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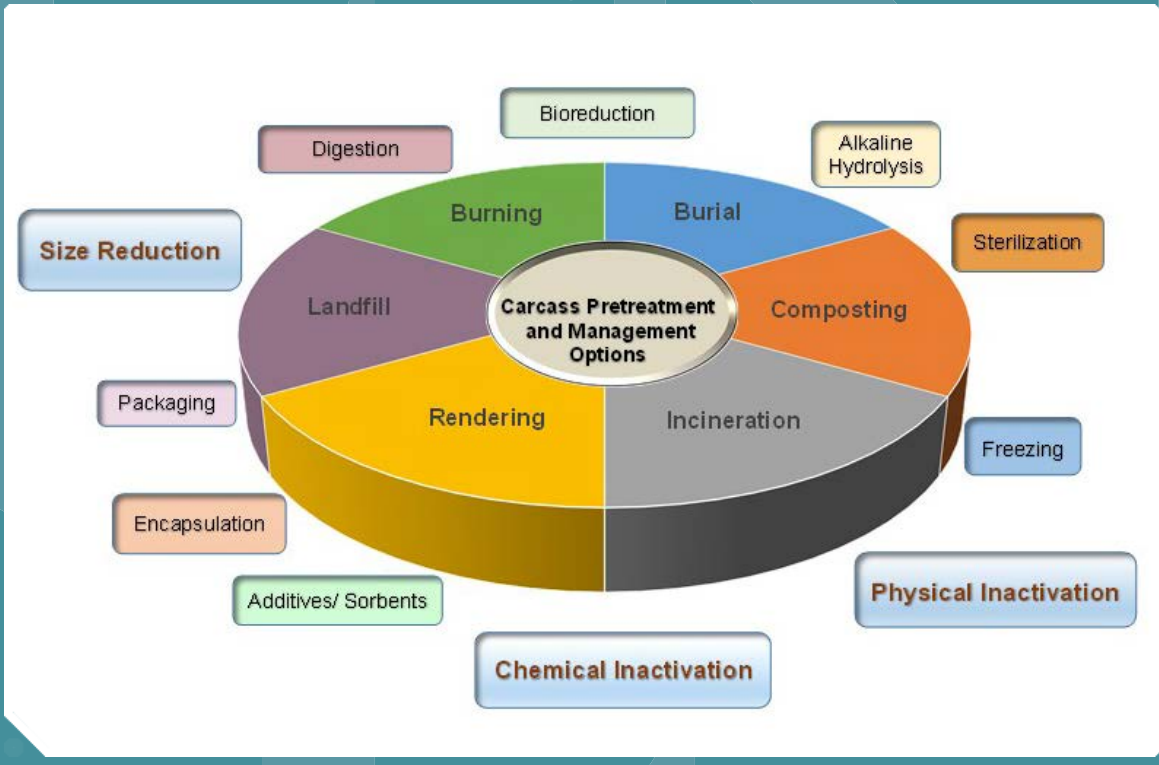
Agency

Feasibility of Selected Infectious Carcass Pretreatment Technologies



Office of Research and Development
National Homeland Security Research Center

Feasibility of Selected Infectious Carcass Pretreatment Technologies

U.S. Environmental Protection Agency
Office of Research and Development
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DISCLAIMER

The United States Environmental Protection Agency through its Office of Research and Development managed the research described here under Interagency Agreement No. RW-70-95849301 with the Department of Homeland Security. The report was developed by Tetra Tech under contract EPC11037 Task Order 10. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency. Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

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Acronyms and Abbreviations

˚C	degree(s) Celsius
A	avian
ABP	Animal By-Product
APHIS	Animal and Plant Health Inspection Service
ATCC	American Type Culture Collection
AU	Animal Unit
AVMA	American Veterinary Medical Association
B	bovine
BAT	best available technique
BLV	Bovine leukemia virus
BOD	biological oxygen demand
BRSV	Bovine respiratory syncytial virus
BSE	bovine spongiform encephalopathy
Bt	bat
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfm	cubic feet per minute
CFR	Code of Federal Regulations
CH_3CO_3H	Peracetic Acid
ClO_2	Chlorine dioxide
CO_2	Carbon dioxide
COD	chemical oxygen demand
Cp	Caprine
Cv	cervine
CWD	chronic wasting disease
DHS	Department of Homeland Security
DS	double stranded
dSV	discounted salvage value
EB	*Enterobacteriaceae*
EC	European Commission
EEE	Eastern equine encephalitis
EFSA	European Food Safety Authority
EIA	Equine infectious anemia virus
ELISA	enzyme-linked immunosorbent assay
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EPS	extracellular polysaccharide
Eq	Equine
EU	European Union
EUSE	exotic ungulate spongiform encephalopathy
f_C	Crushing strength
FAD	Foreign Animal Disease
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FeLV	Feline leukemia virus
FIV	Feline immunodeficiency virus
FMD	foot-and-mouth disease
FOB	Freight on Board
Fr	Ferret

FSE	Feline spongiform encephalopathy
GAO	Government Accountability Office
GC/MS	gas chromatography/mass spectrometry
h	hour(s)
h_a	annual hours of use
HEPA	high-efficiency particulate arrestance
HIV	Human immunodeficiency viruses
HPAI	highly pathogenic avian influenza
hp	horsepower
HPLC	high performance liquid chromatography
HSPDs	Homeland Security Presidential Directives
i	interest rate
IHN	Infectious hematopoietic necrosis
IPN	infectious pancreatic necrosis
IPPC	Integrated Pollution Prevention and Control
K_K	Kick's constant
K_R	Rettinger's constant
kOU	kilo odor unit
kg	kilogram(s)
kW	kilowatt(s)
lb	pound(s)
L	Lagomorph
L	liter(s)
L_1	initial dimensions of particle
L_2	final dimensions of particle
LAL	Limulus amebocyte lysate
LPS	lipopolysaccharide
m^3	cubic meter(s)
MeV	megaelectron volt
mtDNA	mitochondrial DNA
mVOCs	microbial volatile organic compounds
n	years of life
NA	not applicable
NABC	National Agricultural Biosecurity Council
NaBr	Sodium Bromide
NaOCl	Sodium hypochlorite
NaOH	Sodium hydroxide
NASS	National Agricultural Statistics Service
NCRWQCB	North Coast Regional Water Quality Control Board
NHSRC	EPA National Homeland Security Research Center
NIOSH	National Institute for Occupational Safety and Health
NH_3	Ammonia
NHP	non-human primates
NOx	oxides of nitrogen
NPDES	National Pollutant Discharge Elimination System
NPT	National Pipe Thread
O	Ovine
O_2	oxygen
O_3	ozone
OSHA	Occupational Safety and Health Administration
OU	odor unit
OU/s	odor unit per second

ORD	Office of Research and Development
PCR	polymerase chain reaction
P	Porcine
Pb	Lead
PLC	programmable logic controller
POTW	Publicly Owned Treatment Works
PP	Purchase Price
PPE	personal protective equipment
PrP	prion protein
QA	Quality Assurance
QAC	Quaternary Ammonium Compound
QAPP	Quality Assurance Project Plan
R	size reduction ratio
R	Rodent
RCRA	Resource Conservation and Recovery Act
READEO	Regional Emergency Animal Disease Eradication Organization
RIA	radioimmunoassay
RPM	revolution(s) per minute
Sc	scrapie
SCAQMD	South Coast Air Quality Management District
SDS	Safety Data Sheet
SRM	specified risk material
SS	single stranded
STAATT	State and Territorial Association on Alternative Treatment Technologies
TDE	transmissible degenerative encephalopathy
TCLP	Toxicity Characteristic Leaching Procedure
TGE	Transmissible gastroenteritis
TLC	thin layer chromatography
TME	Transmissible mink encephalopathy
TSE	transmissible spongiform encephalopathy
TSS	total suspended solids
TVC	total viable counts
U.S.	United States
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
UV	ultraviolet
VAC	Volts alternating current
VEE	Venezuelan equine encephalitis
W	Rettinger’s energy
Wi	Bond work index
WEE	Western equine encephalitis
WNV	West Nile Virus

Glossary

Disposal: The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid or hazardous waste on or in the land or water. A disposal facility is any site where hazardous waste is intentionally placed and where the waste will remain after a Treatment, Storage or Disposal Facility (TSDF) stops operation.

Pretreatment: Any method, technique, or process designed to physically, chemically, or biologically change the nature of a waste for the purposes of facilitating subsequent additional treatment activities and/or final disposal.

Treatment: Any method, technique, or process designed to physically, chemically, or biologically change the nature of a waste.

Executive Summary

The challenge associated with the management of animal carcasses includes protection of environmental, animal, and public health against potential microbiological threats. An animal carcass is composed of microbiologically active material that may contain viruses, bacteria, protozoa, parasites, prions, toxins, drug residues, and other chemicals. All of the biologically active materials need to be reduced to safe amounts, eliminated, or sequestered to minimize their potential hazard. The management of animal carcasses varies between and within states, and, depending upon how the carcasses are managed, may need to consider both federal and state environmental requirements. Pretreatment of infectious carcasses may be suggested by the carcass management decision makers to improve the operation of the mechanical components of the downstream process equipment and/or to minimize potential biological or physical effects of the carcass management processes. The type of pretreatment will vary according to type of feedstock used, the potential level and type of contamination, feedstock size, the carcass management process to be used, and the desired quality of the end-product. U.S. EPA (2015) identified eleven infectious carcass pretreatment technologies and screened them to describe how each technology can be used prior to, and in conjunction with, the six large-scale carcass management options (Figure E-1).

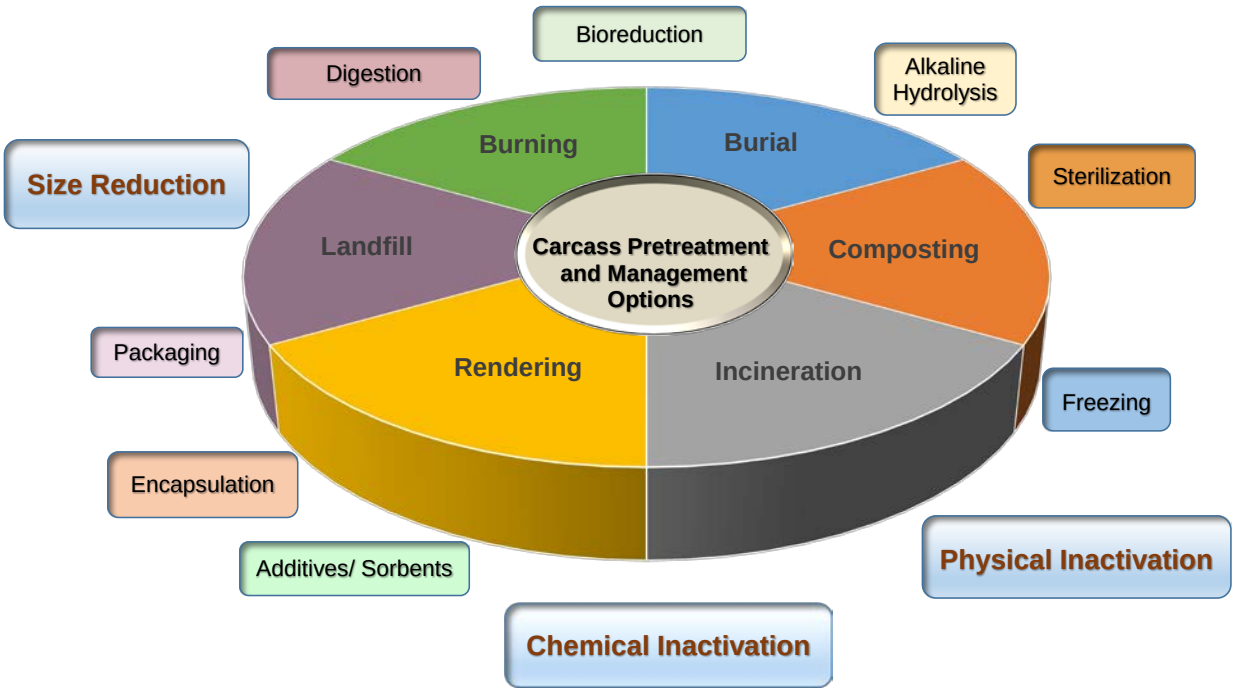

Figure E-1. Key Pretreatments of Infectious Carcasses Prior to Carcass Management Processes.

The six carcass management options considered were: (i) rendering, (ii) burial, (iii) landfill, (iv) composting, (v) incineration, and (vi) burning. These carcass management options require specialized equipment, accessories, and other resources and appropriate geologic, hydrologic,

and climatic conditions. The eleven carcass pretreatment technologies identified and screened were: a) on-site size reduction, b) digestion, c) bioreduction, d) alkaline hydrolysis, e) sterilization, f) freezing, g) physical inactivation, h) chemical inactivation, i) additives/sorbents, j) encapsulation, and k) packaging (U.S. EPA, 2016). The emerging or evolving technologies (such as gasification, plasma technology, irradiation, thermal depolymerization, dehydration, and extrusion) for treatment of carcasses were not included within the eleven pretreatment alternatives as these technologies are in research stage and need additional testing and evaluation. All technologies have strengths and weaknesses. Based on the critical evaluation of eleven infectious carcass pretreatments, three technologies (size reduction, physical inactivation and chemical inactivation) were shortlisted for additional analysis in this report. Animal carcasses considered in this report include whole bodies or body parts of dead animals that may be mixed with manure and bedding or other organic materials that cannot be separated from the animal carcasses. Regulatory issues concerning carcass management vary from state to state, and the treatment and disposal may require special permit(s) approved by one or more state agencies, the United States Department of Agriculture (USDA), and the local health department depending on the state of origin of the material.

Each of these three shortlisted pretreatment technologies was defined and evaluated based on effectiveness, impact on environment, implementability (including ease of use, portability, and throughput capacity), reduction in toxicity, mobility, or volume through treatment, cost, regulatory issues, personnel safety and community acceptance. As identified in Homeland Security Presidential Directives (HSPDs) on Defense of United States Agriculture and Food and Biodefense for the 21st Century, mechanisms for protection of critical infrastructure are fundamental components as part of any comprehensive strategy for biodefense. Focused development and deployment of technologies to foster proactive protection, response and recovery is necessary to protect against any significant infectious disease threat. In the case of high-consequence livestock pathogens, these technologies play a crucial role in the preventative, mitigation and recovery phases of an outbreak. It is crucial to select a pretreatment coupled with an appropriate carcass management technology that encompasses a strategic framework dealing with infectious carcass management to ensure that the maximum environmental, occupational safety, and economic benefits of the technologies can be achieved. The elements of a strategic framework include waste minimization; segregation; developing a safe and effective collection, transport, and storage system; waste management and contingency planning; protecting the health and safety of workers; and proper siting of the treatment technology. The most feasible pretreatment options identified in this study which can be applied singly or in combination prior to the routine and catastrophic management of infectious carcasses includes size reduction and physical and chemical inactivation. If more than one inactivation treatment should be applied to carcasses, the combined microbiological reduction effect might be greater than the effect of one treatment alone. Methods, strategies, and practical applications presented in this report describe acceptable means for treatment of carcasses prior to a given carcass management process. Each treatment has its advantages and disadvantages as costs and benefits. The actual decision on which treatment or combination of treatments are suitable should be based on individual circumstances and the applicable federal, state and local restrictions.

1.0 Introduction

1.1 Purpose and Scope

More than 40 contagious foreign animal diseases are recognized as threats to the U.S. agricultural economy (GAO, 2003). Agriculture is the largest industry and employer in the United States, generating more than $1 trillion in economic activity annually, including more than $50 billion in exports. U.S. agriculture is threatened by the entry of foreign pests and pathogens that could harm the economy, the environment, plant and animal health, and public health (GAO, 2005). A key component of this economy is the livestock industry, which contributes over $100 billion annually to the gross domestic product (GAO, 2005a). Diseases affecting livestock could have significant impacts on the U.S. economy and consumer confidence in the food supply. The introduction of animal and plant diseases at the farm level would cause severe economic disruption, given that agriculture accounts for 13% of the U.S. gross domestic product and 18% of domestic employment (DHS, 2008). Spread of animal diseases has a multicausal origin. Some factors associated with this process include: a) agroterrorism, b) trade and international travel (increased frequency and speed of local and international travel, fostered by the globalization process promotes the spread of microorganisms on a global scale), c) changes in agricultural practices (animal domestication was one of the main promoters of microbial evolution by facilitating the availability of new susceptible hosts at high densities due to the intensification of livestock systems), d) climate change (which causes changes in the eco-geographical distribution of vectors), e) reduction of habitat and increased contact with wild vectors/reservoirs, and f) introduction of wild and domestic animals to new geographic areas where the disease is endemic and immunologically unknown for them (increases zoonotic pool within a geographic region) (Wheelis et al., 2002; Daszack et al., 2007; Brown, 2010; Cartín-Rojas, 2012).

Pretreatment of infectious carcasses may be required to improve the mechanical components of the downstream process equipment and/or to minimize potential biological or physical effects of the final disposal. Pretreatment enhances the process by increasing the process efficiency and ultimately productivity (Genesis, 2007). The type of pretreatment will vary according to the type of feedstock used, the potential level and type of contamination, feedstock size, the carcass management process to be used, and the desired quality of the end-product (such as dry or wet). This report has been prepared based on the information collected under a separate report (U.S. EPA, 2016) that identified eleven infectious carcass pretreatment technologies and screened them to describe how each technology can be used prior to, and in conjunction with, the six large-scale carcass disposal options. The six carcass management options considered were: (i) rendering, (ii) burial, (iii) landfill, (iv) composting, (v) incineration, and (vi) burning. The eleven pretreatment technologies identified for carcasses were: a) on-site size reduction, b) digestion, c) bioreduction, d) alkaline hydrolysis, e) sterilization, f) freezing, g) physical inactivation, h) chemical inactivation, i) additives/sorbents, j) encapsulation, and k) packaging. The emerging or evolving technologies (such as gasification, plasma technology, irradiation, thermal depolymerization, dehydration, and extrusion) for treatment of carcasses were not included within the eleven pretreatment alternatives as these technologies are in research stage and need additional testing and evaluation.

None of these eleven pretreatments, individually or in combination, should be considered absolute. The pretreatment scheme should be approached on a case by case basis. Two or

more pretreatment/ carcass management options can be selected so as not to overburden a processing site. Parallel treatment schemes can be considered by using treatment of part of the feed material by selected technologies while treating remaining parts of the feed material by other method(s). Based on the critical evaluations of the eleven infectious carcass pretreatments (U.S. EPA, 2016), three technologies (size reduction, physical inactivation and chemical inactivation) were shortlisted for additional analysis. These technologies may involve single or multiple steps. For example, size reduction of carcasses may require prebreaking followed by grinding. Effort has been made to focus on the key technologies as some of the sub-processes may be included in the design of a piece of integrated system.

1.2 Analysis of Existing Data and Quality Assurance

An extensive review of the existing literature was an important component of this study. A literature review was conducted to identify and collect the available peer-reviewed journal articles, trade fact sheets, reports, guidance documents, and other pertinent information related to pretreatment for transport of infectious carcasses for management. Various sources of information on carcass management for large-scale animals, where mortality is due to infectious agents, were identified. The peer-reviewed articles were downloaded after libraries were searched across six key databases (Academic OneFile, Academic Search Complete, MasterFILE Complete, Newspaper Source Plus, OAIster, and WorldCat.org) and other web science searches. Technical reports released by various Federal Agencies and international organizations were identified and collected. Additional vendor-supplied data, newsletters, and fact sheets were obtained. Information included in the report was drawn primarily from peer-reviewed publications. Peer-reviewed publications contained the most reliable information, although some portions of the report may contain compilations of data from a variety of sources and non-peer-reviewed literature (workshop proceedings; graduate degree theses/dissertations; non-peer-reviewed reports and white papers from industry, associations, and non-governmental organizations) and unpublished data (online databases, personal communications, unpublished manuscripts, unpublished government data). Non-peer-reviewed and unpublished sources did not form the sole basis of any conclusions presented in the report of results. Generally, these sources were used to support results presented from peer-reviewed work, enhancing understanding based on peer-reviewed sources, identifying promising ideas for innovative pretreatment technologies, and provided discussion of challenges. The qualitative ranking has been performed based on the review of the literature search. Secondary data (Attachment 1) were used as per the U.S. EPA approved Quality Assurance Project Plan and review of published or unpublished data for identifying relevant information and assessment in treatment of infectious carcasses. These secondary data included original research papers published in peer-reviewed journals and pertinent review articles that summarize original research, obtained from hard copies and computerized databases. The sources of the data including costs have been cited. However, no quality assurance (QA) (accuracy, precision, representativeness, completeness, and comparability) of secondary data has been conducted. The costs obtained from the literature were cited, indicating the date of publication. The cost information obtained from a vendor website or via communications was collected during 2014. Unless otherwise mentioned as equipment rental, the cost numbers are equipment purchase costs. A disclaimer has been included at the beginning of this report. The data cited in this report were collected from published literature/fact sheets/web, and no attempt has been made to verify the quality or veracity of data collected from various sources.

1.3 Inventory of Large Animals

USDA's National Agricultural Statistics Service (NASS) reported that the number of cattle and calves in the U.S. as of January 1, 2015, totaled 89.8 million head (USDA, 2015) (see Table 1). The number of all cows and heifers that had calved was pegged at 39.0 million head. The number of beef cows totaled 29.7 million head, and the milk cow count totaled 9.3 million head. Steers (weighing 500 pounds and over) were 15.8 million, bulls (weighing 500 pounds and over) were 2.1 million, calves (under 500 pounds) were 13.7 million. Cattle and calves on feed for slaughter in all feedlots were 13.1 million. The combined total of calves (under 500 pounds) and other heifers and steers (over 500 pounds) outside feedlots was 25.2 million. The National Renderers Association reported approximately 300 rendering facilities (size reduction is one of the key steps in rendering) in North America (Hamilton et al., 2007). The United States processing capacity includes approximately 24.5 billion kilograms (kg) (54 billion pounds) from 100 million hogs, 35 million cattle, and eight billion chickens annually (see Figure 1).

Table 1. Cattle Inventory by Class - States and United States: 2015

State	All Cattle and Calves (100 head)	All Cows that have Calved (1000 head)
Alabama	1,220	680
Alaska	10	4.6
Arizona	880	370
Arkansas	1,640	870
California	5,150	2,380
Colorado	2,600	890
Connecticut	47	24
Delaware	17	7.5
Florida	1,700	1,040
Georgia	1,040	570
Hawaii	135	72
Idaho	2,300	1,060
Illinois	1,140	470
Indiana	870	380
Iowa	3,900	1,130
Kansas	6,000	1,620
Kentucky	2,060	1,070
Louisiana	790	480
Maine	85	41
Maryland	185	91
Massachusetts	38	18
Michigan	1,140	515
Minnesota	2,330	810
Mississippi	910	480
Missouri	4,000	1,970
Montana	2,500	1,520
Nebraska	6,300	1,840
Nevada	435	245
New Hampshire	30	17
New Jersey	28	14
New Mexico	1,340	730
New York	1,450	730
North Carolina	800	410
North Dakota	1,650	920
Ohio	1,250	550
Oklahoma	4,600	1,940
Oregon	1,300	650
Pennsylvania	1,530	680
Rhode Island	5	2.4
South Carolina	335	185
South Dakota	3,700	1,730
Tennessee	1,730	930
Texas	11,800	4,650
Utah	780	420
Vermont	260	144
Virginia	1,470	730
Washington	1,150	475
West Virginia	370	194
Wisconsin	3,500	1,550
Wyoming	1,300	700
United States	89,800	39,000

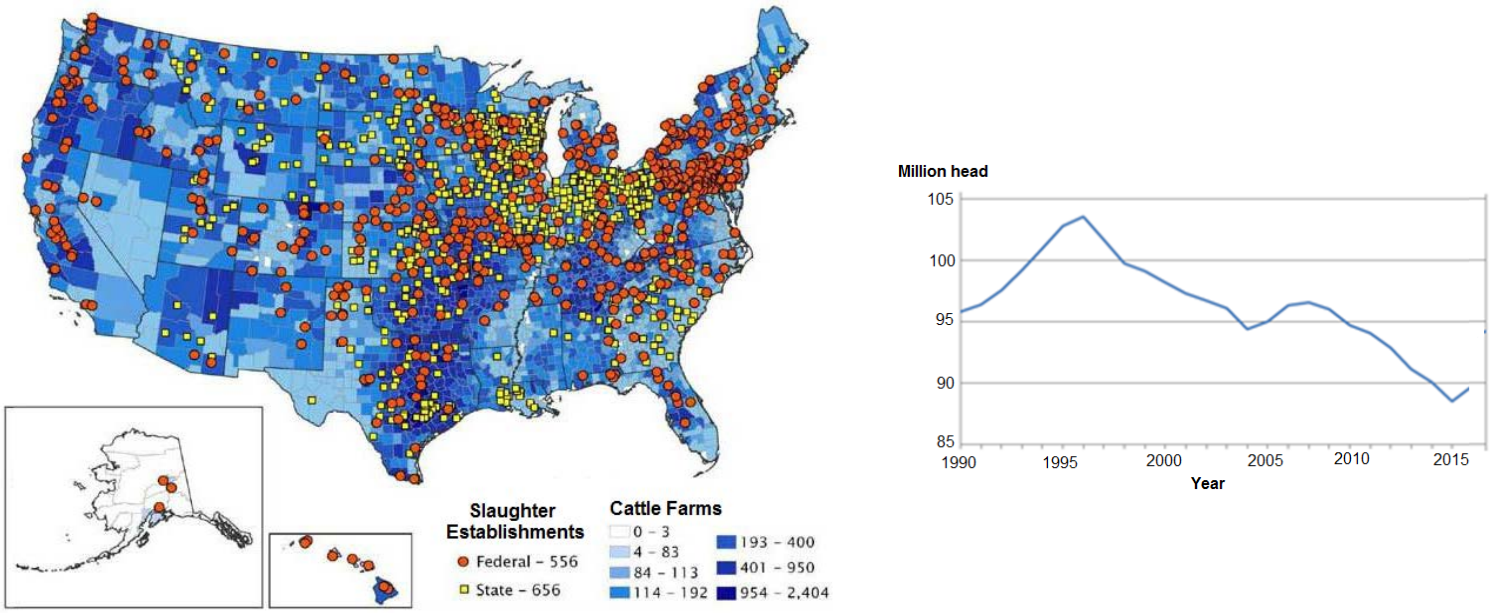

Figure 1. Cattle Farms and Federally Inspected Cattle Slaughter Plants (left) and Cattle Inventory (right) across the U.S. (modified after Gwin and Thiboumery, 2013)

The enormity of US animal agriculture magnifies a number of agricultural biosecurity issues, one of which is carcass treatment prior to appropriate management. Carcasses can be generally categorized as small (e.g., poultry and turkey), medium (e.g., sheep and young swine), large (e.g., mature swine), or very large (e.g., cattle and horses). Handling, treatment and disposal of larger sized whole carcasses (volume, muscle size and shape, weight) pose operational challenges on type of treatment, treatment capacity, space, and other limited resources. Widespread livestock mortalities from either natural occurances or culling (especially large and very large animal) could pose significant carcass handling, pretreatment and carcass management challenges. Table 2 provides the average mass, composition, type of waste generated, energy consumption for typical carcass management, and water consumption during treatment of various types of animals.

Table 2. Conversion of Animal Volume and Mass by Species

Type of Animal*	Average Mass (kg)[1, 5]	Composition (% of Body Mass)[2]	Waste Generation (Industry Benchmark) (kg/head)[3]	Energy Consumption (kWh/ton carcass animal)[3]	Water Consumption (m^3/ton carcass animal)[3]
Cows	635	Boned tissue**: 40 Bone, fat, head, offal: 39 Hide, tongue, Liver, heart, kidney, trotters: 12 Blood: 3 Paunch manure, shrinkage, blood loss: 6	Solid organic waste: 58 By-products for rendering: 110 Blood: 10-20	90-1094 Dry rendering: 400-650 Wet rendering: 570	1.62-9 Rendering: 0.5-1 [1.14 (300 gallons) per head] [4]
Pigs/Swine	200	Boned tissue: 64 Bone, fat, head, offal: 20 Tongue, Liver, heart, kidney, trotters: 10 Blood: 3 Stomach contents, shrinkage, blood loss: 3	Solid organic waste: 2.2 By-products for rendering: 20.8 Blood: 2-4	110-760	1.6-8.3 [0.23 (60 gallons) per head] [4]
Sheep	80	NA	NA	NA	[0.15 (40 gallons) per head] [4]

*One cow, two pigs, three sheep/goats = One animal unit. Auvermann et al. (2004) reported average weights as follows: cattle = 600 pounds, swine = 300 pounds, poultry = 4 pounds.

** Meat generally refers to the skeletal muscle from the carcasses of animals. It is made approximately of (mean value considered for beef meat): water 70%, protein 21%, fat 8%, and ash (mineral) 1% (Delevoye, 2013)

1: St. John & Associates Projects Inc. (2009); 2: UNEP (2008); 3: International Finance Corporation (2007); 4: Gleick et al. (2003)

5: The average masses (kg) of other animals reported were: Heifers = 455, Bulls >1 year old = 727, Steers >1 year old = 635, Calves <1 year old = 210, Horses = 523, Goats = 80, Bison = 455, Llamas and Alpacas = 75, Hens and Chickens = 1.65, Turkeys = 5, and other Poultry = 2.5.

NA: not available.

1.4 Selected Pretreatment: Size Reduction, Physical and Chemical Inactivation

Based on identification and evaluation of eleven pretreatment alternatives, three pretreatments (size reduction, physical inactivation and chemical inactivation) were selected based on the qualitative ranking (see Table 3). None of these pretreatments, individually or in combination, should be considered absolute. The pretreatment scheme should be approached on a case by case basis. Two or more pretreatment/carcass management options can be selected so as not to overburden a processing site. Parallel treatment schemes can be considered by using treatment of part of the feed material by selected methods while treating remaining parts of the feed material by other method(s). This section provides general introduction to these shortlisted technologies and auxiliary activities (such as on-site or off-site treatment/disposal, transport of carcasses). The subsequent section (Section 3) includes detailed discussions of three pretreatment technologies (size reduction, physical inactivation and chemical inactivation) on effectiveness, impact on environment, implementability, control measures, cost, regulatory issues, personnel safety, and community acceptance as outlined in the performance work statement. Several of the subsections have overlapping information on pretreatment technologies. However, they have been described separately under each pretreatment technology following the guidance for conducting remedial investigations and feasibility studies under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (U.S. EPA, 1988).

Table 3. Carcass Pretreatment Options Matrix

Carcass Management Option	On-site Size Reduction	Digestion	Bioreduction	Alkaline Hydrolysis	Sterilization	Freezing	Physical Inactivation	Chemical Inactivation	Additives/ Sorbents	Encapsulation	Packaging
Rendering	+++	++	++	-	++	++	++	++	++	-	-
Incineration	+++	+	+	-	+++	++	++	++	+++	+	++
Composting	+++	+++	+++	-	-	++	++	-	+++	-	-
Burial	++	+	-	+	+++	++	++	++	+++	++	++
Burning	+++	-	-	-	+++	-	++	++	+++	+	++
Landfill	++	+	-	+	+++	++	++	++	+++	++	++

Notes: Several of the pretreatments may have overlapping processes. Some of the activities can be conducted at centralized or mobile locations. +++, ++ and + denote qualitative importance of the criteria (+++ > ++ > +), and – indicate not applicable.

Color Key

Ideal

Subject to acceptability of characteristics of feedstock by the processing facility/plant

Not Suitable

Several pretreatments (such as homogenization and separation) are coupled with size reduction, physical and chemical inactivation that claim to enhance performance (Genesis, 2007). These pretreatments often reduce treatment time and/or improve process efficiency by increasing the destruction of volatile solids.

1.4.1 Homogenization

A homogenization process can be used prior to and/or during the pretreatment processes to ensure uniform composition and stable structure of the material, potentially accelerating the rate and extent of degradation of volatile solids. Selection of appropriate pretreatment technology with homogenization device can help the efficiency of detection, ease of handling, costs, and high-throughput capabilities (Rohde et al., 2015).

1.4.2 Separation

Separation of infectious feedstock, if safe to be handled, can be performed to remove materials that do not require downstream processing (such as removal of grit - sand and gravel, rocks, and other inorganics). Separation of nonhazardous and nonbiodegradable material that can ensure a uniform organic feedstock is helpful for the downstream process. Manual sorting at the source to remove undesirable items prevents or lessens the chance of additional contamination. Mechanical sorters (screens, rotating trammels, or magnetic separators) may be considered to handle large volumes of load where the source separation is difficult to achieve, and manual sorting is inadequate. However, smaller pieces are often not removed and/or are

mixed into the organic mass by the mechanical process. Source separation of specified risk material (SRM) (i.e., tissues that contain the agent that may transmit bovine spongiform encephalopathy (BSE), transmissible spongiform encephalopathy (TSE), or scrapie disease) is required by the Food and Agriculture Organisation (FAO) when treating animal by-products (Böhm, 2002; Genesis, 2007).

1.4.3 Size Reduction

Mechanical processes involving size reductions and associated unit operations (such as shredding, grinding, mixing, agitation, liquid-solid separation, conveying, and compaction) supplement other carcass pretreatment methods. In the case of downstream physical- or chemical-based processes, mechanical devices such as shredders and mixers can also improve the rate of heat transfer or expose more surfaces to chemical inactivation agents. Mechanical processes can add significantly to the level of maintenance required. Size reduction may be required prior to various processes (such as rendering, incineration, composting, burial, burning, and landfill) involving the treatment of animal carcasses. Both North America and the European Union (EU) regulations specify a particle size > 0.236 inch (Genesis, 2007). To ensure proper sterilization/inactivation of a pathogen and to expedite the processing of carcass, feedstock must be reduced to a uniform small particle size. Size reduction of carcasses to an average particle size of less than 2 inches also allows for better heat distribution and gives bacteria access to more surface area and improves the efficiency of the degradation of biomass (Mukhtar et al., 2008). Auvermann et al. (2004) indicated that manufacturing companies design various forms of milling with a variety of particle size of the feed material to meet the time and temperature requirements. The particle size of processed material entering various processing and dewatering systems is as follows: Stork-Duke = 1-2 inches, Stord Bartz = 0.8-2 inches, Anderson Carver-Greenfield Finely = 0.4 inch, and Protec and Stord Bartz Dewatering System = 0.4 inch. Gale (2002) reported that to achieve proper heat transfer in a sterilization process, animal biomass particle sizes must be no larger than 2 inches. DeWitt et al. (2009) indicated their preferred particle size range of carcasses is between 1/8 inch and 2 inches as mixtures of extremely small particles for the composting carcass management option have low porosity. Poor gas transport through the material can impede movement of oxygen (O_2) (inflow) and carbon dioxide (CO_2) and ammonia (NH_3) (outflow). Mukhtar et al. (2008) reported recommended sizes of less than 1 inch for chemical treatment.

Depending on the carcass pretreatment option selected during an event, size reduction processes can range from grinding and maceration, involving cutting and shredding, to pulverization and the reduction of feedstock to slurry in such equipment as a hydropulper.

A number of companies provide equipment that is used for pretreatment of municipal solid waste, food processing waste, slaughterhouse and animal mortalities. The type and size of the equipment varies considerably, depending on what material is being processed. Small carcasses (poultry) require very little grinding and less sturdy equipment but entire bovine carcasses will have to be processed through prebreaker, shredding or cut up prior to grinding or placed into a vertical sturdily built grinder.

A literature search conducted to identify companies and their cost estimates found significant variation; sometimes cost estimates were not able to be acquired. Although not specifically designed for infectious carcass size reduction purposes, the size reduction equipment and accessories for the slaughterhouse industry can be adapted for the management of infectious

carcasses. A bulking agent such as straw is required to eliminate ineffective movement and to achieve homogenization. A list of representative size reduction equipment and equipment manufacturers is provided in Table 4.

Table 4. Size Reduction System Manufacturers, Type and Capacity

Size Reduction System	Description	Capacity
Shredder - Machines that tear particles apart (versus smash). The word "shear" is often added as an adjective, i.e., shear shredder. Compression forces are applied to a particle in offset planes to produce a shearing action. A common shredder is a low-speed, high-torque shear shredder. This machine uses one or more rotating shafts, each with a set of cutting disks or knives mounted closely together on the shaft(s) that sits in a chamber at the bottom of a feed hopper. As the shaft rotates, the cutting devices pull the material down through the small spaces between the cutting disks/knives and the surrounding chamber. Many shredders use a pair of counter-rotating shafts that draw the material down, forcing the pieces out between the two shafts. Particles produced by shredders generally have an elongated shape.		
Doppstadt Single Shaft Shredder, Velbert, Germany	Moderate rotor speed (approximately 32 revolutions per minute, RPM) mechanical drive leads to longer breaks between the shredding tools and significantly reduces noise. Hydraulically controlled shredding comb guides extraneous objects and produce output material in the size range between 3.94 inch and 19.7 inch.	60 – 70 tons/hour (model 3060K)
MOCO Maschinen- und Apparatebau GmbH & Co. KG Viernheim, Germany	Low-noise (idling noise level at 1 m distance approximately 68 decibels) shredder with two counter-rotating toothed shafts with individually exchangeable cutting disks. Compact design, sturdy welded construction, low energy demand.	18 – 30 m^3/hour
Vecoplan LLC High Point, North Carolina	Once shredded, material passes through bar screens or is pulled back into the cutting chamber and re-cut until it passes through the screen bars. The interaction between the rotors and the counter knife, combined with the bar screens, produces a homogeneous, consistently sized output. Systems are available with single and multiple rotor shredders including conveying technologies, air classification systems, rotary trammels, vibratory feeders, oscillating, roller and star screeners, and separators.	11 to 110 tons/hour (hopper capacities 6345 $feet^3$ (maximum)
Crusher - Crushers are used to reduce the size, or change the form, so the end product can be more easily processed. Crushing is the process of transferring a force amplified by mechanical advantage through a material made of molecules that bond together more strongly and resist deformation more than those in the material being crushed. Crushing devices hold material between two parallel or tangent solid surfaces and apply sufficient force to bring the surfaces together to generate enough energy within the material being crushed that its molecules separate from fracturing or change alignment in relation to deformation.		
Berry Extreme Duty Carcass Crusher Clermont, Georgia	Model B-CC-EX crusher decreases carcass volume by fifty per cent	Up to 350 front half carcasses per minute
Harden industry Ltd. Guangzhou, China	Prebreaker for complete carcasses (model DS81) Cost: $60,000 - $80,000/unit Freight on Board (FOB) Guangdong, China	35 tons/hour
Haarslev Industries A/S Søndersø, Denmark	PB30/60 Animal Crusher can handle whole carcasses and is installed in rendering industries	15 – 50 tons/hour

Size Reduction System	Description	Capacity
ANCO-EAGLIN Inc. Greensboro, North Carolina	Designed for bone crushing or whole carcass crushing. One-pass design that discharges a particle size suitable for feeding any conveying system and enough for any batch or continuous rendering process. Duracut crusher with no infeed equipment or removal equipment $150,000. 10 large cattle/hour. Can handle over 10 tons/hour for small hogs (under 0.35 ton). Large sows would be one at a time like the cattle.	5 – 50 tons/hour
The Dupps Company Germantown, Ohio	Precrusher: Breaks large pieces without preliminary cut-up.	25 – 50 tons/hour
Grinder - Grinders reduce particles in size by repeatedly pounding them into smaller and smaller pieces through a combination of tensile, shear and compressive forces. Nearly all grinders, including tub and horizontal feed grinders, rely on a hammermill as the pounding device. A hammermill has club-like projections (hammers) attached to a rapidly rotating drum (rotor). The high rotational speed (more than 1,000 RPM) gives the hammers enough inertia to shred the material (Goldstein and Diaz, 2005). As the drum rotates, the hammers spin rapidly and smash against the material trapped inside the hammermill chamber until the pieces are small enough to pass through the discharge screen or grate. To be effective, the material being ground has to be somewhat rigid and brittle, although the hammers will eventually pulverize almost anything. Particles coming out of a grinder look ragged, broken and smashed. The particles encompass a wide range of shapes and sizes (smaller than the screen opening).		
DuraTech Industries Jamestown, North Dakota	Model 4012 Industrial Tub Grinder capable of large volume grinding	70 – 120 tons/hour (~9450 $feet^3$/hour)
Diamond Z Caldwell, Idaho	Stationary and mobile grinders (tub and horizontal grinders)	70 – 100 tons/hour
KPI-JCI and Astec, Yankton, South Dakota	Crushing, screening, material handling, washing, classifying and feeding equipment	290 – 875 tons/hour
MAVITEC Heerhugowaard, The Netherlands	Extra heavy carbon steel construction, replaceable wear resistant cap and base liners, replaceable hammers, screens supported by chain cradle construction, and carbon steel platform.	1 – 3 ton/hour

1.4.4 Inactivation

The challenge associated with the management of animal carcasses includes protection of environmental, animal, and public health against potential microbiological threats. An animal carcass is composed of microbiologically active material that may contain viruses, bacteria, protozoa, parasites, prions, and toxins. All of the biologically active materials need to be reduced to safe amounts, eliminated, or contained to minimize their potential hazard. Inactivation is the process of eliminating pathogenic microorganisms from inanimate objects. Different inactivation methods have different target ranges, and not all methods can kill all microorganisms. Inactivation is different from sterilization, which is an absolute condition where all the living microorganisms including bacterial spores are killed. Physical inactivation includes application of dry heat (flaming, hot air oven, infrared), moist heat (below 100 ˚C, at 100 ˚C, above 100 ˚C), ultra-high pressure steam, energy (thermal, plasma arc irradiation, pulsed-field electricity, ultrasonic energy, UV light). Chemical inactivation is the use of chemical agents including oxidizers (chlorine, hypochlorite, ozone, and peroxide), organic acids (lactic acid, acetic acid, and gluconic acid), organics (benzoates, propionates), bacteriocins (nisin, magainin [antimicrobial peptides]), acidic and basic electrolyzed water. Inactivation can be used in conjunction with other carcass pretreatment processes such as size reduction.

1.4.5 On-Site or Off-Site Treatment/Disposal

Historically, treatment and disposal of diseased carcasses was done on the infected premises to avoid spreading the infection by transporting the carcasses to an off-site facility. However, the onsite treatment technologies and carcass management options have potentially serious environmental consequences and may be limited by space requirements and access to bulking agents such as wood chips, straw, peat moss or carbonaceous materials. While on-site treatment or disposal may still be a preferred option, off-site methods may increasingly be used in emergencies, particularly for the carcasses of large animals. A decision to move the carcass management activities off-site will be related to the scale of the event (i.e., the volume of material), site capacity, potential human health concerns and environmental concerns. For off-site management, the primary issue will be to identify a suitable site for carcass management and the transportation of carcasses in a safe, sanitary and timely fashion to avoid spreading the disease and/or endangering public health.

1.4.6 Activity Prior to Transport of Carcasses

Transport of infected carcasses must be planned and executed with care, utilizing leak-proof vehicles approved for transporting hazardous material. Refrigerator trucks may be used. Vehicles should not be overloaded – at least 24 inches freeboard, depending on distance to be travelled and temperature, should be left clear for expansion of carcasses. Smaller carcasses should be bagged if feasible and larger carcasses covered with a layer of polymeric sheeting. If vehicles are not enclosed, they should be lined and an airtight vinyl tarp should be placed over the top. All vehicles must be cleaned and disinfected before leaving the infected premises and after unloading. Vehicles should travel on designated routes, preferably with an escort vehicle. They must travel slowly to avoid splashing of contaminated material and a supply of an approved disinfectant should be carried to deal with minor spills during transit. Carcasses and other items awaiting management should be secured to prevent unauthorized access and to prevent wild animals and birds from removing potentially infectious material. Control of insects should be considered if there is a risk of passive transmission by insects to nearby susceptible species. If carcass management is delayed, carcasses should be thoroughly sprayed with an

approved disinfectant. Federal, State, and local transportation, public health and waste management officials should be consulted ahead of time to ensure all transportation requirements are considered prior to off-site transport.

Use of plastic bags and similar material is recognized to be necessary for operator protection. However, their use should be minimized by use of mechanized and automatic feed devices due to potential impacts on the operation of the equipment. Carcasses and by-products may need to be classified according to source (for example, specified risk material). United Nations Environment Programme (UNEP) (2006) recommends that the methods to be considered include:

- Use of mechanized loaders to avoid contact with carcasses;
- Use of macerating and grinding techniques to allow automatic continuous loading and operation; and
- Minimizing contamination from packaging, including use of non-halogenated plastics.

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2.0 Evaluation of Individual Alternatives

2.1 On-site Size Reduction

Size reduction of carcasses typically involves physically breaking material into smaller particles or pieces. The three most common methods for size reduction are grinding, shredding and crushing. Carcass materials can undergo size reduction through different mechanisms: impact (sharp, instantaneous collision of one moving object against another), compression (occurs between two surfaces, with work being done by one or both surfaces), attrition (reduction of material by scrubbing it between two hard surfaces) or a combination of these crushing methods.

Size reduction equipment can be broadly categorized as crushers, grinders, and shredders, where grinders produce finer particles than crushers. Size reduction in impact crushers occurs through particle concussion by a single rigid force. The swing hammer crusher is an example of an impact crusher. Table 5 provides the advantages and disadvantages of shredder, crusher, and grinder.

Table 5. Advantages and Disadvantages of Shredder, Crusher, and Grinder

Shredder		Crusher		Grinder	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
• Preliminary step for large feed to shred down to random, smaller components. • Uses low speed and high torque. • Output ranges between 1 inch and 2 inch and larger.	• Cutting equipment is relatively expensive due to abrasion.	• Energy efficient. • Does not over-reduce materials. • Variable capacity.	• Limited size reduction.	• Large range of equipment capacities are available. • Creates homogeneous blend.	• Energy consuming. • Rings, pins, or rollers wear easily. • Output limited to less than ¼ inch to ½ inch.

Size reduction equipment is manufactured in a wide range of capacities and feedstock size ranges. Equipment for size reduction may also be integrated with densification or drying equipment because smaller particle sizes can be compressed and dried more efficiently (Tallaksen, 2011). When evaluating equipment, there are several considerations and options that make systems suitable for specific uses. Among these considerations are noise level, dust generation, energy consumption, tolerance to moisture, and the final feedstock size. The most commonly used size reduction equipment is a hammermill grinder, which has high speed rotors with metal hammers that essentially beat biomass apart until it fits through the openings of a metal screen. The size of the openings in the screen determines the final size of the processed biomass. While these hammermill systems have a high throughput and are very simple to operate, they are also very noisy and can create a significant release of biomass via splash. Maintaining rotational speed as the hammers strike the carcass requires that rotors be driven by

high amperage electric motors or large diesel engines. Hammermill units are found in most biomass processing systems due to their reliability and flexibility in working with multiple types of feedstocks. Changing processed particle sizes is often as simple as switching screens. High moisture containing carcasses can bind and jam the unit and will definitely reduce throughput. Depending on the hammermill, large chunks of dense biomass may also be difficult for the unit to break apart efficiently. However, both moisture and density issues can be overcome with equipment modifications and a larger motor.

A shredder can process moist, dense, or stringy carcasses effectively. Although often grouped with grinders, shredders tend to be low speed, high torque units that have large teeth to pull apart material. These units have large motors that are connected hydraulically or with reduction gears to the shredding rotor to generate the force needed for processing resistant material. Shredders are much quieter than hammermill grinders because of the lower rotational speed and the lack of hammer strikes on the material. Low speed operation also reduces aerosols. The key disadvantages of shredders are the relatively low throughput and limited flexibility in altering the final particle size. Shredding is normally used as the first processing step. Shredders are well suited for the primary breakdown of large dense feedstocks but may need to be paired with a secondary processing system that reduces material to a final uniform size.

Crushers can be used with dry whole carcasses or bone materials that will shatter under pressure. The advantage of using a crusher is that it is a lower energy process than either grinding or shredding. Most biomass is too fibrous or wet to shatter and will densify as the large rollers put pressure on the biomass.

The selection of the type of equipment available for the size reduction or comminution of carcass materials is dependent on the raw material and the type of product of the processing (such as grindability, sticky, hard/soft, graded, granular, fine, abraded, rounded, sharp, etc.) required.

The laws of size reduction in general use include those of Rettinger, Kick, and Bond (Galanty, 2007). Rettinger's energy, W, required for grinding can be determined by $W = K_R (R - 1)/L_1$ where W is total energy required for size reduction; K_R is Rettinger's constant; f_C is crushing strength; L_1, L_2 are the initial and final dimensions of the particles; and R is the size reduction ratio, L_1/L_2. Kick's law is generally favored for coarse crushing:

$$W = K_K f_C \ln R$$

where K_K is Kick's constant. The energy obtained from this equation is a function only of the size reduction ratio and does not depend on the initial or final sizes.

Bond's law is applicable to both coarse and fine grinding:

$$W = 10W_i \left(\frac{R^{0.5} - 1}{L^{0.5}} \right)$$

where W_i is the Bond work index.

The size and distribution of the carcass material significantly influences the particle size obtained from size reduction equipment. Smaller sizes can be controlled by clearances within the equipment and speed and the retention time. Forces can be applied as compression, tension, shear, impact, and attrition. In size reduction equipment, there is usually more than

one of these forces acting on the material, although one may be predominant. Tension is the cause of fracture in brittle materials (bone, hoof, horn), yet no practical size reduction equipment applies a primarily tensile force. Brittle materials when subjected to compression in a double roll crusher or in a jaw crusher apparently fracture under tension. The mechanical properties of the cattle horn sheath reported by Li et al. (2010) are distinctly dependent on the hydration condition. The sheath is brittle at 0% water content but ductile at 8% and 19% water content based on the stress–strain curves (Li et al., 2010). Compression-type equipment is easily applied to brittle substances but must be more carefully applied to ductile and soft (tissue) materials to avoid flattening or compaction. Shear forces can be introduced by compression-type equipment (such as disk mills) by causing one disk to revolve at a different speed from the other.

While size reduction is governed by basic laws of physics, no single law or rule can take the place of experience and testing in the selection and sizing of suitable size reduction equipment for a given application. A number of factors go into the proper selection of a piece of size reduction equipment for a given application, including the following.

- Will the size reduction equipment handle the maximum required capacity to be processed without undue strain or overload?
- Will the machine handle the maximum size (whole carcass) of the infeed material?
- Will the unit's operating mechanism handle the properties of the material (such as tough, sticky, soft)?
- Is the design and construction suitable for the special application requirements such as resistance to corrosion, maintenance of purity or sanitary requirements?
- Will the size reduction equipment produce the output particle size required?
- Will the equipment produce aerosol or splash material?
- Will the equipment operate with minimal noise or vibration?
- How will the material be fed? Conveyed or dropped by gravity?
- Does the size reduction equipment match the connection configuration (dimensions: round or square)?
- Is the equipment suitable for the operating conditions and operating temperature?
- Does the unit meet the requirement for ease of maintenance and interior access?
- Does the size reduction equipment have seals adequate for the application?
- Is qualified field service and customer support available from the supplier?
- Is the machine built with high quality materials and workmanship?
- Is the size reduction equipment configuration suitable to fit in the available space?

Carcass materials differ in properties as they can be weak, strong, and soft or hard (USDA, 2012), as defined by Young's modulus (Chen et al., 1996), and any combination of these conditions can be met in the size reduction process. Figure 2 provides stress-strain relationship for processing material properties. The first straight line part of the curve follows Hooke's law-i.e., stress is proportional to strain, and the ratio of stress to strain (modulus of elasticity) measures stiffness or softness in pounds per square inch (or dynes per square centimeter). Stress at the knee of the curve is the first yield point that measures resistance to permanent deformation. The total area under the stress strain curve represents the energy required and is also a measure of toughness or impact strength (Figure 2). Three types of force are used to reduce the size of carcasses: a) compression forces, b) impact forces, and c) shearing (or

attrition) forces. In most size reduction equipment, all three forces are present, but often one is more important than the others. In Figure 2, E = elastic limit; Y = yield point; B = breaking point; O–E = elastic region; E–Y = inelastic deformation; Y–B = region of ductility; (1) = hard, strong, brittle material; (2) = hard, strong, ductile material; (3) = soft, weak, ductile material and (4) = soft, weak brittle material. When stress (force) is applied to a material, the resulting internal strains are first absorbed to cause deformation of the tissues. If the strain does not exceed a certain critical level named the elastic stress limit (E), the tissues return to their original shape when the stress is removed, and the stored energy is released as heat (elastic region, O–E in Figure 2). However, when the strain within a localized area exceeds the elastic stress limit, the material is permanently deformed. If the stress is continued, the strain reaches a yield point (Y). The breaking stress is exceeded at the breaking point (B), and the material fractures along a line of weakness. Part of the stored energy is then released as sound and heat. As little as 1% of applied energy may actually be used for size reduction.

Table 6 provides the selected size reduction equipment including shredder, prebreaker, chipper, chunker, hammer hog, hammermill, knife mills, and disk mills. Hammermills and tub grinders are common size reduction equipment to process large carcasses, and brief discussions are included in this section.

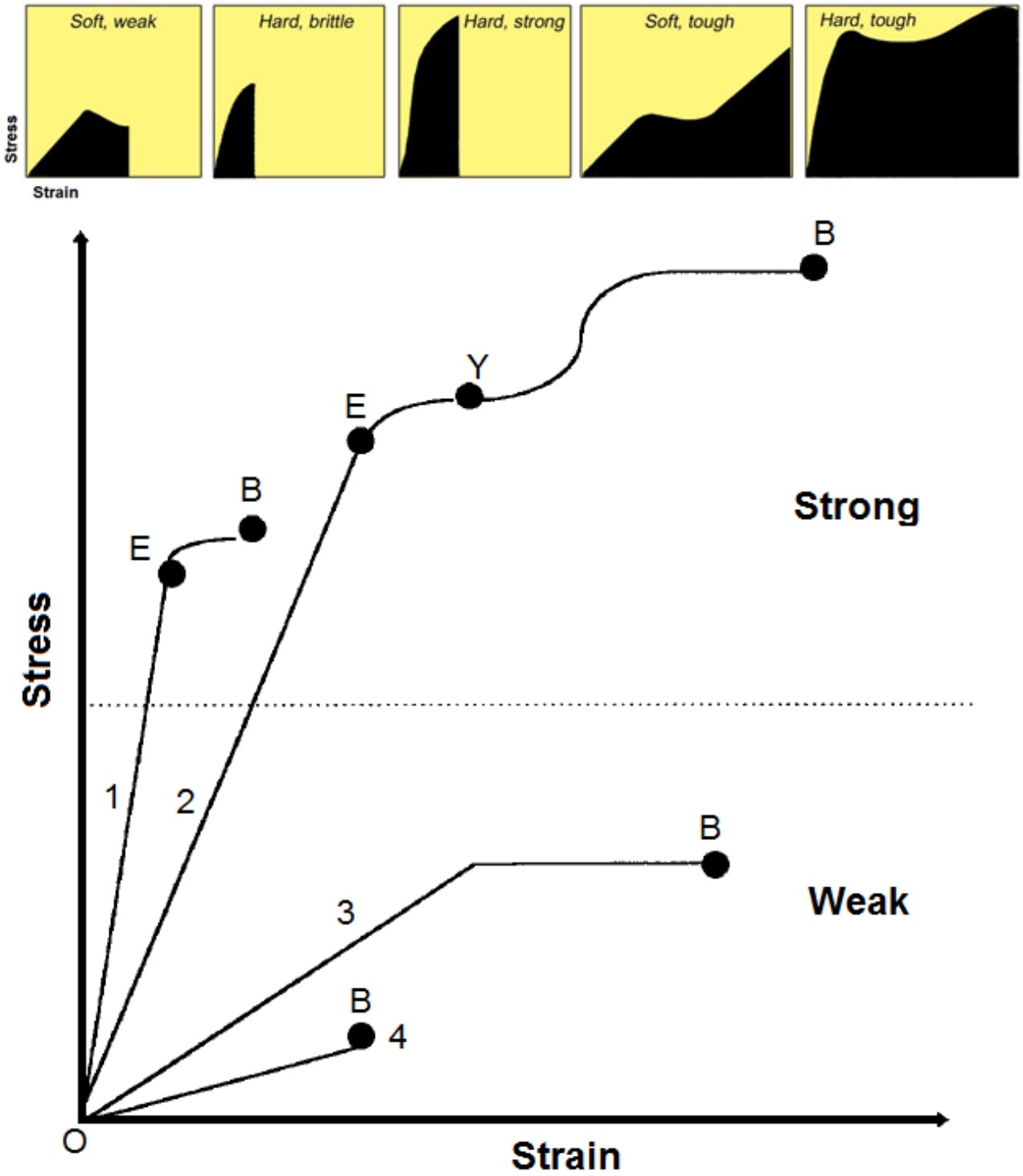


Figure 2. Stress and Strain Relationship:
The modulus of elasticity is low for soft materials and high for hard materials
(Modified after Fellows, 2000).

Table 6. Types of Size Reduction Equipment

Equipment	Shredder	Prebreaker	Chipper	Chunker	Hammer Hog	Hammermill	Knife mills	Disk mills
Types • On-site • Mobile /Portable	• Horizontal shaft with top- or side-feed chute • Controlled feed type with compression feed device for positive feed and uniform power load • Reversible centerfeed • Flail mill	Pre-break large pieces without preliminary cut-up. Hardened machined teeth force material through the prebreaker's rugged anvils with a low-speed shearing action instead of an impact or tearing action	**Disk type chipper** • Horizontal feed • Gravity feed **Drum type chipper** • Horizontal feed • Gravity feed	• Spiral head • Involuted • Double involuted	• Swing hammer • Fixed hammer • Punch and die • Mass rotor • Knife hogs	• Swing hammer • Fixed hammer • Tub grinder • Rotary knife hammer	Material is fed to the cutting chamber via a chute. Size reduction takes place between rotor and housing knives. The size of the end product is determined by a screen installed in the lower part of the housing	Size reduction takes place by cutting and shearing action between toothed segments or alternatively with high pressure refining disks.
Reduction Device[1]	Swinging plates/knives or rotor cutter	High-strength alloy teeth	Replacement knives	Rotating impact surface	Swinging/ fixed/ semi-sharp hammers	Swinging/fixed/ semi-sharp hammers	Replacement knives	Cutting disk with blade hammer
Speed[1]	Moderate	Low	High	Moderate	Moderate	Moderate	Moderate	Low
Geometry of Output	Coarse/multi -surface	Semi-coarse	Clean edge/two-sided	Coarse/multi-surface	Coarse/ multisurface	Coarse/ multisurface	Semi-coarse	Semi-coarse

1: Hoque et al. (2007)

Hammermill

Hammermills are commonly used impact crushers in which the load, a combination of tensile, compressive, or shear forces, is applied to the material by striking the particles in suspension or by hurling them at high speed against stationary surfaces. This action differs from a typical crushing unit such as a rock crusher, which takes a coarse feed and applies pressure gradually to the material which takes the load as simple beams or short columns. The greater part of size reduction by the hammermill is accomplished by brute force. There are horizontal and vertical shaft machines of either swing or rigid hammer type. The principal parts of the horizontal swing hammer unit are the rotor, hammers, grates, frame, and flywheel. The hammer configurations vary from simple rectangular blocks (typical dimensions of 12-inch × 4-inch × 1-inch) to the more elaborate type of chopper, which may have a protruding wearing surface with sharpened edges. Material to be size-reduced enters the equipment through an infeed chute and interacts with the hammers and each other until at least one dimension of the object has reached a size small enough to fall through the grates in the bottom of the unit. Due to rotating hammers, certain portions of the object may be thrown out or ejected because of the impact with the swinging hammers. These airborne objects, which may leave through the input opening, are potentially hazardous to the operators of the equipment. A curtain is often hung over the input opening to deflect the objects that are ejected. In the vertical shaft unit, the rotor is placed in a vertical position, with the input material moving parallel to the shaft axis, assisted by gravity. This unit is relatively slow-turning and does not tend to reject objects in the manner of horizontal shaft hammermill. Rynk (2003) demonstrated that chopping large carcasses in a vertical grinder-mixer produces a homogeneous mixture for downstream processing (rendering and composting) and eventual disposal.

Tub Grinder

A tub grinder can process animal carcasses into smaller pieces by means of a hammermill located at the bottom of the tub. The feed material is placed in the top of the tub that rotates to feed the material into the hammermill. A screen around the hammermill limits oversize material from passing through to the conveyor system that either can feed into a transport container or can be piled onto an intermediate storage container to be loaded later. Models of tub grinders are available on a trailer or self-propelled track carriers.

The method of feeding in most of the tub grinders imposes a heavy shock load on the power train and results in wide power fluctuations. A tractor with a higher power take-off output is needed to prevent tractor stalling due to the power fluctuations. Smaller tractors could be used at reduced grinding rates by adjusting the tub governor. The maximum grinding rate for a tub grinder depends on the type of biomass being ground, its moisture content, temperature, the screen size used, and the available tractor power. Screen size is the most important operating factor directly affecting grinding rate, power consumption and specific capacity. Reducing screen size by a factor of two generally doubles power consumption and halves the grinding rate and specific capacity. The advantage of the tub grinder is that it is generally easier to perform maintenance. Tub grinders require high power input to produce modest throughput (Hoque et al., 2007). The tub grinders may not process whole carcasses without bucking. They have a higher feed height than other grinders, which may limit visibility or feasibility of certain loading methods (such as skid steer with brush attachment) (Smith, 2013).

Trade-offs between coarse and fine size distributions should be considered in terms of producing a feed material with uniform characteristics and yet not creating an energy intensive pretreatment process if fine grinding is required as a secondary size reduction stage.

2.1.1 Effectiveness

Size reductions of the carcass provide the following advantages: 1) creating more surfaces (more sites for rapid sterilization, biodegradation for composting, or oxidation in a combustion process); 2) homogenizing the feed material to provide uniform properties for the downstream processing; 3) multi-stage size reduction units can provide flexibility in the carcass handling operation; 4) preprocessing such as chopping and/or mixing of carcasses helps isolate the fibrous or tissue material from unwanted material; and 5) meeting specifications on size and shape by the downstream processing for easier handling with improved blending efficiency (Wilkinson, 2011).

2.1.2 Impact on Environment

There are environmental issues associated with carcass processing and management options. The decision-makers in the choice of the proper treatment and disposal option should factor the environmental concerns into the decision process so that potential negative consequences can be avoided. The key ten environmental resources issues are: i) solid waste, ii) groundwater, iii) surface water, iv) air quality, v) climate, vi) public health, vii) wildlife, viii) cultural resources, ix) utilities, and x) vegetation (Ellis, 2001). If the death of an animal was due to an infectious organism, then the method that most efficiently prevents further disease spread is usually the preferred choice. Protecting livestock from a disease needs to be weighed against protecting humans from environmental hazards. When a natural disaster is the cause of death, the pretreatment technologies and carcass management options chosen should be the most environmentally acceptable. Catastrophic situations that created large numbers of carcasses in the past indicated that the most expeditious method may be utilized in an effort to solve the problem. Biosecurity, environmental, and logistical issues affecting carcass pretreatment and disposal should be reviewed to select the appropriate method of carcass management for various situations. Some disease agents are readily transmitted to other susceptible animals by transportation off-site, so biosecurity measures must be strictly enforced against an infectious agent.

When selecting a size reduction processing site, it is critical to consider the environmental impacts. The location of the site should minimize the impact of odor and other air quality issues on any neighboring residences and prevent the movement of nutrient-containing water into surface water and groundwater. Other considerations include the direction of prevailing winds, the distance to property lines, proximity to recreational or public sites, aesthetics and the slope of the site. Michigan has specific criteria that carcass processing sites must meet (BODA, 2015):

- A well-drained area with a minimum setback of 200 feet from water (including lakes, streams, wetlands, sinkholes, seasonal seeps or other landscape features that indicate the area is hydrologically sensitive).
- A minimum of 2 feet above the seasonal high water table.
- A minimum of 200 feet from any well.
- A minimum of 200 feet from the nearest neighboring residence.

These factors should all be taken into consideration in determining if a carcass pretreatment facility is appropriate and, more importantly, the type of carcass management that should be considered. There does not appear to be any consensus among governing entities as to the exact distance that sites should be located from specific areas of concern such as wells or homes. There is obvious disparity among states in the recommended offset distances (and depths) for burial sites from the multitude of limiting factors in the selection process (Table 7).

Table 7. Recommended Distances by Selected Agencies

Agency	Minimum Distance from Streams (feet)	Minimum Distance from Water Wells (feet)	Minimum Distance from Dwellings (feet)
USDA READEO[1]	150	150	100
Arkansas Department of Agriculture	600	600	none
Wisconsin Department of Agriculture	150	300	100
North Carolina Department of Agriculture	300	300	none
California Department of Food and Agriculture	100	1000	100

1: Regional Emergency Animal Disease Eradication Organization (READEO).

Other states have minimum offset distances from the above considerations as statute or guidelines to follow. These issues need to be identified in advance by state and local emergency response officials, and mechanisms to waive or modify pre-existing regulations as needed in emergencies should be negotiated in advance. Dr. Mark Sobsey (University of North Carolina, Chapel Hill) raised questions regarding the adequacy of a 75-foot buffer between spray fields and residential property as potential human exposure from the spray may be difficult to control. Studies of the spraying processes have shown that there is some drift away from the spray area. Sobsey recommended a barrier (such as tall vegetation) to disrupt the dispersal of airborne microbes in addition to a sufficient setback distance (Craven County, 1997).

2.1.2.1 Odor

Size reduction may increase the risk of odor problems, particularly if the equipment is not part of an enclosed and exhausted continuous system (European Commission, 2005). Decomposition commences as soon as the carcass has gone through the size reduction process. Undue delays before rendering (or other carcass management option) in conjunction with inadequate temperature control have a direct effect on the state of decomposition and on the consequent severity of any odors. The biological and/or thermal decomposition of carcass materials leads to the formation of odor-intensive substances such as ammonia and amines, sulfur compounds such as hydrogen sulfide, mercaptans, and other sulfides; saturated and unsaturated low-boiling fatty acids; aldehydes; ketones and other organic compounds. Measurements have shown that the average odor concentration can be 80-800 kilo odor units (kOU)/kg raw material (Ireland EPA, 2008). The concentration of odor at the detection limit has been defined to be 1.0 OU/m^3, so that odor emissions can be expressed in odor units per second (OU/s) or odor units per second per animal unit (AU), where 1 AU = 500 kg animal weight (OU/s/AU) (Bottcher, 2001).

The malodorous emissions can also arise from gaseous emissions from downstream processing operations (such as rendering). Odor emissions also arise from discharges from cookers, presses and/or centrifuges receiving hot rendered material for separation and hot separated material prior to storage. Other sources include the displacement of malodorous air from the tallow storage tanks; the cleaning of process equipment; fugitive emissions from process buildings and the operation of an odor abatement plant beyond its design specifications. Malodorous emissions also arise from liquid effluents, including the accumulated liquid at the base of the raw material transport containment and on-site storage hoppers; material spillages and floor washings; cooler condensate; the by-products of abatement techniques and treatment/effluent holding tanks. The storage and handling of animal meal and tallow can also cause odor problems. The non-condensable gases and the condensate liquor have a particularly strong and offensive odor. If the odor is not destroyed at the source, odor can cause problems from within the installation and at the wastewater treatment plant. The National Renderers Association reported that odorous gases generated at various points in the process can be collected by a ductwork system and can be transported along with the non-condensable gases from the condenser to an odor control system for neutralization of odorous components (Hamilton et al., 2007).

The odor from a carcass size reduction processing facility can be detected if odorous gases are generated, released to the atmosphere, and transported to the receptor. Interference with one of these steps diminishes odor. Ways to diminish odors include solid separation and biofiltration. Biofilters reduce odor by directing airflow through filters and can be expensive due to the energy costs to operate the fans at higher operating pressure, sprinkling costs to keep the filter moist, and cost to replace the media after five years (VA DEQ, 2001; Nicolai and Lefers, 2006). The installation and operation and maintenance costs are highly variable. The estimated cost of installation of a biofilter is $150 to $200 per 1000 cubic feet per minute (cfm) fan capacity. Biomass filters may provide an economical solution as they hang outside the buildings in front of fans, allowing dust to settle out of the air and thus reduce odor, since dust transports odor and microbes (Craven County, 1997; Bio-Oxygen, 2012).

2.1.2.2 Infrastructure and Accessibility

Drainage around the size reduction facility is particularly important. Water should not pond around the processing area. Access to the equipment with loading, storage and transportation vehicles should be provided. A solid base (such as concrete or asphalt) and anti-vibration cushioning can provide a solid and impervious foundation for the operation and maintenance of the equipment. Constructing a temporary physical barrier (perimeter fence) around the facility may help prevent scavenging wild animals from rummaging in the vicinity. Constructing a temporary physical barrier can be accomplished using materials such as chain-link or equally restrictive fencing with a gate or gates. Proper care should be taken by cleaning and/or covering the carcass residues, if any. Bulking agent and a biofilter covering of exposed carcass material can provide preventive measures. A biofilter cap is a layer of fresh bulking agent (carbon-rich materials such as chopped straw, dried grass, chopped dried hay, and sawdust or shavings) placed over the processed carcass to reduce odors and discourage pests. Nitrogen-rich materials such as animal manure solids, partially decomposed materials, green grass clippings, freshly cut forages, green leaves and litter cake are less effective in controlling odors, insects and vermin and are not recommended (Rozeboom et al., 2013).

2.1.2.3 Wastewater Treatment

Size reduction of carcass material normally performed by closed system without generating any wastewater (Eaglin, 2015). Wastewater from cleaning and sanitizing equipment and building surfaces, and spillage should be contained and transported to offsite treatment facility. If not contained, the wastewater containing high loading of solids, floatable matter, and organic substances requires an onsite wastewater treatment facility. The concentrations of biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, phosphorous, coliforms, and pathogens are highly variable depending on processes and effectiveness of solids separation. Based on an estimated daily water use of 4.54 m^3 (1,200 gallons) and the values for BOD and TSS as 150 mg/L and 58 mg/L, respectively, the estimated hook-up charge by a new small plant in Washington was $51,950 (Hardesty and Harper, 2013). A BOD level of 2,500 mg/L, as reported Hardesty and Harper (2013), increased the hook-up charge to $275,000, while the other values remain unchanged. A 200 gallons per day modular or fixed water treatment system cost reported to vary between $137,000 and $147,000 (Hardesty and Harper, 2013).

The wastewater requirements of the state water quality control board and regulations that the wastewater treatment facility will need to comply with must be considered. Certain states (such as California) have stringent water quality requirements, and wastewater treatment designs require careful planning. The North Coast Regional Water Quality Control Board (NCRWQCB) regulates the discharge of waste to surface waters as well as to storm drains, ground surfaces, and to ground waters in the California North Coast region. The NCRWQCB is responsible for enforcement of the National Pollutant Discharge Elimination System (NPDES), which includes regulating the discharge of waste to ground surfaces or groundwater and a permitting, surveillance, and enforcement program.

2.1.3 Implementability

State and local governments may have regulations for specific types of operations, which can include infectious animal carcass processing facilities. These typically relate to worker and public health and safety regarding aerosol emissions, noise levels, and hazards of projectiles (objects that can be thrown from grinders, shredders or other size reduction systems). The following section discusses the preventive and mitigation measures and regulatory requirements (both for worker health and safety and public nuisances).

2.1.3.1 Aerosol Control

Air can act as a potential vector of contaminants of carcasses and equipment (Pearce et al. 2006). Pathogens can potentially become airborne owing to the sanitation maintenance and carcass processing, especially within solid particles suspended into the air as single organisms or in droplets in the form of aerosols (Spurlock and Zottola, 1991). Pathogens could potentially be transmitted by air and colonize various surfaces. Infectious airborne particles can be produced from atomized liquids in which the pathogenic microorganisms remain as droplet nuclei. Although to initiate infection, much depends on the density, size and the degree of aggregation of the particles to be able to bypass the protective mechanisms of the nose and reach the alveoli of the workers. Dobeic et al. (2011) recognized that there is still insufficient information available about the environmental conditions, routes, and sources, and on how pathogens can become airborne. The bacterial numbers in the aerosol may reflect specific facility practices and temporal influences. The working procedures result in the formation of

aerosols containing different particle sizes and contamination with different numbers of microorganisms. The predominant bacteria in cattle are reported to be S. *epidennidis*, *E.r agglomerans*, *C. freundii*, *E. coli*, *Salmonella sp.* and *E. aerogenes* with smaller proportions of *S. aureus*, *H. alvei*, *C. diversus*, *P. mirabilis* and other bacteria (Vázquez-Moreno et al., 1990). Vázquez-Moreno et al. (1990) reported that the predominant bacteria in chicken were *E. coli*, *S. epidermidis* and *H. alvei* and smaller proportions of *E. agglomerans*, *P. mirabilis*, *Salmonella sp.*, *C. freundii*, *C. diversus*, *M. morganii*, *S. liquefaciens*, *P. vulgaris*, *S. arizona*, *Pseudomonae* and *S. aureus*. Appearances of airborne pathogens are feasible at locations where the potentially contaminated aerosol was spread into the air, with the air contamination by microorganisms increasing and microclimatic properties being suitable. Wheatley et al. (2014) reported that contamination can be introduced at various steps in the size reduction processes. These authors reported relatively high numbers of total viable counts (TVC) and *Enterobacteriaceae* (EB) at several stages of a size reduction process and highlighted the usefulness of monitoring more than one location within the process for each facility so that high risk stages can be identified, increased controls implemented and ongoing monitoring carried out to assess the effectiveness of additional interventions.

Measurement of aerosolized microorganisms relies upon the collection of a sample into or onto solid, liquid or agar media with subsequent microscopic, microbiological, biochemical, immunochemical or molecular biological analysis. Two distinctly different approaches are being distinguished for the evaluation of microbial exposure: culture-based methods and non-culture methods. Instead of counting culturable or non-culturable microbial propagules, constituents or metabolites of microorganisms can be measured as an estimate of microbial concentration. Toxic (e.g., mycotoxin) or pro-inflammatory (e.g., endotoxin) components can be measured, but non-toxic molecules may also serve as markers of either large groups of microorganisms or of specific microbial genera or species. The use of advanced methods such as polymerase chain reaction (PCR)-based technologies and immunoassays can detect and speciate regardless of whether the organisms are culturable. Table 8 gives an overview of assessment methods for constituents of microorganisms (Douwes et al., 2003).

Table 8. Assessment Methods for Microorganisms in Bioaerosol Samples

Microorganisms	Aetiological Agent	Marker	Analytical Method
Gram-negative bacteria	Endotoxin (LPS)		LAL
		3-Hydroxy fatty acids	GC/MS
Gram-positive and Gram-negative bacteria	Peptidoglycans	Muramic acid	GC/MS
Fungi	β(1→3)-Glucans		LAL, ELISA
		Ergosterol	GC/MS
		EPS	ELISA
		mVOCs	GC/MS
Fungi/bacteria	Allergens		ELISA
	Mycotoxins		TLC, HPLC, GC/MS, RIA, ELISA
		DNA	PCR

LPS: lipopolysaccharide; LAL: *Limulus* amebocyte lysate; GC/MS: gas chromatography/mass spectrometry; ELISA: enzyme-linked immunosorbent assay; TLC: thin layer chromatography; RIA: radioimmunoassay; PCR: polymerase chain reaction; mVOCs: microbial volatile organic compounds; EPS: extracellular polysaccharides; HPLC: high performance liquid chromatography; RIA: radioimmunoassay.

Most manufacturers offer, either as a standard feature or an option, aerosol control systems on their grinders/shredders, screens and turners. In other cases, the equipment design or its mode of operation can keep aerosols under control. For example, Bandit Industries' horizontal grinder turns at a slower rotation and moves downward toward the material so that the aerosol is directed into the mill, not upward (US Compost Council, 2001). Collection augers retain dirt and debris until it is forced out of the discharge. The grinder also has a dust suppression system that sprays water before, during and after the grinding process. The Vecoplan (Archdale, North Carolina) grinder also has a low speed cutting rotor (approximately 80 to 120 RPM), and a pneumatic hood is engineered as part of the design for capturing aerosols and conveying chips from the discharge. The cutting rotors on the Komptech (Frohnleiten, Austria) high torque, low speed shredder sold in the U.S. by Norton Environmental Equipment (Independence, Ohio) run at a low RPM (30 to 36), which minimizes aerosolization from the process. Amada Machine Tools America, Inc. (Schaumburg, Illinois) grinders/shredders have enclosed infeed chutes and its disc and trammel screens come with optional top covers. Rotochopper grinders (Rotochopper, Inc., St. Martin, Minnesota) are equipped with either a grinder chamber or an aerosol/dust control chamber. The Peterson Pacific Corp. (Eugene, Oregon) grinders have discharge conveyor covers. Paying attention to wind direction, feed material condition before grinding, and frequent cleanup of both the machine and the surrounding area are important. Process controls should include turning upwind, stockpiling material as wind barriers, containing the output conveyors on screens and positioning equipment (such as building a wind barrier to the input hopper of the trammel or shredder and building a drop chute on the output conveyors) for containing aerosols based on prevailing winds and site conditions.

Aerosol control measures generally fall into three categories: a) overall control at the site; b) grinding and screening; and c) feed inlet, product outlet, and transport. Control measures are required at the size reduction operations as well as the conveyor or other transfer operations. The size reduction facility must be assessed to ensure that the design, construction, product flow, personnel flow, and overall operation contribute to the infectious carcass type and other processing needs. The entire operation should be analyzed to determine locations and/or activities that can contribute to carcass or cross contamination. Following are a few examples that should be considered to contain aerosol contamination:

- Processing floor guards, baffles and separation can be achieved by adding physical barriers, proper designing of air flows and/or flow of the operation and personnel. The clean vs. dirty concept should include design of facilities, as well as actions taken by maintenance, quality assurance, inspections, and flow of traffic.
- Air flow must be controlled and move through the processing facility coming in from clean areas and moving out through dirty areas. Operations should consider the air flow throughout the facility including air from personnel fans and ensure that air is not carrying contamination into the exposed product.
- Air quality of make-up air pulled into the facility should be assessed for directional source, environmental contamination potential, and appropriate filtration system.
- Roof leaks and leakages must be prevented. Continuous preventive maintenance and quality assessment programs are critical.
- Drains must be assessed for proper construction (such as traps, blockages, breakages, and others) and maintenance.
- Separation of welfare areas for employees (break rooms or locker rooms) from clean areas vs. dirty areas can reduce the potential for contamination.

- Intermediate cleanings should be conducted in a manner to prevent splash and aerosols.
- Programs should be developed to ensure that proper procedures for employee hygienic practices, hand-washing practices, cleanliness of dress, and proper use of equipment are followed.
- Employee training is a critical part of the success of the overall operation so that the employees with the knowledge and the resources can perform their jobs as efficiently and effectively as possible.
- Operations re-using water must follow USDA guidelines (9 Code of Federal Regulations [CFR] 416.2g of Sanitation Performance Standards Compliance Guide) including treatment to ensure that there is no introduction of pathogens. If re-use water is not reaching a potable water standard, then it is important to ensure that this water is not used in areas that could cause contamination of equipment, processed material, contact surfaces or employees.

Bioaerosols, as one type of aerosol particles, are removed whenever aerosol particles as a whole are removed or captured (Chattopadhyay, 2005). Therefore, the methodologies of aerosol control also can be used to control bioaerosols. Many aerosol control methods such as filtration, electrostatic precipitation, and impaction have been developed (Chattopadhyay, 2006). However, there are differences between aerosols and bioaerosols. Bioaerosols have biological characteristics, which means that they can grow and produce offspring even after they are captured by conventional aerosol control methods. Bioaerosols cause secondary problems such as generating rank odors and dispersing pathogenic spores after they are captured; therefore, additional treatments may be necessary for biological aerosol particles. Table 9 provides some of the strategies and technologies for controlling aerosols. The strategies are listed from the most desirable (prevention) to the least desirable (dilution) (Hartman et al., 1997). The particulate filters have been implemented to remove microbes from the air stream, where microbes tend to accumulate on the filter surfaces. However, microbes can later proliferate as humidity increases. Ultraviolet germicidal irradiation has been used to inactivate bioaerosols because bioaerosols are particularly vulnerable to damage from ultraviolet (UV) light at 254 nm (Beggs et al., 2006). Plasmacluster ions (Sharp Corporation of Australia) disable airborne microbes by releasing positive and negative ions into the air, and the rate of inactivation is influenced by texture, shape, and bacterial cell wall. Electrostatic air cleaning (electrostatic space charge system) reduces *Salmonell*a by 77% in poultry houses (Durham, 2000). Other technologies may exist, and the cost and effectiveness of the technologies can vary significantly.

Table 9. Bioaerosol Control Strategies and Technologies

Strategy	Technology	Expense	Bioaerosol Control Efficiency
Prevention	Thermal with electric heating coil in selected facility location	Very High	High
	Ultraviolet irradiation [1]	High	High
	Air ion emission [2]	High	Moderate
	Water/steam infusion	High	Moderate
Removal	Particle collectors (wet/dry)	Moderate	High
	Filtration of air	Moderate	Moderate - High
Suppression	Water sprays	Low	Moderate
	Wet cutting	Low	Moderate
	Waterjet-assisted cutting	High	Moderate
Isolation	Enclosed area	Moderate	Moderate - High
	Exhaust ventilation	Low	Moderate
	Control of airflow		
	Separate air split	Low	Moderate
	Spray fan	Low	Moderate
	Air curtain	Moderate	Moderate
Dilution	Main ventilation stream	Moderate	Low
	Local ventilation stream	Low	Low

1: In the ceiling of surgery rooms of hospitals and health care facilities, UV lamps are often installed and function to inactivate nearby bioaerosols (Kujundzic et al., 2006)

2: The emission of air ions (ion density of 105–106 $e^{\pm}$ cm^{-3}) for 30 minutes results in the removal of 97% of 0.1 µm particles and 95% of 1 µm particles from indoor air (Lee, 2011). The removal of aerosols by ion emission will result in bioaerosols being transferred from the air to the ground, walls, and ceiling.

2.1.3.2 Noise Control

OSHA sets maximum noise limits to protect workers from noise-related injuries depending on the level and duration of the noise. At levels above 85 decibels, hearing conservation precautions must be taken with hearing protection safety equipment including ear muffs and ear plugs. Equipment modifications to minimize impact from noise include use of enclosed cabs, exhaust mufflers, hood over the grinder engine, and motor with sound insulation or building a sound barrier around the size reduction unit. A buffer zone of vegetation around the facility's perimeter also lowers the noise level to the neighborhood. Operating the machine at lower RPM, on earth (rather than on concrete) using electric engines (instead of diesel-powered) can reduce the noise. Rubber mats (10 millimeter thickness) can act as a noise dampening insulation.

2.1.3.3 Minimizing Projectiles

Projectiles generated by the size reduction process can result in dispersion of pathogens, cross contamination and impact worker protection. A tub grinder can project an object as far as 300 feet (Yepsen and Goldstein, 2009). Maintaining the curtains, wearing safety glasses and hard hats, positioning the operator in an enclosed cab and enforcing restricted access to the processing area can provide operator protection during operations.

Size reduction units (such as tub grinders and others) typically have features to deflect and control projectiles. Horizontal grinders, because of their configuration, have less of a tendency to generate flying objects. Low speed operation and a rotor design that turns down toward the

material (not upwards) can contain projectiles. Projectile control features include the direction of rotation of the horizontal rotors, a continuous horizontal feed, containment structures, a floating compression roll that closes automatically on lower loads and a material deflection curtain and shear pin shutdown mechanism. A screen is erected at the front of the horizontal grinder from Fecon, Inc. (Lebanon, Ohio) to prevent any fragments from leaving the immediate work area. The power feeder manufactured by Rotochopper, Inc. (St. Martin, Minnesota) rises 15 inches to minimize the chance of flying materials. Amada Machine Tools America, Inc. (Schaumburg, Illinois) have grinders with enclosed top covers. Tub grinders manufactured by Vermeer Corporation (Pella, Iowa) are equipped with a thrown object restraint system that reduces the distance and amount of material ejected by the grinder by: a) a drum deflector that partially covers the rotor or drum on the upswing, and b) a tub cover partially enclosing the top left side of the tub. The following operations can minimize projectiles and maximize worker safety: a) keeping the tub or feed hopper full at all times, b) avoiding the feeding of nongrindable materials, c) maintaining grinder covers properly and using double covers or impact shields, d) starting to load the tub grinder with prebreaker material and then loading the carcass material that needs to be processed (this practice will cover the rotor or drum with prebreaker material and will not allow large material to contact the rotor or drum initially), e) keeping the tub as full as practicable to reduce the amount and distance of thrown objects, as the material itself acts as a shield over the grinding chamber, f) before ending the size reduction operation, grinding to be finished until the tub is approximately half full, and emptying the tub the next day by opening it and letting the unground material fall out, and g) grinding with the tub cover and deflector in place and over the tub.

2.1.4 Reduction in Toxicity, Mobility, or Volume through Treatment

The best available techniques (BATs) defined as the "*most effective and advanced stage in the development of an activity and its methods of operation, which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission values designed to prevent or eliminate or where that is not practicable, generally to reduce an emission and its impacts on the environment as a whole*" (Ireland EPA, 2008). In addition to the consideration of costs, advantages of alternatives and the precautionary and prevention measures, the European Communities' Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC and the Environmental Protection Agency Acts 1992 to 2007 require the determination of BAT for the management or recycling of animal carcasses and animal waste to consider the following items:

- the use of low-waste technology,
- the use of less hazardous substances,
- the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate,
- comparable processes, facilities or methods of operation, which have been tried with success on an industrial scale,
- technological advances and changes in scientific knowledge and understanding,
- the nature, effects and volume of the emissions concerned (CO_2, SO_2, oxides of nitrogen (NO_x), and dust)
- the commissioning dates for new or existing activities,
- the length of time needed to introduce the best available techniques,

- the consumption and nature of raw materials (including water) used in the process and their energy efficiency,
- the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it, and
- the need to prevent accidents and to minimize the consequences for the environment.

The rendering process is one of the animal carcass management options that involves size reduction, to meet the requirements of Animal By-Products (ABP) Regulation 1774/2002/EC (Regulation No. 1774/2002 of the European Parliament and of the Council health rules related to animal by-products not intended for human consumption). Potential process impacts of a rendering operation on the environment are outlined in Table 10.

Table 10. Impact on Air, Water, Land, and Energy by Rendering

Air*	Water*	Land	Energy Consumption*
Range of Emission (kg per ton of unspecified animal treated by rendering) CO_2: 10.2-14.6 SO_2: 1.2-1.6 NOx: 0.51-0.59 Dust: 0.19-0.21	**Consumption**: 500-1000L/ton of carcass materials (condensers - 200-500 liters (L)/ton; boilers - 150-200 L/ton; and cleaning 200-300 L/ton). **Wastewater Generation**: 1000-1500 L/ton. 5 kg/ton of chemical oxygen demand (COD), 600 g/ton of nitrogen and 1.65 kg/ton of solids. The waste water from the process exhaust air treatment can contain the following contaminants: mercaptans < 2 g/L, hydrogen sulfide < 800 mg/L, ammonium nitrogen < 400 mg/L, volatile oils, phenols, aldehydes, solids and cleaning agents.	Leakage from drainage pipes and tanks can release biological contaminants to soil. In addition, bulk storage of fuels and other chemicals if not properly managed may pose a risk of accidental spillages and leaks.	**Electricity**: Approximately 75 kilowatt hours (kWh)/ton Heat: Approximately 775 kWh/ton Odor abatement and wastewater treatment: Approximately 20 kWh

* European Commission (2005)

2.1.5 Cost

Hoque et al. (2007) defined equipment costs as the sum of the ownership and operating costs, where ownership costs are fixed or overhead costs and independent of the amount of equipment used. The operating costs increase in proportion to the amount of time the machine is used. These authors calculated tub grinding (120 ton/hour) costs on an hourly basis considering a five-year life cycle with 1750 hours per year of actual grinding operation. The capital cost of a grinder (model 1300 Tub Grinder) was $ 535,750, amortized over 8750 hours of machine life, the interest rate was assumed to be 8.00% per year on a declining balance, and the insurance cost was an average rate of $2.40 per $100 per year =$12858, divided by 1750 hours. Table 11 provides an example of the hourly cost estimates of a tub grinder (Hoque et al., 2007).

Table 11. Representative Hourly Cost Breakdown of Tub Grinder Operation

Total Equipment Cost ($/hour)		Maintenance Cost ($/hour)	
Purchase price	61.23	Inserts, nuts and bolts	
Interest	13.26	20 inserts at $18.00 each, every 80 hours	4.50
Insurance	7.35	40 bolts at $2.40 each, every 160 hours	0.60
Subtotal (Owning Cost)	81.84	40 nuts at $2.40 each, every 160 hours	0.60
Machine maintenance	28.62	Grates (2 grates at $1000 each, every 500 hours)	4.00
Fuel cost	70.00	Hammers (20 hammers at $170 each, every 1000 hours)	3.40
Labor cost	30.00	Rakers (18 rakers at $155 each, every 500 hours)	5.58
Subtotal (Operating Cost)	128.62	Rods (8 rods at $160 each, every 2000 hours)	0.64
Total	210.46	Labor involved in changing wear parts	
Estimated Cost ($/ton)	3.01	and general maintenance (at $30/hour, every 8 hours)	3.75
		Grease (1 tub at $4.82 per unit, every 8 hours)	0.60
		Maintenance	
		1 primary fuel filter at $80 each, every 200 hours	0.40
		1 oil filter at $20 each, every 200 hours	0.10
		2 primary air filters at $110 each, every 200 hours	1.10
		2 secondary air filters at $70 each, every 200 hours	0.70
		2 hydraulic filters at $65 each, every 200 hours	0.65
		Miscellaneous parts (nonstandard items - such as seal kits, bearings, etc.)	2.00
		Total maintenance cost	28.62

The above table provides itemized costs in various categories including the parts to be replaced or repaired, labor and materials for daily maintenance involving lubrication, inspection, and wear parts. Hammer life, screen life, and rod life are dependent upon operator experience, material being processed, screen size, climatic conditions, and methods of loading material into the tub grinder. The fuel consumption for the 860 horsepower (hp) Caterpillar 3412 was estimated at 28 gallons per hour with estimated fuel cost of $2.50 per gallon. Labor cost including benefits depends on the area.

Capital recovery of size reduction machinery has been estimated by Turhollow (2002) by the following equation.

$$\text{Capital recovery} = \frac{(PP - dSV) \times \frac{i(1+i)^n}{(1+i)^n - 1} + dSV \times i}{h_a}$$

where:

PP = Purchase price

dSV= is the discounted salvage value which is calculated as the percent of list price at the end of year n by $60(0.885)^n$

i = interest rate

n = years of life

h_a = annual hours of use.

Repair and maintenance of chippers and grinders (hammermills) can be estimated as 10 percent and 20 percent of the purchase price per year, respectively (Naimi et al., 2006).

Fuel use (gallons/hour) = 0.73 × 0.06 × 1.34 × Power (kW)

$$\text{Insurance and taxes} = \frac{(PP+dSV)/2}{h_a} \times i$$

Labor cost is calculated using the following correlation assuming the benefit rate as 10 percent and the wage rate is $20 per hour.

Labor cost = (1+benefit rate) × wage rate

The operating inputs are charged for interest on a six-month basis as per the following equation.

Interest on operating cost = (i/2) × (repair and maintenance cost + fuel cost)

Table 12 shows the hourly cost breakdown of different chippers and hammermills. Chipper cost ranges from $157 to $161 per hour, and hammermill cost ranges from $229 to $252 per hour.

Table 12. Representative Hourly Cost Breakdown of Chipper and Hammermill Operation

Type of Size Reduction Unit	Energy	Capital Cost ($)	Life Time (year)	Operating Time (hours/year)	Hourly Cost ($)
Drum Chipper	200	625,542	8	2,000	157
Large Disk Chipper	448	313,589	8	2,000	161
Mobile Grinder (Hammermill) (not self-propelled)	521.5	381,500	5	1,700	229
Mobile Grinder (Hammermill) (self-propelled)	521.5	471,500	5	1,700	252

A mobile size reduction processing is a self-contained trailer facility that can address small outbreak events, or multiple units that can be used for a larger event. The trailer is normally divided into three sections: mechanical/storage, carcass cooler, and processing area. The design of the unit takes into consideration the need for robust construction while minimizing weight, sanitary operations and cleanup. The cooler and processing sections are wet areas and all materials and electrical fittings are rated for use in wet environments. The capacity of the mobile unit can range up from 10 beef, 24 hogs, or 40 sheep per day with two operators. The cooler in the trailer can hold up 6,000 pound of carcasses. A typical unit is equipped with a diesel generator, water storage, hot water heater, refrigeration and tools to allow for fully self-contained operation. Investment costs range depending on design and other supporting facilities (such as level of processing, freezers, space, etc.). Costs of mobile units range between $150,000 and $250,000, depending on the configuration and equipment. Additional construction costs may be required at each site where the mobile unit is operated to address the following issues: water sources and waste management, maintenance of the grounds immediately surrounding the operational site, sanitary facilities and office accommodations for

personnel, and others. Table 13 provides the approximate costs of typical fixed and mobile size reduction facilities.

Table 13. Estimated Cost of Fixed Plant and Mobile Unit.

Description	Fixed Plant	Mobile Unit
Footprint (square feet)	5,250	300 (34 feet long)
Number of Workers	6-10	2-4
Cost of Trailer for Carcass Hauling ($)	60,000	NA
Truck for Trailer or Mobile Unit ($)	18,000	18,000
Processing Facility Investments ($) [1]	525,000 – 2,187,000	170,000 [3]
Total Processing Facility Cost ($)	603,000 – 2,258,000	303,000 [4]

NA: not applicable.

1: Fixed facility price per square foot = $100-400, depending on materials used, without land acquisition costs (Hardesty et al., 2009; Iowa State University, 2010; Irwin, 2011).

2: Land cost assumes $40,000 per acre (dependent on location) and land requirements for fixed plant and mobile unit are two acres and one acre, respectively.

3: Gooseneck trailer (33 feet long × 8.5 feet wide × 13 feet tall) with 8.5 feet x 11 feet processing area, 8.5 feet x 11 foot holding cooler, 8.5 foot x 10 foot mechanical room, 6000 pound cooler capacity, and F450 Ford Truck as tow vehicle costs $150,000; and a second similar unit costs $110,000 without the tow vehicle (Sleeping Lion Associates, 2005)

4: Includes construction cost of $115,000 for the mobile unit.

A customized cost can be prepared for case specific conditions to evaluate whether it would be better to purchase a machine or to hire the equipment to do the processing during the outbreak. The cost estimate should include site development costs, utility hook-up fees, permits and wastewater pre-treatment costs, and obtaining a site with appropriate zoning and municipal services.

2.1.6 Regulatory Issues

Potential causes of mass animal mortality range from natural disasters to more complex situations involving infectious diseases. Notwithstanding the cause, timely and effective local response is essential to limit impact on the industry and community, and to allow for the mobilization of resources locally and from other levels of government as required. Communications and coordination with local and federal government play an important role as the carcass management guidelines, if any, vary from state to state. A few examples are indicated in Table 14. Analogous to the Resource Conservation and Recovery Act (RCRA) definition of hazardous waste being a subset of solid waste, infectious waste is a subset of medical waste. Local information on carcass management, state resource locators and the American Veterinary Medical Association (AVMA) policies are available at http://www.vetca.org/lacd/index.cfm last accessed September 2, 2015 (Veterinary Compliance Assistance, 2015).

Table 14. Examples of Local Carcass Management Regulatory Issues.

State/ Country	Sample Disposal Issue	Reference
British Columbia, Canada	Guidance included for planning and response within the regional district of Fraser-Fort George including its member municipalities and electoral areas for dealing with mass animal carcasses generated in an emergency and the handling of SRM.	St. John & Associates Projects Inc. (2009)
California	The California Department of Food and Agriculture does not regulate carcass management for animals. Local government (county department of environmental health) and federal agency tasked with public health or air or water pollution are involved.	Doran (2004) Franco (2002) CalRecycle (2015)
Colorado	In the event of any all-hazard event that results in livestock mortality, the Colorado Department of Agriculture shall exercise its authority as lead agency to respond to, direct and otherwise manage any such event.	State of Colorado (2011)
Maine	During catastrophic events a large number of carcasses must be managed and equipment must be brought onto the farm, biosecurity protocols shall be established to minimize the amount of traffic on and off the farm to ensure proper disinfection procedures are used, and to limit exposure of livestock to off-farm traffic. In the case of a disease outbreak, the farm operation shall contact the appropriate state and federal animal health authorities for direction on implementing biosecurity measures.	Maine Department of Agriculture, Conservation and Forestry (2012)
Michigan	Rendering services must be provided by a licensed dead animal dealer, rendering plant or animal food manufacturing plant. Standard operating procedures for mass carcass management are available at http://www.michigan.gov/documents/mda/Mass_Carcass_279789_7.pdf. A list of recent (2015) licensed renderers is available at http://www.michigan.gov/documents/mdard/Transporting__Disposal_of_Dead_Animal_List_by_County_Report_Jan2015_478984_7.pdf last accessed September 10, 2015	Michigan Department of Agriculture and Rural Development, 2015
North Carolina	Veterinary Division is the lead state agency to oversee animal carcass management as regulated under existing Administrative Rules, specifically, Subchapter 52C - Control of Livestock Diseases: Miscellaneous Provisions, Section .0100 - Diseased and Dead Animals. The State Health Director and by extension the Local Health Director in each county is charged with preventing health risks and disease and promoting a safe and healthful environment according to NCGS 130A, Articles 1-20.	State Animal Response Team (2003)
Washington	The solid waste management plan considers that animal carcasses in excess of 15 pounds are agricultural wastes. This plan allows for burial of animal carcasses with a minimum of two feet of cover and 100 feet from any well or surface water during an emergency or disease outbreak. All carcasses must be transported to the carcass management site within 24 hours. Rendering should be performed by a licensed rendering company. Incineration can be performed at a permitted facility suited for this waste type. Composting to be done utilizing Best Management Practices. Washington State Department of Agriculture (2014) indicates that a carcass must be disposed of within 72 hours of the time of death or discovery to avoid nuisance odors or disease. If weather conditions prevent burial within 72 hours and rendering, composting, landfilling, or natural decomposition cannot be accomplished, then the carcass must be buried as soon as the weather permits.	Clark County Department of Environmental Services (2015)

Category 2 material, which includes the carcasses of animals that die on-farm, should be treated according to Method 1 as defined in Annex IV to EU Regulation 142/2011 (i.e., 133°C / 20 min/3 bars/50 mm particle size) before being used as an organic fertilizer (Article 13 (d) of European Commission (EC) Regulation 1069/2009) (European Food Safety Authority (EFSA), 2011). Method 1 is a sterilization process deemed to inactivate heat resistant hazards including bacterial spores with a sufficient safety margin. This method is intended also to cover risks that are not known until now, taking the experience of the BSE crisis into account. Indeed, Method 1 has been shown to reduce the titers of TSE agents between 2 to 3 log10 (Schreuder et al., 1998). Cohen et al. (2001) reported that a batch rendering system can achieve a 3.1 log reduction (1,000-fold) in BSE infectivity, while a continuous system can reduce infectivity 2.0 log (100-fold) to 1.0 log (10-fold). The rendering industry in the U.S. is closely regulated by state and federal agencies, with each routinely inspecting rendering facilities for compliance to BSE-related regulations and chemical residue tolerances. USDA's Animal and Plant Health Inspection Service (APHIS) issues export certificates and inspects rendering facilities for compliance to restrictions imposed by the importing country. State officials inspect and enforce quality, safety policies, issuance of air and water quality permits and rendering licenses, and making sure that dead or diseased animals are not illegally diverted for use in food (Hamilton et al., 2007).

At the installation/facility level, the most appropriate techniques will depend on local factors. A local assessment of the costs and benefits of the available options may be required to establish the suitable option. The overall objective of ensuring a high level of protection for the environment by appropriate management of infectious carcasses can often involve making trade-off judgments between different types of environmental impacts, and these judgments will often be influenced by local considerations. The obligation to ensure a high level of environmental protection including the minimization of long-distance or trans-boundary pollution implies that the most appropriate techniques cannot be set on the basis of purely local considerations. The choice can be made by considering various factors including the following areas as suggested by Ireland EPA (2008): a) the technical characteristics of the facility; b) its geographical location; c) local environmental considerations; and d) the economic and technical viability of upgrading existing installations. The efficient and environmentally safe treatment and management of mass animal carcasses will require:

- early notification;
- an estimate of the scale of carcass management required;
- the selection of an appropriate carcass management methodology;
- the availability of suitable carcass management sites; and
- the timely provision of applicable resources.

Rules and regulations on facilities and equipment for meat and poultry establishments are available (Federal Register, 1997) and may be considered as guidance in considering decisions about design and construction of the carcass pretreatment facilities, as well as the selection of equipment to be used in their operation. The information included in the Federal Register (1997) was drawn from technical knowledge and experience used by the Food Safety and Inspection Service regarding the acceptability of facilities and equipment.

The South Coast Air Quality Management District (SCAQMD) in California is proposing rule 415 to reduce public exposure to odors from rendering facilities (SCAQMD, 2015). This proposed

rule includes establishment of odor management practices and requirements to reduce odors from facilities rendering animals and animal parts, odor best management practice requirements for the transportation and handling of rendering material, and cleaning and maintenance at the rendering plants, enclosure and odor control requirements for the receipt and processing of rendering material and wastewater, and an odor mitigation plan for facilities with continuing odor issues. The enclosure standards and odor control standards of the proposed rule 415 specifically indicate that the size reduction and conveying equipment, material receiving areas, and transfer operations at a rendering facility shall not be operated except that the equipment or process is operated in a closed system or located within the confines of a permanent enclosure.

2.1.7 Personnel Safety

The operation of heavy equipment, handling and processing require the operators and regulators to be vigilant with regard to worker health and safety. There are specific worker protection standards set by the federal Occupational Safety and Health Administration (OSHA) that apply to equipment as well as the operation of the equipment. Personnel safety is an overriding consideration during carcass treatment operations. In a treatment facility setting, microorganisms can enter the body through the mouth, lungs, broken or unbroken skin or the mucous membrane lining of the inner surface of the eyelids. Before commencing treatment/processing work, personnel must be fully briefed on the nature of the disease and any specific hygiene requirements. Safety issues to consider include personal hygiene facilities, the availability of rescue equipment, hearing protection and protection from dust. Protective clothing including respirators must be supplied to personnel when there is any risk to humans from the organism involved, or if large amounts of dust or odor are generated.

The safety and security items generally include the following items:

- Warning signs,
- Prevention of visible contamination to or from the carcass surface,
- Necessary actions in the event of visible contamination,
- Notifying supervisor of abnormal events or activities that may impact product safety,
- Sanitizing of hand tools,
- Portable carcass management site lighting,
- Road pylons,
- Site marking tape, and
- Identification badges.

The personnel protective equipment (PPE) will include the following items:

- Protective clothing including footwear,
- Coveralls,
- Masks or respirators,
- Decontamination equipment and chemicals,
- Medications such as anti-virals (controlled by medical staff),
- Portable toilets,
- Temporary shower and changing facilities,
- Clothes washing facilities, and
- Walk-through footwear disinfectant facility.

In general, for all work or all situations where contact may occur with carcasses, carcass processing or any other potential bioaerosol source, the wearing of PPE is recommended. This equipment for bioaerosol areas must include impermeable coveralls, with rubber gloves and boots, a helmet and visor for dirty work, a type N-95 National Institute for Occupational Safety and Health (NIOSH)-approved disposable respirator (Goyer et al., 2001). For damp locations, a respirator with a valve at the center is recommended.

No employee shall operate and/or cause to be operated any machinery without proper protective guards in place or modify/disable any protective guards on machinery without contacting appropriate health and safety authority for such approval or implementing the lockout/tagout program. Such guards shall be provided to protect the operator and other employees from hazards such as exposed belts, pulleys, sheaves, drive shafts, drive couplings, chains, rotating parts, flying chips and sparks. Special hand feeding tools for placing and removing material shall be such as to permit easy handling of material without the operator placing a hand in the danger zone. Such tools shall not be in lieu of other guarding required by the pretreatment facility policy but shall be used only to supplement protection provided.

The presence of plastics and other contaminants (particularly chlorine compounds) in the carcass feed material for the size reduction facility should be avoided to reduce the generation of persistent organic pollutants during incomplete combustion if incineration and burning carcass management options are considered. Use of plastic bags and similar material is necessary for operator and animal hygiene. However, the use of plastic bags should be minimized by use of mechanized and automatic feed devices. Methods to be considered for safe handling and operations include: a) use of mechanized loaders to avoid contact with carcasses; b) use of macerating and grinding techniques to allow automatic, continuous loading and operation; and c) minimizing contamination from packaging, including use of non-halogenated plastics (UNEP, 2006).

The storage, handling, grinding and charging equipment needs to be cleaned periodically and usually before maintenance, by passing wood chips through the system and then incinerating them.

The management of the facility is the key to ensuring safe and environmentally benign operation. All personnel operating the facility shall be fully conversant with their duties, in particular with regard to routine operation, maintenance, disease control, process upset conditions and local environmental legislation. The competence of operators shall be addressed by suitable training at an appropriate level for the facility.

Tools and procedures should be available to ensure the safe work environment of the workers. Equipment and all accessories should be cleaned and sanitized or used in designated areas to control contamination. The procedures should also address proper dress and PPE for employees. If unexpected interruptions occur (extended mechanical downtime, complete equipment breakdown, refrigeration failure, power outage, etc.), the facility should have procedures in place so that these procedures can be implemented quickly. These procedures may include availability of alternate power generators, microbiological testing of carcasses and contact surfaces, zone cleaning and utilization of bioluminescence testing to demonstrate sanitary conditions.

Advanced Sensors and Monitoring Systems

The capability of the microsystems in meat industries can bring new measuring or monitoring tools that may compensate the investment effort by bringing cost cutting or creating novel added value. A size reduction facility requires a significant quantities of water at different stages of processing. A fast analysis of cleanliness using a disposable 'lab-on-chip' system would allow reduction of the amount of detergent and water to a lower level while routinely checking the efficiency and improved sanitation by providing continuous and statistical measured data (Vivancos et al., 2012). PCR-microarray assays provide new methods for the identification of animal-derived ingredients. For example the mitochondrial DNA (mtDNA) 16S rRNA gene can be selected as a vertebrate molecular marker gene to detect animal-derived ingredients including bovine, goat, pig and chicken (Delevoye, 2013). The PCR amplification and hybridization conditions can be optimized according to the sets of species-specific microarray probes including pairs of quality control probes designed with universal primers so that the animal-derived ingredients can be checked rapidly and accurately. The micro-PCR chips can also detect pathogens. Although the fast detection of microorganism methods are not allowed by regulatory authorities, they can be used for screening of products and materials to reduce the number of expensive tests (ACTIA, 2013). In addition, the antibody-conjugated nanoparticles can readily and specifically identify a variety of bacteria through antibody-antigen interaction and recognition with an extremely high fluorescent signal for bioanalysis and can easily be incorporated with biorecognition molecules, such as antibodies. Handheld and contactless equipment based on miniaturized sensing and detection systems can provide safe handling and processing of infectious carcasses to analyze physical and chemical parameters. The X-ray system can scan up to 38 tons per hour of carcasses and determine fat content and weight with a high accuracy, while also spotting foreign objects. Metal objects as small as 0.0118 inch can be detected with the DETECTRONIC X-ray scanners, as well as other contaminants including bone, shell, stone, rubber, and plastic.

Size reduction of animal carcasses induces a high risk of work-related musculoskeletal disorders, and increases the difficulty of developing efficient working assistance and security tools for workers (Pontonnier et al., 2011). Co-manipulation (manipulation of an object simultaneously held by a robot and a human operator) is an emerging robotics field that can provide biosafety and security tools for musculoskeletal disorders and pathogen exposure (see examples in Figure 3). A generic arm cobot (collaborative robot or exoskeleton-like assistance equipment) can be used in handling and processing of carcasses to acquire parameter values (such as volatile gas sensing, colorimetric analysis). A cobot can be worn by a worker and assist in lifting, or the bodyweight assistant robot could also adjust the optimum working height according to the size of the worker or other conditions.

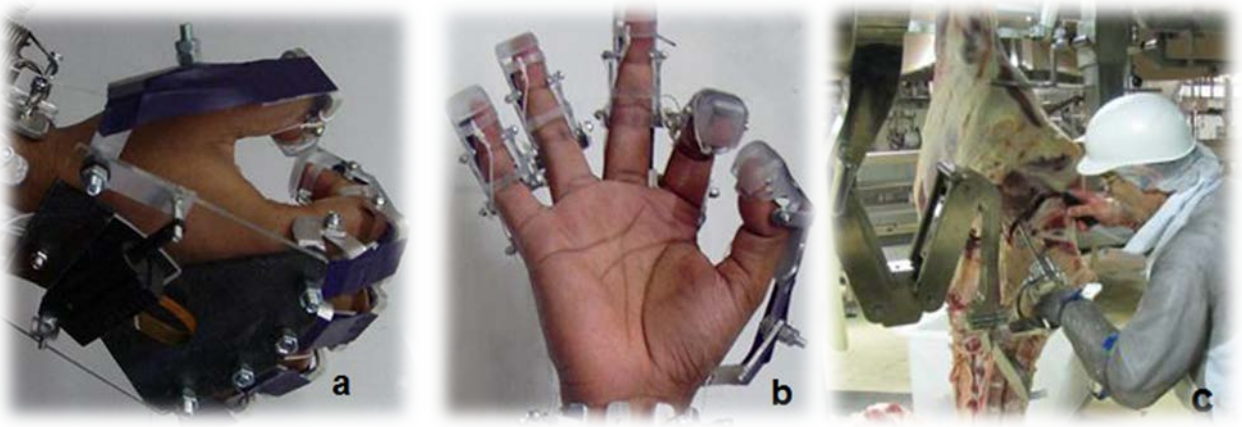


Figure 3. Examples of Robot Integrated Sensors that Could be Adapted to Carcass Handling and Processing Tasks
(photographs are shown with permission from Dr. Elisabeth Delevoye, Université de Grenoble, France)

2.1.8 Community Acceptance

The pretreatment facility and its infrastructure involve interactions with the local community, state and federal agencies. Proper pretreatment and carcass management plans for infectious animal carcasses within an emergency management system must include consideration of the type of event generating the deaths, environmental and regulatory factors that could complicate carcass management efforts, logistical issues (size and scope), cost, disease biosecurity concerns, and public perception. These issues should be integrated vertically to include national, state, and local community and emergency responders, and horizontally to include scientific proficiency from each of the professionals (and their respective state/federal agencies) that will have roles in animal carcass management issues.

2.1.8.1 Media / Public Information

An effective public information strategy is an essential part of managing an emergency. The public will demand information even if the effects of the size reduction of infected carcasses are limited, which will put an enormous premium on what local officials say publicly and how they say it. Negative public reaction can often be defused by an articulate, calm and confident spokesperson who is able to reassure the public that the response is appropriate and effective. It is expected that there will be a high demand for information throughout treatment operations. The effective diffusion of information is particularly important as there are likely to be several levels of responders involved. The key is to have designated public information officers and/or spokespersons from the outset, including industry representatives, who cooperate closely with each other. A clear, timely and consistent message is essential. Appropriate Federal, State, and local organizations involved must ensure that the overarching requirement to deliver information is not unduly delayed by a perceived need to assemble complete information. The public may want to know the situation and should be briefed accordingly. An information officer should be in the Emergency Operations Center (EOC) at all times to collect and coordinate the information being received and to ensure that the media and public are briefed regularly and comprehensively.

2.2 Physical Inactivation

Inactivation can target the extracellular or outer surface components of microorganisms or intercellular or inner components such as nucleic acids, with the aim of impeding the ability of the pathogen to replicate. Inactivation technologies fall into two broad categories, namely, physical and chemical. Physical inactivation includes application of dry heat (flaming, hot air oven, infrared), moist heat (below 100 ˚C, at 100 ˚C, above 100 ˚C), ultra-high pressure steam, energy (thermal, plasma arc irradiation, pulsed-field electricity, ultrasonic energy, UV light). When microorganisms are exposed to UV light, dimerization of the nucleic acids occurs, thereby impeding the ability of these microorganisms to replicate. Thermal inactivation, however, relies on the principle that at certain temperatures, infectivity and immunogenicity of microorganisms are lost at the same rate while at other temperatures, these properties are lost at different rates. Sonication disrupts the morphological structure of microorganisms while retaining the immunogenic components. The effectiveness of key physical inactivation treatment of infectious carcasses is discussed in the following section.

2.2.1 Effectiveness

Water

The removal of pathogens from carcasses by water can sometimes be effectuated using a rinse, spray, immersion bath or steam treatment. Only small reductions in bacterial load can be achieved by rinsing a carcass with pure water. During immersion chilling, a substantial decrease in contamination levels of carcasses can be expected, and the variation in the bacterial load of individual carcasses will be reduced. The effectiveness of spraying carcasses with cold water is not affected by the water pressure, does not decontaminate carcasses, and aerosols that are generated may even spread microbial contamination. The decontaminating effect of a hot water spray is partly caused by the lethal effect and partly by the detachment of pathogens or removal together with melted softened fat. Pathogens that are attached to skin surfaces might be more heat resistant than the pathogens that are not attached (Dickson and Anderson, 1992). High-pressure washing of carcasses with cold water has resulted in improved microbiological quality (Bolder, 1997). Although only a small amount of moisture was taken up by the carcasses, pathogens might be driven into the tissue or interior areas by high pressure. Steam can also be used for inactivation of pathogens on carcass surfaces. The advantages of steam are the efficient heat transfer, lack of residues and an intense additional cleaning of the surfaces. Disadvantages are the difficulties of application in a continuous production process.

Moist heat in the form of saturated steam under pressure is the most widely used and the most dependable method for removal of pathogens from carcasses by water. Steam sterilization is nontoxic, inexpensive, rapidly microbicidal, sporicidal, and rapidly heats. Like all sterilization processes, steam sterilization has some deleterious effects on some materials, including corrosion and combustion of lubricants. The basic principle of steam sterilization, as accomplished in an autoclave, is to expose each item to direct steam contact at the required temperature and pressure for the specified time. Thus, there are four parameters of steam sterilization: steam, pressure, temperature, and time. Specific temperatures must be attained to ensure the microbicidal activity.

Microwave Inactivation

Microwave inactivation is essentially a steam-based process, since inactivation occurs through the action of moist heat and steam generated by microwave energy. A microwave system

consists of a chamber into which the electromagnetic spectrum is directed from a microwave generator (magnetron). Typically, two to six magnetrons are used with an output of approximately 1.2 kW each. Some systems are designed as batch processes and others are semi-continuous. The treatment system consists of a charging system, hopper, shredder, conveyor screw, steam generator, microwave generators, discharge screw, secondary shredder, and controls. The equipment includes hydraulics, high-efficiency particulate air (HEPA) filter, and microprocessor-based controls protected in a steel enclosure.

Gamma Irradiation

Irradiation with a low dose of ɣ-rays is more successful than some of the chemical treatments such as glutaraldehyde or chlorine. Gamma irradiation provides a number of benefits in cost and sterility assurance. It can be applied under safe, well-defined, and controlled operating parameters, and is not a heat- or moisture-generating process. Consequently, there is no heat stress and condensate drainage and outgassing is not required. Most importantly, there is no residual radioactivity after irradiation. Electron accelerators do not require isotopes, but need high energy levels up to 10 megaelectron volts (MeV) and permit an effective penetration of radiation into the product of only 1-2 cm (Corry et al., 1995). This type of pretreatment is insufficient for the overall inactivation of whole carcasses, although superficial contamination will be eradicated.

Electron Beam Radiation

A beam of high-energy electrons from an electron gun is propelled at high speed to strike against a target. Typically, e-beam systems consist of a power supply; a beam accelerator where the electrons are generated, accelerated, and directed towards the target; a scanning system that delivers the required dose; a cooling system to cool the accelerator and other assemblies; a vacuum system to maintain a vacuum in the accelerator; a shield to protect workers; a conveyor system to transport the carcasses; and sensors and controls. The shielding system could be in the form of a concrete vault, an underground cavity, or an integral shield around the treatment area. E-beams do not alter the physical characteristics of the carcass material except perhaps to raise the temperature a few degrees.

Plasma Technology

Plasma is matter that contains partially or wholly ionized gas with a net neutral charge and is often referred to as the fourth state of matter as it shares properties similar to both those of gases and liquids. Plasma is created by energy deposition into a gaseous mixture. Gas turns into plasma due to ionization, dissociation and excitation of the bound states of atoms and molecules of the background gas. Therefore, plasma consists of a gaseous mixture of charged particles (free electrons and ions) and neutral activated species including gas molecules, free radicals, metastables and ultraviolet photons. Energetic electrons generate intensively numerous chemical active species due to collisions between atoms and molecules. In the gas mixture containing oxygen and water vapor, most of the primary radicals are O and OH. Cold plasma produces (gaseous) activated ions, photons, electrons and free radicals, collectively termed plasma, that exert their effects at 30 to 60 °C; hence, the term ‘cold’ or non-thermal. Plasma may inactivate both vegetative cells and bacterial endospores (Aly and El-Aragi, 2013). Synergistic effects between these possible mechanisms of inactivation can be expected, depending on the operational conditions and the design of the plasma generator. Plasma has been used for management of some waste streams in the past, but has not been demonstrated on animal carcasses at the field scale.

Pulsed-field Electricity
Pulsed-field electricity is used for the electrostimulation of carcasses in the cattle industry. Research has shown that the treatment also causes a reduction in bacterial counts and prolongation of the lag phase of bacterial growth (Bawcom et al., 1995).

Ultrasonic Energy
The application of ultrasonic energy to carcasses is possible when they are immersed in water; application is therefore suitable only for small carcasses that can be immersed. The inactivation effect is due to cell disruption, which can be amplified by the combination method of physical and chemical treatment (such as altering the pH and temperature or by chlorination). The presence of fat may reduce the effectiveness of the technique as sonication can be inhibited by the presence of organic material.

Ultraviolet Light
UV light can be used to inactivate pathogens present on the surface of the carcasses, to decontaminate water, and to control the pathogen aerosolized in the atmospheric light in the storage and processing areas. UV radiation has several potential applications, but unfortunately its germicidal effectiveness and use is influenced by organic matter; wavelength; type of suspension; temperature; type of microorganism; and UV intensity, which is affected by distance and dirty tubes. Its use on carcass surfaces can be ineffective if the skin surfaces are highly irregular, with hair and feather follicles causing shadow areas that cannot be reached by the UV light. Bacteria and viruses are more easily killed by UV light than are bacterial spores.

Thermal Processes
Thermal processes are those that rely on heat (thermal energy) to destroy pathogens in the carcass material. This category can be subdivided into low-heat, medium-heat, and high-heat thermal processes. Low-heat thermal processes (93 °C – 177 °C) are those that use thermal energy to inactivate the carcass material at temperatures insufficient to cause chemical breakdown or to support combustion or pyrolysis. The two basic categories of low-heat thermal processes are: a) wet heat treatment that involves the use of steam and is commonly done in an autoclave; and b) dry heat (hot air) processes where no water or steam is added. Instead, the waste is heated by conduction, natural or forced convection, and/or thermal radiation using infrared heaters. Medium-heat thermal processes take place at temperatures between 177 °C to 370 °C and involve the chemical breakdown of organic material. The key processes are reverse polymerization using high-intensity microwave energy and thermal depolymerization using heat and high pressure. High-heat thermal processes generally operate at temperatures ranging from approximately 540 °C to 8,300 °C or higher. Electrical resistance, induction, natural gas, and/or plasma energy provide the intense heat. High-heat processes involve chemical and physical changes to both organic and inorganic material resulting in total destruction of the carcass material. Operating costs, including electricity and consumables (plasma torches have a limited life span), may be significant. Many units are still in the development phase and some technologies may not be fully commercialized.

The agents causing TSEs vary in their resistance to inactivation by physical agents. In general, TSE agents are much more resistant than conventional infectious agents such as bacteria and viruses to heat, ultraviolet radiation, ionizing radiation and microwave irradiation. Ionizing, ultraviolet and microwave irradiation have little effect on transmissible degenerative encephalopathies (TDEs) and have no practical application in their inactivation (Taylor, 2000). A small fraction of hamster-passaged scrapie TDE (strain 263K) infectivity survived exposure to

dry heat at 360 °C for 1 hour, but the brain homogenate had been lyophilized and was heated under anoxic conditions. Drying of scrapie-infected tissue is known to enhance its thermostability (Asher et al., 1987). In contrast, when 7-mg samples of nonlyophilized, macerated, ME7-infected mouse-brain were exposed to dry heat, there was no detectable infectivity after an exposure to 200 °C for 1 h, even though some infectivity survived exposure to 160 °C for 24 hours or 200 °C for 20 min (Taylor, 2000). However, 263K and 301V partially survived exposure at 200 °C for 1 hour (Taylor, 2004).

2.2.2 Impact on Environment

Odors can be a problem around autoclaves if there is insufficient ventilation. If the carcasses, debris and other materials are not properly segregated to prevent hazardous chemicals from being fed into the treatment chamber, toxic contaminants will be released into the air or condensate, or in the treated waste. If proper precautions are taken to exclude hazardous materials, the emissions from autoclaves are minimal. Many autoclave manufacturers offer many features and options such as programmable computer control, tracks and lifts for carts, permanent recording of treatment parameters, autoclavable carts and cart washers.

E-beam systems do not create any pollutant emissions except possibly for small amounts of ozone which breaks down to O_2. The residual ozone helps remove odors and contributes to the disinfection process in the treatment chamber, but it should be converted back to O_2 before being released into the environment or workspace. The waste residue looks exactly as it did before treatment, since e-beam irradiation does not change the physical characteristics of the waste. Therefore, a mechanical process is needed to render the treated waste unrecognizable and reduce volume. E-beam systems may contain lead (Pb) in the shielding; the Pb should be recycled or treated as hazardous waste after the e-beam unit is decommissioned.

High-heat thermal processes predominantly involve pyrolysis (not combustion or burning). Pyrolysis involves a set of reactions different from incineration and hence, different gaseous products and waste residues are produced. In many cases, pollutant emissions from pyrolysis units are at levels lower than those from incinerators. Waste residues may be in the form of a glassy aggregate or carbon black. The high heat needed for pyrolysis can be provided by resistance heating, plasma energy, induction heating, natural gas, or a combination of plasma, resistance heating, and superheated steam. Pyrolysis systems are a relatively new technology and require careful evaluation. Different plasma technology designs have varying emission characteristics but have emissions that are generally lower than the emissions from traditional incinerators. Despite plasma systems having lower emissions than traditional waste incinerators, plasma technologies may still emit dioxin, which has been linked to serious health problems, including cancer. Because of the high energy consumption with plasma systems, the treatment facility should consider total environmental impact to include not just emissions on-site (including pollutants from any co-generation or flaring of the off-gases) but also environmental emissions associated with high electrical usage, i.e., off-site emissions contributed by electric power generating stations. Flaring the off-gas adds to the environmental pollution. The system and equipment design should incorporate a heat recovery process (such as a heat exchanger to obtain steam or hot water) using the product gas. Vendors may indicate the possibility of recycling the carbon black (as a tire filler) or glassy waste residues (as roadbed or construction aggregate). A technical and economic feasibility study should be conducted, if the concept is found to be beneficial, an implementation plan should be developed.

A carcass treatment facility should consider discharges or emissions (including fugitive emissions) to all possible environmental media (workplace air, outside air, waste residues, and wastewater) and select technologies with the least impact on the environment. All liquid discharges after treatment should meet requirements set by the local publicly owned treatment works (POTW) or National Pollutant Discharge Elimination System (NPDES) permits, if discharging directly into surface streams. Solid waste residues should pass the EPA's toxicity characteristic leaching procedure (TCLP) to be disposed at a municipal solid waste landfill.

2.2.3 Implementability

Barriers to direct steam exposure or heat transfer (such as inefficient air evacuation; excessive carcass mass; bulky materials with low thermal conductivities; or waste loads with multiple bags, air pockets, sealed heat-resistant containers, etc.) may compromise the effectiveness of the system to inactivate the material. Air evacuation is more effective in autoclaves with a pre-vacuum cycle or multiple vacuum cycles. With higher vacuum levels and more vacuum cycles, the heat penetration is deeper and the heating of the waste load is more uniform. Certain load configurations such as multi-level racks with sufficient spaces between to allow more surfaces to be exposed to steam are more efficient than other configurations such as tightly stacked containers. The treatment facility should define a standard load and waste configuration for which specific time-temperature parameters can achieve a specific kill. Operators should monitor carcass load sizes, load configurations, containment and other conditions that may result in less-than-optimal heating conditions. Whenever those less-than-optimal conditions arise, exposure times and steam temperatures should be increased to provide a margin of safety. Continuous monitoring of temperature during the exposure time and at various points in the chamber is important in detecting heating problems. Records of chemical or biological indicator tests, time-temperature profiles, maintenance activities (such as replacing filters and gaskets), and periodic inspections should be maintained. Advanced autoclave systems may contain combine steam treatment with pre-vacuuming and various kinds of mechanical processing before, during, and/or after steam inactivation. The combinations include: a) vacuum/steam treatment/compaction, b) steam treatment-mixing-fragmenting / drying/shredding, c) shredding/steam treatment-mixing / drying (and chemical cleaning), d) shredding-steam treatment-mixing / drying, e) steam treatment-mixing-fragmenting/drying, f) pre-shredding/stream treatment-mixing, and g) shredding/steam treatment-mixing-compaction. Each of these systems operates differently. Nevertheless, they treat the same types of carcass materials and have emission characteristics similar to an autoclave.

2.2.4 Reduction in Toxicity, Mobility, or Volume through Treatment

While size reduction (shredding or grinding) reduces the volume of the treated waste by 60 to 80 percent, high-heat thermal processes reduce volume by 90 to 95 percent. Pathogens are not expected to survive under the very high temperatures. However, even with extremely high temperatures, the heat transfer characteristics in a plasma chamber may not necessarily mean uniform heating at elevated temperatures.

2.2.5 Cost

The cost of physical inactivation technologies varies widely. In general, the capital cost of steam-based technologies is lower than the capital cost of high heat thermal systems. Approximate capital costs of equipment and accessories, representative vendors, typical installation and energy requirements, and capacities are shown in Table 15. These technology

descriptions are based on vendor information (such as vendor websites, brochures, and personal communications), non-proprietary technical data provided by vendors or manufacturers, evaluations by non-profit institutions and private consultants, research by academic institutions, government studies, and other sources. An effort was made to corroborate or verify the accuracy of vendor information where possible. Claims by vendors that were deemed misleading or dubious were omitted from the descriptions. The information presented is intended to provide an overview and general understanding of these technologies. While there may be other manufacturers in the market, there was no attempt to make this list comprehensive. As noted earlier, mention of a specific technology in this report should not be construed as an endorsement by the author or by the Agency.

Table 15. Costs of Selected Physical Inactivation Pretreatment Technologies for Carcasses

Technology*	Vendor	Installation Requirements	Capacity (lb/hour)	Capital (Operating) Cost ($)
Autoclave	Bondtech (Somerset, Kentucky)	Steam – 152 °C/55 psig; drain; Electricals	250-6000	100,000-275,000
	Mark-Costello (Carson, California)	Steam – 60 psig; electrical – 115 V/1-phase 5A; Small and medium units ~100 lb of steam/cycle; large standard units ~150-200 lb/cycle.	225-3000	36,000-61,000
	Tuttnauer (Ronkonkoma, New York)	Steam – 137 °C/33 psig; equipped with microcomputer-based controls.	Up to 1500	130,000-250,000
Autoclave-Grinder-Crusher	Enviro-Safe Treatment Solutions, LLC (Covington, Indiana)	Temperature up to 133 °C/45 psi; onboard Clean-in-Place system to prevent spread of disease; mobilization time approximately three weeks.	8000	($0.29 per pound)
Pregrinder/Shredder-Heat Treatment-Liquid Effluent Decontamination-Electrical Generator- Steam Generator	BioSAFE Engineering (Brownsburg, Indiana)	10,000 lb/hr steam; 350 kWh electricity; 31,200 gallons/day water for steam; 105 gallons/h diesel for steam and electricity. Mobile units with integrated control system can be rented. Set-up and mobilization time: ≤8 h, each.	20,000 (14-16 bovines/h)	1.6 M ($0.04 per pound to $0.08 per pound)
Vacuum-Steam-Compaction	San-I-Pak (Tracy, California)	Steam – 1-inch insulated line 65 psig (minimum) to 125 psig (maximum); Water – 30-100 psi.	25-2240	30,000-500,000
Steam-Mixing-Fragmenting/ Drying/ Shredding	Tempico (Madisonville, Louisiana)	Steam – 450 lb/h at 60 psig; water – 75 gpm; electricity – 30 kWh, 250 A; air – 5 cfm at 100 psig.	300-750	400,000 and above
Shredding/Steam-Mixing/Drying, Chemical	Sterile Technologies Inc. (West Chester, Pennsylvania)	NA	600-4000	367,000-427,000
Shredding-Steam-Mixing/Drying	Antaeus Group (Hunt Valley, Maryland)	Hot and cold water; Electrical – 480 V, 60 Hz, 3-phase; Installation takes about 8 hours.	150	250,000
Shredding-Steam-Mixing/Drying	Ecolotec (Union Grove, Alabama)	Electrical – 230 V 200 A disconnect, 115 V 60 A breaker; Steam – less than 80 lb/h at 60 psi; Cold water – 10 gpm, Ventilation – 10 air exchanges/hr.	300	350,000

Technology*	Vendor	Installation Requirements	Capacity (lb/hour)	Capital (Operating) Cost ($)
Steam-Mixing-Fragmenting/ Drying	Hydroclave Systems Corp. (Kingston, Ontario, Canada)	Electrical – 460 V, 3-phase, 60 Hz for drive motor; depending on model. Steam – 40 to 60 psi minimum; Water consumption – 100 to 1,000 gallons per batch; Condenser water flow – 10 to 40 gpm	200-2000	250,000-600,000
Microwave Treatment	Sanitec (West Caldwell, New Jersey)	Electrical – 460/480 Vac; 150 to 200 A, 60 Hz, 3-phase; Water – ¾" NPT hookup. 0.1 kWh per pound of waste treated; peak demand – about 70 kW.	220-550	500,000-600,000
Dry Heat Treatment	KC MediWaste (Dallas, Texas)	Electrical – 480 V, 3-phase, 125 A; Compressed air – 100 scfm and 90 psig at peak; Water – 5 gpm at 60 psig. Energy consumption about 63 kWh per hour.	200	400,000
Pyrolysis-Oxidation	Oxidation Technologies (Annapolis, Maryland)	Electrical – 480 V, 3-phase; Water – 5 to 10 gpm when needed; Compressed air – 100 psig. 0.6-1.2 kWh per pound of waste treated. 80% of the heat is recovered as hot water or steam.	100-1500	1.6 M – 3.3 M
Plasma Pyrolysis	Electro-Pyrolysis, Inc. (Wayne, Pennsylvania)	112 to 2250 kW power and water for cooling.	750	0.6 M – 1.2 M
	HI Disposal Systems (Indianapolis, Indiana)	Processing chamber at about 1,650 °C and uses a 2 MW plasma arc torch.	3000	3 M
	Vance IDS/Bio Arc (Largo, Florida)	A hopper, shredder, two processing chambers, rollers, heat recovery system, inert gas generation system, residue collection, scrubbers, PLC controls with communications, and safety and shutdown systems.	400	800,000
Induction-Based Pyrolysis	Vanish Technologies/LFR (Raritan, New Jersey)	Electrical induction coil surrounding a tube furnace heats the walls of the tube to 982 °C. The waste is conveyed through the tube using an internal rotating screw or auger.	280	1.1 M – 2.0 M
Advanced Thermal Oxidation	NCE Corporation (Carrollton, Texas)	Loader, shredder, primary and secondary chambers, cooling chamber, a 30 hp turbo fan, liquid mist injectors, and liquid filtration system. Volume and mass reductions 97% or more may be achieved.	200	800,000
Electron Beam	BioSterile Technology (Fort Wayne, Indiana)	85 sq. ft. floor space and standard 208 V, 3-phase electrical power. Energy consumption 0.035 kWh/hour	400-550	400,000
Electron Beam-Shredding	University of Miami E-Beam (Coral Gables, Florida)	380/220 VAC, 40 A, 3-phase. Energy consumption is 0.04 kWh/pound of waste treated.	400	1.2 M

*: Combinations of physical and other technology packages are included. Note: Facilities should check with vendors to get the latest and most accurate prices. NA: not available. NPT: National Pipe Thread. PLC: programmable logic controller VAC: Volts alternating current.

2.2.6 Regulatory Issues

Infectious disease transmission has four requirements: a pathogen must be present; a sufficient number and virulence of pathogens to cause infection must also be present; a susceptible host must be available; and a pathogen-specific, appropriate portal of entry into the susceptible host must exist or be created. EPA encourages treatment of regulated infectious waste, which is a subset of medical waste, as early in the waste management chain as possible. The definition of treatment is stated in the Medical Waste Tracking Act (1988) as follows:

40 CFR 259.30 (b)(1)(iv) - "*Ensure that the concentration of microorganisms capable of causing disease in humans is reduced so as to render such waste as non-infectious or less infectious and, thus, safer to handle, transport, and dispose of. However, the waste need not be sterilized. The treatment processes commonly available are not 100% effective in inactivating microorganisms. Complete inactivation is unnecessary, since any refuse is expected to support some level of bacterial activity. Destruction of the waste is satisfied when the waste is ruined, torn apart, or mutilated so that it is no longer recognizable as medical waste*."

For those states that were covered by the Medical Waste Tracking Act, manifesting regulated waste was not necessary if it could be determined that all of EPA's concerns, biological and physical hazards and aesthetic degradation had been accomplished (DiDomenico, 1992). The main purpose for the treatment technology is to inactivate infectious carcasses by destroying pathogens. Facilities should make certain that the technology can meet state criteria for disinfection. Many states require approval of alternative technologies based on microbiological inactivation efficacy (Health Care without Harm, 2001). A consortium of state regulatory agencies called the State and Territorial Association on Alternative Treatment Technologies (STAATT) developed consensus criteria for the levels of microbial inactivation (Bauch, 2000):

Level I: Inactivation of vegetative bacteria, fungi, and lipophilic viruses at a 6 log 10 reduction or greater

Level II: Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria at a 6 log 10 reduction or greater

Level III (selected as the recommended minimum criteria): Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria at a 6 log 10 reduction or greater; and inactivation of *B. stearothermophilus* spores and *B. subtilis* spores at a 4 log 10 reduction or greater

Level IV: Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria, and *B. stearothermophilus* spores at a 6 log 10 reduction or greater.

A 6 log 10 reduction (or a 10^6 kill) is equivalent to a one millionth survival probability in a microbial population or a 99.9999 percent reduction of the given microorganism as a result of the treatment process. The following representative biological indicators were recommended by STAATT: mycobacteria (such as *mycobacterium phlei* and *mycobacterium bovis* BCG American Type Culture Collection (ATCC) 35743) - 6 log 10 reduction; bacterial spores (such as *B. stearothermophilus* ATCC 7953 and *B. subtilis* ATCC 19659) - 4 log 10 reduction. Technology vendors may be able to provide documentation showing that their technology can meet applicable state regulations. If no documentation is available, the facility can request that efficacy testing be conducted using an independent qualified laboratory.

The OSHA requirements for worker safety must be followed at the treatment facility. Periodic general safety inspections including checks based on OSHA regulations and other applicable codes (such as adherence to the electrical code) must be performed. Calibration and checking on function of testing equipment must be conducted regularly.

2.2.7 Personnel Safety

Worker training, including a basic understanding of steam-based treatment systems, standard operating procedures, occupational safety (e.g., ergonomics, proper waste handling techniques, hazards associated with steam and hot surfaces, blood splatter or aerosolized pathogens, etc.), record-keeping, identifying waste that should not be treated in the unit, recognizing heating problems, dealing with unusual carcass loads and other less-than-optimal conditions, periodic maintenance schedules, and contingency plans (e.g., what to do in case of a spill or power outage) should be provided.

2.2.8 Community Acceptance

A plume of smoke or colored liquid from a facility will be a public concern regarding that facility's environmental impact on the surrounding community. Hazardous-release emergency response and hazard communication are covered by the Emergency Planning and Community Right-to-Know Act (EPCRA). A program to inform and discuss physical inactivation technology with the local community is important since many of these processes are not well-known. Choosing a cleaner inactivation technology demonstrates the commitment to protecting public health and the environment. Some vendors represent their technologies as noiseless and odor-free. The best way to evaluate this is to observe the technology during actual operation, either at the manufacturing facility or preferably, at an installation facility. Reducing noise and noxious odors are important aspects of occupational health and community relations. Siting of a new system may be hampered by a lack of public acceptance, especially if the site is located near residences, schools, and sensitive populations. Treatment processes with which the public is familiar such as microwave or steam systems may be accepted by the community more readily than lesser known technologies such as plasma and electron beam technologies. A program to inform and engage the community in the selection of an alternative technology, allowing the community an opportunity to provide input into the decision-making process, would result in greater community satisfaction and improved standing of the health care facility as an environmental leader in the community.

2.2.8.1 Media / Public Information

Because of the dynamic nature of an emergency response to an event, the catastrophic mortality treatment must be implemented in an effective manner relative to the ever-changing understanding of the nature and extent of the disease in question. To allow the mortality management teams to respond quickly to changing field conditions, communication between the teams and incident command must be maintained through the chain of command. Real-time communication and pre-shift meetings constitute the required communication needed to support catastrophic mortality management associated with an outbreak or other natural disaster resulting in large scale livestock loss.

2.3 Chemical Inactivation

This section of this report will discuss chemical inactivation of carcasses. The principles of sterilization, disinfection and decontamination are integral processes in the pretreatment of

carcasses and associated contaminated material. The principles of sterilization, disinfection and decontamination are defined as the principles essential for reducing the risk of transmission within containment zones, to the environment, and within the community.

Sanitation is a heat treatment at lower temperatures over an extended period of time. Sterilization is an absolute process that completely eliminates all living microorganisms. The probability of a microorganism surviving a sterilization process is considered to be less than one in one million (i.e., 10^{-6}), and is referred to as sterility assurance. Given that toxins and prions are not living microorganisms, the concept of sterilization does not apply. Disinfection is a less lethal process than sterilization that eliminates most forms of living microorganisms. The effectiveness of the disinfection process is affected by a number of factors, including the nature and quantity of microorganisms, the amount of organic matter present, the type and state of items being disinfected, and the temperature. Decontamination is the process by which materials and surfaces are rendered safe to handle and reasonably free of microorganisms or toxins. The primary objective of decontamination is to protect containment zone personnel and the community from exposure to pathogens that may cause disease. Depending on the situation, decontamination may require disinfection or sterilization. Decontamination procedures represent a critical containment barrier; failure in the procedures can result in occupational exposure to, or the unintentional release of, infectious material or toxins.

The effectiveness in reduction of pathogens in both processes is affected by temperature, a factor that generally cannot be controlled when used under emergency conditions. Animal carcasses are not always completely heat-treated to eliminate pathogen survival and/or re-growth. This lack of complete heat treatment justifies the need for post-process disinfection with appropriate chemicals. Chemicals in solid, liquid, or gaseous matrices could be used to inactivate pathogens prior to or during pretreatment (such as composting and anaerobic digester) of large infectious animals in case of a catastrophic event. The amount of disinfectant chemicals should be at a sufficient level to inactivate the pathogens by the following mechanism: a) interaction with a microbial surface; b) penetration into microorganisms; and c) action at the target sites. The key four factors to be considered when selecting appropriate chemicals are: 1) pathogen inactivation efficacy, 2) potential health effects, 3) environmental effects, and 4) availability and cost.

Given the wide variety of biological toxins and their considerable differences in physical properties, it is impossible to provide a standardized set of chemical decontamination parameters that apply to all circumstances. The facility where the toxins are handled and/or stored needs to ascertain the risks and determine how best to mitigate them, including appropriate and effective inactivation technologies.

2.3.1 Effectiveness

The selection of a chemical inactivation agent is dependent on a variety of factors, including the resistance of the pathogenic material or toxin, the application (e.g., liquid or gaseous), and the nature and type of surfaces to be treated (such as hard surface, porous materials, organic/fatty tissue – hydrophobic, etc.), concentration of chemical inactivation agent, contact time, temperature, relative humidity, pH and stability. Table 16 describes the influence of chemical inactivation agents on pathogens on carcasses. The susceptibility ranking of microorganisms with respect to chemical inactivation agents is shown in Table 17.

There are many types of pathogens including protozoa, helminths, prions, viruses, fungi, algae, mycobacteria, bacteria, and viroids, but relatively few are directly connected to diseases. Some pathogens change their forms under some circumstances. Certain bacteria and fungi form spores under low-nutrient or dry conditions. Protozoa form oocysts and cysts dependent on their life cycle, while helminths form eggs. After an animal infection, viruses inject their genome into host cells. Among viruses, there are many types such as i) bacteriophages, which infect bacteria, ii) viroids, which are only RNA, devoid of proteins, that infect higher plants causing crop diseases and iii) animal viruses. Animal viruses are divided into two groups: non-enveloped and enveloped. Besides viruses, prions (proteinaceous infectious particles) cause diseases that have been classified as slow viral diseases. Prions are important, because they are the most difficult pathogen to inactivate.

Table 16. Influence of Chemical Inactivation Agents on Pathogens in Carcasses.

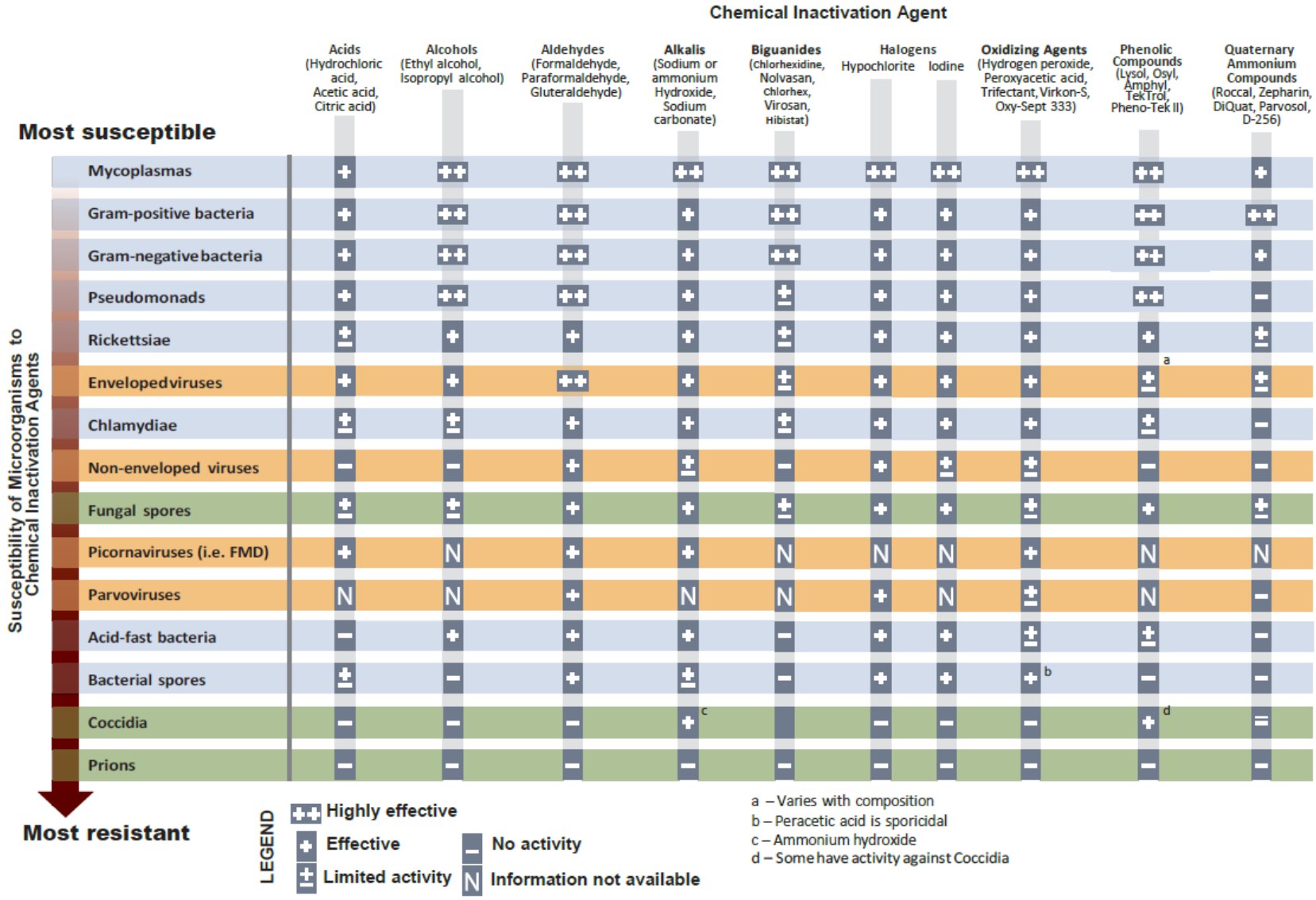


Table 17. Ranking Susceptibility of Pathogens in Carcasses.

Ranking of Susceptibility	Pathogen	Chemical Inactivation Agent
Extremely resistant	Prions	• Unusually resistant to chemical disinfectants • High concentrations of sodium hypochlorite (NaOCl) or heated strong solutions of sodium hydroxide (NaOH)
Highly resistant	Protozoal oocysts	• Ammonium hydroxide, halogens (high concentrations), halogenated phenols
	Bacterial endospores	• Some acids, aldehydes, halogens (high concentrations), peroxygen compounds
Resistant	Mycobacteria	• Alcohols, aldehydes, some alkalis, halogens, some peroxygen compounds, some phenols
	Non-enveloped viruses	• Aldehydes, halogens, peroxygen compounds
Susceptible	Fungal spores	• Some alcohols, aldehydes, biguanides, halogens, peroxygen compounds, some phenols
	Gram-negative bacteria	• Alcohols, aldehydes, alkalis, biguanides, halogens, peroxygen compounds, some phenols, some quaternary ammonium compounds
	Gram-positive bacteria	
	Enveloped viruses	
Highly susceptible	Mycoplasma	• Acids, alcohols, aldehydes, alkalis, biguanides, halogens, peroxygen compounds, phenols, quaternary ammonium compounds

Prion diseases are transmissible protein misfolding disorders in which misfolding of a host-encoded prion protein (PrP) occurs. PrP may exist in two forms: a normal cellular prion protein designated as PrP^{C} and a pathogenic misfolded conformer designated as PrP^{Sc} (see Figure 4). The superscript (Sc) has been used to refer to scrapie, the first and the most ancient animal transmissible spongiform encephalopathy (TSE). The etiology and animal hosts for these disease variants are shown in in Table 18.

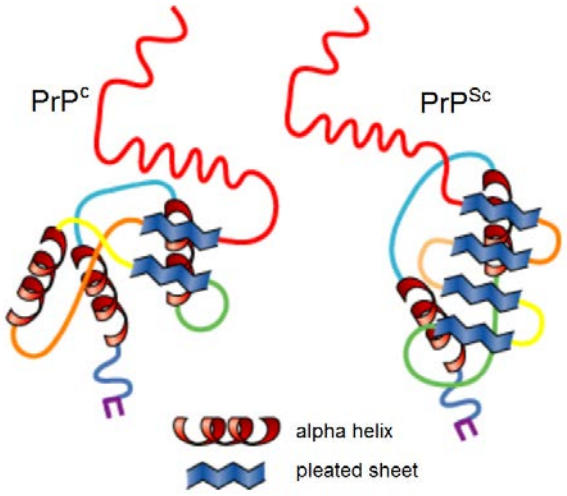


Figure 4. A normal prion (left) and a disease-causing prion (right).

Table 18. Etiology of Animal Prion Diseases and Typical Inactivation of Prions

Disease	Host	Etiology	Inactivation*
Scrapie	Sheep, Goats	Infection with Prions of unknown origin	• NaOCl (2%, 20 ˚C, 1 h) • NaOH (1 N, 20 ˚C, 1 h) • Autoclave under soaked conditions in water (134 ˚C, 18 min) • Alkaline detergent (1.6%, 43 ˚C, 15 min) • Phenolic disinfectant (5%, 20 ˚C, 30 min) • 3% sodium dodecyl sulfate, 100 ˚C, 10 min • 7 M guanidine hydrochloride (room temperature, 2 h) • 3 M guanidine thiocyanate (room temperature, 2 h) • 3 M trichloroacetic acid (room temperature, 2 h) • 60% formic acid (room temperature, 2 h) • 50% phenol (room temperature, 2 h) • Enzymatic detergent (0.8%, 43 ˚C, 5 min) + hydrogen peroxide gas plasma sterilization (1.5 mg/L, 25 ˚C, 3 h) • Vaporized hydrogen peroxide (2 mg/L, 30 ˚C, 3 cycles)
Transmissible mink encephalopathy (TME)	Mink	Infection with Prions of either sheep or cattle origin	
Chronic wasting disease (CWD)	Cervids	Infection with Prions of unknown origin	
Bovine spongiform encephalopathy (BSE)	Cattle	Infection with Prions of unknown origin	
Exotic ungulate spongiform encephalopathy (EUE)	Nyala, Kudu	Infection with Prions of BSE origin	
Feline spongiform encephalopathy (FSE)	Cats	Infection with Prions of BSE origin	
TSE in non-human primates (NHP)	Lemurs	Infection with Prions of BSE origin	

* Tateishi et al., 1991; Fichet et al., 2004; Sakudo et al., 2011.

Prions, the etiologic agents of bovine spongiform encephalopathy and scrapie, are exceptionally resistant to chemical disinfectants, especially if prions are in the tissues. Prions are not considered living organisms because they are misfolded protein molecules that may propagate by transmitting a misfolded protein state. In general, prions are quite resistant to proteases, heat, radiation, and formalin treatments, although their infectivity can be reduced by such treatments (Qin et al., 2006). Table 18 provides examples of inactivation of prions. Whenever possible, two or more methods can be combined to ensure the inactivation of prions. Effective decontamination of prions relies upon protein hydrolysis or reduction or destruction of protein tertiary structure. Examples include bleach, caustic soda, strongly acidic detergents (Race and Raymond, 2004), and pressurized steam autoclave at 134 °C for 18 minutes has been found to be somewhat effective in deactivating the agent of disease (Brown et al., 2000; Collins et al., 2004). Ozone sterilization is currently being studied as a potential method for prion denaturation and deactivation: 2-$\log_{10}$, 3-$\log_{10}$, and 4-$\log_{10}$ inactivation by ozone dosage of 7.6 to 25.7 mg/liter with contact times of 5 seconds and 5 minutes) (Ding et al., 2013). North Carolina State University, the Central Institute for Animal Disease Control in the Netherlands, and BioResource International North Carolina) have demonstrated the effectiveness of a bacterial enzyme called keratinase that can fully degrade a prion or protein particle. Langeveld et al. (2003) and Shih and Wang (2008) reported the effects of keratinase on brain tissues from cows with BSE and sheep with scrapie. Their results showed that, when the tissue was pretreated and in the presence of a detergent, the enzyme fully degraded the prion, rendering it undetectable.

Autoclaving at 134 °C for 1 hour (i.e., single-step inactivation process) or a chemical treatment with 1 N NaOH or NaOCl followed by autoclaving at 121 °C for 1 hour (i.e., two-step process) is acceptable for prion inactivation (Government of Canada, 2013). A solution of 2.5% NaOCl and

0.25 N NaOH, with a contact time of at least 30 minutes, will permit adequate inactivation of most biological toxins, including peptide toxins and mycotoxins (Wannemacher and Wiener, 1997). However, these inactivation measures will reduce prions but may be incompletely effective if dealing with high titer material, when pathogen is protected within dried organic matter or inside the tissue.

2.3.2 Impact on the Environment

Several of the chemical inactivation agents pose significant potential safety hazards for workers and other ecological habitats, if released to the environment. Capture and treatment of residual chemicals in water, solids, and air are necessary. Inactivation agents are classified by their chemical nature and each class has its unique characteristics, hazards, toxicities and efficacy against various pathogens. Environmental conditions such as the presence of organic matter, pH or water hardness can also impact the action of chemical inactivation agents. Therefore, before using any chemical disinfectant, the label instructions should be followed thoroughly. Most of these chemicals can cause irritation to eyes, skin and/or the respiratory tract of operating personnel. Therefore, the safety of all workers should be considered.

Environmental factors can greatly impact the effectiveness of a pretreatment process. Carcass composition and surface properties (such as organic load, surface topography), operating conditions (temperature, relative humidity, pH, water hardness or the presence of other chemicals) are all important environmental factors to consider. Additional environmental factors include runoff, leakage, and residues from the processing unit. Many chemicals are known for their ecological hazards on plants and aquatic life (i.e., sodium carbonate, hypochlorites, phenolics, and others). Therefore, drainage, runoff, biodegradability, and the appropriate treatment needs should be considered.

2.3.2.1 Wastewater Treatment

Effluent treatment systems should be designed to treat liquid waste at 134 °C for 1 hour (Government of Canada, 2013). Precautions should be taken when autoclaving chemically treated (e.g., NaOH, NaOCl) waste as many of the chemical inactivation agents can be damaging to equipment and other exposed surfaces. Proper material for the construction of the containers and surface coatings should be used. In addition, personnel should be cautious when handling hot NaOH (post-autoclave) to prevent potential exposure to NaOH vapor.

Liquid effluent treatment systems are designed to prevent the release of untreated materials into sanitary sewers and the environment (Government of Canada, 2013). An effluent treatment system is required for the liquid waste material generated from operation and handling of non-indigenous animal pathogens and prion areas. Effluent treatment systems may also be a design consideration for other containment zones, depending on the activities undertaken and the pathogens being handled. The liquid waste effluent from sources within or serving the containment zone, including sinks, showers, toilets, autoclaves, washing machines, and floor drains, is also treated. Effluent treatment systems are commonly heat-based. However, a chemical-based system may be practical on a smaller scale where small volumes of liquid effluent require treatment.

Liquid waste is collected in a large stirred tank in traditional effluent treatment systems. When the tank is full, the liquid is heated or chemically treated and, after a sufficient period of time and once treatment is complete, the tank is drained. Achieving a uniform temperature or chemical

concentration in a large tank can be a challenge, which can lead to inadequate pathogen inactivation. To mitigate this risk and maintain a uniform temperature, stirrers or paddles are used to ensure constant mixing of the effluent in a steam jacket that surrounds the effluent vessel shell. In contrast to the stirred tank, the effluent can be collected continuously in a large tank and streamed through a retention pipe where the effluent is heated (e.g., to approximately 150 ˚C) for a specific period of time through a continuous effluent treatment system. In a stirred tank or a continuous effluent treatment system, the key process parameters (e.g., time, temperature) must be verified against the infectious material or toxins of concern. The internal temperature and pressure of the effluent and the decontamination time should be recorded throughout the cycle. In addition, the treatment system must be equipped with alarms to permit failure detection. The effluent treatment system should be configured as fail-safe to ensure no untreated waste leaves the system (World Organization for Animal Health, 2009). Liquid waste released from the effluent treatment system has to meet all local and applicable environmental regulations and bylaws (provisions related to temperature, chemical/metal content, suspended solids, oil/grease, and biochemical oxygen demand). Chemical residues (e.g., chlorine and ozone), if any, need to be neutralized prior to release because they can generate noxious fumes and water-borne residues or by-products that can be harmful to aquatic animals and humans if inhaled, absorbed or ingested. With other types of treatment such as heat, post-treatment cooling of the treated wastewater may be required before discharge. Efforts should be made to minimize the quantity and load of wastewater generated. Treatment of the wastewater can be performed by following the BAT guidance (Ireland EPA, 2008): a) prevent wastewater stagnation; b) perform initial screening of solids using sieves; c) remove fat from wastewater, using a fat trap; d) use a flotation method with the use of flocculants to remove surface solids; e) provide wastewater holding capacity in excess of routine requirements; f) prevent liquid seepage and odor emissions from wastewater treatment tanks by sealing their sides and bases and either covering them or aerating them; g) remove nitrogen and phosphorus through the use of combined oxidation, nitrification and denitrification processes; h) conduct laboratory analyses of the effluent composition regularly and i) maintain records.

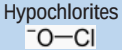
Generally, the range of pathogens in sludge arising from the treatment of carcass processing waste will be similar to the pathogens in sewage sludge, so the requirements for inactivation in terms of heat and/or pH will be similar, although the process parameters to achieve stabilization may differ because of the nature of the waste (Carrington, 2001). The waste produced during the pretreatment of carcasses may contain prions. Gale and Stanfield (2001) reported that treatment of sludge by using lime could potentially destroy at least 90% of BSE agents. Brown et al. (1986) reported alkaline treatment (pH 12) gives a 1-log destruction of sheep scrapie agent after 1 hour exposure. Gale and Stanfield (2001) added quicklime or hydrated lime to raise the pH to greater than 12 for a minimum period of 2 hours and reported that this type of enhanced sludge treatment by lime may destroy the BSE agent. Kemp (2010) reported treatment with alkali (calcium hydroxide in the form of hydrated lime to maintain a pH of 8.5 to 13) and heat (temperature in the range of 60 °C. to 99 °C) eliminates or reduces TDE such as BSE, Creutzfeldt-Jacob Disease and scrapie.

2.3.3 Implementability

Application of chemical inactivation agents to disinfect infectious animal carcasses require biological risk management protocols to prevent, contain and eliminate the spread of disease in case of an outbreak situation. Inactivation protocols may vary, depending on the need of the

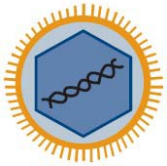
situation. Additionally, the health and safety of personnel and animals are always an important consideration. No single chemical inactivation agent is adequate for all situations. A comparison of key characteristics and considerations of commonly used chemical compounds is shown in Table 19. The use of trade names in Table 19 does not in any way signify endorsement of a particular product. The trade names for some of the chemicals are only provided as examples. For an effective inactivation protocol, consideration should be given to the pathogens (i.e., bacteria, viruses, fungi, or prions) being targeted during an infectious disease outbreak, the characteristics of a specific chemical compound, and environmental issues. In general, Gram-positive bacteria are more susceptible to chemical inactivation agents while mycobacteria or bacterial endospores are more resistant. The hydrophilic, non-enveloped viruses (adenoviruses, picornaviruses, reoviruses, rotaviruses) are more resistant to disinfection than lipophilic, enveloped viruses (coronaviruses, herpes viruses, orthomyxoviruses, paramyxoviruses, and retroviruses) (see Table 20). Pathogens also vary in their ability to survive or persist in the environment (i.e., debris). These pathogens can also be effective at creating a biofilm that enhances their ability to persist in the environment and avoid the action of chemical compounds. Application of surfactants, mechanical scrubbing, brushing and scraping during processing can help reduce biofilm. These issues are important considerations when selecting a chemical compound and protocol to use. Whenever possible, identification of the target pathogen should be done. However, if the pathogen has not been identified, a broad-spectrum approach should be utilized until identification can be made.

Table 19. Characteristics and Considerations for Selected Chemical Inactivation Agents

Chemical Categories	Alcohols 	Aldehydes 	Biguanides 	Halogens: Hypochlorites 	Halogens/Halides	Oxidizing Agents	Phenols	Quaternary Ammonium Compounds (QACs)
Chemical/ Trade Names	Ethyl alcohol, Isopropyl alcohol	Formaldehyde Glutaraldehyde	Chlorhexidine Nolvasan® Virosan®	Bleach	Betadyne® Providone®	Hydrogen peroxide Peracetic acid Virkon S® Oxy-Sept 333	One-Stroke Environ® Pheno-Tek II® Tek-Trol®	Roccal® DiQuat® D-256®
Mechanism of Action	•Precipitates proteins •Denatures lipids	•Denatures proteins •Alkylates nucleic acids	•Alters membrane permeability	•Denatures proteins	•Denatures proteins	•Denature proteins and lipids	• Denatures proteins • Alters cell wall permeability	• Denatures proteins • Binds phospholipids of cell membrane
Advantages	•Fast acting •Leaves no residue	•Broad spectrum	•Broad spectrum	•Broad spectrum •Short contact time •Inexpensive	•Stable in storage •Relatively safe	•Broad spectrum	• Good efficacy with organic material • Non-corrosive • Stable in storage	• Stable in storage • Non-irritating to skin • Effective at high temperatures and high pH (9-10)
Disadvantages	•Rapid evaporation •Flammable	•Carcinogenic •Mucous membranes and tissue irritation •Only use in well ventilated areas	•Only functions in limited pH range (5–7) •Toxic to fish (environmental concern)	•Inactivated by sunlight •Requires frequent application •Corrodes metals •Mucous membrane and tissue irritation	•Inactivated by QACs •Requires frequent application •Corrosive •Stains clothes and treated surfaces	•Damaging to some metals	• Can cause skin and eye irritation	
Precautions	Flammable	Carcinogenic		Not to mix with acids; toxic chlorine gas will be released			May be toxic to animals, especially cats and pigs	
Vegetative Bacteria	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Yes - Gram Positive Limited - Gram Negative
Mycobacteria	Effective	Effective	Variable	Effective	Limited	Effective	Variable	Variable
Enveloped Viruses	Effective	Effective	Limited	Effective	Effective	Effective	Effective	Variable
Non-enveloped Viruses	Variable	Effective	Limited	Effective	Limited	Effective	Variable	Not Effective
Spores	Not Effective	Effective	Not Effective	Variable	Limited	Variable	Not Effective	Not Effective
Fungi	Effective	Effective	Limited	Effective	Effective	Variable	Variable	Variable
Efficacy with Organic Matter	Reduced	Reduced	NA	Rapidly reduced	Rapidly reduced	Variable	Effective	Inactivated
Efficacy with Hard Water	NA	Reduced	NA	Effective	NA	NA	Effective	Inactivated
Efficacy with Soap/ Detergents	NA	Reduced	Inactivated	Inactivated	Effective	NA	Effective	Inactivated

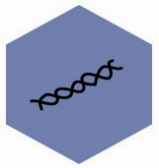
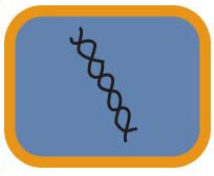
NA: Information not found

Table 20. Selected Viral Families, Virus and Species Affected.

Virus Family (relative size) SS = single stranded DS = double stranded	Foreign Animal Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
DNA Virus Families				
Adenoviridae  80 – 100 nm DS linear			Bovine adenoviruses A, B, C	B
			Canine adenovirus (infectious canine hepatitis)	C
			Caprine adenovirus	Cp
			Equine adenoviruses A, B	Eq
			Fowl adenoviruses A – E	A
			Human adenoviruses A – F (respiratory and/or ocular disease)	NHP
			Ovine adenoviruses A, B, C	O
			Porcine adenoviruses A, B, C	P
Asfarviridae  175 – 215 nm DS linear	Φ		African swine fever	P
Circoviridae  17 – 22 nm SS circular			Chicken anemia virus	A
			Porcine circovirus	P
			Psittacine beak and feather disease virus	A
Hepadnaviridae  42 nm partial DS		Z	Hepatitis B virus	NHP
Herpesviridae  150 - 200 nm DS linear	Φ		Alcelaphine herpesvirus-1 (malignant catarrhal fever)	B, Cv
			Avian herpesvirus 1 (infectious laryngotracheitis)	A
			Bovine herpesvirus 1 (infectious bovine rhinotracheitis)	B
			Bovine herpesvirus 2 (pseudo-lumpy skin disease, bovine mammillitis)	B
			Bovine herpesvirus 3/ bovine cytomegalovirus	B
			Canine herpesvirus 1, 2 (hemorrhagic disease of pups)	C
			Caprine herpesviruses 1, 2	Cp
			Equine herpesvirus 1 (equine viral rhinopneumonitis; equine abortion)	Eq
			Equine herpesvirus 2	Eq
			Equine herpesvirus 3 (equine coital exanthema)	Eq
			Equine herpesvirus 4 (equine viral rhinopneumonitis)	Eq
			Feline viral rhinotracheitis virus	F
			Human herpes simplex virus 1	NHP
			Human herpes simplex virus 2	
			Human herpesvirus 3/ varicella-zoster virus (chicken pox, shingles)	
			Human herpesvirus 4/ Epstein Barr virus	
			Human herpesvirus 5/ human cytomegalovirus	

A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Table 20. Selected Viral Families, Virus and Species Affected (continued)

Virus Family (relative size) SS = single stranded DS = double stranded	Foreign Animal Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
Herpesviridae (continued)			Human herpesviruses 6, 7 (roseola infantum)	
			Ictalurid herpesvirus 1 (channel catfish virus disease)	Fish
			Koi herpesvirus disease	Fish
			Marek's disease virus	A
	Φ		Oncorhynchus masou virus disease (or salmonid herpesvirus type 2 disease)	Fish
			Ovine herpesvirus-1	O
			Ovine herpesvirus-2 (malignant catarrhal fever)	B, Cp, Cv, O, P
			Porcine herpesvirus 2/ porcine cytomegalovirus	P
			Pseudorabies virus (Aujeszky's disease)	B, C, Cp, F, O, P
Iridoviridae  125 – 300 nm DS linear	Φ		Epizootic haemotopoietic necrosis (EHN)	Fish
			Largemouth bass disease	Fish
Papovaviridae  45 - 55 nm DS circular			Bovine papillomavirus	B
			Equine papillomavirus	Eq
			Human papillomavirus	
Parvoviridae  18 - 26 nm SS linear			Adeno-associated viruses 1-6	
			B19 virus	
			Canine minute virus/ canine parvovirus 1	C
			Canine parvovirus 2 ("parvo")	C
			Feline panleukopenia virus (Feline parvovirus)	F
			Porcine parvovirus	P
Poxviridae  250 X 200 X 200 nm DS linear		Z	Bovine papular stomatitis virus	B
		Z	Contagious ecthyma/contagious pustular dermatitis/orf virus	C, Cp, Cv
	Φ	Z	Cowpox virus	B, F, R
			Feline pox virus	F
			Fowlpox virus	A
	Φ		Lumpy skin disease virus	B, Bf
	Φ	Z	Monkeypox virus	NHP, R
		Z	Pseudocowpox virus (milker's nodules)	B
	Φ		Sheep and goat pox viruses	Cp, O
			Smallpox virus (Variola)	
			Swinepox virus	P
		Z	Vaccinia virus	B, L, P

A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Table 20. Selected Viral Families, Virus and Species Affected (continued)

Virus Family (relative size) SS = single stranded DS = double stranded	Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
RNA Virus Families				
Arenaviridae  10 - 300 nm SS linear segments	Φ	Z	Lassa virus	NHP, R
		Z	Lymphocytic choriomeningitis virus	C, NHP, P, R
	Φ	Z	Machupo virus (Bolivian hemorrhagic fever)	NHP, R
Iridoviridae  125 – 300 nm DS linear			Equine arteritis virus (equine viral arteritis)	Eq
			Lactate dehydrogenase elevating virus	R
			Porcine respiratory and reproductive syndrome virus	P
			Simian hemorrhagic fever virus	NHP
Astroviridae  45 - 55 nm DS circular			Avian nephritis viruses 1, 2	A
			Bovine astrovirus	B
			Feline astrovirus (gastroenteritis)	F
			Ovine astrovirus (gastroenteritis)	O
			Porcine astrovirus (porcine acute gastroenteritis)	P
			Turkey astrovirus (poultry enteritis and mortality syndrome)	A
Birnaviridae  18 - 26 nm SS linear			Infectious bursal disease virus	A
			Infectious pancreatic necrosis (IPN) (hemorrhagic kidney syndrome)	Fish
Bunyaviridae  250 X 200 X 200 nm DS linear	Φ		Akabane virus (Akabane/congenital arthrogryposis-hydronencephaly)	B, Cp, O
		Z	Cache Valley virus	B, O
	Φ	Z	California encephalitis virus	R
	Φ*	Z	Crimean-Congo hemorrhagic fever virus	A, B, C, L, O
		Z	Hantaviruses (various serotypes)*	R
		Z	Jamestown Canyon virus	Cv
	Φ	Z	La Crosse virus (La Crosse encephalitis)	Cp, Cv, R
	Φ	Z	Nairobi sheep disease virus	Cp, O, R
			Rift Valley fever virus	B, C, Cp, F, O
Caliciviridae  30 - 38 nm SS linear			Bovine enteric calicivirus	B
			Canine calicivirus	B
			Feline caliciviruses (upper respiratory disease)	F
			Fowl calicivirus	A
		Z	Hepatitis E virus	P
			Noroviruses (Norwalk and Norwalk-like viruses)	
			Porcine enteric calicivirus	P
	Φ		Rabbit hemorrhagic disease virus	L
			San Miguel sea lion virus	Other, P
	Φ	Z	Vesicular exanthema of swine virus (vesicular exanthema)	B, Eq, NHP, P

A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Table 20. Selected Viral Families, Virus and Species Affected (continued)

Virus Family (relative size) SS = single stranded DS = double stranded	Foreign Animal Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
Coronaviridae  80 – 160 nm SS linear			Avian infectious bronchitis virus	A
			Bovine coronavirus	B
			Canine coronavirus	C
			Feline enteric coronaviruses	F
			Feline infectious peritonitis virus	F
			Human coronaviruses (colds)	
	Φ		Porcine epidemic diarrhea virus	P
			Porcine hemagglutinating encephalomyelitis virus	P
	Φ	Z	Severe acute respiratory syndrome (SARS) virus	F
			Transmissible gastroenteritis (TGE) virus	P
			Turkey coronavirus (bluecomb disease)	A
Filoviridae  790 – 970 X 80 nm SS linear	Φ	Z	Ebola virus	NHP
	Φ	Z	Marburg virus	NHP
Flaviviridae  45 – 60 nm SS linear			Border disease virus	O
			Bovine viral diarrhea (BVD) viruses 1, 2	B
	Φ		Classical swine fever virus (hog cholera)	P
	Φ	Z	Dengue virus	NHP
			Hepatitis C virus	
	Φ	Z	Japanese encephalitis virus	A, P
	Φ	Z	Louping ill virus	A,B, C, Cp, Cv, Eq, O, P,R
	Φ	Z	Murray valley encephalitis virus	A, B, C, Eq
	Φ	Z	Omsk hemorrhagic fever virus	R
		Z	St. Louis encephalitis virus	A, Eq
	Φ	Z	Tick-borne encephalitis viruses (various subtypes)	B, C, Cp, O, R
	Φ	Z	Yellow fever virus	NHP
	Φ	Z	Wesselsbron virus	B, Cp, O
		Z	West Nile Virus (WNV) (West Nile fever)	A, Eq
Nodaviridae  30 nm SS linear			Viral encephalopathy and retinopathy (viral nervous necrosis)	Fish

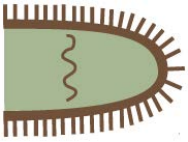
A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Table 20. Selected Viral Families, Virus and Species Affected (continued)

Virus Family (relative size) SS = single stranded DS = double stranded	Foreign Animal Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
Orthomyxoviridae  80 - 120 nm SS linear segments			Infectious salmon anemia	Fish
		Z	Influenza virus A:	A, Eq, F, Fr, P
		Z	Avian influenza	A, Eq, P
			Equine influenza	Eq
		Z	Swine influenza	A, P
			Human influenza	Fr, P
		Z	Influenza virus B: (human influenza)	Fr
			Influenza virus C: (human influenza)	P
Paramyxoviridae  150 – 300 nm SS linear	Φ	Z	Avian paramyxovirus type 1 (Newcastle disease)	A
			Avian paramyxoviruses 2-9	A
			Bovine respiratory syncytial virus (BRSV)	B, O
			Canine distemper virus	C, Fr
			Canine parainfluenza virus	C
	Φ	Z	Hendra virus	Bt, Eq, F
			Human parainfluenza viruses 1-4	
			Measles virus	NHP
			Mumps virus	
	Φ	Z	Nipah virus	Bt, C, Cp, Eq, F, O, P
			Parainfluenza 3 virus	B, O
	Φ		Peste de petitis ruminants virus	Cp, O
			Respiratory syncytial virus	
	Φ		Rinderpest virus	B, Cp, O, P
Picornaviridae  28 - 30 nm SS linear			Avian enteroviruses (encephalomyelitis, hepatitis)	A
			Bovine enteroviruses	B
			Bovine rhinoviruses	B
		Z	Encephalomyelocarditis virus (encephalomyelocarditis)	NHP, P, R
			Equine rhinoviruses 1, 2	Eq
	Φ		Foot and mouth disease virus¥	B, Ca, Cp, Cv, O, P
		Z	Human hepatitis A virus	NHP
			Human rhinoviruses	
			Poliovirus	
	Φ		Porcine enteroviruses (porcine enteroviral encephalomyelitis/Teschen-Talfan disease)	P
	Φ	Z	Swine vesicular disease virus	P
Reoviridae  60 - 80 nm DS linear segments	Φ		African horse sickness viruses 1-10	Eq
			Avian orthoreoviruses	A
			Bluetongue viruses 1-24	B, Cp, Cv, O
		Z	Colorado tick fever virus	R
			Epizootic hemorrhagic disease viruses	B, Cv, O
			Rotaviruses, group A to F (rotaviral gastroenteritis)	B, Eq, L, O, P, R

A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Table 20. Selected Viral Families, Virus and Species Affected (continued)

Virus Family (relative size) SS = single stranded DS = double stranded	Foreign Animal Disease (for US)	Zoonotic (Z)	Virus (Disease)	Animal Species Affected
Retroviridae  80 – 130 nm 2 copies SS linear			Avian leukosis virus	A
			Bovine immunodeficiency virus	B
			Bovine leukemia virus (BLV)	B
			Caprine arthritis-encephalitis virus	Cp, O
			Equine infectious anemia virus (EIA)	Eq
			Feline immunodeficiency virus (FIV)	F
			Feline leukemia virus (FeLV)	F
			Human immunodeficiency viruses (HIV-1, HIV-2)	
			Human T-lymphotropic viruses 1, 2	
			Maedi-visna virus (ovine progressive pneumonia)	Cp, O
			Ovine pulmonary adenocarcinoma virus (pulmonary adenomatosis)	Cp, O
			Simian immunodeficiency virus	NHP
			Simian leukemia viruses 1-3	NHP
Rhabdoviridae  180 X 75 nm SS linear	Φ		Bovine ephemeral fever virus	B
			Infectious hematopoietic necrosis (IHN)	Fish
		Z	Rabies	All mammals
			Spring viremia of carp	Fish
		Z	Vesicular stomatitis virus (Indiana 1 and New Jersey subtypes)	B, Cp, Eq, O, P
	Φ	Z	Vesicular stomatitis virus (Indiana 2 and 3 subtypes)	B, Cp, Eq, O, P
			Viral hemorrhagic septicemia (Egtved disease)	Fish
Togaviridae  70 nm SS linear		Z	Eastern equine encephalitis (EEE) virus	A, Bt, Eq, P, R
			Rubella virus	
		Z	Venezuelan equine encephalitis (VEE) virus	A, Eq, R
			Spring viremia of carp	Fish
		Z	Western equine encephalitis (WEE) virus	A, Eq

A = avian; B = bovine; Bt = bat; Cp = caprine; Cv = cervine; Eq = equine; Fr = ferret; L = lagomorph; R = rodent; NHP = non-human primate; O = ovine; P = porcine; Diseases in RED or with a Φ = Foreign Animal Diseases

Careful consideration of the characteristics of a chemical are essential to select the most useful, effective and cost-effective product. An ideal chemical is one that has a broad spectrum of inactivation capacity, works in any environment and is non-toxic, non-irritating, non-corrosive and relatively inexpensive (Table 21).

Table 21. Properties of Ideal Chemical Inactivation Agent

Properties	What does it mean?
Broad spectrum	Should have a wide antimicrobial spectrum
Fast acting	Should produce a rapid kill
Not affected by environmental factors	Should be active in the presence of organic matter/fatty tissues and compatible with other chemicals encountered in use
Nontoxic	Should not be harmful to the operator
Surface compatibility	Should not corrode (or cause the deterioration of) machine surfaces and instruments
Residual effect on treated surfaces	Should leave an antimicrobial film on the treated surface
Easy to use	Should have label with directions to apply
Odorless	Should have a pleasant odor or no odor to facilitate its use
Economical	Should not be cost-prohibitive
Solubility	Should be soluble in water
Stability	Should be stable in concentrate and use-dilution
Cleaner	Should have good cleaning properties
Environmentally friendly	Should not damage the environment

Unfortunately, no chemical inactivation agent is ideal (Grooms, 2003). Possible causes of inactivation failure include the following: a) over-dilution of disinfectant during pre-mixing or application; b) incomplete or inadequate mixing; c) poor chemical penetration or coverage, d) insufficient contact time on surfaces; and e) inadequate temperature and humidity while the material is being applied. Failure can also result from neutralization of the chemical due to the presence of residual liquids before the chemical was applied. Another example is to select a product that is ineffective against the contaminating organisms present (or suspected). The entire process must be repeated if test samples indicate that pathogens have survived the chemical inactivation procedure.

2.3.3.1 Concentration of Chemical Inactivation Agent

Use of the proper concentration of a chemical is important to achieve the best results for each situation. Certain chemicals may be more effective at higher concentrations, and these levels may be limited by the degree of risk to personnel, surfaces or equipment, as well as the cost of the chemical. However, over-dilution of a product may render the disinfectant ineffective against the target pathogen. The product label may list the best concentration to use for common situations.

2.3.3.2 Application Method

There are a variety of ways to apply chemical inactivation agent ranging from solid addition and mixing to fumigation. Carcass surfaces, equipment, or infrastructures may be treated with a chemical solution by wiping, brushing, spraying, misting, immersion, or fumigation, and application should be conducted as recommended on the product label. Application should occur in a systematic manner to ensure all areas are treated adequately. Ensuring the necessary contact time is essential and surfaces must remain in contact with inactivation agent during this process. Mechanical scrubbing and scraping may be necessary to remove oils, grease, or exudates. Porous, uneven, cracked, or pitted surfaces can hide microorganisms and are difficult to treat. High pressure systems can be effective for porous surfaces. However, in

cases of highly infectious or zoonotic pathogens, high pressure systems should be avoided or used with caution to avoid further dispersal of the pathogen or risk to the applicator. If appropriate, porous surfaces can be soaked in a container of chemical at the desired concentration. Gaseous or vaporous products (for application techniques such as fumigation) can be used in appropriate situations (such as in an enclosed chamber) and/or in combination with a physical inactivation technology (such as ultraviolet light) can be used for treating porous surfaces.

In a cold environment, building/areas should be heated (approximately 68 ˚F) since some chemicals are less effective or ineffective at low temperatures. Following application, rotating parts and machinery (pressure sprayers and pumps), if any, should be cleaned properly to remove potentially corrosive chemicals. Cleaning and disinfection supplies (e.g., towels, mops) should be treated as biohazardous waste and discarded or properly disinfected before removal from the pretreatment facility.

2.3.3.3 Contact time

The contact times vary for chemicals to kill or inactivate pathogens. The minimum contact time needed is normally stated on the product label. Carcass treatment should be performed with the chemicals to achieve the desired contact time. Certain chemicals may require application under wet conditions. Processing of carcasses by chemical activation under wet conditions should be conducted to avoid drying before the end of the optimum contact time. Certain chemicals may have residual activity (such as quaternary ammonium compounds, QACs) while others may evaporate quickly (such as alcohols).

2.3.3.4 Stability and storage

Chemicals (such as sodium hypochlorite) lose stability quickly after being prepared for use or when stored over long periods, especially in the presence of heat or light. Safety Data Sheets (SDSs) and/or product labels will list the shelf life of the concentrated product. To maximize stability and shelf life, products should be stored in a dark, cool location and preferably in stock concentrations. Use of an outdated or inactivated product may result in the use of a non-efficacious product and will lead to a false sense of security.

2.3.3.5 Temperature

Most chemical inactivation agents work best at temperatures above 68 ˚F. Elevated temperatures may aid in microorganism destruction; however, higher temperatures may also accelerate decomposition or evaporation of a chemical, thereby reducing the necessary contact time and efficacy. Heat may also impact the carcass. Cold weather (low temperatures) generally reduces the efficacy of chemical products. Additionally, chemical solutions may freeze outdoors under low temperature conditions.

2.3.3.6 pH

The pH or hydrogen ion concentration of the processed carcass surface can influence both the microorganism and the chemical agent. This effect can alter the charge on the outer surface of the microbe. The pH can also change the degree of ionization of a chemical product, thereby impacting efficacy. For example, the efficacy of glutaraldehyde is dependent on pH, working best at a pH greater than 7. In contrast, quaternary ammonium compounds have the greatest efficacy at a pH of 9-10. The pH can also affect the activity of phenolics, hypochlorite, and iodine compounds.

2.3.4 Control Measures for Chemical Inactivation Agents

The primary consideration is to adopt appropriate preventive measures such as elimination or substitution of chemical inactivation agents, if possible, to directly remove the hazards at the source. A chemical product or process can be replaced by a safer product or process that eliminates or minimizes the risks to an acceptable level. If such measures are not possible, segregation of the chemicals or the processes or other control measures should be taken. The use of PPE should be considered only as a supplementary means or as the last resort to minimize workers' exposure to the hazards. Safety measures can be achieved by engineering and administrative controls. Engineering control measures such as installation of suitable types of ventilation can eliminate or lower the level of chemical concentration in the air at the source. Administrative control measures such as implementation of safe work practices and scheduling of breaks or rotating shifts can limit worker time spent near the hazard, thus reducing worker exposure. The adoption of good housekeeping practices could not be more emphasized when chemicals are concerned.

2.3.4.1 Engineering Control

Ventilation is one of the effective engineering means to prevent accumulation of vapors of chemicals or mixtures of chemicals in the processing area. There are two types of ventilation: general dilution ventilation and local exhaust ventilation. Whatever the type, ventilation should be used together with other methods of control to strengthen the safety protection. Attention must be paid to the relevant environmental protection requirements in the discharge of exhaust air to prevent contamination of the outside environment. Enclosure is an alternative means to contain hazardous substances or work processes if the substance and process cannot be eliminated or substituted. Neat or higher concentrations of toxic chemicals could be handled (such as by dilution) in a closed glove box. Isolation is a safety measure to control exposure to hazards. Personnel could be isolated from a hazardous working environment by engineering control measures (such as an isolation booth). Engineering and work-practice controls that can be used to resolve chemical vapor issues include ducted exhaust hoods, air systems that provide 7–15 air exchanges per hour (the American Institute of Architects recommends no fewer than six air exchanges per hour, and the Association for the Advancement of Medical Instrumentation recommends 10 air changes per hour) (Rutala and Weber, 2008), ductless fume hoods with absorbents for the chemical vapor, tight-fitting lids on immersion baths, personal protection (such as nitrile or butyl rubber gloves but not natural latex gloves, goggles) to minimize skin or mucous membrane contact. If engineering controls fail to maintain levels below the ceiling limit, the treatment facility can consider the use of respirators (e.g., a half-face respirator with organic vapor cartridge or a type "C" supplied air respirator with a full face-piece operated in a positive pressure mode.

2.3.4.2 Administrative Control

Administrative control measures include arrangement of work schedules and stipulation of safe work practices so that the risk of exposure of individual employees to chemical products can be reduced. Employers should ensure that these control measures are incorporated into the management system as far as practicable. Typical safe work procedures that reduce the worker's exposure to chemical products should include the following:

- Ensuring the time spent near the hazard is kept to minimum;
- Keeping containers of chemicals closed when not in use;
- Avoiding skin contact with chemical disinfectants;

- Keeping a minimum amount of chemicals for use in the workplace, usually no more than a half-day's or one shift's supply; and
- Adopting general practices of good housekeeping.

2.3.5 Cost

Economic considerations are always important when selecting a chemical. Since chemical compounds vary in cost, contact time and dilution, costs should always be calculated on per gallon of use/dilution rather than the cost of the concentrate. However, chemical inactivation protocols are generally a cost-effective means of reducing pathogens. For example, a QAC that costs $68.00 per gallon of concentrate will cost $0.27 per diluted gallon (0.5 ounce concentrate per gallon of water). Considering that a gallon of diluted QAC approximately covers 100-150 square feet, the cost for inactivating a 500 square foot surface is $1.35.

A summary of representative chemical inactivation technologies and comparative rankings for specific criteria is shown in Table 22. The rankings are for comparative purposes only for each criterion.

Table 22. Comparison of Costs and Other Criteria of Representative Chemical Inactivation Technologies

Criteria	Chlorine/ Sodium hypochlorite (Cl_2/NaOCl)	Chlorine Dioxide (ClO_2) Liquid	Ozone (O_3)	Sodium Bromide (NaBr)	Peracetic Acid (CH_3CO_3H)
Occupational Safety Requirements	Moderate - High	High	Moderate - High	Moderate	High
Ease of Operation	Simple	Simple - Moderate	Moderate – Complex	Simple - Moderate	Simple - Moderate
Generation Equipment Required	No	Yes	Yes	No	No
Persistent Residuals	Yes	Yes	No	Yes	No
Power Requirements	Low	Low	High	Low	Low
Present Worth Cost	Low	Low - Moderate	High	Moderate	Low

The occupational safety requirements reflect the quantity and complexity of safety barriers required to maintain operator safety.

The persistent residuals are a measure of the chemical inactivation agent that remains as a residual after the inactivation process is complete. This parameter also includes chemical by-products.

Present worth cost includes capital and annual operational and maintenance costs.

2.3.6 Regulatory Issues

In the U.S., many of these chemicals are regulated by EPA and the U.S. Food and Drug Administration (FDA). Chemical inactivation agents intended for use on surfaces are regulated by the Antimicrobials Division, Office of Pesticide Programs, EPA, under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947, as amended in 1996 (FDA, 2000). Under FIFRA, any substance or mixture of substances intended to prevent, destroy, repel, or mitigate any pest, including microorganisms but excluding those in or on living man or animals, must be registered before sale or distribution. The U.S. EPA requires manufacturers to test formulations by using accepted methods for biocidal activity, stability, and toxicity to animals and humans. Manufacturers submit these data to U.S. EPA with proposed labeling. If EPA concludes a product may be used without causing unreasonable adverse effects, the product and its labeling are given an EPA registration number, and the manufacturer

may then sell and distribute the product in the U.S. FIFRA requires users of products to follow the labeling directions on each product explicitly. APHIS recommends that the selection of the chemicals and inactivation methodology should be made from available U.S. EPA registered products (USDA, 2014). The chemical products will either have been registered under FIFRA Section 3 (i.e., a regular label) or exempted under FIFRA Section 18 (i.e., emergency use label). In some situations (such as highly contagious foreign animal diseases), a particular pathogen may not be listed on the product label of an U.S. EPA-registered product. In these cases, Section 18 of FIFRA authorizes U.S. EPA to grant exemptions to Federal Agencies or States to use unregistered chemicals for a limited time, if U.S. EPA determines that emergency conditions exist. Use is allowed only for designated personnel and as described in the exemption. Under regular conditions, the chemicals should be used according to their approved labels following the indicated dilution, use sites, application method, contact time, precautionary statements, and other appropriate information, against the pathogens specified on the label. Not following the specified dilution, contact time, method of application, or any other condition of use is considered misuse of the product. A registered chemical inactivation agent may also be used according to label directions against pathogens not listed on the label provided that this use is not in conflict with State or local regulations. The non-label-listed pathogens should be equally or more sensitive to inactivation by the chemical than the hardiest pathogen listed on the registered label.

Regulations, requirements and protocols for chemical inactivation should be consistent with the State and federal laws. They must have a sound technical basis, and should be clear and easily explained. Individuals responsible for the application, certification or planning of activities and regulations related to chemical inactivation must periodically evaluate the scientific, technical and pragmatic logic of programs (Kahrs, 1995). Effective inactivation of infectious carcasses requires knowledge, a clear plan of action, regulatory discipline, documentation and evaluation. Regulatory surveillance may be required to ensure the following key areas: a) maximum efficiency in product utilization; b) application of all possible safety precautions for personnel, equipment and the environment; c) effective, carefully-engineered handling and processing steps; d) conscientious application of chemicals to the appropriate surfaces. At the policy level, inactivation procedures and regulations must be reviewed constantly and evaluated in the light of rapidly advancing technology and changing public values with respect to human safety, residue hazards and environmental awareness. Chemical additive users and their supervisors must have clear goals for each procedure in each specific setting. The personnel must understand the effective spectrum of the inactivation being used, its limitations, and the potential hazards to users, bystanders, equipment and the environment arising from use of the product. Hazards to personnel can arise from chemical toxicity or infections acquired from the carcasses being handled and processed. Economic factors must be secondary to safety considerations.

2.3.7 Personnel Safety

Before any pretreatment work is initiated, all members of the team should have a complete orientation covering the nature of the disease and the various hazards that may be encountered while serving during an incident. A complete understanding of the specific safety precautions should be obtained before entering the premises. This understanding is particularly important if a zoonotic disease is involved. Most chemical inactivation agents can cause irritation to eyes, skin, and/or the respiratory tract; some may cause burns or other injury. The safety of all personnel must be paramount when handling, mixing, and applying chemical products. It is essential that personnel be trained on proper storage, mixing and application procedures, and

hazards of the products they will be using. PPE such as hand, face, and eye protection should be worn during the mixing or application of chemicals. All chemical compounds have an SDS that includes the environmental hazards (risks, safety, and effect on the environment), stability of the compound, hazards and personal protection needed, as well as first aid information. Personnel engaged in cleaning and disinfection operations should wear at a minimum coveralls, boots and gloves. Face protection (e.g., goggles, mask, face shield) should be worn based on the product or application method (e.g., misting) used and when mixing chemical solutions. Masks should also be worn in situations involving significant amounts of dust generation or zoonotic disease potential. Chemical-resistant suits including both pants and jackets with hoods or respirators may be necessary for some situations (such as formaldehyde or acidic chemical application).

2.3.8 Community Acceptance

The treatment and processing of infectious animal carcasses without releasing pathogens to the environment and treating the whole or processed carcass material to inactivate pathogens or stabilize the carcass material in a manner suitable for appropriate carcass management are essential during a large outbreak. However, the perception of creation and publicized mismanagement of hazardous wastes necessitates the orchestration of a public involvement process to minimize adverse reactions. Environmental acceptability would be the main criterion for selection of a pretreatment facility and treatment processes. The government would reserve the overall right of final selection. Given the potentially volatile nature of the siting issue, the main thrust should be to develop an environmentally sound procedure and to link it to public involvement. Social issues can create far more problems than technical issues. Opposition rises when the public perceives that the project does not solve a local problem. A strong commitment to fostering good community relations on the part of the sponsoring agency, a strong commitment to access to information, the cooperative involvement of government and citizen groups, and training and local job growth can bring significant success. The credibility of the agency is a critical factor in acceptance by the public. If the public perceives that there is need for the protection of human health and environment from infectious carcass materials, then the benefits far outweigh the costs of the facility. The importance of the media cannot be overemphasized.

2.3.8.1 Media/Public Information

The communication of carcass inactivation and treatment plays an important and vital role in the successful emergency response program. The technique to communicate a volatile issue that involves pathogens, chemicals, and hazardous waste requires a well-defined plan with clearly stated objectives. The key factors surrounding the treatment facility can be communicated through: a) provision of communication services to key government officials; b) provision of communication services to public participation personnel with public groups; c) liaison with the media; and d) ensuring that the key personnel are accessible to the media.

2.4 Combined Physical and Chemical Inactivation

The application of a combination of inactivation techniques can have a synergistic effect on the inhibition or inactivation of the prevalence and the numbers of microbial pathogens in the carcasses (Huffman, 2002). The combination of inactivation techniques can be implemented by simultaneous application (such as acid solutions) or the sequential application of treatments (such as hot water treatments and organic acids). Two or more technologies at suboptimal levels are more effective than one at optimal level (Hugas and Tsigarida, 2008). For example, reduction of numbers of *Enterobacteriaceae*, total coliforms, thermotolerant coliforms, and *E.*

coli obtained by steam vacuuming were significantly lower than those obtained by a combination of steam vacuuming with any other sanitizing treatment, e.g. treatments of hot water (95 °C) or 2% lactic acid (Castillo et al., 1999). The agents causing TSEs vary in their resistance to inactivation by physical agents. In general, TSE agents are much more resistant than conventional infectious agents such as bacteria and viruses, to heat, ultraviolet radiation, ionizing radiation and microwave irradiation. The resistance of TSE agents to heat varies with the material in which the agent is present (e.g., tissue size and composition) and has been shown to increase if the agent has been fixed (e.g., by ethanol or formalin) or if material containing the agent becomes attached to glass or metal. During the early stages of procedures such as autoclaving designed to inactivate pathogens, a proportion of the agent may become heat fixed onto surfaces, following which this fraction of the original quantity of the agent becomes resistant to further heating. Incineration at high temperatures (e.g., 1,000 °C) is effective in removing infectivity, although trace infectivity could be detected following incineration at 600 °C followed by rehydration of the resultant ash. TSE agents also are resistant to acids and alkalis. However, a combination of alkali plus heating, e.g., autoclaving at 120 °C for 30-90 minutes following or in the presence of concentrated alkali (1 M or 2 M sodium hydroxide), has been reported to be effective for the inactivation of various scrapie strains (Taylor, 2000).

3.0 Analysis of Pretreatment Technology Alternatives

Each carcass pretreatment technology was evaluated against the nine criteria that are based on the statutory requirements of CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), Section 121; the National Contingency Plan (NCP); and the guidance for conducting remedial investigations and feasibility studies under CERCLA (U.S. EPA, 1988). The first two criteria are thresholds that must be satisfied for a remedy to be eligible for selection; the next five are balancing criteria used to evaluate the comparative advantages and disadvantages of the treatment options; and the final two are modifying criteria generally taken into account after agency and public comments are received on the FS and proposed plan. These criteria to evaluate feasibility of selected carcass pretreatment technologies are summarized below (see Figure 5).

Figure 5. Criteria Evaluated for Selected Carcass Pretreatment Technologies

Overall Protection of Human Health and the Environment: This threshold criterion assesses whether each alternative, as a whole, protects human health and the environment and indicates how each hazardous substance source is to be eliminated, reduced, or controlled. The overall assessment of protection draws on evaluations conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with Applicable or Relevant and Appropriate Requirements (ARARs): This threshold criterion evaluates each alternative's compliance with ARARs, or if an ARAR waiver is required, how the waiver is justified. ARARs consider location-specific, hazard-specific, and action-specific concerns. The selected pretreatment alternatives evaluated and ranked based on APHIS disease response protocols and environmental regulations.

Long-Term Effectiveness and Permanence: This balancing criterion evaluates the effectiveness of each alternative in protecting human health and the environment after the treatment action is complete. Factors considered include (1) magnitude of residual risk remaining from untreated waste or treatment residuals at the completion of the pretreatment

action, and (2) adequacy and reliability of controls such as containment systems that are necessary to manage treatment residuals and untreated waste.

Reduction in Toxicity, Mobility, or Volume through Treatment: This balancing criterion addresses the statutory preference for selecting remedial actions that employ treatment options that permanently and significantly reduce toxicity, mobility, or volume of hazardous substances as their principal element. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction on contaminant mobility, or reduction of total volume of contaminated media.

Short-Term Effectiveness: This balancing criterion addresses the effectiveness of each alternative in protecting human health and the environment during construction and implementation of the remedial action. Factors considered include:

- Potential exposure of the community during implementation of an alternative
- Potential exposure of the workers during construction
- Potential effects to the environment
- Time required to meet the treatment and/or carcass management objective.

Implementability: This balancing criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of the required services and materials during its implementation. Factors considered include:

- Ability to construct and operate the technology
- Availability and reliability of the technology
- Ease of undertaking additional remedial actions
- Administrative implementability
- Coordination activities with other agencies
- Monitoring considerations
- Availability of equipment and specialists.

Cost: This balancing criterion evaluates the present value of the capital and O&M cost for each alternative. Capital and O&M cost estimates are order-of-magnitude-level estimates and have an expected accuracy of minus 30 to plus 50 percent (U.S. EPA, 1988).

State Acceptance: This modifying criterion evaluates the technical and administrative issues and concerns the regulatory agencies may have about each alternative. This criterion has not been ranked as it was assessed under compliance with ARARs.

Community Acceptance: This modifying criterion evaluates the issues and concerns the public may have about each alternative.

Based on the screening and evaluations (section 2), the following carcass pretreatment technologies and process options were retained:

- No Pretreatment
- Size Reduction
- Size Reduction and Physical Inactivation
- Size Reduction and Chemical Inactivation

Under the no pretreatment alternative, carcass would be disposed without implementing any pretreatment or other mitigating actions to control exposure to hazardous material in the environment. This response action would not be effective in reducing potential risks to human health and environment. No cost is associated with this option because no pretreatment is performed. The NCP requires that the no action response be included among the alternatives evaluated in every feasibility study (Title 40 CFR Section 300.430[e][6]). The no action alternative provides a baseline for comparison to the other pretreatment alternatives.

Table 23 provides the overall ranking of the pretreatment alternatives. The ranking of nine criteria was performed using 1 to 5 scale (1 = very negative, 2 = negative, 3 = neutral, 4 = positive, and 5 = very positive). Colors have been assigned to cells as visual aids (= very negative, = negative, = neutral, = positive, and = very positive). The total scores of various alternatives for six carcass management options (EPA, 2016) show the relative ranking of the pretreatments. The size reduction alternative with and without physical inactivation ranked higher for most of the carcass management options. Citric acid and the oxidizing agent (Virkon-S™) are considered more favorable than bleach due to the hazardous decomposition, incompatibility to materials, corrosivity, toxicity, and other potential health effects of hypochlorite.

Table 23. Comparison of Pretreatment Technologies and Overall Ranking against Various Carcass Management Options

Criterion	No Pretreatment	Size Reduction [1]	Size Reduction + Physical Inactivation	Size Reduction + Chemical Inactivation		
Chemical Inactivation Agent				Acid (Citric)	Bleach (Hypochlorite)	Oxidizing Agent (Virkon-S)
Overall protection of human health and the environment	2	3	4	4	1	3
Compliance with ARARs [2]	5	3	5	5	3	4
Long-Term Effectiveness and Permanence	3	3	5	5	5	5
Reduction of Toxicity, Mobility, and volume through Treatment	3	4	5	5	5	5
Short Term Effectiveness	2	3	4	4	4	3
Implementability						
Rendering [3]	4	5	5	3	2	3
Burial	5	3	3	3	2	3
Landfill	3	4	5	4	3	4
Composting	4	5	4	4	3	4
Incineration	2	5	3	4	2	3
Burning	2	5	3	4	2	3
Cost	5	4	2	3	2	1
State Acceptance [4]						
Community Acceptance	3	3	4	4	3	4
TOTAL SCORE						
Rendering	27	28	34	33	25	28
Burial	28	26	32	33	25	28
Landfill	26	27	34	34	26	29
Composting	27	28	33	34	26	29
Incineration	25	28	32	34	25	28
Burning	25	28	32	34	25	28

Legend

1 = very negative (■); 2= negative (▨); 3 = neutral (■); 4 = positive (▨); 5 = very positive (■)

Notes: (1) Assumes aerosols and liquids that are generated during size reduction are contained.
(2) ARARs refers to APHIS disease response protocols and environmental regulations.
(3) Assumes the physical inactivation by heating to be performed at less than 212 °F (100 °C); and the product market will be limited.
(4) Similar to ARARs; thus, not considered twice.

4.0 Summary

The highly pathogenic avian influenza (HPAI) outbreak in the U.S. in 2015 was the worst poultry disease outbreak in the country's history. According to the USDA (2015a), the disease claimed more than 49 million birds on 211 commercial farms or premises. Approximately 7.5 percent and 10 percent of the U.S. turkey and egg layer inventories, respectively, were removed from production due to the outbreak. The availability of carcass management options was limited due to concerns about transporting and disposing of/treating infected material. Should a major disease outbreak occur whether inadvertent or intentional, it is crucial to have an effective infected carcass treatment and carcass management strategy. From an economic sense, such strategies would be designed to minimize the costs arising from livestock losses, economic impacts, government costs, public health hazards, and environmental damages. Carcasses resulting from highly infectious diseases such as HPAI may potentially be disposed of more easily if the materials are pretreated at the farm to inactivate pathogens using an appropriate pretreatment, under the direction of well-trained professionals with regulated supervision.

Feasible pretreatment alternatives evaluated in this study applied prior to the routine and catastrophic management of infectious carcasses include size reduction alone or with physical or chemical inactivation. Size reduction combined with citric acid had the highest overall ranking of the evaluated alternatives.

Direct comparison between pretreatments in this study was complicated by numerous variables such as mode of application, the concentration used, the application of temperature, the exposure time, the point of application during processing, or contamination level of carcasses. If more than one inactivation treatment should be applied to carcasses, the combined microbiological reduction effect might be greater than the effect of one treatment alone. Methods, strategies, and practical applications presented in this report describe acceptable means for treatment of carcasses prior to disposal. Each treatment has its advantages and disadvantages as costs and benefits. The actual decision on which treatment or combination of treatments are suitable should be based on individual circumstances and the restrictions that apply. The overall objective of ensuring a high level of protection for the environment as a whole may involve making trade-off judgments between different types of environmental impact, and these judgments can be influenced by local considerations. The obligation to ensure a high level of environmental protection including the minimization of long-distance or trans-boundary pollution implies that the most appropriate techniques cannot be set on the basis of purely local considerations.

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