Exposure Assessment During a Chemical Attack

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Gilbert Gedeon, P.E.

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Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

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Disclaimer

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Questions concerning this document or its application should be addressed to:

Sandip Chattopadhyay, Ph.D.
National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive, MS NG16
Cincinnati, OH 45268
Phone: 513-569-7549
Fax: 513-487-2555
E-mail: chattopadhyay.sandip@epa.gov

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Executive Summary

This exposure assessment does not address a specific emergency scenario, but includes chemicals of concern representing two categories that have been involved in past events. These are diazinon, an organophosphate pesticide, and dioxins/furans, which are persistent organic pollutants. Potential chemical emergency scenarios affecting livestock could include intentional criminal or terroristic acts such as chemical poisoning of food supplies or sabotage of agricultural production or commodity markets. The contamination could be unintentional as well. Examples of unintentional chemical emergencies include industrial accidents, accidental contamination of feed or other agricultural supplies, and transportation-related accidents (e.g., tanker truck or rail car spillage).

The livestock carcass management options included in this exposure assessment are seven well-established methods with sufficient capacity for large-scale carcass management: on-site open burning (pyre), on-site air-curtain burning, on-site unlined burial, on-site composting, off-site fixed-facility incineration, off-site landfilling, and off-site carcass rendering.

With the three off-site options, all releases to the environment (e.g., incinerator emissions to air, rendering facility discharge to surface water) are restricted by, and are assumed to comply with, applicable U.S. federal regulations. Therefore, chemical releases from off-site commercial facilities are assumed to be adequately controlled. Because the chemical exposures with the off-site options are not quantitatively assessed, they are not individually ranked with the on-site options.

As shown in Table ES.1, the off-site options, collectively, are compared with the on-site options in the first tier of a two-tier assessment. The first column of Table ES.1 shows that the off-site options are ranked higher (i.e., Rank 1) than the on-site options (i.e., Rank 2) because of their greater level of pollution control under applicable regulations. The top section of Table ES.2 shows that off-site options are not ranked further relative to each other, because they are not quantitatively assessed.

In the Tier 2 assessment, for the on-site management options, rankings are based on a quantitative assessment in which different methods are applied to estimate combustion releases to air and subsequent deposition to ground level, and to assess fate and transport in surface and subsurface soils, groundwater, and an on-site lake. The assessment is based on carcass management at a hypothetical site, using a standardized set of environmental conditions (e.g., meteorology), assumptions about the scale of mortality, and how the carcass management options are designed and implemented.

The findings for the Tier 2 chemical assessment are summarized in the bottom section of Table ES.2. Potential exposures are ranked relative to one another based on ratios of exposure estimates to applicable toxicity reference values. As shown in Table ES.1 and ES.2, the exposures and relevant exposure pathways for each management can differ by chemical. This is due to chemical-specific fate properties, such persistence and mobility in different media. In addition, site-specific circumstances (e.g., the presence of a drinking water well) can affect which exposure pathways are relevant at a site. For these reasons, there is not “best” carcass management option for every event.

This report provides information to compare options and support decision-making in the event of actual chemical emergencies. It provides a scientifically based understanding of the potential environmental releases and exposure pathways for each option, and information to evaluate the likely relative contribution of specific exposure pathways based on chemicals of concern, site settings, and steps in carcass management processes. The assessment also can aid selection and priority setting for mitigation and best management practices.

Because well-informed carcass management decisions are site-specific, the exposure estimates presented in this report should not be interpreted as “actual” exposures associated with the management options.

Table ES. 1. Tier 1 Ranking of Livestock Carcass Management Options – Off-site versus On-site Management Options

Tier 1 Ranking	Management Options	Chemical Exposure Pathways[a]		Controls and Limits to Environmental Releases
Rank 1: Negligible to minimal exposure—releases regulated to levels acceptable for human health and the environment	Incineration	6		Air emissions regulated under the Clean Air Act (CAA), including pollution control equipment (e.g., scrubbers, filters), with tall stacks to prevent localized deposition; residuals (i.e., ash) managed under the Resource Conservation and Recovery Act (RCRA); wastewater managed under the Clean Water Act (CWA).
	Rendering	3		Releases to air and to water regulated under the CAA and CWA, respectively.
	Landfilling	2		Landfill design and operation regulated under RCRA; controls include leachate collection and management and methane recovery.
Tier 1 Ranking	**Management Options**	**Chemical Exposure Pathways[a]**	**Exposure Pathways by Chemical[a]**	**Controls and Limits to Environmental Releases**
Rank 2: Higher exposure potential—uncontained releases to the environment	Open Burning	10	Dioxins: 6 Diazinon: 0	Uncontrolled combustion emissions; possible releases from combustion ash if managed on site
	Air-curtain Burning	10	Dioxins: 6 Diazinon: 0	Partially controlled combustion emissions, possible releases from combustion ash if managed on site
	Burial	6	Dioxins: 0 Diazinon: 4	Uncontrolled leaching from unlined burial; slow gas release to air
	Compost Windrow	6	Dioxins: 0 Diazinon: 4	Partially controlled releases from compost windrow (minor leaching, runoff, and gas release to air); where finished compost is tilled into soils, potential runoff and erosion from amended soil
	Compost Application	2	Dioxins: 2 Diazinon: 2	

Abbreviations and acronyms: CAA, Clean Air Act; RCRA, Resource Conservation and Recovery Act; CWA, Clean Water Act.

[a] See Section 3 for identification of the pathways. Individual chemicals are not present in certain pathways due chemical specific properties (e.g., dioxins have low mobility in soil and groundwater) or the effects of management processes (e.g., diazinon is combusted). The number of exposure pathways does not necessarily indicate the relative level of exposure among the management options because the potential levels of exposure vary substantially by pathway.

Table ES. 2. Tier 2 Ranking of Livestock Carcass Management Options

Tier 1 Description	Management Option	Principal Rationale
The qualitative Tier 1 assessment distinguishes the off-site options from the on-site options based on level of regulatory control. The off-site options are considered to pose lower risk than the on-site options, which have uncontrolled environmental releases. The off-site options are not ranked relative to each other.	Off-site Rendering	Carcasses processed into useful products; wastes released under permits; availability decreasing
	Off-site Landfill	Carcass leachate contained and methane captured; landfills at capacity are closed and new ones built
	Off-site Incinerator	Destruction of materials; air emissions are regulated; ash is landfilled

Tier 2 Description	Rank [a]	Highest Ranking Ratio		Management Option	Principal Rationale
		Dioxin	Diazinon		
The quantitative Tier 2 assessment ranks the on-site options relative to each other by comparing ratio of estimated exposures (from data on source emissions and fate and transport modeling) with toxicity reference values (TRVs).	1	np	6.9E-08	Compost Windrow	Bulking material retains most chemicals
	2	np	5.4E-05	Burial	Soils filter out chemicals traveling toward groundwater
	3	1.8E-01	np	Air-curtain burning	Similar release profiles; emissions sensitive to type and quantity of fuels used and burn temperature; Open burning emissions include mercury from coal used as fuel.
	4	2.8E-01	np	Open Pyre burning	
	5	3.5E+00	4.0E-04	Compost Application	Applied to soil, chemicals are available for uptake by plants and livestock, or surface water and aquatic biota; Mitigate with appropriate use/disposal and erosion controls.

Acronyms: np = not present.

[a] Rank 1 poses the lowest relative risk and higher numbers indicate higher relative risk.

Acronyms and Abbreviations

Acronym/Abbreviation	Stands For (Country or Agency Affiliation)
ac	acre(s)
ADD	average daily ingestion dose
AERMOD	AMS/USEPA Regulatory Model air dispersion model
APHIS	Animal and Plant Health Inspection Service (USDA)
ATSDR	Agency for Toxic Substances and Disease Registry (ATSDR)
°C	degrees Celsius
CAA	Clean Air Act
CAS	Chemical Abstracts Service
CDD	chlorinated dibenzodioxins
CDF	chlorinated dibenzofurans
cm	centimeter(s)
CSEFH	Child-Specific Exposure Factors Handbook (USEPA)
CSFII	Continuing Survey of Food Intakes by Individuals
d	day(s)
DAF	dilution attenuation factor
EFH	Exposure Factors Handbook (USEPA)
EPACMTP	EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP)
°F	degrees Fahrenheit
FAD	foreign animal disease
ft	foot (feet)
ft^2	square foot (feet)
g	gram(s)
gal	gallon(s)
GW	groundwater
hr	hour(s)
ha	hectares
Hg	mercury
HHRAP	Human Health Risk Assessment Protocol (USEPA)
Kd	Soil-water partition coefficient
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
L	liter(s)
LADD	lifetime average daily dose
lb	pound(s) (weight)

Acronym/Abbreviation	Stands For (Country or Agency Affiliation)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mg	milligram(s)
MIRC	Multimedia Ingestion Risk Calculator
mL	milliliter(s)
mm	millimeter(s)
na	not assessed
nc	not considered carcinogenic by ingestion exposures
np	not present
PAHs	polycyclic aromatic hydrocarbons
PBB	polybrominated biphenyl
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxin
PCDFs	polychlorinated dibenzofurans
pH	potential of hydrogen
POPs	persistent organic pollutants
/rain_hr	per hour of rain
RAIS	Risk Assessment Information System, of Oak Ridge National Laboratory
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RSD	risk specific dose
sec	second(s)
SW	surface water
TEF	toxicity equivalency factor
TEQ	toxicity equivalency quotient
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TRV	toxicity reference value
µm	micrometer(s)
µg	microgram(s)
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
yr	year(s)

1. Introduction

Proper management of livestock carcasses following large-scale livestock mortalities protects humans, livestock, and wildlife from chemical and biological hazards; maintains air, water, and soil resources; protects ecological resources and services; and enhances food and agricultural security. In support of the National Response Framework, the U.S. Department of Homeland Security Science and Technology Directorate funds research in collaboration the U.S. Environmental Protection Agency's (USEPA's) Office of Research and Development, Homeland Security Research Program (HSRP) and the U.S. Department of Agriculture's (USDA's) Animal and Plant Health Inspection Service (APHIS) to support the proper management of animal carcasses following major environmental incidents. Mass livestock mortalities can result from a natural disaster, foreign animal disease (FAD) outbreak, chemical or radiological incident, or other large-scale emergencies. As a product of the collaborative research between USEPA and USDA, this report evaluates livestock carcass management options following a chemical emergency through a comparative exposure assessment. This assessment helps to inform a scientifically-based selection of environmentally protective methods in times of emergency. Preceding phases of this project assessed exposures following natural disaster and foreign animal disease outbreaks. A separate report examines exposures following radiological incidents.

Established by the Department of Homeland Security, the National Response Framework is a single comprehensive approach to domestic incident management.[1] The Framework provides a context for Department of Homeland Security and other federal agencies to work with each other and with communities to prevent, prepare for, respond to, and recover from hazards such as natural disasters, acts of terrorism, and pandemics.

In support of the National Response Framework, the Department of Homeland Security is funding research in collaboration with the United States Environmental Protection Agency's (USEPA's) Homeland Security Research Program and the United States Department of Agriculture's (USDA's) Animal and Plant Health Inspection Service (APHIS) to assure the proper management of animal carcasses following major environmental incidents such as a natural disaster, foreign animal disease (FAD) outbreak, chemical or radiological contamination incident, or other large-scale emergencies. Proper management of livestock carcasses following such emergencies is needed to protect humans, livestock, wildlife, and the environment, and to enhance food and agricultural security.

1.1 Purpose and Scope

This report focuses on relative exposures and hazards for different livestock carcass management options in the event of a *chemical emergency*. Selection of chemical agents for the assessment is described under Problem Formulation in Section 2.

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[1] Information about the National Response Framework is available at https://www.fema.gov/national-response-framework

This exposure assessment builds on earlier research by using consistent assumptions about the carcass management options (e.g., pyre construction and fuels), scale of mortality, and site conditions (USEPA 2017, 2018). These documents are referenced in this report when previous assumptions, methods, and conclusions remain relevant to carcass management for the current scenario. The natural disaster assessment (USEPA 2017) is particularly relevant because it evaluated exposures to chemicals (i.e., metals naturally present in livestock and combustion products).

Livestock could be contaminated with chemicals due to intentional or unintentional events. Examples of intentional events include criminal or terroristic acts such as chemical poisoning of food or water supplies, sabotage of agricultural production or commodity markets, or use of a chemical warfare agent. These possibilities could involve many different types of chemicals and levels of contamination. The emergency could expose livestock to lethal or sublethal levels of contamination and could affect small to very large numbers of animals. This assessment examines how human exposures from carcass management would vary in response to various levels of contamination, numbers of carcasses, and other factors. The assessment assumes that livestock are contaminated by a chemical emergency, but does not address the type of emergency or routes of exposure to the livestock. With this approach, the assessment is not limited to a specific type of emergency. In addition, the assessment evaluates human exposure to chemical releases from carcass management, without including direct exposure from the emergency event or exposure through environmental media unrelated to carcass management.

Exposure Assessment Objective and Conceptual Modules

The objective of this exposure assessment is to support the selection of environmentally protective livestock carcass management methods in times of emergency by providing scientifically-based information on potential hazards to human health, livestock, wildlife, and the environment. Exposures to chemicals considered the same conceptual modules as considered in natural disaster assessment (USEPA 2017).

1.2 Report Organization

This Final Report is organized in six sections. Section 2 explains the conclusions of problem formulation for the assessment, while Section 3 describes the approaches for estimating chemical releases from carcasses, fate and transport, and human exposure. Section 4 presents the results of the exposure assessment and an uncertainty analysis that discusses how the findings may be applied to chemical emergencies with larger numbers of carcasses, varying levels of contamination, or variations from the assessment scenario. The Final Report concludes with quality assurance documentation in Section 5 and literature cited in Section 6.

2. Problem Formulation

Problem formulation for the exposure assessment defines the scope of the assessment including the chemical emergency scenario, scale of mortality, carcass management activities, and chemical hazards. Problem formulation for this assessment builds on and uses many of the same methods and assumptions as the previous assessments of managing livestock carcasses following a natural disaster (USEPA 2017) and foreign animal disease (FAD) outbreak (USEPA 2018).

2.1 Scenario Description

As in exposure assessments for the natural disaster and FAD scenarios, the base case for this assessment assumes 100 cattle carcasses weighing 50 U.S. tons (45,359 kilograms [kg]) for all management options. Because some cattle ranches have more than 100,000 head, the number and total weight of carcass could be much higher than the base case. An uncertainty analysis presented in Section 4.2 examines how exposures would differ with 500, 1000, and 10,000 carcasses.

To focus the assessment on outcomes of carcass management, the carcasses are assumed to be intact when promptly collected for management (i.e., within 48 hours [hr]), and management of the carcasses is not impeded by other impacts (e.g., damage to or availability of resources and equipment) of the emergency scenario.

To be consistent with the previous assessments, this assessment uses the same site setting and exposed individuals. The humans potentially exposed include adult and child onsite (farm) residents and workers participating in carcass management. The farm includes agricultural fields and a home garden that supplies the farm residents' fruits and vegetables. The residents also produce their own livestock food products at home, including beef, dairy, pork, poultry, and eggs; fish for consumption are caught in an on-site lake. Farm residents obtain drinking water from an on-site groundwater well. Further description of these assumptions is provided in the natural disaster assessment report (USEPA 2017).

Potential chemical emergency scenarios could include intentional criminal or terroristic acts such as chemical poisoning of food or water supplies, sabotage of agricultural production or commodity markets, or use of a chemical warfare agent. The contamination could be unintentional as well. Examples of unintentional chemical emergencies include industrial accidents, accidental contamination of feed or other agricultural supplies, and transportation-related accidents (e.g., tanker truck or rail car spillage).

Kosal and Anderson (2004) reviewed past incidents of livestock feed poisonings and concluded that feed security is a vulnerable target for terrorism. For example, a small amount of a very toxic chemical (e.g., a bag of pesticide) added at a single point in in the feed supply can lead to very rapid and wide distribution of the chemical with potentially severe health or economic consequences.

Table 2-1 describes 10 incidents in which livestock have been contaminated with chemicals. These incidents include contamination from an industrial accident, accidental contamination of livestock feed, and intentional poisoning of livestock through contaminated drinking water or feed. Three of the incidents in Table 2-1 resulted in large numbers of cattle deaths from toxic chemical exposure.

The scenario for this assessment does not necessarily require a specific type of emergency – if the assessment begins after the chemical emergency has killed the livestock or contaminated animals are culled, the event itself has no bearing on the exposure modeling approach. By this same logic, natural disaster assessment (USEPA 2017) did not include a specific disaster scenario. However, information on livestock contamination from actual chemical emergencies is relevant to selecting chemicals of concern.

2.2 Chemical Hazards

Virtually any toxic compound could affect livestock through a conceivable chemical emergency scenario. Considerations used to choose chemicals for this assessment included:

- Availability of chemical property and other data (i.e., biotransfer factors) needed for fate and transport modeling;
- Availability of toxicity reference values (TRVs) with which to assess the potential for exposure to result in adverse health effects;
- Relative toxicity as indicated by comparing TRVs among chemicals;
- Environmental persistence as indicated by media half-life values; and
- For pesticides, current registered pesticide uses (i.e., not banned).

Some or all of these criteria are met by all of the chemicals involved in the ten incidents described in Table 2-1. Of these ten chemicals, four involved dioxins, three involved pesticides, two involved polychlorinated or polybrominated biphenyls, and one involved cyanide.

2.2.1 Dioxins

Dioxins, unless separately identified in this report, include polychlorinated dibenzo-p-dioxin (PCDD) compounds and polychlorinated dibenzofurans (PCDFs). Collectively, these groups of similarly structured compounds, called congeners, are among the so called “dirty-dozen” persistent organic pollutants (POPs) subject a 2001 United Nations treaty. The United States and other signatories to the Stockholm Convention agreed to reduce or eliminate the production, use, and/or release of these chemicals.

Dioxins are hydrophobic (also called lipophilic), resistant to metabolism, and persistent in the environment (USEPA 1994, 2012). Their toxicity depends on the degree of chlorination and which functional sites on the molecule are substituted with chlorine (i.e., the congeners with chlorine substituted at the 2,3,7, and 8 positions are the toxic isomers), and 2,3,7,8-tetrachlorinated dibenzo-p-dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin [TCDD]) serves as the index chemical for relative toxicity factors (USEPA 2010).

In air, dioxins can travel long distance and deposit to soils and surface waters. Because they generally have very low solubility and a high affinity for organic matter, in surface water they tend to either volatilize to air or adsorb to suspended particles that eventually settle to the bottom. Dioxins can bioaccumulate in the fatty tissues of fish and other animals and can be of concern in milk products from exposed cattle and goats because of the high lipid content of milk. In aquatic communities, dioxins can bioaccumulate through successive steps in the food web, resulting in higher concentrations in the top trophic level fish. Also because of their low solubility and tendency to sorb to organic material, dioxins do not travel far in subsurface soil and are not generally associated with groundwater contamination. Based on these properties, human exposures to dioxins/furans from carcass management options are expected to occur primarily through air transport and deposition pathways and not through leaching from storage piles, burial trenches, or compost windrows.

The level of dioxin/furan contamination in carcasses assumed for the assessment is based on the maximum level observed in beef during the 2008 contamination incident in Ireland described in Table 2-1. That level was 400 times the applicable European Union dioxin limit of 0.2 ng toxic equivalency quotient [TEQ]/g fat, or 80 ng[TEQ]/g fat (Pogatchnik 2008). Assuming that a 1,000-kg adult beef carcass is 30% fat (Topel and Kauffman 1988) and that dioxins are found only in the fat, the total body burden of dioxin based on the 2008 incident in Ireland is 24 mg per carcass. This is the base-case level of contamination assumed for the assessment. Contamination levels one order of magnitude higher and lower than the base-case level are evaluated in the uncertainty analysis presented in Section 4.2.

2.2.2 Diazinon

Because most dioxin congeners have very low mobility in soil and groundwater, the assessment also includes a chemical that might be expected to leach to groundwater and meets criteria listed above. Based on the incidents included in Table 2-1, the assessment includes a pesticide, specifically diazinon. Diazinon is organophosphate insecticide (other organophosphate pesticides include chlorpyrifos, fenamiphos, malathion, disulfoton, and ethyl parathion). These are among the most widely used pesticides, with USEPA registered uses in agriculture, homes, gardens, and veterinary practices. All organophosphate insecticides can cause acute and subacute toxicity by affecting the functioning of the nervous system (Roberts and Reigart 2013). Considering the selection criteria above, the specific organophosphate insecticide for the assessment is diazinon.

Diazinon has been limited to agricultural uses since 2004. It is considered to be of moderate toxicity compared to other organophosphates. It is found in all environmental media without a pronounced tendency for any particular one (ATSDR 2008). Spray applications and volatilization can release diazinon to the air, making inhalation exposure is possible. It is moderately mobile in soils and groundwater under certain conditions. In surface water, it does not bioconcentrate significantly in aquatic food webs (ATSDR 2008). It is not considered a persistent organic pollutant because it is degraded in time by abiotic and biotic processes.

Table 2-1. Documented Chemical Emergencies Involving Livestock

Incident	Chemical(s)	Summary
Ireland, 2008	Polychlorinated biphenyls (PCBs) and dioxins	A feed manufacturer in Ireland used hot gases from fuel oil combustion to dry animal feed. In 2008, the facility used contaminated oil that resulted in feed contamination with PCBs and dioxins. All pork products were recalled, and 170,000 pigs and 5,700 cattle were destroyed. (Marnane 2012)
Nebraska, 2003	Organophosphate insecticide	250 cattle died of apparent feed poisoning. Preliminary investigations concluded that a neurotoxic insecticide was deliberately placed in a feed bin. (Kosal and Anderson 2004; Columbus Telegram 2003)
Belgium, 1999	Dioxins	Fat used in animal feed was contaminated with dioxins. This animal feed was distributed to farms in Belgium, France, the Netherlands, and Spain. The contamination was discovered when poultry began showing heath and reproductive impacts. (Kosal and Anderson 2004; Lok and Powell 2000)
Germany, 1997	Dioxins	Dioxin-contaminated citrus pulp used in ruminant animal feed originating from Brazil was distributed to German farms. The origin of the dioxin was a contaminated lime included as an ingredient in the manufacture of citrus pulp. Elevated levels of dioxins were detected in samples of milk, butter, beef and veal from various German farms. Contaminated feed was destroyed. (APHIS 2000)
Wisconsin, 1996	Organochlorine pesticide (chlordane)	Feed products from a rendering plant were contaminated with the organochlorine pesticide chlordane. Contaminated feed was shipped to 4,000 farmers in four states. The impact was primarily economic, with the recall of feed and other rendering products, as well as the slaughter of cattle. (Kosal and Anderson 2004; Neher 1999)
Mississippi, 1996	Dioxins	Contaminated ball clay was used as an anti-caking additive in soybean animal feed. Ball clay can naturally contain dioxins that can be released during processing. Elevated dioxin concentrations were measured in chickens that ate the feed. No health impacts were reported. (APHIS 2000; ATSDR 1998; USEPA 2013)
Wisconsin, 1981	Organophosphate insecticide	131 beef cattle were killed and four sickened when organophosphate corn root worm insecticide was deliberately added to a feed silo. (Kosal and Anderson 2004; Neher 1999)

Incident	Chemical(s)	Summary
Italy, 1976	Dioxins	An industrial explosion in Seveso, Italy spread an estimated 1.3 kg of 2,3,7,8-TCDD over a 2.8 km^2 area, exposing livestock and 17,000 people. (ATSDR 1998)
Michigan, 1973	Polybrominated biphenyl (PBB)	PBB manufactured in the same plant as a cattle feed supplement (magnesium oxide) was accidentally used in the production of dairy cattle feed. This mistake was detected after the feed had been distributed and used in farms throughout Michigan. Within two years, 1.5 million chickens, 30,000 cattle, 5,900 pigs, and 1,470 sheep were slaughtered, and up to 85% of the state's human population was exposed. Elevated rates of cancer and other health effects were observed among the most highly exposed populations (MDCH, 2011; Fries 1985; Kosal and Anderson 2004)
Alabama, 1970	Cyanide	Thirty cattle were killed and nine sickened when their water supply was poisoned with cyanide, allegedly by members of the Ku Klux Klan to intimidate black Muslim farmers. (Kosal and Anderson 2004; Pate and Cameron 2001)

Abbreviations and acronyms: km^2 = square kilometer(s); PBB = polybrominated biphenyl; PCB = polychlorinated biphenyl.

Persistence varies by medium and environmental conditions. For example, diazinon half-lives in sandy loam soil are 66, 209, and 153 days at pH values of 4, 7, and 10, respectively (Schoen and Winterlin 1987).

The base-case level of diazinon contamination for the assessment is a body burden of 5 g per carcass. This is based on a lethal dose of 20-25 mg/kg (Junquera 2017). For a 1,000-kg cow, the body burden associated with the upper bound lethal dose would be 25,000 mg (25 g). A sublethal dose of 5 g per carcass (20% of the lethal dose) is selected as the base-case body burden. Body burdens of 0.5, 50, and 500 g per carcass are included in the uncertainty analysis (Section 4.2).

2.2.3 Other Potential Chemical Hazards

When coal is used as a fuel for combustion-based carcass management, naturally present mercury will be emitted. Although coal combustion was included in the natural disaster assessment, mercury was not included in the emissions data used for the assessment. Data to include mercury now have been obtained and are included in this assessment. Exposures to mercury estimated in this report would apply equally to the previously assessed scenarios.

The exposure assessment does not include chemicals (e.g., trace metals) that are naturally present in livestock, veterinary drugs, or other chemicals unrelated to the chemical emergency. Human exposure to chemicals naturally present in cattle was evaluated in the exposure assessment for the natural disaster scenario (USEPA 2017), and exposure to those chemicals would not differ when the carcasses are in the chemical emergency scenario.

The natural disaster assessment also evaluated exposure to chemicals produced as combustion products from carcasses and fuels, specifically dioxins, polycyclic aromatic hydrocarbons (PAHs), and various metals. Production of, and exposure to, the combustion products would not differ with the natural disaster and chemical emergency scenarios, and it is not necessary to repeat the assessment for those chemicals. However, dioxins from combustion are included in this assessment because the chemical emergency scenario includes contamination with dioxins, as discussed further in Section 2.2.1. As a result, the assessment examines the total exposure to dioxins following the chemical emergency scenario.

This assessment does not include exposure to microbes. The natural disaster scenario assessment (USEPA 2017) evaluated exposures to microbes that are typically found in healthy cattle, and the findings of that assessment would apply equally to the chemical emergency scenario.

2.3 Livestock Carcass Management Options and Assumptions

The carcass management options included in this assessment are the same seven well-established methods included in the exposure assessments for the natural disaster and FAD outbreak scenarios. These options, which are listed in Table 2-2, can be distinguished as occurring *on-site* or *off-site*. The on-site management options (i.e., open burning, air-curtain combustion, burial, and composting) typically are performed on the livestock owner's property if a suitable location is available. Therefore, residues from carcass management including from carcasses and fuels, woodchips, or other management materials could remain on-site after the carcass management operation is complete.

Table 2-2. Livestock Carcass Management Options Considered for the Exposure Assessment

Management Type	Specific Management Option
Combustion-based Management	▪ On-site Open Burning (Pyre) ▪ On-site Air-Curtain Burning ▪ Off-site Fixed-facility Incineration
Land-based Management	▪ On-site Unlined Burial ▪ On-site Composting ▪ Off-site Lined Landfill
Materials Processing	▪ Off-site Rendering

Additionally, the carcass management options can be categorized by degree of containment, as summarized in Table 2-3. All management options are assumed to operate in compliance with applicable regulations and best practices so that releases from commercial off-site facilities are within permitted limits. Thus, exposures from permitted releases from the three regulated off-site management options (i.e., rendering, commercial incineration, placement in lined landfills) are not evaluated. These assumptions are consistent with the previous exposure assessments for the natural disaster and FAD outbreak scenarios.

Table 2-3. Containment of Releases from Management Options

Combustion		Land-Based		Material Processing	
On-Site	Off-Site	On-Site	Off-Site	On-Site	Off-Site
🟧 Air Curtain	🟩 Incineration	🟧 Composting	🟩 Landfill	Not Evaluated	🟩 Rendering
🟥 Open Burning (Pyre)		🟥 Burial			

🟩 = Releases restricted by regulation
🟧 = Releases partially restricted by physical barriers
🟥 = No barrier to releases

All of the carcass management options are preceded by activities with the potential for chemical releases and exposures. Among these are carcass handling, temporary storage before the selected management option, and transportation of the carcasses from the storage location to the management location. Each of these is discussed and evaluated in the assessment of livestock management options for natural disasters (USEPA 2017). They are not included in this assessment due to the following reasons:

- The natural disasters assessment (USEPA 2017) concluded that they have a small contribution to potential chemical exposures compared with the carcass management options

- Exposures from these activities are similar for all of the options. Moreover, compared with the natural disaster scenario, workers engaged in a chemical emergency response are more likely to use protective equipment (e.g., personal protective equipment) and practices to limit exposure.

Table 2-4 summarizes scoping assumptions for the chemical emergency assessment scenario. Assumptions about the design and application of the management options (e.g., design of the pyre and burial trench) are consistent with those used in the assessment for natural disasters (USEPA 2017).

Table 2-4. Scoping Assumptions for the Chemical Emergency Assessment

Issue	Assumptions
Carcass Management and Post-Management Assumptions	▪ Carcass management options include those with documented use and sufficient capacity for large-scale carcass management. ▪ The exposure assessment begins with collection of carcasses from where animals died or they are euthanized at the management location. ▪ Carcasses are intact when placed in management and begin normal decomposition when placed. ▪ Exposures to hazardous materials released from management units and from post-management processes (e.g., residuals disposal) are both assessed. ▪ On-site management options are designed and operated in compliance with applicable state and federal guidance and regulations. ▪ Off-site commercial management options include containment technologies that should restrict emissions to permitted levels. Moreover, the releases of particles and chemicals at or below regulatory limits are assumed to be health protective. Therefore, the three regulated, off-site carcass management options (i.e., placement in landfills, commercial incineration, and rendering) are not assessed for chemical releases.
Chemical Emergency Type and Related Effects	▪ Livestock are contaminated by an unspecified chemical emergency and the contamination could have resulted from an intentional or unintentional event (e.g., feed contamination, industrial explosion). ▪ Livestock may have been killed directly by the emergency event or are culled due to contamination. ▪ The emergency and its effects (e.g., residual environmental contamination, damage to infrastructure and equipment) do not impede collection, movement, or handling of the carcasses or implementation of any of the carcass management options.
Livestock Types	▪ The exposure assessment focuses on the management of cattle carcasses. Other livestock categories (e.g., swine and poultry) are discussed where relevant. Category-specific livestock characteristics (e.g., body size) influence handling and management of carcasses (e.g., poultry and juvenile pigs can be moved by hand, movement of cattle and hogs requires heavy equipment), whereas other characteristics are similar across categories (e.g., basic elemental composition of terrestrial vertebrate animals).
Hazard Types	▪ Hazardous agents of concern include dioxins/furans and diazinon, which are released directly from decomposing carcasses or from carcass management (including dioxins/furans formed by combustion of carcasses and fuels) and post-management processes. ▪ For the open-burning option, the assessment includes mercury that is naturally present in coal used as a pyre fuel. Mercury is not present in the carcasses.

Issue	Assumptions
Scale of Livestock Mortality	▪ For all carcass management options, 45,359 kg (50 U.S. tons) of carcasses are managed.
Geographic and Spatial Issues	▪ All carcass management activities take place at a hypothetical farm. ▪ All carcass management options are evaluated with identical on-site spatial and geographic assumptions (e.g., same size watershed, nearby water bodies, precipitation, land gradient, depth to aquifers). ▪ The site location and regional factors do not preclude the availability or feasibility of any carcass management option (e.g., no shallow water tables). ▪ A single set of values is used for meteorological and other environmental parameters (e.g., wind speed, air mixing height, soil porosity, soil fraction organic carbon, slope and erosion rates, rainfall-related soil percolation and runoff rates). The values are based on data from a representative agricultural region, nationally representative values (if available and vetted as such by USDA or USEPA), and/or health protective values.
Human Health	▪ Farm residents consume farm products as part of their regular diet. ▪ Farm residents regularly consume fish caught from an on-site lake. ▪ Farm residents are not exposed to other chemicals or other sources of the chemicals analyzed in this report (that is, all doses are directly from the carcass management option). ▪ Worker exposures arise solely from the carcass management option.
Legal Requirements	▪ All federal requirements must be met. ▪ State and local requirements for carcass management vary by location and are not addressed in the assessment.

Abbreviations and acronyms: kg = kilograms.

3. Exposure Estimation

Section 3.1 describes the approaches used to estimate chemical releases to air and to soil for all management. Section 3.2 describes the modeling methods employed for specific environmental media for these scenarios. Section 3.3 describes how the estimated concentrations of chemicals in exposure media (e.g., air, drinking water, fruits and vegetables) are used to estimate exposure doses for adults and children.

3.1 Estimation of Releases

This section describes estimated chemical release rates from the four on-site management options: open-pyre burning (Section 3.1.1), air-curtain burning (Section 3.1.2), unlined burial (Section 3.1.3), and composting (Section 3.1.4).

3.1.1 On-site Open Burning (Pyre)

The conceptual model for the on-site open burning (pyre) management option is presented in Figure 3-1, and further assumptions for open burning are provided in Table 3-1. With this option, the carcasses are burned in a single pyre resulting in release of gases and particles. When constructed according to USDA standard operating procedures (USDA 2005), combustion should be complete within 48 hours. Ash could be managed on site or removed to an off-site landfill. For this exposure assessment, the ash is managed on site, specifically by being buried or covered with clean soil in place (i.e., over the area of ground on which the pyre burned). The fuels used to promote burning of the carcasses also will release some chemicals in vapor and particulate-phase to air while leaving other chemicals in the residual ash. Further details about the pyre design, including fuel types and quantities and ash management, are provided in the report for the natural disaster assessment (USEPA 2017).

Table 3-1. Source and Exposure Pathway Assumptions for On-site Open Burning Management Option

Conceptual Model Feature	Assumptions
Pyre Design and Use	▪ Based on pyre construction guidelines provided by USDA (2005), 45,359 kg (50 tons) of carcasses are burned in a single pyre that is 2.4 m (8 ft) wide by 91.4 m (300 ft) long. ▪ Fuels used in construction of the pyre include: 300 hay bales, 300 timbers (8 ft by 1 ft^2 (2.4 m by 0.30 m by 0.30 m) each, 50 lb (22.7 kg) kindling, 10,000 lb (4,536 kg) coal, and 100-gal (378.5 L) fuel oil (USDA 2005). ▪ Combustion is complete within 48 hr (USDA 2005). ▪ The combustion temperature is 550°C (1022°F). ▪ After combustion, the ash is buried in place. Cover depth is sufficient to place ash below the root zone.
Air Pathways	▪ Inhalation of particulate matter and vapor-phase gasses by humans is estimated at distances between 100 m and 10 km from the center of the source. ▪ Downwind air concentrations of vapor-phase chemicals could be absorbed by plant leaf stomata. ▪ Downwind air deposition of particulate-phase chemicals to the top surfaces of leaves are unlikely to result in chemical absorption.
Soil Ingestion Pathways	▪ Chemicals deposited from air to soil near the source are primarily particulate-phase and are distributed in the top two centimeters of surface soil; leaching to deeper soils is limited and not evaluated. ▪ A fraction of chemicals deposited to surface soil will run off or erode to a 100-acre on-site lake. ▪ Farming, livestock pasturing, and grazing will not be performed on the pyre site until after revegetation with grasses or cover crops that appear healthy.
Groundwater and Well Water	▪ The water table is assumed to be 1 m (~ 3 ft) below the surface. ▪ An on-site groundwater well downgradient from the pyre site is used for drinking water, but not for watering livestock. ▪ Leaching to groundwater is assumed only for the ash burial; leaching following air deposition to the agricultural field is unlikely to contribute substantially to groundwater concentrations. ▪ Groundwater is not treated before use.
Production of Food on the Farm	▪ Residents of the farm consume farm-grown plants. ▪ Livestock also consume farm-grown plants, then humans consume livestock products (e.g., meat, milk, eggs). ▪ Residents consume recreationally caught fish from an on-site lake.

Abbreviations and acronyms: USDA = U.S. Department of Agriculture; kg = kilograms; m = meter; km = kilometer; ft = feet; ft^2 = square foot; lb = pound; gal = gallon; L = liter; hr = hour; °C = degrees Celsius; °F = degrees Fahrenheit.

Releases of Combustion Products to Air from Open Burning

Chemicals released to air from open burning for this assessment include dioxins present in the carcasses due to the chemical emergency, dioxins formed by the combustion of carcasses and pyre fuels, and mercury present in coal used as pyre fuel. With a combustion temperature of

550°C (1022°F), the pyre will decompose diazinon, which has a flash point of 82.2° C (180° F) (NIOSH 2016), to various aliphatic organophosphates, substituted pyrimidines, and hydrogen cyanide, phosphorus oxides, sulfur oxides, and nitrogen oxides. Because incineration destroys dioxins only at temperatures above 982°C (1800°F) (NRC 2000), none of the dioxin body burden is destroyed by the pyre. Dioxins are highly lipophilic and all of the dioxin contamination in the carcasses is assumed to be in fat, which burns completely leaving no ash. With these assumptions, all of the dioxin contamination in the carcasses is emitted to air from the pyre.

Rates of dioxin emission to air (in g/sec) are estimated separately for carcasses and woody materials (i.e., timbers, kindling, straw) used to build and fuel the pyre. For each of these, particulate and vapor phase emissions are estimated separately, and the total emissions of each phase is divided among 17 dioxin/furan congeners. The emissions are separated by phase and congener using congener emissions profiles from the literature. The dioxin profile for the woody materials, shown in Table 3-2, was developed for the natural disaster scenario assessment and is further documented along with emission rates in Appendix B USEPA (2017).

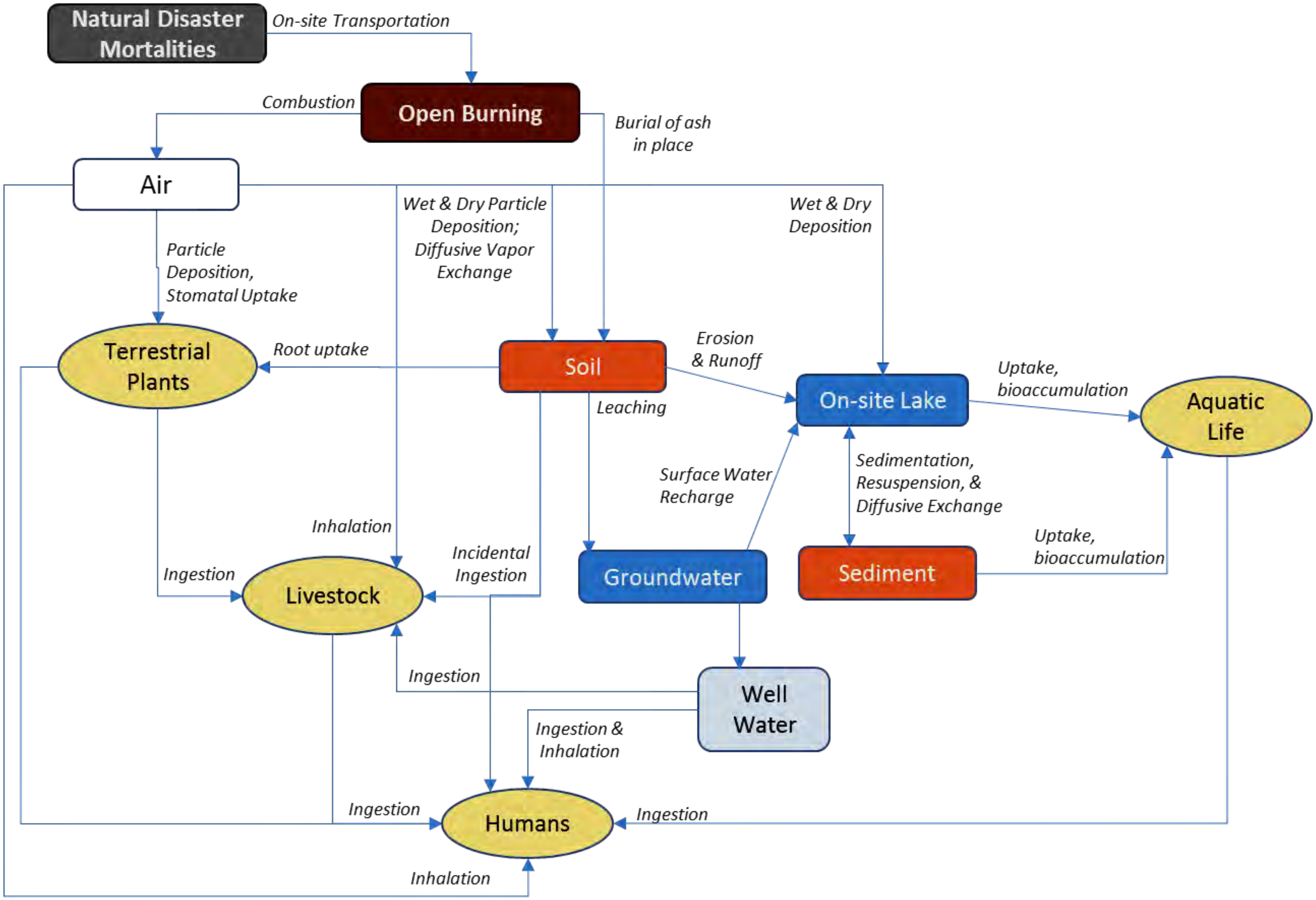

Figure 3-1. Conceptual model of exposure pathways from on-site open burning of livestock carcasses.

Table 3-2. Dioxin Emission Profiles for Carcasses and Woody Fuels

Dioxin/Furan Congener	CAS Registry Number®	Dioxin Profile for Contaminant in Carcasses		Dioxin Profile for Combustion of Woody Pyre Materials		Dioxin Profile for Combustion of Woody Air Curtain Burner Fuel	
		Particulate	**Vapor**	Particulate	Vapor	Particulate	Vapor
OctaCDD, 1,2,3,4,6,7,8,9-	3268-87-9	75.62%	0.076%	30.722%	1.646%	21.860%	1.149%
OctaCDF, 1,2,3,4,6,7,8,9-	39001-02-0	5.373%	0.005%	8.997%	0.373%	4.422%	0.184%
HeptaCDD, 1,2,3,4,6,7,8-	35822-46-9	9.543%	0.019%	13.167%	2.524%	4.890%	0.931%
HeptaCDF, 1,2,3,4,6,7,8-	67562-39-4	4.752%	0.029%	2.743%	0.527%	6.933%	1.324%
HeptaCDF, 1,2,3,4,7,8,9-	55673-89-7	0.040%	0.000%	0.571%	0.109%	0.743%	0.142%
HexaCDD, 1,2,3,4,7,8-	39227-28-6	0.302%	0.005%	1.097%	0.669%	0.756%	0.445%
HexaCDF, 1,2,3,4,7,8-	70648-26-9	0.150%	0.005%	0.812%	0.571%	2.461%	1.711%
HexaCDD, 1,2,3,6,7,8-	57653-85-7	0.431%	0.007%	1.317%	0.768%	0.906%	0.532%
HexaCDF, 1,2,3,6,7,8-	57117-44-9	0.382%	0.017%	0.373%	0.263%	2.742%	1.905%
HexaCDD, 1,2,3,7,8,9-	19408-74-3	0.510%	0.008%	1.646%	0.955%	2.105%	1.237%
HexaCDF, 1,2,3,7,8,9-	72918-21-9	0.038%	0.001%	0.735%	0.516%	1.168%	0.812%
PentaCDD, 1,2,3,7,8-	40321-76-4	0.038%	0.002%	1.097%	3.072%	0.518%	1.399%
PentaCDF, 1,2,3,7,8-	57117-41-6	0.033%	0.006%	1.756%	3.840%	2.667%	5.665%
HexaCDF, 2,3,4,6,7,8-	60851-34-5	0.921%	0.035%	1.097%	0.790%	1.262%	0.874%
PentaCDF, 2,3,4,7,8-	57117-31-4	1.171%	0.223%	1.975%	4.169%	2.548%	5.421%
TetraCDD, 2,3,7,8-	1746-01-6	0.080%	0.056%	0.900%	4.718%	0.260%	1.368%
TetraCDF, 2,3,7,8-	51207-31-9	0.036%	0.083%	1.317%	4.169%	4.484%	14.178%

To prepare emission rates for dioxin contamination in the carcasses, the dioxin body burden per carcass was multiplied by 100 carcasses and divided by the 48 hr burn duration in seconds. This total emission rate was divided among 17 dioxin/furan congeners using a congener profile for meat and bone meal obtained from Srogi (2008). The congener profile for meat and bone meal does is not an air concentration profile and is not separated by particulate and vapor phases. For this assessment, the congener profile was divided between the particulate and vapor phases for each congener using data reported by Cohen et al. (2002). Table 3-3 shows the congener-specific emission rates, including dioxins from carcass contamination and fuel combustion.

Table 3-3. Dioxin Emission Rates from Combustion-based Management Options

Dioxin/Furan Congener	CAS Registry Number	Dioxin Emission Rates for Open Burning (g/sec)		Dioxin Emission Rates for Air-curtain Burning (g/sec)	
		Particulate	Vapor	Particulate	Vapor
OctaCDD, 1,2,3,4,6,7,8,9-	3268-87-9	1.1E-05	1.6E-08	2.2E-05	6.2E-07
OctaCDF, 1,2,3,4,6,7,8,9-	39001-02-0	7.7E-07	1.9E-09	3.1E-06	9.9E-08
HeptaCDD, 1,2,3,4,6,7,8-	35822-46-9	1.3E-06	2.9E-09	1.4E-06	1.8E-08
HeptaCDF, 1,2,3,4,6,7,8-	67562-39-4	6.6E-07	4.0E-09	7.7E-07	2.5E-08
HeptaCDF, 1,2,3,4,7,8,9-	55673-89-7	5.6E-09	4.3E-11	1.7E-08	2.3E-09
HexaCDD, 1,2,3,4,7,8-	39227-28-6	4.2E-08	6.9E-10	4.3E-08	1.4E-09
HexaCDF, 1,2,3,4,7,8-	70648-26-9	2.1E-08	7.2E-10	2.5E-08	3.5E-09
HexaCDD, 1,2,3,6,7,8-	57653-85-7	6.0E-08	9.8E-10	6.1E-08	1.8E-09
HexaCDF, 1,2,3,6,7,8-	57117-44-9	5.3E-08	2.3E-09	5.7E-08	5.4E-09
HexaCDD, 1,2,3,7,8,9-	19408-74-3	7.1E-08	1.2E-09	7.4E-08	3.1E-09
HexaCDF, 1,2,3,7,8,9-	72918-21-9	5.3E-09	2.1E-10	7.2E-09	1.5E-09
PentaCDD, 1,2,3,7,8-	40321-76-4	5.3E-09	2.5E-10	5.4E-09	4.7E-10
PentaCDF, 1,2,3,7,8-	57117-41-6	4.7E-09	1.0E-09	1.9E-08	3.1E-08
HexaCDF, 2,3,4,6,7,8-	60851-34-5	1.3E-07	4.9E-09	1.3E-07	6.3E-09
PentaCDF, 2,3,4,7,8-	57117-31-4	1.6E-07	3.1E-08	1.6E-07	3.4E-08
TetraCDD, 2,3,7,8-	1746-01-6	1.1E-08	7.8E-09	1.1E-08	8.0E-09
TetraCDF, 2,3,7,8-	51207-31-9	5.0E-09	1.2E-08	1.2E-08	3.4E-08

Abbreviations and acronyms: g = gram; sec = second.

If constructed according USDA standard operating procedures (USDA 2005), the pyre will be constructed with 100 lb (45 kg) of coal per cattle carcass. According to USEPA (1997a), the mercury content of coal is assumed to be 0.22 mg[Hg]/kg[coal]. Although coal is variable in composition, the mercury content is similar for bituminous and subbituminous coal and anthracite coal. With these assumptions, a pyre for 100 carcasses contains about 990 mg of mercury. Speciation of mercury emissions is based on data for data for electric utility fossil fuel boilers emissions summarized by USDA (2013). Specifically, 50% is elemental mercury [Hg(0)], which will stay in the air as vapor, 30% is divalent mercury [Hg(+2)], and 20% is bound to particulates, which can be emitted in fly ash or remain in bottom ash. Data on the composition of fly ash and bottom ash from Dutch waste incinerators reported by the International POPs Elimination Network (IPEN 2005), showed mercury to be distributed 91% in fly ash and 9% in bottom ash. Based on these data, this assessment assumes that 90% of the particulate mercury is emitted to air and 10% remains in ash. Using the sources and data described above, the mercury emission factors and ash content for this assessment are presented in Table 3-4.

Table 3-4. Mercury Emission Rates and Bottom Ash Mercury Content for a Coal-fueled Pyre for 100 Cattle Carcasses

Vapor $Hg^{(0)}$ from Coal (g/sec)	Vapor $Hg^{(+2)}$ from Coal (g/sec)	Particulate Hg from Coal (g/sec)	Bottom Ash Hg from Coal (g)
2.9E-06	1.7E-06	1.0E-06	1.8E+01

Abbreviations and acronyms: g = gram; Hg = mercury; sec = second.

Leaching from Remaining Open-Burning Ash

Following combustion of the pyre, the remaining ash will contain dioxins formed by the combustion of carcasses and pyre fuels, and mercury present in coal used as pyre fuel. As discussed in Section 2.2, all dioxin contamination from the chemical emergency will be released to air and will not be present in the ash. In addition, diazinon will not be in the ash because it is destroyed by combustion.

Pyre ash on the ground might be removed to a landfill. For this assessment, however, the ash is assumed to be buried or covered in place with a layer of clean soil of sufficient depth to isolate the ash from plant roots. The area over which the ash is distributed is the area of the pyre, which is 91.4 m long by 2.4 m wide (300 foot [ft] long by 8 ft wide), or 223 m^2 (equal to 0.056 acres or 400 ft^2). Because the soil cover is permeable to rainwater, contaminants in the ash have the potential to leach into subsurface soil and groundwater each time it rains. In addition, colloids and small particulates (e.g., on order of microns) with sorbed chemicals can percolate through any larger interstitial spaces or pores (e.g., along plant roots) through subsurface soils.

The amount of ash remaining from open burning is estimated from the quantities of carcasses (i.e., 45,359 kg or 50 U.S. tons) and fuels placed in the pyre. The weight of ash remaining after burning the carcass is assumed to be 6% of the uncombusted weight of carcasses (NRC 2000). This assumption is the approximate midpoint of a distribution of body-ash content estimated by the National Research Council (NRC 2000) for cattle with various body condition scores (based on visual assessments of animal fatness).

Quantities of fuel materials for open burning, shown in Table 3-1, are based on USDA (2005) recommendations for constructing a large animal carcass pyre. The ash remaining from woody and other plant-based fuels, including timbers, kindling, and straw, is assumed to weigh 1% of the original weight (Pitman 2006). Coal ash is assumed to weigh 2% of the uncombusted weight (Butalia 1999). Diesel, which is used as an accelerant, is not included in the ash contaminant data because no ash remains from its combustion. The total ash quantity estimates based on this information is 3,235 kg, including 2,722 kg from carcasses and 514 kg from fuels.

Concentrations of mercury in the pyre ash are discussed above and concentrations estimated for this assessment are presented in Table 3-4. There are no available studies reporting concentrations of combustion-produced dioxin in bottom ash (i.e., ash remaining on the ground) from open burning of livestock carcasses. Consequently, dioxin concentrations in bottom ash are estimated by combining concentrations known to be present as combustion products from each of the different fuel types. The resulting concentration of total dioxins in fuel ash 7.8E-02 µg/kg and 1.2E-02 µg/kg in all pyre ash. Further details about dioxin contamination in combustion ash are available in USEPA (2017).

Uncertainty Analysis Design for Open Burning

The uncertainty analysis varies the open-burning base-case scenarios by (1) varying the level of dioxin and diazinon contamination in the carcasses and (2) varying the number of carcasses.

To vary the level of dioxin contamination, the base-case body burden of 24 mg per carcass (see Section 2.2.1) is decreased to 2.4 mg per carcass an increased to 240 mg per carcass. All other attributes of the base-case are unchanged in the uncertainty analysis. Diazinon contamination is not varied of the combustion-based options because it is entirely consumed by combustion.

To evaluate how exposures vary with the scale of mortality, the base-case number of carcasses (i.e., 100) is increased to 500 and 1,000 carcasses. Increasing the scale of mortality increases the size of the pyre, contaminant emission rate, amount of ash and ash disposal area. Table 3-5 summarizes the sizes and orientation of the pyres for each number of carcasses evaluated. Management of 10,000 carcasses is evaluated for burial and composting, but not for the combustion-based options (i.e., open-burning and air-curtain burning). Feasibility at this scale is unlikely based on the land area and the resources that would be required. For example, pyre construction would require 5,000 U.S. tons of coal and 30,000 timbers. Although mortality at this scale, or greater, is possible, carcass management probably would require a combination of management options.

Table 3-5. Pyre Design Assumptions for the Uncertainty Analysis for Greater Numbers of Carcasses

Number of Carcasses	Pyre Design
100 (base case)	▪ Single pyre that is 2.4 m (8 ft) wide by 91.4 m (300 ft) long. ▪ Fuels used in construction of the pyre include: 300 hay bales, 300 timbers (8 ft by 1 ft^2 (2.4 m by 0.30 m by 0.30 m) each, 50 lb (22.7 kg) kindling, 10,000 lb (4,536 kg) coal, and 100-gal (378.5 L) fuel oil (USDA 2005). ▪ Combustion is complete within 48 hr (USDA 2005).
500	▪ Five parallel, 100 carcass pyres separated by 5 m. ▪ Fuels, ash amount, and ash disposal area are five times larger than the 100-carcass pyre. ▪ Combustion complete within 48 hours.
1,000	▪ Five parallel pyres that are twice as long as a single 100-carcass pyre. ▪ Pyres are separated by 5 m. ▪ Fuels, ash amount, and ash disposal are ten times larger than the 100-carcass pyre. ▪ Combustion complete within 48 hours.
10,000	▪ Open burning alone is not evaluated because feasibility is unlikely at this scale.

Abbreviations and acronyms: m = meter; ft = foot, ft^2 = square foot; lb = pound; kg = kilograms; gal = gallon; L = liter; USDA = U.S. Department of Agriculture.

Air-curtain Burning

The conceptual model for on-site air-curtain burning is presented in Figure 3-2. Note that the compartments in this conceptual model are identical to those in the on-site open burning conceptual model (Figure 3-1). The two management options differ with respect to air emissions profiles and residual ash composition. With air-curtain burning, carcasses are burned in a partially enclosed (partially open on top) refractory fire box. A forced air flow, driven by a diesel-powered blower, creates an air “lid” over the burn area that recirculates much of the smoke and soot within the fire box and provides additional mixing of air within the burning mass. Hazardous chemicals can be released to the environment when combustion products escape to air and when the ash is buried on-site under a layer of clean fill. Further assumptions for the air-curtain burning management option are stated in Table 3-6, and additional background information on the technology and its use in carcass management is available in the USEPA (2017).

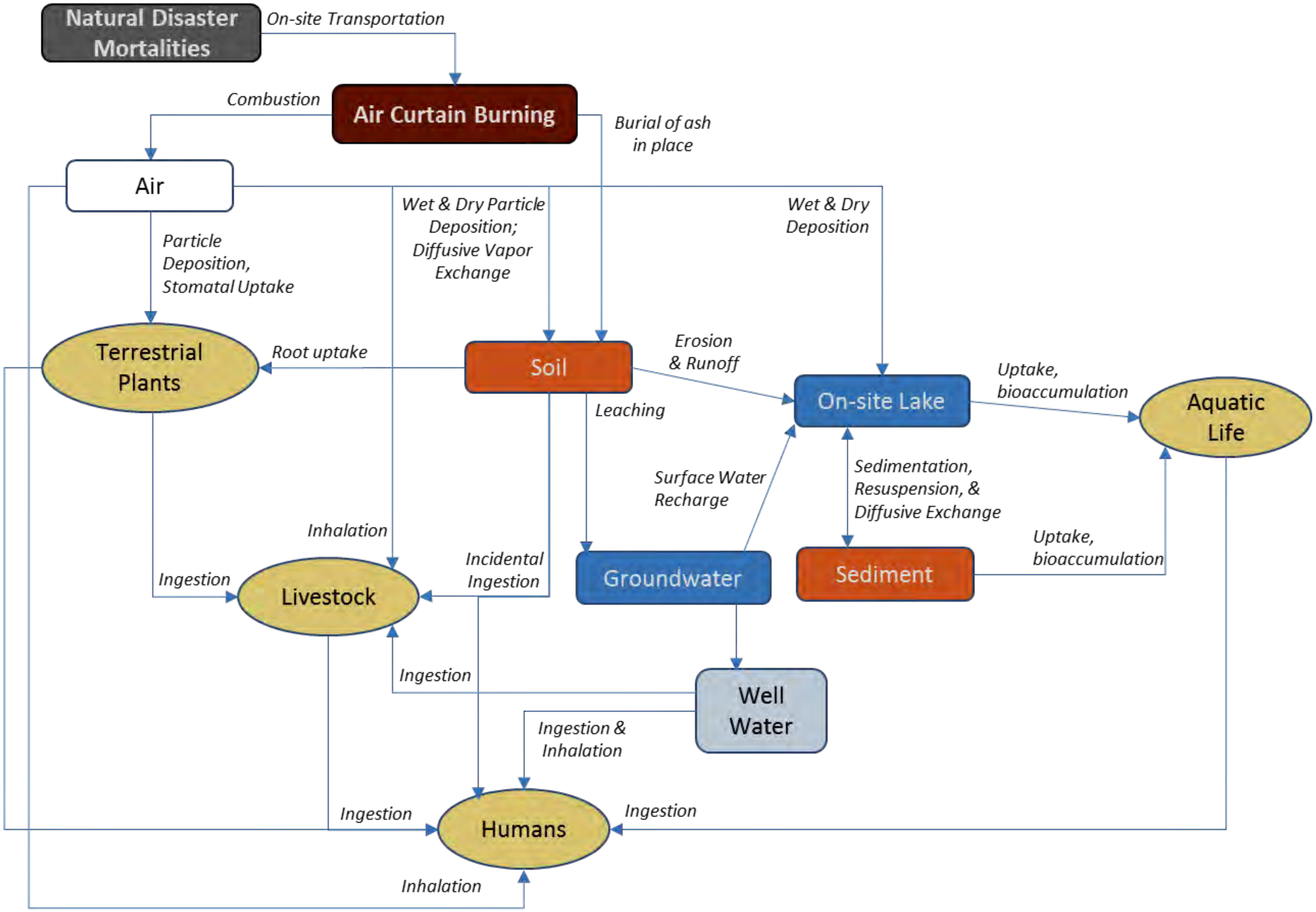

Figure 3-2. Conceptual model for exposure pathways from on-site air-curtain burning of livestock carcasses.

Table 3-6. Assumptions for On-site Air-curtain Burning of Livestock Carcasses

Conceptual Model Feature	Assumptions
Burner Design and Use	▪ Carcasses are burned in an above-ground refractory box with a forced-air "curtain" on top. The fire box measures 8.3 m long, by 2.6 m wide, and 2.5 m height, and the overall dimensions of the air-curtain burner unit are 11.4 m long, by 3.6 m long, and 2.9 m high.[2] ▪ Combustion fuels include scrap wood, previously stockpiled logs, and diesel fuel to power the air blower. Wood fuel is supplied at a 4:1 ratio by weight to carcasses. ▪ The combustion temperature in the carcass mass is 850°C (1,600 °F). ▪ To burn 100 carcasses, the air-curtain burner is operated continuously for 48 hr. ▪ Combustion ash is placed in an excavated 21.6 m^2 pit with a length and width equal to the dimensions of the fire box (8.3 m long by 2.6 m wide). ▪ The burial trench for the ash is unlined and covered with clean fill.
Air Pathways	▪ Inhalation of particulate matter and vapor-phase gasses by humans is estimated at distances between 100 m and 10 km from the center of the source. ▪ Downwind air concentrations of gas-phase chemicals could be absorbed by plant leaves. The short combustion duration (48 hr) relative to the time required by crop plants to mature to harvest suggests that foliar absorption from the air and incorporation into plant tissues would be negligible.
Soil Pathways	▪ Incidental soil ingestion by humans and livestock is considered for agents deposited from air to soil. Deposition from air occurs over a short period of approximately two days. ▪ Farming, livestock pasturing, and grazing do not occur on the ash disposal site. If the cover fill is disturbed by these activities, plants might suffer root burn, while animals might be exposed to specific metals from negligible to toxic concentrations. This is not further considered in the assessment because of the high levels of uncertainty associated with this type of exposure. ▪ Buried ash does not contribute to surface soil concentrations.
Groundwater and Well Water	▪ Leaching to groundwater is assumed only for the ash burial trench; leaching following air deposition to the agricultural field is assumed to not contribute significantly to groundwater concentrations. ▪ The water table will be assumed to be 1 m below the bottom of the ash pit. ▪ An on-site groundwater well is used for drinking water. ▪ Groundwater is not treated or filtered before use.
Production of Food on the Farm	▪ Residents of the farm consume farm-grown plants. ▪ Livestock also consume farm-grown plants, then humans consume livestock products (e.g., meat, milk, eggs). ▪ Residents consume recreationally caught fish from an on-site lake.

Abbreviations and acronyms: m = meter; m^2 = square meter; °C = degrees Celsius; °F = degrees Fahrenheit; km = kilometer; hr = hour.

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[2] Assumptions about the refractory box design are based on the specifications of Air Burners Inc., Model S-372, Air Burners Inc. (2012), available at: http://www.airburners.com/DATA-FILES_Print/ab-s327_Specs_PRNT.pdf

Releases of Combustion Products to Air from Air-curtain Burning

Releases to air from air curtain burning are estimated using the same approach as described above for open burning. Differences in determining emission rates for the two combustion options are fuel types and amounts, combustion temperatures, and the size and configuration of the combustion sources. Emissions rates for fuels for the base-case scenario are the same as used for the natural disaster assessment (USEPA 2017). Air-curtain burning is fueled with scrap wood at a 4:1 ratio with the carcasses by weight. Dioxin emissions from the wood fuel are calculated with the congener profile included in Table 3-2. Dioxin emission from carcass contamination are the same as for open burning because the amount of contamination and burn duration are the same, and the combustion temperature is below the temperature at which dioxins are destroyed (NRC 2000). Emission rates, including dioxins from carcasses and fuel combustion, are provided in Table 3-3.

No mercury is emitted from air curtain burning because coal is not used as a fuel, and no diazinon is emitted because it is consumed by combustion. The combustion temperature and the size and configuration of the air-curtain burner processing chemical-impacted carcass are the same as developed for the natural disaster assessment and are summarized in Table 3-6.

Leaching from Air-curtain Burner Ash

Exposures are not expected from leaching from air-curtain burning combustion ash. Dioxins have very low mobility in soil due to their low solubility and their tendency to partition to organic matter. Modeling of contaminant release, including leaching from ash, showed essentially negligible dioxin reaching groundwater(USEPA 2017). Neither diazinon nor mercury are present in the air curtain burner ash as discussed previously.

Uncertainty Analysis for Air-curtain Burning

Uncertainty analyses in Section 4.2 examine varying levels of dioxin contamination and scales of mortality as discussed above for open burning. The uncertainty analysis for the level of dioxin contamination uses the same range of body burden values used for open burning.

The uncertainty analysis for the scale of mortality affects assumptions about the duration of combustion and the size and orientation of air release sources. Like the related sensitivity analysis for open burning, the sensitivity analysis considers air-curtain burning of 100, 500, and 1,000 carcasses. As described above, the base-case includes 100 carcasses burned over 48 hours in a single air-curtain burner unit. Managing larger number of carcasses could be accomplished by a using a single unit for a longer time, using multiple units simultaneously, or a combination of these options. Longer durations are limited by the progressive decomposition of the carcasses. As reported by Ellis (2001), within 7 to 10 days after death the decomposed carcasses lose structural integrity making them difficult to move. Based on this, burn durations greater than 10 days are considered infeasible for this assessment.

Assuming the base-case burning rate, (i.e., 48 hr to burn 100 carcasses with a single unit), some options for managing 500 carcasses include a single unit operating for 10 days, 2 units operating for 5 days, 5 units operating for 2 days, and ten units operating for a single day. Options with multiple units become increasingly infeasible as the number of units increases due to cost and availability limitations. Considering feasibility constraints, options selected for the uncertainty analysis are summarized in Table 3-7. Air-curtain burning is not likely to be feasible for 10,000 carcasses and is not included in the uncertainty analysis. At least 20 air-curtain burners operating simultaneously would be required to manage 10,000 carcasses within 10 days.

Table 3-7. Air-curtain Burning Assumptions for the Uncertainty Analysis for Greater Numbers of Carcasses

Number of Carcasses	Air-curtain Burner Design
100 (base case)	▪ Carcasses are burned in an above-ground refractory box with a forced-air "curtain" on top. The fire box measures 8.3 m long, by 2.6 m wide, and 2.5 m height, and the overall dimensions of the air-curtain burner unit are 11.4 m long, by 3.6 m long, and 2.9 m high. ▪ Combustion fuels include scrap wood, previously stockpiled logs, and diesel fuel to power the air blower. Wood fuel is supplied at a 4:1 ratio by weight to carcasses. ▪ To burn 100 carcasses, the air-curtain burner is operated continuously for 48 hr (2 days).
500	▪ Two parallel air-curtain burner units operating for 5 days ▪ Parallel units are separated by 5 m. ▪ Fuels, ash amount, and ash disposal area are 5 times larger than with 100 carcasses.
1,000	▪ Four parallel units operating for 5 days. ▪ Parallel air-curtain burners are separated by 5 m. ▪ Fuels, ash amount, and ash disposal are 10 times larger than with 100 carcasses.
10,000	▪ Air-curtain burning alone is not evaluated because feasibility is unlikely at this scale.

Abbreviations and acronyms: m = meter; hr = hour

An additional sensitivity for air-curtain burning analysis examines the wood fuel to carcass ratio. For the base-case, four tons of wood fuel are burned for each ton of carcasses (i.e., a 4:1 ratio). This assumption represents the conservative upper bound of values identified from the literature (USEPA 2017). However, available sources (e.g., NABCC 2004; SKM 2005) indicate that lower fuel ratios are more typical. Therefore, the uncertainty analysis examines exposures with a fuel ratio of 2:1.

3.1.2 Burial

Figure 3-3 provides an overview of the conceptual model for the on-site livestock carcass burial option. In this option, livestock carcasses are placed in an unlined, excavated pit or trench in a suitable location on site.[3] The carcasses are covered with clean fill creating a mound over the site that will flatten over time as the carcasses lose fluids and other mass during decomposition. Although access to the site is not restricted, it will not be used in the relatively near future for crop farming or raising livestock; it will be seeded over for soil stabilization.

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[3] Mass livestock burial trenches might be created off-site following some natural disasters. It is assumed that in those cases, state and federal representatives would participate in selection of location(s) with appropriate conditions (e.g., high over groundwater, far from any groundwater wells).

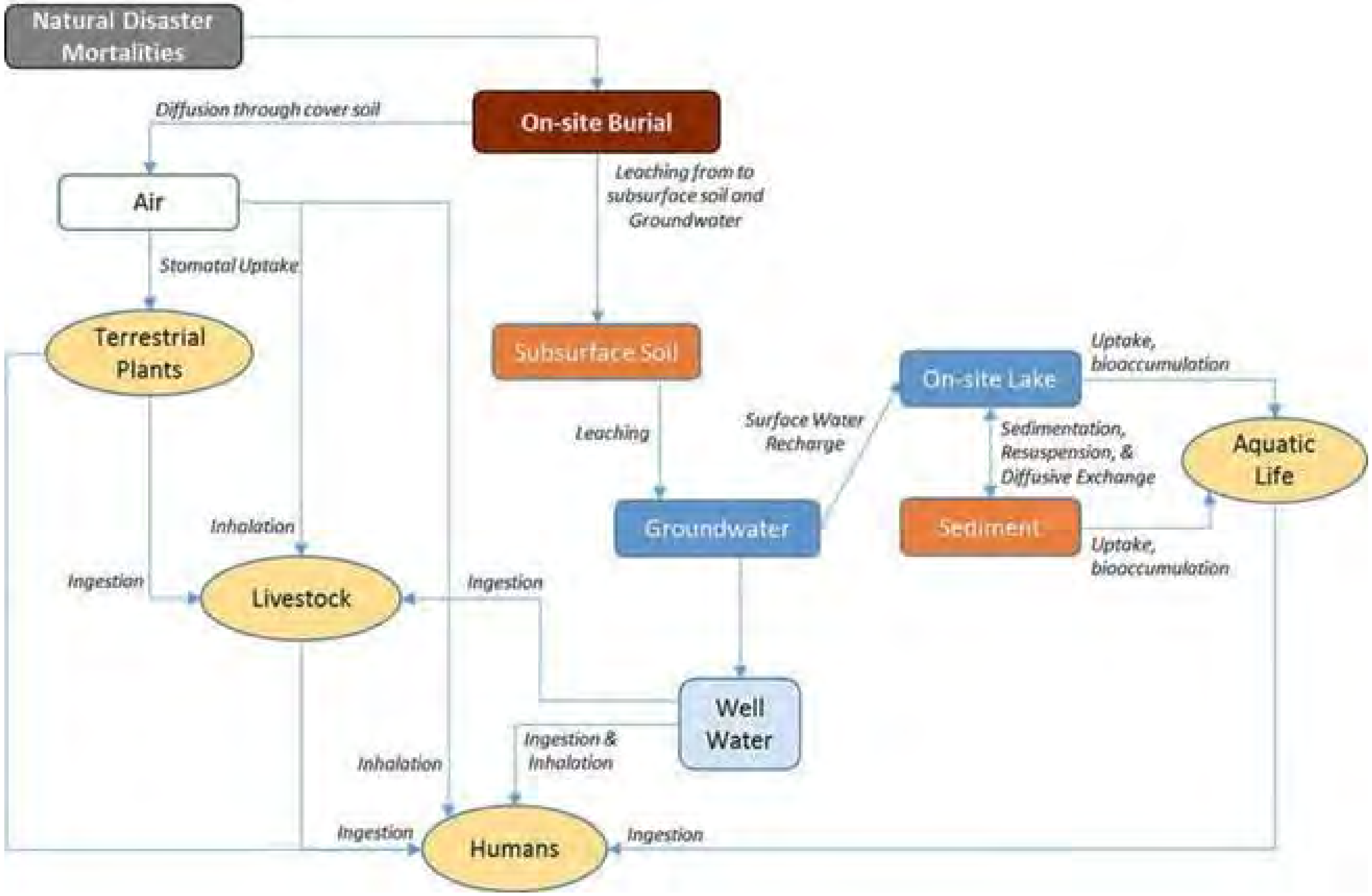

Figure 3-3. Conceptual model for exposure pathways from on-site burial of livestock carcasses.

As the carcasses decompose rapidly at first (over months) with the remainder decomposing more slowly (over years), vapor-phase chemicals can diffuse upward though the soil cover to aboveground air. When gases reach the surface, they are readily diluted in ambient air. For this reason, the inhalation pathways pictured in Figure 3-3 do not affect the assessment. Leaching of chemicals toward groundwater is the focus of the exposure pathway assessment for burial. Soluble chemicals can leach with carcass fluids and with rainwater permeating through subsurface soils to groundwater. Table 3-8 summarizes assumptions for the on-site burial management option.

Table 3-8. Assumptions for the On-site Burial of Livestock Carcasses

Conceptual Model Feature	Assumptions
Burial Trench Design and Use	▪ 100 cattle carcasses are placed in a single trench that is 9 ft deep, 7 ft wide, and 300 ft long (2.7 × 2.1 × 91.4 m) based on guidelines provided by USDA (2005). ▪ The carcasses are covered with 6 ft (1.8 m) of soil, including 3 ft (0.9 m) mounded over the site starting at ground level (USDA 2005). ▪ An unsaturated zone of 1 m (3.3 ft) extends below the bottom of the burial trench.
Air Pathways	▪ Gases generated by carcass decomposition can slowly seep upward through cover soil to air.
Soil Pathways	▪ Soil erosion and runoff from the burial site to surface water are not included in the conceptual model, because there is soil capping the burial site.
Groundwater and Well Water	▪ Chemicals can leach to groundwater from carcasses and subsurface soil beneath the burial trench. ▪ The water table remains at least 1 m below the burial trench throughout the year. ▪ An on-site groundwater well is used for drinking water. ▪ Groundwater is not treated before use.
Surface Water, Sediment, and Aquatic Life	▪ Chemicals from buried carcasses can reach the on-site lake only via groundwater (assuming appropriate hydrology). ▪ Humans on the farm ingest fish caught from the on-site lake.

Abbreviations and acronyms: ft = feet; m = meter; USDA = U.S. Department of Agriculture.

Unlike combustion of carcasses, which is completed over a few days, decomposition of buried carcasses and leaching of materials from carcasses occurs over much longer time frames. The volume of leachate from burial is estimated based on figures from Young et al. (2001). As described by Young et al. (2001), the release of bodily fluids for buried livestock carcasses is rapid at first, with steadily declining release rates after the first few months or year. They estimate that approximately 33% of the carcass mass is released as fluids during the first 2 months after burial, of which half is released within the first week. If the leachate has the density of water (i.e., 1 kg/L), for 45,359 kg (50 U.S. tons) of carcasses, approximately 15,000 L of fluid would be released in the first 2 months, with 7,500 L released during the first week.

The amount of fluid released from buried carcasses depends on the time after death. Most of the releases during the first week after death occur after the abdomen of an animal bursts from gas buildup. According to expert opinion provided for this project (see Section 2.5 in USEPA 2017), the abdomen in a livestock carcass typically bursts 3 to 4 days after death, with leachate releases occurring 3 to 7 days after death. Before the abdomen bursts, liquid matter unrelated to decomposition (e.g., feces, urine, blood, ingesta, serum, saliva) can be released (UM-CAHFS 2014). Because liquids could be released at varying but unknown rates throughout the first post-mortem week, the total amount released during the first week is averaged to calculate a daily rate. For 100 carcasses, 7,500 L/week divided by 7 days is 1,070 L per day. This equates to 10.7 L/day per carcass. For the remaining duration of the first two months (i.e., days 8 through 60), the average volume of leachate is 1.4 L per day per carcass.

Exposure is calculated based on chemical leaching from the carcasses during the first two months. Because the fluid release is highest during the first week after death, contributions to exposure are calculated separately for leaching during the first week and for weeks 2 through 8. Daily average chemical concentration in leachate during each period are calculated by dividing the total amount of chemical released per day during each period divided by the daily leachate volumes described above. Chemical releases per day per carcass are calculated by multiplying the body burden of contaminant by the percentage of carcass mass released as fluid per day during the time period. For the base-case, an estimated 117.9 mg of diazinon are released per carcass per day during the first week, and 15.6 mg of diazinon are released per carcass per day during weeks 2 through 8. Throughout the first two months, the concentration of diazinon in fluid released is 11 mg/L.

The chemical release from burial the burial trench is estimated only for diazinon; mercury from coal is not present for air-curtain burning and dioxin leaching is not estimated due to its low mobility in subsurface soil and water.

Uncertainty Analysis for Burial

Sensitivity analyses for the burial option evaluate varied diazinon body burdens and scales of mortality. As discussed in Section 2.2.2, the base-case diazinon body burden is 5 g. The uncertainty analysis evaluates leaching to groundwater from burial of 100 carcasses with body burdens of 0.5, 5, 50, and 500 g per carcass per carcass.

The uncertainty analysis evaluates burial of 100, 500, 1,000, and 10,000 carcasses, all with the base-case body burden (i.e., 5 g diazinon per carcass). Table 3-9 summarizes the assumptions for this uncertainty analysis.

Table 3-9. Assumptions for the Uncertainty Analysis for Burial with Greater Numbers of Carcasses

Number of Carcasses	Burial Trench Design
100 (base case)	▪ 100 cattle carcasses are placed in a single trench that is 9 ft deep, 7 ft wide, and 300 ft long (2.7 m × 2.1 m ×91.4 m) based on guidelines provided by USDA (2005). ▪ The carcasses are covered with 6 ft (1.8 m) of soil, including 3 ft (0.9 m) mounded over the site starting at ground level (USDA 2005). ▪ An unsaturated zone of 1 m (3.3 ft) extends below the bottom of the burial trench.
500	▪ Carcasses are placed in a single trench that is 10 times as long (457 m) as the base case. ▪ All other design assumptions are equivalent to the base case.
1,000	▪ Carcasses are placed in a single trench that is 5 times as long (914 m) as the base case. ▪ All other design assumptions are equivalent to the base case.
10,000	▪ Carcasses are placed in ten parallel trenches that are equivalent to the trench for 1,000 carcasses.

Abbreviations and acronyms: ft = feet; m = meter; USDA = U.S. Department of Agriculture.

3.1.3 Composting

The conceptual model for the composting option is shown in Figure 3-4. In this management option, the carcasses are placed in outdoor composting windrows that are constructed according to specifications provided by USDA (2005). Carcasses are placed on a base layer and covered with a 2 ft (0.6 m) thick layer of bulking material (e.g., woodchips) on the top and all sides. For large animals, Glanville et al. (2006) recommends placing one U.S. ton (907 kg) of carcass, in a single layer, per 8 ft (2.4 m) of windrow. Using this recommendation, the total length of windrow for 45,359 kg (50 U.S. tons) of large animal carcasses is 122 m (400 ft). For the base case, 100 carcasses are placed in two 16 ft (4.9 m) wide by 60 m (200 ft) long windrows. The windrow is assumed to be placed on bare earth in a well-drained area that is at least 1 m (~3 ft) above the high water-table level. Other specific assumptions used to model the composting option are shown Table 3-10.

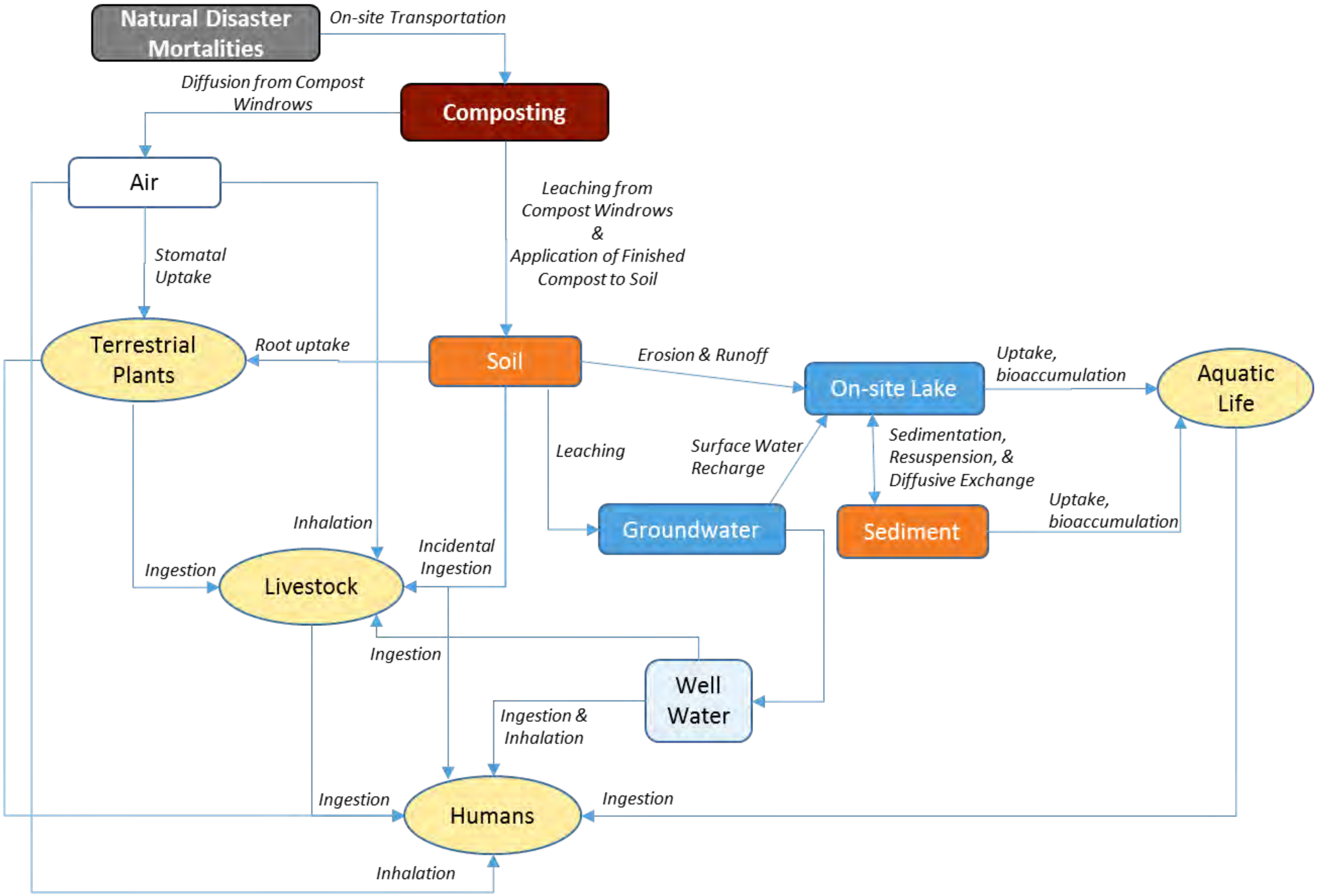

Figure 3-4. Conceptual model of exposure pathways from livestock carcass composting.

Gases liberated by decomposition diffuse upward through the bulking material to the atmosphere. Due to its low volatility and high affinity for organic matter, dioxin is assumed not to be released to air from the windrow. Inhalation also not assessed for diazinon. Diazinon can volatilize to air, but is less likely to permeate through the bulking layer than lighter inorganic cases from decomposition.

Bulking material absorbs most of the liquid released from the carcass during decomposition. Glanville et al. (2006) and Donaldson et al. (2012) both reported volumes of leachate from experimental compost windrows to not exceed 5% of the precipitation that falls on the windrows. Based on that information, the assessment assumes that only 5% of the volume of fluids released by decomposition will seep into the ground beneath the windrow.

Table 3-10. Assumptions for the Composting Management Option

Conceptual Model Feature	Assumptions
Compost Windrow Design	▪ Composting is performed on bare earth (USDA 2005, 2015) in two windrows that are 4.9 m (16 ft) wide by 61 m (200 ft) long. ▪ An initial layer of bulking material (e.g., woodchips) 2 ft deep are placed across the entire base of the eventual windrow (USDA 2005). ▪ An additional two feet of bulking material are placed on the sides and top of the windrow (USDA 2005). ▪ Runoff from the windrows will be contained with hay bales.
Air Pathways	▪ Inorganic gases generated by carcass decomposition diffuse upward through the top cover of woodchips to air, where they quickly disperse to non-hazardous levels. ▪ Releases of dioxin and diazinon to air are insignificant.
Soil Pathways	▪ The base layer of bulking material beneath the windrows limits contamination of groundwater. Woodchips used as carbon bulking material absorb all but 5% of the liquid released from the carcasses inside the windrow (Glanville et al. 2006). This leakage can seep through soil to groundwater.
Production of Food on the Farm	▪ For this assessment, compost is applied to a field according to a federal- or state-approved nutrient management plan and crops human consumption are grown in that field. ▪ Compost is tilled into the soil to a depth of 20 cm, based on a default assumption from (USEPA 2005).
Surface Water, Sediment, and Aquatic Life	▪ Agents from composted carcasses can reach the lake only via runoff/erosion from the compost application site (not from the windrow itself). ▪ 50% of the soil eroded from the compost application area is deposited to untreated land between the application site and the on-site lake.

Abbreviations and acronyms: ft = feet; m = meter; USDA = U.S. Department of Agriculture; cm = centimeter; USEPA = U.S. Environmental Protection Agency.

According to Looper (2001), composting of dairy cow carcasses generally takes six to eight months, with 90% of the flesh decomposed after eight weeks. The assessment assumes the finish compost is applied to an on-site agricultural field in accordance with a nutrient management plan. Transport of chemicals from the compost application site can occur by runoff/erosion to the lake.

Leaching to Groundwater from the Windrow

The approach to estimating leaching to the ground from the windrow is similar to the approach described in Section 3.1.3 for leaching from the burial trench. For the same number of carcasses and level of contamination, the amount of liquid released and the concentration of diazinon in the leachate is the same for buried and composted carcasses. While all of the leachate from burial seeps into the soil below the burial trench, most of the leachate from composting is absorbed by bulking material. As an absorbent, the bulking material allows water to evaporate while the bulk of the minerals and non-volatile organic and inorganic compounds remain in the bulking material, which later is mixed into the finished compost.

Using corn stalks as the sorbent bulking material, researchers including Glanville et al. (2006) and Donaldson et al. (2012) found the volume of leachate from experimental compost windrows to be no more than 5% of precipitation falling (500–600 mm) on the windrows (i.e., the bulking material facilitated evaporation of water back into the air for 95% of the rainfall). Based on these findings, the assessment assumes that 5% of the liquid released from the carcasses seeps to the ground below the windrow. Contaminants in the remaining 95% of the leachate remain in the windrow.

Using the approach and data described above, the windrow releases 0.53 L per day per carcass during the first week after death and 0.07 L per day per carcass during weeks 2 through 8. The amounts of diazinon released per carcass per day are 5.9 mg and 0.8 mg during the first week and weeks 2-8, respectively. Throughout the first two months the concentration of diazinon in leachate released from the windrow is 11 mg/L.

Application of Compost to Soil

The determination of the appropriate rate of finished compost application to soil (i.e., tons of compost per acre) and the total area of soil receiving compost assume the nitrogen (N) content of the compost is at an agronomic rate, ostensibly following the farm's nutrient management plan. An agronomic rate of application occurs when the nutrient content added to the soil does not exceed the uptake capabilities of crops to be planted at the site, nor does it result in fertilizer "burn" (i.e., leaf and root damage) (NABCC 2004). Agronomic fertilization rates also help to protect air, soil, and water quality. For example, nutrients supplied in excess of the agronomic rate can run off or leach to surface water, causing eutrophication, or to groundwater, degrading its quality.

Compost volume and agronomic application rate calculations for the compost of 100 cattle carcasses were performed for the exposure assessment for the chemical attack scenario, and the details of those calculations are presented in the assessment report (USEPA 2017). Based on those calculations, the estimated area over which the finished compost can be applied is about 4 hectares (ha) (~40,000 m^2 or 10 acres [ac]). This amounts to an application rate of about 24 dry tonnes of compost per hectare. In the compost application area, the resulting loading rates (g/m^2) and soil concentrations (mg/kg) for dioxins and diazinon are shown in Table 3-11.

Table 3-11. Estimated Loading of Chemicals to Soil with Compost Application

Contaminant	Loading Rate to Soil (g/m^2)	Concentration in Soil after Tilling (mg/kg)
Dioxin/Furans	6.0E-05	2.0E-04
Diazinon	1.2E-02	4.1E-02

Abbreviations and acronyms: g = gram; kg = kilogram; mg = milligram; m^2 = square meter.

As discussed in Section 2.2.2, diazinon is susceptible to biotic and abiotic degradation processes and half-lives can vary on the order of months with varying conditions (Schoen and Winterlin 1987). Significant degradation is likely in the windrow before compost application to soil. For example, Schoen and Winterlin (1987) reported diazinon half-lives in sandy loam soil to be 66, 209, and 153 days at pH values of 4, 7, and 10, respectively, and Dougherty (1999) reported the pH of finished mortality compost to be in the range 5.5 to 8.0. Assuming a decay half-life of 209 days based on this information, and assuming that composting is complete in 6 months (183 days), the amount decay would reduce the diazinon concentration in the finished compost by 46 percent.[4] The resulting concentration in soil after compost application would be 2.2E-02 mg/kg. Because this estimate uses the longest half-life reported by Schoen and Winterlin (1987), the amount of biological decay would be at least 46 percent for the same composting duration.

The actual amount of diazinon decay is very uncertain due to the wide ranges the composting duration, potential pH values in the finished compost, and uncertainty in the relationship between pH and decay rate, as well as the effects of other environmental factors (e.g., temperature, moisture. This uncertainty is examined in the uncertainty analysis presented in Section 4.2.6.

Uncertainty Analysis for Composting

The uncertainty analysis for composting examines amounts of dioxin and diazinon contamination in the carcasses, the number of carcasses, and the amount of runoff from the compost application site to the on-site lake.

Concentrations of dioxin and diazinon are varied by the same amounts described previously for the other management options. Specifically, dioxin body burdens evaluated are of 2.4, 24, and 240 mg per carcass, and diazinon contamination is evaluated at 0.5, 5, 50, and 500 g per carcass. These variations are all evaluated for composting 100 cattle carcasses.

With base-case levels of contamination, composting is evaluated or 100, 500, 1,000, and 10,000 carcasses. The length of the windrows, amount of finished compost, and compost application area increases in proportion to the number of carcasses. Table 3-12 describes this uncertainty analysis further.

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[4] Calculated using http://www.calculator.net/half-life-calculator.html?type=1&nt=&n0=4.1E-2&t=182.5&t12=209&x=68&y=15

Table 3-12. Assumptions for the Uncertainty Analysis for Composting with Greater Numbers of Carcasses

Number of Carcasses	Compost Windrow Design
100 (base case)	▪ Composting is performed on bare earth (USDA 2005, 2015) in 2 parallel windrows that are 4.9 m (16 ft) wide by 61 m (200 ft) long. ▪ An initial layer of bulking material (e.g., woodchips) 2 ft deep are placed across the entire base of the eventual windrow (USDA 2005). ▪ An additional 2 feet of bulking material are placed on the sides and top of the windrow (USDA 2005). ▪ Runoff from the windrows will be contained with hay bales.
500	▪ Carcasses are placed in 2 parallel windrows that 305 m long, 5 times the length of the 100-carcass windrows. ▪ All other design assumptions are equivalent to the base case.
1,000	▪ Carcasses are placed in 4 parallel windrows that 305 m long, 5 times the length of the 100-carcass windrows. ▪ All other design assumptions are equivalent to the base case.
10,000	▪ Carcasses are placed in 20 parallel windrows that 610 m long, 10 times the length of the 100-carcass windrows. ▪ All other design assumptions are equivalent to the base case.

Abbreviations and acronyms: ft = feet; m = meter; USDA = U.S. Department of Agriculture.

3.2 Fate and Exposure Estimation Methods

The methods described in this section simulate processes that occur between the carcass management units and the locations where people are exposed. These processes determine chemical concentrations in air, soil, groundwater, surface water, aquatic biota, and agricultural products.

3.2.1 Air Dispersion Modeling

Dispersion of airborne chemicals is modeled with the AMS/USEPA Regulatory Model air dispersion model (AERMOD) (version 14134).[5] AERMOD calculates air concentrations and rates of wet, dry, and total deposition to the ground resulting from particle and vapor phase chemical releases from the combustion management options. The assessment assumes emissions originate at the height of the pyre or air-curtain burner and that emissions occur at a continuous rate throughout the duration of combustion. Emission rates for dioxins and mercury are provided in Tables 3-3 and 3-4, respectively. However, air curtain burning is not in Table 3-4, which details mercury emissions, because coal is not used as a fuel.

AERMOD calculates average hourly air concentrations and deposition rates for each hour during the full year of meteorological data (described in USEPA 2017). All estimated air concentrations are in units of $\mu g/m^3$, and deposition rates are in units of g per m^2 per hour. Concentrations and deposition rates are calculated at 304 locations on a radial grid centered on the source: each of the 16 radial lines is separated by 22.5° and includes 19 locations (at 0.1 km intervals from the source to 1 km, and at 1 km intervals thereafter to 10 km). The radial grid is shown in Figure 3-5.

Dioxins and furans emitted from open burning and air-curtain burning include 17 compounds (i.e., congeners) with similar chemical structures and toxic health effects. The compounds are modeled individually and then totaled to present results as total dioxins. Although similar, the individual compounds differ in their toxic potency. Previous researchers developed relative toxicity equivalency factors (TEF) that express the toxicity of each compound relative to an index compound (2,3,7,8-TCDD). The compound-specific concentrations are multiplied the TEFs, which are presented in Table 3-13, before totaling to a single 2,3,7,8-TCDD equivalent (TEQ) concentration (i.e., total dioxins/furans).

Because the base-case combustion options are assumed to last 48 hours, the hourly results are processed to find the highest 48-hour average air concentrations during the year for each location. For comparison purposes, all results are also recorded for 1-hour averaging periods. These results are presented in Table 3-14 for dioxins and for mercury in Table 3-15. Peak 48- and 1-hour average dioxin concentrations in air are plotted in Figures 3-6 and Figure 3-7, at distances from 100 m to 10 km from the source.

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[5] Complete documentation of AERMOD and related tools, including AERMOD, AERMET, and AERSURFACE, is available at <http://www3.epa.gov/scram001/dispersion_prefrec.htm>.

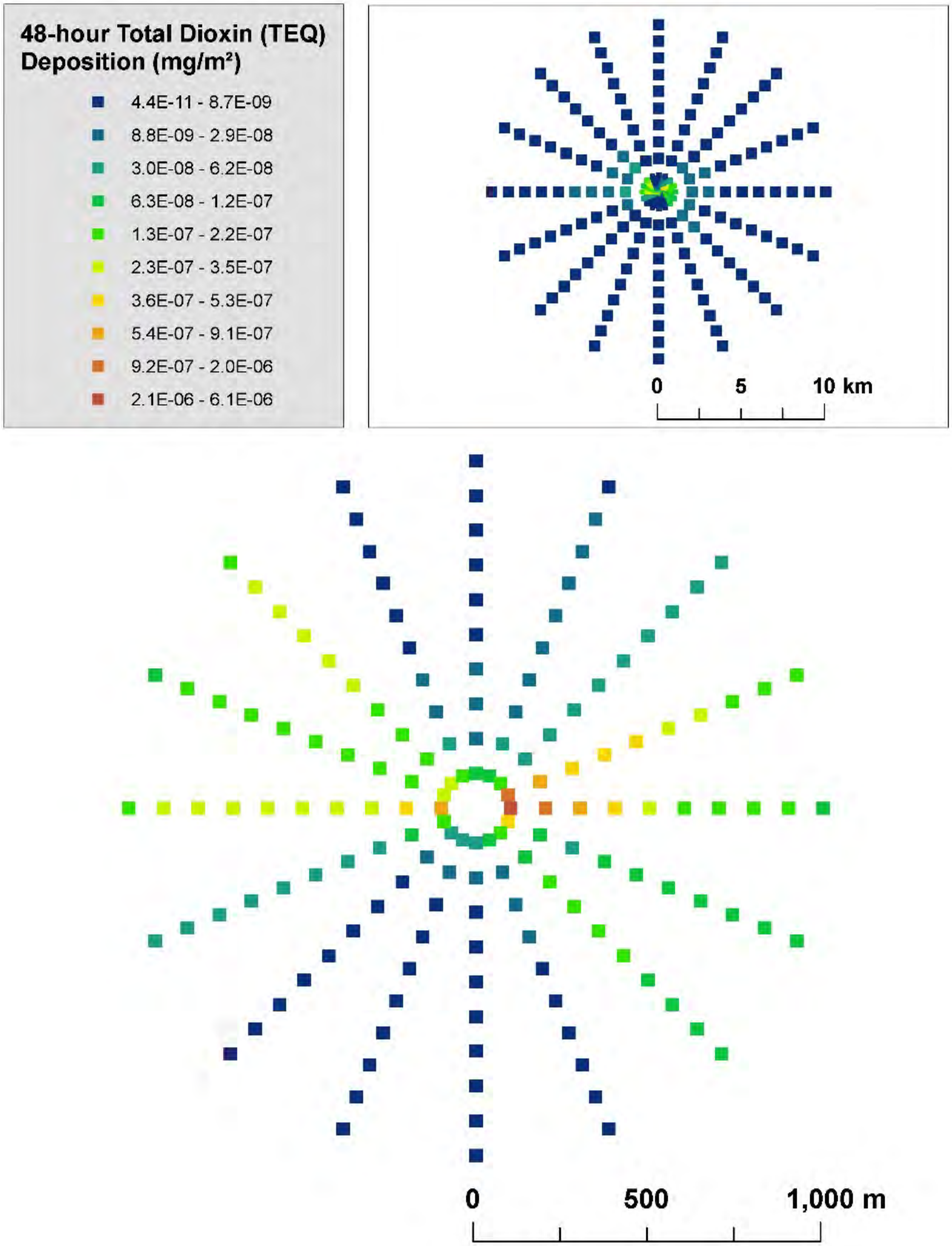

Figure 3-5. Modeled, annual-total deposited mass of chemicals emitted from open-pyre and air-curtain burner units, using hourly meteorology.

Table 3-13. Toxicity Equivalency Factors for Dioxins/Furans

Compound	CAS Reg. Number	TEF (USEPA)
OctaCDD, 1,2,3,4,6,7,8,9	3268-87-9	0.0003
OctaCDF, 1,2,3,4,6,7,8,9	39001-02-0	0.0003
HeptaCDD, 1,2,3,4,6,7,8	35822-46-9	0.01
HeptaCDF, 1,2,3,4,6,7,8	67562-39-4	0.01
HeptaCDF, 1,2,3,4,7,8,9	55673-89-7	0.01
HexaCDD, 1,2,3,4,7,8	39227-28-6	0.1
HexaCDF, 1,2,3,4,7,8	70648-26-9	0.1
HexaCDD, 1,2,3,6,7,8	57653-85-7	0.1
HexaCDF, 1,2,3,6,7,8	57117-44-9	0.1
HexaCDD, 1,2,3,7,8,9	19408-74-3	0.1
HexaCDF, 1,2,3,7,8,9	72918-21-9	0.1
PentaCDD, 1,2,3,7,8	40321-76-4	1
PentaCDF, 1,2,3,7,8	57117-41-6	0.03
HexaCDF, 2,3,4,6,7,8	60851-34-5	0.1
PentaCDF, 2,3,4,7,8	57117-31-4	0.3
TetraCDD, 2,3,7,8	1746-01-6	1
TetraCDF, 2,3,7,8	51207-31-9	0.1

Abbreviations and acronyms: CAS = Chemical Abstracts Service; TEF = toxic equivalency factor; CDD = chlorinated dibenzodioxins; CDF = chlorinated dibenzofurans.
Source: USEPA (2010). The complete reference is at the end of the report.

Table 3-14. Estimated Dioxin/Furans in Air by Distance from Center of Source, Base Case

Distance from Source (km)	Concentration of 2,3,7,8-TCDD Equivalents (TEQs) in Air ($\mu g/m^3$)			
	Peak 1-hr		Peak Event Average	
	Open Burning	Air-curtain Burning	Open Burning	Air-curtain Burning
0.1	1.3E-05	1.8E-06	1.8E-06	9.6E-07
0.2	7.0E-06	3.2E-06	1.3E-06	4.6E-07
0.3	4.3E-06	2.4E-06	1.0E-06	4.0E-07
0.4	3.0E-06	1.8E-06	7.7E-07	3.4E-07
0.5	2.3E-06	1.5E-06	6.1E-07	2.9E-07
0.6	1.8E-06	1.2E-06	5.2E-07	2.6E-07
0.7	1.5E-06	1.1E-06	4.6E-07	2.2E-07
0.8	1.3E-06	8.9E-07	4.2E-07	2.2E-07
0.9	1.1E-06	7.9E-07	3.9E-07	2.1E-07
1	1.0E-06	7.1E-07	3.6E-07	2.0E-07
2	7.0E-07	4.6E-07	2.0E-07	1.3E-07
3	6.5E-07	4.4E-07	1.7E-07	9.7E-08
4	5.5E-07	4.0E-07	1.4E-07	8.1E-08
5	4.8E-07	3.6E-07	1.1E-07	7.4E-08
6	4.7E-07	3.2E-07	9.7E-08	6.8E-08
7	4.6E-07	2.9E-07	8.5E-08	6.1E-08
8	4.6E-07	2.6E-07	7.5E-08	5.5E-08
9	4.5E-07	2.4E-07	6.7E-08	5.0E-08
10	4.4E-07	2.2E-07	6.1E-08	4.5E-08

Abbreviations and acronyms: TEQ = toxicity equivalency factor; µg = microgram; m^3 = cubic meter; hr = hour.

Table 3-15. Estimated Mercury Concentrations in Air by Distance from Center of Source, Base Case

Distance from Source (km)	Concentration of Total Mercury in Air (µg/m^3)		Concentration of Particulate-bound Hg in Air (µg/m^3)		Concentration of Divalent Mercury Vapor (Hg2+) in Air		Concentration of Mercury Vapor (Hg0) in Air (µg/m^3)	
	Peak 1-hr	Peak Event Average	Peak 1-hr	Peak Event Average	Peak 1-hr	Peak Event Average	Peak 1-hr	Peak Event Average
0.1	4.9E-04	6.6E-05	9.1E-05	1.2E-05	1.5E-04	2.0E-05	2.5E-04	3.4E-05
0.2	2.7E-04	5.1E-05	5.0E-05	9.5E-06	8.1E-05	1.5E-05	1.4E-04	2.6E-05
0.3	1.7E-04	3.9E-05	3.1E-05	7.3E-06	5.1E-05	1.2E-05	8.6E-05	2.0E-05
0.4	1.2E-04	3.0E-05	2.2E-05	5.5E-06	3.6E-05	8.9E-06	6.0E-05	1.5E-05
0.5	9.0E-05	2.3E-05	1.7E-05	4.3E-06	2.7E-05	7.1E-06	4.6E-05	1.2E-05
0.6	7.0E-05	2.0E-05	1.3E-05	3.7E-06	2.1E-05	6.0E-06	3.6E-05	1.0E-05
0.7	5.7E-05	1.7E-05	1.1E-05	3.2E-06	1.7E-05	5.3E-06	2.9E-05	8.9E-06
0.8	4.9E-05	1.6E-05	9.0E-06	3.0E-06	1.5E-05	4.9E-06	2.5E-05	8.1E-06
0.9	4.3E-05	1.5E-05	7.9E-06	2.7E-06	1.3E-05	4.5E-06	2.2E-05	7.5E-06
1	3.8E-05	1.4E-05	7.0E-06	2.5E-06	1.2E-05	4.1E-06	1.9E-05	6.9E-06
2	2.7E-05	7.6E-06	5.1E-06	1.5E-06	8.3E-06	2.3E-06	1.4E-05	3.9E-06
3	2.6E-05	6.5E-06	4.9E-06	1.2E-06	7.9E-06	1.9E-06	1.3E-05	3.3E-06
4	2.2E-05	5.4E-06	4.1E-06	1.0E-06	6.8E-06	1.6E-06	1.1E-05	2.8E-06
5	1.9E-05	4.4E-06	3.5E-06	8.4E-07	5.8E-06	1.3E-06	9.7E-06	2.3E-06
6	1.8E-05	3.7E-06	3.3E-06	7.1E-07	5.5E-06	1.1E-06	9.2E-06	2.0E-06
7	1.8E-05	3.2E-06	3.3E-06	6.2E-07	5.4E-06	9.0E-07	9.0E-06	1.7E-06
8	1.7E-05	2.8E-06	3.2E-06	5.5E-07	5.3E-06	7.8E-07	8.8E-06	1.5E-06
9	1.7E-05	2.5E-06	3.1E-06	4.9E-07	5.2E-06	6.8E-07	8.6E-06	1.4E-06
10	1.6E-05	2.3E-06	3.0E-06	4.4E-07	5.0E-06	6.1E-07	8.4E-06	1.2E-06

Abbreviations and acronyms: Hg = mercury; µg = microgram; m^3 = cubic meter; hr = hour.

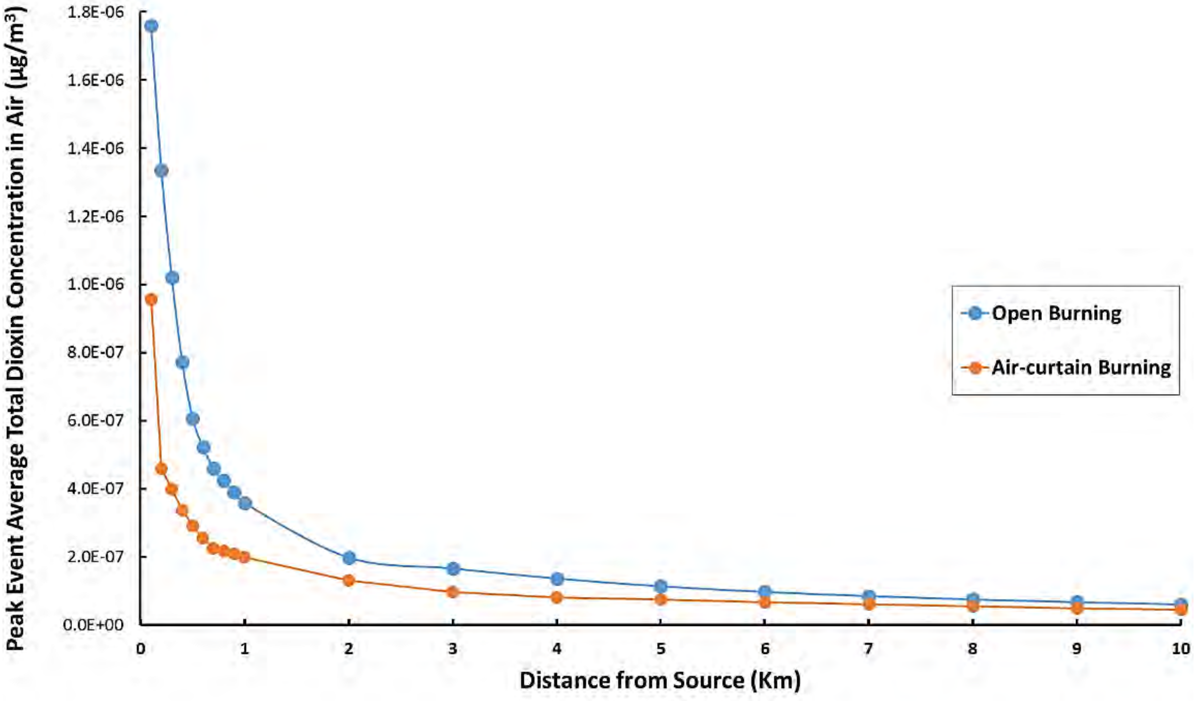

Figure 3-6. Peak event average dioxins concentrations in air with distance from source.

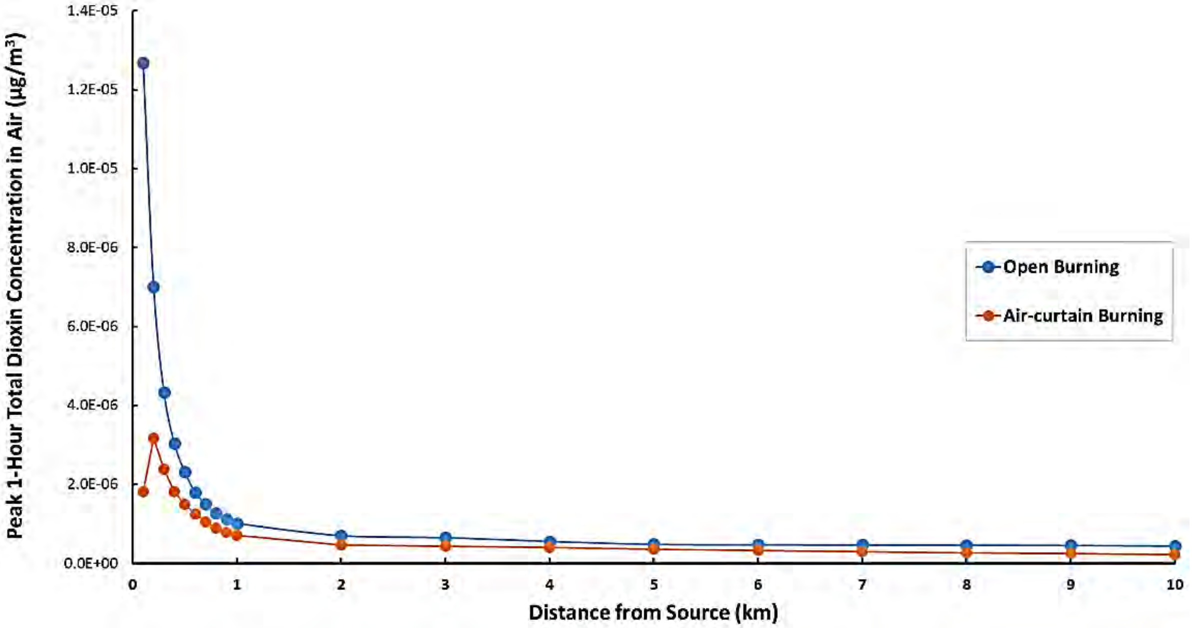

Figure 3-7. Peak 1-hour average dioxins concentrations in air with distance from source.

For both combustion-based management options, 48-hour average dioxin concentrations in air are highest at 100 m and decline gradually with distance. The highest 1-hour average dioxin concentrations are at 100 m for open burning and 200 m for air-curtain burning. For all mercury species and total mercury, the highest concentrations are at the location closest to the pyre (i.e., 100 m). Mercury concentrations are not presented for air-curtain burning because the mercury-containing coal is used as a fuel only for open-burning.

Dioxin concentrations in air from both combustion options decline rapidly within the first kilometer from the source and begin to level off at low concentrations within 2 km and 1 km with 48-hour and 1-hour averages. The 1-hour average concentrations are higher than 48-hour averaged, as would be expected.

For deposition, the AERMOD results are processed to find the highest 48-hour total deposition at each location, as shown in Figure 3-5. Separate results are obtained for wet, dry, and total deposition at each location. In all cases, total deposition is highest at 100 m from the source with a gradual decline at distances further from the source. Deposition rates are used to calculate concentrations in surface soil (see Section 3.2.2), and deposition to the lake surface and watershed contribute to surface water concentrations (see Section 3.2.4).

Some uncertainty analysis variations involve combustion durations longer than the base case. Results for these cases are averaged over the event duration, just as the base-case concentrations are averaged over 48 hours.

Table 3-14 and Figure 3-6 show that dioxin concentrations are greater from open burning than from air-curtain burning at all distances. This observation during chemical attack scenario is opposite to the results of the natural disaster scenario assessment (USEPA 2017), which found dioxin concentrations to be substantially higher from air-curtain burning even though the same number of carcasses were burned and the same fuels were used. Table 3-16 shows the total dioxin emissions per 48-hour combustion event for both management options and both assessment scenarios. The table also shows the contributions of fuels and carcass contamination to the total dioxin emissions.

Three factors contribute to this difference between the natural disaster and chemical attack scenario assessments. First, the chemical emergency scenario adds dioxin contamination in the carcasses to the total dioxin emissions, and this narrows the difference in emissions between the two management options as shown in Table 3-16. For example, while woody fuels were responsible for 100% of the dioxin emissions from open burning in the natural disaster assessment, the same emissions accounted for just 0.6% of the emissions when the carcass contamination was added in the chemical emergency assessment. For air curtain burning, the addition of the same amount of carcass contamination had a much smaller effect on the total emissions.

Table 3-16. Comparison of Dioxin/furan Emissions by Emergency Scenario, Management Option, and Combustion Material

Source of Dioxin/furans	Total Particulate and Vapor Emissions of Dioxin/furan per 48-hour Event and Percentage of Total	
	Natural Disaster Assessment	Chemical Emergency Assessment

	Open Burning	Air-Curtain Burning	Open Burning	Air-Curtain Burning
Woody Fuels	1.6E-05 (100%)	2.8E-03 (100%)	1.6E-05 (0.6%)	2.8E-03 (52.1%)
Carcass Contamination	np (0%)	np (0%)	2.5E-03 (99.4%)	2.5E-03 (47.9%)
Total	1.6E-05 (100%)	2.8E-03 (100%)	2.6E-03 (100%)	5.3E-03 (100%)

Abbreviations and acronyms: np = not present.

Still, Table 3-16 shows that the event-total dioxin emissions are greater from air-curtain burning than from open burning. This apparent discrepancy is explained in part by second factor, a difference in the modeling domains of the two assessments. For the natural disaster assessment, the combustion source was placed in the center of a Cartesian grid of receptor points, and results were presented for the receptor points with the highest concentrations. Trends by distance from the source were not presented. For the chemical emergency assessment, the source is placed at the center of a radial grid of receptor points, and results are presented for receptor points with the greatest concentrations at 19 regular distance intervals from the source as in Table 3-14. One consequence of radial grid configuration is that the greatest reported air concentration (e.g., at the closest distance interval, 100 m) is not necessarily the greatest concentration anywhere, which is more likely to be observed using a Cartesian grid. With the Cartesian grid, however, the concentrations reported for the two management options are not necessarily at the same distances from the source.

A third factor concerns the location of the sources within the radial grid of the chemical emergency assessment. Even with the radial grid, the concentrations reported for the two management options for a particular distance (e.g., 100 m) might differ in their actual distance from the source. This is because of differences in the shapes and modeling setups for the pyre and air-curtain burner. The air-curtain burner is 8.3 m long and modeled as a single point source at the center of the radial grid. However, the pyre is a long source (91.4 m), and emissions are split equally among five equi-distant points over its length. The radial grid is centered at the center of the pyre where one of the five points is located. With this configuration, receptor points 100 m from the center of the radial grid are less than 100 m from the distal emission points.

In practice, people try to avoid conducting open-pyre burning activities on windy days, and it is not possible to keep pyres lit during heavy precipitation. Consequently, the modeling assumes that burns do not occur during particularly windy or heavy precipitation periods. Such periods are defined as having at least 10% of the combustion hours (e.g., at least 5 hr of a 48 hr combustion event) with wind speeds of at least 8.94 m/s (20 mi/hr) and/or precipitation amounts of at least 2.5 mm/hr (0.1 in/hr).

3.2.2 Concentrations in Surface Soil

The assessment estimates chemical concentrations reaching the surface soil from the combustion-based management options and the composting management option. With the combustion-based options, the deposition results discussed in the previous section (3.2.1) are used to calculate chemical concentrations in surface soil. During the composting management option, metals and other persistent chemicals present in the finished compost are applied to soil with the compost, at rates provided in Table 3-11. Chemical additions to soil from air deposition and composting (i.e., in mg [chemical]/m^2 [soil]) are used to estimate concentrations in surface soil with Equation 3.1 (below) from USEPA's (2005) *HHRAP for Hazardous Waste Combustion Facilities*.[6] This Human Health Risk Assessment Protocol (HHRAP) is a peer-reviewed environmental modeling framework developed, refined, and used by USEPA's Office of Resource Conservation and Recovery (formerly the Office of Solid Waste) to estimate chemical transport of chemicals released to air from a point source and their subsequent fate and transport in soil, surface water, and terrestrial plants and animals. In Equation 3.1, the total chemical deposition or addition with compost is mixed with the surface soil layer. The resulting estimate, Cs, is the concentration of chemical per kg bulk soil at the deposition location.

$$Cs = (vDp_t) / (Zs * BD) \qquad \textbf{(Eqn. 3.1)}$$

where:

Cs = Concentration of chemical in surface soil, from deposition, mg/kg

vDp_t = Total chemical deposition or addition, mg/m^2

Zs = Soil mixing zone depth (m)

BD = Soil bulk density, kg/m^3

Soil parameter values used in these calculations are HHRAP default assumptions. Specifically, HHRAP provides default assumptions for bulk-soil density at 1,500 kg per m^3 (93.6 pounds [lb] per ft^3) (surface soil, unsaturated) and mixing depth assumptions. For deposition form air, HHRAP assumes that deposited particles mix with the top 0.02-meter (m) (0.79 inches [in]) soil layer. Compost is assumed to be tilled into the soil to a depth of 20 cm. Tables 3-17 and 3-18, respectively, present the estimated chemical concentration in soil from air deposition (i.e., from the combustion-based options) and compost application.

The exposure assessment does not include direct exposure by humans to contaminants in soil. However, the soil contaminants are taken up by plants and livestock products consumed by farm residents. In addition, a portion of the soil eroded from the compost application site reaches the on-site lake where it may enter the aquatic food web, including recreationally caught fish included in the residents' diet. Except for leaching to groundwater, which is discussed in Section 3.2.3, chemical losses from soil (e.g., runoff, erosion, plant root uptake) are calculated with equations from HHRAP (USEPA 2005). Further details about HHRAP formula and assumptions used for this assessment are provided in Appendices D through G of USEPA (2017).

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[6] Further information on HHRAP is available at: https://archive.epa.gov/epawaste/hazard/tsd/td/web/html/risk.html.

Table 3-17. Chemical Concentrations in Soil from Air Deposition

Distance from Source (km)	Soil Chemical Concentration from Total Deposition (mg/kg)			
	Total Dioxins		Total Hg	
	Open Burning	Air-curtain Burning	Open Burning	Air-curtain Burning
0.1	1.0E-07	5.9E-08	5.5E-06	np
0.2	6.8E-08	2.3E-08	2.4E-06	
0.3	5.1E-08	3.0E-08	1.8E-06	
0.4	5.0E-08	2.6E-08	1.3E-06	
0.5	3.9E-08	2.5E-08	9.9E-07	
0.6	2.9E-08	2.4E-08	7.7E-07	
0.7	2.7E-08	2.0E-08	6.2E-07	
0.8	2.3E-08	1.6E-08	5.1E-07	
0.9	2.0E-08	1.5E-08	4.2E-07	
1	1.6E-08	1.4E-08	3.6E-07	
2	3.5E-09	4.2E-09	1.4E-07	
3	1.1E-09	1.6E-09	7.8E-08	
4	6.3E-10	7.6E-10	5.2E-08	
5	4.1E-10	4.6E-10	3.9E-08	
6	2.7E-10	2.9E-10	3.1E-08	
7	2.2E-10	2.3E-10	2.5E-08	
8	1.7E-10	1.8E-10	2.1E-08	
9	1.5E-10	1.4E-10	1.8E-08	
10	1.3E-10	1.2E-10	1.5E-08	

Abbreviations and acronyms: mg = milligram; kg = kilogram; Hg = mercury; np = not present.

Table 3-18. Chemical Concentration in Soil from Application of Finished Compost

Chemical Species	Concentration in Soil after Tilling (mg/kg)
Total Dioxins	2.0E-04
Diazinon	4.1E-02

Abbreviations and acronyms: mg = milligram; kg = kilogram.

3.2.3 Soil to Groundwater Transport Modeling

Estimates of concentrations or amounts of chemicals in groundwater are needed to estimate human exposure from use of well water in the home (e.g., drinking, cooking, and washing). The assessment estimates chemical fate and transport in groundwater from the following sources:

- Buried carcasses releasing liquids (leachate) that seeps into soil beneath the burial trench;

- Compost windrows leaking leachate from the carcasses that is not absorbed by the bulking material; and
- Buried combustion ash that leaches chemicals to infiltrating precipitation.

The conceptual models for all four on-site management options include groundwater recharge to the on-site lake, followed by chemicals from groundwater entering the aquatic food web. This pathway is not included in the assessment because the groundwater modeling approach used to estimate well water concentrations is not designed to enable estimation of groundwater recharge. See Section 3.2.4 for further discussion of this issue.

Leaching from Burial Trenches and Composting Windrows

After seeping into the ground beneath the burial trench or composting windrow, leachate first passes downward through unsaturated soil until it reaches the water table where it is carried in the direction of the ambient groundwater flow. The leachate is diluted as it moves through these two subsurface zones, and the leached chemicals may be affected by the physical, chemical, and biological process that tend to further reduce concentrations with distance from the source (USEPA 1996). The combined effect of these processes is complex and dependent on site-specific soil and hydrodynamic properties.

To support regulatory analyses, the USEPA (1996) created the *EPA Composite Model for Leachate Migration with Transformation Products* (EPACMTP). The model simulates physical, chemical, and biological processes in both the unsaturated and saturate zones and has been found by the USEPA's Science Advisory Board to be suitable for generic applications (USEPA 1996). One such application was a background study supporting for Soil Screening Level guidance for USEPA's Superfund program. Using Monte Carlo simulations with EPACMTP and nationwide site data (e.g., soil properties at contaminated sites, well location and depth), USEPA estimated chemical concentrations in soil that correspond to safe drinking benchmark concentrations at downgradient wells. One of the products of this application was a set of Dilution Attenuation Factors (DAFs), ratios of the original soil leachate concentration to the concentration in water at a downgradient well. With a DAF of 1, chemical concentrations at the well would equal concentrations at the source. DAFs greater than 1 indicate dilution and attenuation before contaminants reach the well.

EPA prepared DAFs for six well-placement scenarios. Distances from the source to the well in these scenarios were 100 m, 25 m, or 0 m from the source, or randomly selected from a distribution of nationwide data. The well's horizontal offset distance from the plume center line was randomly selected, either within the plume's width or half the width. Well depths were randomly selected from nationwide data for most scenarios.

Because sensitivity analyses determined that soil types and the size of the contaminated area have the greatest effect on the DAFs, USEPA developed DAFs for sources ranging in size from 1,000 to 5,000,000 ft^2 (93 to 464,515 m^2). With further analysis, USEPA prepared a default nationwide DAF for sources up to 0.5 acres (0.2 hectares).

The EPACMTP modeling effort described above included simplifying assumptions that make the estimated DAFs conservative. For example, retardation due to absorption/desorption kinetics were excluded by assuming that soil and porewater concentrations are at equilibrium. In addition, chemical and biological degradation processes were not considered (USEPA 1996). Thus, the modeling approach is likely to overestimate chemical concentrations in groundwater.

For this assessment, the DAFs produced by with the EPACMTP Monte Carlo analysis are used to estimate chemical concentrations in drinking water obtained from a groundwater well 100 m downgradient from a burial trench or compost windrow. Because DAF are sensitive to the size of the leachate source, the areas of the burial trench and compost windrow were matched to the distribution of DAF values by sized presented by USEPA. For each source size, USEPA presented DAFs corresponding to the 85th, 90th, and 95th percentile of Monte Carlo simulations. Because USEPA based the default DAF on 90th percentile results, the DAFs for this assessment were based on the 90th percentiles as well. The DAFs for the base case (i.e., management of 100 carcasses) are shown in Table 3-19. The table also shows the estimated diazinon concentrations in leachate (from Section 3.1.3) and drinking water for the burial and composting options.

Table 3-19. **Estimated Diazinon Concentrations in the Groundwater Pathway for the Base-case**

Source	Average Concentration in Leachate in the Burial Trench	DAF	Average Concentration in Household Drinking Water (mg/L)
Burial Trench	11.0	878	1.3E-02
Windrow	11.0	315	1.7E-03

Abbreviations and acronyms: DAF = dilution attenuation factor; mg = milligram; L = liter.

The EPACMTP analysis to develop DAFs uses soil infiltration rates rather than leachate volumes as inputs to the unsaturated soil zone. Although the concentrations of diazinon in leachate from burial and the compost windrow are the same, the amount of leachate from the compost windrow is 5% of the leachate volume from burial (see Section 3.1.4). For sources of equal size (i.e., the same DAF) the drinking water estimate for burial and composting would be the same despite the large differences in leachate volume. To account for the difference the well water concentration estimated for the compost windrow is multiplied by 5%.

Leaching from Combustion Ash

Chemical leaching from pyre ash begins with the concentrations in ash described in Section 3.1.1. As precipitation passes through the ash, chemicals partition between the ash and water, which then seeps into the soil below. The partitioning of contaminants from the ash to water is estimated with chemical-specific, equilibrium soil-water partitioning coefficients (K_d). The K_d values can be derived from experimental observations and Equation 3.2.

$$K_d = \frac{mg\ [solid\ phase\ contaminant]/kg\ [soil]}{mg\ [aqueous\ phase\ contaminatn/L\ [water]} \qquad \textbf{Eqn. 3.2}$$

For brevity, the equation can be rewritten as:

$$K_d = (mg_s/kg_s)/(mg_a/L_a) \qquad \textbf{Eqn. 3.3}$$

where:

mg_s = mg [solid-phase contaminant]
mg_a = mg [aqueous phase contaminant]
kg_s = kg [dry weight of solids]
L_a = L [volume of water]

To estimate chemical concentrations in precipitation after it passes through the ash, Equation 3.4 is rewritten as follows:

$$K_d = (mg_{init} - mg_a / kg_s)/(mg_a / L_a) \qquad \textbf{Eqn. 3.4}$$

Where mg_{init} is the initial concentration of chemical in the ash, as presented in Section 3.1.1. Equation 3.5 is then solved for mg_a, to estimate the mass of chemicals carried with water percolating through the ash.

$$mg_a = (L_a * mg_{init})/(kg_s * K_d + L_a) \qquad \textbf{Eqn. 3.5}$$

Kg_s is the weight of ash, which for the base case is 3,235 kg for open burning (see Section 3.1.1) and 3,220 kg for air-curtain burning.

In these calculations, the amount of infiltrating water (L_a) is calculated by multiplying the total rainfall (in m/yr) during the first year after carcass management by the area (m^2) of the ash disposal. At the hypothetical site, there were 168 “precipitation events” in 2014, with at total amount of 38.1 in (0.968 m) (see Table 3-20). The area of ash disposal, 223 m^2 and 41 m^2 for open burning and air-curtain burning, respectively (see Section 3.1.1.). For example, the total volume of water seeping through the pyre ash for the base case is 0.968 m/yr * 223 m^2 = 216 m^3/yr = 216,000 L/yr.

Chemicals with high K_d values have a high affinity to solids and lower mobility than chemicals with lower K_d values. A modeling study by the New Jersey Department of Environmental Protection (NJDEP 2008) found that, over a 100-year simulation period, chemicals with a K_d value greater than 100 L/kg moved vertically 11 inches or less in sandy loam. Chemicals with a Kd value greater than 200 L/kg moved 3.6 inches or less.

Table 3-20. Summary of Precipitation Data Used in This Assessment[a]

Parameter	Value (units)
Total annual precipitation	96.84 (cm/yr)
Number of rain events	168 (events/yr)
Total duration precipitation	435 (hr/yr)
Precipitation per event	0.5764 (cm/event)
Precipitation per hour of rain	0.2226 (cm/rain_hr)
Average hours per event	2.6 (hr/event)
Water volume per event	5764 (centimeters [cm]^3/m^2)
Water volume per year	968.4 (L/m^2)

Abbreviations and acronyms: cm = centimeter(s); yr = year; hr = hour; /rain_hr = per hour of rain; L = liter; m^2 = square meter.

[a] The assessment uses one year (2014) of meteorological data for a station in Iowa City, Iowa. Further information on the selection of these data is available in USEPA 2017. The complete reference is at the end of the report.

K_d values for dioxins, diazinon, and mercury were obtained from a database of chemical properties provided with HHRAP (USEPA 2005). The K_d values from HHRAP used for this assessment are 38,904 L/kg for 2,3,7,8-Tetrachlorodibenzo-p-dioxin, 1,000 L/kg for mercury, and 55.88 L/kg for diazinon.

Using Equation 3.5 and the parameter values discussed above, the estimated concentration of total mercury in leachate from the base case pyre ash is 5.6E-3 mg/L.

Dioxins, especially the higher chlorinated congeners, have a very strong tendency to partition to soil organic content (ATSDR 1998). This is consistent with the very high K_d value used (38,904 L/kg) for dioxins. Because dioxin contamination in groundwater is unlikely, this fate pathway is not modeled for dioxins.

Once the mercury-bearing leachate seeps in to the soil beneath the ash, its fate is modeled with the DAF approach described above for leaching to groundwater from burial trenches and the compost windrow. Table 3-21 presents the concentration of diazinon in ash leachate, the DAF, and the resulting concentration in drinking water.

Table 3-21. Estimated Mercury Concentrations in the Groundwater Pathway for the Base-case

Source	Average Concentration in Leachate from Ash Disposal (mg/L)	DAF	Average Concentration in Household Drinking Water (mg/L)
Pyre Ash	5.6E-03	777	2.7E-06

Abbreviations and acronyms: DAF = dilution attenuation factor; mg = milligram; L = liter.

3.2.4 Surface Waters and Sediment

As described in Section 2.1, the assessment includes an on-site lake used for recreational fishing. None of the on-site management options directly release chemicals to the lake, but chemicals could be transported to the lake by one or more processes:

- Wet and dry deposition of particles with sorbed chemicals from air (following combustion);
- Diffusive exchange of vapor-phase chemicals between the air and surface water;
- Runoff and erosion of chemicals from surface soils into the surface water; and
- Groundwater flow (i.e., recharge) into the lake from the sediment bed.

Wet and dry deposition rates are estimated with AERMOD (Section 3.2.1). The second and third of these processes are modeled using HHRAP equations and default assumptions for chemicals associated with each of the carcass management options (see Section 5 and Equation 5-35 in USEPA, 2005). The HHRAP approach to estimating concentrations of chemicals in surface water includes three abiotic loss processes: volatilization, hydraulic turnover or flushing, and sediment burial. Various reports (USEPA 2017 - Appendix E; USEPA 2005) summarize the methods and assumptions for the modeling the surface water and sediment compartments. There is no net diffusion of vapor-phase chemicals expected from air to surface water. The assessment assumes vapor-phase chemicals deposited to the lake in precipitation are revolatilized to air.

To model deposition to the lake surface, the hypothetical lake (approximately 40.5 ha) is set directly southeast of the source in the direction of the highest deposited mass, and its hypothetical watershed (approximately 202 ha) surrounds the lake on three sides (see red polygon in Figure 3-5). This placement is most likely to receive the maximum amount of modeled chemical deposition for an open-pyre or air-curtain burner combustion event at any time during the year.

Chemicals deposited to the soil may erode to the lake. The HHRAP calculations for used for this assessment estimate the erosion process and the fate of chemicals in the water column and sediment bed (see additional details in USEPA 2017 - Appendix E and Appendix F).

The same HHRAP calculations are used to estimate soil erosion to the lake from the compost application site. However, HHRAP was developed to model broad-scale deposition of air pollutants to a watershed and erosion cannot be limited to a specific area within the watershed. For estimate erosion from the compost application site, the watershed size is set to the area of compost application. This approach does not include a means to specify a distance of untreated land between the compost application area and the lake, which would trap a portion of the eroded soil eroded before it reaches the lake. Because it is unlikely that the compost would be applied at the lake shore, soil erosion to the lake estimated with HHRAP is reduced by a percentage. Specifically, the assessment assumes 50% of the eroded soil is captured before reaching the lake.

HHRAP does not include equations to estimate recharge from groundwater to surface water. However, above ground processes are expected to carry much greater amounts of chemicals than groundwater recharge. For example, if it is conservatively assumed that the entire amount of diazinon leached from the burial trench enters the lake from recharge within one year and the dilution attenuation at the point of recharge is the same as at the groundwater well, then the concentration of diazinon in the water column would be 1.1E-7 mg/L.[7] However, this estimate does not include the three abiotic loss processes (i.e., volatilization, hydraulic turnover or flushing, and sediment burial) included in the contributions from aboveground sources. Using the same similar simplified calculations for mercury leached from pyre ash, the concentration of mercury in the lake from groundwater recharge would be 8.7 E-10 mg/L. Because of the limitations and increased uncertainty associated with groundwater recharge it is not included in the assessment.

When combined, the chemical loadings to the 40.5 ha lake from all of the aboveground processes listed at the top of this section are summed to estimate the concentrations in surface water (i.e., in the on-site lake) shown in Table 3-22. In the table, "np" indicates that the chemical is not present in the pathway (e.g., no diazinon in combustion ash), and "na" indicates that the pathway or chemical was not included in the assessment for reasons discussed above.

Table 3-22. Estimated Total Concentrations of Chemicals in Surface Water

Chemical Species	Concentrations in Surface Water (µg/L), Large Lake (40.5 ha)				
	Open Burning	Air-curtain Burning	Burial	Composting Windrow	Compost Application
Dioxins	2.0E-08	1.0E-08	na	na	1.1E-04
Diazinon	np	np	na	na	6.4E-01
Mercury	4.6E-06	np	np	np	np

Abbreviations and acronyms: µg = microgram; L = liter; ha = hectares; na = not assessed; np = not present; PAHs = polycyclic aromatic hydrocarbons.

3.2.5 Bioaccumulation in Fish

Concentrations of chemicals in aquatic animals in the on-site lake allow estimation of human exposures from consuming fish caught from the lake. Although fish ingestion exposures are included in the conceptual models for all four on-site carcass management options, chemicals contributions from groundwater recharge to the lake and aquatic food web are not included in the assessment (see Section 3.2 4).

Estimating concentrations of chemicals in the aquatic food web begins with the estimated concentrations in surface water (Table 3-22) and sediment (not presented). For organic chemicals (i.e., dioxins and diazinon), bioaccumulation is estimated using similar modeling approach as the natural disaster scenario assessment (USEPA 2017). In particular, partitioning of chemicals between the surface water and sediment compartments is modeled with HHRAP (USEPA 2005) methods (Appendix E in USEPA 2017). Then, bioaccumulation is modeled with AQUAWEB, a steady-state solution model of aquatic bioaccumulation created by Arnot and Gobas (2004) and

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[7] The volume of the 40.5 ha (100 ac) lake is calculated by multiplying the surface area (40.5 ha = 404,686 m^2) by the average depth (4.38 m, see Section 2.3.3). The resulting volume is 1.8E+06 m^3, which equals 1.8E+09 L.

available for downloading from Arnot Research & Consulting.[8] This two-step modeling approach was used and further details are provided in Appendix J of USEPA (2017).

Table 3.23 shows the concentrations of dioxins and diazinon in fish tissue estimated with these methods. These concentrations lead to estimates of chemical exposure from fishing by the farm residents. Chemical concentration in fish are not estimated for burial and the compost windrow. For these options, fish can be contaminated only by groundwater recharge to the lake which is not assessed, as discussed in Section 3.2.4.

Table 3-23. Estimated Chemical Concentrations in Fish from the On-site Lake

Chemical Species	Estimated Concentration in Trophic Level 3 and 4 Fish (mg/kg)[a]									
	Open Burning		Air-curtain Burning		Burial		Compost Windrow		Compost Application	
	T3	T4	T3	T4	T3	T4	T3	T4	T3	T4
Total Dioxins	5.9E-07	1.0E-06	3.0E-07	5.2E-07	na	na	na	na	9.9E+01	1.7E+02
Diazinon	np	np	np	np	na	na	na	na	1.6E-02	5.8E-03

[a] Trophic level 4 (T4): top predatory fish in water column (e.g., walleye, northern pike); Trophic level 3 (T3): “pan” fish (e.g., bluegill, yellow perch); mg = milligram; kg = kilogram.

AQUAWEB is not designed to model the behavior of inorganic chemicals, including metals, in aquatic food webs. For mercury to accumulate in fish, it first must be methylated in the lake sediments, a process that occurs over an extended time. Although mercury bioaccumulation in fish is not modeled, the estimated concentration in surface water from open burning can be compared with background concentrations. The comparison between background and additional levels could determine whether additional mercury would have a significant impact on existing environmental levels of mercury and resulting body burdens. Care should be taken during site-specific evaluations to assess the potential for health risks inherent in ingesting fish on any farm affected by the release or presence of persistent bioaccumulative toxic chemical contamination. Unlike dioxin and diazinon, mercury is ubiquitous in the environment from both natural and anthropogenic sources. Background concentration in surface waters in the United States vary by location due to natural geological sources and the distribution of industrial sources (e.g., coal-fired electricity generation, mining, smelting). The USEPA (1997b) estimated post-industrial background concentrations of total mercury in surface water to be 9.0E-04 µg/L and 2.0E-04 in the eastern and western United States, respectively, and Gilmour and Henry (1991), as cited by ATSDR (1999), describe background surface water concentrations as “generally less than” 5.03E-03. These concentrations are all greater than the concentration (i.e., 4.6E-06 µg/L) estimated for the open burning options, as shown in Table 3-22. This indicates that mercury concentrations in fish from open burning could be below background levels. However, it should be noted that the background concentrations are not a health benchmark.

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[8] Further information and model download are available at: <http://www.arnotresearch.com/index.html#!/page_AQUAWEB>.

3.2.6 Terrestrial Plants and Livestock

The concentration of dioxin and diazinon in plants and livestock grown at the farm are modeled to estimate human exposure for those consuming home-grown food products. Concentrations of chemicals in farm-grown plants and livestock are estimated with an existing Excel®-based computer model called the Multimedia Ingestion Risk Calculator (MIRC), which uses equations and default assumptions from HHRAP (USEPA 2005; USEPA 2017- Appendix K). Detailed documentation of the relevant HHRAP methods and default assumptions is available in USEPA (2005).

The Multimedia Ingestion Risk Calculator (MIRC) requires chemical-specific parameter values as inputs including empirical partitioning and biotransfer factors (e.g., soil-water partition coefficients, soil-to-plant biotransfer factors). Values for most of the parameters in MIRC are from a chemical database developed by USEPA for use with HHRAP.

3.2.7 Terrestrial Plants

With the HHRAP methods built into MIRC, produce (vegetables and fruits) can be contaminated directly by deposition of airborne chemicals to foliage and fruits or indirectly by uptake of chemicals in soil. In this assessment, the dioxins are deposited to both foliage and soil by the combustion-based options. Diazinon is destroyed by combustion and therefore does not reach terrestrial plants with these options. Dioxins and diazinon both may be present in finished compost, and this assessment includes home-grown food and feed production where compost has been amended to soil.

Given the two terrestrial plant pathways (i.e., foliar deposition and root uptake), produce is divided into two main groups: aboveground and belowground. Aboveground produce is divided into fruits and vegetables. As described above, those groups are further subdivided into "exposed" and "protected" depending on whether the edible portion of the plant is exposed to the atmosphere or is protected by a husk, hull, or other outer covering. These pathways are summarized in Table 3-24.

The methods used to estimate exposure concentrations in produce for human consumption are also used to estimate concentrations in forage, silage, and grain grown on-site for livestock feed. Concentration estimates provided by HHRAP include wet-weight concentrations (mg/kg) of each chemical in exposed vegetables, protected vegetables, exposed fruits, protected fruits, and roots. Dry-weight (dw) concentration estimates are provided as well for above-ground produce.

Table 3-24. Chemical Transfer Pathways for Produce

Farm Food Media		Chemical Transfer Pathways
Aboveground Produce	▪ Exposed fruits and vegetables	▪ Direct deposition from air of particle-bound chemical (generally washed off) ▪ Air-to-plant transfer of vapor phase chemical ▪ Root uptake from soil
	▪ Protected fruits and vegetables (e.g., grains, peas)	▪ Root uptake from soil
Belowground Produce	▪ Root vegetables (e.g., onions, potatoes)	▪ Root uptake from soil

MIRC provides concentration estimates for each chemical and each food source. These results lead to estimates of the combined ingestion exposure from eating produce (see Section 3.3).

3.2.8 Livestock

Concentrations of chemicals are estimated in livestock products, including beef and dairy products, pork, and poultry and eggs. Note that the HHRAP methods used to model livestock do not include inhalation of vapor-phase and particulate contaminants by livestock or use of well water for watering livestock.

Chemical concentrations in animal products are estimated based on the amount of chemical consumed by each animal group through each type of feed and incidental ingestion of soil for ground-foraging animals. Table 3-25 summarizes the pathways by which chemicals are transferred to the farm-raised animal food products. Beef and dairy cattle consume three plant feeds (i.e., forage, silage, and grain), while pigs consume only silage and grain, and chickens consume only grain. These feed products are grown on-site and might contain chemicals.

Incidental ingestion of chemicals in soils by livestock during grazing or consumption of feed placed on the ground is estimated for the combustion-based management options using empirical soil ingestion rates and a soil bioavailability factor for livestock. The default value for that factor, which is used for the exposure assessment, for all chemicals is 1.0 (i.e., the chemical in soil is assumed to be 100% bioavailable to the animal).

HHRAP calculates chemical ingestion by livestock so that chemical concentrations in human food products can be estimated, not to estimate risks to the livestock animals. The relevant estimates provided by HHRAP are mg chemical per kg fresh or wet-weight product. Concentrations are estimated separately for beef, total dairy, pork, poultry, and eggs. These results, for each management option and chemical, are used to estimate ingestion exposure from food. Those estimates are presented in Section 3.3.

Table 3-25. Chemical Transfer Pathways for Livestock

Farm Food Media		Chemical Transfer Pathways
Animal Products	▪ Beef and total dairy (including milk)	▪ Ingestion of forage, silage, and grain[a] ▪ Incidental soil ingestion
	▪ Pork	▪ Ingestion of silage and grain[a] ▪ Incidental soil ingestion
	▪ Poultry and eggs	▪ Ingestion of grain[a] ▪ Incidental soil ingestion

[a] Chemical concentrations in forage, silage, and grain are estimated via intermediate calculations analogous to those used for aboveground produce.

3.3 Exposure Estimation

In this assessment, chemical exposure can occur via inhalation and ingestion by adults and children. Inhalation exposure is included only in the combustion-based management options and only for the duration of the burn. Exposure concentrations (i.e., mg chemical/m^3 air) are estimated as event-average concentrations, which can be compared directly concentration-based human health benchmarks (i.e., reference concentrations).

Ingestion exposure is assessed for drinking water consumption, incidental soil ingestion, fish ingestion, and ingestion of the ten types of agricultural products identified in Tables 3-24 and 3-25. Ingestion exposure is evaluated relative to exposure-dose health benchmarks (i.e., mg chemical per kg body weight per day). Therefore, the chemical concentrations in abiotic and biotic media discussed in Section 3.2 are used to calculate ingestion exposure doses for adults and children. These calculations are made by MIRC with the following inputs:

- Total concentration of the chemical in the air;
- Fraction of the chemical in the air in the vapor-phase;
- Wet and dry deposition rates for particle-phase chemical;
- Concentration of the chemical in drinking water;
- Concentration of the chemical in soil; and
- Concentration of the chemical in upper trophic-level fish.

Inputs to MIRC also include chemical-specific parameters values, the exposure scenario (e.g., which foods are eaten and at what rate), and assumptions about the potentially exposed adults and children. Section 3.3.1 describes the approach to characterizing the adult and children exposure receptors including exposure factors (e.g., body weight) used to estimate their exposures. Section 3.3.2 presents the chemical exposure estimates for each of the onsite management options.

3.3.1 Characterization of Exposed Individuals

This section discusses who the assessment assumes is exposed to the chemical, as well as characteristics about them (e.g., age) and their levels of exposure (e.g., how much home-grown food they eat).

3.3.2 Description of Exposed Persons

Exposure is estimated for three types of farm residents: infants who consume drinking water in their formula, young children (age 1-2 years old), and adults who live on the farm near the carcass management unit for at least one year after carcass management. A young child (e.g., age 1 to 2 years) consumes more food per unit body weight on a daily basis than older children and adults. For the young child, exposure is calculated from estimated concentrations of chemicals in a limited diet of foods produced on the farm, using assumptions about a small body weight, and higher metabolic rates (ingestion and inhalation rates). For the adult, exposure is calculated from estimated concentrations of chemicals in the drinking water and food items using mean values for various exposure factors (e.g., body weight, ingestion rates for different foods and water, inhalation rates).

3.3.3 Exposure Durations

The assessment includes two exposure routes and durations: inhalation over the duration of combustion (i.e., 48 hours for the base case) and ingestion (i.e., of drinking water, home-grown food products, and fish) over one year. Inhalation exposures are assessed only for the combustion-based management options. Inhalation exposure concentrations in mg chemical/m^3 air are estimated as event-average concentrations. For the base case, that means the assessment uses average chemical concentration present in the air during that 48-hour period (at the location of maximum air concentrations).

Ingestion exposures are evaluated for a one-year period starting with the beginning of the carcass management actions. The one-year exposure periods for the various ingestion sources do not necessarily coincide with one another. For example, drinking water exposure begins when the chemicals in groundwater reach the well. Ingestion of home-grown foods begins for the combustion-based options after chemicals are deposited from air to soil and plants, and for the composting option after finished compost is applied as a soil amendment.

All ingestion exposures are assumed to be constant and uniform throughout the one-year periods. Chemical concentrations in drinking water, home-grown produce, and fish based on the total chemical released during the first year to an environmental medium after accounting for chemical movement to other environmental media (e.g., from surface soil to the lake) are assumed to represent the average daily exposure concentrations for one year. The exposure assumptions, such as the availability and consumption of home-grown food products, are assumed to be consistent throughout the year (i.e., data for seasonal changes not available).

3.3.4 Human Exposure Factor Values

This assessment uses mean life-stage-specific exposure-factor values that are included in MIRC. Those values are from the most recent version of USEPA's *Exposure Factors Handbook* (USEPA 2011), its *Child-specific Exposure Factors Handbook* (USEPA 2008), and its *Child-Specific Exposure Scenarios Examples* (USEPA 2014). These handbooks include a thorough review of relevant original data and list the USEPA-recommended values for use in exposure assessments. The handbooks provide mean, median, and percentile (e.g., 75th, 90th, 99th percentiles) values to allow the user to determine the degree of conservatism appropriate for each factor as used in their particular type of exposure assessment (e.g., screening, ranking, refined).

The purpose of this assessment is to compare the management options by their exposure potential relative to each other, not to estimate possible real-world maximum individual or population exposures or risks for any of the options. Consequently, the most appropriate value to select for each exposure factor is the mean value, not an upper percentile value as often is selected for screening-level risk assessments to represent most exposed individuals. Mean exposure factor values are preferred for several reasons:

- Mean values are the most robust (i.e., have the narrowest confidence limits) of the statistical descriptors of parameter distributions. The more extreme values (i.e., values near the "tails") in a natural distribution of parameter values, such as a 95th or 99th percentile value, are more uncertain (i.e., and have much wider confidence limits). Upper percentile values (i.e., upper tail of a distribution) can be highly skewed by outlier values in the data set.

- The expected value, or mean, of the sum of two random variables is the sum of the means (additive law of expectation).

- The mean of the product of two parameters (with any type of distribution of values) is the product of the mean values if (and only if) the two parameters are not correlated with one another.

- If the variables are correlated (e.g., body weight positively correlates with daily quantities of food ingested), then the product of the mean values for each parameter will likely be smaller than the mean of the product of the values (e.g., the same individual). To avoid this error, original data on food ingestion rates for each individual should be expressed as kg food ingested per kg of body weight per day. The mean of that distribution should be a more accurate measure than taking the mean of food ingestion rates (kg/day) across all adults and dividing by the mean body weight of all adults (in kg).

- Percentiles for random variables generally are not additive or multiplicative whether the variables are correlated to some degree or not. Instead, reasonably accurate estimates of a percentile (e.g., 90th percentile) for the sum, product, or ratio of two (or more) random variables generally requires a Monte Carlo simulation in which the distribution of each variable and its correlation with the others are well defined. For example, multiplication of upper percentile values for two independent parameters (e.g., 95th percentile for exposure concentration in water in mg/L multiplied by the 95th percentile water ingestion rate in L/kg body weight/day) yields a much more conservative (i.e., higher) percentile value (e.g., 99.9th) than the original percentile value (e.g., 95th). Moreover, using the percentile requires knowledge of the shape of the original distributions and their variances even if the two parameters are completely uncorrelated.

To compare the livestock carcass management options based on their relative exposure potential, *mean* values for adult and child body weight, and food and water ingestion rates are used. These values are shown in Table 3-26 and are further documented in Appendix K of USEPA (2017). For infants, exposures are considered from well water used to mix with formula, with both mean and high-end exposure factor values as listed in Table 3-27.

3.3.5 Exposure Estimation

This section describes the methods used to estimate chemical exposures for each carcass management option. Separate estimation methods are used for human inhalation and ingestion exposures.

Inhalation

Inhalation exposures are calculated for adult farm residents at a location of maximum concentrations of the chemicals in air as estimated by AERMOD on a date for which meteorological conditions resulted in the highest-event-average concentration. These exposure concentrations are presented in Tables 3-13 and 3-14 for dioxin/furans and mercury, respectively. In Section 4, the average inhalation exposure concentrations are compared to health-based benchmark concentration. Separate exposure estimates are not made for adults and children because evaluation of inhalation exposures occurs on an air-concentration basis and not an exposure-dose basis.

For dioxins, compound-specific concentrations in air are multiplied by the TEFs (see Table 3-13) for conversion to 2,3,7,8-TCDD equivalent (TEQ) concentration. The 17 TEQ concentrations are then added and presented as total dioxins/furans.

The conceptual models for each of the onsite management options includes inhalation of aerosolized chemicals from home uses of well water (specifically showering as the worst-case home-use scenario). However, given the low mobility of the assessed chemicals in soil and groundwater, this inhalation exposure pathway is considered negligible, and is not estimated.

Table 3-26. Mean Exposure Factors for Children and Adults

Exposure Factor	Child 1-2	Adult
Body Weight (kg)	12.6[a]	80.0[b]
Drinking Water ingestion (mL/d)	332[c]	1,219[d]
Beef Ingestion (g/kg-d)[e]	4.14	1.93
Dairy Ingestion (g/kg-d)[f]	91.6	2.96
Eggs Ingestion (g/kg-d)[e]	2.46	0.606
Exposed Fruit Ingestion (g/kg-d)[e]	6.14	1.19
Exposed Vegetable Ingestion (g/kg-d)[e]	3.48	1.38
Pork Ingestion (g/kg-d)[e]	2.23	1.10
Poultry Ingestion (g/kg-d)[e]	3.57	1.37
Protected Fruit Ingestion (g/kg-d)[e]	16.6	5.19
Protected Vegetable Ingestion (g/kg-d)[e]	2.46	0.862
Root Vegetable Ingestion (g/kg-d)[e]	2.52	1.03
Fish Ingestion	27.31[g]	81.08[h]
Incidental Soil Ingestion (mg/d)[i]	50	20

Abbreviations and acronyms: mL = milliliter; USEPA = U.S. Environmental Protection Agency.
The complete reference is at the end of the report.

[a] The body weight represents a time-weighted average of body weights for age groups 1 to <2 years and 2 to <3 years from Table 8-3 of the 2008 *Child-Specific Exposure Factors Handbook* (CSEFH). Original sample sizes for each of these age groups can also be found in Table 8-3.

[b] The body weight represents the recommended body weight from USEPA's (2011) *Exposure Factors Handbook* (EFH) (USEPA 2011). Although the 18-to-74 year age category in USEPA's EFH does not match exactly the age 20-to-70 year categorization of adults in MIRC, the magnitude of error in the mean and percentile body weights is likely to be very small (i.e., less than 1%).

[c] Each ingestion rate represents a time-weighted average of ingestion rates for age groups 1 to <2 years and 2 to <3 years from Table 3-4 of the 2008 CSEFH.

[d] Adult drinking water ingestion rates were obtained from USEPA (2004), Appendix E, Part I, Table A1 for community water, both sexes (ages 20+), direct plus indirect water ingestion.

[e] Primary source for values was the 1987–1988 Nationwide Food Consumption Survey; compiled results are presented in Chapter 13 of USEPA's (2011) *Exposure Factors Handbook*. When data were unavailable for a particular age group, intake rate for all age groups was used multiplied by the age-specific ratio of intake based on national population intake rates from *Continuing Survey of Food Intakes by Individuals* (CSFII).

[f] Primary source for values was 1987–1988 Nationwide Food Consumption Survey, compiled results presented in Chapter 13 of 2011 *Exposure Factors Handbook* (USEPA 2011). When data were unavailable for a particular age group, intake rate for all age groups was used multiplied by the age-specific ratio of intake based on national population intake rates from an NHANES 2003–2006 analysis in Chapter 11 of the 2011 *Exposure Factors Handbook*.

[g] A fish ingestion rate for ages 1-2 years was not available. The value represents the consumer-only fish ingestion rate for ages 3 to 5 from USEPA (2002) (Section 5.2.1.1 Table 5 [freshwater/estuarine habitat]), scaled down by the ratio of the mean Child 1-2 body weight to the mean Child 3-5 body weight.

[h] This value represents the consumer-only fish ingestion rate for individuals 18 years and older from USEPA (2002), Section 5.2.1.1 Table 4 (freshwater/estuarine habitat). Sample size = 1,633.

[i] For mean and 50th percentile soil ingestion rates for children, value represents a "central tendency" estimate from USEPA's (2008) CSEFH, Table 5-1. For adults, value is the recommended mean value for adults from USEPA's (2011) EFH, Chapter 5, Table 5-1.

Table 3-27. Typical and High-end Exposure Factor Values for Infant Water Consumption

Parameter	Typical or Mean Scenario mL/kg-d	High-end Scenario mL/kg-d (95th %)	Rationale or Source
Intake by infant < 1 month	137	238	Table 3-1 in USEPA (2011) Exposure Factors Handbook, Consumers-Only drinking water
Intake by infant:			Table 3-1 in USEPA (2011) Exposure Factors Handbook, Consumers-Only drinking water
1–3 months	119	285	
6–12 months	53	129	

Abbreviations and acronyms: mL = milliliter; kg = kilogram; d = day; USEPA = U.S. Environmental Protection Agency.

Ingestion Media

Ingestion media in the exposure assessment include drinking water, incidentally ingested soil, fish caught locally in the on-site lake, five types of home-grown produce, and five types of home-raised animals or animal products. Equations and assumptions to estimate those exposures are based on relevant portions of HHRAP as implemented in MIRC.

Average daily ingested doses (ADDs in mg/kg/day) are estimated using generic Equation 3.6:

$$ADD_{ing} = \left(C_{prod} * IR * FC * ED/BW * AT\right) * (EF/365\ days) \qquad \textbf{Eqn. 3.6}$$

where:

ADD_{ing} = Average daily ingestion dose (mg/kg/day)
C_{prod} = Concentration of chemical in ingestion medium (mg/kg or mg/L)
IR = Age-group specific ingestion rate for ingestion medium (kg/day or L/day)
FC = Fraction of food type harvested from the contaminated farm area
ED = Exposure duration (yr)
BW = Age-group-specific body weight (kg)
AT = Averaging time (yr)
EF = Annual exposure frequency for age group (days)

A version[9] of this equation is used in MIRC for each ingestion medium to calculate average daily doses (ADDs) for each receptor age group (i.e., adult or young child) and chemical.

The above equation accounts for the chemical concentration in each ingested food, the quantity of food brought into the home for consumption, how much of that food is consumed per year, the amount of the food obtained from the affected area, and the consumer's body weight (USEPA 2011). MIRC includes factors for food preparation and cooking losses account for the amount of a food product as brought into the home that is not ingested due to loss during preparation, cooking, or post-cooking (USEPA 2017, Appendix K). Two additional exposure media are included to estimate the total daily dose of each chemical ingested: drinking water and soil (from incidental ingestion). In MIRC, ADDs are calculated separately for each chemical, ingestion

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[9] Variations of the equation include units, conversion factors, cooking loss factors, or other adjustments for the specific ingestion source.

medium, and receptor age group. All the ADDs for a given carcass management option are then summed for each combination of receptor age group and chemical.

For fish ingestion, the assessment assumes that farm residents catch and consume both water-column game fish (e.g., walleye, northern pike) and pan fish (e.g., yellow perch, bluegill). The fish ingestion rates are mean values for the general population developed by USEPA's Office of Air Quality Planning and Standards for use in multimedia risk assessments in support of USEPA's Risk and Technology Review program. In particular, the USEPA's Office of Air Quality Planning and Standards estimated the values of 7 g/person/day for adults and 1.4 g/person/day for children age 1 to 2 years from data presented in USEPA's (2002) *Estimated Per capita Fish Consumption in the United States* and the Agency's (2008) *Child-Specific Exposure Factors Handbook*. Subsistence fish ingestion rates are not used because the farm residents also rely on home-grown plants and livestock for food. Further details are available in USEPA 2017, Appendix K.

All ingestion ADDs are calculated assuming one year of exposure to the chemicals (ED of 1 yr), exposure that every day during the year (i.e., exposure frequency of 365 days/yr), and that all of the food or drinking water ingested is from potentially contaminated food and drinking water obtained on site (i.e., the fraction from the contaminated area is 1.0). The averaging time in the equation above (AT of 1 yr) is the period of time over which the average daily chemical exposure is averaged. Only the first year following management of the carcasses on site is assessed, because that is the year in which chemical concentrations will be highest in environmental media. Chemical concentrations in subsequent years will be lower as various loss processes (e.g., diffusion, dispersion, degradation, movement of chemicals to other environmental media) continue over time. Thus, exposures will continue, but decrease at a rate that is difficult to calculate across carcass management options.

For each carcass management option, chemical-specific ingestion exposures, expressed as ADDs, for each age group (i.e., adult and child aged 1-2), are summed across ingested drinking water, soil, fish, five types of home-grown produce, and five types of home-raised animals or animal products. Total ADD for a particular age group y ($ADD_{(y)}$) is estimated as the sum of a given chemical ingested from all pathways from which the chemical could be consumed. The ADDs for dioxins are totaled using the TEQs described in Section 3.2.1.

Ingestion exposure estimates (i.e., ADDs) for adults and young children associated with each management option are presented in Tables 3-28 through 3-32. These tables include ADDs for each food ingested, drinking water, and incidental soil ingestion, which are added to calculate the total ingestion exposure for each chemical. The tables show “np” where a chemical is not present in the exposure medium. For example, diazinon is combusted and is not present in any pathway for the two combustion-based options, and mercury is present only for open burning because its only source is coal used as pyre fuel. Including the “not present” pathways in Tables 3-28 through 3-32 helps to show how potential exposure pathways differ among the management options.

The tables show “na” if where exposure is not assessed. Reasons for not assessing particular chemicals and pathways are discussed in Sections 3.1 and 3.2. For example, dioxins are not assessed in the drinking water ingestion because their low mobility. Mercury exposure is not assessed in fish and home-grown produce. Mercury exposure needs to be evaluated based on site specific physical/chemical characteristics and other environmental conditions.

Ingestion exposures estimated for adults and young children generally are within an order of magnitude. Estimated ingestion exposures for children are greater than those for adults, because children ingest more food and water per unit body weight than do adults.

Infants under the age of 1 year might be bottle fed with powdered formula reconstituted with water drawn from an on-site groundwater well. Estimated infant ingestion exposures for the livestock carcass burial option included in Table 3-33.

The exposure estimates in this section are based on the hypothetical farm setting, a standardized set of environmental conditions (e.g., meteorology), methods with considerable uncertainties, and assumptions that are not necessarily representative of site-specific carcass management efforts. For these reasons, this exposure assessment should not be regarded as providing

Table 3-28. Ingestion Exposure Estimates for Open Burning, Coal Fueled

Chemical Species	Ingestion Average Daily Dose (mg/kg-d)				
	Drinking Water	Farm Produce	Fish	Soil	Total Ingestion
Adults					
Total Dioxins/furans	na	3.7E-10	4.7E-11	2.5E-14	4.0E-10
Diazinon	np	np	np	np	np
Mercury	1.1E-07	na	na	3.0E-14	1.1E-07
Children 1 to <2 Years Old					
Total Dioxins/furans	na	5.6E-09	6.0E-11	4.0E-13	5.6E-09
Diazinon	np	np	np	np	np
Mercury	1.9E-07	na	na	4.8E-13	4.9E-07

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed; np = not present.

Table 3-29. Ingestion Exposure Estimates for Air-curtain Burning, Wood and Diesel Fueled

Chemical Species	Ingestion Average Daily Dose (mg/kg-d)				
	Drinking Water	Farm Produce	Fish	Soil	Total Ingestion
Adults					
Total Dioxins	na	2.4E-10	8.0E-12	1.5E-14	2.5E-10
Diazinon	np	np	np	np	np
Mercury	np	np	np	np	np
Children 1 to <2 Years Old					
Total Dioxins	na	3.6E-09	7.4E-12	2.3E-13	3.6E-09
Diazinon	np	np	np	np	np
Mercury	np	np	np	np	np

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed; np = not present.

estimates of actual exposures likely from the management options. Despite their inherent uncertainty, the exposure estimates are useful for comparing the management options relative to one another, in terms of the number of potential pathways and relative exposure levels, with each chemical exposure normalized to levels that can cause adverse effects on human and environmental health). Uncertainties in the assessment are evaluated and discussed further in Sections 4.3 and 4.4.

Table 3-30. Ingestion Exposure Estimates for Burial

Chemical Species	Ingestion Average Daily Dose (mg/kg-d)		
	Drinking Water	Fish	Total Ingestion
Adults			
Total Dioxins	na	na	na
Diazinon	3.1E-05	na	3.1E-05
Mercury	np	np	np
Children 1 to <2 Years Old			
Total Dioxins	na	na	na
Diazinon	4.5E-05	na	4.5E-05
Mercury	np	np	np

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed; np = not present.

Table 3-31. Ingestion Exposure Estimates for Composting -- Windrow

Chemical Species	Ingestion Average Daily Dose (mg/kg-d)		
	Drinking Water	Fish	Total Ingestion
Adults			
Total Dioxins	na	na	na
Diazinon	4.4E-06	na	4.4E-06
Mercury	np	np	np
Children 1 to <2 Years Old			
Total Dioxins	na	na	na
Diazinon	7.6E-06	na	7.6E-06
Mercury	np	np	np

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed; np = not present.

Table 3-32. Ingestion Exposure Estimates for Composting – Compost Application

Chemical Species	Ingestion Average Daily Dose (mg/kg-d)				
	Drinking Water	Farm Produce	Fish	Soil	Total Ingestion
Adults					
Total Dioxins	na	8.6E-09	2.0E-09	5.0E-11	1.1E-08
Diazinon	na	1.2E-04	9.3E-07	1.0E-08	1.2E-04
Mercury	np	np	np	np	np
Children 1 to <2 Years Old					
Total Dioxins	na	6.6E-08	2.5E-09	7.9E-10	6.9E-08
Diazinon	na	4.0E-04	1.2E-06	1.6E-07	4.0E-04
Mercury	np	np	np	np	np

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed; np = not present.

Table 3-33. Ingestion Estimates for Infants with Formula Made Using Well Water[a] for Open Burning, Burial, and Composting Options

Chemical Species	Ingested Daily Dose (mg/kg-d)					
	Open Burning		Burial		Composting	
	Mean	95th%	Mean	95th%	Mean	95th%
Diazinon	na	na	1.2E-03	2.6E-03	1.5E-04	3.4E-04
Mercury	2.4E-07	5.3E-07	na	na	na	na

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; na = not assessed.

[a] Mean columns calculated using a time-weighted mean water ingestion rate of 0.0898 L/kg-day for an infant less than 1 year of age (original data listed in Table 6.2.1; an intermediate ingestion rate of 0.128 L/d was assumed for infants 3 to 6 months of age). 95th% = ingested daily dose assuming time-weighted 95th percentile water ingestion rate for infant less than 1 year (0.197 L/kg-day). (original data in Table 6.2.1; an ingestion rate of 0.262 L/kg-day for infants was assumed 3 to 6 months).

4. Results and Discussion

This section compares options for managing dioxin- and diazinon-contaminated carcasses relative to each other in terms of potential exposures to onsite residents and workers. In Section 4.1 the carcass management options are evaluated in a two-tiered approach. Tier 1 (Section 4.1.1) groups the seven carcass management options in two categories of potential exposure based on the level of regulatory pollution controls that limits releases of chemicals to the environment. Tier 1 is qualitative because the off-site options are not included in the quantitative exposure assessment.

In Tier 2 (Section 4.1.2), the four on-site management options are evaluated further based on the quantitative exposure assessment. Specifically, the exposure estimates presented in Sections 3.2 and 3.3 are normalized to chemical-specific Toxicity Reference Values (TRVs) to allow a relative comparison of the management options in terms of their potential for exposures at levels of concern for human health.

The quantitative assessment presented in Section 4.1 uses a “base-case” set of reasonably conservative values identified from available literature and previously developed default assumptions for the hypothetical farm site. Section 4.2 examines how assumptions such as the scale of mortality and level of chemical contamination affect the magnitude of exposure and the relative exposures for the on-site management options. Section 4.3 discusses the uncertainties and limitations of the assessment to help readers understand and use the findings of this assessment, including how these findings may relate to site-specific circumstances in the event of an actual chemical emergency.

All of the on-site management options include preceding carcass transportation and handling steps. Chemical exposures from these steps are not included in this assessment. However, they were included, either qualitatively or quantitatively, in the chemical and microbial exposure assessments for the natural disaster (USEPA 2017) and foreign animal disease (FAD) outbreak (USEPA 2018) scenarios. The FAD assessment concluded that temporary carcass storage, if employed as part of the overall carcass management response, can be the primary source of potential exposure. This finding applies to the foot and mouth disease, the subject of the FAD assessment, but not necessarily to other microbial hazards. For chemical hazards, the natural disaster assessment concluded that exposures from temporary carcass storage are well below exposures from the combustion-based options and roughly comparable in magnitude to the exposures from burial and the composting windrow. Based on these findings, the handling and transportation steps were not re-examined in this assessment. For this assessment, the on-site carcass transportation and handling steps, and their resulting chemical exposures, are assumed to be the same for all management options, and therefore do not affect the relative levels of chemical exposure across the options.

Readers of this document should recognize that the exposures estimated for the hypothetical base case scenario might differ from those of the different carcass management options in specific locations and under various conditions. This document does not replace the need for county or statewide planning for chemical or other disasters with mass livestock mortality based on availability of off-site management options and suitability of on-site options for the region.

4.1 Exposure Assessment

This section compares the livestock carcass management options relative to each other in a two-tiered approach. Tier 1 (Section 4.1.1) groups the seven carcass management options in two categories of potential exposure based on the level of regulatory pollution controls that limits releases of chemicals and microbes to the environment. Tier 1 also considers the number of potential exposure pathways identified in the conceptual models for each management option (Appendix C) and describes why the three off-site carcass management options present minimal to negligible relative risks. In Tier 2 (Section 4.1.2), the four on-site management options are evaluated further based on the quantitative exposure assessments presented in Sections 3 through 6.

4.1.1 Tier 1 Comparison of the Seven Carcass Management Options

As discussed in Section 2, this assessment considers seven well-established carcass management options with documented use following chemical emergencyies or with sufficient capacity for large-scale carcass management. With the three off-site options, releases to the environment (e.g., incinerator emissions to air, rendering facility discharge to surface water) are restricted by, and are assumed to comply with, applicable regulations. Therefore, chemical releases from off-site commercial facilities are assumed to be adequately controlled. The on-site management options all include uncontrolled or minimally controlled chemical releases to air, soil, or water, for which exposures are modeled as described in Section 3. Moreover, the on-site management options tend to have more potential exposure pathways than the off-site options. Acknowledging the distinction between off-site and on-site options based on regulatory pollution control constitutes the first tier ranking of the seven carcass management options. Table 4-1 presents that ranking and lists the numbers of conceptual model pathways for chemicals. Table 4-1 also describes controlling legislation and technologies to limit releases to permitted levels or below. The table shows that the three off-site options are ranked higher (i.e., less potential for exposure and risk) than the four on-site options based on these considerations.

4.1.2 Tier 2 Ranking of On-site Carcass Management Options

In Tier 2, the four on-site carcass management options are compared using the exposure estimates presented in Section 3.3. In particular, ranking ratios are calculated and compared for each combination of management option, chemical, exposure route (i.e., inhalation or ingestion), and health effect (i.e., cancer or noncancer) for which exposures are estimated. Some exposure pathways were not quantified for one or more reasons (e.g., the chemical is not present). These reasons are noted in in general categories in Table 4-2 and explained more specifically in Sections 3.1 and 3.2.

By itself, an exposure concentration does not indicate whether adverse effects on human health or environmental quality are possible or likely. To support a risk-based comparison of the exposure estimates, they are normalized to inherent toxicity using toxicity reference values (TRVs). A TRV is a concentration- or dose-based estimate of the exposure level below which adverse health effects are not expected for individual humans in the population evaluated. TRVs are chemical-specific and are developed by various agencies (e.g., USEPA, ATSDR) using agency- or program specific-methods and definitions. TRVs also are developed for various exposure durations, and the TRVs for this assessment are those most appropriate, as available, for the exposure durations of the exposure estimates. Table 4-3 presents the TRVs used in the assessment, all of which were identified from the Oak Ridge National Laboratory's Risk Assessment Information System (RAIS).[10]

Table 4-1. Tier 1 Ranking of Livestock Carcass Management Options – Off-site vs. On-site Management Options

Tier 1 Ranking	Management Options	Chemical Exposure Pathways[a]		Controls and Limits to Environmental Releases
Rank 1: Negligible to minimal exposure—releases regulated to levels acceptable for human health and the environment	Incineration	6		Air emissions regulated under the Clean Air Act (CAA), including pollution control equipment (e.g., scrubbers, filters), with tall stacks to prevent localized deposition; residuals (i.e., ash) managed under the Resource Conservation and Recovery Act (RCRA); wastewater managed under the Clean Water Act (CWA).
	Rendering	3		Releases to air and to water regulated under the CAA and CWA, respectively.
	Landfilling	2		Landfill design and operation regulated under RCRA; controls include leachate collection and management and methane recovery.
Tier 1 Ranking	**Management Options**	**Chemical Exposure Pathways[a]**	**Exposure Pathways by Chemical[a]**	**Controls and Limits to Environmental Releases**
Rank 2: Higher exposure potential—uncontained releases to the environment	Open Burning	10	Dioxins: 6 Diazinon: 0	Uncontrolled combustion emissions; possible releases from combustion ash if managed on site
	Air-curtain Burning	10	Dioxins: 6 Diazinon: 0	Partially controlled combustion emissions, possible releases from combustion ash if managed on site
	Burial	6	Dioxins: 0 Diazinon: 4	Uncontrolled leaching from unlined burial; slow gas release to air
	Compost Windrow	6	Dioxins: 0 Diazinon: 4	Partially controlled releases from compost windrow (minor leaching, runoff, and gas release to air); where finished compost is tilled into soils, potential runoff and erosion from amended soil
	Compost Application	2	Dioxins: 2 Diazinon: 2	

Abbreviations and acronyms: CAA = Clean Air Act; RCRA = Resource Conservation and Recovery Act; CWA = Clean Water Act.

[a] See Section 3 for identification of the pathways. Individual chemicals are not present in certain pathways due chemical specific properties (e.g., dioxins have low mobility in soil and groundwater) or the effects of management processes (e.g., diazinon is combusted). The number of exposure pathways does not necessarily indicate the relative level of exposure among the management options because the potential levels of exposure vary substantially by pathway.

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[10] The Risk Assessment Information System is available at: <https://rais.ornl.gov/>.

Table 4-2. Human Exposure Pathways for Livestock Carcass Management

Exposure Source	On-site Carcass Management Options			
	Open Burning and Air-curtain Burning	**Burial**	**Compost Windrow**	**Compost Application**
Inhalation	1) Air[a] 2) Ash → GW → In-home Aerosol[b]	1) Air[b] 2) Leachate → GW → In-home Aerosol[b]	1) Air[b] 2) Compost → GW → In-home Aerosol[b]	—
Incidental Ingestion	3) Air → soil[b]	—	—	—
Fish Ingestion	4) Air → SW → Fish[a] 5) Air → soil → SW → Fish[a] 6) Ash → GW → SW → Fish[a]	3) Leachate → GW → SW → Fish[a]	3) Compost → GW → SW → Fish[a]	1) Compost → Soil → SW → Fish[a]
Groundwater Ingestion	7) Ash → GW[a]	4) Leachate → GW[a]	4) Compost → GW[a]	—
Ingestion of Food Produced on the Farm	8) Air → Plants/livestock[a] 9) Air → Soil → Plants/ Livestock[a] 10) Ash → GW → Livestock[b]	5) Air → Plants/ Livestock[b] 6) Leachate → GW → Livestock[b]	5) Air → Plants/ Livestock[b] 6) Compost → Soil → GW → Livestock[b]	2) Compost → Soil → Plants/ Livestock[a]

Abbreviations and acronyms: "—" = no exposure pathways; SW = surface water; GW = groundwater.
Exposure pathways shown in bold were included in the quantitative exposure assessment. Pathways were not quantitatively assessed for the following reasons:
[a] Quantitative methods were available for exposure assessment; results are presented in Section 3.3.
[b] Potential exposures were assumed to be negligible based on source conditions or chemical properties.

The selected TRVs are referred to by the general term “benchmarks,” because they include values for cancer and non-cancer endpoints, are developed by various agencies for various exposure durations, and differ for inhalation and oral exposures. As described below, exposure estimates for each management option, chemical, and exposure route are compared to the cancer and non-cancer benchmarks for purpose of comparing or ranking the management options relative to one another.

The benchmarks for inhalation exposure are expressed as air concentrations (i.e., (µg [chemical]/m^3[air]) that can be compared directly to the concentrations estimated at a receptor location (e.g., 100 m from the source). The exposure concentrations are presented in Section 3.2.1 as peak 1-hour concentrations during combustion and averages over the duration of combustion, which is 48 hours for the base case. Because these concentrations are short-term (i.e., hours to days), the preferred TRVs for the inhalation benchmarks are acute toxicity reference concentrations (RfCs). The benchmarks are based on sub-chronic or chronic RfCs (unadjusted) when acute RfCs are unavailable.

Benchmarks for ingestion exposure are expressed as the ingested dose (i.e., mg[chemical]/kg[human body weight] per day). As discussed in Section 3.3, ingestion exposures are assumed to occur over the first year of maximum exposures. Accordingly, the preferred TRVs for evaluating non-cancer health effects from ingestion exposures are subchronic oral reference doses (RfDs), which are developed for periods up to 7 years (USEPA 1989). Chronic oral RfDs (unadjusted) are selected when subchronic RfDs are unavailable.

The TRVs for evaluating cancer health effects from ingestion are oral slope factors in units of per mg/kg-day (i.e., (mg/kg-day)$^{-1}$), based on lifetime exposure. The slope factors require a transformation for direct comparison to exposure estimates, which are in units of mg/kg-day. Specifically, a target individual risk level of 1E-04 (one in 10,000) is divided by the oral slope factor to calculate the corresponding risk-specific dose (RSD), that is, the dose that corresponds to a target risk level of 1E-04 over a lifetime of exposure. This risk target is selected because, in general, USEPA considers excess cancer risks above 1E-04 to be sufficiently large that some response action is merited (USEPA 1991). Because the RSD represent cancer risk based on a lifetime of exposure, the estimated average daily exposure dose for the first year (i.e., the ADD) is divided by 70 years to calculate the lifetime average daily dose (LADD).

Even in comparative or relative risk assessments, cancer and non-cancer endpoints generally are not grouped into one category. There are no consensus guidelines at USEPA by which risk assessors can combine estimates of cancer risk (a probability or incidence rate) with a hazard quotient (ratio of a point estimate of exposure to the appropriate benchmark, either $\geq$1.0 indicating adverse effects are possible or <1.0 indicating adverse effects are unlikely). Severity of effects is also a complicating factor for comparisons. Some health effects upon which non-cancer toxicity RfCs or RfDs are based are more severe than others. Some types of cancer are associated with limited expected future survival whereas others have better prognoses.

For the relative risk comparison of the four on-site carcass management options, the estimated exposures (Section 3.3.2) are compared with the relevant benchmarks (Table 4-3) by calculating the ratios of exposure to benchmarks. These ratios, which normalize each of the exposure estimates to inherent toxicity, are referred to as “ranking ratios.” Risk managers and the public should not interpret risk ratios as “actual likely” exposures or risks, particularly given the data limitations and generic assumptions of this assessment. However, the ranking ratios can be compared to evaluate the relative exposure among management options within the base case (this section) or when certain base case assumptions are changed (Section 4.2).

Mercury originating from coal combustion is included in the assessment, but only pertains to the open burning option. Therefore, mercury exposures are discussed separately in the sections below.

Inhalation Exposure

Ranking ratios for base-case inhalation exposure are presented in Table 4-4. The table includes dioxins only, because diazinon is not present in the combustion emissions and mercury is discussed separately below. Considering either peak 1-hour or event average concentrations, open burning produces dioxin inhalation exposure that is similar to, but greater than, inhalation exposures from air-curtain burning. As discussed in Section 3.2.1, dioxin emissions, and exposures, from the two management options are more similar in this assessment than they were in the previously completed assessments (USEPA 2017). A reason for this is that dioxin from the contaminated carcasses, which are assumed to be equivalent with the two management options, contribute 48% or more of the total dioxin emissions with the base case. As the amount of dioxin contamination becomes greater relative to the dioxins formed as fuel combustion products, their contribution to total dioxin emissions increasingly outweighs the difference between the options due to the fuels alone.

With both open burning and air-curtain burning, the estimated exposures for the base case are below the dioxin inhalation benchmark. Diazinon exposure is not included in the inhalation assessment because it would be decomposed and fumes might ignite during combustion.

For the open burning option, base case inhalation exposure to mercury is well below the reference concentration (i.e., 0.6 µg/m3). For example, the highest peak 1-hour concentration at the closest receptor location (100 m) is 4.9E-4 µg/m3 as shown in Table 3-14.

Table 4-3. Toxicity Reference Values

Chemical Species	Ingestion Benchmarks				halation Benchmarks, RfC µg/m^3)	RfC Basis
	RfD (mg/kg-d)	RfD Basis	RSD (mg/kg-d)	RSD Basis		
al Dioxins/ furans	2.0E-08	Sub-chronic Oral RfD; ATSDR Final	7.7E-10	E-4 Target Risk / 1.3E+5 (mg/kg-d)$^{-1}$ Oral Slope Factor; CalEPA	4.0E-05	Chronic Inhalation RfC; CalEPA
zinon	2.0E-03	Short-term Oral RfD; TSDR Final	nb	nc	na	na
mental Mercury	1.6E-04	Chronic Oral RfD; CalEPA	not available	nc	0.6	Acute Inhalation RfD; alEPA

Acronyms and abbreviations: mg = milligram; kg = kilogram; d = day; µg = microgram; m^3 = cubic meter; RfD = reference dose; RfC = reference concentration; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily exposures; na = not assessed; nb = benchmark (non-cancer) not available for oral exposure; nc = probably not carcinogenic to humans by ingestion route by IARC or a confirmed animal carcinogen with unknown relevance to humans by ACGIH.

Note: Ingestion sources include fish caught from the on-site lake and drinking water drawn from an on-site well.

[a] Cancer TRVs represent cancer risk based on a lifetime of exposure. Therefore, average daily exposure dose (i.e., the ADD) for the first year is divided by 70 years to calculate the lifetime average daily dose (LADD).

Table 4-4. Ranking Ratios for Dioxin Inhalation

Distance from Source (km)	Ranking Ratios for Dioxin Inhalation			
	Peak 1-hr/RfC		Event Average/RfC	
	Open Burning	Air-curtain Burning	Open Burning	Air-curtain Burning
0.1	3.2E-01	4.5E-02	4.4E-02	2.4E-02
0.2	1.8E-01	7.9E-02	3.3E-02	1.1E-02
0.3	1.1E-01	6.0E-02	2.6E-02	1.0E-02
0.4	7.6E-02	4.6E-02	1.9E-02	8.4E-03
0.5	5.8E-02	3.7E-02	1.5E-02	7.3E-03
0.6	4.5E-02	3.1E-02	1.3E-02	6.4E-03
0.7	3.7E-02	2.6E-02	1.1E-02	5.6E-03
0.8	3.2E-02	2.2E-02	1.1E-02	5.4E-03
0.9	2.8E-02	2.0E-02	9.7E-03	5.2E-03
1	2.5E-02	1.8E-02	8.9E-03	5.0E-03
2	1.8E-02	1.2E-02	5.0E-03	3.3E-03
3	1.6E-02	1.1E-02	4.1E-03	2.4E-03
4	1.4E-02	1.0E-02	3.4E-03	2.0E-03
5	1.2E-02	9.0E-03	2.8E-03	1.9E-03
6	1.2E-02	8.1E-03	2.4E-03	1.7E-03
7	1.2E-02	7.3E-03	2.1E-03	1.5E-03
8	1.1E-02	6.6E-03	1.9E-03	1.4E-03
9	1.1E-02	6.0E-03	1.7E-03	1.2E-03
10	1.1E-02	5.6E-03	1.5E-03	1.1E-03

Notes: Exposure duration is 48 hours. Cancer risk is not evaluated for this short-term exposure.
Abbreviations and Acronyms: km = kilometer; hr = hour; RfC = reference concentration.

Table 4-5. Ingestion Exposure Estimates for the Base Case

Chemical Species	Estimated Ingestion Average Daily Dose (mg/kg-d)[a]	Ranking Ratios	
		ADD/RfD	LADD/RSD
Open Burning			
Total Dioxins	5.6E-09	2.8E-01	1.0E-01
Air-curtain Burning			
Total Dioxins	3.6E-09	1.8E-01	6.7E-02
Burial			
Total Dioxins	na	na	na
Diazinon	5.4E-05	2.7E-02	nb
Compost Windrow			
Total Dioxins	na	na	na
Diazinon	7.6E-06	3.8E-03	nb
Compost Application			
Total Dioxins	6.9E-08	3.5E+00	1.3E+00
Diazinon	4.0E-04	2.0E-01	nb

Abbreviations and acronyms: mg = milligram; kg = kilogram; d = day; ADD = average daily dose; LADD = lifetime average daily dose; na = not assessed; nb = benchmark (non-cancer) not available for oral exposure; np = not present; RfD = reference dose; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily exposures

[a] Estimates presented are those for children age 1-2.

Ingestion Exposure

Ranking ratios for base case ingestion exposure are presented in Table 4-5. For ingestion, ranking ratios are calculated only with the exposures estimated for children 1 to <2 years of age, because that age group is more highly exposed (e.g., ingest more food per unit body weight) than older children and adults. The first data column Table 4-5 shows the estimated magnitude of exposure for the young children. These are followed by the ranking ratio(s) for exposure compared to non-cancer and cancer benchmarks. The ranking ratios also are shown in Figure 4-1.

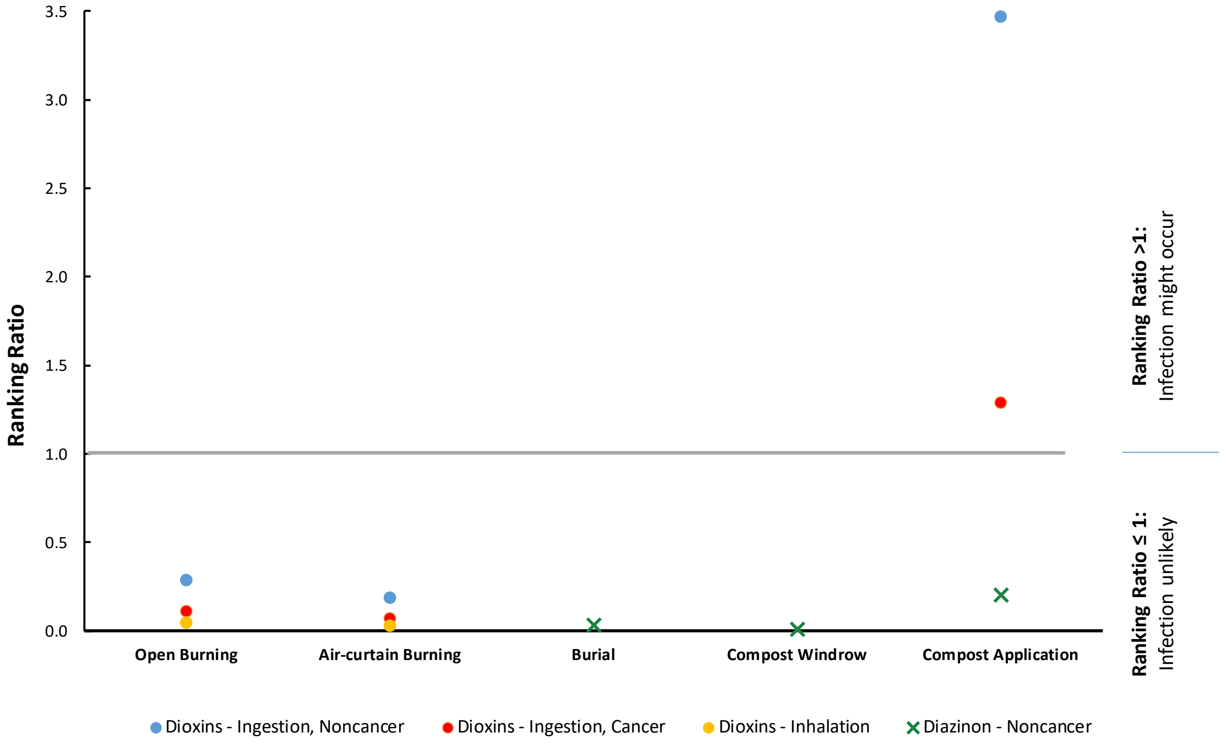

Figure 4-1. Ranking ratios for base case exposure.

Using the base case assumptions, compost application has a greater potential ingestion exposure to dioxin than the other management options. The reasons for this are that dioxins are not destroyed by composting and are present in the finished compost when, as in this scenario, it is amended to surface soil. In this assessment, a portion of the soil at the compost application erodes and reaches the on-site lake. Dioxins being highly bioaccumulative concentrate in the aquatic food web, and are consumed by farm residents. In addition, this assessment assumes that home-grown foods products are grown on amended soil. With the combustion based options, the dioxin contamination from the carcasses is transported by air to soil, along with additional dioxins formed from fuel combustion. A portion of the combustion-product dioxins remain with the ash, which is buried on site. Although the combustion-based options also result in dioxin contamination in surface soil, the contamination is dispersed over a larger area resulting in lower soil concentrations and erosion to the lake.

For compost application, the diazinon ranking ratio is lower than the dioxin ranking ratios and more similar to the ranking ratios for burial and the compost windrow. Two reasons for these results are that diazinon is not as bioaccumulative as dioxins and has a lower inherent toxicity. Diazinon also would be subject to degradation processes more than dioxins (e.g., during composting), but these are not included in the assessment.

Ingestion exposure to mercury is estimated for drinking water and incidental soil ingestion, but not for fish and home-grown food ingestion (see Sections 3.2.5 and 3.2.6). The total ingestion for drinking water and soil ingestion is 4.9E-07 mg/kg-day, which is below the RfD, 1.6E-4 mg/kg-day. Ingestion exposure might be underestimated by the absence of estimates for the fish ingestion and home-grown food pathways. The estimated mercury concentrations in soil and surface water are shown in Table 4-6.

Ranking ratios for bottle-fed infants under 1 year are presented in Table 4-7. The 95th percentile exposure estimate for diazinon leached from the burial pit is greater than the RfD. However, exposure is likely to be overestimated because biotic and abiotic degradation processes are not included in the exposure estimate.

Table 4-6. Mercury Background Concentrations in Soil and Surface Water

Medium	Highest Estimated Concentration of Total Mercury	Background Concentration	Background Concentration Source
Soil	5.5E-6 mg/kg	0.112 mg/kg dry weight	Shacklette et al. (1971)
Surface Water	4.6E-06 µg/L	9.0E-04 µg/L	USEPA (1997b)

Abbreviations and acronyms: mg = milligram; kg = kilogram; µg = microgram; L = liter.

Table 4-7. Ingestion Ranking Ratios for Infants with Formula Made Using Well Water

Chemical Species	Ranking Ratio					
	Open Burning		Burial		Composting	
	Mean	95th%	Mean	95th%	Mean	95th%
Diazinon	np	np	5.8E-01	1.3E+00	7.6E-02	1.7E-01
Mercury	1.5E-03	3.3E-03	np	np	np	np

Abbreviations and acronyms: np = not present.

The Tier 2 rankings are based on the inhalation and ingestion ranking ratios presented above. The ranking summary table, Table 4-8, includes both tiers. It should be noted that potential exposures have been assessed using an approach that facilitates a relative ranking of carcass management options by the degree of hazard associated with the exposure pathways for each scenario. The potential for exposure for each evaluated exposure pathway has been given an ordinal scale ranking supported by a weight-of-evidence discussion of the available data. The top section of the table shows that carcass management options grouped as Rank 1 in Tier 1 (i.e., the off-site options) are not further ranked relative to each other.

Table 4-8. Tier 2 Ranking of Livestock Carcass Management Options

<table>
<tr><th>Tier 1 Description</th><th colspan="3">Management Option</th><th colspan="2">Principal Rationale</th></tr>
<tr><td rowspan="3">The qualitative Tier 1 assessment distinguishes the off-site options from the on-site options based on level of regulatory control. The off-site options are considered to pose lower risk than the on-site options, which have uncontrolled environmental releases. The off-site options are not ranked relative to each other.</td><td colspan="3">Off-site Rendering</td><td colspan="2">Carcasses processed into useful products; wastes released under permits; availability decreasing</td></tr>
<tr><td colspan="3">Off-site Landfill</td><td colspan="2">Carcass leachate contained and methane captured; landfills at capacity are closed and new ones built</td></tr>
<tr><td colspan="3">Off-site Incinerator</td><td colspan="2">Destruction of materials; air emissions are regulated; ash is landfilled</td></tr>
<tr><th rowspan="2">Tier 2 Description</th><th rowspan="2">Rank ^a</th><th colspan="2">Highest Ranking Ratio</th><th rowspan="2">Management Option</th><th rowspan="2">Principal Rationale</th></tr>
<tr><th>Dioxin</th><th>Diazinon</th></tr>
<tr><td rowspan="5">The quantitative Tier 2 assessment ranks the on-site options relative to each other by comparing ratio of estimated exposures (from data on source emissions and fate and transport modeling) with toxicity reference values (TRVs).</td><td>1</td><td>np</td><td>6.9E-08</td><td>Compost Windrow</td><td>Bulking material retains most chemicals</td></tr>
<tr><td>2</td><td>np</td><td>5.4E-05</td><td>Burial</td><td>Soils filter out chemicals traveling toward groundwater</td></tr>
<tr><td>3</td><td>1.8E-01</td><td>np</td><td>Air-curtain burning</td><td rowspan="2">Similar release profiles; emissions sensitive to type and quantity of fuels used and burn temperature; Open burning emissions include mercury from coal used as fuel.</td></tr>
<tr><td>4</td><td>2.8E-01</td><td>np</td><td>Open Pyre burning</td></tr>
<tr><td>5</td><td>3.5E+00</td><td>4.0E-04</td><td>Compost Application</td><td>Applied to soil, chemicals are available for uptake by plants and livestock, or surface water and aquatic biota; Mitigate with appropriate use/disposal and erosion controls.</td></tr>
</table>

Acronyms: np = not present.

[a] Rank 1 poses the lowest relative risk and higher numbers indicate higher relative risk.

The bottom section of Table 4-8 summarizes the Tier 2 assessment, which includes the carcass management options (i.e., the on-site options) grouped as Rank 2 in Tier 1. The on-site options are numerically ranked based on their highest ranking ratios, considering either chemical.

Tables 4-1 and 4-8 both show that potential exposures and exposure pathways can differ by chemical. This is due to chemical-specific fate properties, such persistence and mobility in different media. In addition, site-specific circumstances (e.g., the presence of a drinking water well) can affect which exposure pathways are relevant at a site. For these reasons, there is no "best" carcass management option for every event.

4.2 Uncertainty Analysis

The exposure estimates presented in Sections 4.1.2 are affected by several scoping decisions about the chemical emergency (e.g., chemicals present, contamination levels, number of carcasses) and about the design and use of the carcass management options (e.g., configuration, type and amount of combustion fuels). In addition, several parameter values are likely to vary substantially across locations and by season, and available input data and models are subject to limitations. Although the assessment approach generally uses conservative values for parameters that vary substantially in the real world, parameter values assumed when preferred types of data are not available might over- or under-estimate exposures. Sources of uncertainty are discussed further in Section 4.3.

This section examines how changes to various aspects of the base case scenario affect the magnitude of the estimated exposures, and resulting differences in exposures among the options, pathways, and chemicals. The aspects evaluated include the following:

- Chemical selections
- Scale of mortality
- Contamination level
- Distance from source
- Air-curtain burner fuel ratio
- Chemical degradation

4.2.1 Chemical Selections

This assessment evaluated just two of thousands of chemicals that could contaminate livestock in the event of a chemical emergency. As discussed in Section 2.2, the two chemicals (i.e., dioxins and diazinon) represent two categories, halogenated organics and pesticides, respectively, involved in past livestock contamination events. In addition, data required for the assessment (e.g., TRVs) are available for both chemicals.

Another reason for selecting dioxin and diazinon is their distinct environmental fate characteristics. The effects of these differences are discussed throughout Sections 3 and 4. For example, the partitioning behavior of dioxins causes them to have low mobility through the groundwater pathway and a strong tendency to bioaccumulate in the aquatic food web. Dioxins are persistent and will not degrade significantly during composting, and are not likely to be destroyed at the combustion temperatures of on-site open burning or air-curtain burning. In contrast, diazinon is destroyed at these combustion temperatures. Diazinon also is moderately mobile in the groundwater pathway and not strongly bioaccumulative. In addition, diazinon is subject to degradation processes that would decrease exposure. These processes are not included in the environmental fate modeling because they are dependent on many location specific factors (e.g., temperature) as well as time. Thus, diazinon exposures are likely to be overestimated in this assessment. This issue is examined further in Section 4.2.6.

4.2.2 Scale of Mortality

To examine how exposure is affected by the scale of livestock mortality from the chemical emergency, inhalation and ingestion exposures were estimated when the number of cattle carcasses increases from 100 (i.e., the base case) to 500, 1,000, and 10,000. The combustion options were not evaluated with 10,000 carcasses because using these options alone is not likely to be feasible (see Sections 3.1.1 and 3.1.2).

Open Burning and Air-Curtain Burning

In the event of a chemical emergency involving dioxin contaminated livestock carcasses, open burning and air curtain burning would release dioxins to air, which could result in inhalation exposure or ingestion exposures associated with deposition to soil and the onsite lake. Because diazinon would be consumed by combustion, diazinon exposures are unlikely with these options.

For open burning, 100 carcasses are burned in a single pyre that is 91.4 m. With 500 carcasses, the assessment assumes there are five pyres of the same length set parallel to each other. With 1,000 carcasses, there are five parallel pyres are that are twice as long (182.8 m). In all three cases combustion is complete in 48 hours.

For air-curtain burning, one air-curtain burner is operated for 48 hours (2 days) to manage 100 carcasses. The assessment assumes that 500 carcasses are managed with two burners operating for five days, and 1,000 carcasses are managed with four burners operating for five days.

Tables 4-9 and 4-10 show how inhalation and ingestion exposures, respectively, are affected by the number of carcasses managed. These results also are shown in Figures 4-2 (inhalation) and 4-3 (ingestion).

Increasing the number of carcasses from 100 to 1,000, a factor of 10, is expected to increase dioxin exposures no more than an order of magnitude. This is confirmed by the dioxin inhalation and ingestion exposures expressed relative to benchmarks in Tables 4-9 and 4-10. For example, the dioxin inhalation exposure 100 meters from the source from open burning of 500 carcasses is 4.5 times greater than open burning of 100 carcasses.

Table 4-9. Dioxin and Mercury Inhalation Exposure with Increased Numbers of Carcasses

Number of Carcasses	Event Average Air Concentration (µg/m3)[a]		Concentration/RfC	
	Total Dioxins	Total Mercury	Total Dioxins	Total Mercury
Open Burning				
100	1.8E-06	6.8E-05	4.4E-02	1.1E-04
500	7.9E-06	3.1E-04	2.0E-01	5.2E-04
1000	3.7E-06	7.9E-04	9.3E-02	1.3E-03
Air-curtain Burning 4:1 Fuel Ratio				
100	9.6E-07	np	2.4E-02	np
500	2.0E-06	np	4.9E-02	np
1000	3.9E-06	np	9.8E-02	np

Abbreviations and acronyms: µg = microgram; m^3 = cubic meter; np = not present.

[a] Concentration estimates at 100 m from source.

Table 4-10. Ingestion Exposure with Increased Numbers of Carcasses

Number of Carcasses	Ranking Ratios					
	ADD/RfD			LADD/RSD		
	Dioxins	Mercury	Diazinon	Dioxins	Mercury	Diazinon
Open Burning						
100	2.8E-01	1.2E-03	np	1.0E-01	nb	np
500	1.3E+00	5.2E-03	np	4.6E-01	nb	np
1000	3.4E-01	9.9E-03	np	1.2E-01	nb	np
Air-curtain Burning						
100	1.8E-01	np	np	6.7E-02	np	np
500	7.5E-01	np	np	2.8E-01	np	np
1000	1.5E+00	np	np	5.4E-01	np	np
Burial						
100	na	np	2.7E-02	na	nb	nb
500	na	np	1.2E-01	na	nb	nb
1,000	na	np	2.3E-01	na	nb	nb
10,000	na	np	1.9E+00	na	nb	nb
Compost Windrow						
100	na	np	2.2E-03	na	nb	nb
500	na	np	9.6E-03	na	nb	nb
1,000	na	np	1.8E-02	na	nb	nb
10,000	na	np	1.5E-01	na	nb	nb
Compost Application						
100	3.6E+00	np	2.0E-01	1.3E+00	nb	nb
500	1.8E+01	np	9.9E-01	6.6E+00	nb	nb
1,000	3.6E+01	np	2.0E+00	1.3E+01	nb	nb
10,000	3.6E+02	np	2.0E+01	1.3E+02	nb	nb

Abbreviations and acronyms: na = not assessed; nb = benchmark (non-cancer) not available for oral exposure, np = not present.

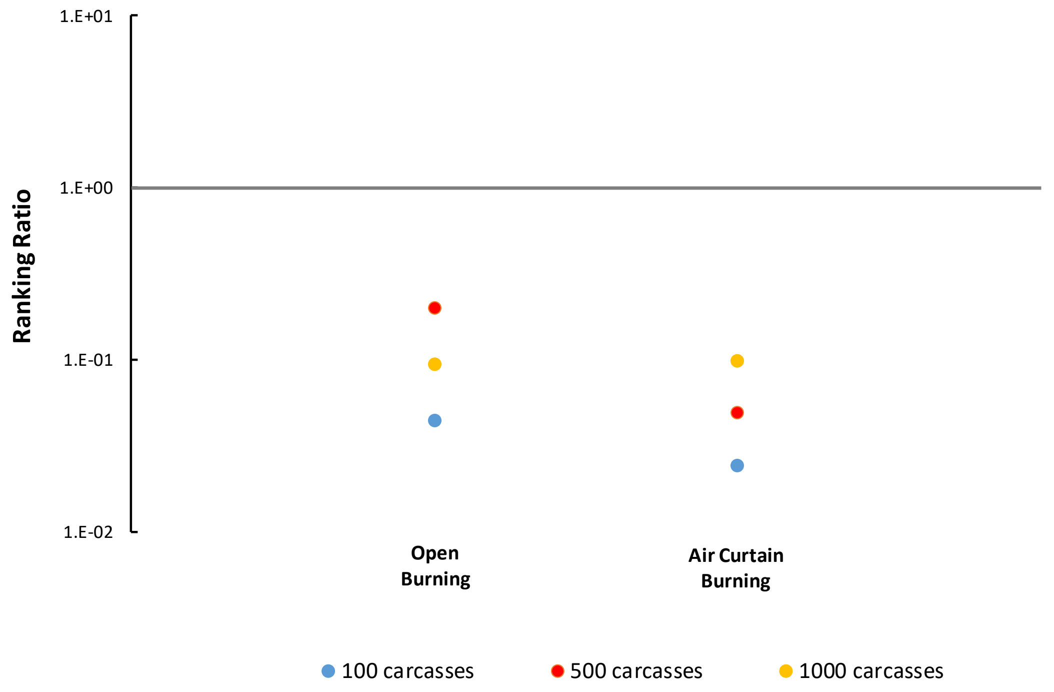

Figure 4-2. Inhalation exposure to dioxin with increasing numbers of carcasses.

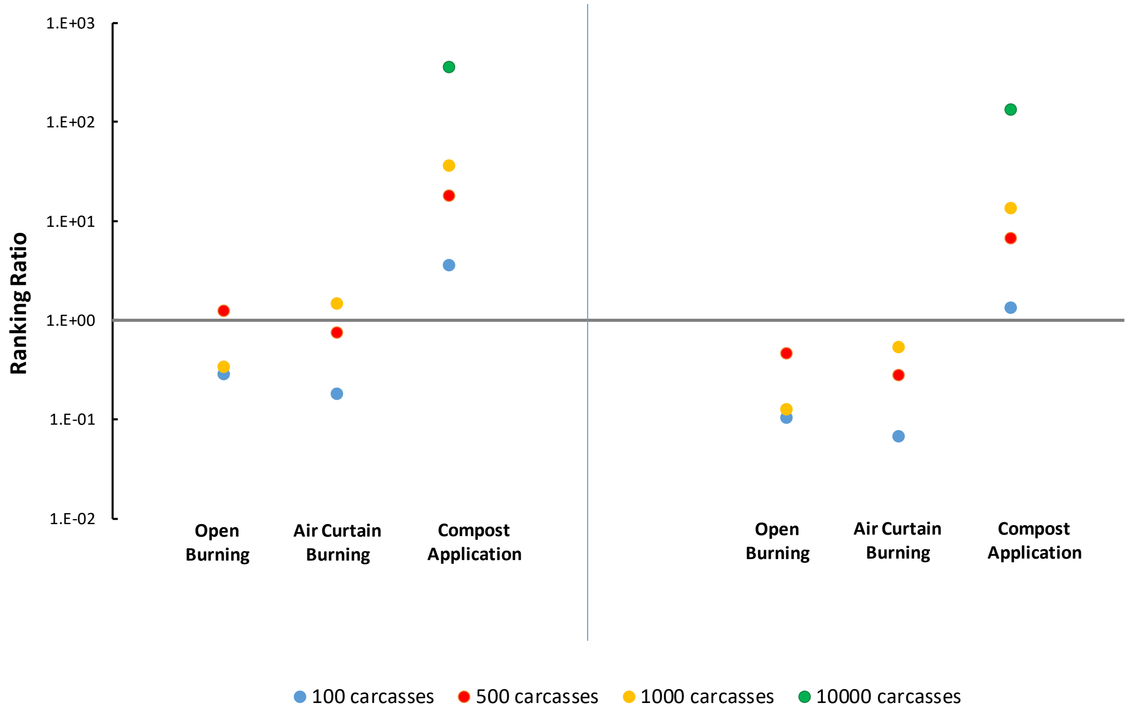

Figure 4-3. Ingestion exposure to dioxin with increasing numbers of carcasses.

For open burning, inhalation and ingestion exposure at a distance of 100 m is estimated to be greater with 500 carcasses than with 1,000 carcasses. Two factors contribute to this finding. First, as described above the size and configurations of the combustion sources change as more carcasses are managed. Because the 100 m distance is measured from the center of the management units, the distance from the nearest edge is not necessarily the same with different configurations. These differences affect the concentration unequally, particularly at distances close to the sources. In addition, with more carcasses, the air-curtain burning duration increases from two to five days, while open burning remains 48 hours.

A second factor that affects dioxin concentrations and exposures is the emission profile, which includes the relative proportions of the 17 individually modeled congeners, the proportions of the emission in vapor and particular phases, and the size distribution of particles. From available literature, the assessment uses separate congener profiles for dioxins from carcass contamination and formed as combustion products of the woody fuels. In addition, the transport of each congener is affected by chemical-specific properties (e.g., Henry's law constants). Differences between the emissions profiles, along with differences in emission rates and the sizes and shapes of the sources affect the air concentration and depositional patterns.

For mercury, emissions are modeled separately for vapor and particulate divalent mercury and vapor phase elemental mercury. All of the mercury comes from coal used to fuel the pyre. Consequently, all the pyre emissions have the same mercury profile and total mercury inhalation and ingestion exposures are approximately proportional to the scale of mortality.

Burial and Composting

The burial and composting options are evaluated for the management of 100 (base case), 500, 1,000, and 10,000 carcasses. In the event of a chemical emergency with diazinon contamination, only the burial and composting options would pose potential exposures; diazinon would be eliminated by the combustion-based options. In an emergency with dioxin contamination exposures might occur from compost application, as well as the combustion options, but exposures are unlikely from the burial option and leaching from the compost windrow due to low mobility in the relevant pathways.

In this assessment, the only exposure pathway evaluated for the burial option is the ingestion of drinking water from an on-site well contaminated by leachate from the burial trench. A number of site-specific factors might eliminate this pathway at actual sites. For example, the well, if present, might be located away from the direction of groundwater flow or draw from a deeper aquifer. This assessment assumes that a drinking water well intersects contaminated groundwater 100 m from the source as discussed in Section 3.2.3. Exposures estimates for this scenario are included in Table 4-10 and Figure 4-1.

Drinking water exposure to diazinon increases with the number of carcasses. However, the increase in exposure is not in proportion to the number of carcasses managed. For example, with 10,000 carcasses the exposure is 69 times greater than with 100 carcasses (an increase in carcasses of 100 times). This pattern is attributable to the DAFs used in the assessment, which are based on EPACMTP modeling and the areal extent of the burial trench. In the EPACMTP modeling, increasing the source area increases the infiltration rate, which lowers the DAF, but also increases the mixing zone depth, which increases the DAF (USEPA 1996). The Monte Carlo modeling that produced the DAFs determined the balance of these relationships.

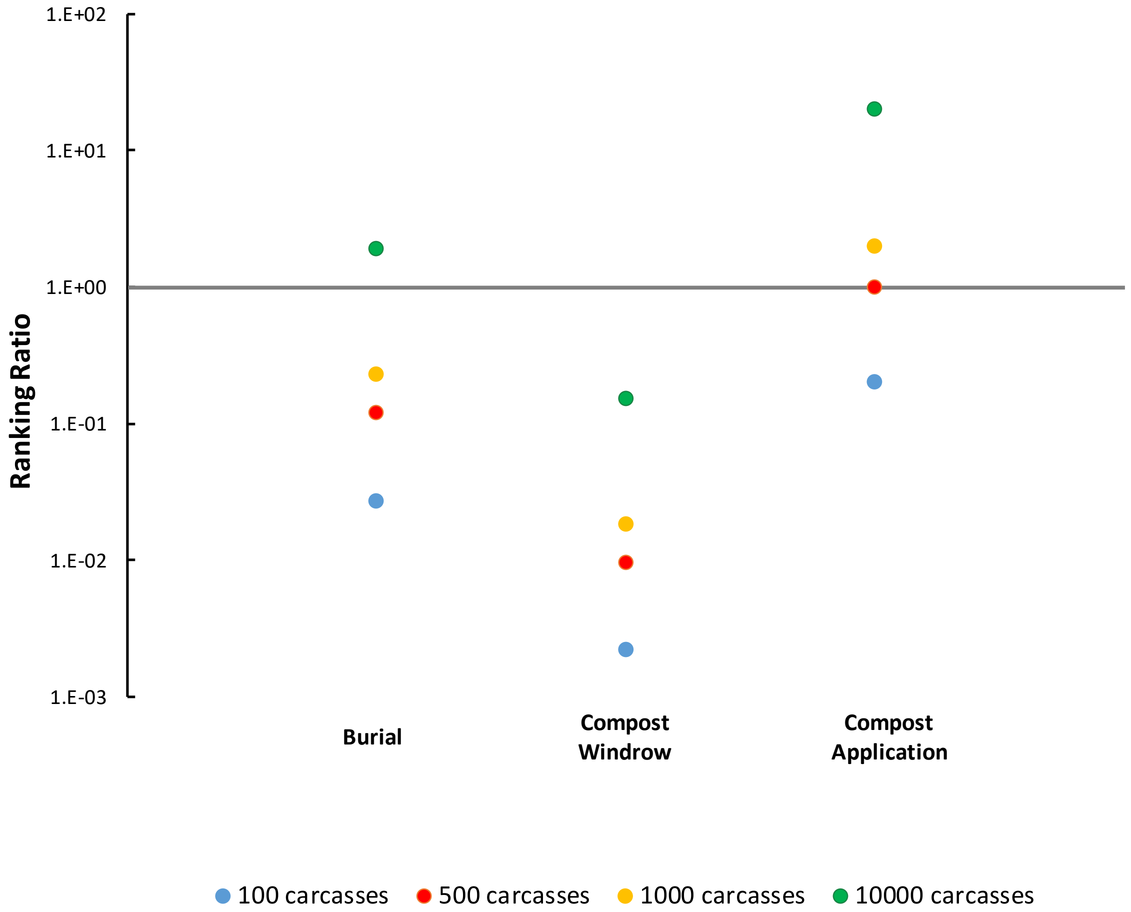

Figure 4-4. Ingestion exposure to diazinon with increasing numbers of carcasses.

As previously discussed, exposures are estimated separately for the compost windrow and compost application portions of the composting option. Exposure estimation for the composting windrow is the same as for the burial option, except the amount of leachate is less (i.e., 5%) for the compost windrow. Also, the windrows and burial trenches have different DAFs, because their areas are different for the same number of carcasses. Although the DAFs are different from burial, the relationship between the DAF and number of carcasses is the same. Based on these differences, drinking water exposures to diazinon from the compost windrow are less (about 8%) than exposures from the burial trench. This indicates that when comparing groundwater exposure from the two sources, the most significant factor is the assumed adsorption of carcass leachate by the bulking material.

For compost application, estimated exposure pathways include ingestion of home-grown food, ingestion of fish caught in the onsite lake, and incidentally ingested soil. Including these pathways in the assessment can be considered conservative. In the event of a chemical emergency, the finished compost might be managed as a residual product of the emergency response, and either buried or managed off site, and farm residents might avoid eating agricultural products grown on site and fish caught from the lake.

Given the scenarios assumed for this assessment, incidental soil ingestion accounts for about 1% of the exposure, of either dioxins or diazinon, resulting from compost application. With diazinon contamination, more than 98% of the exposure from compost application comes from home-grown vegetables, fruits, and livestock products, with less than 2% coming from fish ingestion. Fish ingestion is larger source of exposure in a dioxin contamination emergency. In particular, the dioxin contributions from the ingestion of fish and home-grown foods are 31% and 68%, respectively for adults and 7% and 92%, respectively, for young children. As discussed in Section 3.1.4, this assessment assumes that 50% of the contaminated soil eroded from the compost application is captured by a buffer area before it reaches the lake. Without this assumption, the contributions of fish ingestion to total exposure is 47% and 13% for adults and children, respectively.

4.2.3 Contamination Level

As discussed in Section 2.2, the base case level of dioxin contamination in cattle (0.024 g/carcass) is based on a past contamination event, and the base case level of diazinon contamination (5 g/carcass) is based on toxicity data. In actual chemical emergencies involving these chemicals, the average amount of contamination in the carcasses could be higher or lower than the base case. For this reason, this assessment may under- or over-estimate exposures in those actual emergencies. As noted elsewhere, the purpose of this assessment is not to estimate absolute levels of exposure or risk that would occur in an actual emergency. It is to compare the management options relative to each other in terms of exposure levels and exposure pathways.

For a simple exposure scenario, one would expect exposure to change in direct proportion to the level of contamination. To test this hypothesis, the levels of dioxin and diazinon contamination are varied from the base case by powers of ten. Specifically, dioxin and diazinon are both evaluated for 1/10th to 10 times the base case level. Diazinon is also evaluated at 100 times the base case level.

Table 4-11 shows how dioxin and mercury exposures from open burning and air-curtain burning change with increasing levels of dioxin contamination in the cattle. Mercury exposure with open burning is unaffected, which is expected because the amount of coal burned is not affected by the dioxin contamination level. The slight increase in mercury exposure at the highest dioxin contamination level is attributable to differences in the hourly meteorological data that can occur between modeling runs.

Dioxin inhalation exposures are similar with the two combustion-based options, and concentrations in air are below the non-cancer reference concentration with all levels of dioxin contamination evaluated. With open burning, dioxin inhalation exposure increases in direct proportion (i.e., by factors of 10) to the initial level of contamination as shown in Figure 4-5. With air-curtain burning, however, the dioxin exposures increase approximately 5 times when the carcass contamination increases 10 times from 0.0024 g/carcass to 0.024 g/carcass. The likely cause for this is that at the lowest contamination level, wood burning, which does not increase, accounts for a larger share of the total dioxins emitted. At the two higher contamination levels, the dioxin exposure increases by a factor of 10. This pattern is not seen with open burning because the amount of woody fuel per carcass is about one-fourth of that used for air-curtain burning.

Ingestion exposure with increasing dioxin contamination is shown in Table 4-12 and Figure 4-6. Overall, dioxin exposures are highest with compost application followed by similar levels of exposure with open burning and air-curtain burning. Exposures increase in direct proportion to contamination levels with open burning and compost application, and slightly less than proportionally with air curtain burning due to the larger contribution of dioxins from wood burning with this option and assumed fuel ratio.

Table 4-11. Inhalation Exposure with Varied Levels of Dioxin Contamination

Initial Body Burden (g TEQ /carcass)	Event Average Air Concentration (µg/m3)^a		Ranking Ratios Concentration/RfC	
	Total Dioxins	Total Mercury	Total Dioxins	Total Mercury
Open Burning				
0.0024	1.8E-07	6.6E-05	4.4E-03	1.1E-04
0.024	1.8E-06	6.8E-05	4.4E-02	1.1E-04
0.24	1.8E-05	8.4E-05	4.4E-01	1.4E-04
Air-curtain Burning				
0.0024	1.8E-07	np	4.5E-03	np
0.024	9.6E-07	np	2.4E-02	np
0.24	8.7E-06	np	2.2E-01	np

Abbreviations and acronyms: TEQ = toxicity equivalency factor; RfC = reference concentration; µg = microgram; m^3 = cubic meter; np = not present.
a Concentration estimates at 100 m from source.

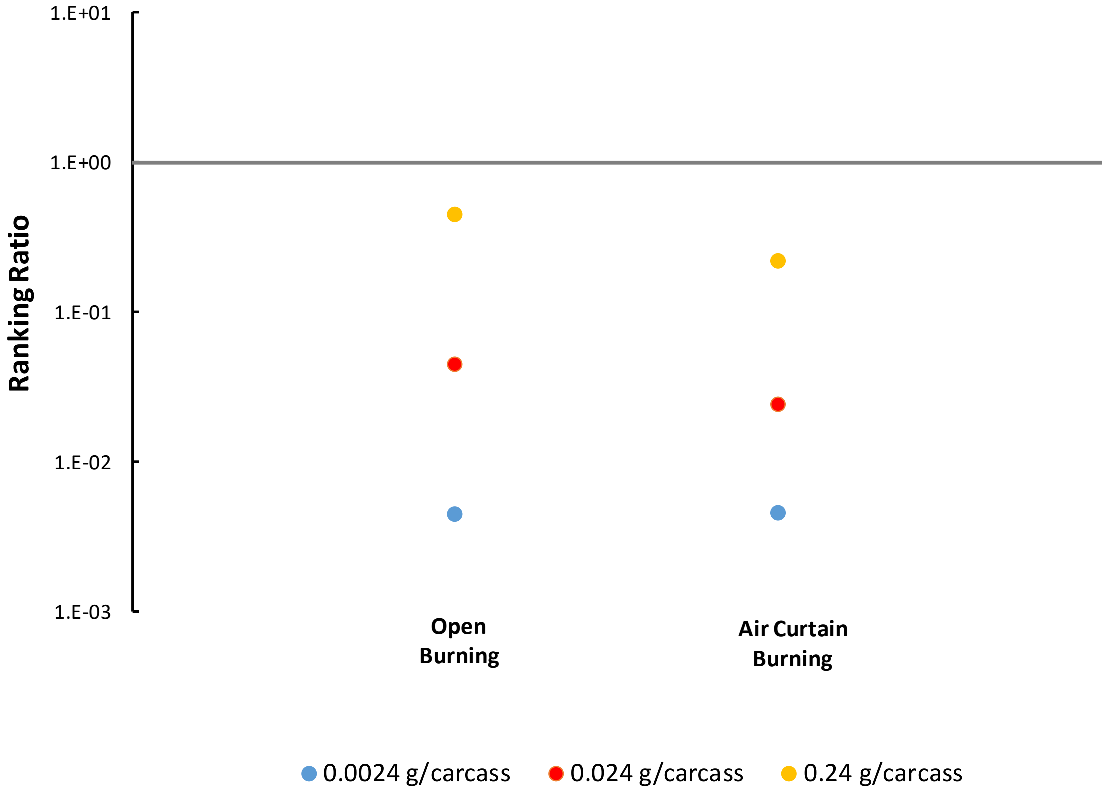

Figure 4-5. Inhalation exposure to dioxin with varied levels of contamination.

Table 4-12. Ingestion Exposure to Dioxin with Varied Levels of Dioxin Contamination

Initial Body Burden (g [TEQ] /carcass)	Ingestion Ranking Ratios	
	ADD/RfD	LADD/RSD
Open Burning		
0.0024	2.9E-02	1.1E-02
0.024	2.8E-01	1.0E-01
0.24	2.8E+00	1.0E+00
Air-curtain Burning		
0.0024	2.5E-02	9.3E-03
0.024	1.8E-01	6.7E-02
0.24	1.8E+00	6.5E-01
Burial		
0.0024	na	na
0.024	na	na
0.24	na	na
Compost Windrow		
0.0024	na	na
0.024	na	na
0.24	na	na
Compost Application		
0.0024	3.6E-01	1.3E-01
0.024	3.6E+00	1.3E+00
0.24	3.6E+01	1.3E+01

Abbreviations and acronyms: na = not assessed; TEQ = toxicity equivalency factor; ADD = average daily dose; LADD = lifetime average daily dose; RfD = reference dose; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily.

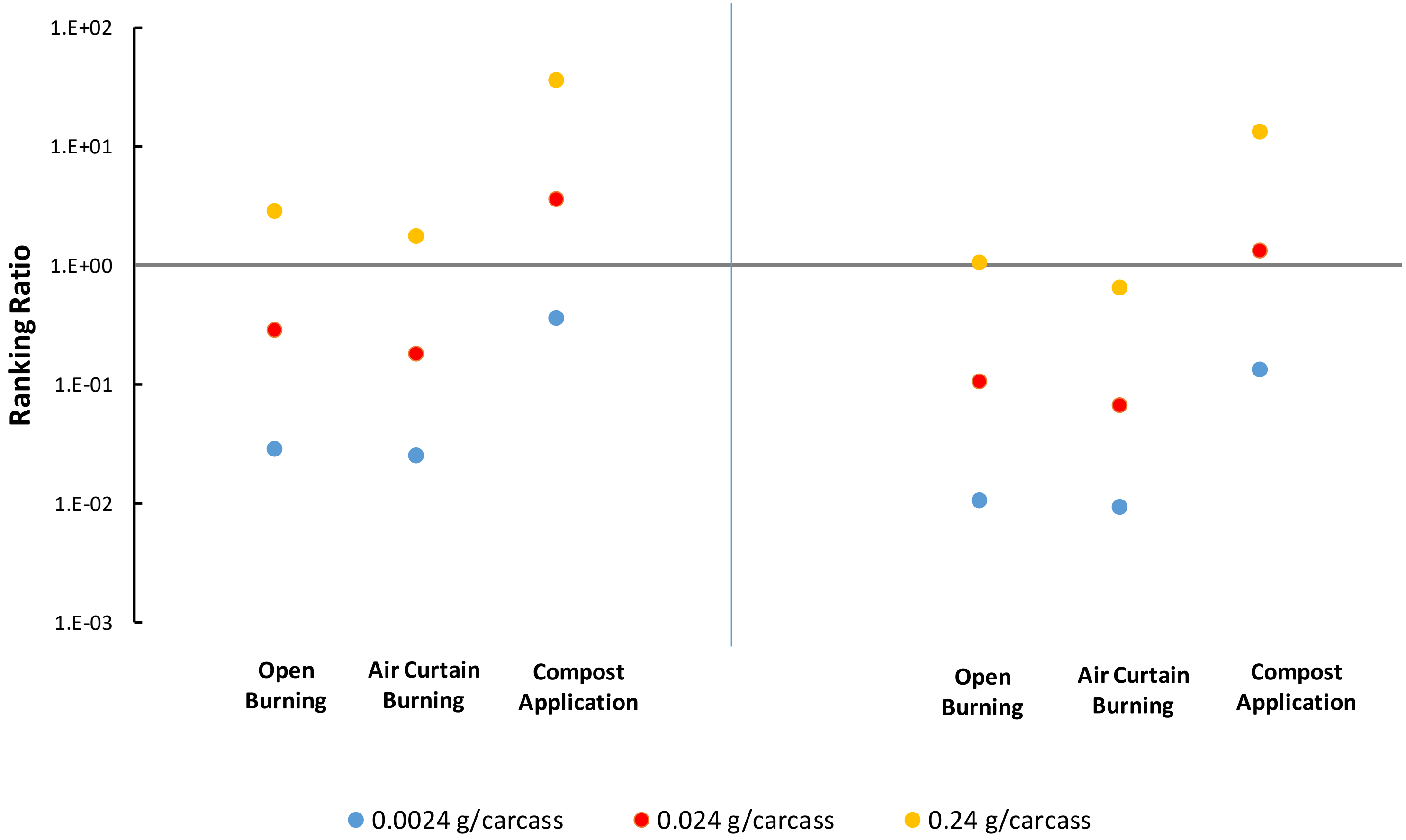

Figure 4-6. Ingestion exposure to dioxin with varied levels of contamination.

Table 4-13. Ingestion Exposure with Varied Levels of Diazinon Contamination

Initial Body Burden (g/carcass)	Estimated Ingestion Average Daily Dose (mg/kg-d), Adult	Estimated Ingestion Average Daily Dose (mg/kg-d), Child (1-2)	Ranking Ratios	
			ADD/RfD	LADD/RSD
Burial				
0.5	3.1E-06	5.4E-06	2.7E-03	nb
5	3.1E-05	5.4E-05	2.7E-02	nb
50	3.1E-04	5.4E-04	2.7E-01	nb
500	3.1E-03	5.4E-03	2.7E+00	nb
Compost Windrow				
0.5	4.4E-07	7.6E-07	3.8E-04	nb
5	4.4E-06	7.6E-06	3.8E-03	nb
50	4.4E-05	7.6E-05	3.8E-02	nb
500	4.4E-04	7.6E-04	3.8E-01	nb
Compost Application				
0.5	1.2E-05	4.0E-05	2.0E-02	nb
5	1.2E-04	4.0E-04	2.0E-01	nb
50	1.2E-03	4.0E-03	2.0E+00	nb
500	1.2E-02	4.0E-02	2.0E+01	nb

Abbreviations and acronyms: g = gram; mg = milligram; kg = kilogram; d = day; nb = no benchmark; TEQ = toxicity equivalency factor; ADD = average daily dose; LADD = lifetime average daily dose; RfD = reference dose; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily.

Exposures with increasing levels of diazinon contamination are presented in Table 4-13 and Figure 4-7. These results include ingestion exposure only, and only non-cancer health effects. Carcass contamination is the only source of diazinon in the assessment, and the estimated exposures increase in direct proportion to contamination level. This contrasts with the dioxin results discussed above, which were affected by dioxins formed by fuel combustion as well as contamination in the carcasses.

Diazinon exposures occur only with the burial and composting options; diazinon is destroyed by the combustion options. As shown in Figure 4-7, compost application has the greatest potential for diazinon exposure followed by burial and leaching from the compost windrow. However, all of the exposures for diazinon are overestimated because biological and chemical decay is not addressed.

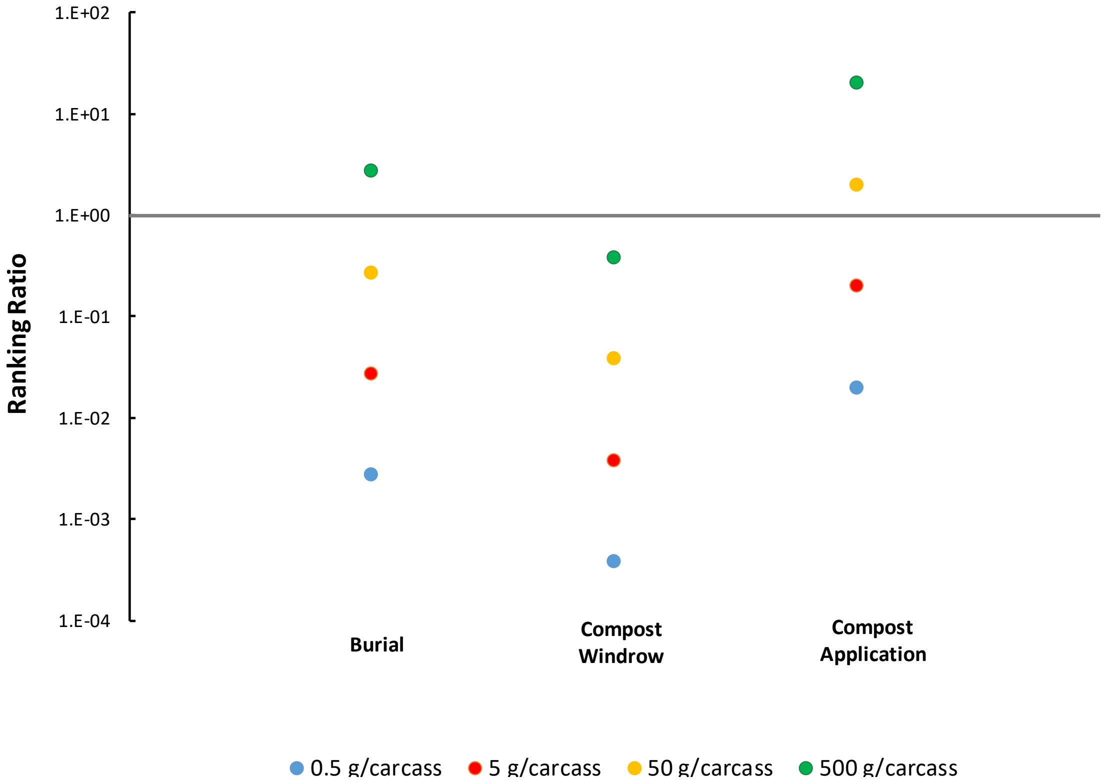

Figure 4-7. Ingestion exposure to diazinon with varied levels of contamination.

4.2.4 Distance from Source

The exposure estimates of this assessment depend on scenario assumptions about where the exposed individuals are in relation to the carcass management sources. Estimates of inhalation exposure from open burning and air-curtain burning are calculated for persons located at distance intervals from 100 m to 10 km from the source. Drinking water exposures are calculated assuming water is obtained from a well located 100 m away from the source (e.g., burial trench) in the direction of groundwater flow, and location assumptions also affect exposure estimates for ingestion of homegrown foods and fish from the onsite lake. Each of these is discussed below.

With contaminant concentrations in air and air deposition to soil calculated at regular distance intervals, the assessment provides information about how exposure and distance are related. Dioxin concentrations in air drop off rapidly within the first half kilometer from the source and begin to level off at 1 km with 1-hour averaging (Figure 3-6) and at 2 km when averaged over the 48-hour combustion duration (Figure 3-5). Total mercury concentrations also decline rapidly with a leveling off at 1 km. These patterns cannot be assumed to apply at actual open burning or air-curtain burning sites, because the actual distribution of airborne chemicals is affected by site-specific meteorology, terrain, and other factors. In addition, air concentrations and deposition rates are affected by chemical-specific properties. In the event of an actual chemical emergency where carcasses are managed with on-site combustion, exposures can be minimized or avoided by siting the combustion unit(s) where there are few if any downwind contaminants. Siting is likely to be circumscribed by state and local requirements.

The base case assessment assumes that diazinon leached from the burial pit and compost windrow reaches a drinking water well 100 m away. This is a conservative scenario that is unlikely to exist at an actual chemical emergency site where contaminated carcasses are managed. Several conditions must be met for a drinking water well to be contaminated. For example, the drinking water well must draw from the same shallow aquifer affected by leachate, and the well must be in the direction of groundwater flow. A complete drinking water pathway also requires that any chemicals of concern are mobile in soil and groundwater and that they are not subject to rapid degradation. The movement of contaminants through soil and groundwater can be very slow, particularly over large distances, and dilution and degradation processes can reduce chemical concentrations before contamination reaches the well. In the event of an actual chemical emergency, site managers can first determine whether a complete drinking water pathway exists based on these conditions.

Fish are contaminated in this assessment by deposition of airborne chemicals to the lake and its watershed, or by erosion of soil from a compost application site near the lake. For air deposition, the lake is assumed to be downwind from the source and within one kilometer. The potential for fish ingestion exposure at an actual carcass management site is likely to be lower than estimated for this assessment if the lake is either not downwind or is not nearby (e.g., within a kilometer), or if fish are not consumed or are consumed infrequently. In addition, fish ingestion exposure will be lower with chemicals that are not as strongly bioaccumulative as dioxins/furans.

Soil erosion from a compost application site to surface water can be reduced with erosion control practices or by applying compost away from the lake. Erosion to the lake will be reduced if there is an uncontaminated “buffer” between the application site and the lake. For this assessment there is no assumed distance; however, it is assumed that 50% of the contaminated soil eroded from the compost application site reaches the lake.

4.2.5 Air-curtain Burning Fuel Ratio

Emissions from air-curtain burning for the base case are calculated with a 4-to-1 ratio of wood fuel to carcasses by weight. In practice, the fuel ratio may vary depending on factors such as the quality and moisture of woody fuels used (Peer et al. 2006) and the rate at which fuel and carcasses are place in the burner. Various fuel ratios have been reported in the literature, and the base-case assumption is at the upper end of the range. Lower ratios around 2-to-1 have been cited by multiple authors (e.g., NABCC 2004; SKM 2005). To evaluate the effect of the fuel ratio assumption on exposure, the air-curtain burning base case was run with the fuel ratio is reduced to 2:1. In addition, the reduced fuel ratio was run with increased numbers of carcasses, as in Section 4.2.2, and varied levels of dioxin contamination, as in Section 4.2.3.

Table 4-14 compares dioxin exposures from air-curtain burning with 4:1 and 2:1 fuel ratios and varied levels of dioxin contamination. Overall, halving the amount of wood fuel reduces dioxin exposures by less than half. This is expected because the amount of dioxin from the carcasses is the same with both fuel ratios. As seen in the ingestion results, the difference between the exposures with the two fuel ratios is greatest with the lowest level of carcass contamination. As the contamination level increases, the carcass contamination contributes a larger share of total dioxins emissions and the effect of the fuel ratio is less significant. Inhalation exposures are lower when there is less wood burned. However, the inhalation exposure differs in a more than ingestion exposure with varied contamination levels. This might be because ingestion exposure occurs over a longer period of time (i.e., beyond 40 hours) than inhalation. In addition, factors such as temperature, air mixing, and vapor and particle phase differences might have a greater dynamic effect on air concentrations than on deposition during the 48 hour burn.

When the number of carcasses increases (Table 4-15), the amount of wood fuel increases in proportion, and rate of increase in exposure should be about the same with either fuel ratio. This is seen in the ingestion exposure estimates in Table 4-15, where there is little or no difference between the fuel ratio results. In all cases, the results in this table include the base case level of dioxin contamination (i.e., 0.024 g[TEQ]//carcass), which, as shown in figure 4.2.6, appears to be large enough to overshadow the dioxin contribution from wood burning.

Table 4-14. Exposures from Air-curtain Burning with Varied Fuel Ratios and Dioxin Contamination

Initial Dioxin Body Burden (g[TEQ]/carcass)	Ranking Ratios		
	Dioxin Inhalation	Dioxin Ingestion	
	Air Concentration/RfC	ADD/RfD	LADD/RSD
Air-curtain Burning 4:1 Fuel Ratio			
0.0024	4.4E-03	2.5E-02	9.3E-03
0.024	4.4E-02	1.8E-01	6.7E-02
0.24	4.4E-01	1.8E+00	6.5E-01
Air-curtain Burning 2:1 Fuel Ratio			
0.0024	3.3E-03	2.1E-02	7.8E-03
0.024	2.3E-02	1.8E-01	6.7E-02
0.24	2.2E-01	1.8E+00	6.5E-01

Abbreviations and acronyms: TEQ = toxicity equivalency factor; ADD = average daily dose; LADD = lifetime average daily dose; RfC = reference concentration; RfD = reference dose; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily.

Table 4-15. Exposures from Air-curtain Burning with Varied Fuel Ratios and Numbers of Carcasses

Number of Carcasses	Ranking Ratios		
	Dioxin Inhalation	Dioxin Ingestion	
	Air Concentration/RfC	ADD/RfD	LADD/RSD
Air-curtain Burning 4:1 Fuel Ratio			
100	4.4E-02	1.8E-01	6.7E-02
500	2.0E-01	7.5E-01	2. 8E-01
1000	9.3E-02	1.5E+00	5.4E-01
Air-curtain Burning 2:1 Fuel Ratio			
100	2.3E-02	1.8E-01	6.7E-02
500	4.7E-02	7.0E-01	2.6E-01
1000	9.3E-02	1.5E+00	5.4E-01

Abbreviations and acronyms: TEQ = toxicity equivalency factor; ADD = average daily dose; LADD = lifetime average daily dose; RfC = reference concentration; RfD = reference dose; RSD = risk-specific dose for carcinogenic chemicals for a target risk of 1E-04 assuming ingestion of contaminated media occurs over a lifetime of daily.

[a] All carcasses modeled with base case contamination level of 0.024 g TEQ dioxin per carcass.

4.2.6 Chemical Degradation

As discussed in Section 3.1.4, diazinon exposures are overestimated in this assessment because biotic and abiotic chemical degradation processes are not included. The amount of degradation can vary widely depending on the length of time, temperature, pH, oxygen availability, and soil type of other medium. Based on information presented in Section 3.1.4, Table 4-16 provides estimated percentage of the initial diazinon remaining in finished compost after various time periods and at three compost pH values.

The estimates in Table 4-16 are specific to diazinon. However, Equation 4.1 can be used to estimate chemical degradation during composting for any chemical when a degradation half-life value is available.

Table 4-16. Percentage of Diazinon Remaining in Finished Compost by Time and Compost pH

Composting Duration (months)	pH of Finished Compost and Diazinon Half-life		
	pH = 4 Half-life = 66 days	pH = 7 Half-life = 209 days	pH = 10 Half-life = 153 days
4	28%	67%	58%
5	20%	60%	50%
6	15%	55%	44%
7	11%	49%	38%
8	8%	45%	33%
9	6%	40%	29%
10	4%	36%	25%
11	3%	33%	22%
12	2%	30%	19%

Abbreviations and Acronyms: pH = measure of hydrogen ion activity.

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{\frac{1}{2}}}} \qquad \textbf{(Eqn. 4.1)}$$

Where:

$N(t)$ = The amount of chemical remaining at time t

N_0 = The initial amount of chemical before degradation

$t_{½}$ = The half-life of degradation

The percentage remaining, then, is

$$Percentage\ Remaining = \frac{N_t}{N_0} \qquad \textbf{(Eqn. 4.2)}$$

Degradation rates estimated with this method will be approximate, because actual degradation may be affected by site-specific parameters including the temperature, pH, moisture, and levels of oxygen and nutrients in the windrow.

4.3 Uncertainty Summary

In addition to the parameters varied in Section 4.2, this exposure assessment includes uncertainties and assumptions about the emergency scenario, response activities, and environmental conditions that might differ from those of an actual chemical emergency. This section identifies a number of those factors and discusses how the exposure assessment might over- or underestimate exposures in the event of an actual chemical emergency.

Tables 4-17 through 4-19 on the following pages summarize three types of “uncertainties” in the exposure assessment:

- Parameters with Moderate to High Natural Variation
- Uncertain Parameter Values
- Simplifying Assumptions

Table 4-17 describes parameters for which substantial variation exists across the United States, and the base case assessment uses value selected either to be nationally representative, to be health protective (i.e., overestimate exposure), or for another reason. The table lists the expected magnitude (low, medium, high) and direction (under- or overestimate) of bias in the exposure estimates for each one.

Table 4-18 describes parameters for which limited data were available to calculate a central tendency value or to estimate likely variation across conditions possible in the country. Uncertainty is characterized as low, medium, or high. By definition, the direction of bias is unknown.

Finally, Table 4-19 includes several “simplifying assumptions” that are required to compare management options relative to each other within a reasonable level of effort. As for Table 4-17, the expected magnitude (low, medium, or high) and direction (under- or overestimate) of bias introduced by the assumption is summarized.

Table 4-17. Moderate to High Natural Variation in Parameter—Potential Bias from Selected Values

Key Topic	Selected Parameter Value	Bias	Rationale
Chemical Emergency Scenario			
Scale of Mortality	▪ The assessment assumes a “base case” mortality of 100 cattle at one farm with a total weight of 50 short tons. ▪ Larger scale losses of 500, 1,000, and 10,000 are also evaluated.	Possibly High Underestimate	▪ The base case scale of mortality could be “small” relative to mass mortality or euthanasia (e.g., in the event of wide-spread fee contamination). Mortalities in the hundreds to tens of thousands of cattle are possible. ▪ Larger scale losses could make some management options technically infeasible. For example, the assessment discusses why open burning air-curtain burning are likely to be infeasible for 10,000 carcasses. ▪ Large-scale mortalities could limit availability of or access to resources and equipment required for onsite carcass management options. Capacity of off-site management facilities could be overwhelmed with large-scale mortalities. ▪ Large scale mortality might require periods of temporary carcass storage due to capacity or resource limitations, which increases the potential for exposures.
Site Setting and Environmental Conditions			
Surface Water	▪ The hypothetical farm layout includes a 100-acre lake that might be large enough to support recreational or subsistence fishing.	Variable Overestimate	▪ This aspect of the site design is likely to overestimate exposure. Exposure might be overestimated for sites without a fishable pond or lake. ▪ Fish consumption might be prohibited or voluntarily avoided when the lake is near a chemical emergency.

Key Topic	Selected Parameter Value	Bias	Rationale
Groundwater	▪ The assessment assumes that contaminants leached from the burial trench, compost windrow, and buried combustion residuals can reach groundwater. ▪ The groundwater is assumed to supply domestic water well 100 m downgradient from the source of leachate. ▪ The assessment uses DAFs developed USEPA using a Monte Carlo analysis of nationwide database of aquifer and well data.	Variable Overestimate	▪ In the event of a chemical emergency, it is unlikely that carcass management would be sited 100 m from a domestic water well. ▪ Although the domestic well exposure pathway is possible, the domestic well would have to be shallow enough to directly intersect leachate from surface sources. In addition, well contamination would require the well to be located down gradient (in the direction of groundwater flow) from the source.
Meteorological Conditions	▪ The assessment uses 1 year of meteorological data from a weather station in Iowa, chosen to represent a moderate climate in the U.S. agricultural heartland. The data are used to model fate and transport of releases to air. Precipitation data are used to estimate leaching from combustion ash to groundwater.	Moderate Over- or Underestimate	▪ The meteorological data used for this assessment could over- or underestimate relevant conditions in other areas of the country (e.g., having stronger or weaker winds, winds predominantly in one direction compared with other patterns, higher or lower temperatures, more or less precipitation).
Soil Type and Properties	▪ This assessment uses recommended default soil properties from HHRAP (USEPA 2005a), which were chosen to reflect national average conditions. ▪ Concentrations of chemicals in soil following air deposition and compost application are calculated with mixing depth assumptions from HHRAP (USEPA 2005a).	Moderate Over- or Underestimate	▪ Although the HHRAP soil assumptions were chosen to represent national average conditions, sites with different soils could have higher or lower rates of exposure.

Key Topic	Selected Parameter Value	Bias	Rationale
Exposure Receptors and Estimation			
Human Receptors	▪ Exposures are assessed for three types of farm residents: infants who consume drinking water in their formula, young children (age 1-2 years old), and adults.	Moderate Overestimate*	▪ In the event of a chemical emergency that causes contamination throughout the site, residents might be prohibited from or voluntarily avoid living on-site. ▪ Although exposures might be over or underrepresented for receptors or receptor populations included in the assessment, the approach includes a range of age categories and is based on USEPA exposure assumptions.
Exposure Factors	▪ Exposure factors (e.g., ingestion rates, body weights) are mean values from USEPA's Exposure Factors Handbook and related guidance.	Neutral	▪ Means are used so that exposure is not over or underestimated by this aspect of the approach.

* The moderate overestimate assertion is less plausible if one considers the breastfeeding route of exposure for infants, which was not addressed in this study. Modeling based on exposures associated with environmental background levels of dioxin found that the breast-feeding for 6 months or more is predicted to result in an accumulated [dioxin] exposure 6 times higher than a formula-fed infant during the infant's first year of life.

Table 4-18. Uncertainty in Parameter Value(s) Selected

Parameter	Description	Uncertainty	Rationale for Uncertainty Category
Chemical Emergency Scenario			
Chemicals Included	▪ Chemical contaminants included in the assessment were identified from relevant published sources, including reports of past chemical emergencies with livestock contamination. ▪ Although the assessment includes dioxins formed by fuel combustion and mercury naturally present in the coal, it does not include other chemicals naturally present in the carcasses, fuels, or their combustion products.	Moderate	▪ The assessment includes just two of many thousands of chemicals that could contaminate livestock in a chemical emergency. ▪ However, the chemical contaminants, dioxins/furans and diazinon, were selected to represent categories of chemicals with distinct environmental fate characteristics. ▪ Exposure to chemicals released by combustion of uncontaminated carcasses and fuels is evaluated (USEPA 2017).
Carcass Management Options			
Combustion Fuels	▪ The assessment assumes one estimate of the quantity of coal, diesel, timbers, and other woody materials for the 100 carcasses. ▪ Air-curtain burning is fueled by wood at a 4:1 ratio with carcasses by weight. Air-curtain burning with a 2:1 fuel ratio is assessed as well. ▪ The types and amounts of fuels affect the composition and amounts of emissions to air and combustion residuals.	Moderate	▪ Combustion fuel assumptions could contribute to over or underestimation of exposure. ▪ Open burning fuel types and amounts are based on USDA guidance. ▪ Air-curtain burning is evaluated with two fuel ratios identified from literature and expert opinion.
Ash Disposal	▪ The assessment assumes that combustion ash is managed on site, buried in place using in the assumed length and width of the combustion units.	High	▪ After a chemical emergency, combustion ash might require off-site disposal as a solid or hazardous waste. Exposures are overestimated if combustion ash is not disposed of on site as assumed. ▪ Concentrations of chemicals leached from ash may be over- or underestimated depending on the area of ash disposal (i.e., amount of ash per unit of area).
Releases and Release Rates			

Parameter	Description	Uncertainty	Rationale for Uncertainty Category
Releases Estimates	▪ Each exposure pathway in the assessment begins with a release of chemicals from a carcass management unit. These include emissions to air from combustion, liquid releases from burial and composting, and leaching from combustion ash. Data to characterize the composition, quantity, and rate of these releases are very limited.	High	▪ Although release estimates were based on the best available information, releases might be over or underestimated. In addition, actual releases can vary significantly due to many factors (e.g., unit design, environmental conditions).

Parameter	Description	Uncertainty	Rationale for Uncertainty Category
Fate and Transport Modeling			
Models	▪ The assessment uses various screening-level models and calculations to estimate chemical fate and transport through air, water, soil, and terrestrial and aquatic food chains.	High	▪ The uncertainties associated with fate and transport modeling data and methods can individually contribute to under-or over-estimation of exposures. In general, the assessment uses more conservative assumptions and approaches, which would most likely result in over-estimates of possible exposures. ▪ Because the approach uses pre-existing models that were developed for different purposes, they are likely to differ in their level of sophistication and uncertainty. This could cause the level of uncertainty to differ among media pathways and, consequently, management option.
Chemical Properties and Other Inputs	▪ Fate and transport modeling uses various chemical properties (e.g., Henry's Law constants, partitioning and biotransfer factors) and assumed numerical inputs (e.g., soil properties, food web composition).	Moderate	▪ Uncertainty associated with modeling inputs may contribute to over- or underestimation of exposure. This uncertainty is lowest for experimentally derived chemical properties and greater for more variable inputs. Many modeling inputs are from USEPA's HHRAP, which generally uses central-tendency values.
Diazinon Degradation	▪ Diazinon is degraded by abiotic and biotic processes (e.g., hydrolysis, biodegradation) at rates that vary widely depending on environmental factors such as pH, temperature, oxygen availability, and soil type. ▪ Some degradation products (e.g., diazoxon - a toxic degradate of diazinon) are also toxic (ATSDR 2008). ▪ Degradation is not included in the environmental fate modeling, but is discussed quantitatively in Section 4.2.	Moderate	▪ Diazinon exposure is moderately overestimate because degradation processes are not included in environmental fate modeling. The degree of overestimation varies depending on the exposure pathway and exposure scenario.

Table 4-19. Simplifying Assumptions—Effects on Exposure Estimates

Key Topic	Simplifying Assumption	Effect	Rationale for Effect
Chemical Emergency Scenario			
Type of Livestock Affected	▪ The assessment scenario includes management of cattle carcass. Livestock species differ somewhat in terms of body composition (e.g., percent fat vs. muscle; feathers vs. fur), which can affect combustion temperature and residual materials and affect rate of decomposition for other options.	Moderate Over- or Underestimate	▪ Although cattle are larger than most other livestock species, smaller animals (e.g., poultry) can die in large numbers resulting in a comparable mass of carcasses to manage. Body composition varies among species, but variability is limited by the general similarity in warm-blooded vertebrate bodies. ▪ Adult swine have higher fat content and burn more readily at higher temperatures with less fuel than cattle. ▪ Poultry feathers inhibit burning, requiring extra fuel.
Effect of the Chemical Emergency on Management Activities	▪ Some chemical emergency scenarios include personal injuries, property damage, or environmental contamination. This assessment assumes that the chemical emergency does not impede, preclude, or otherwise affect any of the carcass management options. In reality, a chemical emergency might hinder access to the site or work in the affected area.	Moderate Underestimate	▪ A disruptive chemical emergency (e.g., tank or facility explosion) might underestimate exposure if the effects of the emergency interfere with timely and effective carcass management. The impact of this uncertainty will be reduced if site managers comply with applicable regulations and follow standard carcass management practices.

Key Topic	Simplifying Assumption	Effect	Rationale for Effect
Site Setting and Environmental Conditions			
Site Layout	▪ A goal of this assessment is designed to assess exposure for reasonably anticipated exposure pathways from carcass management. Therefore, the conceptual models and site layout were intentionally designed to include all feasible complete exposure pathways. For example, the site is assumed to include a lake and its location is downwind and downgradient from carcass management locations.	Moderate Overestimate	▪ The assessment is likely to overestimate exposure because the layout assumes a worst-case exposure for each possible pathway, which is unlikely at most locations.
Carcass Management Options			
Off-site Carcass Management Options	▪ The assessment assumes that off-site carcass management facilities (i.e., commercial incinerators, landfills, and rendering plants) comply with applicable regulations and that those regulations are sufficiently protective of human health and the environment. ▪ The assessment assumes that controlled environmental releases (i.e., from off-site regulated facilities) generally provide better health and environmental protection than uncontrolled releases (i.e., on-site options).	Low Underestimate	▪ Potential exposures from off-site management options are underestimated where the facilities do not comply with applicable regulations. ▪ Exposures could be underestimated where emergency exemptions to the CAA, CWA, and RCRA are the applicable regulations. ▪ In some cases, permitted releases of some chemicals from off-site facilities might be greater than uncontrolled releases from on-site management options. If applicable regulations provide adequate protection for off-site options, then the on-site releases in these cases are likely to be below levels of concern as well.
Design of On-site Management Units	▪ Basic assumptions about the design of on-site management options (e.g., pyre structure and materials, burial pit dimensions, combustion fuel types and amounts) are based USDA guidance and other relevant sources and an assumed 50 short tons of carcasses. For larger mortalities, the spatial pattern and nature of environmental releases could be different.	Moderate Over- or Underestimates	▪ Assumptions about many aspects of carcass management units could lead to over- or underestimation of exposure.

Key Topic	Simplifying Assumption	Effect	Rationale for Effect
Carcass Handling Before Management	▪Workers who handle contaminated livestock carcasses are assumed to use recommended personal protective equipment.	Moderate Underestimate	▪Exposure to workers is underestimated if inadequate personal protective equipment is used.
Temporary Storage	▪In an actual emergency, circumstances might require temporary storage (e.g., piling) of carcasses until management options are readied. ▪This assessment does not include temporary carcass storage. ▪A 48-hour temporary carcass storage pile is included in the microbial exposure assessment for a foreign animal disease outbreak.	Moderate Under- or Overestimates	▪Exposures might be underestimated if carcass management is delayed, especially long enough for the carcasses begin to release liquid from decomposition. ▪However, if releases from the carcasses are collected and managed appropriately managed, releases from subsequent management (e.g., burial) is overestimated.
Carcass Transportation	▪Based on a semi-quantitative assessment (USEPA 2017), exposures associated with carcass transportation are assumed to be insignificant and are not included in this assessment.	Low Underestimate	▪If carcass transportation results in a significant exposure, the assessment underestimates overall exposure. ▪Transportation-related exposures could occur with any of the management options, but have a slightly greater likelihood with off-site management options.
Compost Application	▪The assessment assumes that finished compost is tilled into soil on site at an application rate based on an assumed nutrient content.	Low Over- or Underestimate	▪The concentrations of contaminants in soil may be over- or underestimated depending on the actual application rate (e.g., kg compost per acre) and tillage depth.
	▪The assessment assumes that finished compost is tilled into soil on-site and the compost application site is used to for home grown food production.	High Overestimate	▪Depending on the nature of the chemical emergency and the chemical(s) involved, use of the compost, or even unamended soil at the site, might be considered unsuitable for food production.
	▪Contaminants in the amended soil are assumed to runoff toward the on-site lake with 50% eventually reaching the lake.	Moderate Over- or Underestimate	▪It the compost contains residual contamination is unlikely that compost would be applied near to a lake without erosion and runoff controls. ▪The amount of runoff to the lake depends on site specific factors that may over- or underestimate exposure.

Key Topic	**Simplifying Assumption**	**Effect**	**Rationale for Effect**
Exposure Receptors and Estimation			
Homegrown Farm Products	▪ Farm residents are assumed to consume only home-grown fruits, vegetables, and livestock products.	Moderate Overestimate	▪ Exposure from home-grown foods is estimated using USEPA methods and assumptions; however, most farm residents also rely on store-bought foods.
Homegrown Livestock Products	▪ Chronic human exposures via homegrown livestock products are based on HHRAP methods and assumptions (i.e., transfer factors from soils to produce and livestock).	Low Underestimate	▪ This limitation would contribute to underestimation of exposure through ingestion of home-grown livestock products.
Fish Ingestion	▪ Farm residents are assumed to consume recreationally caught fish from the on-site lake.	Moderate Overestimate#	▪ Fish ingestion exposure is based on USEPA methods and assumptions. ▪ Exposure via fish ingestion would not occur at sites without a nearby fishable lake or where the residents do not eat available fish.

Abbreviations and acronyms: HHRAP = Human Health Risk Assessment Protocol (USEPA 2005).
Complete references are found at the end of the report.
Mercury exposure from fish ingestion was not considered – assessments need to be performed for site-specific conditions.

4.4 Summary of Findings

This assessment is meant to support selection of environmentally protective livestock carcass management methods in the event of a chemical emergency in which livestock are intentionally or unintentionally contaminated. Examples of intentional livestock contamination include criminal or terroristic acts such as chemical poisoning of food or water supplies, sabotage of agricultural production or commodity markets, or use of a chemical warfare agent. Examples of unintentional livestock contamination include industrial accidents, accidental contamination of feed or other agricultural supplies, and transportation-related accidents.

Based on documented past livestock contamination events, this assessment evaluates exposures for two chemicals with distinct environmental fate properties. Dioxins are chemically stable and not readily degraded (e.g., by sunlight or microbes). They persist for years in the environment and can travel long distance in air, but have very low mobility in soil and groundwater. Dioxins are hydrophobic and may bioaccumulate in in the fat of animals that consume contaminated prey, feed, or food. Diazinon is an organophosphate pesticide that does not strongly partition to any particular environmental medium, is moderately mobile in soil and groundwater, and is degraded by biotic and abiotic processes. These are just two of thousands of chemicals that could contaminate livestock in conceivable scenarios.

Exposures are assessed for these chemicals using generally conservative scenarios and assumptions that would overestimate exposures at most actual carcass management locations. For example, the assessment is designed to assess exposure for reasonably anticipated exposure pathways from carcass management. Therefore, the conceptual models and site layout were intentionally designed to include all feasible complete exposure pathways. **The purpose of the assessment is to compare the management options by their exposure potential relative to each other, not to estimate the level of exposure that can be expected in any real event.**

In Tier 1 of a two-tier assessment, the three off-site livestock carcass management options, collectively, are ranked above the on-site options. This is because off-site commercial facilities are assumed to be adequately controlled under applicable pollution control regulations. The on-site management options all include uncontrolled or minimally controlled chemical releases to air, soil, or water.

In Tier 2, the on-site options are ranked relative to each other based on estimated exposures to dioxins and diazinon. When exposures are compared among the management options, differences are evident due to the environmental fate properties of the two chemicals. Diazinon exposures are greater with burial and composting than the combustion-based options, which destroy the chemical. Dioxins is resistant to combustion, but has low mobility in soil and groundwater pathways from burial and composting. While diazinon is reduced by degradation processes during months in the compost windrow, dioxins persist and become more concentrated in the compost as carcass decomposition progresses. Because chemical-specific environmental fate characteristics greatly influence the relative potential for exposure from the carcass management options, there is no “best” option across all chemicals.

Several site-specific factors also affect which option will best protect human health and the environment in the event of an actual chemical emergency. Examples include proximity to residential areas and surface water bodies; availability of land area, resources, and equipment; and depth to groundwater and the presence of potentially affected wells.

Additional findings of the assessment are presented in the bullets below and in Table 4-20.

- The three off-site management options could be more protective than on-site options. The off-site treatment facilities expected to have applicable and appropriate pollution prevention technologies in place to comply with U.S. federal regulations. Thus, the off-site facilities and infrastructures might be capable to contain contaminants and environmentally more protective than a resource-limited on-site setting. The on-site management options all include uncontrolled or minimally controlled chemical releases to air, soil, or water.
- In general, options that destroy contaminants (e.g., combustion) are more effective than those that contain them. However, metals are not destroyed by combustion and some organic chemicals (e.g., dioxins, polycyclic aromatic hydrocarbons) are resistant to combustion or are formed as combustion products. Based on available information (USEPA 2017), this assessment assumes that the combustion temperatures of open burning, air-curtain, burning, and off-site incineration are 550°C, 850°C, and >1,000°C, respectively. Some chemicals may be degraded over time while in containment (e.g., burial, compost windrow).
- Comparing on-site options at a specific site will benefit from understanding all of the potential exposure pathways identified in the conceptual models provided in Section 3. Considering the site and contaminants of concern, determine which pathways are and are not relevant at the site.
- Chemical-specific environmental fate properties that should be considered in the event of an actual chemical emergency include partitioning and mobility in soil, surface water, and groundwater. Persistence, as indicated by degradation half-lives in relevant media, flammability at incineration temperatures, and bioaccumulation potential, also should be considered.
- Although chemical releases are minimal from properly constructed compost windrows, consideration should be given to the use of the finished compost. If carcasses are contaminated with persistent chemical pollutants, using the compost as a soil amendment might result in remobilization and exposure.
- Each of the on-site management options can be designed and implemented to avoid or reduce potential exposures (see Table 4-20).

This assessment cannot identify which option would be most protective in every situation. However, this report provides information to managers can use in site-specific decision-making. In addition to the exposure-based rankings, it provides conceptual models and environmental fate and effects concept for scientifically based understanding of potential chemical releases and exposure pathways. Site managers can use this report with site-specific information to identify possible exposure pathways, determine whether complete exposure pathways exist, which carcass management options are compatible at their site, and to determine how exposures can be avoided.

Table 4-20. Summary of Livestock Carcass Management Options and Mitigation Measures for a Chemical Emergency Scenario

Option or Activity	Exposure Summary	Potential Mitigations
On-site Combustion	▪ Metal and some organic chemical are not destroyed by combustion, and the combustion process generates new chemical agents of concern such as dioxins/furans and PAHs. ▪ Coal used as a fuel for open burning, contains naturally present metals, including mercury. This assessment finds that mercury concentrations in soil and surface water from air emissions are concentrations from mercury below typical background levels. ▪ Because ash might contain potentially high concentrations of metals and persistent organic compounds and has a high pH, care should be taken to manage ash appropriately (e.g., in a commercial landfill or adequately buried or encapsulated on site).	▪ When possible, install combustion units downwind from human, agricultural, and environmental receptors, including homes, businesses, farm buildings, crops, pastures, and surface waters. Otherwise, install combustion units more than 1,000 meters from these environmental receptors to reduce the potential for inhalation and deposition of contaminants in the air. ▪ Monitor burn piles to ensure combustion attains and maintains even heating for the appropriate duration of time, and provide an ample ratio of fuel to carcasses. ▪ Wet the ash prior to burial, and minimize other handling and processing to avoid resuspending contaminants in the air. Do not use the ash as a surface soil amendment.
On-site Burial	▪ Leachate may carry some chemicals into groundwater supplies. Identify the mobility and persistence of chemicals of concern when considering burial as an option. ▪ Burial removes the land from other productive uses, and proper site selection for the burial trench ensures separation from the aquifer, downgradient wells, and water bodies.	▪ Do not place burial sites up-gradient of groundwater wells or surface water bodies; ensure compliance with required setback distances and other site restrictions. ▪ Comply with the minimum requirements for depth above the water table to minimize releases to groundwater. ▪ If feasible, include a liner of compacted clay in the burial trench. Ventilation shafts can be included to facilitate escaping gases and to maintain the integrity and effectiveness of the cover soil.

Option or Activity	**Exposure Summary**	**Potential Mitigations**
On-site Composting	▪ Chemical releases are minimal from properly constricted composting windrows. During composting, some chemicals can be degraded by natural biological and chemical processes. ▪ Metals and persistent organic chemicals that may remain in finished compost could increase mobility of the contaminants.	▪ Use appropriate carbon material in a quantity sufficient to provide adequate aeration and adsorption of liquids. ▪ Apply adequate cover material to the windrow to discourage potential scavengers and other pests. ▪ Allow at buffer distance or runoff/erosion controls between the compost application area and the nearest surface water body.
Off-site Options	▪ For this assessment, release of chemicals from off-site carcass management facilities are assumed to be from regulated pollution control systems. These releases were not quantified and are assumed to be controlled to levels protective of human health and the environment.	▪ Following a chemical emergency involving a persistent chemical, do not allow the products of off-site carcass management options to enter the production stream for consumable products or soil amendments, such as bone meal.
Carcass Handling	▪ Exposures to workers are not quantified in this assessment and are assumed to be effectively mitigated by the use of personal protective equipment	▪ All workers should wear personal protective equipment appropriate for the chemical emergency response.
Temporary Carcass Storage	▪ If carcasses must be stored temporarily before management, liquids could be released that may or may not contain chemicals of concern depending on their mobility properties. ▪ Chemical releases from the temporary storage pile are influenced by the duration of storage, the level of carcass decomposition and leakage, and management practices.	▪ Locate carcass storage piles on impervious surfaces or liners to prevent leaching to soil and leachate flowing to groundwater. Manage drainage to collect any leachate, leakages, or runoff. ▪ Cover the carcass storage pile to minimize releases of chemicals to air, to control scavengers and to divert precipitation. ▪ Ensure adequate ventilation, particularly for storage indoors.

Option or Activity	Exposure Summary	Potential Mitigations
Carcass Transportation	▪ If carcasses are managed off-site, carcass contaminants might be released during transportation in liquid leakage from the truck bed, emissions to air, and spillage in the event of an accident. ▪ A previous assessment (USEPA 2017) estimated that with eight truck trips of 100 km each the likelihood of a truck accident with spillage is 7.1E-05. ▪ For this assessment, exposures from truck bed leakage and emissions to air are assumed to be negligible at locations along the transportation route.	▪ Select leak-proof vehicles to transport carcasses. Because some leakage can be expected from vehicles designed to be leak-proof, use of plastic liners or absorbent material can minimize leakage. ▪ Use a tarp or similar covering for vehicles that are open on the top. ▪ Load vehicles to no more than 60% capacity by volume because carcasses may bloat and expand in volume as decomposition progresses. ▪ Transport carcasses as soon as possible.

Complete references are found at the end of the report.

5. Quality Assurance

This report used scientific information extracted from sources of secondary data including journal articles, publications in the open literature, and government reports both published and non-published, including distribution limited reports. Data and information were gathered from published reports to identify the significant pathways by which pathogens might reach individuals and estimate how many microorganisms an individual is likely to be exposed to through each pathway. A targeted literature review was performed to identify the most highly relevant data to inform an exposure assessment. Scientific and technical information from various sources were evaluated using the assessment factors below:

- Focus: The extent to which the work not only addresses the area of inquiry under consideration, but also contributes to its understanding; it is germane to the issue at hand.
- Verity: The extent to which data are consistent with accepted knowledge in the field, or if not, the new or varying data are explained within the work. The degree to which data fit within the context of the literature and are intellectually honest and authentic.
- Integrity: The degree to which data are structurally sound and present a cohesive story. The design or research rationale is logical and appropriate.
- Rigor: The extent to which work is important, meaningful, and non-trivial relative to the field. It exhibits sufficient depth of intellect rather than superficial or simplistic reasoning.
- Soundness: The extent to which the scientific and technical procedures, measures, methods, or models employed to generate the information is reasonable for, and consistent with, the intended application.
- Applicability and Utility: The extent to which the information is relevant for the intended use.
- Clarity and Completeness: The degree of clarity and completeness with which the data, assumptions, methods, QA, and analyses employed to generate the information are documented.
- Uncertainty and Variability: The extent to which variability and uncertainty (quantitative and qualitative) related to results, procedures, measures, methods, or models are evaluated and characterized.

6. Literature Cited

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