- Spatial distribution of water pressure with time
- Spatial distribution of water saturation with time
- Velocity distribution with time
- Pumping/injection rates and volume vs. time

Transport (for each species):

- Spatial distribution of concentration with time
- Mass dissolved in water vs. time
- Mass remaining in NAPL phase vs. time
- Mass adsorbed on the solid phase vs. time

Selected References:

http://www.scisoftware.com/products/bioft_details/bioft_details.html.

http://www.scisoftware.com/products/bioft_overview/bioft_overview.html

No. C8: 3DFATMIC

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: 3DFATMIC is designed to simulate transient and/or steady-state density-dependent flow field and transient and/or steady-state distribution of a substrate, a nutrient, an aerobic electron acceptor (e.g., the oxygen), an anaerobic electron acceptor (e.g., the nitrate), and three types of microbes in a three-dimensional domain of subsurface media. Examples include saltwater intrusion models, virus transport models.

Model Name: 3DFATMIC

Overview

3DFATMIC computes and predicts the distribution of pressure head, moisture content, flow velocity, and total head over a three-dimensional region in either completely saturated, or completely unsaturated, or partially unsaturated or partially saturated subsurface media. It also computes and predicts the spatial-temporal distribution of microbes and multi-chemical components. The media may consist of as many types of soils and geologic units as desired with different material properties. Each soil type may be isotropic or anisotropic. The processes governing the distribution of chemical and microbe concentration and temperature include: (1) reversible sorption, (2) microbe-chemical interaction, and (3) hydrological transport by flow advection/convection, dispersion/diffusion, and effect of unsaturation. Source: Scientific Software Group:

Applicable Scale: Site design

Computer System Requirements: Pentium class with 16 MB RAM and FORTRAN Compiler. Any Workstation, e.g., IBM RS6000, DEC Alpha, Silicon Graphics, Sun SparcStation, and HP 9000 Series.

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data:

- Geometry in terms of nodes and elements, and boundaries in terms of nodes and segments.
- Soil properties including:
  - Saturated hydraulic conductivities or permeabilities.
  - Compressibility of water and the media, respectively.
  - Bulk density.
  - Three soil characteristic curves for each type of soil or geologic unit which are the retention curve, relative conductivity vs. head curve, and water capacity curve.
  - Effective porosity.
  - Dispersivities and effective molecular diffusion coefficient for each soil type or geologic unit.
- Enitial distribution of pressure head over the region of interest.
- Net precipitation, allowed ponding depth, potential evaporation, and allowed minimum pressure head in the soil.
- Prescribed pressure head on Dirichlet boundaries.
- Prescribed fluxes of chemicals and heat on Cauchy and/or Neumann boundaries.
- Artificial withdrawals or injections of water.
- Number of chemical components as well as microbes and microbe-chemical interaction parameters such as specific yields, utilization coefficients, saturation constants, etc.
- Artificial source/sink of water and all chemical components, heat and microbes.
- Prescribed concentrations of all chemical components and microbes as well as temperature on Dirichlet boundaries.
- Prescribed fluxes of all chemical components and heat on variable boundaries.
- Initial distribution of all chemical component and microbe concentrations and temperature. All inputs in items 4 through 11 can be time-dependent or constant with time. Source: Scientific Software Group.

Output Results:

- Pressure head, total head, moisture content, and flow velocity over two-dimensional grid at any desired time.
- Water fluxes through all types of boundaries and amount of water accumulated in the media at any desired time.
- Distribution of chemical concentrations, microbes, and temperature over a three-dimensional grid at any desired time.
- Amount of chemical and heat fluxes through all boundary segments. Source: Scientific Software Group.

Selected References:

http://www.scisoftware.com/products/3dfatmic_details/3dfatmic.PDF.

Web site:

http://www.scisoftware.com/products/3dfatmic_overview/3dfatmic_overview.html

No. C9: MIGRATEv9

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: For modeling landfills, buried waste deposits, spills and disposal ponds. Model contaminant sources as surface boundary conditions or as a physically buried layer to generate time-distance-concentration output.

Model Name: MIGRATEv9

Overview

Using the MIGRATEv9 software, contaminant transport from multiple sources, either at the surface or buried, can be modeled quickly and accurately in two dimensions. Unlike finite-element and finite-difference formulations, MIGRATEv9 does not require the use of a time-marching procedure. MIGRATEv9 uses a finite-layer technique that provides numerically accurate and stable results while requiring relatively little computational and data entry effort.

In addition to advective-dispersive transport, MIGRATEv9 can consider sorption, radioactive and biological decay, and transport through fractures. One or more landfills, buried waste deposits, spills, or disposal ponds can be modeled. These contaminant sources may be adjacent or offset from each other. Model properties may be either constant or transient, with the concentrations calculated at specified times, depths, and distances. (Source: Scientific Software Group)

Applicable Scale: Site

Computer System Requirements: Microsoft Windows ™

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data: Each constant properties dataset is composed of: general data (e.g., number of landfills, layers), top and bottom boundary conditions (e.g., finite mass), and layer data (e.g., porosity and diffusion coefficient).

Boundary conditions, layer data and time-varying conditions can be set. Predefined models include Subtitle C and Subtitle D landfills. Geomembranes, clay layers and aquifers can be specified.

Output Results: The concentration of the contaminant is calculated at variable specific times and distances.

Selected References:

http://www.scisoftware.com/products/migratev9_description/migratev9_description.html

http://www.scisoftware.com/products/migratev9_details/migratev9_details.html

Appendix D – Air quality models list

No. D1: OBODM

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculate pollutant concentration from open burn

Model Name: Open Burn/Open Detonation Dispersion Model (OBODM)

Overview

The Open Burn/Open Detonation Dispersion Model (OBODM) was developed to evaluate the impacts of open burning on potential air quality problems. The OBODM model first determines the total amounts of pollutants released from an open burn using either theoretical or empirical emission factors. The OBODM uses plume rise and dispersion model algorithms to simulate downwind transport, dispersion, and deposition of pollutants from short-term quasi-continuous, such as an open burn, sources – point/volume and/or line sources. The OBODM model can be used to calculate peak concentration, time-mean concentration, time-integrated concentration, and particulate deposition from open burn sources. The movement of odor, toxic gases, particulate matter, and airborne pathogens from open burning can be simulated with this model.

Applicable Scale: Field scale

Computer System Requirements: DOS and Windows

Cost: Public domain

Input Data: Receptor locations and heights, meteorological data, wind speed and direction, air humidify, temperature, and either Pasquill stability category or the Net Radiation Index (NRI), half-life or the pollutant if pollutant decays with time.

Output Results: Peak concentration, dosage, concentration time-averaged concentration.

Selected References:

Bjorklund, J.R., Bowers, J.F., Dodd, G.C., & White, J.M. (1998). *Open Burn/Open Detonation Dispersion Model (OBODM) User's Guide*. (DPG Document No. DPG-TR-96-008a). Dugway, Utah: West Desert Test Center, US Army Dugway Proving Ground.

http://www.epa.gov/scram001/tt22.htm#obodm

No. D2: CTSCREEN

Category: Air quality

Evaluation State: Screening

Specified Use: Assess plume impaction in complex terrain

Model Name: Complex Terrain Screening Model (CTSCREEN)

Overview

CTSCREEN model was developed to calculate a worst-case 1-hour concentration in complex terrain with predetermined meteorological conditions.

When meteorological data are not available, CTSCREEN can be used to obtain conservative, yet realistic, impact estimates for particular sources. These estimates can provide conservative emission-limit estimates. The movement of odor, toxic gases, particulate matter, and airborne pathogens from burial, incineration, and composting can be simulated with this model.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data: Source location, height, stack diameter and exit velocity, stack exit temperature and emission rate, receptor, and terrain (contour) information.

Output Results: Source-receptor location, geometrical relationships between the source and the hill, plume characteristics at each receptor, summary table of up to 4 concentrations at each receptor, source contribution at each receptor, estimated 3-hour, 24-hour, and annual concentrations.

Selected References:

Perry, S.G., Burns, D.J., & Cimorelli, A.J. (1990). *User's Guide to CTDMPLUS: Volume 2, The Screening Model (CTSCREEN).* Abridgement of EPA-600/8-90-087. Atmospheric Research and Exposure Assessment Laboratory. US Environmental Protection Agency.

http://www.epa.gov/scram001/tt22.htm#ctscreen

No. D3: SCREEN3

Category: Air quality

Evaluation State: Screening

Specified Use: Ground-level concentrations for point, Area, Flare, and Volume sources.

Model Name: SCREEN3

Overview

The SCREEN3 model is the US EPA's current regulatory screening model for many air permitting applications and the New Source Review. The SCREEN3 model is based on steady-state Gaussian plume algorithms and is applicable for estimating ambient impacts from point, area, and volume sources out to a distance of about 50 kilometers. In addition, SCREEN3 can be used to model flares. The SCREEN3 model utilizes a matrix of meteorological conditions covering a range of wind speed and stability categories. The model is designed to estimate the worst-case impact based on the meteorological matrix for use as a conservative screening technique.

Applicable Scale: Field scale

Computer System Requirements: DOS or Windows

Cost: Public domain for DOS version and Commercial for Windows version

Input Data: Source type – point, flare, volume, or area source, urban or rural terrain, emission rate, physical stack height, stack gas exit velocity, and stack gas temperature.

Output Results: A dispersion curve showing the change in chemical concentration vs. distance from source.

Selected References:

US EPA. (1995). *SCREEN3 Model User's Guide* (US EPA Publication No. EPA-454/B-95-004). Office of Air Quality Planning and Standards Emissions, Monitoring, and Analysis Division Research Triangle Park, North Carolina 27711.

http://www.epa.gov/scram001/tt22.htm#screen3

No. D4: ADMS

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Concentrations of pollutants emitted both continuously from point, line, volume, and area sources

Model Name: Atmospheric Dispersion Modeling System (ADMS)

Overview

ADMS is an advanced model for calculating concentrations of pollutants emitted either continuously from point, line, volume, and area sources, or discretely from point sources. The model takes account of the following: effects of main site building; complex terrain; wet deposition, gravitational settling, and dry deposition; short-term fluctuations in concentration; chemical reactions;

radioactive decay; plume rise as a function of distance; averaging time ranging from very short to annual; condensed plume visibility; and meteorological preprocessor.

Applicable Scale: Field scale

Computer System Requirements: Windows

Cost: Public domain in selected circumstances

Input Data: Source location, emission rate, stack height, elevation, particle size distribution with corresponding settling velocities, hourly meteorological data.

Output Results: Concentration for specified averaging times at receptor points or on an output grid: averages of concentration over a specified period and percentiles of these averages. Short- and long-term average of wet, dry, and total deposition and radioactive activity.

Selected References:

Carruthers, D.J., Holroyd, R.J., Hunt, J.C.R., Weng, W.S., Robins, A.G., Apsley, D.D., Thompson, D.J., & Smith, F.B. (1994). UK-ADMS: A new approach to modeling dispersion in the earth's atmospheric boundary layer. *Journal of Wind Engineering and Industrial Aerodynamics*, *52*, 139-153. Elsevier Science B. V.

http://www.cerc.co.uk/software/adms3.htm

No. D5: ALOHA

Category: Air quality - 5

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Evaluate releases of hazardous chemical vapors

Model Name: Areal Locations of Hazardous Atmospheres (ALOHA)

Overview

ALOHA is an atmospheric dispersion model used for evaluating gas transport and dispersion in atmosphere in emergency conditions. It takes into account both the toxicological and physical properties of the pollutant and the characteristics of the site, such as the atmospheric conditions and the release conditions. ALOHA predicts how a hazardous gas cloud might disperse in the atmosphere after an accidental pollutant release. ALOHA can be used for emergency management and remediation planning.

Applicable Scale: Field scale

Computer System Requirements: Windows or Macintosh

Cost: Free

Input Data: Geographic location, time and date, site and chemical definition, atmospheric data, source definition.

Output Results: Footprint showing the affected area with uncertainty in footprint location, which results from uncertainty in wind direction. Plot showing the pollutant concentration in the air at ground level at a location specified by the user. Also plots showing dose vs. time and source strength vs. time.

Selected References:

ALOHA User's Manual from World Wide Web: http://www.epa.gov/ceppo/cameo/pubs/aloha.pdf.

http://response.restoration.noaa.gov/cameo/cameo.html

No. D6: INPUFF

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Simulate dispersion from semi-instantaneous or continuous point sources over a spatially and temporarily variable wind field.

Model Name: Integrated PUFF (INPUFF)

Overview

INPUFF is an air quality model which uses the Gaussian equation to evaluate the diffusion of a puff generated by a single point source. It may be used also with multiple point sources and deals with nonreactive pollutants, but may include deposition and sedimentation. The user may choose among different algorithms to simulate the puff behavior and may also enter its own routines to evaluate the plume effective height and puff dispersion. It works on flat terrains within few tens of kilometers of distance.

Applicable Scale: Field scale

Cost: Public domain

Input Data: Wind speed and direction, dispersion coefficient option, receptor location, fraction of crosswind dispersion, elevation, azimuth angle, air temperature, minimum distance to receptor, deposition velocity, settling velocity.

Output Results: Simulation period, time, and puff type. Intermediate source concentrations. Table of average concentration for each receptor for all meteorological periods. Average concentrations for all sources.

Selected References:

Perersen W.B., & Lavdas, L.G. (1986, August). INPUFF 2.0 A Multiple Source Gaussian Puff Dispersion Algorithm – User's Guide (US EPA Publication No. EPA/600/8-86-024).

http://www.epa.gov/ttn/nsr/psds1/sup6_21.html

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

15

Geographic Information Systems (GIS) Technology

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Table of Contents

Abbreviations

CAFO	confined animal feeding operation
FEMA	Federal Emergency Management Agency
FMD	foot and mouth disease
GADER	GIS for animal disease and emergency response
GIS	geographic information systems
GPS	global positioning system
POTW	publicly owned treatment works
PRV	pseudorabies virus
SSURGO	soil survey geographic

Section 1 – Key Content

Geographic information systems (GIS) should play a significant role in the management of mapped or spatial data prior to, during, and after carcass disposal events. At the simplest level, GIS can provide maps, while at the more complex level can serve as a decision support capability. This chapter contains an overview of GIS and its applications. Examples of how GIS has been used in recent livestock disease and carcass disposal efforts are also provided.

The site requirements for specific carcass disposal technologies vary, as do their site-specific impacts on the environment. GIS can play a significant role in the analysis or screening of potential sites by considering the requirements of carcass disposal technologies and identifying and mapping locations within a region that meet these criteria. For example, burial sites should be some distance from surface waters and various cultural features, should not impact groundwater, may require certain geologies, and may have other site requirements. The result of analysis of these requirements in a GIS is a map or series of maps that identify sites where carcass disposal technologies would likely be suitable. Further on-site analysis of locations would be required prior to actual site-selection for carcass disposal.

GIS data layers are critical to determining the appropriate use of carcass disposal technologies. This chapter expands on the GIS data layers that would be useful. Checklists describing the data layers that can be used to refine the selection of the specific GIS data layers are included. Note that it is important to collect, organize, and preliminarily analyze data prior to a carcass disposal event due to the time required for such efforts.

Web-based GIS capabilities have improved significantly in the last few years. The creation of web-based GIS capabilities to support carcass disposal efforts could overcome some of the access and other issues related to desktop GIS and make mapped information available to decision-makers and field personnel in real time.

GIS are important in the application of environmental models to address environmental concerns associated with carcass disposal. GIS can provide the data required by these models and can provide visualization of the modeled results in map form.

Section 2 – Introduction

Recent advances in information technology–including hardware, software, and the Internet–have provided capabilities to potentially enhance problem solving in areas that require information processing. Among several information technologies that have been incorporated with other areas, Geographic information systems (GIS) are one of the most popular tools to be utilized in decision making. GIS have had a profound effect on decision support system development, especially environmental modeling and model development, because GIS can supply functionality for dealing with spatial information that is required in most decision-making processes.

Fire, flooding, or a disease outbreak can suddenly result in a large number of dead livestock, presenting a challenge in the disposal of carcasses. Carcass disposal should be handled correctly and quickly because various environmental impacts may result on surface water, groundwater, soil, and air. A massive carcass disposal effort requires careful analysis of carcass disposal site selection and transportation issues.

GIS can play a significant role in carcass disposal in several areas including site selection, transportation planning, and environmental evaluation due to its spatial information processing and data query capabilities. For example, spatial information processing can assist with disposal site selection using layer overlay operations, map algebra, and buffering, while road map queries and routing can be used to assist with identification of carcass transportation routes.

Maps can also be a valuable tool to help epidemiologists identify spatial patterns of disease as cases occur. Perhaps one of the best known examples of this was the observation by John Snow, a physician working in London in 1854, who demonstrated a spatial association between cholera cases and a single water supply (Freier, 2003). Eliminating public access to the contaminated water supply brought an end to the outbreak (Snow, 1994).

Carcass disposal and treatment sites are usually environmentally vulnerable, because large numbers of carcasses present difficulties in removing potentially harmful sources, such as pathogens, liquids, and organic material. Spatial information that is pre- and post-processed in GIS also can assist with environmental impact assessment before and after carcass disposal.

This document overviews how to utilize GIS capability for responding to an emergency outbreak requiring disposal of a large number of carcasses, carcass disposal site selection, and environmental assessment. It also provides a short overview of GIS to provide essential knowledge in using the spatial information and processing capabilities of GIS.

Section 3 – Strategic Use of GIS

3.1 – Role of GIS Task Forces in Decision Support Strategy Using GIS

To use GIS as a spatial information tool in carcass disposal processes, specialized GIS task forces should be organized with team members that are familiar with GIS functionalities (Figure 1). Human resources are a key component among the five GIS project components that include hardware, software, data, human resources, and methods. GIS task forces should be composed of a manager, developer, and data manager, with each having a specific role.

3.2 – GIS Role for Animal Health Issues

Spatial database construction

Spatial data collection and database construction is important to ensure the GIS provides appropriate information to decision makers, because the data quality in the database affects secondary information quality. A well-prepared database can make analysis fast and efficient and provides versatile support in carcass disposal decision making. Data collection through site investigation, for instance using Global Positioning System (GPS), and collection of spatial data from a clearinghouse or other sources such as federal, state, or local government agencies, are typically necessary for spatial database construction. In most instances, it is desirable to develop a spatial database prior to a carcass disposal event, since the development of such a database can require a significant level of effort and time.

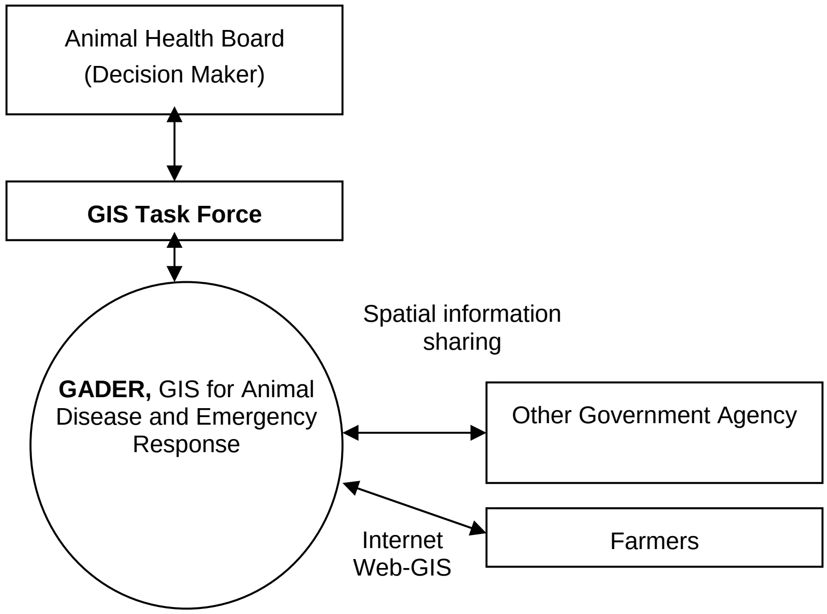

FIGURE 1. Schematic diagram of spatial information sharing among agency and people related with the animal disease outbreak using GIS.

Historical/spatial transaction and surveillance for animal health issues

Time series analysis and GIS-derived spatial statistics based on observations of disease spread can be helpful to animal disease propagation analysis efforts. Such analyses can provide information key to preparation for an animal emergency. Spatially tracking animal health issues and creating digital maps showing animal disease outbreak cases can provide an opportunity for optimal decision making in preparing for an emergency.

GIS and spatial analysis are especially well-suited to farm-level, environmental, and epidemiological applications. The first steps in GIS may involve collecting data in the real world and converting this to a series of representative objects within the GIS to create mathematical representations of landscape features. Once the spatial components have been assembled, various visualization tools, exploratory data analysis methods, and model-building techniques can be applied. GIS provides a powerful means of managing data related to a disease outbreak, especially in designing surveillance strategies and monitoring spatial-temporal trends as cases are reported.

Although GIS methods offer a data-organizing mechanism that can be used to enhance knowledge about how infectious agents are maintained and spread, there are many challenges to overcome in spatially referencing information about an epidemic, as well as protecting the confidentiality of data. While many aspects of emergency management can benefit from GIS use, each phase is likely to have different goals and specialized needs that must be satisfied. Unfortunately, GIS is interpreted by many to be simply the making of maps. It is important that emergency managers have a better understanding of the planning, surveillance, analysis, and modeling tools available within GIS. Finally, if GIS is going to be used effectively in emergency management, it is critical that response plans incorporate spatial methods from the beginning.

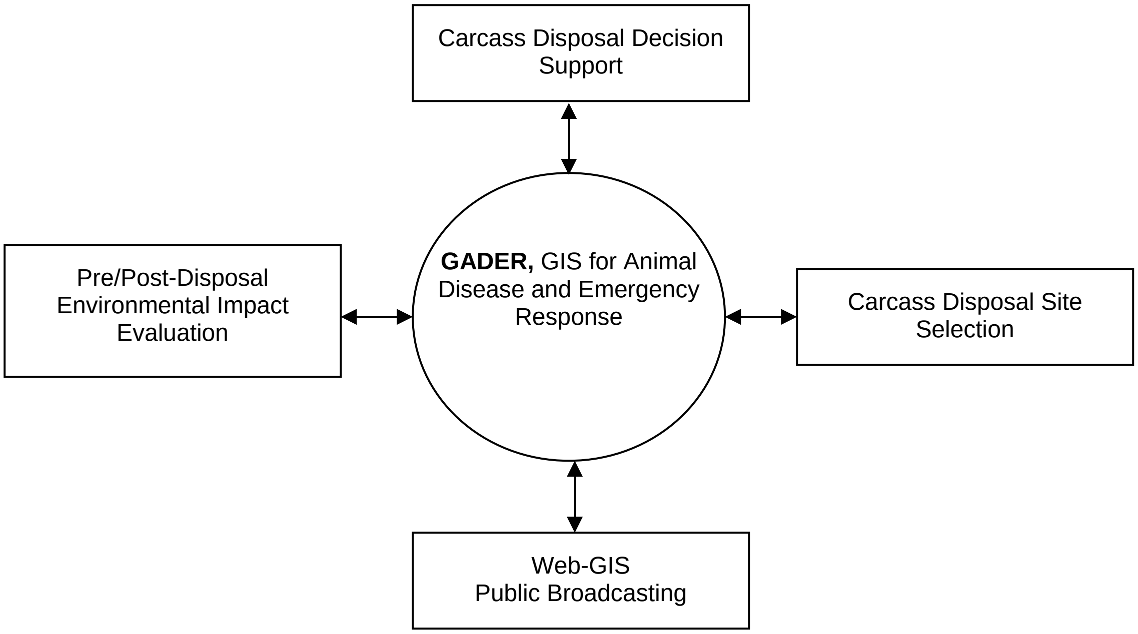

FIGURE 2. GIS tasks while disposing of carcasses.

Before a carcass disposal event, it is vital that certain essential information be available about administrative boundaries, roads, terrain, watersheds, and vegetation. In addition, a national spatial infrastructure regarding livestock and poultry movement is needed, as well as established partnerships with data providers to obtain appropriate population and environmental information to help prevent disease spread.

Organizing data in a GIS for use in epidemiological studies presents several challenges. The most vexing of these challenges are: (1) representing exposure in spatial terms that can be used in statistical analyses, (2) showing activity spaces (e.g. home ranges), (3) incorporating residential histories of animals, and (4) modeling the social environment. In addition to showing exposure, activity spaces, residence, and interaction models, one of the most important decisions to make is that of scale. The scale level should be appropriate for the issues being investigated in an analysis; otherwise, the results will not be meaningful and may be misleading. Finally, a major challenge when working with farm-level information is the problem of data confidentiality. These challenges are receiving significant attention by the ever-growing number of health workers utilizing GIS methods. The animal health community will benefit greatly by becoming actively involved in finding solutions to these challenges associated with gathering spatial data (Freier, 2003).

3.3 – GIS Support Categories for Carcass Disposal

Map production and spatial information sharing

GIS can strategically support carcass disposal staff through a variety of map products created from spatial databases. During eradication of an emergency animal disease, maps from spatial analysis provide an important communication and planning aid which can be useful in defining the location and extent of the disease and spatial relationships between properties within and adjacent to the affected areas. Maps provide two major management advantages. The ability to encompass the incident within boundaries gives better definition and visualization of the tasks and advances the probability of their achievement. Progress can be instantly recognized; for example, the change of status from "red" to "blue" can be a powerful stimulus for encouragement (AUSVETPLAN, 1999). Maps can be shared with users ranging from decision makers to farmers through Web-based GIS capabilities as shown in Figures 1 and 2. A GIS task force might operate GIS for animal disease and emergency response (GADER), and provide decision support materials including maps and tables. The GADER component could also provide Web-based GIS maps to the public and other government agencies involved in the emergency.

Role of GIS during carcass disposal site selection

The spatial analysis functionalities of GIS can be applied to select carcass disposal sites considering the site characteristics required for various disposal technologies and the potential for environmental impact, transportation accessibility, and secondary infection of nearby livestock. Incorporating GIS analysis in the decision-making process can minimize environmental, social, human, and economic impacts. The GADER concept depicted in Figure 2 can also be used for preliminary carcass disposal site selection before an emergency, in the selection of an actual carcass disposal site during an emergency, and in follow-up environmental evaluation and monitoring of disposal sites. Spatial information and post-visualization functions in GADER can be integrated with environmental impact evaluation models to assist in site selection. Preselection or some level of screening of carcass disposal sites can accelerate response during carcass disposal, because emergency response staff can more quickly identify appropriate disposal locations. Possible GIS output for supporting animal carcass disposal tasks are described in Figure 3.

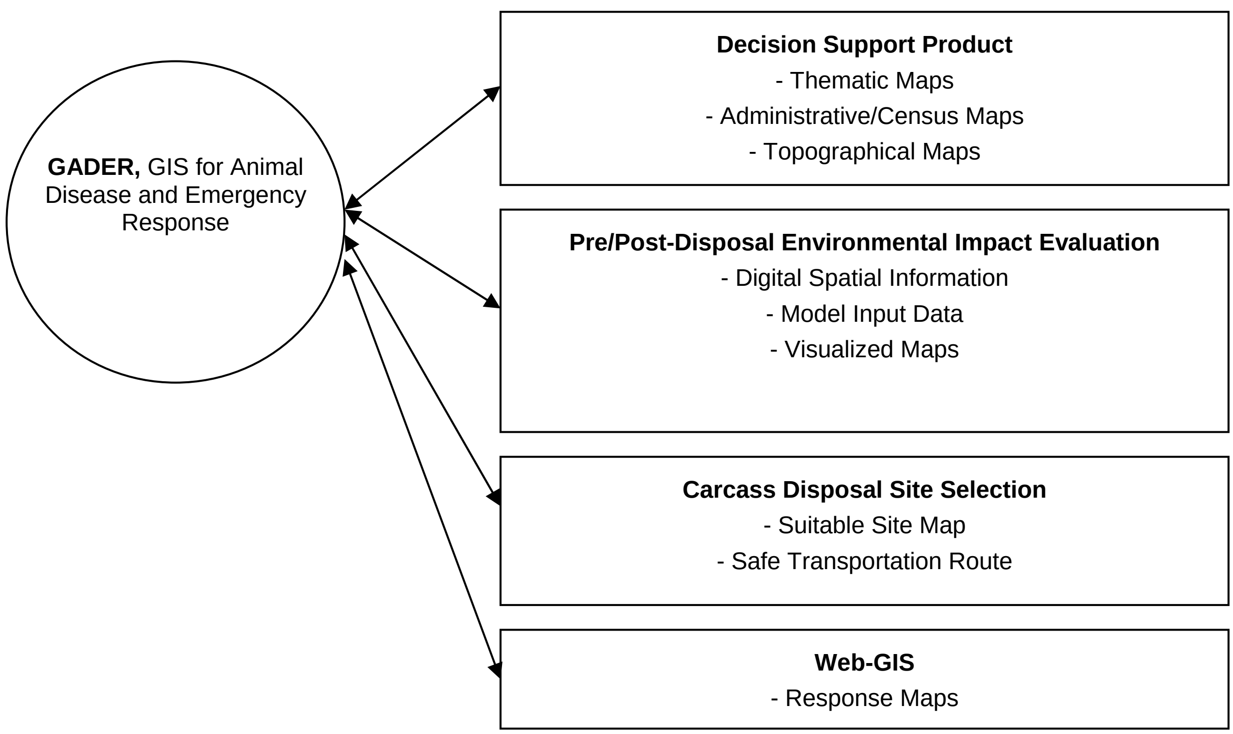

FIGURE 3. GIS output for supporting animal carcass disposal tasks.

Several examples were implemented to show how GIS can assist in the carcass disposal process and are appended at the end of this chapter. The examples presented are as follows:

- Preliminary carcass disposal site selection in six Indiana counties (Appendix A).
- Web-based GIS and airborne disease propagation example (Appendix B).
- Disposal site layers ranking system (Appendix C).

Decision support strategy using GIS

Reaching a final decision in many areas including carcass disposal often includes quite complicated processes; for optimal decision making, information from various sources is required. Spatial information is essential to address animal health and carcass disposal issues during an emergency situation. Due to several distinct capabilities, GIS has been commonly included in decision support systems to provide spatial information and analysis capability.

The Federal Emergency Management Agency (FEMA) has defined an emergency response cycle include preparation and prevention, disasters and emergencies, and response and recovery. By reflecting on the response cycle steps, a strategic use of GIS diagram is presented in Figure 4.

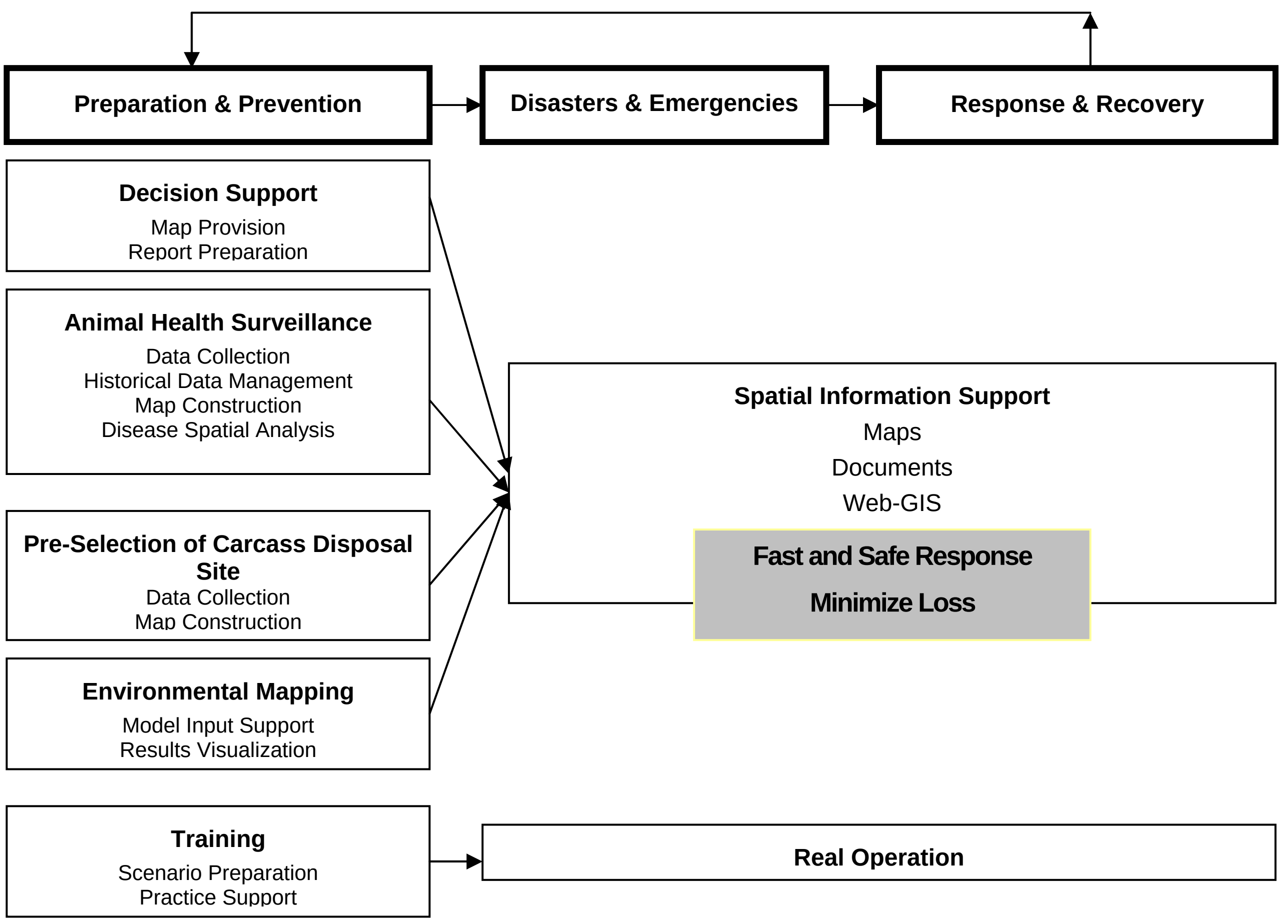

FIGURE 4. Decision support strategy using GIS following FEMA's emergency response cycle for animal health issues.

During the preparation and prevention stage, GIS can assist with several tasks in animal health and carcass disposal management including:

- Decision support
  - Map provision
  - Report preparation
- Animal health surveillance
  - Data gathering
  - Historical data management
  - Map construction
- Preselection of carcass disposal site
  - Data gathering
  - Map construction
- Environmental mapping
  - Model input support
  - Results visualization
- Training
  - Scenario preparation
  - Practice support

Those jobs during the preparation and prevention stage using GIS can promote the next two stages for emergencies and response in terms of safety and speed. Visualization of data and trained staff can improve emergency response. It may also minimize losses, prevent disease propagation into other places, and increase efficiency of resource use.

Section 4 – GIS Application

4.1 – Map Making During a Disaster

During an animal disease outbreak or carcass disposal event, several maps can be created to assist response efforts. These maps can be distributed to staff involved in responding to the emergency. The maps can include:

- Preselected carcass disposal sites.
- Transportation routes.
- Disease development and propagation status.
- Evacuation area and contagious possibility.
- Farm/industry/public facilities inventory.

The preselected carcass disposal site map can be prepared before the disaster by a GIS task force using GADER to respond quickly to an animal disease outbreak or carcass disposal event. The map can assist decision makers in identifying appropriate places to dispose of carcasses safely and efficiently. Transportation route maps can be useful to find safe routes to transport contagious material. Disease development and propagation status maps, evacuation area and contagious possibility maps, and farm/industry/public facilities inventory maps can be useful for predicting the disease spread trend and sanitizing the places likely to be contaminated. GIS also can be used to prevent propagation of the disease by setting control lines based on the map of the disease movement and can help identify the possible evacuation area.

4.2 – Spatial Data and Analysis for Disposal Site Selection

Analysis methods

A common task in GIS analyses is to rank a group of layers which affect a process, then sum the rankings to display where something is impacting the process. In such a fashion, GIS processes may be used to create exclusion zones where an activity such as carcass burial is inappropriate, unsuitable, or less desirable. The simple concept of an exclusion zone where something is forbidden (for example, the typical practice of forbidding home building in 100-year floodplains) can be modified to show levels of suitability, or a suitability ranking, where an activity is increasingly less appropriate based on the physical characteristics of the site.

To define exclusive or inclusive areas, a buffering technique is frequently adapted. Buffering is a typical spatial function in GIS to define a zone of a specified distance around coverage features such as roads as shown in Figure 5. For instance, both constant- and variable-width buffers can be generated for a set of roads based on each road's attribute values, like pavement or number of lanes. The resulting buffer zones form polygons-areas that are either inside or outside the specified buffer distance from each feature. Buffers are useful for proximity analysis (e.g., find all stream segments within 300 feet of a proposed carcass burial area). Map algebra and data overlay is another spatial analysis function to sum the rankings to display where something is impacting the process. Figure 6 is a prototype approach for carcass disposal site selection procedures using GIS spatial analysis. Refer to Appendix B for additional information.

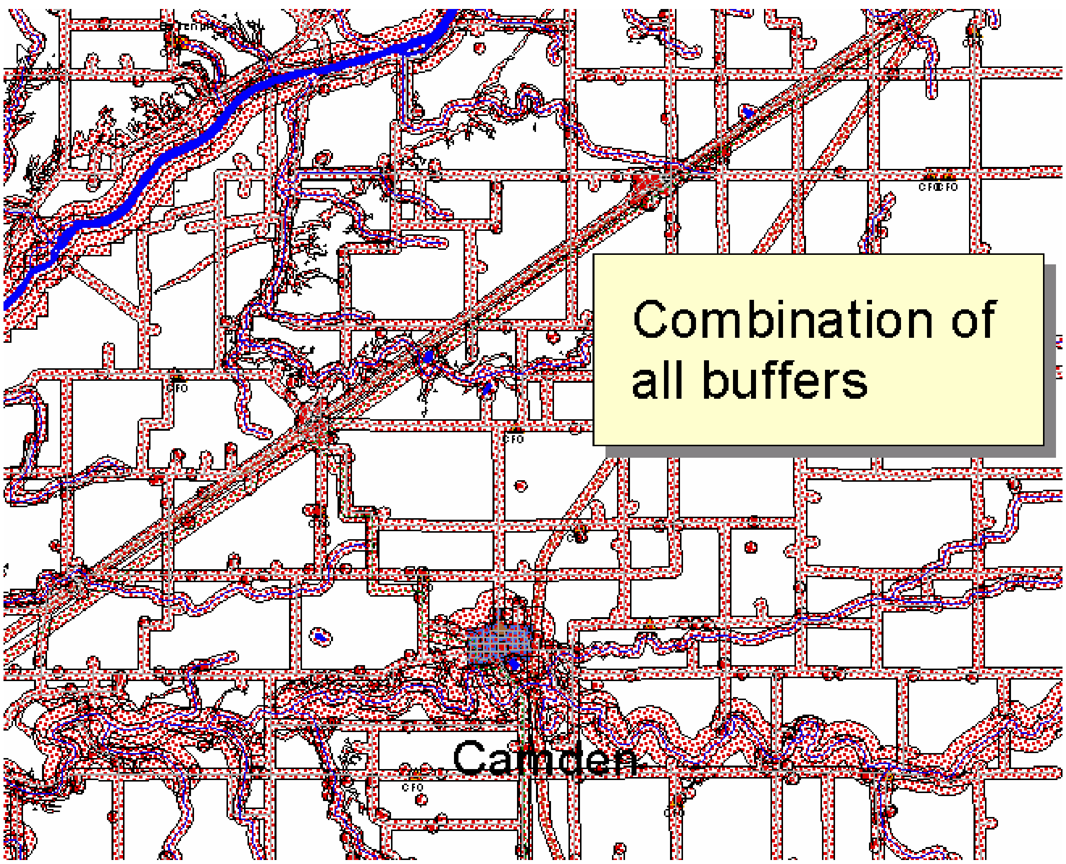

FIGURE 5. Map overlay of road, well, and stream buffering.

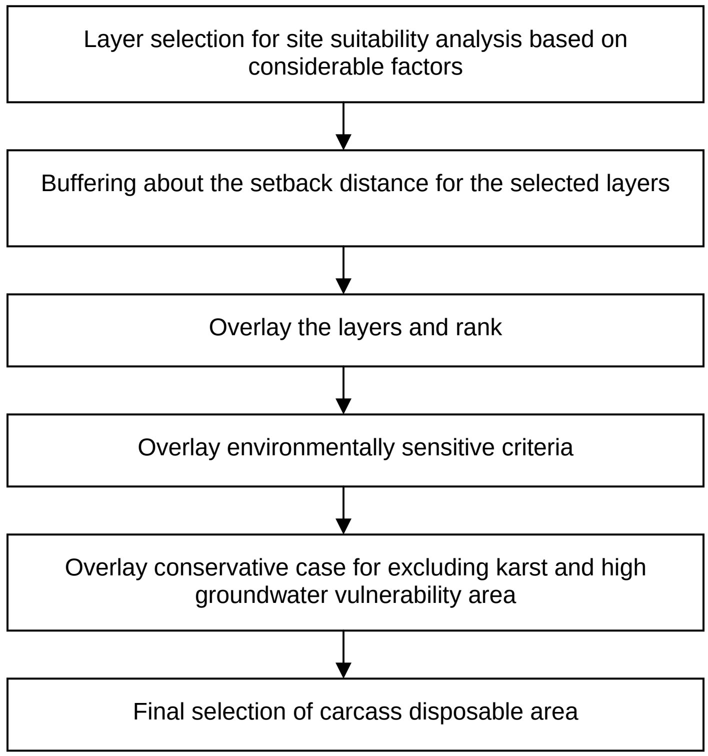

FIGURE 6. Carcass disposal site selection procedures using GIS spatial analysis approach.

Data layers

For the carcass disposal site selection analysis, seven layers were selected and analyzed to define an exclusive or inclusive area as follows.

- Forbidden
  - Soil with slope > 6%
  - Karst areas
- 300-foot setback
  - Roads
  - Private wells
  - Streams, lakes
  - Property lines (No detailed GIS layer exists, so this was not implemented in the model.)
- 1000-foot setback
  - Public water supply wells

These layers are intended to create a ranking system for estimating the appropriateness of a site for large-scale carcass burial. The basic model is designed from the approach taken to site a manure lagoon as shown by the sample ranking in Table 1. Other, more regional, considerations are added to improve the way the ranking considers groundwater features.

When summed, the layers will create a ranking where 3 is forbidden, 2 is a concern at a county scale, 1 is a possible local concern, and 0 is not a concern. It would be appropriate to establish that rank 1 and 2 should be evaluated on site.

TABLE 1. Sample layer description for the ranking.

Layer	Buffer (ft)	Burial rank	Description	Rule
Basic Themes				
Roads	300	3	Roads that can be used to "geocode" a street address, placing it at a specific location on the map.	Manure lagoon
Streams and rivers	300	3	National Hydrography Database, medium resolution (USGS digitized from 1:100,000 maps)	Manure lagoon
Lakes and Rivers	300	3	Polygons from NHD	Manure lagoon
Wetlands	300	1	This layer contains the National Wetlands Inventory (NWI) developed by the US Fish and Wildlife Service.	Polygon
Private wells	300	3		Manure lagoon
Public wells	3000	1	Wells for non-community public water supply systems, from 2001	WHPA
Public wells	1000	3	Wells for non-community public water supply systems, from 2001	Manure lagoon

Section 5 – Utilizing GIS for Animal Disease Cases

GIS has frequently been considered a tool that has potential to be utilized in several aspects of animal related disasters. Through several different examples, GIS has shown its applicability for improving disaster response efficiency by supplying maps and spatial analysis capabilities. Examples introduced in this section are typical applications for utilizing GIS in animal disease cases.

5.1 – North Carolina Department of Agriculture Veterinary Division

In North Carolina, the North Carolina Department of Agriculture Veterinary Division developed a GIS for use in animal health programs during the late 1980s. They have utilized GIS for animal health issues since that time during mitigation and disease response processes (McGinn et al., 1996, McGinn et al., 1998, McGinn, 2002).

GIS was used with pseudorabies virus (PRV) outbreaks in Duplin County, North Carolina to display 12 swine herds circulating PRV and a one-mile buffer around each circulating herd. In Figure 7, buffers of three, four, and five miles are shown around the cluster of circulating farms and their neighbors. Quarantine disease status, farm type, and ownership are displayed on the map and ghost circles are used to show where the virus has stopped circulating. This information is important in the containment of the virus and in epidemiological investigations. As preparation for an emergency, the use of GIS in the situation allowed decision makers to develop a containment and elimination plan in a timely manner via a conference call. It also provides directions and medical herd/area history to investigators, such as foot and mouth disease (FMD) diagnosticians (McGinn et al., 1998).

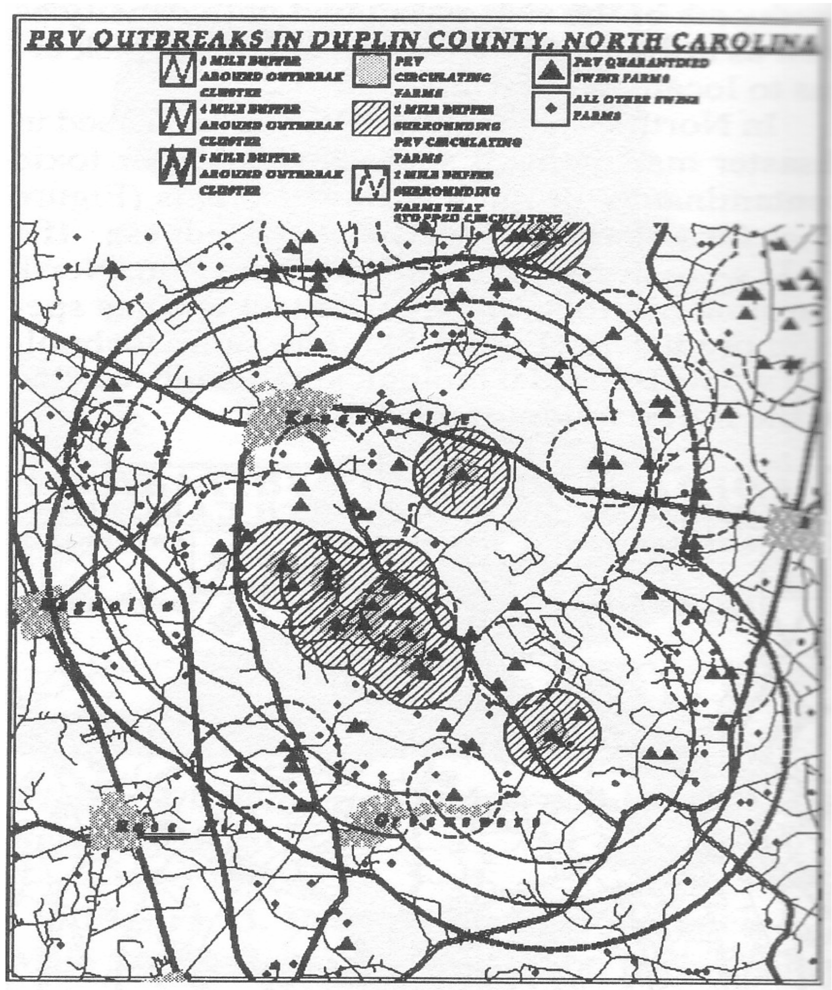

FIGURE 7. Pseudorabies virus outbreaks in Duplin County, North Carolina, and buffers (McGinn et al., 1998).

Routing applications enhance biosecurity for farms by controlling which truck(s) visit each farm, decreasing cost of operations, and shortening training period for new drivers (Figure 8). Computerized truck routing allows management to make better decisions for preventing the spread of disease such as pseudorabies in swine and the corona virus in turkey operations. Computer-aided truck routing enables companies to immediately update farm information such as disease status and quickly change routes and directions to reflect the new information. In an emergency or a disaster situation, routing applications aid in reducing exposure to noninfected animals by quickly moving the infected animals on a minimized path to a disposal site. Management overall has more information in which to make better decisions (McGinn et al., 1998).

5.2 – Animal Health Surveillance in Alberta, Canada

Agri-Food Surveillance Systems Branch, Agriculture, Food and Rural Development, Alberta, Canada, has considered a GIS for animal health surveillance. Renter (2002) indicated in the Animal Health Forum that “a GIS can be a valuable tool in addressing animal health and food safety issues. Maintaining the confidentiality of producers (and other information sources) and assuring the accuracy of the data are essential when using a GIS. When used correctly, a GIS can help identify clusters of disease, manage and predict disease outbreaks, identify risk factors, assess sample and population distributions, and supplement other areas of food safety and animal health surveillance and research (Figure 9).

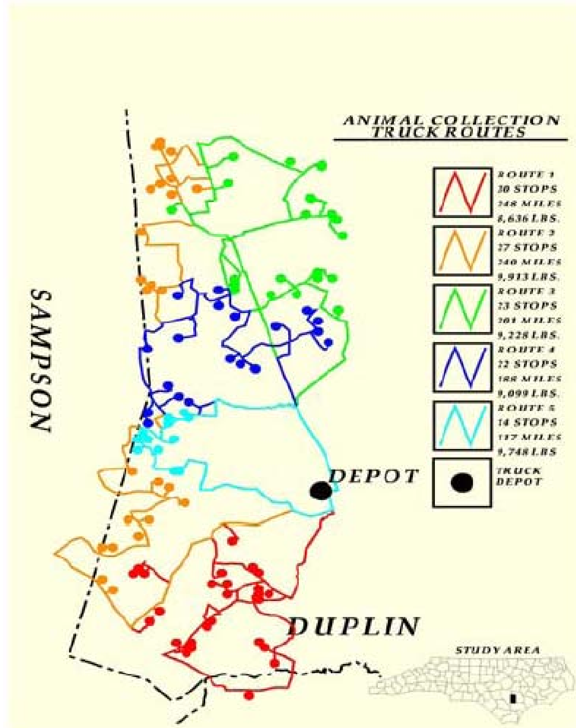

FIGURE 8. Truck route map from GIS for animal carcass collection (McGinn et al., 1998).

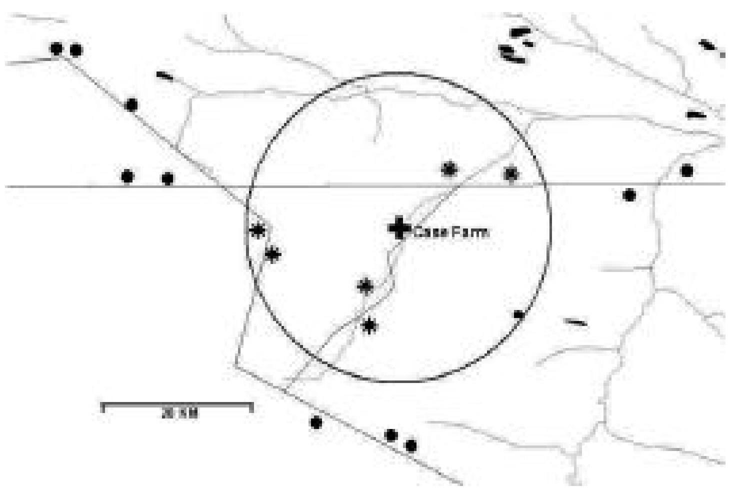

FIGURE 9. A simulated GIS map that could be generated for disease response. When a disease is diagnosed, the case farm (**+)** is displayed and all farms (*****) within a specified zone (circle) can be identified. Roads, waterways, and farms outside the zone (·) are also shown (Renter, 2002).

5.3 – Foot and Mouth Disease Outbreak in Great Britain, 2001

Although the FMD disaster in Great Britain in 2001 was a great stress on people who were involved, they learned several lessons from the disastrous outbreak (Scudamore and Harris, 2002). Among the lessons were the usefulness of GIS and its role in an animal health emergency response process. Scudamore and Harris (2002) noted in their article: "The value of a geographic information system (GIS), already recognized during the classical swine fever outbreak, was confirmed by use during the FMD epidemic at both local and national levels. The GIS provided location data and allowed separate databases to be combined to provide graphical representations of disease status. The production of high quality and specific maps greatly helped the effort to deal with the disease and to explain the process to others. The GIS is a data handling tool that will play an increasing role in any future disease outbreak and resources are being made available to ensure such a tool is available."

5.4 – Debris Recovery Effort for the Shuttle Columbia

While it is difficult to find published examples of the use of GIS in carcass disposal projects that are national in scale, there are a few examples, primarily the English response to FMD. Certainly one example of the use of GIS in a national catastrophe that has serious implications for carcass disposal is the recent debris recovery effort for the Shuttle Columbia (Brown et al., 2003).

How is this related to the carcass disposal effort? There were teams of thousands of responders, untrained in GIS or GPS, who were performing coordinated actions across five states as rapidly as possible. The activities of thousands of small groups were coordinated using GIS. Several lessons can be learned as reported in the recent article by Brown et al. (2003). The sheer scale of this operation makes it similar in size and complexity to a multi-state outbreak of FMD in the US

As the shuttle debris field was spread across state borders, multiple federal, state, and local organizations mobilized large numbers of small mapping parties. These parties had GPS receivers to create a location for use in a GIS, but no previously agreed-upon mapping standards existed between local, state, and federal authorities. This resulted in maps made with different units; for example, county surveys often use feet, federal agencies may use meters, and some organizations used degrees of longitude and latitude. The latter can be collected in two different formats, which results in the coordinating groups receiving map data in at least four different types of data units, requiring conversion before they can be incorporated into a map used for the following day's coordination (Brown et al., 2003).

The authors conclude that the numerous agencies involved should coordinate on mapping standards and data formats in advance. They further stated: "Even a simple 1 hour instruction on how to use a GPS receiver for data collection, navigation, and coordinate system configuration would have saved countless hours in data conversion" (Brown et al., 2003).

The authors report that in Central Texas, the effort by the University of Texas San Antonio provided GIS support for approximately 4000 field personnel, mobilizing daily with fresh maps printed showing progress and search areas. "At any given time, there were three to four GIS personnel making needed maps to support the recovery efforts. Unfortunately...printing was excruciatingly slow." The authors conclude advance procurement of the highest speed postscript plotters with expanded memory is critical to future efforts (Brown et al., 2003).

The most important lesson here for carcass disposal is that prior coordination of resources and data formats would greatly leverage scarce resources during a disaster.

Section 6 – Critical Research Needs

The following research needs have been identified based on the review of materials related to the use of GIS in carcass disposal events, activities completed as part of this effort, and the authors' experiences in application of GIS to various issues.

1. A set of decision rules to select the best carcass disposal technology for a particular location and situation are needed. These decision rules will need to be created in a manner that can be implemented within GIS. GIS should play a critical role in the development of resulting decision support tools to identify the likely suitability of locations for carcass disposal.
2. A site analysis decision support tool is needed that will allow prescreening of sites to identify whether they are likely suitable for carcass disposal. The decision rules from recommendation #1 combined with spatial data in GIS can be used to create maps that depict areas to be considered further for carcass disposal. Such a tool will also require use of environmental models.
3. Further analysis of the GIS data layers required for carcass disposal management is needed. Once the key data layers are selected, these should be assembled in a common format and integrated for use in the event of an emergency. There will not be sufficient time to assemble these data during an emergency.
4. Web-based GIS capabilities should be developed to provide some of the key data assembled within recommendation #3. By making the data available within a Web-based GIS, the amount of training of decision makers and field personnel can be reduced and the data can be made widely and quickly available.
5. A range of training materials on the use of GIS for carcass disposal are needed. For example, materials that would provide simple and rapid training to field personnel on the use of simple capabilities such as those provided within WWW-GIS are needed. More comprehensive GIS training materials are also required that would target personnel in central coordinating locations.

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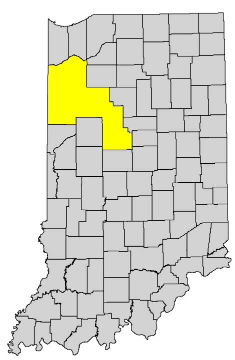
Appendices

Appendix A – GIS: Multicounty Exclusion Model

This appendix describes the creation of a six county carcass disposal site exclusion zone model. In this analysis, an exclusion zone was created where carcass burial is not deemed appropriate. The object of this exercise is to provide a quick reference map (prepared in advance) to emergency responders which can guide their decision-making in choosing disposal options, and disposal locations.



This example is based on detailed geographic information for a multi county area of north-central Indiana. The area includes the counties of Benton, Carroll, Clinton, Jasper, Newton, and White.

Total area 1715100 acres.

This is a fairly level, till-plain topography with a large animal agriculture base. The area is mostly rural but also includes some medium–sized cities.

For step one, the GIS team used current Natural Resource Conservation Service manure lagoon criteria to eliminate areas that would not be acceptable for manure lagoons. The basic assumption is that a carcass burial site is as environmentally sensitive as a manure lagoon. The manure lagoon management criteria for Indiana include the following:

- Forbidden: soil with slope > 6%
- Forbidden: Karst areas, a region in Southern Indiana which is underlain by limestone that has been extensively eroded, forming an interconnected network of sinkhole, springs, and limestone caverns with flowing water. A legal definition of Karst extent was created by the Indiana Department of Environmental Management (IDEM) using Indiana Geological Survey (IGS) data for the management and licensing of confined animal feeding operations. This map layer is used for the model.

- 300-foot setback:
    - Roads
    - Private wells
    - Streams, lakes
    - Property lines (No detailed GIS layer exists, so this was not implemented in the model.)
- 1000-foot setback:
    - Public water supply wells

This model was created using a 300-foot buffer around all private wells from the 2003 IGS database, and 1,000-foot buffer around all public wells (2001 database from IGS). This first buffer layer, water wells, represents 119,513 acres excluded. Using 300-foot buffer around general streams and waterbodies creates a buffer of 271,690 acres. Using 300-foot buffer around all roads represents 532,236 acres excluded (overlap is not removed from these numbers yet).

We also created a buffer for the 6% or greater slope area. This was created from 30-meter by 30-meter cells (the National Elevation Data Digital Elevation Model layer), so it is a measure of where general slope averages greater than 6%. It will include local areas of lesser slope. These high-slope areas are generally around the river valleys. The calculated area for this is 9,133 acres. This part of Indiana does not have Karst topography.

Additional environmentally sensitive criteria:

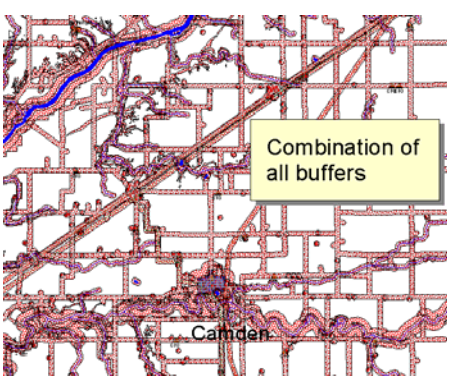
We then increased the buffer from 300 feet to 1000 feet around these water features:

- Legally designated "Scenic" or "Exceptional use waters."
- Legally designated "Impaired waters."
- Public Recreation Water Bodies (from an Indiana Department of Natural Resources database of sites with public access to water recreation).

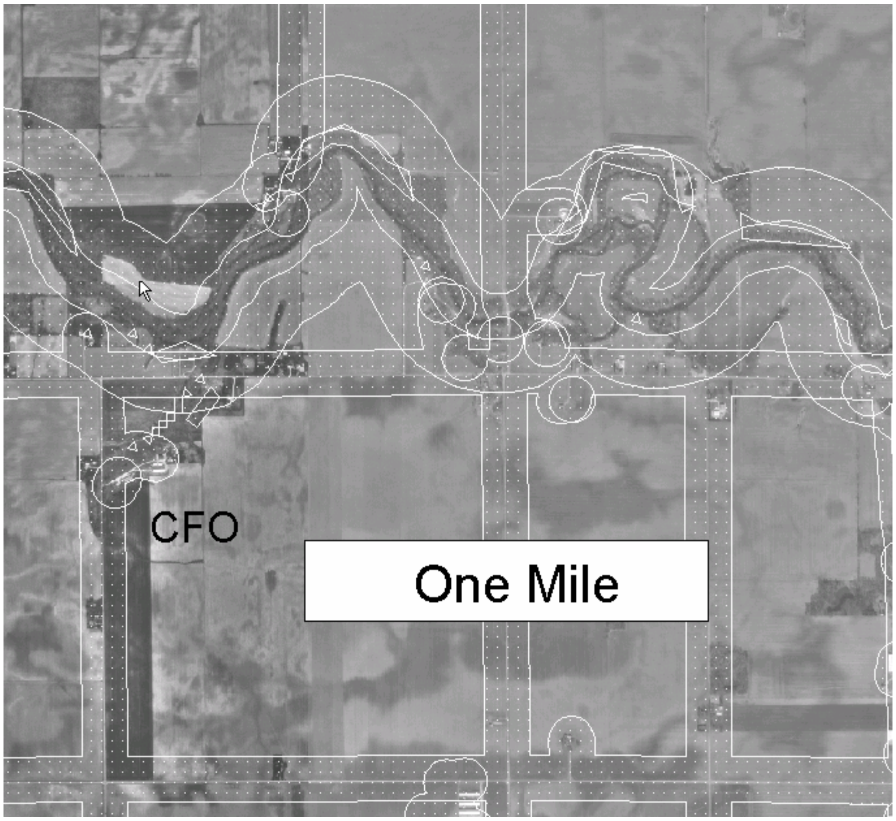
This increased the water body buffer to 518,171 acres for mapped water features.

We assigned a 1,000-foot buffer to Census Urbanized Areas and urban clusters; these two map layers from the US Census Bureau include Defined Places (towns and cities) and also include suburbs where population density is judged to be more than 5,000 per mile. So this area is slightly larger than the actual town limits. In some areas, it is quite a bit larger than actual town limits. This created a buffer of 132,927 acres. These numbers still include overlap.

We assigned 300-foot buffer to pipelines, major power lines, schools, cemeteries, churches, fairgrounds, petroleum wells, hospitals, and underground storage tanks. This created a buffer of 190,201 acres (much of which is inside the town buffer map layer). A representation of what this looks like on the ground also follows.



Total exclusion zone without "high Drastic" is 718,134 acres (from a total of 1,715,100 acres); thus 42% of the total area is excluded in advance of a disaster, 58% is available for consideration by local responders.



Exclusion zones are displayed with a white hachured area.

This rural area displays zones mainly around streams, roads, and wells.

Large areas remain which are outside the exclusion zones.

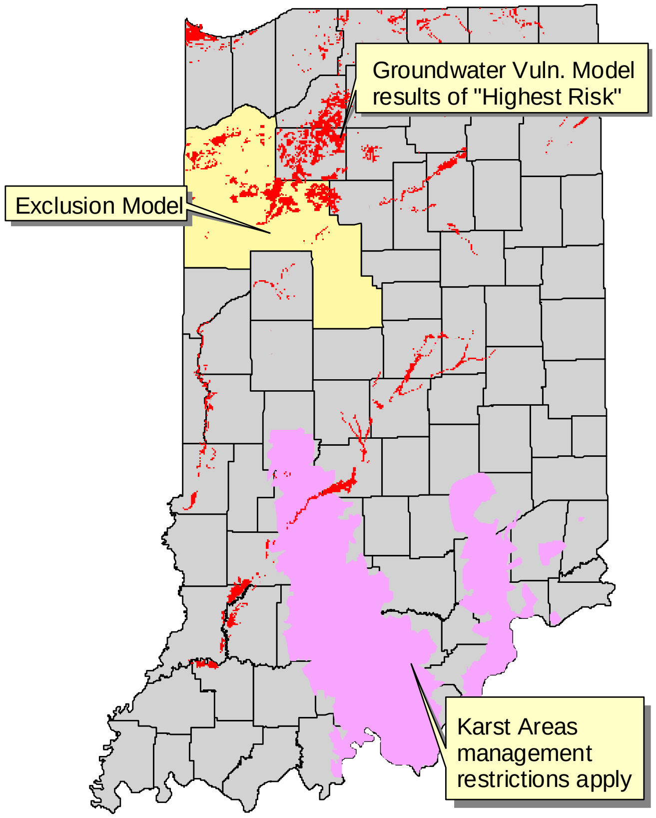
The model assumes local responders will choose the most appropriate or accessible sites from the non-excluded areas.

Most conservative case

We created a buffer for the areas designated by the Indiana Groundwater Vulnerability Study to be at "Highest risk" of nitrate loss (Grid value 4). This area is extensive where it is present, and is the only rating factor besides Karst topography which eliminates large chunks of entire counties. Excluding this factor, but with all the other factors, a suitable site remains within a mile or so of any operation. This should be carefully considered before employing this particular factor (Highest risk from DRASTIC model) on a large scale.

This DRASTIC model Highest-risk area is 346,366 acres. That number includes overlap with other factors.

Total exclusion zone including the "Highest-risk vulnerability to Nitrates" area is 801,160 acres, or 47% of the available land (in the six-county test area) in the more conservative case.



This figure illustrates the extent of two agricultural practice management restriction areas.

The red illustrates the "Highest risk to Nitrate contamination" area from the Indiana Groundwater Vulnerability Study. This map layer is used in pesticide use management.

The pink illustrates the extent of the "Karst area" as defined for Confined Animal Feeding Operations(CAFO) management by IDEM.

Appendix B – Prototype of Airborne Disease Propagation Based on Web-GIS

To show the applicability of Web-based GIS in dealing with animal health issue, a prototype Airborne Disease Propagation system based on Web-GIS has been developed.

1. Web-GIS and Interface Development

   The MapServer Web-GIS tool was selected as the Common Gateway Interface (CGI) engine for developing the Web-GIS map user interface. MapServer was originally developed by the University of Minnesota ForNet project in cooperation with NASA and the Minnesota Department of Natural Resources (MNDNR) (http://mapserver.gis.umn.edu). The CGI, running on the server side, provides a "light weight" page for the client. Thus, if the server is powerful enough to control the processes from multiple connections within a reasonable time, it is the preferable choice to support potential users, since concerns regarding client side computer capability and connection speed are minimized.

2. Exposure zoning

   Airborne propagation simulation with wind direction, wind speed, and duration from an outbreak was programmed to display exposure zoning on the Web-GIS interface. Using the input data from the HTML form map interface, an exposure zone can be delineated as a cone shape boundary. The cone shape boundary is used to extract the information for school locations, public recreation areas, and public water supply locations from the database.

The Web-GIS also has several functions like coordinate conversion from latitude and longitude to Universal Transverse Mercator (UTM) and printable page preparation.

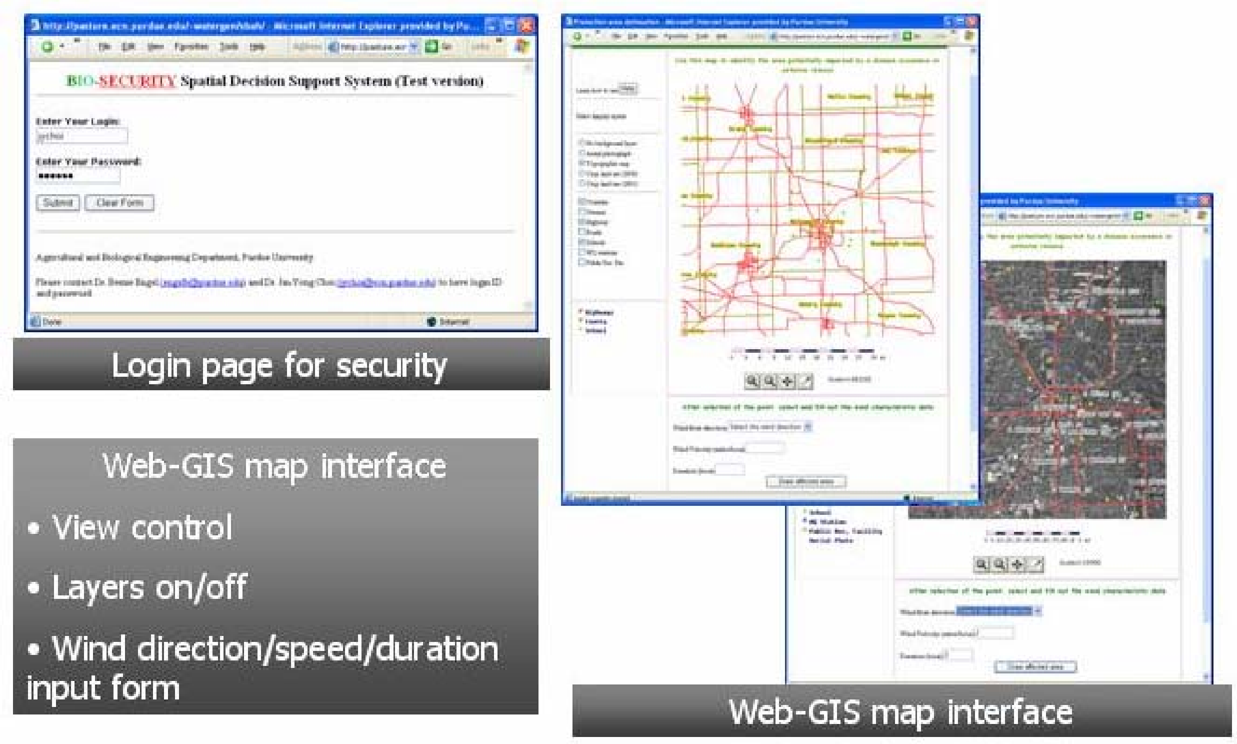


FIGURE B1. Login page and map interface of the airborne disease propagation simulation Web-GIS.

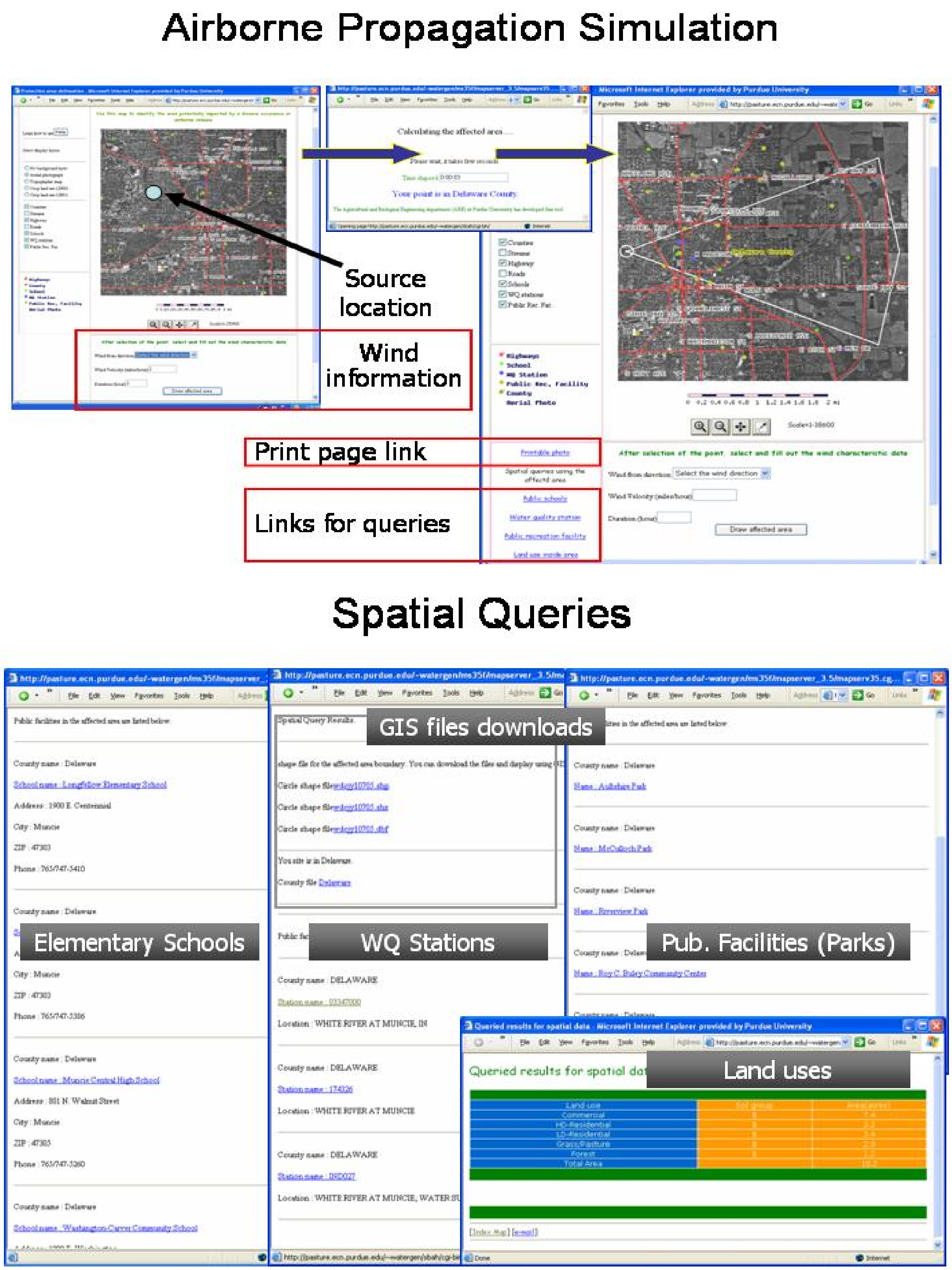


FIGURE B2. Airborne disease propagation simulation and result display on the Web-GIS map interface.

Appendix C – Layers Ranking System

Information Request, US Department of Agriculture (USDA) Carcass Disposal Working Group (CDWG), GIS subcommittee

Discussion

This subcommittee of the CDWG is requesting an evaluation of GIS data layers which relate to the decision-making process in carcass disposal operations.

For each of the disposal operations (e.g. burial, burning, etc.) under consideration by various teams, we have identified GIS layers which may aid in the process of deciding which mechanism to employ and where to employ it. Establishing this foundation of decision support data would enable individual states to make recommendations or guidelines for site suitability and technology selection in advance of an emergency.

The GIS planning group envisions state-level planning using both pre-emergency screening techniques and post-emergency decision support. Typical actions include:

- Pre-disposal evaluation of suitable sites and technologies.
- Decision support during an emergency.
- Post-disposal evaluation of site.
- Monitoring and observation after carcass disposal if required.

The function of the questionnaire is to prompt discussions among the various technology teams. Using the questionnaire to develop a list of useful data layers, or expose incorrect assumptions in the GIS planning strategy, becomes a process of creative strategic design as experts in various technologies are exposed to the GIS planning groups assumptions.

For example, in meetings at Purdue with the chemical digestion team, the concept was put forward that employing digestion technologies that produce liquid waste would benefit from a map layer (list) of publicly owned treatment works (POTW). The plan would be to send the liquid fraction of the digestion output to sewage treatment plants, perhaps after buffering the pH.

Ideally the person in command could quickly organize the shipment of liquid waste to POTWs working from a map layer showing nearby POTWs with phone numbers. This idea led to further discussions with faculty who have expertise in that issue. In Indiana, there is a map layer of POTW facilities with phone numbers and capacities included. However, some clarification will be required before it is useable in carcass disposal scenarios.

This liquid digestion waste material is statutorily banned from disposal in some communities, and many POTW no longer are equipped to handle large trucks. The material will probably need to be sent to tertiary treatment plants for several reasons (basically, large cites). In fact, preapproval is strongly suggested here. It became apparent that this would be very useful data layer to have in advance, but it will require some work on the ground to make it happen. This is an important result of this discussion process.

Another aspect of GIS planning data needs that came to light during this discussion was the need to arrange for refrigerator trucks to store carcasses as well as tankers to move digestion products. Because of the slow throughput, the digestion technology would also need refrigerator trailers to store carcasses till the digesters(s) could handle them. Planning to acquire these trailers can be done in advance and would benefit from being spatially arranged. (One strategy would be to assume it will pay to locate sources of trucks near the densest areas of livestock.)

In an infectious disease scenario, the amount of truck and trailer type equipment which will repeatedly be disinfected becomes significant, even in an on-site chemical digestion scenario. As reported elsewhere, in England the widespread and copious use of disinfectant on barns and equipment had a negative impact on shallow groundwater supplies.

Therefore, operational planning would benefit from a map layer displaying areas where shallow groundwater or drinking water aquifers or reservoirs are particularly vulnerable to surface spills of disinfectant. Such a map layer has been produced already for several states such as Indiana and Texas, and location of that map data in advance of the emergency is good planning.

In a similar fashion, discussing the usefulness of various GIS layers with the composting team brought out the usefulness of creating or finding planning layers such as pallet suppliers (because shredded pallet debris can be a compost amendment). The sheer volume of amendment needed for composting large numbers of carcasses strongly supports the need for advance planning to locate nearby supplies. The discussion of which map data is useful in planning seems to quickly bring up requests for map data which is not commonly used, but not impossible to come by. Working in advance of emergencies, these data layers can be constructed or, more frequently, tracked down where they already exist in obscure state agencies.

Conclusion

To support this strategic planning discussion, each operational disposal technique has a list of specific map layers that may or may not be useful (in your opinion) to implementers dealing with an event. GIS support for these screening efforts will include collecting existing data layers as well as determining what new layers should be created.

In addition to the list for the specific disposal technique, there is a Basic Planning Layer list which includes layers that may or may not be useful to pre-disaster response planning.

We would like you to look over the GIS data layer list and rate the layers in regard to usefulness to the disposal techniques you are considering. Add any layers you feel are useful that do not appear on the list.

Executive summary

For each of the disposal operations (rendering, biodigestion, incineration, composting, burial, and chemical digestion) under consideration by various teams, we have identified GIS layers which may aid in the process of deciding which mechanism to employ and where to employ it. Establishing this foundation of decision support data would enable individual states to make recommendations or guidelines for site suitability and technology selection in advance of an emergency.

The GIS planning group envisions state-level planning using both pre-emergency screening of techniques and post-emergency decision support. Typical actions include:

- Pre-disposal evaluation of suitable sites and technologies.
- Decision support during an emergency.
- Post-disposal evaluation of site.
- Monitoring and observation after carcass disposal if required.

The function of this questionnaire is to develop a list of useful data layers, or expose incorrect assumptions in the GIS planning strategy.

Each operational disposal technique has a list of specific map layers that may or may not be useful (in your opinion) to implementers dealing with an event. GIS support for these screening efforts will include collecting existing data layers as well as determining what new layers should be created.

In addition to the list for the specific disposal technique, there is a Basic Planning Layer list which includes layers that may or may not be useful to pre-disaster response planning.

We would like you to look over the GIS data layer list and rate the layers in regard to usefulness to the disposal techniques you are considering. Add any layers you feel are useful that do not appear on the list.

We seek input from your group as to whether each specific layer is:

5 – needed, and present in your state

4 – needed, and could be constructed

3 – needed, but the basic data probably does not exist

2 – useful, but not needed

1 – not applicable in my state

0 –not useful in any case

Disposal Option 1 Rendering

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts, during storm emergencies.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as burn or burial sites. “Points-on-a-map” rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a “dot-on-the-map” for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	

Disposal Option 1 Rendering

Layer	Uses	Rating 0 - 5
Location of possible render processing sites.	Transport of carcasses long distances into undiseased areas may preclude use in some cases.	
Location of current rendering pickups	With some diseases render pickup points outside disease area may need to be closed to minimize spread. Use with road layer and CAFOs layer to map contamination warnings	
Transportation buffer	CAFO or animal owners can be alerted to movement of carcass to render pickups. Useful with airborne contamination possibility.	
Trucking contractors	May need refrigerator trailer trucks to hold carcasses till pickup.	

Disposal Option 2 Biodigestion

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts, during storm emergencies.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as burn or burial sites. “Points-on-a-map” rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a “dot-on-the-map” for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	
Land application permits	Areas where “sludge” is licensed for application. (A sludge material is also a digestion by-product in some technologies.)	
Soil map	Useful for screening sites that will use large amounts of disinfectant on trucks, tractors, and digesters.	
Water table depth	Useful for screening sites that will use large amounts of disinfectant on trucks, tractors, and digesters. Groundwater contamination by disinfectant was an issue in England.	
POTW locations	Public water treatment plants. To be useful for disposal of digestion liquids, this list needs to be prescreened for tertiary treatment plants, plants with truck unloading facilities, and plants not statutorily forbidden from accepting off-site waste.	
Landfill locations	Dry residue product of some technologies could be landfilled if burial is not an option.	
Schools, hospitals layer	With some technologies odor will be a problem.	

Biological digestion on site

Layer	Uses	Rating 0 - 5
Census designated places (updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning where the smell of digestion might preclude its	

	use.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning where the smell of digestion might preclude its use.	
CAFOs location maps	With species, size, and contact info, this database becomes an aid in planning where to move carcasses. Also useful to track the disposal sites in the future.	
Corn oil and other agricultural process facility locations	Contact for "bio-solids" supply for filler.	
Trucking contractors	May need refrigerator trailer trucks to hold carcasses till digesters have capacity on site.	

Biological digestion at collection points

Layer	Uses	Rating 0 - 5
Location of possible render / digestion processing sites	Transport of carcasses long distances into undiseased areas may preclude use in some cases. Makes decision easier if determined in advance no site is within reach.	
Location of current rendering pickups	With some diseases render pickup points outside disease area may need to be closed to minimize spread. Use with road layer and CAFOs layer to map contamination warnings.	
Transportation buffer	CAFO or animal owners can be alerted to movement of carcass to render pickups. Useful with airborne contamination possibility.	

Disposal Option 3 Incineration

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts, during storm emergencies.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne	

	contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as burn or burial sites. "Points-on-a-map" rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a "dot-on-the-map" for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	

On-site pyre incineration

Layer	Uses	Rating 0 - 5
Lumber yards	Untreated timber for pyre construction fuel.	
CAFOs location maps	Useful to track the burial sites in the future.	
Census designated places (updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
County-level Soil Survey Geographic (SSURGO) map	Useful for excavation suitability and soil drainage ratings.	
FEMA flood zones, county-level	Useful to eliminate unsuitable excavation sites due to flooding or saturated soils. Also useful to distinguish sites where it may be impossible to recover or move carcasses.	
Pallet sales and manufacturing locations	Shredded or scrap pallets can be used as fuel.	

Incineration pyres at collection points

Layer	Uses	Rating 0 - 5
Lumber yards	Untreated timber for pyre construction fuel. "Points-on-a-map" rather than lists may speed planning process.	
Straw sources	Bales/bulk straw/hay for pyre construction. "Points-on-a-map" rather than lists may speed planning process.	
Wholesale coal suppliers	Fuel for pyre construction. "Points-on-a-map" rather than lists may speed planning process.	
Municipal/industrial incinerators or kilns	May be used as burn site. "Points-on-a-map" rather than lists may speed planning process.	
CAFOs location maps	With species, size, and contact info, this database becomes an aid in planning where to move carcasses for pyres. Also useful to track the burial sites in the future.	
Military bases	May be used as burn site. "Points-on-a-map" rather than lists may speed planning process.	
Municipal landfills	May be used as burn site. "Points-on-a-map" rather than lists may speed planning process.	

Coal mines/reclamation areas	Excavated or "clinker" beds may be used as a burn site.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Census designated places (updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
Schools and outdoor recreation areas	These layers are environmentally sensitive and are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
Public drinking water reservoirs	These layers are environmentally sensitive and presence in a smoke plume area might preclude use as a pyre collection point.	
County-level SSURGO map	Useful for excavation suitability and soil drainage ratings.	
County-level stream and water-body layers	Useful in states where there is a "minimum distance rule" or buffer established for burial or burning operations near still or moving water. Also useful for planning environmental impact of burning by pyre or burial.	
County-level aquifer or aquifer-sensitivity maps	Useful to eliminate unsuitable excavation sites based on groundwater contamination possibility.	
FEMA flood zones, county-level	Useful to eliminate unsuitable excavation sites due to flooding or saturated soils. Also useful to distinguish sites where it may be impossible to recover or move carcasses.	
Extended flooding vulnerability maps	Layers extending the flood zone to encompass additional low-lying areas that are possible inundation areas, outside floodplains in unusual storms or high-water conditions. Aids in planning where burial might not be appropriate or where it may be impossible to recover or move carcasses.	

Air curtain burning at collection points

Layer	Uses	Rating 0 - 5
Census designated places (updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning where the smell/smoke/particulates of burning might preclude its use.	
FEMA flood zones, county-level	Useful to eliminate unsuitable collection sites due to flooding or saturated soils. Also useful to distinguish sites where it may be impossible to recover or move carcasses. Useful in some situations to map where flood debris may provide fuelwood. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and	

	viaducts.
CAFOs location maps	With species, size, and contact info, this database becomes an aid in planning where to move carcasses for burial. Also useful to track the burial sites in the future.
Bulk fuel depots	Contact and location of source of diesel fuel for fire. (For example, 500 swine would use 200 gal of fuel.)
Transportation buffer	CAFO or animal owners can be alerted to movement of carcass with airborne contamination possibility to burn sites pickups.
Wholesale lumber yards	Untreated timber for fire fuel. (For example, 500 swine would also use 60 tons of wood.) Display of timber supply as "points-on-a-map" rather than lists to speed planning process.
County-level SSURGO map	Useful for excavation suitability and soil drainage ratings.
Straw sources	Bales/bulk straw/hay for fire construction. "Points-on-a-map" rather than lists may speed planning process.
Military bases	May be used as burn site. "Points-on-a-map" rather than lists may speed planning process.
Municipal landfills	May be used as burn site. "Points-on-a-map" rather than lists may speed planning process.

Disposal Option 4 Composting

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as burn or burial sites. "Points-on-a-map" rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a "dot-on-the-map" for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	

On-site composting

Layer	Uses	Rating 0 - 5
Census designated places (updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning where the smell of composting might preclude its use.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning where the smell of composting might preclude its use.	
CAFOs location maps	With species, size, and contact info, this database becomes an aid in planning where to move carcasses for burial. Also useful to track the burial sites in the future.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators, within a fixed distance of the highway systems, that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Pallet sales and manufacturing locations	Shredded or scrap pallets can be used as filler.	
Recycle paper wholesalers	Contact info on supply of filler for compost piles. “Points-on-a-map” rather than lists may speed planning process.	
Lumber yards	Untreated sawdust for filler. “Points-on-a-map” rather than lists may speed planning process.	
Straw sources	Bales/bulk straw/hay for filler. “Points-on-a-map” rather than lists may speed planning process.	
Bulk storage (fertilizer) facilities	May need “starter” fertilizer for composting with wood products.	
Corn oil and other ag process facility locations.	Contact for “bio-solids” supply for composting filler.	
County-level SSURGO map	Useful for excavation suitability.	
County-level SSURGO map	Useful for soil drainage ratings.	
County-level SSURGO map	Useful for soil type/series ratings.	
County-level SSURGO map	Useful for soil texture ratings.	
County-level slope maps	Useful to eliminate unsuitable excavation sites (due to steep slopes).	
County-level aquifer or aquifer-sensitivity maps	Useful to eliminate unsuitable excavation sites based on groundwater contamination possibility.	
County-level water well maps	Useful to eliminate unsuitable excavation sites due to drinking water contamination issues.	
Street-address type roads layer	Allows the GIS to make a “dot-on-the-map” for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	
County-level aerial photos	Useful for planning.	
Land application permits	Areas where “sludge” is licensed for application (compost product may be considered a sludge in some states.)	
Schools, hospitals layers	With some technologies odor will be a problem.	

Disposal Option 5 Burial

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts, during storm emergencies.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as burn or burial sites. “Points-on-a-map” rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a “dot-on-the-map” for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	

On-site burial

Layer	Uses	Rating 0 - 5
County-level SSURGO map	Useful for excavation suitability.	
County-level SSURGO map	Useful for soil drainage ratings.	
County-level SSURGO map	Useful for soil type/series ratings.	
County-level SSURGO map	Useful for soil texture ratings.	
County-level slope maps	Useful to eliminate unsuitable excavation sites (due to steep slopes).	
County-level aquifer or aquifer-sensitivity maps	Useful to eliminate unsuitable excavation sites based on groundwater contamination possibility.	
County-level water well maps	Useful to eliminate unsuitable excavation sites due to drinking water contamination issues.	
Extended flooding vulnerability maps	Layers extending the flood zone to encompass additional low-lying areas that are possible inundation areas outside floodplains in unusual storms or high-water conditions. Aids in planning where burial might not be appropriate or where it may be impossible to recover or move carcasses.	
FEMA flood zones, county-level	Useful to eliminate unsuitable excavation sites due to flooding or saturated soils. Also useful to distinguish sites where it may be impossible to recover	

	or move carcasses.	
County-level stream and water-body layers	Useful in states where there is a "minimum distance rule" or buffer established for burial or burning operations near still or moving water. Also useful for planning environmental impact of burning by pyre or burial.	
CAFOs location maps	Useful to track the burial sites in the future.	
Street-address type roads layer	Allows the GIS to make a "dot-on-the-map" for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	
County-level aerial photos	Useful for planning.	

Burial at collection points such as CAFOS

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful to eliminate unsuitable excavation sites due to flooding or saturated soils. Also useful to distinguish sites where it may be impossible to recover or move carcasses. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
CAFOs location maps	With species, size, and contact info, this database becomes an aid in planning where to move carcasses for burial. Also useful to track the burial sites in the future.	
Military bases, especially National Guard and training grounds	May be used as burial sites. "Points-on-a-map" rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
County-level SSURGO map	Useful for excavation suitability and soil drainage ratings	
County-level water table maps	Useful to eliminate unsuitable excavation sites based on groundwater contamination possibility.	
County-level aquifer or aquifer-sensitivity maps	Useful to eliminate unsuitable excavation sites based on groundwater contamination possibility, including large amounts of disinfectant use.	
Street-address type roads layer	Allows the GIS to make a "dot-on-the-map" for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	
County-level stream and water-body layers	Useful in states where there is a "minimum distance rule" or buffer established for burial or burning operations near still or moving water. Also useful for planning environmental impact of burning by pyre or burial.	

Burial at municipal or commercial landfill

Layer	Uses	Rating 0 - 5
Landfill locations	With contact info, this database is useful in planning transport.	

Disposal Option 6, 7 Chemical digestion, other

Basic planning layers for carcass movement

Layer	Uses	Rating 0 - 5
FEMA flood zones, county-level	Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts, during storm emergencies.	
Bridge layer	Layer which lists the height of the bridge over flood stage, to use in planning carcass movement. Useful with highway layers to map transportation problems in carcass movement, such as closed bridges and viaducts.	
Census designated places (2000 updated town boundaries)	These layers are outlines of the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, local jurisdictions.	
Census urbanized areas and urban clusters	These layers are outlines of urban sprawl outside the official boundaries of metropolitan areas. They are useful for planning transportation problems in carcass movement, such as closed bridges and viaducts, etc.	
Transportation buffer	Used with a CAFO database to alert the CAFO operators within a fixed distance of the highway systems that carcasses capable of airborne contamination have been or will be transported nearby. Typically constructed using some average wind direction and windspeed.	
Military bases, especially National Guard and training grounds	May be used as residue burial sites. "Points-on-a-map" rather than lists may speed planning process. Armories may be used as equipment marshalling areas.	
Street-address type roads layer	Allows the GIS to make a "dot-on-the-map" for any street address. In rural areas this may be difficult to do, and should be prepared in advance.	
Land application permits	Areas where "sludge" is licensed for application. (A digestion by-product may be considered "sludge" in some technologies.)	
Soil map	Useful for screening sites that will use large amounts of disinfectant on trucks, tractors, and digesters.	
Water table depth	Useful for screening sites that will use large amounts of disinfectant on trucks, tractors, and digesters. Groundwater contamination by disinfectant was an issue in England.	
POTW locations	Public water treatment plants. To be useful for disposal of digestion liquids, this list needs to be prescreened for tertiary treatment plants, plants with truck unloading facilities, and plants not statutorily forbidden from accepting off-site waste.	
Landfill locations	Dry residue product of some technologies could be landfilled if burial is not an option.	

Chemical digestion at collection points

Layer	Uses	Rating 0 - 5
Location of existing digestion sites	Makes decision easier if determined in advance no site is within reach.	
Location of possible processing sites	Transport of carcasses long distances into undiseased areas may preclude use of existing digestion locations in some cases.	
Location of current rendering	With some diseases render pickup points outside disease area may need	

pickups	to be closed to minimize spread. Use with road layer and CAFOs layer to map contamination warnings.
Transportation buffer	CAFO or animal owners can be alerted to movement of carcass to render pickups. Useful with airborne contamination possibility.
Trucking contractors	May need refrigerator trailer trucks to hold carcasses till digesters have capacity on site.
Schools, hospitals layers	With some technologies odor will be a problem.

Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
USDA APHIS Cooperative Agreement Project
Carcass Disposal Working Group

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Chapter

16

Decontamination of Sites & Carcasses

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Abbreviations

APHIS	Animal and Plant Health Inspection Service
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BSE	bovine spongiform encephalopathy
END	exotic Newcastle disease
FDA	Food and Drug Administration
FMD	foot and mouth disease
QACs	quaternary ammonium compounds
USDA	United States Department of Agriculture

Section 1 – Key Content

1.1 – Situation Assessment

The first, and most important, step in the process of decontamination is the identification of the disease agent present.

The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) decontamination procedures manual identifies three categories of viruses that should be considered. These three categories are:

- **Category A** includes those viruses that are lipid-containing and intermediate-to-large in size. These viruses are very susceptible to detergents, soaps, and disinfectants because of their outer lipid envelope. Examples include paramyxoviridae and poxviridae.
- **Category B** viruses are hydrophilic and resistant to detergents. They are also sensitive, but less susceptible to other disinfectants. Classical disinfectants like quaternary ammonium compounds are not effective against them. Examples include picornaviruses and parvoviruses.
- **Category C** viruses are between Category A and Category B viruses in sensitivity to the best antiviral disinfectants. Examples include adenoviruses and reoviruses.

1.2 – Possible Infectious Agents

A list of selected possible infectious agents would include bovine spongiform encephalopathy (BSE), foot and mouth disease (FMD), exotic Newcastle disease (END), swine vesicular disease, vesicular stomatitis, and anthrax. Each of these diseases has specific symptoms and concerns, which are addressed in Section 2. Table 1 summarizes the information available on these particular diseases, and further information can be gathered by visiting the Animal and Plant Health Inspection Service (APHIS) web sites listed for each agent in the References section.

1.3 – Six General Groups of Disinfectants

The six most common disinfectant groups include soaps and detergents, oxidizing agents, alkalis, acids, aldehydes, and insecticides. Choosing the correct disinfectant is crucial to ensuring the most efficient decontamination. Example compounds from each group are described in Section 2, and summarized in Table 3.

1.4 – Decontamination Preparation

After a presumptive or confirmed diagnosis is made, a state quarantine should be placed on the farm, and a zone of infection established (USDA, 2002e). Within this infected zone, movement restrictions will apply, and no animals or animal products will be allowed to leave.

Decontamination of personnel is essential for the prevention of cross-contamination so that people can leave an infected premise with minimal risk of transporting the disease agent (ARMCANZ, 2000). There should be an area designated near an exit point of the property as the site for personnel decontamination. The area should be decontaminated with the proper disinfectant and be equipped with a water and drainage supply. A disinfectant should be available at this site for anyone entering or leaving the property. Personnel should be provided with overalls, footwear, head covering, gloves, and goggles. All clothing items should be decontaminated by disinfection every time the person enters or leaves the area. Disinfectant mats or wheel baths filled with disinfectant should be accessible at all vehicle entrances and exits. Every effort should be made to ensure that no vehicles leave an infected property without thorough decontamination.

1.5 – Property Cleanup

The aim of the cleanup process is to remove all manure, dirt, debris, and contaminated articles that cannot be disinfected. This will allow all surfaces to be exposed to detergents and disinfectants. This is the most crucial phase of the cleanup process because the presence of organic material reduces the effectiveness of disinfectants (ARMCANZ, 2000). All gross organic material should be flushed using a cleaner/sanitizer or detergent compound. The entire building should be treated with a detergent solution and left for at least 24 hours if possible. The detergent or sanitizer must be completely rinsed or flushed away after cleanup is complete

1.6 – Disinfection

The selected disinfectant should be applied using a low-pressure sprayer, beginning at the apex of the building and working downwards. Disinfectant must be left on surfaces for as long as possible and then thoroughly rinsed. The property should be left vacant for as long as possible before post-disinfection samples are collected (Kahrs, 1995). Upon completion, the premises should be left empty for some period of time and sentinel (susceptible) animals introduced to detect any remaining contamination (Fotheringham, 1995a).

Section 2 – Situation Assessment

Decontamination can be defined as the combination of physical and chemical processes to kill or remove pathogenic microorganisms and is vital for disease eradication (ARMCANZ, 2000). The importance of disinfection can be assessed according to three factors: mode(s) of transmission, likely contamination of the environment, and susceptibility of the causal agent to disinfectants (Fotheringham, 1995b). The first, and most important, step in the process of decontamination is the identification of the disease agent present. In order to begin decontamination, those involved must understand how the causative agent works and exactly how it spreads.

The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) decontamination operational procedures manual (2000) identifies three categories of viruses that should be considered and defines them as follows:

- **Category A** includes those viruses that are lipid containing and intermediate-to-large in size. These viruses are very susceptible to detergents, soaps, and disinfectants because of their outer lipid envelope. They are susceptible to dehydration, and are only present in cool, moist environments. Examples include paramyxoviridae and poxviridae.
- **Category B** viruses are hydrophilic and resistant to detergents. They are also sensitive, but less susceptible to other disinfectants. Classical disinfectants like quaternary ammonium compounds (QACs) are not effective against them. Examples include picornaviruses and parvoviruses.
- **Category C** viruses are between Category A and Category B viruses in sensitivity to the best antiviral disinfectants. Examples include adenoviruses and reoviruses.

As indicated by Fotheringham (1995b), decontamination is a vital element in disease eradication. It includes the elimination of the disease agent in infected premises, the reduction of the possibility of dissemination to other areas, and the minimization of the period between slaughter and re-stocking. Infected animals excrete pathogenic microorganisms. Pathogens present within the upper respiratory tract can be expelled to nearby animals through breathing, coughing, and sneezing. Fotheringham (1995b) indicates that dust particles from the animals' coats, bedding, and feed become contaminated with skin, hair, saliva, pus, and body excretions. Also, some microorganisms can survive for long periods in the environment, particularly if protected by organic soiling such as manure.

2.1 – Possible Infectious Agents

Bovine spongiform encephalopathy (BSE)

Bovine spongiform encephalopathy, otherwise known as "mad cow disease," is a transmissible prion disease in cattle that requires inactivation. BSE is a chronic degenerative disease that affects the central nervous system with a prolonged incubation period of 2 to 8 years (USDA, 2002b). Transmission occurs through ingestion of contaminated meat and bone meal that contains nervous tissue from affected animals or, possibly, from scrapie-infected sheep (Geering, Penrith, and Nyakahuma, 2001). The cattle most commonly affected by BSE range in age from three to seven years.

Clinical signs of the disease include changes in animal temperament, abnormal posture, lack of coordination, difficulty rising, loss of weight and appetite, and ultimately death (USDA, 2002b). There is no evidence that BSE is spread by physical contact among cattle, or from cattle to other species.

Most common disinfectants are not effective against BSE. Kahrs (1995) states that prions defy identification, fail to stimulate immunological responses, persist for years, and are resistant to heat and disinfectants. Transmissible degenerative encephalopathies like BSE are fairly resistant to inactivation by standard decontamination procedures, and the only methods that may be effective in worst-case scenarios are strong sodium hypochlorite solutions or hot solutions of sodium hydroxide (Taylor, 2000).

Foot and mouth disease (FMD)

Foot and mouth disease is a highly contagious, viral, vesicular disease affecting cloven-hoofed animals. Geering et al. (2001) defines FMD as a Category B picornavirus with a 3-5 day incubation period. They characterize the virus as one that is excreted from nasal passages, saliva, milk, semen, feces, and urine and, in vast amounts, from ruptured vesicles. FMD is rapidly spread by direct and indirect contact with contaminated individuals, as well as through the air. Cattle remain carriers for at least 27 months and sheep for 9 months (Geering, et al., 2001). Bartley, Donnelly, and Anderson (2002) indicated that the FMD virus could survive in the absence of animal hosts, including at 4° C (39.2° F) on wool for approximately two months, and for two to three months in bovine feces or slurry. Survival is affected by several environmental- and virus-related factors. Potter (2002) finds that high temperatures and low humidity will destroy FMD mainly by desiccation. Exposure to 56° C (132.8° F) for 30 minutes is sufficient to destroy most strains (Potter, 2002). Potter (2002) also notes that FMD virus is stable at a pH of 7.4-7.6, and rapid inactivation occurs below pH 5 and above pH 11. The use of ethylene oxide, formaldehyde, and γ radiation may be an appropriate control measure (Dekker, 1998). The most rapid inactivation of FMD can occur in the presence of acids or alkalis as long as their pH is maintained at appropriate levels (Sellers, 1968).

Clinical signs can include fever and blister-like lesions followed by erosions on the tongue and lips, in the mouth, on the teats, and between the hooves (USDA, 2002c). Animals may also exhibit increased temperatures, reduced feed consumption, lameness, and aborted pregnancies.

If contact is made with infected cattle, it is recommended for individuals to refrain from contact with susceptible livestock for 72 hours (Geering et al., 2001). Following an outbreak, a minimum period of three months must elapse between the last reported FMD case and the declaration of disease-free status (Bartley et al., 2002). The US Department of Agriculture (USDA) (2002c) indicates FMD is not recognized as a zoonotic disease transmissible to humans.

Exotic Newcastle disease (END)

Exotic Newcastle disease is a highly contagious, generalized, viral disease of domestic poultry and caged and wild birds. Geering et al. (2001) defines END as a Category A paramyxoviridae with three strains that vary in virulence: velogenic (high), mesogenic (moderate), and lentogenic (low). The incubation period is between 2 and 15 days. The virus is known to spread via the respiratory tract and in feces, and can spread rapidly within a flock. END is disseminated by direct contact and by carrier state birds for up to 120 days after infection. Indirect transmission can also occur by contaminated individuals, articles, fomites, manure, feed, and vehicles under certain environmental conditions. END has been known to disseminate over a wide area through the air, and flies transmit the disease mechanically (Geering et al., 2001).

END is so virulent that many birds die without showing any clinical signs, and a USDA (2003) report on END projects a death rate of nearly 100% in an unvaccinated flock. Clinical signs include sneezing and coughing, watery diarrhea, depression, decreased egg production, and sudden death. Geering et al. (2001) indicate Newcastle can cause headache and flu-like symptoms in humans, and it is suspected that person-to-person transmission may be possible. This virus is destroyed rapidly by dehydration and by the ultraviolet rays in sunlight (USDA, 2003).

Swine vesicular disease

Swine vesicular disease is a contagious viral disease found in pigs that exhibit clinical signs difficult to distinguish from FMD. Geering et al. (2001) defines this as a Category B enterovirus with an incubation period of 2-7 days. The virus is excreted from ruptured vesicles for up to 10 days and in feces for more than 3 weeks, but a prolonged "carrier" state does not occur. It is spread by direct contact between animals and indirectly by contaminated vehicles, fomites, people, and illegal swill feeding. Sodium hydroxide, sodium hypochlorite, and formaldehyde can be used against this disease agent; however, their effectiveness will be decreased in the presence of organic material (Blackwell, Graves, and McKercher, 1975). Swine vesicular disease is resistant to heating and drying, but is not likely to affect humans.

Vesicular stomatitis

Vesicular stomatitis is a contagious viral disease of cattle, pigs, horses and, possibly, sheep and goats. Geering et al. (2001) defines vesicular stomatitis as a rhabdoviridae (Category A virus) with two distinct serotypes: Indiana and New Jersey. This virus has an incubation period of 1 to 10 days, is shed in vesicular fluid and saliva for a few days, and is spread by direct contact. Transmission is not fully understood, but insect vectors, mechanical transmission, and movement of animals may be responsible (USDA, 2002d).

Vesicular stomatitis is characterized by vesicular lesions on the tongue, oral mucosa, teats, or coronary bands of cattle, horses, and swine (USDA, 2002d). Clinical signs can also include fever, drooling or frothing at the mouth, and severe weight loss, but generally not death. USDA (2002d) indicates that its outward signs are similar to, but less severe than, those of FMD. Human infection occurs through the respiratory tract, conjunctiva, and skin abrasions with disease symptoms similar to influenza (Geering et al., 2001). Phenolic- and halogen-based disinfectants work best in footbaths to control disease transmission (USDA, 2002d). Chlorine bleach at a 0.645 percent concentration is effective enough to destroy the agent with 10 minutes of contact time.

Anthrax

Anthrax is a mammalian disease caused by a spore forming bacterium called Bacillus anthracis that is endemic to the United States and most other countries (USDA, 2002a). Ruminants such as cattle, sheep, and goats are the farm animals most susceptible to anthrax. It is usually contracted through ingestion of soil-born anthrax spores, and infected animals die acutely. Spores may enter the skin through abrasions, swallowing, or inhalation. Anthrax does not spread by contact between living animals, but humans can be exposed to the disease by handling animals or animal products such as hides and wool. Anthrax may be perpetuated in nature by hosts such as wildlife, which may spread the disease to the domestic livestock population. Spores are highly resistant to heat, cold, chemical disinfectants, and drying, and have survived for years in the environment. Environmental persistence may be related to a number of factors, including high levels of soil nitrogen and organic content, alkaline soil, and ambient temperatures higher than 60° F (USDA, 2002a).

Anthrax should be contained quickly to prevent the release and sporulation of vegetative cells from dying or dead animals (Turnbull, 2001). The list of recommended disinfectants includes: 10% formaldehyde, 4% gluteraldehyde, 3% hydrogen peroxide, and 1% peracetic acid. Hydrogen peroxide and peracetic acid will not work in the presence of blood. Soil from areas of anthrax contamination should be removed for incineration or soaked with 5% formaldehyde. Contaminated materials should be incinerated, and non-disposable items should be soaked with 4% formaldehyde or 2% gluteraldehyde (Turnbull, 2001).

A list of common infectious agents complete with basic recommendations on how to handle these agents is listed in Table 1.

TABLE 1. List of common infectious agents with recommendations on disposal and disinfection (ARMCANZ, 2000; Geering et al., 2001)

Agent	Classification	Preferred Disposal Method	Recommended Disinfectants
BSE/ Scrapie	Prion, non-viral	Bury, burn, or alkaline hydrolysis	Bury or burn any contaminated materials, then use soap and detergent followed by sodium hypochlorite
Avian influenza/ Newcastle	Category A virus	Bury or burn	Soaps and detergents, sodium hypochlorite, calcium hypochlorite, VirkonS®, alkalis
FMD/ Swine vesicular disease	Category B virus	Bury or burn	Acids for FMD; oxidizing agents and alkalis for animal housing and equipment; soaps, detergents, and citric acid for humans
Vesicular stomatitis	Category A virus (vector-borne)	Bury or burn	Soaps and detergents; alkalis and acids; insecticides – organophosphates, synthetic pyrethroids, and Ivermectin®
Anthrax	Bacterial spore	Burn	Formaldehyde, gluteraldehyde, hydrogen peroxide, peracetic acid

2.2 – Possible Decontamination Chemicals or Disinfectants

A disinfectant can be described as a chemical, or mix of chemicals, capable of killing pathogenic microorganisms associated with inanimate objects (Geering et al., 2001). A report by Maris (1995) states that disinfectants can impact microorganisms in two different ways: growth inhibition or lethal action. Lethality should be considered the desired outcome. Chemicals usually kill microorganisms by toxic reactions, and effective disinfectants are often toxic for animal and human tissues as well, so they must be used with care (Geering et al., 2001). For an antiseptic or disinfectant molecule to reach its target site, the outer layers of a cell must be crossed (McDonnell and Russell, 1999). If lipid is found within a virus, it is uniformly associated with a high degree of susceptibility to all disinfectants (Maris, 1995). But if a virus is without lipid, and small in size, it could be associated with resistance to lipophilic chemical agents. Many factors can affect the efficacy of the disinfectant (e.g. temperature, pH, the presence of organic materials, composition of the surface), making it difficult to predict efficiency (Tamasi, 1995). The Food and Drug Administration must approve all disinfectants and pesticides used.

General groups of disinfectants

Soaps and detergents

This class is most useful for Category A viruses because it can disrupt outer lipid envelopes. This disinfectant group is used to effectively clean surfaces for decontamination. The most common types include combinations of phenolics, QACs, and chlorines.

Quaternary ammonium compounds (QACs). QACs are not sporicidal, and are relatively ineffective against mycobacterium (Jeffery, 1995). They are usually formulated with compatible non-ionic detergents to increase detergency. Also, QACs can lose some of their activity if the ratio of ingredients is incorrect. Action is rapid, but strong concentrations can corrode mild steel or iron. These compounds work by irreversibly binding to the phospholipids and proteins of cell membranes to impair permeability (Maris, 1995). Also known as cationic detergents, QACs also work well to clean and deodorize hard surfaces (McDonnell and Russell, 1999). Jeffery (1995) states that the only way to prove their efficacy in a given situation is to assess these products in practice.

Oxidizing agents

This category is recommended for most applications on viruses within Categories A, B, and C (ARMCANZ, 2000).

Sodium hypochlorite. Sodium hypochlorite compounds are halogen-releasing. This is a concentrated liquid used against all categories of viruses except in the presence of organic material and warm, sunny conditions over 15°C (59° F) (Geering et al., 2001). Sodium is a good broad-range disinfectant that is only effective at a neutral to moderate pH of 6-9, and has a diminished effect in the presence of organic material (ARMCANZ, 2000). Hypochlorites are toxic to the eyes and skin, and corrosive to many metals (Geering et al., 2001). Jeffery (1995) reports that sodium hypochlorite is usually formulated with a little sodium hydroxide to enhance stability. He also notes potassium hypochlorite is similar to sodium hypochlorite, and neither is stable in solid form.

Calcium hypochlorite. Calcium hypochlorite is a solid used against all categories of viruses but not in the presence of organic material. Because it is stable as a solid, it can be used to formulate a powder. Evans, Stuart, and Roberts (1977) determined that hypochlorites could be effective disinfectants for viruses provided that storage of the concentrate does not exceed the time when chlorine falls below 10 percent. As a result, hypochlorite solutions must be freshly prepared.

Virkon S®. Virkon S® is a powder form that is easy to mix and dilute on site. It is a well-known, name-brand oxidizing agent manufactured by Antec International. This popular disinfectant has a low toxicity and is approved for use on all 17 families of viruses. It may be sprayed on surfaces at a 1 percent dilution rate of 300 mL/m^2 for decontamination. It can also be used to disinfect vehicles at a 1 percent dilution. Virkon S® may be used as a skin disinfectant for personnel decontamination. As with all disinfectants, performance is optimized on a clean surface (Antec International, 2003).

Alkalis

The alkali group is considerably inexpensive and has a natural saponifying action on fats to aid cleaning (ARMCANZ, 2000). This group can be used against all virus categories and even some bacterial spores. They work well in the decontamination of animal housing, yards, drains, waste pits, and sewage tanks. Alkali activity is slow, but can be increased by raising temperatures and using increased concentrations. Alkalis are very corrosive, and must be handled with care. Jeffery (1995) notes calcium oxide, or quicklime, is often used to disinfect animal carcasses.

Sodium hydroxide. Sodium hydroxide, also known as caustic soda, is a strong surface disinfectant, which can kill bacterial spores in high concentrations (Bruins and Dyer, 1995). The pellet form of sodium hydroxide can be used against all three categories of viruses unless aluminum is present. It is caustic to eyes, skin, and mucous membranes, and should always be kept away from strong acids. Water runoff from this disinfectant must be handled with extreme care, because it may have a severe effect on the pH of surface water and plant life. Sodium hydroxide and potassium hydroxide both have good microbicidal properties as well as effective grease and debris removing properties (Jeffery, 1995).

Sodium carbonate. Sodium carbonate is a powder that Geering et al. (2001) recommend for use in the presence of high concentrations of organic material. It is mildly caustic to eyes and skin and should not be used on aluminum.

Acids

The acid group is particularly useful in the inactivation of Category B viruses such as FMD, and can be used for personnel and clothing decontamination (ARMCANZ, 2000). A study performed by Sellers (1968) found that the most rapid inactivation of FMD virus occurred in the presence of acids and alkalis provided the pH was maintained as directed. Jeffery (1995) reports that inorganic acids have microbial properties due to their low pH levels. They are generally slow-acting efficient cleaners, but have strict limitations due to corrosiveness to skin and materials. Organic acids are used in disinfectant formulations to enhance virucidal and fungicidal properties. Their activity is increased in the presence of anionic detergents of the sulphonate or ether sulphate type.

All acids are slow-acting and have a low concentration exponent (Jeffery, 1995). Maris (1995) indicates that both acids and alkalis have their efficiency dependent on the concentration of hydrogen (H+) and hydroxyl (OH-) ions.

Hydrochloric acid. Hydrochloric acid is corrosive for many metals and concrete. It is considered toxic to eyes, skin, and respiratory passages. Hydrochloric acid should only be used when better disinfectants are not available (Geering et al., 2001).

Peracetic acid. Peracetic acid is a very strong oxidizing agent that is also fast-acting (Bruins and Dyer, 1995). This acid is effective against bacteria, viruses, molds, yeasts, and bacterial spores. Peracetic acid is used for the decontamination of serum and other fluids and is effective against a range of viruses (Evans et al., 1977). Peracetic acid can be considered as a viable disinfectant for anthrax-infected properties. The environmental impact of this compound is relatively small, but it is mildly corrosive and should always be handled with care (Bruins and Dyer, 1995).

Citric acid. Citric acid is safe for clothes and body decontamination, and especially useful against FMD (Geering et al., 2001). Citric Acid BP (2-Hydroxyl-1, 2, 3-Propanetricarbolic Acid Anhydrous) in a 5500:1 dilution was approved for use in England in 1999 and 2000 to effectively kill FMD (UK Environment Agency, 2002). Some concentrations of acids and alkalis apart from citric acid are corrosive and caustic, but adding a detergent or soap can reduce harshness and increase wettability and penetrating power (Sellers, 1968).

Aldehydes

The aldehyde group can work in most conditions, even those with heavy soiling (Jeffery, 1995), and can be effective in all virus categories. Aldehydes act slowly, oxidize slowly, and are relatively reactive with other chemicals. Aldehydes can be formulated in conjunction with QACs to obtain more rapid action and higher activity over a wider spectrum.

Gluteraldehyde. Gluteraldehyde is effective on all virus families in low concentrations, and is only mildly corrosive, but is very costly (ARMCANZ, 2000). Gluteraldehyde is normally used as a 2% solution to achieve a sporicidal effect, and is more active at alkaline than acidic pHs (McDonnell and Russell, 1999). It is commonly used in the chemical sterilization of sensitive equipment, and it is at least three times as active as formaldehyde (Jeffery, 1995). Users should avoid contact with eyes and skin.

Formalin. Formalin is an aldehyde that is effective against BSE and scrapie at 8 percent, but is dangerous and toxic (Geering et al, 2001). Formalin can be irritating to the mucous membranes.

Formaldehyde. The gas form of formaldehyde is very toxic, and is rarely used because it must only be applied in completely airtight situations (ARMCANZ, 2000). It must be neutralized before being released into the atmosphere. Maris (1995) states that its action is pH dependent, and it works better at an alkaline pH than one that is neutral or acidic. The aqueous form of formaldehyde is an effective bactericide, tuberculocide, fungicide, and sporicide (Bruins and Dyer, 1995). It is generally used in clinical settings as a disinfectant or sterilant in liquid or in combination with low-temperature steam, but works more slowly then gluteraldehyde (McDonnell and Russell, 1999). Formaldehyde is fairly inexpensive, is only minimally affected by environmental pH and organic matter, and has an unlimited shelf life. Its major drawback is that it is potentially carcinogenic, has a pungent odor, and must be handled with extreme care.

Insecticides

Insecticides can be used to combat insect or vector-borne diseases such as vesicular stomatitis. Major examples of commonly used insecticides include organophosphates, synthetic pyrethroids, aluminum phosphide (Phostoxin), and Ivermectin®. Remember to use these products safely to minimize risk to the environment.

Miscellaneous

Phenols. Phenol compounds are rarely used in present-day situations because of their toxicity. Phenols have an unpleasant odor, and may induce skin irritation and depigmentation (Bruins and Dyer, 1995). They act specifically on the cell membrane and inactivate the intracytoplasm enzymes by forming unstable complexes (Maris, 1995). Formulating with phenols requires great care. Jeffery (1995) defines three phenol categories: clear soluble, white fluid, and black fluid. Phenol effectiveness will be decreased if they are used with soaps containing tallow, tall oil, or oleic acid. Halogenated phenols are less soluble, less corrosive, and less toxic, but also less effective in the presence of soiling material. Chloroxylenol is the key halophenol used in antiseptic or disinfectant formulation (McDonnell and Russell, 1999).

Chlorines. Bruins and Dyer (1995) identify chlorination as the most important water-treatment process in preventing the spread of infectious disease. Disinfectants based in chlorine can be unstable because they are significantly affected by heat and light. These products are also very corrosive to metals, release a strong odor, and are easily neutralized by organic matter.

Disinfectant effectiveness

The major factors that affect the efficacy of disinfection are: choice of disinfectant, dilution rate, application rate, detergency, contact time, temperature, organic challenge, and water quality (Meroz and Samberg, 1995). Regardless of how "good" a disinfectant can be, dilution will dramatically reduce its effectiveness. Citric acid or sodium carbonate can be added to wash water to induce antiviral conditions by raising or lowering pH which helps inactivate disease agents (ARMCANZ, 2000). For safety purposes, acids and alkalis should always be added to water instead of vice versa. Disinfectant should flood the floor for at least ten minutes, and preliminary cleaning must be accomplished before chemical disinfectants are used. Time, dehydration, temperature, and sunlight should all be considered in planning (ARMCANZ, 2000). Most disinfectants have decreased effectiveness in the presence of fat, grease, and organic dirt.

Because surfaces on the property will differ, it is likely that more than one disinfectant will be needed to clean a property. The type of surface and the amount of ceiling and wall space to be covered will be the factors that determine how much disinfectant is needed. The most important factor to consider is the time of contact. Not all products are suitable for all applications. When deciding which formulation to use, determine if heavy soiling is present, and whether or not the product is compatible with the cleaning agent used (Jeffery, 1995). Something else to consider is microbial resistance to disinfectants, which can be a result of natural or acquired properties (McDonnell and Russell, 1999). Table 2 (Bruin and Dyer, 1995) identifies the use and toxicity guidelines for various types of disinfectants. Table 3 provides a summary of background information on these six major disinfectant groups.

TABLE 2. Use and toxicity of various types of disinfectants (Bruins & Dyer, 1995).

Disinfectant type	Bacteria	Mycobacteria	Viruses	Bacterial spores	Yeasts	Molds	Toxicity
Chlorine	++	++	++	+	++	++	medium
Formaldehyde	+	+	+	+	+	+	high
Phenolics	+	+	+/-	-	+	+	high
Peracetic acid	++	++	++	++	++	++	low
QACs	+/-	-	-	-	++	+	low
Hydrogen peroxide	++	+	+	+/-	+	+	low
Iodophors	++	++	++	+	+	+	medium
Sodium hydroxide	+	+	+	+	+	+	high

Legend: ++ kills rapidly, + kills most, +/- kills some, - negligible kill

TABLE 3. Background information on six major disinfectant groups (ARMCANZ, 2000; Geering et al., 2001).

Disinfectant Group	Form	Contact Time	Applications	Precautions
Soaps and detergents				
Quaternary Ammonium Compounds (QACs)	Solid or liquid	10 min.	Use for thorough cleaning before decontamination and for Cat. A viruses	N/A
Oxidizing Agents				
Sodium hypochlorite	Concentrated liquid	10-30 min.	Use for Cat. A, B, and C viruses except in the presence of organic material	N/A
Calcium hypochlorite	Solid	10-30 min.	Use for Cat. A, B, and C viruses except in the presence of organic material	N/A
Virkon S®	Powder	10 min.	Effective against all virus families	N/A
Alkalis				
Sodium hydroxide	Pellets	10 min.	Cat. A, B, and C if no aluminum	Caustic to eyes and skin
Sodium carbonate	Powder/crystals	10-30 min.	Use with high concentrations of organic material	Mildly caustic
Acids				
Hydrochloric acid	Concentrated liquid	10 min.	Corrosive, use only if nothing better is available	Toxic to eyes, skin, and respiratory passages
Citric acid	Powder	30 min.	Use for FMD on clothes and person	N/A
Aldehydes				
Gluteraldehyde	Concentrated liquid	10-30 min.	Cat. A, B, and C viruses	Avoid eye and skin contact
Formalin	40% formaldehyde	10-30 min.	Cat. A, B, and C viruses	Releases toxic gas
Formaldehyde gas	Gas	15-24 hours	Cat. A, B, and C viruses	Releases toxic gas

Section 3 – Disposal and Decontamination

3.1 – Methods of Disposal

The overall goal of carcass disposal is to control the spread of disease. The USDA Disposal Operational Guidelines draft manual (2002) states that carcasses should be disposed of within 12 hours in order to minimize the opportunity for pathogen dispersal. Animals should be humanely slaughtered by chemical, mechanical, or electrical means. Depopulation must not overrun disposal because of the increased risk to animal welfare, biosecurity, and pest infestation. These procedures must prevent the agent from spreading, so disposal must follow euthanasia as soon as possible. There are several options to consider when a disposal situation arises, and selection of the proper method will depend on individual circumstances. Common methods of disposal include burial, incineration, rendering, composting, and alkaline hydrolysis (USDA, 2002e).

The USDA identifies burial as the preferred method of disposal when practical, except in situations involving BSE. Carcasses infected with BSE should be disposed of using an alkaline hydrolysis tissue digester. Compared to other disposal methods, burial is simpler, more economical, faster, and less likely to cause adverse environmental effects (USDA, 2002e). Forty-two cubic feet are required to bury one bovine, five pigs, or five sheep.

The USDA states incineration should only be used when burial is infeasible because burning tends to be difficult and expensive in terms of labor and materials. Burning is also detrimental to the environment. Glanville and Trampel (1997) have identified composting as another alternative that strives to achieve biological degradation of organic residues under aerobic conditions. This provides an option for areas where mass burial is not feasible because of factors like shallow water tables and bedrock.

3.2 – Decontamination Procedures

Disease confirmation

Once again, the first step in this process is to determine the agent involved and how it is spread and transmitted. Viruses that can be spread to remote animals by personnel and equipment contamination will require the most involved plans. USDA APHIS has published an executive summary that details the national emergency response to a highly contagious animal disease (2001). In an emergency response to a highly contagious animal disease, a "confirmed positive" results when a specific agent is isolated and identified. After a presumptive or confirmed diagnosis is made, a state quarantine will be placed on the farm, and a zone of infection will be established. The zone of infection should extend at least 6 miles beyond the presumptive or confirmed infected property (USDA, 2001). This zone is determined by many factors including wind direction, livestock movement, and terrain conditions.

Within this infected zone, movement restrictions are established, and no animals or animal products will be allowed to leave. The USDA APHIS national emergency response to a highly contagious animal disease executive summary (2001) gives the right to state authorities to remove all susceptible animals from this zone. Outside of this infection zone there should exist a surveillance zone established to ensure containment of the outbreak. The zone is placed under surveillance, and all animal health professionals should heighten their awareness for biosecurity issues (USDA, 2001). Preventing and reducing the spread of animal disease depends heavily on the following: good biosecurity, decontamination, disinfection, and sanitation (Ford, 1995).

Personnel decontamination

People – with their clothes, shoes, tools, and machinery – constitute the most often implicated means of spreading disease from one herd or flock to another (Ford, 1995). Decontamination of personnel is essential for the prevention of cross-contamination, so people can leave an infected premise with minimized fear of transporting the disease agent (ARMCANZ, 2000). The goal of personnel decontamination is to safely remove any contamination of the body or clothing. Geering et al. (2001) warn that the heaviest personnel contamination will occur at the inspection of live and dead animals, the site of slaughter, and the disposal site.

There should be an area designated near an exit point of the property as the site for personnel decontamination. The owner or manager of the property should help identify the level of property contamination based on the amount of contact with animals and animal waste (Geering et al., 2001). The chosen site should be one that will allow an easy exit of the property without recontamination. It should first be decontaminated with the proper disinfectant and be equipped with a water and drainage supply. Site managers must ensure that runoff water from contaminated areas does not enter the clean area. A disinfectant should be available at this site for anyone entering or leaving the property. Warm, soapy water is recommended for washing the face, hair, and skin. Heavy plastic garbage bags can be used to dispose of contaminated items such as rubber gloves, and bags containing contaminated items should be sprayed on the outside to aid in disinfection (Geering et al., 2001). These bags can then be burned or buried on property, or can be carried off-site for further disinfection.

Personnel supplies

Personnel should be provided with overalls, footwear, head covering, gloves, and goggles. Clothing items should be decontaminated by disinfecting every time the person moves around the area. A changing area must be provided with a shower or washing facility. Fotheringham (1995a) recommends buckets of disinfectant be used for moving disinfected articles. If the suspected contaminated organism is exotic or has zoonotic potential, or if the disinfectant has toxic, irritant, or corrosive properties, then protective clothing, masks, and rubber footwear must be worn (Kahrs, 1995). Personnel will also need supplies for cleaning and disinfecting that include: plastic buckets, brushes, towels, plastic refuse bags, footbath pans, antiseptic soap, and disinfectant (Ford, 1995).

Foot baths

Braymen, Songer, and Sullivan (1974) report that floors have been identified as reservoirs of infection and are therefore important in disease spread. Footwear is mobile and may serve as a transfer vehicle for moving microorganisms from place to place. A logical place to install footbaths is at the doorways of animal quarters. Fotheringham (1995b) states they probably serve more as biosecurity reminders than as effective disease control mechanisms, but they can be effective if refilled every two to three days. Studies show that footwear accommodate the microflora already existing on the floor, therefore every effort should be made to minimize their cross-contaminating potential (Braymen et al., 1974).

Fotheringham (1995b) warns that in locations where footbaths may freeze, they should be heated, because adding antifreeze or salt could disturb the effectiveness of the disinfectant. These techniques can also be applied to wheel baths for trucks entering and leaving an infected premise.

Property preparation

Vehicles

All trucks, trailers, and other equipment used to transport contaminated animals, feed, bedding, or equipment can potentially spread disease. Carcasses should be soaked with the appropriate disinfectant before they are loaded for transportation. Vehicles must only enter infected facilities if absolutely necessary, and those that do must be thoroughly disinfected before leaving. The route taken by vehicles entering or leaving the contaminated premises should minimize the chance of its contamination by dust or manure (Ford, 1995). The materials required for cleaning and disinfecting vehicles include brushes, sponges, buckets, overalls, goggles, face masks, containers for mixing disinfectants, and high-pressure sprayers that can operate at a minimum of 200 p.s.i. (Poumian, 1995).

Begin with a preliminary rinse at 38-46°C (100.4-114.8°F) (Poumian, 1995). This should be followed by the addition of a cleaning agent and an increase in water temperature to 49-77°C (120.2-170.6°F). All organic material and rubbish from vehicles should be burned or buried. Spray the entire surface of the vehicle with an effective disinfectant, and carefully clean and disinfect the wheels, fender wells, and vehicle frame.

Disinfectant mats or wheel baths filled with disinfectant should be utilized at all vehicle entrances and exits. Every effort should be made to ensure that no vehicles leave an infected property without thorough decontamination. Any rubber floor mats on the driver's side should be removed and scrubbed with disinfectant, and the dashboard, steering wheel, gear stick, and driver's seat should all be wiped with the appropriate disinfectant (ARMCANZ, 2000). Spray aerosol pesticide in the vehicle to kill any insects which may have entered, and allow pesticide to work for a few minutes prior to entry (Ford, 1995). Remove all contaminated clothing and equipment, and thoroughly clean hands and face with antiseptic soap and water before entering a vehicle.

Cleaning/disinfecting supplies

This step in the process will require a generous supply of water. A list of typical required equipment includes brushes, scrapers, pumps, power washers, and knapsack sprayers (Fotheringham, 1995b). Sensitive equipment should be used inside plastic bags where possible, and wiped down with disinfectant after use.

Drainage

When considering the drainage or disinfectant runoff sites, consideration must be given to the proximity of waterways and wells and possible contact with humans, wildlife, livestock, or poultry (Kahrs, 1995). Disinfectants may cause water pollution and pose a risk to sewers. Do not pour unused disinfectant solutions on the ground, but dispose of them in approved containers (Ford, 1995). As noted by an FMD report issued by the UK Environment Agency (2001), some small sewage treatment plants in England were disrupted by disinfectant drainage during their massive FMD outbreak. Temporary lagoons were built to hold disinfectant wash water and slurry, and they were unfortunately constructed in locations where watercourses or groundwater could be affected by spills.

Wildlife/pest control

It is extremely important to control wildlife, pets, insects, and birds from coming into contact with diseased animal carcasses or contaminated runoff. All of these can serve as carriers to spread the disease agent out of the containment area rapidly. The first step to take to prevent this type of spread or cross-contamination is to quickly dispose of carcasses, or cover them until disposal can be performed. Rodent control should be performed immediately and all feed should be removed so as not to attract rodents (Meroz and Samberg, 1995).

Property cleanup

This is the point in the process to remove all animals, utensils, and equipment. Any animal feed material should be removed and disposed of properly. Fotheringham (1995a) reports the necessity to switch off electricity and extractor fans to stop airborne spread of pathogens. Drains and runoffs should be blocked to allow for later disinfection, and gullies and channels emptied and their contents buried.

The aim of the cleanup process is to remove all manure, dirt, debris, and contaminated articles that cannot be disinfected. This will allow all surfaces to be exposed to detergents and disinfectants. This is the most crucial phase of the cleanup process because the presence of organic material reduces the effectiveness of disinfectants (ARMCANZ, 2000). Burn or bury all debris, and break up soil floors to expose them to disinfectants.

Manure

Manure, soiled bedding, and unused feed should be removed using a manual or mechanical scrapper. Water use should be avoided at this point to minimize the volume and weight of runoff to handle (ARMCANZ, 2000). The easiest way to dispose of feces is burial. Bedding and litter that has come into contact with infected stock should be sprayed with a strong disinfectant and burned or buried (Meroz and Samberg, 1995).

Manure and slurry pits may need to be decontaminated by raising or lowering the pH and leaving undisturbed for at least seven days (Fotheringham, 1995a). It is also recommended that semi-solid slurry be treated with caustic soda and allowed to stand. Procedures should be established to control insect and vermin around manure to minimize disease spread. If manure is allowed to remain uncovered too long, feed, insect larvae, and worms in the manure will attract birds and scavengers which may become contaminated and spread pathogens to nearby farms (McDaniel, 1991).

First cleaning

After all manure, debris, and equipment have been removed, gross organic material should be flushed away using a cleaner/sanitizer or detergent compound. Blood, urine, feces, food debris, fats, and dust are the most likely organic soils to be encountered in or on animal housing (Fotheringham, 1995b). Water is the preferred solvent and cleaning medium, and its efficacy can be increased by adding energy, temperature, and cleaning agents (Poumian, 1995). Detergent and hot water should be applied starting at the top of a building and working down. The entire building should be treated with a detergent solution and left for at least 24 hours if possible. Fotheringham (1995b) reports that detergents break down organic soiling and reduce the amount of time required for subsequent cleaning. The detergent should be applied through a power washer, and washing solution should be used at a dosage of 2-10 l/m^ 2. Pressures should remain below 90 bar (1 bar = 10^ 5 Pa), and the appropriate angle for nozzles used in cleaning is 25-45°.

Rinsing

The detergent or sanitizer must be completely rinsed or flushed away upon completion of cleaning. Kahrs (1995) indicates that residual detergent can reduce the effectiveness of the chosen disinfectant by diluting, neutralizing, or inactivating it. After rinsing, the building should be visibly inspected, and allowed to fully dry. Drying can kill sensitive microorganisms, and drying removes the possibility of further diluting the disinfectant (Fotheringham, 1995b). The thoroughness of pre-disinfection cleaning is the most important determinant of the efficacy of the disinfection process (Kahrs, 1995).

First disinfection

The aim of the first disinfection is to inactivate the disease agent using physical and chemical methods (ARMCANZ, 2000). Disinfection will lower the microbial load on surfaces to a level that causes neither the spread of pathogens, nor the reduction of animal productivity. Raising the temperature at which a disinfectant is used will increase its disinfection action. All disinfectants work best at temperatures above 68°F (20°C) (Meroz and Samberg, 1995). Hot disinfectant solutions are more effective than cold to penetrate and disinfect, which is especially important in surfaces with cracks and crevices. An increased contact time will result in an increase in efficacy for the disinfectant. As a result, disinfectants should be left in contact with housing and equipment for as long as possible (Fotheringham, 1995b). Contact time can be greatly increased with the use of foam. Foam takes a lot longer to dry, resulting in increased disinfectant activity (Meroz and Samberg, 1995).

Disinfectants should not be mixed with other chemicals or placed in containers used for other chemicals. The appropriate quantity of disinfectant will vary greatly depending on the circumstances involved. For a polished, nonporous floor, 100 ml/m3 can be sufficient, but this amount may need to be doubled or tripled for porous surfaces such as concrete or wood (Geering et al., 2001). Fotheringham (1995b) recommends disinfectant solution should be used at a dosage of 0.3-1l/m^ 2. Hard water generally reduces the effectiveness of the diluted disinfectant and may cause the precipitation of acids and alkalis, thus reducing disinfectant activity.

Disinfectant should be applied using a low-pressure sprayer such as a knapsack sprayer or a pump with spray attachment, and all areas should be covered to damp down dust, which could spread airborne microorganisms (Fotheringham, 1995b). Application should begin at the apex of the building and move downward. All surfaces should be covered while the creation of pools of liquid should be avoided. Flame guns may be used in some spaces to aid drying of decontaminated surfaces or to reaching difficult areas such as pipes. Flame guns should not be relied upon to decontaminate alone, and they add risks of fire and injury (ARMCANZ, 2000).

Water systems

If possible, water pipes should be dismantled, cleaned, and left to soak in disinfectant for 24 hours (Meroz and Samberg, 1995). The water system should be drained, tanks cleaned, and disinfectant added for a minimum of 10 minutes. They should then be flushed and left to dry (Fotheringham, 1995a).

Disinfection completion

Following decontamination, all equipment and supplies should be thoroughly cleaned and disinfected. Disinfectant must be left on surfaces for as long as possible, then thoroughly rinsed and the property left vacant for as long as possible before post-disinfection samples are collected (Kahrs, 1995). Upon completion, the premises should be left empty for some period of time and sentinel (susceptible) animals introduced to detect any remaining contamination (Fotheringham, 1995a).

Restocking with healthy animals should only be undertaken when post-disinfection tests and/or sentinel evaluation reveal that the premise has a low probability of harboring residual pathogens (Kahrs, 1995).

Disposal areas

Slaughter sites should be disinfected several times a day and disposal sites thoroughly once disposal is completed (ARMCANZ, 2000). Special attention should be given to feed and water troughs, as well as roads, pathways, fences, and gates.

Burial pits will emit large quantities of noxious gas and fluid. Once this emission has stopped, the ground around the site should be broken up and liberally soaked with the appropriate disinfectant (ARMCANZ, 2000). Extreme care should be taken to disinfect personnel, machinery, and vehicles close to the site and not allow recontamination of previously disinfected areas near buildings.

Disinfection failure

Cleaning and disinfection involve the physical and chemical removal of contaminating debris, and the reduction or elimination of pathogenic organisms in or on materials, so that these no longer present a health hazard (Meroz and Samberg, 1995). Causes of disinfection failure include over-dilution of disinfectant during pre-mixing or application, incomplete or inadequate cleaning, poor disinfectant penetration or coverage, insufficient contact time on surfaces, inadequate temperature and humidity while the material is being applied, and/or inactivation or neutralization of the disinfectant due to the presence of residual cleaning liquids which were not adequately flushed away (Kahrs, 1995). McDaniel (1991) identifies the widespread misconception that solutions that are more concentrated than directions indicate will be more effective. In fact, stronger solutions may not be better disinfectants and they are usually more dangerous for personnel, more corrosive, and increase the risk for pollution (McDaniel, 1991).

Section 4 – Critical Research Needs

- Evaluate the use of technologies like VerifEYE available from eMerge Interactive to detect microscopic levels of organic contamination present on presumed-to-be-clean surfaces. This patented technology utilizes a fluorescent signature to detect levels of organic contamination not observable to the naked eye. VerifEYE uses wavelength-specific spectroscopy and image processing to provide instant verification of the presence or absence of organic material on a surface. Because insufficient cleaning and organic surface contamination play such a big role in the effectiveness of a disinfectant, verifying that no organic matter has been left behind after cleaning and before disinfection could provide insurance that the decontamination procedure is successful. http:://www.verifeye.net/tech/.

- Conduct mock training demonstrations that test outlined decontamination procedures, and identify gaps within those procedures.
- Conduct further research on the viability of certain disinfectants on highly contagious animal diseases and the disinfectants' suitability for use in the field.
- Identify levels of resistance developed by various agents of highly contagious animal diseases, along with possible alternatives to combat this resistance with other disinfectants.
- Examine innovative methods of pathogen containment suitable for large-scale application (e.g., at confined animal feeding operations).

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Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
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Carcass Disposal Working Group

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Chapter

17

Transportation

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Table of Contents

Section 1 – Key Content

The transportation of large numbers of diseased animals/carcasses resulting from a natural disaster or terrorism event requires significant planning and preparation in order to prevent further dissemination of the disease to susceptible animal or human populations. Defining and following critical protocols will be essential to the safe and successful transportation of such animals to an off-site disposal location following a disaster. While carcass disposal information is widely available, relatively little is currently predefined concerning the transportation of such cargo.

Specific guidelines should be developed prior to disasters that define necessary preparations, response, and recovery methods for potential animal disease outbreaks and/or significant death losses. Providing transportation equipment operators, supervisors, and drivers with the necessary guidelines and training in the use of personal protective gear, handling diseased animals/carcasses in various states of decay, responding to inquisitive public sources such as the media, and becoming familiar with all pertinent permits and other transportation documents are vital to planned preparation for a disaster. There may be significant health risks, stress variables, manpower issues, and emotional trauma associated with the handling and transportation of diseased animals in an emergency situation. Employers must be prepared to credibly explain the risks and safety precautions necessary to minimize the negative impact a potential disaster can have on the transportation workforce. In addition, workers involved in the transportation between multiple city, county, and state jurisdictions must be made aware of the regulations regarding public health, transportation, agriculture, and the environment of those jurisdictions along the selected travel route.

The logistics issues involved in the transportation of diseased animals or carcasses include the use of skilled labor and necessary equipment to dispose of the potential health threat and/or emotional impact of a visible disaster. As a result of Hurricane Floyd, North Carolina's State Animal Response Team recommends the pre-arrangement of contracts for such resources, including plans for financial reimbursement for such contracts. Local emergency responders must be aware of the process of acquiring these resources and develop resource lists in order to expedite a successful disaster response.

Transportation issues involving off-site disposal include carefully selecting a travel route to limit human exposure, minimizing the number of stops required, and ensuring close proximity to the infected site in order to limit refueling. The load may require special permitting for hazardous waste. There may be a need for prepared public announcements regarding the transportation of diseased animals/carcasses, as well as the need for law enforcement involvement to assist with the safe, uneventful completion of the transportation and disposal process.

When biosecurity is a primary concern, disease confinement is a necessity. Planning for the possibility of disease control may be defined by conducting a vulnerability assessment which will help determine the most likely scenarios that are possible for a breakdown in the transportation process. The response to an incident involves containment and correction of the unfolding situation. Regulatory agencies must be prepared to work together in the best interests of the public in these situations. Emergency managers must assess the situation quickly and quantify information pertaining to the disaster. Completion of a preliminary or initial damage assessment will quantify disaster information necessary to determine response needs.

The physical condition of the diseased animals/carcasses will determine the required transportation equipment. Separate loads are required for live animals and carcasses. Containment within the transport is critical. The location of the selected disposal site will affect load requirements and limits for transportation. Containment of possible pathogenic organisms may require particular vehicles equipped with an absorption and/or liquid collection system. Air-filtering systems will be required for live animal transport, and may be used in carcass transport as well.

A breach in biosecurity is possible during transit. An inspection of the selected travel route may be necessary. For security measures, an escort service may be used to guard against terrorist activity. Upon arrival at the disposal site, biosecurity measures must continue until the completion of disposal. The disposal rate will depend on the method of disposal.

Once disposal is complete, the recovery phase will include the disinfection of transportation workers and equipment prior to returning to the highways. In addition, payment for transportation services must be handled in the recovery phase. An estimate of the cost of animal disposal can be difficult to determine. A unit price contract is commonly used, where costs are assigned to an agreed unit then counted to determine cost. While it is impossible to predetermine an exact transportation cost of a disaster, the development of some pre-established contracts is possible, and can improve the disaster response time. The transportation of diseased animals/carcasses is a part of debris management. In order to improve emergency response time nationwide, cities, counties, and states are developing preestablished debris management contracts. Final recovery phase considerations involve the health and well-being of those involved in the disaster. Post-incident health monitoring and/or counseling should be considered for all who came in contact with the diseased animals.

Finally, the resolution of any incident requires a review of the outcome and the identification of any lessons learned. The transportation of diseased animals/carcasses as a result of a terrorist incident should be carefully reviewed. More documentation of the transportation experience may improve the success of combating a large-scale carcass disposal event. Suggested courses of action include developing an emergency action plan and exercising it, participating in educational training for emergency responders, and maintaining a list of resources and subject matter experts to be consulted upon incident.

Future research should be done on special purpose designs for mass animal transportation. This may include a combination of disposal methods. Issues such as disease containment, processing, and cargo disposal methods regarding transportation are essential to improving emergency response.

Section 2 – Introduction

As a result of a natural disaster or terrorism event, large numbers of diseased and/or dead animals will need to be transported to a disposal site when they cannot be disposed of on site. A bioterrorism event directed at US agriculture could result in entire large-animal feedlots and poultry facilities being infected, requiring disposal of diseased and decaying animal carcasses to protect against further dissemination of the disease and/or etiologic agents throughout the industry.

This chapter focuses on critical issues related to established protocols during the transport of diseased animals/carcasses from the property of infection/mortality to an off-site disposal location. Research efforts consisted of internet searches for information related to the disposal/transportation of diseased animals/carcasses, open interviews with people who held leadership positions for the transportation of animal carcasses resulting from disaster and/or disease, open interviews with people who are experienced and trained in responding to weapons of mass destruction and biohazard emergencies, and review of research papers on the subject of animal carcass disposal.

The information search was limited to English-speaking people and publications in English. While a significant amount of information was available regarding the disposal of infected animals/carcasses, comparatively little was available regarding the transportation of animals/carcasses. The majority of available information was comprised of regulatory documents and supporting guidelines that did not include details of results achieved or potential applications. The protocols for managing an agricultural disaster seemed to be consistent across all sources: human health and welfare, agriculture industry, and animal health.

Section 3 – Preparation

3.1 – Preparing Operators/Drivers/Supervisors

Transporting diseased animals and carcasses en masse is not a part of daily life for most American transportation and construction workers. Prior to engagement in such a project, supervisors, equipment operators, and drivers should be provided training and guidelines in (1) using personal protective equipment, (2) handling diseased animals and carcasses in various states of decay, (3) completing/maintaining required written transportation documentation, and (4) responding to media personnel seeking information for public broadcast.

As discovered by Waste Management, Department of Riverside County, California, during a recent Newcastle disease outbreak in Southern California, workers fear for their health and that of their families when confronted with transporting and handling diseased animals (Midwest Regional Carcass Disposal Conference, 2003). In order to maintain the workforce, employers must be prepared to credibly explain health risks and precautions to be taken by workers in order to ensure their safety and protection (Mummert, 2001). Ronnie Philips, of Philips and Jordan, Inc., cited that workers become very stressed when working with mass quantities of animal carcasses for long periods of time (Midwest Regional Carcass Disposal Conference, 2003). According to Philips, workers must be rotated away from direct contact with the carcasses periodically. In order to avoid short- and long-term worker health problems, preparations must be made to deal with the emotional impact of working with mass volumes of carcasses continuously for extended periods of time.

Transporting diseased animals and carcasses is well regulated through agencies with federal, state, county, and city jurisdictions. Examples include:

- Department of Agriculture and Food of Ireland
- Florida Statutes 2003
- Florida Department of Agriculture and Consumer Services – Animal Movement
- Idaho Department of Agriculture, Division of Animal Industries
- City of Rolla, Missouri – Municipal code of ordinances, Chapter 5 animals and fowl.
- Nevada Revised Statutes 2003
- City Codes for St. James, Missouri
- US Department of Agriculture – US State and Territory Animal Import Regulations

Since a mass outbreak may require employees from wide regions, and transporting animals and carcasses may cross jurisdictional lines, workers will need to be briefed on all pertinent regulations including environmental, transportation, public health, and agriculture.

3.2 – Preparing Logistics

A primary logistic concern is the resources, skilled workers, and equipment required to dispose of the diseased animals and carcasses expediently (Mummert, 2001). The disposal of thousands of animal carcasses in North Carolina in the wake of Hurricane Floyd resulted in additional provisions regarding carcass handling. In the County Plan recommended by the North Carolina State Animal Response Team, the Mortality Management Section coordinators, Drs. Jim Kittrell and Dan Wilson, identify the need to "prearrange contracts for resources to handle dead animal removal, burial and disposal." Under the State Plan, it is recommended to "work out financing so counties can arrange local contracts with understanding of reimbursement" (Kittrell and Wilson, 2002). An important consideration in any contract is how the contracted work is to be measured and compensated. In developing such contracts, consideration should be given to how the animal will be handled and the condition of the carcass. Both parties of the designated contract, the payee and payer, must be able to accurately and consistently measure and count the unit (Ellis, 2001; Department of Agriculture and Food of Ireland; Kittrell and Wilson, 2002).

Plans must be coordinated so that all workers and agencies are moving toward the same objectives. It will be very important for local emergency responders to know the process for acquiring the necessary resources. Developing and maintaining a resource list before an incident is paramount to a successful response. When the disposal location is off site, a travel route must be carefully selected to limit exposure of humans to the bio-contaminants in the load. People may be infected with the disease or may assist in the propagation of the disease.

Socially, people are emotionally impacted by the sight of large volumes of animal carcasses. Selecting a travel route through areas with limited or no population is the best way to avoid conflict. The route should be as direct as possible with few stops to ensure an efficient transportation operation. The ideal disposal site will be as close to the infected site as possible to avoid the need to refuel. Truck trip cycles should be planned to refuel on the return trip to the loading site. The carcasses may be considered a hazardous waste and require special permitting from regulatory agencies. It may be necessary to obtain permits from regulatory agencies for the selected travel route (Ellis, 2001; Fulhage, 1994).

While there is no desire to alarm the surrounding communities, there is a duty and purpose to inform the public. Large numbers of trucks traveling on low volume roadways will attract attention. Transportation officials should work with the Public Information Officer to prepare a public notice statement informing citizens about the operation. Drivers should be briefed on responding to the media and directing them to the Public Information Officer. If the event has been identified as a terrorist incident, law enforcement security should assist in ensuring that the load is secure during transit, is not used as a weapon itself, and reaches its destination safely (Ellis, 2001; Fulhage, 1994; Department of Agriculture and Food of Ireland).

Since biosecurity is a primary concern, preparing appropriate measures to help confine the disease outbreak and planning for them is a necessity. Consideration of all the factors that can work in opposition to disease control is termed a vulnerability assessment. Conducting vulnerability assessments for various most-likely scenarios will identify areas to be addressed in order to prevent or limit enlarging the outbreak as the result of a breakdown in the transportation process (Ellis, 2001; Department of Agriculture and Food of Ireland).

Section 4 – Response

When an incident occurs, a response that attempts to contain and correct the situation must be a priority. While regulations govern daily routines, including "normal" emergencies; those same regulations may not be practical during extreme events due to conflicting values. For example, strictly following truck load weight requirements may exacerbate a public health problem during the emergency by slowing the removal of diseased carcasses. Mechanisms must be in place in order for agencies to work together for the public good in such situations.

Every emergency manager must assess the situation and quickly answer two questions: How big is big? How bad is bad? Emergency managers use a preliminary damage assessment or initial damage assessment to evaluate situations that may require state or federal disaster assistance (Federal Emergency Management Agency, 2003). Although the forms and information required vary, the assessment will quantify information pertaining to the disaster and resulting debris (animals/carcasses) such as the physical condition of the animals/carcasses, the animal count, estimated unit weight of animals to be transported, and/or the total estimated volume.

Diseased animals/carcasses may be in various states of physical condition from appearing healthy to liquefied. Live animals and carcasses should not be mixed in the same load. The condition of the animals/carcasses will determine the equipment required to load them and contain the diseased organism. Containers for transporting diseased animals/carcasses are dependent upon the size and the condition of the animals/carcasses. In any condition, the primary consideration should be to contain the load within the transport vehicle. Live animal transportation must additionally consider ventilation, feeding, and watering of the animals. At a minimum, vehicles should be disinfected before loading diseased animals/carcasses, and made liquid-tight from loading to unloading.

The travel route and distance to the disposal site will affect allowances and limitations on the transport vehicles. If the travel route allows the use of large off-road haulers, the quantity of animals/carcasses carried in each load will be greater, reducing the number of loads and, therefore, reducing the risk of a biosecurity breach incident. More likely, the transportation route will utilize existing public roadways and commercial vehicles. The California Department of Food and Agriculture (2003) Web site provides a partial list of commercial dead animal haulers in that state. Other states may have similar resources.

Various systems may be employed to contain the pathogenic organism, depending on the size and condition of the animals/carcasses (Ellis, 2001; Fulhage, 1994; Department of Agriculture and Food of Ireland). Containers must be liquid tight. Typically, they will be equipped with an absorption system and/or liquid collection system. A self-contained air filtering system is a must for transporting live diseased animals, and may be advantageous for order mitigation for carcass transport. Covers must securely prevent debris from blowing out of the top and/or prevent vector pilferage.

Transport vehicles may be most vulnerable to a breach of biosecurity while in transit. The route must be thoroughly inspected and monitored during the transport operation. An escort service may be necessary to guard against a hijacking of the load for the purpose of sale, ransom, or increased disease propagation of the pathogen(s) and negative impact of the terrorist incident (Ellis, 2001; Fulhage, 1994; Department of Agriculture and Food of Ireland).

The unloading of vehicles should be conducted at or as close to the disposal site as practical. All of the biosecurity measures to contain the pathogenic organism must actively continue until disposal is completed. It is possible animals/carcasses may have to be stored in the transport vehicles until they are disposed. The rate of disposal is dependent upon the selected method of disposal (Fulhage, 1994).

Section 5 – Recovery

In order to maintain strict biosecurity and prevent the spread of infection, the transport vehicle and driver must be disinfected after each unloading operation. This will ensure the pathogenic organism is contained or rendered passive prior to the vehicle returning to the highways.

Ireland's Department of Agriculture and Food offers a foot and mouth disease (FMD) Operations Manual Contingency Plan on its Web site. Chapter 21 Disposal of Carcass and Chapter 22 Cleaning and Disinfection of Infected Premises (http://www.agriculture.gov.ie/index.jsp) provide guidance for disinfection of vehicles, persons and premises in response to FMD.

Estimating the cost of mass animal disposal is a challenge. The most common costing tool for major efforts involving large quantities is a unit price contract where costs are assigned to an agreed unit, and that unit is then simply counted to determine the amount owed the contractor. The critical elements of such a contract are the description of the unit and the description of the payment. For example, a unit might be defined as 100 individual chickens, each estimated to weigh one to six pounds (live weight). The agreed unit in this example is 100 chickens, so described. The price is then defined, and the contract includes such information as what work will be done to the unit for the contract price, and may include language about how partial units will be paid.

Operating under such a contract, the conditions of unit and services included for the cost vary greatly depending on the incident. Without building a specific scenario, it would be impossible to predetermine an exact cost for transportation of any given animal disaster. However, that should not preclude development of pre-established contracts for the transportation of diseased animals/carcasses (Kittrell and Wilson, 2002). Many conditions of the contract can and should be established in preparation for a mass emergency. By doing so, the response time for the disposal of the animals/carcasses is shortened. Animal/carcass transportation and disposal is a part of debris management. States, counties, and cities across America are developing preestablished debris management contracts to improve their response to such emergencies. When developing a unit price contract, the primary consideration, in addition to accomplishing the desired result, is to be able to identify and count or measure the unit. For that reason, load weight, volume, and round trips are often utilized. Animal count could be used for live animals if they can be counted easily. Since carcasses vary greatly by physical state, weight or volume may be measured.

Before the records are closed on an incident, it is important for those involved to have closure. It has been determined from past experience that people will be emotionally changed as the result of their involvement in the disaster. Post-incident counseling may be necessary for some. Post-incident health monitoring should be considered for all who came in contact with the diseased animals (Ellis, 2001).

Section 6 – Research Needs

In emergency management circles, one of the final actions in any incident is to review the incident and the outcome to identify lessons learned. The transportation of mass quantities of diseased animals/carcasses in response to a terrorist incident should be carefully reviewed for lessons learned. Within the context of research for this subsection, little detail is documented relevant to the transportation of diseased animals/carcasses. Biosecurity, as related to on-site disposal and cleanup, was discussed quite extensively for diseased animal responses. More detailed attention to the transportation issue may improve the probability of successfully combating a mass animal casualty. Some suggested courses of action for assuring a successful response might be to develop emergency action plans and exercise them regularly, develop and/or participate in training and education programs for responders, develop and maintain a list of necessary and available resources, and cultivate and maintain a list of available subject matter experts to be consulted for specific disease outbreaks.

Future study should be conducted on special purpose design for transporting mass quantities of diseased animals/carcasses. In some cases, this may involve a combination of disposal methods. For example, if carcasses were allowed to decompose in sealed containers on site, could the liquid be pumped from those sealed containers to another sealed container and transported to an incinerator that could burn the pathogenic organism? The on-site container with remaining solids and residue could be loaded onto a transport and moved to an incinerator to consume the remaining pathogenic organisms. If developed, this system could provide for rapid containment of large quantities of diseased carcasses on site, and a biosecure environment for moving the remains to a disposal site.

Could disposal and transport be combined, using a transport trailer similar to a pressure cooker? Diseased animals would be loaded into the trailer, processed in transit, and disposed when processing is complete. This would seal the diseased carcasses off from air and vectors immediately, and keep them sealed until either the pathogen is no longer a threat, or is disposed. If feasible, this option may reduce exposure and help to control the outbreak more quickly.

Moving quantities of live, large, diseased animals to a disposal/processing site is a challenge, especially for large quantities. If the equipment -- such as a sealed circulating ventilation system, waste containment system, and feed and water systems --

were available, rendering and, therefore, cost recovery could be possible in large events. This type of process may require a transportation system on rail.

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