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Ruminant Carcass Disposal Options for Routine and Catastrophic Mortality

Various types of ruminants: feedlot cattle (photo courtesy of CHS, Inc., St. Paul, MN); beef cow (photo courtesy of SXC.hu, Kim Groves, photographer); and sheep (photo courtesy of USDA Agricultural Research Service Image Gallery)

Abstract

Animal agriculture is an enormous industry in the United States, and it is critical to address specific agricultural security challenges that accompany it, such as carcass disposal. Death losses, also referred to as mortalities, may be classified broadly as either routine or catastrophic. Routine ruminant mortalities represent a small proportion of overall herd size and can be expected to occur and fluctuate throughout the normal course of production; catastrophic mortalities, however, involve larger numbers of losses within a distinct time period and result from a single event such as a barn fire, natural disaster, or epidemic disease. Regardless of the manner of death or numbers of animals affected, safe, effective carcass disposal is essential. This Issue Paper provides a critical, scientific assessment of the predominant methods for carcass disposal in commercial ruminant production.

Burial and landfill are often a convenient and affordable means of carcass disposal, but environmental or regulatory considerations may make these methods less feasible, especially if an infectious material is involved. Rendering is an established, cost effective method for carcass disposal, but the process does not completely inactivate prions (disease-causing agents) and rendering facilities may not be conveniently located. The effectiveness of incineration as a carcass disposal method varies depending on the technique used: open-air burning can be inexpensive but has the potential for environmental contamination; fixed-facility incineration is biosecure but is expensive and has limited capacity;

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and air-curtain incineration is mobile, but it is fuel intensive and requires experienced personnel to operate. When used for carcass disposal, alkaline hydrolysis at elevated temperatures for extended amounts of time will destroy all known pathogens, but the technology is currently expensive and limited in capacity.

Concerns about disease outbreaks in U.S. livestock and the potential consequences from the disposal of diseased carcasses—environmental contamination, spread of the infectious agent to other animals, or human disease transfer—require that additional precautions be taken when disposing of carcasses known or suspected to be infected with transmissible spongiform encephalopathies. The most reliable disposal methods for infected carcasses are incineration or high temperature-extended time alkaline hydrolysis.

Each of the established methods for ruminant carcass disposal has strengths and limitations for routine and catastrophic mortality situations that are addressed in this Issue Paper. The decision to use a particular disposal method will depend on the number of mortalities, the cause of death, environmental implications, regulatory requirements, operational costs, and producer preference.

Introduction

Agriculture in the United States represents an economically significant industry, comprising an estimated 13% of annual gross domestic product and nearly 17% of all jobs (USDA-NASS 2004). Today animal agriculture represents more than half of the total value of agricultural sales, with revenue of $100 billion in 2000 (USDA-NASS 2004). In the late 1990s, livestock and poultry production was a component of approximately 1.3 million farm and ranch operations nationwide (USDA-NASS 2004). The enormity of U.S. animal agriculture magnifies a number of agricultural security challenges, one of which is carcass disposal. The ever-increasing concentration of modern animal production operations, combined with the tremendous mobility of food-animal populations, accentuates the country's vulnerability to high death losses caused by disease outbreaks or natural disasters.

Recent animal disease events have illustrated the need for safe, efficient, timely, environmentally sound, cost effective, and scientifically justified options for the elimination of large and small ruminant carcasses. Currently accepted and available carcass disposal methods (burial/landfill and *rendering*[1]) generally prove sufficient to dispose of the nearly 3 billion pounds of ruminant carcasses that result annually from typical production mortalities and natural disasters.

In the event of catastrophic mortality—whether from accidental disease entry, weather, or an act of bioterrorism—disposal strategies must minimize the economic, animal health, and public health impacts quickly and effectively. In a mass-casualty situation, the number of carcasses to be disposed of may exceed the capacity of any given disposal method. The most effective disposal strategies will be those that are prepared in advance and make maximum use of all available and suitable disposal options.

An optimal disposal method should mitigate the disease agent or other cause of mortality. For complete effectiveness, certain disease agents or other causes of mortality may require specific disposal methods or technologies (e.g., high-temperature incineration or *alkaline hydrolysis* for *transmissible spongiform encephalopathy (TSE)*-infected material).

[1] Italicized terms (except genus and species names) are defined in the Glossary.

Although the preference may be for the causative agent or chemical to be completely destroyed, preventing the further spread of the agent is the most critical requirement. This consideration is important for highly infectious diseases such as *foot-and-mouth disease (FMD)*, which may continue to be spread during the disposal process, or for disease agents that may persist in the environment, such as *anthrax*.

Further, one must evaluate the environmental impacts of disposal methods. Each method will have various impacts, resulting from the interactions of (1) the technology's ability to mitigate the disease agent; (2) the technology's capacity to handle the required volume of material; and (3) the geographic, environmental, and legal characteristics of the location in which the technology is used. For example, isolated mortality on the open range or normal production mortality requires a different disposal response than planned depopulation at a feed lot or processing plant. For planned mass depopulation, it is best to decide on the disposal method and work out details before the depopulation.

Ultimately, all factors must be weighed against the cost and feasibility of the disposal method. In many instances, the financial and manpower resources will be limited. Unfortunately, the success or failure of mass casualty disposal may depend on the cost of the disposal method.

The primary purpose of this Issue Paper is to present information about various technologies for ruminant carcass disposal. The authors have provided information about the methods for routine carcass disposal and for disposal of large numbers of ruminants resulting from catastrophic losses. An Appendix is included to offer specific information about TSEs and how each disposal method handles TSE-infected carcasses. This Issue Paper will help increase understanding and appreciation for available disposal methods to meet the needs of ruminant producers.

Predominant Methods of Mortality Disposal in Commercial Ruminant Production

Burial and Landfill

Historically, the burial of a few aged animals has been considered a routine part of animal agriculture. On-site burial of carcasses from routine mortality rarely has created significant concern or notice. Catastrophic and disease-related mortalities resulting in large numbers of carcasses, however, draw more attention and raise concerns among agriculture and environmental agencies, local governments, health departments, and the general public. The disposal of large or even small numbers of ruminant carcasses has posed serious issues for landfills during the last two decades.

Landfill Facilities

Three types of landfills exist in the United States: construction and demolition, hazardous waste, and municipal solid waste. Municipal solid waste landfills (subtitle D)[2] are the only type appropriate for routine and catastrophic ruminant disposal. These landfills are generally clay and synthetically lined and have *leachate* collection and gas recovery.

Approximately 1,600 solid waste landfills currently operate in the continental United States (NSWMA 2006). The ownership of these properties is split among municipalities, privately held companies, and publicly traded companies. Municipalities and publicly traded companies dominate the solid waste business.

Most facilities operate with host community agreements. These contracts with the local city governments and/or the surrounding community often establish limits on the types of materials that the facility can accept. In some instances, acceptance of carcasses may be prohibited. In other instances, the site operator will be required to obtain additional regulatory approvals before accepting the materials. Geographic origin of the waste also may restrict or prohibit carcass disposal. Operational issues at a landfill—opening of a new disposal cell, recent odor complaints, pending permit approvals, or lack of available capacity—may limit carcass disposal or make it unacceptable to the landfill operator.

[2] Municipal solid waste landfills operate in accordance with the Environmental Protection Agency's Subtitle D regulations.

Expertise and Resource Requirements

Most waste disposal companies employ environmental engineers and health experts who are familiar with animal carcass disposal. Companies have written procedures and training programs to guide their personnel in dealing with carcass disposal. Each site has individual permits that regulate its ability to accept small quantities of animal carcasses and their components, including animal parts and rendered biomass (see Rendering section, page 6).

The acceptance of non-diseased animals and rendered components requires approval of a waste profile document by the state regulatory agency before disposal. Profiles generally are valid for one year and can be renewed annually. Land filling options exist at landfills specifically designated for carcass disposal, including the placement of the carcasses in discrete landfill cells or sealed plastic vaults as deemed necessary by regulation or good environmental stewardship.

Regulations and Permitting

A variety of regulatory and community stakeholder missions and views must be considered when assessing carcass disposal options. These stakeholders may include

- Federal agencies, e.g., the U.S. Environmental Protection

Agency, the Department of Homeland Security, the Centers for Disease Control and Prevention (CDC), and the U.S. Department of Agriculture (USDA);

- State environmental, agricultural, animal health, and public health agencies;
- Local government agencies, e.g., health departments and local landfill inspectors; and
- Local community groups such as a citizens' advisory board.

Catastrophic disposal regulations vary from state to state and also may be influenced by local codes and standards. Carcass material from a farm may be less regulated than the same material from a processing facility, especially if the material remains on the farm premises. Catastrophic carcass disposal usually requires a special permit approved by one or more state agencies, depending on the state of origin of the material. These permits may require the participation of the local landfill management and the corporate environmental protection department, as well as external coordination and approval with the state office of solid waste. In many instances, the USDA and the local health department also may be involved. These procedures vary by state. In most instances, permits should include both approval for acceptance of carcasses and bedding and acceptance of free-flowing liquids as part of the waste stream.

Landfill Process

At a site of ruminant mortalities, a synthetic 20-cubic-yard vault, made of high-density polyethylene, is partly filled with kiln dust or hydrated lime. The carcasses are then placed in the vault, and any voids are covered with additional kiln dust or lime, which impedes fermentation and absorbs generated liquids. The vault is sealed and transported to the disposal facility in a conventional roll-off-box truck. These boxes also may serve as temporary storage vessels, if modified for gas removal by providing a small vent in the container. Once the vaults are deposited in the landfill, the vault locations are mapped and recorded, and the area is deemed off limits for subsequent drilling and placement of methane gas recovery wells.

Safety Concerns About Diseased Carcasses

Carcass disposal is divided into two broad categories: non-diseased mortalities (e.g., weather-related) and fatalities related to a known or unknown pathogen. Non-diseased mortalities generally are handled quickly and without incident, unless the disposal site lacks qualified space or the filling sequence at the landfill is at a stage where disposal may compromise construction safety or impact leachate quality. (Refer to the Environmental Implications section, page 5, for further information on these potential issues.)

If the animals were infected with bacterial, viral, or *prion*-related diseases—those caused by an altered protein that destroys nervous system tissue—the approval process can be more complicated. Potentially infected carcasses require careful consideration of hauling procedures, landfill worker health and safety, impacts to leachate, and leachate treatment procedures. In some states, municipal solid waste landfills are prohibited from receiving known human-susceptible disease material. And although permits for some facilities may allow the receipt of infected material from a specific area, the permits do not require the facilities to accept the infected material or establish the fees for handling the infected material.

Several documented case histories in which the landfill industry has disposed of avian influenza-infected birds and other diseased livestock (VDACS 2002; VDEQ 2002) show that viral and non-spore-forming bacterial agents typically do not remain infectious after long-term exposure to an anaerobic environment. These case histories often are the result of USDA or state action. The case histories are built into a company's safety plan but are seldom published. Nonetheless, even where diseased-animal carcasses can be buried effectively and safely in a landfill using any approved procedure, safe management of the fluids resulting from the decay process must be considered. For example, an adult bovine is estimated to lose up to 42 gallons of liquid in the first 60 days after burial (Nutsch and Spire 2004). Ideally, all fluids should be captured and further degraded in the waste mass underlying the carcass. The safe distance from the carcasses to the leachate collection system generally is thought to be a minimum of 40 vertical feet and 60 horizontal feet from any side slope of the landfill. In some instances, landfill managers also may choose to install a layer of compacted soil or cover—a minimum of six and as much as eighteen inches—before carcass disposal to retard the vertical movement of fluids. In the absence of adequate soil amounts, substitutes, such as ground yard waste, *fly ash*, or *auto fluff*, are used. The USDA or the CDC often can provide information about the longevity and viability of specific disease agents under various conditions (Textbox 1).

The disposal of carcasses associated with confirmed mortalities from *chronic wasting disease (CWD)* in landfill sites is not recommended in the United States at the present time. The behavior of the infectious agent associated with TSEs, the prion, in a landfill presently is not clearly understood. (See Appendix 1, page 14, for more information about disposal of TSE-infected carcasses.) If a catastrophic situation arose in which thousands of diseased carcasses needed to be disposed of in a landfill, the liability likely would have to be accepted and indemnified by the federal government.

Textbox 1. Fate of various disease agents in burial and landfill situations

Carcasses infected with non-human bacterial disease agents generally may be disposed of safely in sanitary landfills, although insufficient data exist on the advisability of disposing of anthrax-infected materials. Other non-spore-forming bacteria generally do not survive once the environment within the landfill becomes anaerobic. The changeover from an oxidative to a reducing (anaerobic) environment takes a period of weeks, requiring that the area where carcasses are disposed of remains undisturbed at least until this process has taken place naturally. Individual states may have regulations addressing the burial of carcasses infected with certain bacterial agents.

The potential fate of viruses in the landfill environment often is assessed using laboratory data. The existing laboratory data generally take into account the *redox potential*, moisture, and temperature in the mass of the landfill. Redox potential, the measurement of the oxidizing and reducing potential, is critical when conducting fate studies that are mimicking the harsh reducing environments in landfills. Data on well-known viruses generally can be accessed in agricultural and CDC literature. Landfill disposal involving rarer infectious vectors may not be well studied, and the available data may be sparse. In all instances, the transport mechanisms for vectors reaching leachate collection systems are not understood completely.

Fungi and protozoans do not remain active in an anaerobic environment. Discussions about prions in landfills have taken place only recently. In the early stages of the *bovine spongiform encephalopathy* (*BSE*) epidemic in the U.K., some BSE-infected carcasses were disposed of in landfill sites before routine incineration was introduced. Most of these sites were unlined municipal solid waste disposal landfills. Nevertheless, a risk assessment carried out for the Environment Agency concluded that the potential risks to people through contaminated drinking water were extremely small. But the fate of prions in landfills and leachate presently is unknown, and no clear method of study or testing exists. There are current studies to address these questions, but the results will not be known for some time. Presently, the majority of landfill owners in the United States are not accepting prion-infected ruminant carcasses for disposal because of (1) the inability to monitor for the long-term viability of prions and (2) potential liability issues. (See Appendix 1 for further information on the disposal of TSE-infected carcasses.)

Table 1. Recommended actions for handling and disposal of carcasses during burial and landfill

Routine, Noninfectious Material	Potentially Infectious Material (Actions in Addition to Those for Routine Material)
Prepare waste profile paperwork	Excavate site before carcass arrival and cover with soil immediately after burial
Cover transportation vehicles (with tarp or similar covering)	Avoid transportation of carcasses through neighborhoods
Avoid free liquids by using adsorbent materials	Dispose of infectious material in a separate area of the landfill
Minimize odors with quick, efficient handling	Monitor air for presence of bacteria
Avoid personnel coming into direct contact with materials	Use proper personal protection equipment for workers unloading infectious material
Bury as soon as possible	Dispose of material 40 feet above leachate collection system
Keep birds and vermin away from working landfill surface as much as possible	Implement formal bird-control program on landfill surface
Account for stability considerations if volume is large, because subsidence may be significant and the decaying carcasses may be slimy and have little geotechnical strength	Map and record vault disposal area and store information with asbestos data
	Decontaminate transportation vehicles
	Protect heavy-equipment operators by using pressurized cabs
	Hire specialized contractors to handle infectious material (biosecurity)

Environmental Implications

Environmental implications of carcass disposal by burial or landfill can be short- or long-term. Short-term issues generally are concerned with handling the carcasses in an efficient and professional manner and require more attention if the material is potentially infectious. Table 1 outlines recommended actions for carcass handling that address short-term concerns.

Long-term environmental issues from disposal in landfills vary based on the amount of material and details of the landfill burial technique used. Small to moderate disposals require few additional measures after the material is buried. If the material was infectious, care must be taken to avoid road construction, well installation, trenching, or drilling in the disposal area. Individual state environmental regulations may address these considerations. Disposal of hundreds or thousands of animal carcasses resulting from a catastrophic event may pose additional long-term concerns:

- Offensive odors may require more cover soil and/or improved gas collection in that area.
- Subsidence during the first six months may be significant; it is suggested that stacking carcasses more than three high be minimized.
- Mass burial should avoid formation of potential *slip planes* and should never be closer than 60 feet from the edge of a slope.

- Cover may have to be replaced as the area settles.
- Various agencies may require special leachate and air sampling.
- If carcasses containing an infectious agent are buried, workers may have to be monitored for disease symptoms.
- Seeps or leachate breakouts must be fixed immediately with qualified protocols.
- Some agencies may require leachate recirculation as a precautionary treatment for leachate.
- As areas become filled with carcasses, it will be necessary for landfill operators to avoid them and to construct new working areas instead.
- Long-term liability may be unknown, especially if the site is undergoing an expansion-permitting process. Mass disposal may affect public opinion even though local and state agencies support the initial burial actions.
- Long-term indemnity of all organizations involved in transportation and disposal activities will be required and may determine which companies and contractors are willing to participate in a response.

Estimated Costs

The costs for routine and catastrophic carcass disposal in a landfill vary based on the facility location, operational status, and required handling practices. Some landfills charge by weight, others by the number of carcasses. Typically, a minimum charge is offset by a cost per ton. When major mortality events occur, costs often escalate based on the demand, special handling practices, or services needed. An additional working area, special handling, and added monitoring can either increase the cost per ton or add to the overall project costs. In some instances, the host community may set special host fees (Flory 2006).

Best Practices

Routine

1. Profiles should detail the location and cause of mortality. Disease-related mortalities are not routine.
2. Immediate burial to prevent odors and interaction with birds is mandatory and required by regulation. The time factors established in regulation are often inadequate for mass disposal events, but they emphasize the importance of having a disposal option in place before killing any animals. In addition, interim methods of containment for dead animals may be required when the time of death is not controlled.
3. Minimize worker contact with the shipment.
4. Operations management should monitor for increasing frequency of routine loads and investigate abnormalities.

Catastrophic

1. All influencing and permitting agencies, operating companies, and owners of the facility must be notified. Public notification is appropriate under some conditions, but public information planning and accurate risk communications are required for all disposal activities.
2. Plans and profiles must be approved and contracts must be signed.
3. During all operations, including acceptance of the carcasses, worker health and safety must be maintained and the work plan must be followed to prevent injury and environmental impacts. The work plan must include health and safety practices, transportation practices, and decontamination of equipment.
4. Visual and analytical monitoring should be recorded and filed. Mapping of the affected areas is strongly encouraged and may be required by regulation. It is suggested to follow asbestos guidance in the absence of specific requirements for biological disposal. Many states require the identification of burial sites during any due diligence activities related to land transfer.
5. If the disease-causing vector is unknown, pretreatment of the affected animals or *macro-encapsulation* is recommended.
6. Indemnification and transfer of contingent liability to the appropriate federal agency is necessary in some instances.
7. If the deaths are disease related, contact the CDC in Atlanta for information regarding public health risks and infectivity. Remember “healthy” animals carry a significant biologic risk potential.

Advantages/Disadvantages of Landfill Burial

Tables 2 and 3 describe the advantages and disadvantages of landfill disposal for both routine and catastrophic mortalities.

Rendering

Rendering has been a disposal option for animal by-products and mortalities for a long time. The North American rendering industry handles approximately 59 billion pounds of raw material annually, with dead stock representing nearly 5% of this total (Meeker 2006). Ruminants (cattle, sheep, lamb, and goats) combine to account for approximately 22% of all mammalian livestock that die before slaughter each year in the United States (the balance being mostly swine), but because cattle are so large and heavy, the volume (weight) of ruminant mortalities accounts for about 67% of the total death loss each year. Beef cattle account for the largest proportion of mammalian livestock mortalities requiring disposal, and nearly 50% of the 1.6 billion pounds of annual volume (Sparks 2002).

Table 2. Advantages/disadvantages of landfill burial of routine mortalities

Advantages	Disadvantages
Costs can be set for a year at a time	Sanitary conditions must be maintained for landfill personnel, facilities, and equipment
Profiling allows for long-term tracking and monitoring of the waste stream	Special transportation and biosecurity arrangements must be made. Inexperienced transporters create a nuisance
Burial is generally local	Minimum costs per load can be an issue

Table 3. Advantages/disadvantages of landfill burial of catastrophic mortalities

Advantages	Disadvantages
Cost per ton is manageable in many instances	Potential for odors is great if there are no set procedures
Infrastructure is in place to accept large quantities of materials quickly	Permitting is different or nonexistent by state and local area governments, leading to potential lack of animal and human health control and substantial delays in approval for burial
Backup safety and compliance teams exist	Public opinion may inhibit acceptance
A large resource of consultants is already working for the landfill operations	Operator refusal to accept materials, construction, pending permits, and fill sequence may eliminate some local facilities from use
Subtitle D liner systems are well established for containment	Standard practices are different for each operator
Systems design allows for adequate monitoring of gas, leachate, and air	Associated costs for special treatment prevent general pricing across the country
Operation hours can generally be adjusted to fit emergency needs	Bird and vermin control must be increased

Table 4. Efficacy of the U.S. rendering system for the destruction of pathogenic bacteria (Samples from 17 different rendering facilities during winter and summer. Troutt et al. 2001)

Pathogen	Raw Tissue % Samples Positive	Post Process % Samples Positive
Clostridium perfringens	71.4	0
Listeria species	76.2	0
L. monocytogenes	8.3	0
Campylobacter species	29.8	0
C. jejuni	20.0	0
Salmonella species	84.5	0

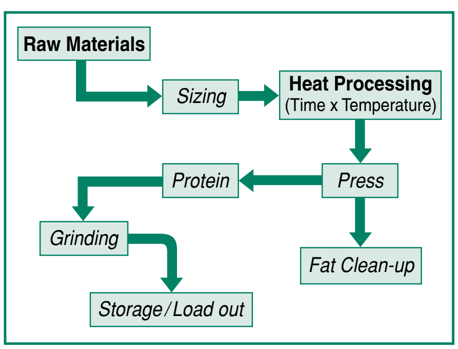

Figure 1. Basic production process of rendering.

Principles of Rendering

Rendering involves both physical and chemical transformation of the materials using a variety of equipment and processes. All rendering processes involve the application of heat, the extraction of moisture, the separation of fat, and the grinding of meat and bone meal. Figure 1 illustrates the rendering process (Hamilton 2004). The temperature and cooking time are critical and are the primary determinants of the quality of the finished product. Animal fats and proteins derived from the process are valuable ingredients for animal feeds and other uses. Conserved nutrients within rendered products help sustain animal agriculture and protect marginal lands from misuse.

Rendering processes vary according to the raw material composition. All rendering system technologies include the collection and sanitary transport of raw material to a facility where it is ground into a consistent particle size and conveyed to a cooking vessel, either continuous-flow or batch configuration. Most North American rendering systems are continuous-flow units. Cooking is generally accomplished with steam at temperatures of 240º to 290ºF (approximately 115º to 145ºC) for 40 to 90 minutes, depending on the type of system and materials. Regardless of the cooking method, the melted fat is separated from the protein and bone solids, and a large portion of the moisture is removed. Most importantly, cooking temperatures are sufficient to inactivate bacteria (Alder and Simpson 1992), viruses (Perkins 1969), protozoa (Fayer 1994), and parasites (Jarrol, Hoff, and Meyer 1984) of concern (Table 4).

Modern rendering facilities are constructed to separate raw material handling from the processing and storage areas. The process is performed and monitored through computer technology to achieve time/temperature recordings for appropriate thermal kill values for specific microorganisms. Temperatures far above the required thermal kill value are unnecessary and avoided because they can lower nutritional values and digestibility of the finished product. Rendering processes in North America generally do not incorporate cooking under pressure except with materials such as feathers and other high-keratin-containing tissues.

In April 2008, the U.S. Food and Drug Administration (FDA) finalized additional restrictions to the Feed Rule (USFDA-HHS 2008) to decrease the risk of BSE in the United States. The restrictions take effect in April 2009. The rule defines "cattle material prohibited from animal feed" or CMPAF, prohibiting its use in all animal feed; CMPAF includes

- Brains and spinal cords from cattle more than 30 months of age
- Entire carcasses of cattle not inspected (ante mortem) and passed for human consumption
- unless shown to be less than 30 months of age **OR**
- brain and spinal cord are removed
- Entire carcasses of BSE-positive cattle
- *Tallow* derived from BSE-positive cattle
- Tallow from CMPAF if containing impurities great than 0.15%
- Mechanically separated beef made from CMPAF.

Since additional regulations for BSE controls were enacted, some rendering plants have specialized in handling a single species of animals, such as poultry or swine.

In the U.K., products from rendering *specified risk materials* have been incinerated, the fat used as a fuel in the rendering plant, and the meat and bone meal used as a fuel in power stations. Meat and bone meal also have been processed with the fat into pelletized fuel for boilers and furnace applications. Such alternatives may develop in the United States, but such development will depend on economics and volume of materials banned from feed. The removal of brains and spinal cords from cattle carcasses is difficult in some circumstances, which could increase the volume of materials prohibited in feed.

Regulatory Influence

The rendering industry is regulated closely by state and federal agencies, and each agency routinely inspects rendering facilities for compliance with applicable regulations and finished product safety tolerances. Officers of the FDA inspect rendering facilities for compliance with BSE-related regulations and chemical residue tolerances. The Animal and Plant Health Inspection Service of the USDA issues export certificates and inspects rendering facilities for compliance with restrictions imposed by the importing country. Renderers also are required to register with the Food Safety Inspection Service, which helps ensure dead or diseased animals are not diverted into the food supply and allows confirmation that condemned carcasses and meat are disposed of outside the human food supply. State feed control officials inspect and test finished products to enforce policies regarding quality, adulteration, and feed safety. Other state agencies also regulate the rendering industry by issuing air and water quality permits and feed and rendering licenses.

The rendering industry uses internal controls to maintain biosecurity and ensure that the finished products are safe and in compliance with all state and federal regulations and tolerances. Two types of control procedures common among rendering companies are good manufacturing practices (GMPs) and process control programs. The GMPs minimize product safety hazards by instituting basic controls or conditions favorable for producing a safe product. For example, a "raw material GMP" would provide validation that raw materials were not exposed to toxic chemicals or metals before processing in a rendering facility.

Infrastructure

Full-service rendering companies are capable of efficiently transporting and processing large volumes (one million or more pounds per day) of raw animal by-products and mortalities. Even though the rendering industry has undergone significant consolidation during the past 30 years (Table 5), most areas of the United States continue to be serviced by one or more renderers.

The rendering industry uses specialized equipment that is not commonly found in other segments of the agricultural industry. To safeguard the food supply, prevent the spread of disease, and prevent damage to the environment, many states regulate the collection and transportation of unprocessed animal by-products and mortalities and require that only vehicles equipped with leak-proof vessels be used to transport these materials. This industry-specific equipment is not commonly found on farm equipment or on vehicles used by common carriers. Renderers also must install air scrubbers, thermal-oxidizers, wastewater treatment facilities, and other equipment necessary to meet state air emissions, odor, and water discharge permits for their facilities. Tens of millions of dollars in equipment, monitoring instrumentation, and analytical testing are invested at rendering facilities to meet state and federal standards.

Capacity

Throughput and capacity will be dependent on the type of rendering facility and its scale of operations, although there are a number of facilities capable of handling many tons per

Table 5. Decrease in number of U.S. rendering plants (Meeker 2006)

	1921	1927	1975	1997	2006
Number of Plants	823	913	724	282	273

Note: A similar trend occurred in Canada, where there are currently 29 plants.

Table 6. Estimated annual quantities of dead and *downer cattle* rendered (Informa 2004)

	Mortalities and Downers			Volume		
	Head	Rendered Percentage	Head Rendered	Produced[1]	Rendered	Percentage Rendered
Cattle						
Dairy cow/bull	584.55	62.0	364.76	818,370	510,663	
Feedlot	300.00	94.4	283.20	270,000	254,880	
Beef cow	1,025.75	20.0	205.15	1,025,750	205,150	
Total	1,910.30	44.7	853.11	2,114,120	970,693	45.9
Calves						
Dairy calves	740.43	43.8	324.31	185,107	81,077	
Beef calves	1,625.17	20.0	325.03	406,293	81,259	
Total	2,365.60	27.4	649.34	591,400	162,336	27.4
Total cattle and calves	4,275.90	35.1	1,502.45	2,705,520	1,133,028	41.9

[1]Assumes the following weights per mortality: dairy cow, 1,400 lb; feedlot, 900 lb; beef cow, 1,000 lb; calves, 250 lb

day. Recent industry estimates suggest that renderers currently process approximately 50% of all livestock mortalities (i.e., mortalities from all species, including bovine, poultry, and swine), and approximately 42% of all cattle mortality volume. Table 6 shows the estimated volume of cattle mortalities currently processed but does not show the reserve capacity of the rendering industry. The reserve capacity figure may be as large as 40% or more of current processing.

If dead animals are not preserved, they should be transported to a rendering facility within 24 hours. Preservation allows mortalities to be stored on the farm until quantities are sufficient to warrant the cost of transport for rendering. Freezing and fermentation have been used for preservation of mortalities before processing.

Rendering Catastrophic Losses

Rendering is a business—the traditional routine rendering system depends on marketable end products to finance the system. If the end products of catastrophic mortalities are considered unsuitable for use in animal feeds (because of the nature of an animal disease or other cause of death), rendering companies could not justify economically the processing of carcasses in the absence of additional compensation. The rendering industry may need to develop a twofold system consisting of (1) dedicated facilities for disposal rendering and (2) a process to ensure the use of added specialized capacity. In case of a major disease outbreak, such as the FMD outbreak in the U.K., the dedication of a centrally located rendering plant to the diseased carcass disposal effort might be an appropriate response, technically as well as financially.

Many plants are capable of processing one million or more pounds per day of *offal* and dead animal materials on a routine basis. In addition, many plants are capable of increasing capacity and throughput in times of emergency. Depending on the weather, cold storage may be necessary to hold excess material if capacities are temporarily overwhelmed. Decision makers involved in emergency animal management should communicate with renderers in the area and adjacent states about the conditions and amounts of material that can be handled by this process, as well as the cost for its use. Also, the rendering industry can provide *biosecure* carcass hauling in times of disease outbreak that can be used with other disposal methods.

In areas where rendering operations are used for routine mortality and processing waste, the mass reduction component accomplished through rendering could not be handled easily by other disposal resources. Each rendering plant routinely handles millions of pounds of raw material per week, and most plants could handle much more material in emergencies.

Estimated Costs

The cost of rendering depends on location, energy costs, and prices of rendered products. Nationally, the average charge by renderers to pick up a dead bovine is $25. If the products from ruminant mortalities cannot be used for feed, the pick-up charge could increase to $100 per head. Ruminant meat and bone meal has declined in value considerably since the 1997 FDA feed regulation restricting its use, but there is still a market for these materials.

Advantages/Disadvantages of Rendering

Table 7 describes the advantages and disadvantages of rendering as a carcass disposal option.

The experiences with large numbers of mortalities during the 2001 FMD eradication efforts in the U.K. were analyzed and summarized retrospectively, and rendering was deemed to be the best disposal option (Table 8). Because sufficient rendering capacity was not available in the

Table 7. Advantages/disadvantages of rendering as an option for carcass disposal

Advantages	Disadvantages
Existing infrastructure	Possible capacity constraints in handling surges in a specific geographic area
Industry familiarity with animal mortalities	Biosecurity concerns with transport, especially in the event of significant volume escalation
Environmentally sound	Some geographic areas not served
Biosecure after processing (although it does not fully inactivate prions)	
Usable end product; value captured helps pay for process	

required locations, however, other options such as burial and burning were used.

Composting

The process of composting has been used to stabilize or dispose of a variety of organic wastes including yard trimmings, manure, municipal biosolids, food waste, and animal carcasses. The end product of this aerobic degradation process is used widely as a soil amendment. Composting is a managed process that requires an appropriate balance of carbon and nitrogen sources, as well as appropriate oxygen and moisture conditions. As a means of carcass disposal, composting has become increasingly appealing—especially for routine mortalities—when considering concerns about the cost, availability, and environmental impacts of other methods. Composting also is attractive because it can be performed on-site, eliminating the need to transport infected or potentially infected material during a disease outbreak. It is advisable, however, to consult local and state authorities regarding regulations governing composting of ruminant carcasses; there may be issues with composting carcasses infected with certain biological agents or TSEs. The regulations may describe what can be done with the composted material or may prevent composting altogether.

Research assessing the environmental impacts and biosecurity issues associated with composting livestock mortalities during an emergency suggests that composting can be a relatively biosecure process when performed properly (Glanville et al. 2006). (See Appendix 1 for a more in-depth discussion of disposal options for TSE-infected carcasses.)

Considerations for using com-

Table 8. Summary of potential health risks for various methods of handling animal by-products[1, 2]

	Exposure of Humans to Hazards from Each Option				
Disease/Hazardous Agent	Rendering	Incineration	Landfill	Pyre	Burial
Campylobacter, E. coli, Listeria, Salmonella, Bacillus anthracis, C. botulinum, Leptospira, Mycobacterium tuberculosis var bovis, Yersinia	Very small	Very small	Moderate	Very small	High
Cryptosporidium, Giardia	Very small	Very small	Moderate	Very small	High
Clostridium tetani	Very small	Very small	Moderate	Very small	High
Prions for BSE, scrapie[3]	Moderate	Very small	Moderate	Moderate	High
Methane, CO_2	Very small	Very small	Moderate	Very small	High
Fuel-specific chemicals, metal salts	Very small	Very small	Very small	High	Very small
Particulates, SO_2, NO_2, nitrous particles	Very small	Moderate	Very small	High	Very small
PAHs, dioxins	Very small	Moderate	Very small	High	Very small
Disinfectants, detergents	Very small	Very small	Moderate	Moderate	High
Hydrogen sulfide	Very small	Very small	Moderate	Very small	High
Radiation	Very small	Moderate	Very small	Moderate	Moderate

[1] Adapted from UKDH 2001

[2] Legend:
Very small—least exposure of humans to hazards
Moderate—intermediate exposure of humans to hazards
High—greatest exposure of humans to hazards

[3] Risk of human exposure to TSEs was rated as very small when solid products of rendering were incinerated

posting to dispose of animal carcass mortalities have been summarized by various authors (DeRouchey, Harner, and Murphy 2005; Kalbasi et al. 2005; Mukhtar, Kalbasi, and Ahmed 2004; Wilkinson 2007). Where large numbers of carcasses are concerned, composting generally is better suited to the disposal of small- to medium-sized carcasses (e.g., poultry and swine) than large carcasses (e.g., cattle). For disposing of routine mortalities, composting is more common in poultry and hog production than in cattle production (Sparks 2002). Thus, only a cursory overview of composting considerations is provided here. (For additional information regarding composting for swine and poultry, see CAST 2008a and 2008b. For more specific information on composting techniques, see Bagley, Kirk, and Farrell-Poe 1999.)

Incineration

Incineration has been used extensively in the past for disposal of ruminant carcasses and other livestock species. Incineration descriptions date back to early recorded history and are indicated in biblical times. Factors that have affected the acceptance and desirability of this disposal method include environmental concerns, availability and cost of necessary fuel, equipment development, and potential for spread of infectious agents. Presently, there are three broad categories of incineration techniques: open-air burning, fixed facility incineration, and mobile air-curtain incineration. The latest advancement in incineration disposal technology is gasification, which is pyrolysis of the carcass material in a controlled oxygen environment. It is very similar to computer controlled enclosed incineration.

Although large municipal incinerators provide resource recovery of energy and produce electricity from incineration of solid wastes, the incinerators normally are designed for burning household or industrial wastes of 20 to 25% moisture. Because ruminant and other animal carcasses are typically about 70% moisture, and because retention time in burning chambers is limited to intervals insufficient for carcass burning, these facilities are unsuitable for and do not usually accept carcasses for burning (S. DiLiberto, 2002. Personal communication). Enclosed incinerators have been licensed for years for carcass disposal for animal research and treatment facilities, but the permits for such facilities usually prohibit the disposal of carcasses from outside sources. Also, the permitted disposal levels are too low for catastrophic applications.

Open-air Burning

This open system of burning carcasses can take place either on-farm or in collective sites fueled by additional materials of high energy content. Open-air burning has been used throughout history as a means of carcass disposal and was used extensively in the 1967 and 2001 outbreaks of FMD in the U.K. (NAO 2002). Open-air incineration may be accomplished by burning on open land at an above-ground site, in a dug-out pit, or on combustible heaps called pyres. Combustible materials or fuels used for open-air burning may include straw or hay, untreated timbers, wood, coal, or petroleum products such as diesel fuel. Open-air burning may be contrary to environmental standards for air, water, and soil and has no verification of pathogen inactivation, because burning temperatures may vary markedly. In some instances, there has been suspicion that infectious agents have been transmitted via open-air burning resulting from incomplete pathogen combustion or inactivation (Champion et al. 2002). Additionally, because the process is open to view, there may be negative reaction and lack of acceptance by the public. Open-air burning also may pose a fire or air quality hazard.

Fixed-facility Incineration

Fixed-facility incineration occurs in an established facility in which whole carcasses or carcass portions are completely burned and reduced to ash. Because these facilities allow for control and monitoring of burning temperatures, effective inactivation of pathogens can be achieved. Fixed-facility incinerators typically are fueled by natural gas, diesel fuel, or propane. The exhausts usually are fitted with afterburner chambers to completely burn hydrocarbon gases and particulate matter from the primary combustion chamber. With increased costs of combustion fuels and the large amount of energy required to dehydrate the high moisture content of ruminant carcasses, diseased animals may first be rendered and then the resultant meat and bone meal and tallow burned in fixed-facility incinerators, such as in the 2001 FMD outbreak in the Netherlands (de Klerk 2002). Compared with open-air burning, cleanup of ash is less problematic with fixed-facility incineration, and the ash is considered safe for disposal in landfills. The exception to this practice may be the incomplete inactivation of prions of TSEs, in which case burial of ash may not be acceptable. (See Appendix 1 for further information on TSEs.)

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 accelerated up to six times faster than open-air burning. In addition to the increased speed of burning, higher temperatures are achieved, thereby decreasing the possibility of pathogens surviving the burning process. Burning temperatures of 1000 degrees Celsius have been recorded (Kastner and Phebus 2004; TAHC 2005). The equipment for this process can be mobile so that it can be taken on site, but the potential for fire hazard must be considered. Because the equipment can be used on site, there is no requirement for transportation of the animal material if co-combustion materials are available on site. Materials needed for air-curtain incineration include wood or petroleum products such as diesel fuel (for both the carcass burning and the air-curtain fan). Properly trained operating personnel also are needed. Fueled by diesel engines, high-velocity air is blown into either a metal refractory box or a dug-out burn pit. In one recent operation, incineration of 500 adult swine required 30 cords of dry wood and 200 gallons of diesel fuel (Kastner and Phebus 2004; TAHC 2005).

Comparisons

Open-air burning can be relatively inexpensive, but it is not suitable for destroying prions of TSE-infected carcasses. The method is dependent on weather and fuel availability, has the potential for environmental contamination, and may pose a problem for public acceptance.

Fixed-facility incineration is capable of effectively destroying prions of TSE-infected carcasses and is highly biosecure (Kastner and Phebus 2004; TAHC 2005). Disadvantages of fixed-facility incineration are limited availability, high cost of operation, necessity of transporting carcasses to the facility, difficulty of securing local licensure or allowance, and inability of equipment to burn large volumes of carcasses.

Air-curtain incineration is mobile and relatively environmentally acceptable. In addition, this method is suitable for combination with combustible debris removal, such as downed trees from weather-related damage, if dry. Air-curtain incinerators are fuel intensive and require experienced personnel operators. Currently, open air-curtain incinerators are not validated to dispose of TSE-infected carcasses safely.

Alkaline Hydrolysis

Description of Process

Alkaline hydrolysis is a natural process by which complex molecules are broken down into the constituent small molecules from which they were synthesized. The process of alkaline hydrolysis occurs through the action of the hydroxyl ions (OH^-) on the bonds connecting the small molecules. This process occurs in nature when animal tissues and carcasses are buried in soil of neutral or alkaline (high) pH, aided by the digestive processes of soil organisms. In digestion, alkaline hydrolysis is the primary process whereby the complex molecules of proteins, fats, and nucleic acids are broken down in the small intestine into small nutrient molecules that are absorbed by the intestinal cells. Alkaline hydrolysis for carcass disposal is based on the same chemical reaction, with strong alkali and heat used to speed the process.

The current process for application of alkaline hydrolysis to the disposal of animal carcasses and tissues—including infectious and radioactive tissues, carcasses, and biohazardous and hazardous materials—dates back to 1992. The method was introduced for the release of *radionuclides* from experimental animal carcasses so that this type of low-level radioactive waste could be disposed of safely and economically (Kaye, Methe, and Weber 1993; Kaye and Weber 1994). Subsequently, the method was applied to the disposal of other research animals and infectious human and animal tissues and carcasses. Equipment is commercially available for disposal of animal carcasses by this process.

In the simplest current application, whole animal carcasses and tissues are loaded into a stainless steel, steam-heated pressure vessel. Once the vessel is loaded and the lid is sealed, an appropriate amount of concentrated alkali solution and water are added. The vessel is heated to 302ºF (150ºC) and maintained at that temperature for a minimum of 3 hours (depending on the target pathogen, vessel, and carcass sizes) and up to 6 hours for destruction of prions. At the end of the process, the *hydrolyzate*—a solution of amino acids, small peptides, sugars, soaps, and electrolytes—is cooled and drained, leaving only "bone shadows" (i.e., the pure calcium phosphate remains of bones and teeth from which all the collagen has been digested). The hydrolyzate is a resource that can be used directly as liquid fertilizer, dried or absorbed to make a dry fertilizer, used as feedstock for anaerobic fermentation biogas generation, or further treated to precipitate the lipid components for subsequent conversion to biodiesel, still leaving the nutrient solution for other uses.

Alkaline hydrolysis leads to the random breaking of nearly 40% of all peptide bonds in proteins, the major solid constituent of animal cells and tissues. Under the extreme conditions of high temperature and alkali concentration, the protein coats of viruses are destroyed and the peptide bonds of prions are broken. Validation testing has demonstrated that all pathogens in animal tissue (Kaye et al. 1998), including prions, are completely destroyed under the combined operating conditions of heat, moisture, and pH. Alkaline hydrolysis has been written into European Union Animal By-Products legislation as the only alternative technology approved for all categories of animal by-products, including the most highly infectious and prion-contaminated material (EC 2005).

Types of Systems

Alkaline hydrolysis systems may be fixed or mobile. The capacity of currently available equipment is up to 10,000 lb/cycle for fixed systems and 4,000 lb/cycle for mobile systems. Designs are available, however, for systems that combine pulverization and initial steam disinfection with the tissue destruction and resource conservation capability of mobile systems capable of processing more than 25,000 lb/hr.

Fixed-base and mobile systems currently are able to handle the routine disposal of infectious and suspect animal carcasses and tissues brought to state and federal veterinary diagnostic laboratories. These systems also could serve for disposal of materials, such as specified risk material, at livestock processing facilities. Since 2004, a single 4,000 lb-capacity mobile system has been used to dispose of more than one million pounds of deer confirmed or suspected of having CWD, a TSE, in a depopulation program near Madison, Wisconsin.

It is important to distinguish between the issues related to disposal of routine infectious and TSE-infected or suspect animals and the issues related to disposal in mass animal epidemics or other catastrophic situations. Fixed-base systems are able to handle routine and TSE material because the volumes are relatively small. Also, TSE outbreaks can be managed by isolation and transport of the affected animals without risk to noninfected animals. In mass animal epidemics or natural disasters, however, disposal often must take place at the site of the outbreak and be done quickly to prevent spread of infectious disease; for these situations, mobile systems can be used. The hydrolyzate from such a system is only partly hydrolyzed; it exits the system as *slurry* into a tanker truck or rail tank car in which hydrolysis continues until the hydrolyzate is emptied into a fertilizer storage trench, fed into a biogas generation system, field spread, or otherwise processed for resource recovery.

Fixed-base systems generally use institutional steam supplies for heating the vessels and domestic water for filling and cooling. Mobile systems require "slave trucks" carrying diesel or propane-fired electrical and steam generators, as well as alkali and water (if needed). In theory, a fleet of large-volume *mobile comminution-disinfection-digestion systems*, strategically distributed around the country in a sort of "fire station" pattern, could be gathered on short notice to deal with mass animal disposals. When not in use in emergency situations, these units could be kept operable and their operators trained by using the units for routine depopulations of avian and ruminant livestock and control of small outbreaks. The fixed-base units would always be in use for disposal of animal carcasses and tissues after routine *necropsy* and diagnostic procedures.

Operational Costs

Currently, fixed-base systems large enough to handle ruminant livestock cost $500,000 to $1.2 million. Once the prototype is tested and the final design improvements are added, it is estimated that large mobile systems will cost approximately $2 million each. Operating costs of tissue digestion systems are determined primarily by the cost of bulk alkali solution; according to manufacturers, fixed-base units using institutional steam have been estimated to operate at $0.04-$0.07/lb on-off costs. Mobile unit operating costs are higher because of the fuel costs for the generators, slave trucks, and hydrolyzate transport.

Conclusions

Burial and landfills often are a convenient, inexpensive, and expedient means of carcass disposal. Only municipal solid waste landfills or similarly designed private facilities are appropriate for routine or catastrophic disposal of animal carcasses. There are, however, a variety of issues to consider for burial and landfill to be an option for animal carcass disposal, including

- whether or not the disposal is routine or catastrophic
- whether the carcasses are infectious or non-infectious
- the nature of the infectious agent
- short-term versus long-term environmental considerations
- geographic limitations
- regulatory and community considerations.

In many situations, rendering is the best available disposal technology for ruminant mortalities. The rendering industry has infrastructure and process controls in place to accomplish volume reduction and heat treatment while adhering to feed safety and environmental regulations. In most locations where livestock are concentrated, rendering plants are available for collection, transportation, and processing of ruminant mortalities. Costs of rendering are reasonable when compared with other properly conducted safe methods.

The effectiveness of incineration as a tool for ruminant carcass disposal varies depending on the technique used. Open-air burning can be relatively inexpensive, although it is weather dependant, has the potential for environmental contamination, and may cause public concern. Fixed-facility incineration is highly biosecure, but this method has a high operational cost and limited capacity, and it requires transporting carcasses to the facility. In addition, securing local licensure and equipment for this type of incineration is difficult, and large volumes of carcasses cannot be burned. Air-curtain incineration is mobile, relatively environmentally acceptable, and suitable for combination with combustible debris removal such as dry, downed trees from weather-related damage. Air-curtain incinerators are fuel-intensive and require experienced personnel operators. Gasification is an emerging incineration technology that offers significant promise for diseased carcass disposal applications, but currently is limited in availability and high in cost.

Alkaline hydrolysis at elevated temperature is a method that will reliably destroy all known pathogens—including prions. The end product of alkaline hydrolysis is a nutrient solution of amino acids, small peptides, sugars, soaps, and electrolytes. This end product can be used as feedstock to anaerobic fermentation methane generation processes, used as a fertilizer in liquid or dried form, or absorbed onto cellulosic materials or peat. Whereas the largest tissue digesters currently in use can process two or three 10,000-pound loads/day, larger mobile units capable of processing 25,000 to 30,000 pounds/hour have been designed. These units add pulverizing and steam disinfection as initial steps in the process and produce a partly digested hot slurry that would be delivered to tank trucks, rail tank cars, or fertilizer trenches in which the hydrolysis process continues to equilibrium.

Transmissible spongiform encephalopathy diseases are not deactivated by the procedures that destroy most disease agents, so it is important to assess the potential for TSE infection when selecting the best option for ruminant carcass disposal. Fixed facility incineration and alkaline hydrolysis effectively eliminate prion infectivity; their use, however, may be limited by scale and practicality. Rendering can reduce, but not eliminate, infectivity and may be a useful pre-treatment option (e.g., in conjunction with landfill or burial). Composting has not been effective in reducing TSE infectivity and should not be used with such material. Uncertainties remain about the behavior of TSE infectivity in landfills. The evidence suggests that infectivity would decay slowly over time and that the prion agent is likely to remain strongly bound to the solid matter in a landfill. Risk assessment studies have concluded that the risk of exposure to people or animals from the disposal of TSE material in a contained landfill would be very low.

When deciding which disposal method is best in a given situation, considerations must include the cause of the mortality (disease or natural disaster), the effect on (preferably destruction of) an infectious agent, ease of use, efficiency, cost, and environmental effects. For the most part, any of the methods described in this paper could be used for routine disposal without adverse effect. The more difficult decision is determining the appropriate method to use during a catastrophic event. Under current conditions, none of the available technologies provide an optimum solution or capacity. Therefore, during a catastrophic disposal event, it is necessary to consider using multiple disposal technologies, making exceptions to standard disease control and/or environmental policies, and considering provisions for management and reimbursement of exceptional costs. Depending on the nature of the event, it is possible that the optimal solution will be to dispose of the carcasses in place on the farm by burial or open decomposition.

For producers to make the best decisions for carcass disposal, additional research is necessary about (1) how best to overcome the difficulties in scaling up the various technologies to accommodate carcass disposal after a catastrophic disease event, and (2) new heat or chemical technologies that can accommodate the large amounts of tissue generated in a mass casualty event in a safe, efficient, and cost-effective manner. It also would be beneficial to develop a preprocessing technology that would destroy or contain the disease of primary concern, allowing more time to select and implement a suitable final disposal method.

Appendix 1: Special Considerations for Material Potentially Infected with TSEs

Introduction to TSEs

Transmissible spongiform encephalopathies (TSEs) are a group of rare neurodegenerative diseases, sometimes called prion diseases, that can affect both animals and humans. The discovery of prion-related cattle diseases in England between 1986 and 2002 changed the disposal industry's perception of the risk involved in disposing of even a small number of ruminant carcasses (Karesh and Cook 2005). The occurrence of bovine spongiform encephalopathy (BSE) in England changed policies in the United States as well, even though there have been only two cases of BSE identified in the United States (OIE 2008) and a relatively small number of TSEs identified in other susceptible species.

The main characteristics of TSE diseases are

- Progressive debilitating neurological illness that is always fatal
- Spongiform change in grey matter areas of the brain
- Long incubation period of months to several years
- No detectable specific immune response in the host.

These diseases are experimentally transmissible and some (e.g., familial *Creutzfeldt-Jakob Disease [CJD], Gerstmann-Sträussler-Scheinker syndrome (GSS)*, and *fatal familial insomnia*) are genetically inherited.

Types of TSEs

There are several forms of TSEs in different animal species and humans. *Scrapie* is a TSE disease of sheep and goats that has been recognized for more than 200 years and is endemic in North America and many parts of Europe. Despite this occurrence, there has never been any proven association between scrapie in sheep and any human disease. In cattle, BSE first appeared in the U.K. in 1986. There have been approximately 184,000 cases of BSE in the U.K., plus an additional 5,200 cases in 21 other countries. In 1996, the identification of a new form of Creutzfeldt-Jakob Disease (vCJD) in young people in the U.K. raised the concern that the causative agent for BSE had transmitted from cattle to humans. There is strong evidence that this is the case, and it is now generally accepted that vCJD in humans is caused by exposure to material from BSE-infected cattle, although many questions remain about the exact nature of the route of transmission. There are other forms of TSEs in humans; sporadic CJD is the most common. Other TSEs in animals include CWD, present in wild and farmed deer and elk populations in some areas of North America, and transmissible mink encephalopathy that appeared in farmed mink populations.

TSEs and Prions

The commonly accepted infectious agent for TSEs (generally designated as PrP^{Sc} or PrP^{TSE} [3]) is a misfolded isoform of a normal cellular protein (PrP^{c}) and is called a prion (Prusiner 1998). The term prion was derived from **pro**teinaceous and **in**fectious and is defined by Prusiner (1998) as a proteinaceous infectious particle that lacks nucleic acid. The normal isoform is soluble and primarily *monomeric* in solution, whereas the infectious form creates insoluble aggregates.

Prions are not deactivated by the normal procedures that would destroy most disease agents. They are resistant to inactivation by heat, chemical disinfection, radiation, and proteolytic enzymes (Taylor 2000). Disposal of prion-infected carcasses requires high heat, is costly, and is not practical.

Potential for Human Infection

When assessing the significance of TSE infection in making decisions about carcass disposal, it is important to take account of the potential impact of exposure to infectivity. For example, scrapie has been present in sheep flocks in many countries for decades, yet there has never been any link to any human disease. With BSE, it is known that the U.K. public was exposed to substantial amounts of infective material (Comer and Huntly 2004) because many infected animals would have been slaughtered for food in the early stages of the epidemic, before control measures, such as the Specified Risk Material controls, were put in place. Despite this, there have been only 167 cases of vCJD in the U.K. as of November 2008; it now seems that the epidemic reached a peak in 2000, and there has been a subsequent decline in the numbers of vCJD cases (NCJDSU 2008). Current estimates of the vCJD epidemic have decreased significantly from the high numbers thought possible several years ago to an upper limit of 550 in a more recent report (Clarke and Ghani 2005). In fact, Clarke and Ghani (2005) estimate 70 future deaths and state that "even in the worst case scenario, when non-MM homozygous individuals are equally susceptible but have longer mean incubation period than MM homozygous individuals, the best estimate of the potential scale of the epidemic is unlikely to exceed 400 future cases." Considering the estimate of the U.K. public exposure from Comer and Huntly (2004) and Clarke and Ghani's (2005) estimate of total cases, the cattle-to-human species barrier must be substantial, and the BSE infectious agent may not be as infectious to people as was once feared (EFSA 2005). (For a review of current knowledge of the persistence and stability of prions in the environment, see Wiggins 2008.)

Considerations for Specific Disposal Options

Burial and Landfill

Concerns about worker and public safety, associated with the fate and transport of prions disposed in landfills, have prompted the U.S. disposal industry to reassess the long-term risks of this type of disposal. Analytical methods presently do not exist to quantify the destruction and retention of prions in the landfill mass. The majority of landfill operators will not accept even rendered carcasses that are known to be infected with prions. Discussants and presenters at the National Carcass Disposal Symposium in December 2006 generally agreed that disposal of carcasses potentially infected with TSEs may not be a conservative option (Hater, Hoffman, and Pierce 2006; Lin 2006).

There are no data on what might happen to the infective agent in a landfill, although some studies are now in progress. The original limited data on the behavior of a TSE agent when buried in the ground is from a single experiment reported by Brown and Gajdusek (1991); this research has been used to support the assumption that TSE infectivity will degrade in the ground. Comer and colleagues (1998) indicated that 98% of TSE infectivity will degrade in the ground over 3 years (or longer). The results also showed only limited leaching, with most of the residual infectivity remaining in the originally contaminated soil. Johnson and colleagues (2006) have studied the interaction of PrP^{TSE} with common soil minerals and soils. They showed that PrP^{TSE} can bind strongly to soils and could be difficult to desorb, and they found that the PrP^{TSE} bound to the soil particles remained infectious. Leita and colleagues (2006) also showed that PrP^{TSE} was absorbed in all three soil types tested. More recently, Seidel and colleagues (2007) have shown that the scrapie agent can transmit disease by the oral route after persistence in soil for up to 29 months. The change in infectivity over time was not measured, but Western blot analysis clearly showed a marked decrease in the strength of the target protein after one month and further decrease over time up to 29 months.

The Institute for Animal Health in Edinburgh currently is conducting a study of the behavior of infectivity in carcasses buried in the ground. An initial report was given at Prion 2006 (Fernie et al. 2006), which stated that TSE infectivity may bind strongly to soil components and has very limited mobility in soils with controlled rates of water percolation.

These results and the biophysical properties of the prion protein suggest that any infectivity released from decaying animal material is likely to remain bound to solid matter in the landfill and, thus, is unlikely to be present in the leachate. With current knowledge, however, it is not possible to be certain that TSE infectivity could not be present at some level in leachate.

A number of risk assessment studies have considered the risks from TSE material deposited in landfill sites or by burial. Not all these studies are in the public domain, but they have shown that the potential risk to people or other livestock through contamination of drinking water is extremely small (DNV 1997a, 2001b).

Isolation using macro-encapsulation in the landfill is an option for TSE-related deaths. Macroencapsulation, however, is an unusual practice in subtitle D landfills and does add significant costs to landfill disposal. Current research may determine whether the additional costs are justified.

Rendering

Research has demonstrated that rendering lowers the infectivity of prions, but no currently available rendering processes totally inactivate the prions (Taylor, Woodgate, and Atkinson 1995). Cohen and colleagues (2001) reported that batch rendering systems achieved a 1,000-fold reduction in BSE infectivity, whereas continuous systems with and without fat recycling reduced infectivity 100-fold and 10-fold, respectively. Because rendering does not totally inactivate prion infectivity, any product from the disposal of TSE-diseased carcasses should not be used in animal feeds.

There may be other practical difficulties with rendering as an option for prion-contaminated materials. As was found during the 2001 FMD outbreak in the U.K.—when rendering was regarded as the preferred option—rendering facilities may already have existing functions and requirements, limiting their capacity. In addition, rendering plants may rely on the sale of meat and bone meal and tallow as part of their production cycle; use of those end products would almost certainly cease to be an option if there was risk of TSE-agent contamination in them.

Composting

Presently, no work has been done to demonstrate TSE-agent inactivation by composting. There has been some laboratory work related to prion destruction by specific enzymes, but no field research has been done involving the addition of such enzymes to composting operations.

Certain challenges exist in using composting for prion disposal, including (1) the need for some form of enclosed vessel to avoid environmental contamination and to prevent scavenger access, (2) the need for complete mixing, (3) potential difficulties in accessing neural tissue encased within bone (skull and spinal cord), and (4) ensuring the correct conditions are maintained (e.g., temperature and levels of microbial degradation).

Incineration

Incineration is one of the most effective techniques for removal of infectivity from prion-contaminated material. Disadvantages, however, include the large energy requirement, environmental concerns, location of incinerators, and the need to ensure a consistent and complete burn. Incinerators vary from small animal incinerators, used to dispose of small amounts of material, to large commercial operations, or even to power station furnaces used to dispose of the products of rendering. Analysis of the ash for protein content after incineration of BSE-infected carcasses suggests that prion infectivity is reduced by at least 1 million-fold (DNV 1997b, 2001a). Some facilities in the U.K. currently use fixed gasification units for processing carcasses that potentially contain prions. Research continues in the United States on similar portable gasification equipment that should offer a daily capacity of more than 25 tons per unit.

Alkaline Hydrolysis

The alkaline hydrolysis process has been through a validation study by the Institute of Animal Health, and an Opinion has been issued by the Scientific Steering Committee of the European Commission (EC 2002) on the effectiveness of the process. There was detectable infectivity from samples held for 3 hours, but not from samples held for 6 hours. The committee concluded that the by-products after 3 hours of processing could contain some residual TSE infectivity and that this risk may decrease with increased duration of processing.

Glossary

Alkaline hydrolysis. Natural process by which complex molecules are broken down into the constituent small molecules from which they were synthesized.

Anthrax. An infectious, usually fatal disease of mammals, especially cattle and sheep, caused by the bacterium *Bacillus anthracis.*

Auto fluff. A complex mixture of nonferrous materials including plastics, foam, textiles, rubber, and glass.

Biosecure. Security from transmission of infectious diseases, parasites, and pests.

Bovine spongiform encephalopathy (BSE). An infectious degenerative brain disease occurring in cattle. Also called mad cow disease.

Chronic wasting disease (CWD). A wildlife disease (similar to bovine spongiform encephalitis) that affects deer and elk.

Creutzfeldt-Jakob Disease (CJD). A rare degenerative disease of the central nervous system of humans characterized by sudden development of rapidly progressive neurological and neuromuscular symptoms; a variant form (vCJD) is thought to be associated with BSE or mad cow disease.

Downer cattle. Cattle that cannot walk or stand on their own; often as a result of illness or disease.

Fatal familial insomnia. A fatal degenerative disease of the central nervous system of humans featuring severe and intractable insomnia.

Fly ash. Fine particulate ash sent up by the combustion of a solid fuel, such as coal, and discharged as an airborne emission or recovered as a by-product for various commercial uses.

Foot-and-mouth disease (FMD). A contagious viral disease of cattle, sheep, swine, etc., characterized by the formation of vesicles and ulcers in the mouth and about the hoofs.

Gerstmann-Sträussler-Scheinker syndrome (GSS). A fatal degenerative disease of the central nervous system of humans; begins at an earlier age than sporadic Creutzfeldt-Jakob Disease and has a prominent cerebellar (in coordination) component and evolves over a longer period of time (years rather than months).

Hydrolyzate. A product of hydrolysis.

Leachate. A liquid or solution, including any suspended components that has percolated through or drained from soil or waste.

Macro-encapsulation. The process of entirely enclosing a given specimen in order to eliminate potential waste leakage and processing problems.

Mobile comminution-disinfection-digestion systems. Alkaline hydrolysis systems that are portable and that combine the processes of comminution, disinfection, and digestion.

Monomer. Consisting of a single component. In genetics, pertaining to a disease or trait controlled by genes at a single locus.

Necropsy. An examination and dissection of animal tissue to determine cause of death or the changes produced by disease.

Offal. Waste parts, especially of a butchered animal.

Prion. An abnormal version of a protein normally found on cell surfaces, the prion is believed to be the infectious agent that causes transmissible spongiform encephalopathies such as CJD and mad cow disease. For reasons still unknown, this protein becomes altered and destroys nervous system tissue.

Proteolytic enzymes. Any enzyme that catalyzes the splitting of proteins into smaller peptide fractions and amino acids.

Radionuclides. A nuclide that exhibits radioactivity.

Redox potential. The reducing/oxidizing power of a system measured by the potential at a hydrogen electrode.

Rendering. To reduce, convert, or melt down fat by heating.

Scrapie. A usually fatal disease of sheep and goats, marked by chronic itching, loss of muscular coordination, and progressive degeneration of the central nervous system.

Slip planes. Areas of earth and rockfill dams, excavations, and natural slopes in soil and soft rock susceptible to compromised slope stability.

Slurry. A thin mixture of a liquid, especially water, and any of several finely divided substances.

Specified risk materials. General term designated for tissues of ruminant animals that transmit BSE and other TSE prions.

Tallow. Hard fat obtained from parts of the bodies of cattle, sheep, or horses.

Transmissible spongiform encephalopathies (TSE). A group of progressive conditions that affect the brain and nervous system of humans and animals and are transmitted by prions.

Western blot. A technique for identifying specific antibodies or proteins in which proteins are separated by electrophoresis, transferred to nitrocellulose, and reacted with antibody.

Literature Cited

Alder, V. and R. Simpson. 1992. Sterilization and disinfection by heat methods. Pp. 483–498. In A. Russel, W. Hugo, and G. Ayliffe (eds.). *Principles and Practice of Disinfection, Preservation, and Sterilization*. 2nd ed. Blackwell Scientific, Oxford, U.K.

Bagley, C. V., J. H. Kirk, and K. Farrell-Poe. 1999. *Cow Mortality Disposal*. AG-507. Utah State University Extension electronic publishing, http://extension.usu.edu/files/publications/publication/AG-507.pdf (15 August 2008)

Brown, P. and D. C. Gajdusek. 1991. Survival of scrapie virus after 3 years' interment. *Lancet* 337:269–270.

Champion, H. J., J. Gloster, D. B. Ryall,

I. S. Mason, R. J. Brown, A. I. Donaldson, and A. J. M. Garland. 2002. Investigation of the possible spread of foot-and-mouth disease virus by the burning of animal carcasses on open pyres. *Vet Rec* 151:593–600.

Clarke, P. and A. C. Ghani. 2005. Projections of the future course of the primary vCJD epidemic in the UK: Inclusion of subclinical infection and the possibility of wider genetic susceptibility. *J R Soc Interface* 2(2):19–31.

Cohen, J. T., K. Duggar, G. M. Gray, S. Kreindel, H. Abdelrahman, T. HabteMariam, D. Oryang and B. Tameru. 2001. *Evaluation of the Potential for Bovine Spongiform Encephalopathy in the United States*. Report from the Harvard Center for Risk Analysis, Harvard School of Public Health and Center for Computational Epidemiology, College of Veterinary Medicine, Tuskegee University, http://www.aphis.usda.gov/newsroom/hot_issues/bse/background/documents/mainreporttext.pdf (10 December 2008)

Comer, P. J. and P. J. Huntly. 2004. Exposure of the human population to BSE infectivity over the course of the BSE epidemic in Great Britain and the impact of changes to the Over Thirty Month Rule. *J Risk Res* 7(5):523–543.

Comer, P. J., J. R. Spouge, and S. Stearn. 1998. Risk assessment of BSE infectivity in the environment from rendering of over thirty month scheme cattle. *J Risk Res* 1(4):281–293.

Council for Agricultural Science and Technology (CAST). 2008a. S*wine Carcass Disposal Options for Routine and Catastrophic Mortality*. Issue Paper 39. CAST, Ames, Iowa.

Council for Agricultural Science and Technology (CAST). 2008b. *Poultry Carcass Disposal Options for Routine and Catastrophic Mortality*. Issue Paper 40. CAST, Ames, Iowa.

de Klerk, P. F. 2002. Carcass disposal: Lessons from the Netherlands after the foot and mouth disease outbreak of 2001. *Rev Sci Tech Off Int Epiz* 21(3):789–796.

DeRouchey, J. M., J. P. Harner, and J. P. Murphy. 2005. Catastrophic mortality composting: Is it safe and effective? *J App Poultry Res* 14(2):414–416.

Det Norske Veritas (DNV). 1997a. Assessment of risk from BSE carcasses in landfills. *Report to Environment Agency C7243*. A compendium of five reports. Environmental Agency, United Kingdom.

Det Norske Veritas (DNV). 1997b. Risks from disposing of BSE infected cattle in animal carcass incineration. *Report to Environment Agency C7243*. A compendium of five reports. Environment Agency, United Kingdom.

Det Norske Veritas (DNV). 2001a. Risk assessment of SRM incinerators. *DNV Consulting Report No. 100089 for U.K. Ministry of Agriculture Fisheries and Food*, March.

Det Norske Veritas (DNV). 2001b. Assessment of risk due to BSE infectivity from disposal of cattle due to FMD. *DNV Consulting Report No. 716018 for U.K .Ministry of Agriculture Fisheries and Food*, April.

European Commission (EC). 2002. Scientific Steering Committee Opinion and Report on: The treatment of animal waste by means of high temperature and corresponding high pressure Alkaline Hydrolysis. Opinion adopted May 16, 2002, http://ec.europa.eu/food/fs/sc/ssc/out266_en.pdf (10 December 2008)

European Commission (EC). 2005. Commission Regulation No. 92/2005 of 19 January 2005 implementing Regulation (EC) No 1774/2002 of the European Parliament and of the Council as regards means of disposal or uses of animal by-products and amending its Annex VI as regards biogas transformation and processing of rendered fats, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:019:0027:0033:EN:PDF (10 December 2008)

European Food Safety Authority (EFSA). 2005. Opinion of the Scientific Panel on Biological Hazards of the European Food Safety Authority on the Assessment of the Human and Animal BSE Risk Posed by Tallow with Respect to Residual BSE risk. Adopted April 27-28, 2005. *EFSA J* 221:1–47.

Fayer, R. 1994. Effect of high temperature on infectivity of *Cryptosporidium parvum* oocysts in water. *Appl Environ Microbiol* 60:2732–2735.

Fernie, K., A. Smith, C. Cooke, G. Shaw, J. Rodger, and R. A. Somerville. 2006. Assessment of Hazards from Environmental Persistence of TSE Infectivity. *Proceedings of Prion 2006*, Torino, Italy, October 4–6, 2006.

Flory, G. 2006. Landfilling of poultry carcasses: Lessons learned from the Virginia avian influenza outbreak of 2002. *National Carcass Disposal Symposium*, Beltsville, Maryland, December 4–7, 2006.

Glanville, T. D., T. L. Richard, J. D. Harmon, D. L. Reynolds, H. K. Ahn, and S. Akinc. 2006. Final project report: Environmental impacts and biosecurity of composting for emergency disposal of livestock mortalities. Iowa State University, Ames, http://www3.abe.iastate.edu/cattlecomposting/ (30 Jan 2008)

Hamilton, C. R. 2004. Real and perceived issues involving animal proteins. Pp. 255–276. In *FAO Animal Production and Health Proceedings "Protein Sources for the Animal Feed Industry."* Expert Consultation and Workshop. Bangkok, April 29–May 3, 2002. Food and Agriculture Organization of the United Nations, Rome.

Hater, G., B. Hoffman, and C. Pierce. 2006. Analysis for the disposal of carcasses in sanitary landfills. *National Carcass Disposal Symposium*. Beltsville, Maryland, December 4–7, 2006.

Informa Economics. 2004. *An Economic and Environmental Assessment of Eliminating Specified Risk Materials and Cattle Mortalities from Existing Markets*. National Renderers Association, Alexandria, Virginia.

Jarrol, E., J. Hoff, and E. Meyer. 1984. Resistance of cysts to disinfection agents. Pp. 311–328. In S. Erlandsen and E. Meyer (eds.). *Giardia and Giardiasis: Biology, Pathogenesis, and Epidemiology*. Plenum Press, New York. 407 pp.

Johnson, C. J., K. E. Phillips, P. T. Schramm, D. McKenzie, J. M. Aiken, and J. A. Pedersen. 2006. Prions adhere to soil minerals and remain infectious. *Plos Pathogens* 2(4):e32.

Kalbasi, A., S. Mukhtar, S. E. Hawkins, and B. W. Auvermann. 2005. Carcass composting for management of farm mortalities: A review. *Compost Sci Utilization* 13(3):180–193.

Karesh, W. and R. Cook. 2005. The human-animal link. *Foreign Affairs* 84(4):37–50.

Kastner, J. and R. Phebus. 2004. Incineration. Chapter 2. In *Carcass Disposal: A Comprehensive Review*. Report prepared by the National Agricultural Biosecurity Center Consortium, Carcass Disposal Working Group, National Agriculture Biosecurity Center, Kansas State University, Manhattan, http://krex.k-state.edu/dspace/handle/2097/662 (2 June 2008)

Kaye, G. I. and P. B. Weber. 1994. Disposal of radioactive animal carcasses by alkaline hydrolysis. *Proceedings of the 15th Annual U.S. DOE Low-Level Waste Management Conference*.

Kaye, G. I., B. M. Methe, and P. B. Weber. 1993. Low-level radioactive waste management in an academic medical center. Pp. 229–244. In G. G. Eicholz and J. J. Shonka (eds.). *Hospital Health Physics, Proceedings of the 1993 Health Physics Society Summer School*. Research Enterprises, Richland, Washington.

Kaye, G. I., P. B. Weber, E. Evans, and R. A. Venezia. 1998. Evaluation of the efficacy of alkaline hydrolysis as an alternative treatment technology for disposal of infectious animal waste. Contemporary Topics in Lab. *Anim Sci* 37:43–46.

Leita, L., F. Fornasier, M. De Nobili, A. Bertoli, S. Genovesi, S., and P. Sequi. 2006. Interactions with prion proteins with soil. *Soil Biol Biochem* 38(7):1638–1644.

Lin, H. S. 2006. Chronic wasting disease carcass disposal plan in Pennsylvania. *National Carcass Disposal Symposium*. Beltsville, Maryland, December 4–7, 2006.

Meeker, D. L. (ed.). 2006. *Essential Rendering—All about the Animal By-products Industry.* National Renderers Association, Alexandria, Virginia. 302 pp.

Mukhtar, S., A. Kalbasi, and A. Ahmed. 2004. Composting. Chapter 3. In *Carcass Disposal: A Comprehensive Review*. Report prepared by the National Agricultural Biosecurity Center Consortium, Carcass Disposal Working Group. National Agriculture Biosecurity Center, Kansas State University, Manhattan, http://hdl.handle.net/2097/662 (10 December 2008)

National Audit Office (NAO). 2002. *The 2001 Outbreak of Foot and Mouth Disease*. Report by the Comptroller and Auditor General, HC 939, Session 2001–2002. The Stationery Office, London.

National Creutzfeldt-Jakob Disease Surveillance Unit (NCJDSU). 2008. *Creutzfeldt-Jakob Disease Surveillance in the UK*. Sixteenth Annual Report 2007, http://www.cjd.ed.ac.uk/report16.pdf (11 December 2008)

National Solid Wastes Management Association (NSWMA). 2006. *MSW (Subtitle D) Landfills*, http://wastec.isproductions.net/webmodules/webarticles/anmviewer.asp?a=1127 (5 December 2008)

Nutsch, A. and M. Spire. 2004. Burial. Chapter 1. In *Carcass Disposal: A Compressive Review*. Report prepared by the National Agricultural Biosecurity Center Consortium, Carcass Disposal Working Group. National Agriculture Biosecurity Center, Kansas State University, Manhattan, http://hdl.handle.net/2097/662 (2 June 2008)

Perkins, J. J. 1969. Thermal destruction of microorganisms: Heat inactivation of viruses. Pp. 63–94. In J. J. Perkins (ed.). *Principles and Methods of Sterilization in Health Science*. 2nd ed. Charles C. Thomas, Springfield, Illinois.

Prusiner, S. B. 1998. Prions. *Proc Natl Acad Sci* 95(23):13363–13383.

Seidel, B., A. Thomzig, A. Buschmann, M. H. Groschup, R. Peters, M. Beekes, and K. Terytze. 2007. Scrapie agent (Strain 263K) can transmit disease via the oral route after persistence in soil over years. *PLoS ONE* 2(5):1–8.

Sparks Companies, Inc. 2002. *Livestock Mortalities: Methods of Disposal and Their Potential Costs*. National Renderers Association, Alexandria, Virginia.

Taylor, D. M. 2000. Inactivation of transmissible degenerative encephalopathy agents: A review. *Vet J* 159(1):10–17.

Taylor, D. M., S. L. Woodgate, and M. J. Atkinson. 1995. Inactivation of the bovine spongiform encephalopathy agent by rendering procedures. *Vet Rec* 137:605–610.

Texas Animal Health Commission Report (TAHC). 2005. Appendix 3.6.5. *General Guidelines for the Disposal of Carcasses*.

Troutt, H. F., D. Schaeffer, I. Kakoma, and G. Pearl. 2001. Prevalence of selected foodborne pathogens in final rendered products. *FPRF Directors Digest* #312. Fats and Proteins Research Foundation, Alexandria, Virginia.

U.K. Department of Health (UKDH). 2001. A rapid qualitative assessment of possible risks to public health from current foot and mouth disposal options—Main Report. Department of Health, London.

U.S. Department of Agriculture-National Agricultural Statistics Service (USDA–NASS). 2004. 2002 Census of Agriculture, United States Summary and State Data.

U.S. Food and Drug Administration-Health and Human Services (USFDA–HHS). 2008. 21 CFR Part 589. Substances prohibited from use in animal food or feed: Final Rule. *Fed Reg* 73(81):22720–22758.

Virginia Department of Agriculture and Consumer Services, Division of Animal Industry Services—Office of the State Veterinarian (VDACS). 2002. *Requirements for Transport of Infected Materials to Landfills*. Richmond, Virginia, April 4.

Virginia Department of Environmental Quality (VDEQ). 2002. *Requirements for Burial of Infected Bird Carcasses in Sanitary Landfills*. Richmond, Virginia, April 5.

Wiggins, R. C. 2008. Prion stability and infectivity in the environment. *Neurochem Res* DOI 10.1007/s11064-008-9741-6.

Wilkinson, K. G. 2007. The biosecurity of on-farm mortality composting. *J Appl Microbiol* 102(3):609–618.

World Health Organization (WHO). 2006. *WHO Guidelines on Tissue*

Infectivity Distribution in Transmissible Spongiform Encephalopathies. World Health Organization, Geneva Switzerland, http://www.who.int/bloodproducts/cs/TSEPUBLISHEDREPORT.pdf (11 December 2008)

World Organization for Animal Health (OIE). 2008. Number of reported cases of bovine spongiform encephalopathy (BSE) in farmed cattle worldwide (excluding the United Kingdom), http://www.oie.int/eng/info/en_esbmonde.htm (4 December 2008)

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