Carcass Disposal: A Comprehensive Review

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

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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.

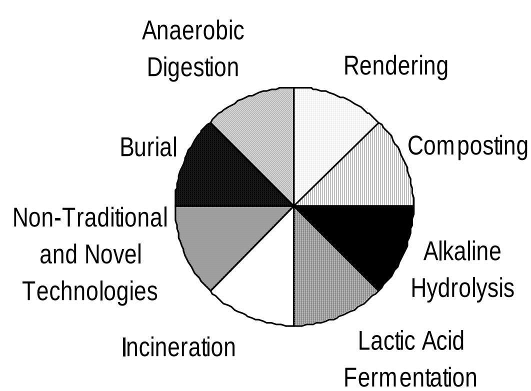

FIGURE 1. Equal consideration given to each of several carcass disposal technologies.

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).

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, coffeecolored, 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.

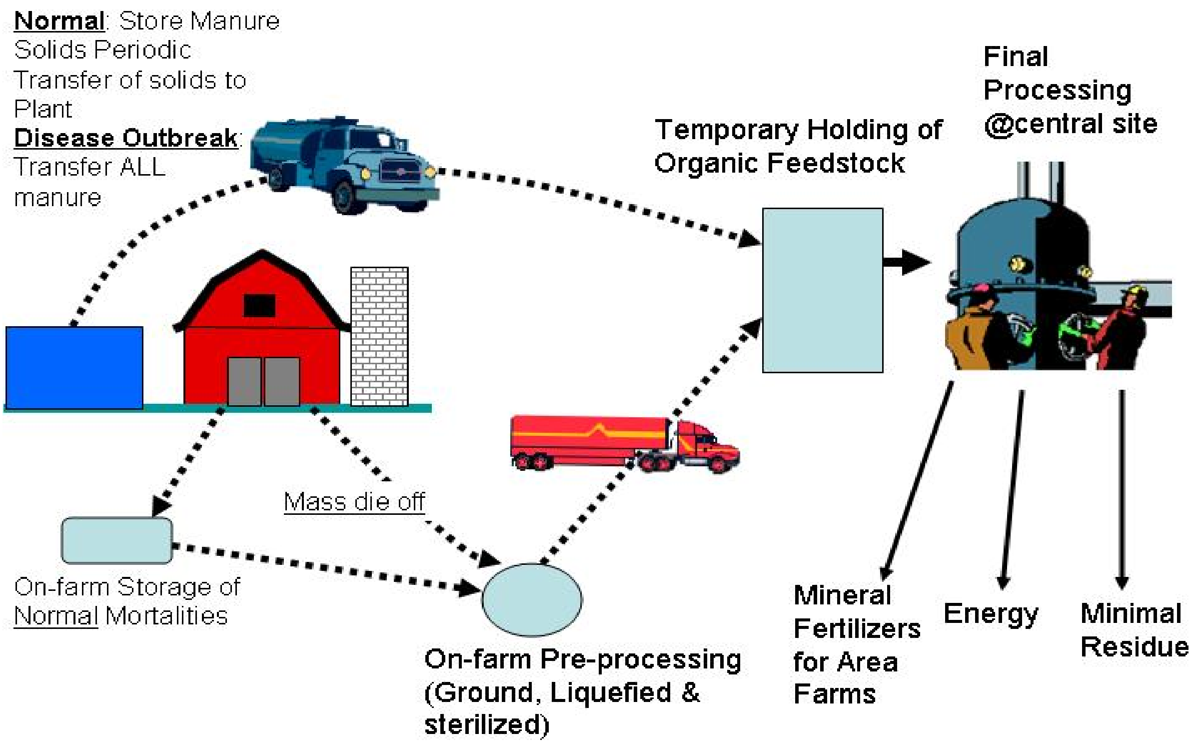

FIGURE 2. Model of decentralized collection and centralized processing. In the event of a mass die-off due to communicable disease, it may be necessary to process all affected stored manure on the farm.

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.

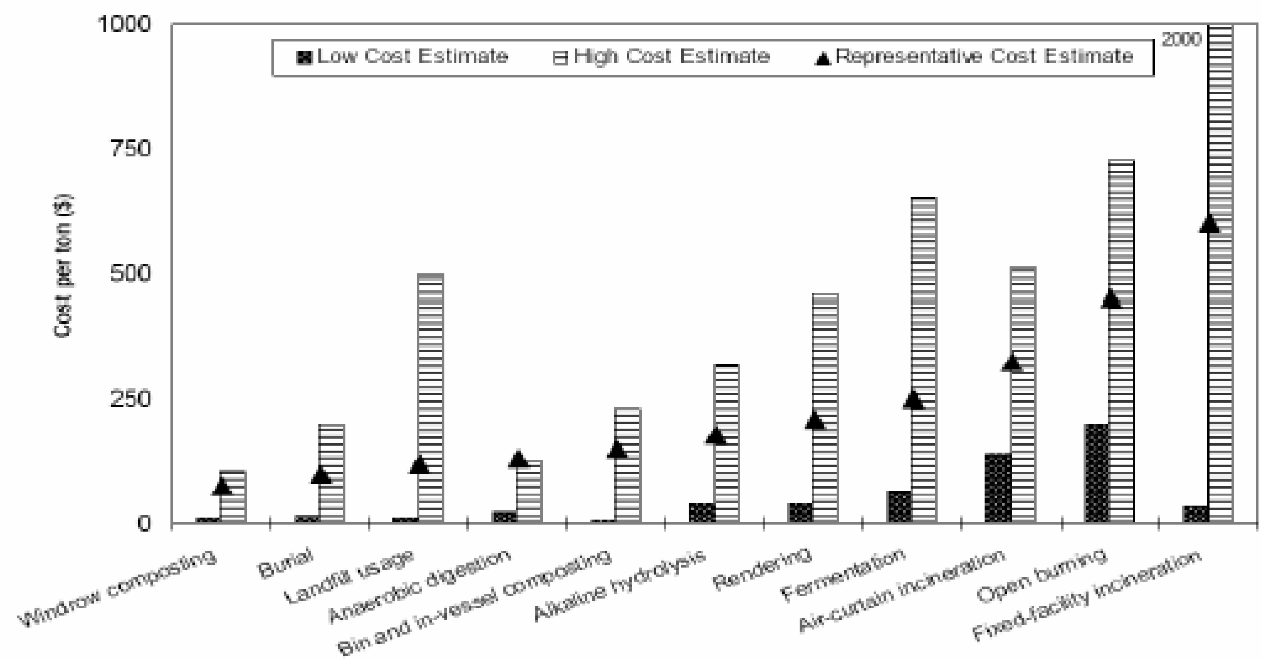

FIGURE 3. Summary of technology costs.

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 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 encounter the 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.