Human Health and Ecological Risk Assessment Report

FOR THE MERCURY MANAGEMENT EIS

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List of Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
DLA	Defense Logistics Agency
DNSC	Defense National Stockpile Center
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentrations
ERA	Ecological Risk Assessment
ER-L	Effects Range - Low
ERPG	Emergency Response Planning Guidelines
ERPG-2	Emergency Response Planning Guidelines (second-level)
Hg	mercury
HQ	Hazard Quotient
IDLH	immediately dangerous to life and health
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
LC_{50}	median lethal concentration
LD_{50}	median lethal dose
LOAEL	lowest observed adverse effect level
MM EIS	*Mercury Management Environmental Impact Statement*
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effects levels
NRC	U.S. Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
REL	recommended exposure limit
RfC	reference concentration
RfD	reference dose
RMP	Risk Management Program
SSLs	soil screening levels

List of Acronyms
(continued)

TLV	threshold limit value
TRAGIS	Transportation Routing Analysis Geographic Information System
TRV	toxicity reference values
TWA	time weighted average
Y–12	U.S. Department of Energy's Y–12 National Nuclear Security Complex

Units of Measure

ºC	degrees Celsius (Centigrade)
ºF	degrees Fahrenheit
µg	microgram
cm	centimeter
ft	foot
ft^2	square foot
g	gram
gal	gallon
ha	hectare
hr	hour (in compound units)
kg	kilogram
l	liter
lb	pound
m	meter
m^2	square meter
m^3	cubic meter
mg	milligram
mi	mile
min	minute
mph	miles per hour
ng	nanogram
ppm	parts per million
s	second
ton	short ton
yr	year (in compound units)

Metric Conversion Chart

To Convert Into Metric			To Convert Out of Metric		
If You Know	**Multiply By**	**To Get**	**If You Know**	**Multiply By**	**To Get**
Length					
inches	2.54	centimeters	centimeters	0.3937	inches
feet	30.48	centimeters	centimeters	0.0328	feet
feet	0.3048	meters	meters	3.281	feet
yards	0.9144	meters	meters	1.0936	yards
miles	1.60934	kilometers	kilometers	0.6214	miles
Area					
sq. inches	6.4516	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.092903	sq. meters	sq. meters	10.7639	sq. feet
sq. yards	0.8361	sq. meters	sq. meters	1.196	sq. yards
acres	0.40469	hectares	hectares	2.471	acres
sq. miles	2.58999	sq. kilometers	sq. kilometers	0.3861	sq. miles
Volume					
fluid ounces	29.574	milliliters	milliliters	0.0338	fluid ounces
gallons	3.7854	liters	liters	0.26417	gallons
cubic feet	0.028317	cubic meters	cubic meters	35.315	cubic feet
cubic yards	0.76455	cubic meters	cubic meters	1.308	cubic yards
Weight					
ounces	28.3495	grams	grams	0.03527	ounces
pounds	0.45360	kilograms	kilograms	2.2046	pounds
short tons	0.90718	metric tons	metric tons	1.1023	short tons
Temperature					
Fahrenheit	Subtract 32 then multiply by 5/9ths	Celsius	Celsius	Multiply by 9/5ths, then add 32	Fahrenheit

Metric Prefixes

Prefix	Symbol	Multiplication Factor
exa-	E	1 000 000 000 000 000 000 = 10^{18}
peta-	P	1 000 000 000 000 000 = 10^{15}
tera-	T	1 000 000 000 000 = 10^{12}
giga-	G	1 000 000 000 = 10^{9}
mega-	M	1 000 000 = 10^{6}
kilo-	k	1 000 = 10^{3}
hecto-	h	100 = 10^{2}
deka-	da	10 = 10^{1}
deci-	d	0.1 = 10^{-1}
centi-	c	0.01 = 10^{-2}
milli-	m	0.001 = 10^{-3}
micro-	µ	0.000 001 = 10^{-6}
nano-	n	0.000 000 001 = 10^{-9}
pico-	p	0.000 000 000 001= 10^{-12}
femto-	f	0.000 000 000 000 001 = 10^{-15}
atto-	a	0.000 000 000 000 000 001= 10^{-18}

Chapter 1
Introduction

This Risk Assessment Report has been prepared for the Defense National Stockpile Center (DNSC) of the Defense Logistics Agency (DLA). This document provides the detailed health and ecological risk assessments that support the *Mercury Management Environmental Impact Statement* (MM EIS). The findings of this report are summarized in Chapter 7.

The **change bars** that appear in the margins indicate the locations of changes made between the draft and final. Change bars are used for both text additions and deletions.

The DNSC maintains stockpiles of 56 essential industrial commodities. The mercury stockpile consists of 4,890 tons (4,436 metric tons) of 99.5 to 99.9 percent pure elemental mercury kept in sealed 76-lb (34-kg) steel flasks in warehouses. The warehouses are located at the New Haven Depot near New Haven, Indiana; the Somerville Depot in Hillsborough, New Jersey; the Warren Depot near Warren, Ohio; and the Department of Energy's (DOE's) Y–12 National Nuclear Security Complex (Y–12) in Oak Ridge, Tennessee. Flasks at New Haven, Somerville, and Warren are stored (overpacked) in sealed 30-gal (114-l) steel drums, six flasks to a drum. Five drums are stored on each metal catch tray on a wooden pallet. Flasks at Y–12 are stored on wooden box pallets, 45 flasks to a pallet. The pallets are organized in rows on sealed concrete floors.

Mercury is a naturally occurring metal that is a liquid at normal air temperatures and pressures. Mercury occurs widely in the environment, and in some chemical forms it can undergo long-range global transport. Although mercury is naturally occurring, at sufficient levels of exposure it can be toxic to both humans and non-human species.

The risk assessment provides an evaluation of potential releases, exposures, and human and ecological consequences related to activities involved in managing the mercury stockpile, including potential accidents associated with those activities. This information is used in the MM EIS to facilitate comparisons between several alternatives for disposition of the mercury stockpile.

1.1 RISK ASSESSMENT SCOPE

This report focuses on the human health and ecological risks that might arise under normal operating conditions and from storage- and transportation-related accidental releases for each of the identified mercury management alternatives. The methods used are based on the *Draft Risk Assessment Plan for the Mercury Management Environmental Impact Statement* (SAIC 2000).

When considering accidental releases of mercury in this report, risk is expressed as a function of the frequency of occurrence of an accident and the magnitude of the consequences. Most of this risk assessment is concerned with how to estimate those frequencies and consequences for a variety of potential or hypothetical accident sequences that might occur anytime during the 40-yr timeframe of activities considered in the EIS. The assessment of frequencies in this report is not complex, and is generally based on rate statistics from industry or professional judgment. Once the frequency has been calculated, it is then assigned to a high, moderate, low, or negligible category as follows:

- High – more than or equal to once in a hundred years
- Moderate – less than once in a hundred years to once in ten thousand years
- Low – less than once in ten thousand years to once in a million years
- Negligible – less than once in a million years

The assessment of consequences is considerably more complex. The source term is defined by various factors such as the rate at which mercury vapor is released to the atmosphere, the height of release, or the heat content of the release. These characteristics are needed to calculate the atmospheric dispersion of mercury transported downwind. The predicted airborne concentrations encountered by maximally exposed workers and members of the public are then estimated and used as the consequence part of the estimate of health consequences via inhalation. In addition, the dispersion model is used to predict how much mercury is deposited on the ground or in a body of water. Once this has been done, the concentration of mercury in soil or water can be estimated and used as the basis for the calculation of the magnitude of the health effects incurred by the most exposed individual, and the magnitude of adverse consequences incurred by sensitive ecological receptors such as plants, birds, and aquatic biota.

1.1.1 Human Health Consequences

Human health risk assessment generally addresses either risks to exposed populations or risks to certain individuals in the exposed population as a result of exposures to various stressors (e.g., pollution, radiation). Population risk is usually estimated as the expected number of additional cases of an adverse effect in the exposed population during a specified time period. Individual risk is estimated as the probability that an individual of interest might experience an adverse impact within a specified time period. It is commonly assumed that actions taken to protect the maximally exposed individual will likely be sufficient to protect the population as a whole. Consequently, this human health risk assessment focuses on the risks posed to the maximally exposed individuals.

Exposures can be either short term (i.e., “acute”) or long term (i.e., “chronic”). Exposures are classified as acute or chronic depending on the duration of the exposure. Although there is no precise consensus on the definitions of these terms, the U.S. Environmental Protection Agency (EPA) defines acute exposures as those lasting up to or less than 24 hours, while exposures lasting a significant portion of a lifetime are defined as occurring on a chronic basis. This risk assessment includes acute exposures arising during accidents, and long-term exposures resulting from residual environmental contamination after accidents. Other chronic exposures are also discussed that could arise from small, chronic releases during normal operating conditions.

For short-term releases of mercury, the inhalation exposure pathway is of most concern. For short-term exposures to an onsite worker, the chosen benchmark for acute exposures is the airborne concentration that is Immediately Dangerous to Life and Health (IDLH) as defined by the National Institute for Occupational Safety and Health (CDC 2002). The IDLH is based on health effects that might be incurred by unprotected workers during a 30-min exposure.

For consideration of the immediate consequences of short-term airborne exposures to the public, a quantity defined by the American Industrial Hygiene Association (AIHA), the second-level Emergency Response Planning Guideline (ERPG-2) is used. ERPG-2 is defined as “the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual’s ability to take protective actions. The term “nearly all individuals” means that the ERPGs are intended to be protective of all except a few unusually or hyper susceptible members of the population, so ERPGs are protective of the general population which includes “normal” children and the elderly (i.e., generally expected sensitivities). The ERPG-2 has been selected as most appropriate for this assessment to protect members of the public, as implicitly endorsed by EPA. The toxic endpoints EPA has published for substances regulated by the Risk Management Program (RMP), 40 CFR 68, are in fact ERPG-2s where available.

In some cases, airborne releases of mercury can result in dry (i.e., particulate) or wet (i.e., due to rainfall) deposition to soil. Subsequent long-term exposures to mercury in the soil and chronic health effects are then possible.

Chronic individual exposures to pollutants or other stressors can be evaluated in several different ways. Cancer risks are usually expressed as the additional lifetime probability that an individual will develop cancer as a result of a chronic exposure. However, mercury is not thought to be a carcinogen, so this type of health effect is not discussed further. When assessing non-cancer health hazards, the consequences are expressed as the ratio of an exposure to an exposure-based benchmark. The most common benchmarks used in non-cancer risk assessment of chronic exposures to the general public are the reference dose (RfD) and the reference concentration (RfC) developed by EPA. The RfD is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (EPA 2002a). Similarly, the RfC is an "estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (EPA 2002a). It is important to note that these benchmarks are risk-based and are protective of sensitive populations. In practice, surrogates are used for these benchmarks. They are expressed as a concentration of mercury in soil that is protective of human health.

In order to define a spectrum of acute effect consequences for this report, the severity of consequence is deemed to be negligible if it is one-tenth or less than ERPG-2; it is low if it is greater than one-tenth of ERPG-2 and equal to or less than ERPG-2; it is moderate if it is greater than ERPG-2 and equal to or less than ten times the ERPG-2; and it is high if it exceeds ten times ERPG-2. A similar spectrum of acute effect consequences for the worker is defied with respect to the IDLH. For chronic health effects related to long-term exposures, the severity category to which a particular consequence estimate is assigned is obtained by dividing the predicted exposure point concentration of mercury by the appropriate benchmark for chronic human health effects. If the ratio is equal to or less than 0.1, a consequence level of negligible is assigned; if the ratio is greater than 0.1 and equal to or less than 1, a consequence level of low is assigned; if the ratio is greater than 1 and equal to or less than 10 a consequence level of moderate is assigned; if the ratio is 10 or higher a consequence level of high is assigned.

1.1.2 Consequences for Ecological Receptors

The ecological risk assessment considers chronic exposures to a number of potentially sensitive ecological receptors: plants, soil invertebrates, the short-tailed shrew, the American robin, the red-tailed hawk, the great blue heron, aquatic biota, and sediment-dwelling (i.e., benthic) biota. Ecological exposures from mercury deposited onto surface soil, sediment, and surface water are expected to be the greatest risk for ecological receptors. The ecological health consequence levels for these receptors are expressed in terms of media- and receptor-specific ecological benchmark values that are the upper concentration limits for mercury in soil, sediment, and surface water.

In a similar manner (using professional judgment to define a spectrum of consequences) to the human health evaluation, the severity category to which a particular ecological consequence estimate is assigned is obtained by dividing the predicted exposure concentration of mercury by the appropriate benchmark for ecological effects. For ecological effects, if the ratio is 20 or higher, a consequence level of high is assigned; if the ratio is between 10 and 20, a consequence level of moderate is assigned; if the ratio is between 1 and 10, a consequence level of low is assigned; and if the ratio is below 1, a consequence level of negligible is assigned.

1.1.3 Risk

Once the frequency of the release events and the severity of the consequences are determined, an assignment is made placing the frequencies and consequences into the high, moderate, low, or negligible category. The corresponding risk is determined by making use of a simple risk matrix presented in Figure 1–1. Figure 1–1 is adapted from a matrix that originally appeared in EPA's *Technical Guidance for Hazards Analysis* (EPA 1987). There are three categories of risk in the three by three matrix in Figure 1–1; they are high, moderate, and low. Negligible is implicitly included, but falls outside the matrix. If either the frequency or severity of the consequences is negligible, the risk is determined to be correspondingly negligible.

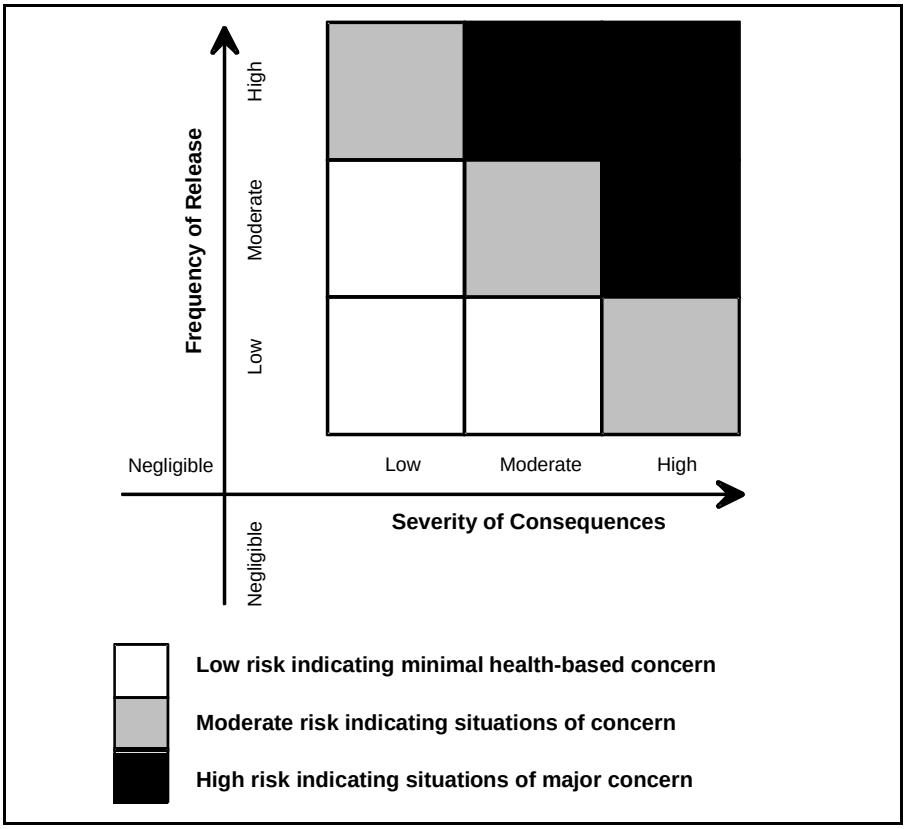

Figure 1–1. Risk (Frequency and Consequence) Ranking Matrix

Finally, the reader should be aware that the risk is typically expressed in the following form: frequency/consequence/risk. For example, Figure 1–1 indicates that a scenario with a low event frequency and a high health effect consequence has a moderate risk: low/high/moderate.

1.2 OVERVIEW OF THE ALTERNATIVES

The alternatives considered in the risk assessment are described in detail in Chapter 2 of the MM EIS. As described in the *Scope of the MM EIS* (DLA 2001), the maximum timeframe covered by the analysis is 40 years.

1.2.1 No Action – Continued Storage at Current Locations

The No Action Alternative maintains the current storage of the mercury stockpile, with maintenance activities focused on continued safe storage of the stockpile for up to 40 years. This alternative represents the lowest level of activity that could result in an accidental release of mercury from the stockpile.

1.2.2 Consolidated Storage

Under the Consolidated Storage Alternative, the existing mercury stockpile would be shipped to a single storage location. This could be at one of the existing warehouses (that now contain the mercury stockpile) at New Haven, Somerville, or Warren, or at existing warehouses (that do not currently contain the mercury stockpile but could accept mercury for storage) at the Hawthorne Army Depot, PEZ Lake Development, or Utah Industrial Depot. Flasks at Y–12 would be overpacked prior to transport or soon after at the designated consolidation site. As described in Appendix C of the MM EIS, staging and transportation would take less than 1 year. It is assumed that a new warehouse would likely be very similar to the existing warehouses. The relocation of the mercury stockpile is a source of additional risks. When compared to the No Action Alternative, this alternative represents an increased potential for accidental releases of mercury from the stockpile due to the higher level of handling and shipping activity that would be required.

1.2.3 Sales

The Sales Alternative allows for reduction of the mercury inventory by selling it in various amounts. The rate of sale would be controlled to avoid disrupting the market for mercury. Mercury remaining in the warehouses would be safely stored and maintained as it is under the No Action Alternative. Under one of the Sales Alternatives, the buyer is assumed to accept the mercury at a rate of 5,000 flasks per year until the entire inventory is sold. Under the other Sales Alternative, a mercury mining company may accept the entire surplus mercury inventory as soon as it can be delivered. Overseas transportation occurs using overpacked mercury drums within 40-ft (12-m) International Organization for Standardization- (ISO-) freight containers, delivery via highway or railroad to a suitable domestic water port, loading the container onto a roll-on/roll-off container ship for delivery to one of two generic foreign ports where it is then offloaded, and delivery via truck to its final destination. Under the 5,000 flask-per-year rate Sales Alternative, the mercury is presumed to be shipped in one continuous process with each container shipped separately aboard a different ship to bound the maximum number of shipments. Under the bulk Sales Alternative, all of the mercury would be loaded aboard a single ship, minimizing the number of shipments but maximizing the potential release volume. The Sales Alternative has more potential for accidental releases of mercury from the stockpile than the No Action or Consolidated Storage Alternative because it requires the highest level of handling and shipping activity.

Sales at the maximum allowable market rate of 5,000 flasks per year could occur to both foreign and domestic buyers. Transportation to foreign buyers is analyzed in this report. The impacts of transportation to domestic buyers are essentially the same as those identified for transportation to the six consolidated storage locations and, therefore, were not specifically analyzed.

1.2.4 Summary

Each alternative is considered in the context of the following analyses:

- **Onsite Hazard and Accidents:** Defines the facilities, activities, and releases from the stockpile under each alternative. Develops estimates of the concentration and the form of mercury

occurring in environmental media. Assigns a frequency of occurrence for each release event. Accidents could occur under any alternative, but the likelihood is greater for the more active Consolidated Storage and Sales Alternatives.

- **Offsite Transportation Hazards and Accidents:** Considers postulated increases in the rate of accidents due to handling and miles traveled to consolidate or sell the stockpile under the Consolidated Storage and Sales Alternatives. Evaluates consequences of spills and fires resulting from any such accidents.
- **Human Health Effects:** Compares the estimated concentrations in environmental media to toxicity-based concentration limits designed to protect workers and the general public. Both acute and chronic health effects are considered.
- **Ecological Effects:** Compares the estimated concentrations in environmental media to toxicity-based concentration limits designed to protect a variety of ecological receptors.

In each of these analyses the postulated consequence of the accident (i.e., as if the event did happen) is combined with the estimate of the event frequency (i.e., whether or not the event is likely) to form a qualitative estimate of the postulated risk by using the risk matrix shown in Figure 1–1.

1.3 ORGANIZATION OF THIS REPORT

This report is organized as follows: Chapter 2 describes the accident scenarios considered and the frequencies for each scenario. Any scenario for which the frequency is determined to be negligible is screened out at this stage. Chapter 3 is an assessment of human toxicity for exposures to mercury. Chapter 4 presents the exposure assessment and the human health consequences and risks per Figure 1–1.

Chapter 5 presents the ecological risk assessment. It describes the general aspects of mercury toxicity to ecological receptors and the derivation of benchmarks for each receptor expressed as concentration in soil, sediment, or water. The consequences associated with alternatives are used with the results of the frequency analysis described in Chapter 2 and Figure 1–1 to assess ecological risks. Chapter 6 is the assessment of uncertainties, and Chapter 7 presents conclusions. Appendix A describes the atmospheric dispersion and deposition models.

Chapter 2
Onsite and Offsite Release Events and Their Frequencies

The purpose of this section is to describe the accident scenarios that were considered for this risk assessment and to provide estimates of their frequency. The frequencies are then assigned to a high, moderate, low, or negligible category as described in Table 2–1. The event frequencies are used to determine whether a particular event scenario should be evaluated further in the risk assessment, or whether the event can be dismissed as having negligible risk on the basis of frequency alone.

Table 2–1. Frequency Categories for Accidental Events

Frequency Category	Estimated Annual Frequency of Occurrence	Description
High	$f > 1\times10^{-2}$	Incidents that may occur several times during the lifetime of the facility. (Incidents that commonly occur.) Accidents of this frequency range are evaluated further.
Moderate	$1\times10^{-2} \geq f > 1\times10^{-4}$	Accidents that are not anticipated to occur during the lifetime of the facility. Natural phenomena of this probability class include: design basis earthquake, 100-yr flood, maximum wind gust, etc. Accidents of this frequency range are evaluated further.
Low	$1\times10^{-4} \geq f > 1\times10^{-6}$	Accidents that will probably not occur during the life cycle of the facility. This class includes most design basis accidents. Although unlikely, accidents of this frequency range are evaluated further.
Negligible	$f \leq 1\times10^{-6}$	Accidents that are not credible and are not evaluated further.

The frequency category is used with the estimated human and ecological effect consequences to derive a subsequent estimate of the overall risk.

Potential releases are divided into three types—

- Releases that might take place on site at the storage locations during normal operations
- Releases that might take place on site at the storage locations during accidents
- Releases that might take place during offsite transportation accidents

At such a time that activities do occur, the working assumption of this EIS is that as many as 5,000 flasks could be handled during any given year. At this maximum rate of handling, a minimum of about 3 to 4 years would likely be required for New Haven, Warren, and Oak Ridge, whereas a minimum of 15 years would likely be required for the larger quantity stored at Somerville. When the entire stockpile of 128,762 flasks is considered, a minimum of about 26 years would be required to liquidate the existing stockpile. It is not currently known when any given activity will occur at any given facility, or at what rate the handling will occur. The probability of any given activity considered in this report is thus distributed over the prescribed 40-yr timeframe.

2.1 RELEASES DURING NORMAL OPERATIONS

Although mercury is compatible with steel, the potential exists for an aging flask to develop a slow leak of mercury at an improperly prepared weld, resulting in an unintended release of liquid mercury to the overpack drum in which the flask is located or a direct release where flasks are not overpacked. In cases

where flasks leak inside the overpack drums, but the overpack drums do not leak, the leaked mercury will not be discovered until inspected during the last year of the 40-yr storage period.

Leaks have occurred in older flasks with welded seams. In 1996, 36 lbs (16 kg) of mercury were found in a catch tray beneath flasks at the New Haven Depot. Subsequent analysis of the flask indicated an improperly constructed weld, rather than a degraded weld. Given that this appears to be an isolated incident, the total volume of mercury released from such events during normal operations in the future is likely to remain small. Mercury that has been reflasked is even less likely to leak because there are no seams in the newer containers. Experience indicates that the liquid mercury is likely to remain contained at all times even during a leak from a faulty flask (i.e., in the catch tray). The remaining release mechanism of concern is the hypothetical long-term, slow escape of mercury vapor. Little is known about actual release rate under normal conditions, although monitoring for vapors is conduced regularly. Although the magnitude of such a release would be small, the exposure scenario is evaluated as a concession to the possibility that small amounts of mercury might escape from competent and properly stored flasks. This concession lead to a high (f>10^{-2}/yr) estimated frequency for slow leaks occurring via incidental vapor release during the 40-yr timeframe for storage activities at any given site.

2.2 ONSITE ACCIDENTS AND RELEASE SCENARIOS

These releases apply to any alternative in which the mercury is stored for a period of time. In order to conduct this risk assessment, information was gathered from site visits, phone calls, and various documents in the library established for the MM EIS. The primary focus was to identify specific hazards associated with each identified alternative.

The inspection reports for the mercury storage areas were reviewed for information about past releases of mercury. Further information about past releases is summarized in the *Mercury Investigation Report* (TVA 2000). No mercury has reportedly escaped from any of the warehouses; and there is no known member of the public that has been affected at any of the existing storage locations.

Decades of experience in maintaining the stockpile of mercury indicates that spills of mercury resulting in environmental contamination have not occurred, and that that normal (accident-free) operating conditions will be maintained at the storage facilities. The storage facilities are built to ensure containment of the mercury under most conditions. Spilled mercury is not known to overrun the catch trays (that can hold the contents of several flasks) containment berms or penetrate the concrete floors and reach any surface water or groundwater sources before cleanup occurs. For these reasons the only initial release pathway from the stockpile is via air.

2.2.1 Single Flask Drop

A single flask is dropped during handling resulting in the breach of the flask, which is a highly conservative assumption for flasks of such robust construction. The frequency for this postulated accident scenario is based on handling individual leaking flasks during reflasking or similar activities at the end of the 40-yr storage period. It is assumed that one flask will be dropped and breached for every 1,000 flasks handled. This is believed to be a conservative assumption given that there is no record of spills occurring in this manner. It is also assumed that no more than 0.1 percent of the total number of flasks will develop leaks that require reflasking. Therefore, the frequency for dropping and breaching a single flask is <10^{-2}/yr (moderate) for the No Action, Consolidated Storage, and Sales Alternatives. Every flask at Y–12 must be handled once in order to be overpacked for the Consolidated Storage and Sales Alternatives, resulting in a higher event frequency >10^{-2}/yr (high) for this location.

2.2.2 Single Pallet Drop/Puncture

A single pallet is dropped during handling resulting in the breach of all overpack drums and flasks on the pallet. It is assumed that there are six flasks in each overpack drum and five drums on each pallet. At Y–12, where the flasks have not been overpacked, there are 45 flasks per pallet. The flasks in a single pallet could also be punctured with the forklift tines. This is believed to be a very conservative assumption based on professional judgment since experience indicates a spill of this extent is not expected.

For the No Action Alternative, only those pallets with leaking flasks will be moved at the end of the 40-yr storage period, and only one pallet will be dropped or punctured for each 1,000 pallets moved. The frequency for breaching a single pallet is therefore $<10^{-2}$/yr (moderate) for the No Action Alternative. The frequency is higher (high) for the Consolidated Storage and Sales Alternatives based on loading the pallets onto either a truck or a railcar at the originating location and unloading the pallets at the destination.

2.2.3 Double Pallets Collapse

Y–12 is the only storage location with pallets in a stacked storage array. As a conservative and hypothetical scenario, storage pallets containing the flasks are assumed to fail, resulting in the collapse of two pallets in a stack and the release of liquid mercury to the floor. It is unlikely that the entire contents of two pallets will be spilled from a single stack to the floor. On a qualitative basis, this event is considered to carry a negligible frequency and, therefore, is not evaluated further because any resulting risks would be negligible as discussed in Section 1.1.3.

2.2.4 Forklift Fire

A fire is initiated by an accidental release of the fuel contained on a forklift, consuming a pallet of mercury flasks. It is assumed that the flasks in the pallet carried by a forklift are engulfed in the central position of the fire resulting in complete evaporation of the mercury. This is a conservative assumption for flasks that have been overpacked into drums. The fire is not expected to spread beyond the immediate vicinity of the forklift due to activation of the fire suppression system.

For the No Action Alternative, the frequency for a forklift fuel fire is considered to be negligible because handling activities involving forklifts at the storage location are not expected. For the Consolidated Storage or Sales Alternative, however, the frequency of using forklifts is considered to be higher due to the activities that involve loading pallets onto trucks or railcars, unloading them at the destination storage location, and moving them to their final storage location. The frequency is assigned to the low category.

2.2.5 Building Fires

A severe fire occurs involving combustible materials associated with mercury storage operations. This includes wood storage pallets and miscellaneous materials such as plastic sheeting, paper, cardboard, and flammable materials of construction. Potential ignition sources include electrical control panels, distribution circuits, and fixtures.

Refueling and maintenance of the forklifts are not performed in the warehouses. Forklift fuel is present in the buildings only in an individual forklift fuel tank. The amount of combustible material in the storage areas is maintained at as low a level as feasible. DNSC storage procedures (DNSCM 4145.1) require that

mercury be stored in different sections of the warehouse than highly combustible commodities such as rubber.

Observations at the Warren Depot indicated that loading materials are minimally combustible (other than wooden pallets), and there are limited ignition sources. There is no wood in the structure of the warehouse itself. In addition, the installed fire suppression system reduces the likelihood of building fires that result in the breach of the flasks. Therefore, building fires over the course of time during storage are assigned to the negligible frequency category. Based on experience and professional judgment, there is less than one chance in a million per year (negligible at $<10^{-6}$/yr) for this event and it is thus associated with negligible risk. Conditions at Somerville and Y–12 are similar.

At the New Haven Depot, the wood frame structural system of the warehouse and wood roof deck provide additional combustible material. However, limited ignition sources, the installed fire suppression system, and the combined experience over the prior 50 years of storage indicate that the likelihood of building fires is negligible. Therefore, this event is not evaluated further.

2.2.6 Wildfires at Hawthorne Army Depot

The substantial lack of precipitation in the region of the Hawthorne Army Depot facility contributes greatly to the availability of combustible vegetation. The Hawthorne Army Depot facility is located in the Walker Lake Valley. The valley trends north-northwest and is located on a high plateau between mountain ranges. The high desert climate is semi-arid with an average annual temperature of 54 ºF (12 ºC) and average monthly temperatures ranging between 34 ºF (1.1 ºC) in January and 75 ºF (24 ºC) in July. The average annual rainfall is 6.4 in (16 cm) with maximum rainfall occurring in late spring and fall and minimal rainfall in July and August. Winds in the vicinity of the facility are from the north and west-northwest with an average speed of 6 mph (9.7 km/hr) gusting to approximately 60 mph (97 km/hr) (Army 2000). Low humidity contributes to the dry air masses that may act to catalyze or spread ignited wildfires.

Conditions conducive to the occurrence of wildfires in the vicinity of the Hawthorne Army Depot are dynamic and include reduced precipitation combined with high daily air temperatures, dry wind, and the availability of sufficient combustible vegetation, infrastructure, and ignition sources. Grasses and brush provide the most probable source material for the development of surface fires in the vicinity of the Hawthorne Army Depot. Floral habitats in and surrounding the facility transition from a lower sagebrush community on the valley floor to a pinion-juniper community with increasing elevation. The dominant species are scrub conifers. The Hawthorne Army Depot contains a combination of mixed desert shrub, sagebrush, and pinion-juniper (Army 2000).

Potential ignition sources include lightning strikes and anthropogenic sources (cigarettes, camp fires, exhaust heat sources, fireworks). Regional statistics indicate that the number of wildfires occurring in the Western Great Basin Area of Nevada between 1999 and 2001 ranged from 1,152 to 1,277 (NBLM 2002). Approximately 700 wildfires were reported in Nevada between January and September 2002 (NIFC 2002). The Bureau of Land Management Carson City field office, located approximately 75 mi (121 km) northwest of Hawthorne, reported between 101 to 142 wildfire incidents in their jurisdiction between 1999 to 2001.

The regional frequency of wildfires occurring in uncontrolled areas in the region falls into the high category (more than once in 100 years). The likelihood that the fire will consume the warehouse containing the mercury, however, is considered to be negligible for several reasons. The proposed mercury storage warehouses are constructed with concrete floor, walls, and transite (fire-resistant)

roofing. Information regarding the current threat from wildfires is available to Hawthorne Army Depot via the Wildland Fire Assessment System. The Wildland Fire Assessment System is an Internet-based information system that provides a national view of weather and fire potential including national fire danger, heavy fuel moisture, Haines Index, and greenness. The system provides a source for current assessment of potential weather-related wildfire threat in the vicinity of Hawthorne Army Depot (USFS 2002). Furthermore, emergency response and contingency plans for the facility incorporate comprehensive fire suppression through the fire department located at Hawthorne Army Depot and from the Hawthorne City Fire Department through a mutual aid agreement.

2.2.7 Wildfires at Storage Facilities Within the Eastern United States

Conditions conducive to the occurrence of wildfires in the vicinity of facilities located in the eastern United States (New Haven, Somerville, Warren, Y–12, and PEZ Lake Development) are dynamic and include periodically reduced precipitation combined with high daily air temperatures, dry wind, the presence of sufficient combustible vegetation and infrastructure, and ignition sources. For example, the PEZ Lake Development and surrounding areas are located in a generally humid climate with weather systems influenced by continental air masses from Canada enhanced by the effects of interactions with Lake Ontario. The potential for extensive wildfires is thus lower than for the storage sites within the western United States. The mean monthly temperature at the facility is 48 ºF (8.9 ºC) with a range of temperatures from -27 ºF (-33 ºC) to 98 ºF (37 ºC). The frost-free season averages 160 days during the year and generally occurs between May and October. Normal precipitation is evenly distributed throughout the year as rainfall and snow with an average annual precipitation of 31 in (79 cm) in the facility area. Snowfall averages 53 in (135 cm) annually. The humid climate and evenly distributed precipitation events limit the development of conditions conducive to wildfires during non-drought seasons. The prevailing wind direction is northwesterly at 10 mph (16 km/hr) and rarely exceeds 30 mph (48 km/hr).

Tree cover is typical for the areas outside the immediate vicinity of the storage buildings. The former Seneca Army Depot can be used as an example of typical conditions in the eastern United States. Approximately one-third of the Seneca Army Depot Activity facility is wooded with both hardwood and softwood tree cover. Hardwoods account for 95 percent of the total woodland acreage and include red maple, silver maple, shagbark hickory, bitternut hickory, pignut hickory, and oak varieties. White pine and eastern hemlock comprise the remaining 5 percent of the wooded area. Agricultural fields on the depot are characterized by sapling shrub community containing maple, white ash, hawthorn, grape, raspberry, blackberry, poison ivy, and various grasses. According to Seneca County Soil and Water Conservation District, noxious weeds are not known to occur on the depot (Army 1998). Clear zones are maintained by mowing along roads and within the igloo storage area (USFWS 1995).

Ignition sources posing a wildfire threat for the facilities within the eastern United States include lightning strikes and anthropogenic sources (cigarettes, camp fires, exhaust heat sources, fireworks, etc). Once again PEZ Lake Development provides a useful example for these facilities in general. Regional statistics provided for property managed by the U.S. Fish and Wildlife Service indicate that the number of wildfires occurring in New York between 1995 and 2000 ranged from 1 to 14 with a 6-yr average of 4 fires per year (USFWS 2002). Approximately 294 wild-land fires were reported in New York between January and September 2002 (NIFC 2002) reflecting ongoing drought conditions in the state. A high potential thus exists for wildfires within the eastern portion of the United States (more than once in 100 years), although they are likely to occur in more remote areas that are not maintained. They are also less likely to spread as extensively as in the western United States due to the generally higher levels of humidity and green vegetation. In the event of a wildfire, these facilities are served by local fire departments. PEZ Lake Development is located near Romulus, New York, and is thus in the immediate

vicinity of the local emergency response services including fire, emergency medical, hazardous material, search and rescue, and extrication. Furthermore, the landscape around active warehouses in general is maintained such that vegetative fuel sources are minimal. The likelihood that the fire will consume the warehouse and result in a release of mercury from a warehouse in the eastern United States is thus considered to be negligible.

2.2.8 Wildfires at Utah Industrial Depot

Conditions conducive to the occurrence of wildfires in the vicinity of the Utah Industrial Depot are dynamic and include reduced precipitation combined with high daily air temperatures, dry wind, the availability of sufficient combustible vegetation and infrastructure, and ignition sources. Structures with shake roofing, wood framing, wood decks, or other readily flammable materials occur within the Utah Industrial Depot providing a concentration of fuel in the path of a spreading wildfire. The buildings do not currently maintain real time fire-suppression systems.

The Utah Industrial Depot facility lies within the Tooele Valley and is characterized by hot summers and moderately cold winters. Weather systems in the valley are influenced by air circulation within the Great Salt Lake Basin and the effects of the Great Salt Lake with wind direction toward the lake at night when the land is warmer and away from the lake during the day when the lake surface is cooler. The average annual temperature in the valley is 62 ºF (17 ºC) with a range of temperatures from -14 ºF (-26 ºC) to 110 ºF (43 ºC). The frost-free season generally occurs between April and October. Normal precipitation at the Utah Industrial Depot occurs as rainfall and snow with an average annual precipitation of 12 in (30 cm) in the facility area and 40 in (102 cm) per year in the adjacent mountains. Significant reductions in precipitation contribute greatly to the availability of combustible vegetation. The prevailing wind direction during the summer is to the north and toward the south during the winter. Low humidity in the valley contributes to the dry air masses that may act to catalyze or spread ignited wildfires.

Grasses and brush provide the most probable source material for the development of surface fires in the vicinity of the Utah Industrial Depot. Floral habitats in and surrounding the facility are distinguished based on soil type and consist of pinyon-Utah juniper communities, Wyoming big sagebrush, and mountain big sagebrush (Army 1996). Common plant species of the pinyon-Utah juniper community within the Utah Industrial Depot include bluebunch wheatgrass, cheatgrass, mountain big sagebrush, Utah juniper, Indian ricegrass, and bluegrass. Similar grasses and brush predominate in areas surrounding the facility.

Ignition sources include lightning strikes and anthropogenic sources (cigarettes, camp fires, exhaust heat sources, fireworks etc). Regional statistics indicate that the number of wildfires occurring in Utah between 1996 and 2000 ranged from 298 to 779 with a 5-yr average of 541 fires (USBLM 2001). Approximately 1,110 wildfires were reported in Utah between January and September 2002 (NIFC 2002). The event frequency for the region thus falls into the high category.

Important mitigating factors indicate that the expected frequency for wildfires consuming the warehouse and resulting in a release of mercury is negligible. The Utah Industrial Depot is located in the former southeast corner of the Tooele Army Depot and is protected from wildfire migration by approximately 135 mi (217 km) of 30-ft- (9.1-m-) wide fire break, graded, and maintained in vacant land areas surrounding the depot boundary to protect the railroad, roads, and structures (Army 1996). Furthermore, emergency response plans for the facility incorporate comprehensive fire suppression through the Tooele City fire department and an agreement with the Tooele Army Depot Fire Department (Ward 2001).

2.2.9 Earthquake

During an earthquake, a percentage of the flasks and overpack drums are breached by disruption of the storage positions, and could be complicated by collapsing exterior and overhead structures. A certain percentage of the flasks and overpack drums are expected to be breached by the disruption of the storage positions, and the collapse of exterior walls and overhead structures. The earthquake is the only release mechanism in this report utilizing the working assumption that a percentage of the volume of mercury is breached during such an event at a given location.

There is no documentation to determine what degree of earth shaking the buildings at the depots can withstand. Seismic disruption of building walls, failure of overhead services (fire sprinkler system, etc.), and coincident breach of some flasks is considered to be the bounding scenario for an earthquake with a peak horizontal ground acceleration of 0.15g and a hazard exceedance frequency of once in a thousand years (10^{-3}/yr; moderate). This failure behavior is typical of similarly constructed warehouse facilities (DOE 1994).

Visual inspection of the flasks suggests that they are at least as robust as 55-gal (208-l) storage drums, so these estimates should be conservative. It is further assumed that, if a flask is damaged, it is 100 percent certain to be breached, with 100 percent of the contents being spilled. Based on professional judgment, the overall failure rate is assumed to be 5 percent of the total amount of mercury stored.

2.2.10 High Winds/Tornados

Facilities similar to those at the storage sites can withstand a fastest mile wind speed of 73 mph (117 km/hr) (DOE 1994). The high wind exceedance probability for such a wind is once in a hundred years (10^{-2}/yr). Although not explicitly evaluated, the concrete block/poured concrete wall construction of the buildings most likely will survive a 73-mph (117-km/hr) wind without adversely impacting the stored mercury. Based on the weather information presented in Chapter 3 of the MM EIS, the weather conditions at the facilities are not likely to exceed these design parameters. Therefore, it is concluded that the anticipated frequency of a mercury release due to high winds is negligible, and the event is not evaluated further.

A violent tornado (F4 or F5 on the Fujita Tornado Damage Scale) has wind speeds between 207 and 318 mph (333 to 512 km/hr). Less than 2 percent of all tornados are violent tornados. A tornado of this magnitude would likely demolish most wood frame structures in its path. At the Warren Depot, there was a tornado in 1986 that demolished or partially demolished several buildings (DeLeon and Whetsell 1999). The probability that such a tornado would occur again and impact the specific area of mercury storage area is less than the probability of the occurrence of the high winds described above–about once in 10,000 years (1×10^{-4}). According to recent work by the National Oceanic and Atmospheric Administration (NOAA) Severe Storms Laboratory, the probability of a violent tornado hitting within 25 mi (40 km) of the New Haven Depot and the Warren Depot is 5.5×10^{-4}/yr and 2.7×10^{-4}/yr, respectively. The probability of a violent tornado hitting within 25 mi (40 km) of the Somerville Depot, Y–12 site, Hawthorne Army Depot, PEZ Lake Development, and Utah Industrial Depot, is 1.4×10^{-4}/yr, or approximately once in 10,000 years. The probability of a violent tornado hitting a particular location within the 25-mi (40-km) area is even lower, so the probability that a violent tornado would hit the mercury storage building is very low. It is assumed that the effect of the roof and walls falling on the stored mercury would be similar to that of an earthquake. Thus, the high wind/tornado risk is bounded by the earthquake risk and is not considered further.

2.2.11 Lightning

Severe weather could result in the buildings being struck by lightning. A single lightning strike is not expected to result in a fire of sufficient magnitude to involve the stored mercury flasks. Larger fires are evaluated as part of the building fires scenario (see Section 2.2.5). The frequency of this scenario is therefore considered to be negligible, and the risk is negligible at any depot. Therefore, this event is not evaluated further.

2.2.12 Snow Loads

Severe winter weather could result in a large accumulation of snow on the roof of the buildings. This can potentially cause the roof to collapse and subsequently breach a small number of mercury flasks. This postulated accident scenario is considered to be a low risk event, primarily due to the design of the buildings. The buildings are assumed to have been designed in accordance with requirements that specify snow loads be taken into account in the design of the roof support structure. If a roof collapse were to occur, results would be expected to be similar to a collapse caused by an earthquake. Therefore, this event is not evaluated further.

2.2.13 Aircraft Crash

An aircraft could crash into the area of the buildings where the mercury is stored and result in a breach of the mercury flasks stored in the buildings. An aircraft crash that results in a breach of mercury flasks stored in the buildings is considered to have a negligible frequency of occurrence. The area of the buildings where the mercury is stored represents a very small area given the size of the buildings, the type of aircraft in the airspace, and associated flight vectors. This event is not evaluated further. Transport of DNSC mercury via aircraft is not anticipated under any conditions.

2.2.14 Vehicle Crash

An out-of-control vehicle on a road or a rail spur near the building could strike an exterior door or wall, disrupting the stored mercury. Although significant damage to the building exterior and interior masonry block/poured concrete walls could occur if a vehicle were to crash into a building, breaching of the stored mercury flasks in such an event is considered to have a negligible frequency. Therefore, this event is not evaluated further.

2.2.15 Nearby Facility Fire/Explosion

A fire or explosion in a nearby building could occur, resulting in disruption of the stored mercury. The only buildings located near the mercury storage area are other warehouse buildings. There are no explosive hazards associated with storage at other buildings. Because these buildings are primarily constructed of concrete and masonry block (Somerville and Warren depots and Y–12) or poured concrete (New Haven), they do not pose a fire or explosion risk to the mercury storage area and are not analyzed further. No hazards associated with adjacent facilities/operations were found that could have an impact on the mercury storage areas. The frequency for this event is negligible.

2.3 OFFSITE TRANSPORTATION ACCIDENTS AND RELEASES

Offsite accidents could occur in any alternative that involves transport of mercury either to or from a given storage facility or to or from a port. Transportation can occur by truck, rail, or an oceangoing

vessel. Transportation by air is excluded from this assessment. In general, the probability of a transportation accident or fatality during a specified operation (such as consolidation at one site) is calculated by multiplying the number of miles traveled during the operation by a standard factor derived from empirical statistics, which is expressed in terms of the number of accidents per mile or the number of fatalities per mile. This transportation risk assessment considers a series of assumptions for three types of accidents:

- Accidents that cause a spill of mercury that subsequently evaporates (no fire). The frequency of such accidents is derived from the above-mentioned empirical accidents-per-mile factor, multiplied by the probability that, given an accident, a spill of mercury will occur.
- Accidents that cause a major fire that is sufficient to evaporate some of the mercury. The frequency of such accidents is derived from the above-mentioned empirical accidents-per-mile factor, multiplied by the probability that, given an accident, a major fire will occur.
- Accidents that cause fatalities due to mechanical impact (i.e., accidents that are unrelated to the fact that the cargo is mercury). The predicted frequency of such accidents is derived from the above-mentioned empirical fatalities-per-mile factor.

In order to calculate the frequency of occurrence of transportation accidents, certain input data are required. The input data include the definition of the transportation route, the estimation of the number of miles traveled, and the empirical accident factors and conditional probabilities discussed above.

2.3.1 Data on Transportation Routes

This subsection considers transportation by road or rail during consolidation, and transportation by road, rail, and vessel for the Sales Alternative. The truck routes considered are conventional commercial routes (i.e., commercial traffic allowed and the most efficient trip possible). The domestic truck and rail routes considered and their associated mileage were obtained from the Department of Energy's Transportation Routing Analysis Geographic Information System (TRAGIS).

2.3.1.1 Consolidated Storage Alternative

The Consolidated Storage Alternative involves the movement of mercury inventory from its existing storage locations to a different storage location. As explained in Chapter 2 of the MM EIS these locations include the New Haven Depot, Somerville Depot, Warren Depot, Hawthorne Army Depot, PEZ Lake Development (at the former Seneca Army Depot), and Utah Industrial Depot. The transportation risk for this alternative is based on the estimated number of truckloads and/or railcar loads to be shipped from the four current storage locations for consolidation at a single location. Currently, there is no requirement for overpacking prior to ground transport, and as such no credit is given for the overpack containing leaks, spills, or other accidental releases of the mercury cargo. Table 2–2 represents the current inventories at the mercury depots and the estimated number of truckloads or railcars they represent assuming that the transport vehicles are loaded to a reasonable capacity. Assumptions for loading include:

- A single pallet contains five drums; each drum contains 6 flasks of mercury (86 lbs [39 kg] per flask). The total weight of the five drums, pallet, and drip shield is estimated to be approximately 2,800 lbs (1,270 kg).
- The effective useable floor area in a single truck is assumed to be 8 ft (2.4 m) wide by 48 ft (15 m) long. Each pallet is 4 ft (1.2 m) by 4 ft (1.2 m). Pallets will not be stacked; therefore, the maximum number of pallets in a single truck based on floorspace alone would be 24.

- The effective useable floor area in a single railcar is assumed to be 10 ft (3.0 m) wide by 59 ft (18 m) long. Each pallet is 4 ft (1.2 m) by 4 ft (1.2 m). Pallets will not be stacked; therefore, the maximum number of pallets in a single railcar based on floorspace alone would be 28.
- The capacity of a truck is 40,000 lbs (18,144 kg), therefore only 14 of the possible 24 pallets of mercury could be accommodated. The capacity of a railroad box car is 75 tons (68 metric tons), therefore all 28 pallets could be accommodated.

Table 2–2. Truck and Rail Shipments Required From The Existing Stockpile Locations

Location	Total Number of Flasks	Number of Pallets	Number of Truck Shipments	Number of Railcar Shipments
New Haven, Indiana	16,151	538	39	20
Oak Ridge, Tennessee	20,276	676	49	25
Somerville, New Jersey	75,880	2,529	181	91
Warren, Ohio	16,355	545	39	20
Total	128,662	4,289	308	156

2.3.1.1.1 Y–12

Y–12 is located in Oak Ridge, Tennessee, nearby I–40, a major east-west interstate highway that bisects the state, and I–75, a major north-south interstate highway that extends between Michigan and Florida. Railroad service is provided by the CSX Railway. The rail tracks do not extend to the mercury storage area so the mercury would be transferred by truck to a convenient loading area. Another option is to load the truck, then transport the mercury to the nearby East Tennessee Technology Park, which has extensive rail service by the Norfolk-Southern Railway. As described in Chapter 2 of the MM EIS, because of space limitations and conflict with DOE's mission, Y–12 is not considered a viable mercury consolidation destination.

2.3.1.1.2 New Haven Depot

The New Haven Depot consists of approximately 268 acres (108 ha) of land owned by the Federal Government. The entrance to the depot is located on the north side of Dawkins Road (State Route 14), approximately 3 mi (4.8 km) east of New Haven, Indiana. The depot is bordered to the south by the Norfolk Southern Railroad and State Route 14, and to the north by Edgerton Road and a small industrial park.

2.3.1.1.3 Somerville Depot

The Somerville Depot consists of approximately 77 acres (31 ha) of land owned by the Federal Government. The entrance to the depot is through Veterans Administration property on the western side of Route 206 approximately 2.5 mi (4.0 km) south of Somerville, New Jersey. Access to the Somerville Depot is obtained via the two-lane U.S. Highway 206. Interstate Highway 287 is located approximately 4 mi (6.4 km) from the depot. The Norfolk-Southern and CSX railroads serve the depot.

2.3.1.1.4 Warren Depot

The Warren Depot consists of approximately 160 acres (65 ha) of land leased from the Conrail Railroad Company. The entrance to the depot is located on the west side of Niles-Warren River Road, approximately 950 ft (290 m) north of DeForest Road.

2.3.1.1.5 Total Road and Rail Miles Traveled During Consolidation

Table 2–3 shows the estimated total mileage for each of the six consolidated storage locations considered in the MM EIS (i.e., total one-way mileage from the other three locations into the consolidated storage location, if it is one of the three existing depots).

Table 2–3. Road and Rail Miles Traveled During Transportation Activities

Consolidated Storage Location	Total Road Miles	Total Rail Miles
New Haven, Indiana	141,533	88,128
Somerville, New Jersey	72,718	45,689
Warren, Ohio	104,536	70,015
Hawthorne, Nevada	770,816	414,849
Romulus, New York	117,400	75,634
Tooele, Utah	616,478	351,373

2.3.1.2 Sales Alternative

For this alternative, transportation options would include truck, rail, and/or ship to a variety of possible domestic and foreign destinations. One of the key issues in assessing the risk of the mercury Sales Alternative is in assessing whether making fewer shipments (containing larger amounts of mercury) is preferred to making a larger number of vessel shipments (containing smaller amounts of mercury). Another issue is whether any one of the assessed alternatives provides a clear safety or cost advantage over the others. The transportation risk for this option contains a number of different potential scenarios, but for this analysis the following assumptions are made in an effort to define bounding conditions:

1. The overpacked mercury will be transported via truck or rail to one of two domestic ports of departure: the Port of New York, or the Port of San Francisco in California. The mercury may or may not be overpacked in drums upon reaching port (because overpacking may or may not be used during transport to port, no credit is given for overpacking in this assessment).
2. The mercury will be packed into standard (ISO) shipping containers and loaded onboard a commercial (roll-on/roll-off) container ship. A typical large-capacity roll-on/roll-off ship can hold up to 6,000 40-ft (12-m) container boxes. To transport the entire mercury inventory 308 trips are needed.
3. The mercury will be transported to one of two foreign destination ports: Amsterdam, Netherlands, or Bombay, India.
4. Container ships may depart from either domestic port. There are four transportation routes:
    - New York to Amsterdam
    - New York to Bombay via Suez Canal
    - New York to Bombay via Panama Canal
    - San Francisco to Bombay
5. The overpack drums will most likely be unloaded from the shipping container at the arrival port for road transportation to its destination. Road transportation in the foreign country will be assumed to be 500 mi (805 km) from the destination port.

The transportation risk aspects were analyzed in three segments (i.e., domestic, at sea, and foreign) in order to quantify the overall transportation risk. The risk from all of the segments may be combined to estimate the potential risk of the Sales Alternative. The first segment (see Table 2–4) is domestic surface transportation from the existing storage sites to the Port of New York or the Port of San Francisco by

truck and rail. Note that the mileages for the two options are about an order of magnitude different as are the estimated fatalities and accidents.

Table 2–4. Mileage for Truck Transport from Existing Stockpile Locations to Shipping Port

Storage Location	Total Road Miles to Port of New York	Total Road Miles to Port of San Francisco
Oak Ridge, Tennessee	35,839	123,784
New Haven, Indiana	25,342	88,854
Somerville, New Jersey	8,308	521,334
Warren, Ohio	16,158	97,683

The mileage for rail transportation to the Port of New York or the Port of San Francisco is given in Table 2–5.

Table 2–5. Mileage for Rail Transport from Existing Stockpile Locations to Shipping Port

Storage Location	Total Rail Miles to Port of New York	Total Rail Miles to Port of San Francisco
Oak Ridge, Tennessee	14,450	66,398
New Haven, Indiana	15,166	46,754
Somerville, New Jersey	3,813	277,059
Warren, Ohio	10,484	50,192

Note: Miles traveled on a barge to reach a port were not included in the calculations for rail miles.

Given that only 5,000 flasks can be sold in any given year, it is unlikely that dedicated round trips will be necessary; based on the assumption that the mercury cargo will be incorporated into routine commercial freight schedules, the miles considered cover the portion of the trip in which mercury is carried since these miles will be traveled anyway.

The second transportation segment covers the oceangoing vessel transportation. Four potential vessel routes were studied, as shown in Table 2–6. A working assumption for this analysis is that the mercury cargo will be included in normally scheduled freight traffic; miles traveled after the mercury is offloaded are not considered (i.e., since these miles will be traveled anyway). Furthermore, the miles shown are those reasonably expected for normal shipping operations; unpredictable detours are not considered although they could theoretically increase the miles traveled and ports visited.

Table 2–6. Mileage for Ocean-Going Vessel

Vessel Origin Port, Destination, and Route	Vessel Estimated Miles per Route	Total Vessel Miles
New York to Amsterdam	8,800	2,710,000
New York to Bombay via Suez Canal	12,800	3,942,400
New York to Bombay via Panama Canal	14,500	4,466,000
San Francisco to Bombay	10,300	3,172,400

The third transportation segment under the Sales Alternative involves the delivery of the mercury from the port of destination to the mercury users. Under this segment, it is assumed that the shipments would be done entirely by truck over an estimated 500 mi (805 km) per trip; a total estimated truck mileage at the foreign destination is 154,000 mi (247,832 km) (308 trips × 500 mi [805 km]).

Sales at the maximum allowable market rate of 5,000 flasks per year could occur to foreign or domestic buyers, although transportation to foreign buyers is analyzed in this report. The impacts of transportation to domestic buyers are bounded by the analysis of transportation to the six consolidated storage locations.

2.3.2 Transportation Probability Data

The transportation analysis begins with the empirically determined accident rate (the number of accidents per mile). It must be remembered that this rate is actually an average obtained from data that encompasses millions of miles. The number of accidents that occurred is divided by that number of miles. The transportation analysis proceeds by multiplying the accident rate by the total number of miles traveled to complete a given activity (e.g., relocation to a given site). This gives the average number of accidents that are predicted to occur during the specific activity. The strict mathematical interpretation is that the predicted number is the average of the number of accidents that would occur if the activity were repeated over and over a large number of times. In order for there to be a meaningful comparison with the predictions of the frequency of occurrence of other sorts of accidents (such as those occurring at a fixed site), the estimated mean is converted into a frequency. The Poisson Distribution analysis discussed in this section performs this conversion.

The empirically based accident rate is based on *Comparative Assessment of Risk Model Estimates for the Transport of Dangerous Goods by Road and Rail* (Saccomanno, Leeming, and Stewart 1993), the probability of a heavy truck accident used in this risk assessment is 2.1×10^{-6} accidents per mile and for rail at 6.0×10^{-7} accident per mile. The same reference indicates that the conditional probability of release of hazardous cargo after such an accident is 9.2 percent for trucks and 19 percent for rail. According to *Shipping Container Response to Severe Highway and Railway Accidents Conditions* (NUREG/CR-4829), the probability of a fire after a truck accident is less than 1 percent and following a rail accident is 1 percent. The bounding conditional probability for both these cases is taken as 1 percent. It is assumed for the purpose of this report that these rates reasonably represent potential releases of mercury for commercial trucks and railcars used during truck and rail accidents.

The statistic for heavy truck highway accident fatalities caused by mechanical impact is based on *Large Truck Crash Profile: The 1998 National Picture* (FMCSA 1998). The statistic used to determine rail hazard risks comes from *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight* (Saricks and Kvitek 1994). The statistic is 2.3×10^{-8} fatalities per mile for trucks and 4.3×10^{-8} fatalities per mile for rail.

With respect to transportation by ship, according to the U.S. Maritime Administration, over 2.3 billion tons (2.1 billion metric tons) of material and goods were shipped from the United States in 1999 aboard 363,000 shiploads, including nearly 60,000 full-container ships. Accident or release rates are difficult to quantify because statistics for loss are driven by the largest loss category, theft and piracy. The vessel accident rate was established as 2.06×10^{-7} per nautical mile by *Waste Transport and Public Safety* (Pangea Resources 2001), which discussed the relative risks of vessel shipments of spent nuclear fuel.

As an example of applying the conditional probabilities to the accident rate, the frequency estimate for a truck accident with release of mercury that is $2.1\times10^{-6}\times0.92 = 1.9\times10^{-7}$. In a similar manner, the frequency estimate for a truck accident with release of mercury and a fire is $2.1\times10^{-6}\times0.01 = 2.1\times10^{-8}$. These accident frequencies shown below in Table 2–7 are assumed to be reasonably representative and useful for predicting accidents while transporting the mercury cargo.

Table 2–7. Basic Probabilities Used in the Transportation Risk Analysis

Description	Value
Truck accident with no mercury spill or no fire	2.1×10^{-6} per mile
Probability of release of contents from truck	0.092
Truck accident with mercury spill (no fire)	1.9×10^{-7} per mile
Probability of fire after truck accident	0.01
Truck accident with fire and release of mercury	2.1×10^{-8} per mile
Truck accident with mechanically induced fatality (no fire)	2.3×10^{-8} per mile
Rail accident with no mercury spill or no fire	6.0×10^{-7} per mile
Probability of release of contents from railcar	0.092
Rail accident with mercury spill (no fire)	1.1×10^{-8} per mile
Probability of fire after rail accident	0.01
Rail accident with fire and release of mercury	6.0×10^{-9} per mile
Rail accident with mechanically induced fatality	4.3×10^{-8} per mile
Ocean-going vessel accident (all types)	2.1×10^{-7} per nautical mile

The above data are used in this report to calculate the predicted number of accidents per operation. For example, Table 2–3 indicates that the total number of truck miles traveled to complete consolidation at New Haven, Indiana, is 141,533. The probability of an accident with fire and mercury release per mile is 2.1×10^{-8}. The product of this probability and the number of miles is 0.003. The interpretation of this number is that it is the predicted mean number Λ of fires that will occur during consolidation at New Haven. The mean must be associated with a probability distribution, and the most appropriate is the Poisson Distribution, which is a discrete probability distribution which takes on the values n = 0, 1, 2, 3, … . It is often used as a model for the number of events (such as the number of telephone calls at a business or the number of accidents at an intersection) in a specific time period. It has the following form:

- $P(n) = (\Lambda^n/n!)\exp(-\Lambda)$ (n = 0,1,2,3… being the number of accidents)
- $P(0) = \exp(-\Lambda)$ (the probability that there will be no accidents)
- For $\Lambda = 0.003$, $P(0) = \exp(-0.003)$ approximately 0.997
- $P(n\geq1)$ - the probability of one or more accidents - is $1-\exp(-\Lambda)$ approximately 0.003 in this case (when Λ is small $P(n\geq1)$ approximately Λ: this relationship breaks down as Λ approaches unity or greater)

$P(n\geq1)$ is the probability that one or more accidents will occur during the consolidation operation. In order to convert it to a frequency, it is averaged over the period of operation of the storage facilities (40 years) to be consistent with the frequency definitions for the onsite accidents. In this case, dividing 0.003 by 40 gives a frequency of 7.5×10^{-5} per year, which is in the low category—i.e., transportation accidents during consolidation at New Haven lead to truck crashes with a fire (and associated release of mercury) with a low frequency of 7.5×10^{-5}/yr.

2.3.3 Spills into Waterbodies

Spills occurring during a transportation accident could result in leakage of the mercury cargo into the surrounding environment. The most significant and challenging scenario (from a cleanup standpoint) would be a spill directly into a surface water body such as a lake or river. Table 2–8 shows that all significant waterbodies encountered during transport are perpendicular to the road. This indicates that the

likely proportion of total vehicle miles traveled that are represented by bridges crossing waterbodies is negligible.

Table 2–8. Waterbodies Encountered During Transportation Activities

Origin/Destination[a]	Distance (miles)	Major Bridge
Oak Ridge, TN to Somerville, NJ	692	Tennessee River bridge in Tennessee, Potomac River in Virginia and Maryland, and Susquehanna River in Pennsylvania
Oak Ridge, TN to Warren, OH	536	Ohio River in Kentucky and Ohio
Oak Ridge, TN to New Haven, IN	421	Ohio River in Kentucky and Ohio
Oak Ridge, TN to Romulus, NY	829	Ohio River in Kentucky and Ohio, Lake Erie in Ohio, Pennsylvania, and New York
Oak Ridge, TN to Hawthorne, NV	2,256	Ohio River in Kentucky and Ohio, Mississippi River in Illinois and Missouri, Missouri River in Missouri
Oak Ridge, TN to Tooele, UT	1,826	Ohio River in Kentucky and Ohio, Mississippi River in Illinois and Missouri, Missouri River in Missouri
Somerville, NJ to Warren, OH	380	Ohio and Susquehanna Rivers in Pennsylvania
Somerville, NJ to New Haven, IN	615	Ohio and Susquehanna Rivers in Pennsylvania
Somerville, NJ to Romulus, NY	258	Susquehanna River in New York
Somerville, NJ to Hawthorne, NV	2,697	Susquehanna River in Pennsylvania, Lake Erie in Ohio, Lake Michigan in Indiana and Illinois, Mississippi River in Illinois and Iowa
Somerville, NJ to Tooele, UT	2,182	Susquehanna River in Pennsylvania, Lake Erie in Ohio, Lake Michigan in Indiana and Illinois, Mississippi River in Illinois and Iowa
Warren, OH to Somerville, NJ	380	Ohio and Susquehanna Rivers in Pennsylvania
Warren, OH to New Haven, IN	245	None encountered
Warren, OH to Romulus, NY	278	Lake Erie in Ohio, Pennsylvania, and New York
Warren, OH to Hawthorne, NV	2,321	Lake Michigan in Indiana and Illinois, Mississippi River in Illinois and Iowa
Warren, OH to Tooele, UT	1,806	Lake Michigan in Indiana and Illinois, Mississippi River in Illinois and Iowa

[a] Return trips may cover the same miles and may encounter the same waterbodies.

2.3.4 Populations and Accident Scenarios

The consequences of a mercury release are related to the affected population within 1 mi (1.6 km) of the release. Urban and suburban areas may have populations exceeding 3,226 people per square mile, whereas rural areas typically have a population density of 139 people per square mile or less. In general, an average of 30 percent of the miles traveled in the eastern United States will be within urban or suburban areas, with the remaining 70 percent in less populated rural areas. For the western United States, the rural road mileage increases to 92 percent, with only 8 percent of the mileage in urban or suburban areas.

Note that although the traffic accident rate is higher in urban and suburban areas, the posted speed limits are lower, generally limiting the severity of vehicle accidents. In rural areas the speed limits tend to be higher. Because the traffic density is lower, the probability of collision decreases; however, it is reasonable to expect that the consequence of an occurring collision can be more severe. In urban and suburban areas, the emergency response capability (i.e., mitigating reactions) is generally only minutes away; whereas, in the rural areas, initial emergency response can take up to an hour.

2.3.5 Transportation Frequency – Results

The results of the transportation frequency analysis for the Consolidated Storage Alternative are presented in the following sections.

2.3.5.1 Consolidated Storage Alternative

Based on the definitions presented in Section 2.3, Table 2–9 presents estimates of frequency of truck and rail accidents while consolidating the stockpile resulting in a mercury spill, but no fire. Table 2–10 presents estimates of frequency of truck and rail accidents with fire and a mercury release. Table 2–11 presents the estimated frequency of mechanically caused fatalities related to truck and rail accidents.

Table 2–9. Transportation Accident Frequency (yr^{-1}) – Mercury Spill (No Fire)

		Truck				Rail			
Consolidated Storage Location	**Operational Years**	**Highway Miles**	**Accident Rate (per mile)**	**Accident Mean**	**Accident Frequency**	**Rail Miles**	**Accident Rate (per mile)**	**Accident Mean**	**Accident Frequency**
New Haven, IN	40	141,533	1.9×10^{-7}	0.027	6.7×10^{-4}	88,128	1.1×10^{-8}	0.001	2.4×10^{-5}
Somerville, NJ	40	72,718	1.9×10^{-7}	0.014	3.5×10^{-4}	45,689	1.1×10^{-8}	0.0005	1.3×10^{-5}
Warren, OH	40	104,536	1.9×10^{-7}	0.020	5.0×10^{-4}	70,015	1.1×10^{-8}	0.00077	1.9×10^{-5}
Hawthorne, NV	40	770,816	1.9×10^{-7}	0.15	3.7×10^{-3}	414,849	1.1×10^{-8}	0.0046	1.1×10^{-4}
Romulus, NY	40	117,400	1.9×10^{-7}	0.022	5.6×10^{-4}	75,634	1.1×10^{-8}	0.00083	2.1×10^{-5}
Tooele, UT	40	616,478	1.9×10^{-7}	0.12	2.9×10^{-3}	351,373	1.1×10^{-8}	0.0039	9.7×10^{-5}

Note: Miles traveled × accident rate = accident mean. Accident mean/operational years = accident frequency.

Table 2–10. Transportation Accident Frequency (yr^{-1}) – Fire with Mercury Release

		Truck				Rail			
Consolidated Storage Location	**Operational Years**	**Highway Miles**	**Accident Rate (per mile)**	**Accident Mean**	**Accident Frequency**	**Rail Miles**	**Accident Rate (per mile)**	**Accident Mean**	**Accident Frequency**
New Haven, IN	40	141,533	2.1×10^{-8}	0.0030	7.4×10^{-5}	88,128	6.0×10^{-9}	0.00053	1.3×10^{-5}
Somerville, NJ	40	72,718	2.1×10^{-8}	0.0015	3.8×10^{-5}	45,689	6.0×10^{-9}	0.00027	6.9×10^{-6}
Warren, OH	40	104,536	2.1×10^{-8}	0.0022	5.5×10^{-5}	70,015	6.0×10^{-9}	0.00042	1.1×10^{-5}
Hawthorne, NV	40	770,816	2.1×10^{-8}	0.016	4.0×10^{-4}	414,849	6.0×10^{-9}	0.0025	6.2×10^{-5}
Romulus, NY	40	117,400	2.1×10^{-8}	0.0025	6.2×10^{-5}	75,634	6.0×10^{-9}	0.00045	1.1×10^{-5}
Tooele, UT	40	616,478	2.1×10^{-8}	0.013	3.2×10^{-4}	351,373	6.0×10^{-9}	0.0021	5.3×10^{-5}

Note: Miles traveled × accident rate = accident mean. Accident mean/operational years = accident frequency.

Table 2–11. Transportation Fatality Frequency (yr^{-1}) – Mechanically Induced

		Truck				Rail			
Consolidated Storage Location	**Operational Years**	**Highway Miles**	**Fatality Rate (per mile)**	**Fatality Mean**	**Fatality Frequency**	**Rail Miles**	**Fatality Rate (per mile)**	**Fatality Mean**	**Fatality Frequency**
New Haven, IN	40	141,533	2.3×10^{-8}	0.0033	8.1×10^{-5}	88,128	4.3×10^{-8}	0.0038	9.5×10^{-5}
Somerville, NJ	40	72,718	2.3×10^{-8}	0.0017	4.2×10^{-5}	45,689	4.3×10^{-8}	0.0020	4.9×10^{-5}
Warren, OH	40	104,536	2.3×10^{-8}	0.0024	6.0×10^{-5}	70,015	4.3×10^{-8}	0.0030	7.5×10^{-5}
Hawthorne, NV	40	770,816	2.3×10^{-8}	0.018	4.4×10^{-4}	414,849	4.3×10^{-8}	0.018	4.5×10^{-4}
Romulus, NY	40	117,400	2.3×10^{-8}	0.0027	6.8×10^{-5}	75,634	4.3×10^{-8}	0.0033	8.1×10^{-5}
Tooele, UT	40	616,478	2.3×10^{-8}	0.014	3.5×10^{-4}	351,373	4.3×10^{-8}	0.015	3.8×10^{-4}

Note: Miles traveled × fatality rate = fatality mean. Fatality mean/operational years = fatality frequency.

The estimated frequency of both truck and rail accidents with a mechanically induced fatality or a fire with a release of mercury is low. The estimated frequency of truck and rail accidents with a mercury spill but no fire is moderate.

2.3.5.2 Sales Alternative

The transportation frequencies were analyzed in three segments in order to quantify the overall transportation frequency. The three segments are:

1. Domestic ground transport from stockpile location to port
2. Ocean transport from departing to destination port
3. Foreign ground transport from port to user facility

The risk from all of the segments must be added together in order to correctly assess the potential risk of the Sales Alternative. The first segment is domestic surface transportation from the existing storage sites to the Port of New York and the Port of San Francisco by truck and rail. The following discussion focuses on the frequency of accidents with fire and mercury release. The estimated frequencies for road and rail transportation accidents are given in Tables 2–12 and 2–13.

Table 2–12. Transportation Accidents with Fire and Mercury Release for Truck Transport from Existing Stockpile Locations to Shipping Port – Frequencies (yr^{-1})

		To Port of New York				To Port of San Francisco			
Consolidated Storage Location	Operational Years	Highway Miles	Accident Rate (per mile)	Accident Mean	Accident Frequency	Highway Miles	Accident Rate (per mile)	Accident Mean	Accident Frequency
Somerville, NJ	40	8,308	2.1×10^{-8}	1.7×10^{-4}	4.4×10^{-6}	521,334	2.1×10^{-8}	1.1×10^{-2}	2.7×10^{-4}
Warren, OH	40	16,158	2.1×10^{-8}	3.4×10^{-4}	8.5×10^{-6}	97,683	2.1×10^{-8}	2.1×10^{-3}	5.1×10^{-5}
New Haven, IN	40	25,342	2.1×10^{-8}	5.3×10^{-4}	1.3×10^{-5}	88,854	2.1×10^{-8}	1.9×10^{-3}	4.7×10^{-5}
Oak Ridge, TN	40	35,839	2.1×10^{-8}	7.5×10^{-4}	1.9×10^{-5}	123,784	2.1×10^{-8}	2.6×10^{-3}	6.5×10^{-5}

Note: Miles traveled × accident rate = accident mean. Accident mean/operational years = accident frequency.

Table 2–13. Transportation Accidents with Fire and Mercury Release for Rail Transport from Existing Stockpile Locations to Shipping Port – Frequencies (yr^{-1})

		To Port of New York				To Port of San Francisco			
Consolidated Storage Location	Operational Years	Rail Miles	Accident Rate (per mile)	Accident Mean	Accident Frequency	Rail Miles	Accident Rate (per mile)	Accident Mean	Accident Frequency
Somerville, NJ	40	3,813	6.0×10^{-9}	2.3×10^{-5}	5.7×10^{-7}	277,059	6.0×10^{-9}	1.7×10^{-3}	4.2×10^{-5}
Warren, OH	40	10,484	6.0×10^{-9}	6.3×10^{-5}	1.6×10^{-6}	50,192	6.0×10^{-9}	3.0×10^{-4}	7.5×10^{-6}
New Haven, IN	40	15,166	6.0×10^{-9}	9.1×10^{-5}	2.3×10^{-6}	46,754	6.0×10^{-9}	2.8×10^{-4}	7.0×10^{-6}
Oak Ridge, TN	40	14,450	6.0×10^{-9}	8.7×10^{-5}	2.2×10^{-6}	66,398	6.0×10^{-9}	4.0×10^{-4}	10.0×10^{-6}

Note: Miles traveled × accident rate = accident mean. Accident mean/operational years = accident frequency.

The second transportation analysis segment covers the Sales Alternative. The Sales Alternative would require transport of mercury by truck or rail from the stockpile location to either the Port of New York or the Port of San Francisco. At the port, the mercury would be loaded into oceangoing vessels and shipped to either of the ports indicated in Table 2–14.

Table 2–14. Transportation Accidents for Ocean-Going Vessel – Frequency of All Accidents

Vessel Origin Port, Destination and Route	Vessel Estimated Miles per Route	Total Vessel Miles	Total Estimated Accident Frequency (yr^{-1})
New York to Amsterdam	8,800	2,710,000	0.014
New York to Bombay via Suez Canal	12,800	3,942,400	0.021
New York to Bombay via Panama Canal	14,500	4,466,000	0.023
San Francisco to Bombay	10,300	3,172,400	0.017

Any releases of mercury that occur would affect three distinct marine environments: the harbors of departing or destination ports; the continental shelf, which is the shallow ocean reaching the departing or destination harbors; or the deeper portions of the ocean from the continental margin (includes the continental shelf, slope and rise). Figure 2–1 shows these portions of the ocean floor. The continental margins comprise about 21 percent of the total ocean to the Abyssal Plain (the deep and relatively flat portion of the ocean floor).

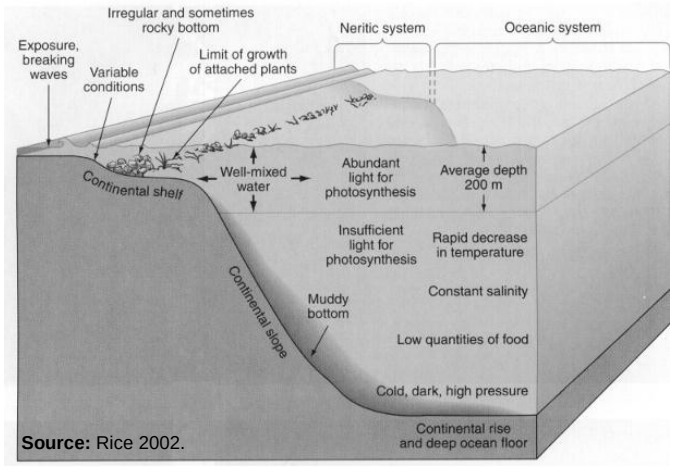

Figure 2–1. The Ocean Floor

The likelihood of spills of mercury occurring at the port is believed to be minimal. Container handling accidents for oceangoing vessels in port are most likely to occur at the time a container is being loaded or unloaded from a ship, and thus is a critical point in the handling cycle for the cargo. Loading or unloading trucks to and from shipping containers is likely to be very similar in nature to the activities already postulated in this report for the stockpile facilities during consolidation or sales. Once in the shipping container, the consequence of an accident in port (as well as those at sea) is likely to be negligible given that a release of mercury would require breaching the shipping container, the overpack drum, and the steel flask which contains the mercury. Furthermore, an accident occurring in port would be subject to immediate emergency response to contain any release. Finally, the frequency of accidents related to overland transport noted in other sections of this report (i.e., getting to and from the port) overwhelms the frequency of accidents for oceangoing vessels. Spilled mercury in the port harbor has the highest likelihood of localized, practical recovery and mitigation efforts. Mercury is only sparingly soluble in water and would tend to associate with the harbor sediments. Harbor sediments are shown in Figure 2–2, which is an example of San Francisco harbor that is generally applicable.

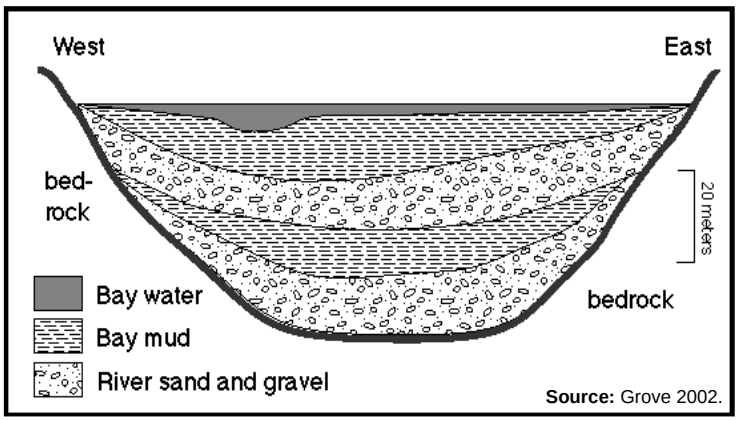

Figure 2–2. Sediments in San Francisco Harbor

Cleanup efforts could then be directed to the immediate area where the spill occurred. Although sediments can be mobilized during extreme weather events, the prospect of recovering contaminated sediment is much better than recovering mercury from water if it were highly soluble or miscible in water.

Mercury that is lost to the environment as a result of a spill has the greatest potential to dramatically impact areas with the highest density of marine organisms. The density of marine organisms is linked to available opportunities for viable habitat. Although there is abundant diversity in the species inhabiting the deeper portions of the ocean, the opportunities for habitat are greatest in the shallower portions of the ocean. The density of marine organisms is thus greatest in the shallower portions. It is important to note that although the continental margins occupy a significant portion of the ocean (Grove 2002), the continental shelf with the most abundant habitat represents a smaller portion of this area.

Loss of the mercury cargo over the continental shelf would present difficult mitigation strategies, although recovery of the cargo may be possible depending on the disposition of the spill (i.e., the cargo remains intact and is identifiable) and the depth of water encountered. Loss of mercury cargo occurring in the deep ocean would present great challenges for mitigation of spills or recovery of the cargo. Such efforts would likely be entirely impractical and it is unlikely that the lost cargo would be subject to effective mitigation or recovery efforts.

For several reasons, precise estimates of the environmental consequences are not possible. As indicated in this section, although releases of mercury cargo during shipment via oceangoing vessels are possible (as indicated by the estimated frequencies), the environmental impacts of such a loss of the cargo is highly dependent on the conditions encountered at the time of the loss. For example, topographic variability along the shore produces significant influences on the near shore circulation, which would dramatically affect mixing of any mercury released within the shallow waters (Allen 2002). As is the case for the releases into harbor waters, any mercury released will tend to associate with the marine sediment due to the low solubility of mercury in water. Over time and under the influence of environmental processes (i.e., oxidation/reduction, complexes with inorganic and organic material, etc.), mercury remaining in direct contact with seawater will dissolve at a low rate based on the solubility and form of the mercury. The mercury would then be entrained in the prevailing ocean currents and enter the global mercury cycle.

The frequency of accidents occurring over four potential vessel routes were estimated using the rate for oceangoing vessels given in Table 2–7. The estimated frequencies are shown in Table 2–14. The frequencies shown in Table 2–14 are averaged over the expected 40-yr duration of sales activities (as defined in the introduction to Chapter 2).

It is likely that the actual probability of a catastrophic accident is overstated in this report which considers a high number of marine miles traveled by placing one shipping container at a time on a ship. It is more likely that multiple containers will be placed on a single ship rather than shipping only one container per shipload. An alternate hypothesis is that a single 20-ft (6.1-m), half-height cargo container (built for heavy loads such as a single tier of pallets) could contain up to 10 4×4-ft (1.2×1.2-m) pallets. With 5 drums per pallet, each containing 6 flasks (see Section 2.3.1.1), such a shipping container could contain up to 300 flasks. At the maximum permissible sales rate of 5,000 flasks per year, up to 17 containers laden with mercury could hypothetically be shipped aboard a single vessel. Shipment via ocean transport is likely to use somewhere between 1 and 17 cargo containers. Shipment of one cargo container at a time is a simple, yet plausible assumption made in lieu of specific shipping information. Furthermore, it is important to note that the estimated vessel accident frequencies refer to all types of accidents and rather than those specifically likely to result in cargo loss; the probability of actual cargo loss is only a faction of the estimated frequencies. To predict the frequency of vessel accidents with fire and mercury release requires knowledge of: (a) the fraction of vessel accidents that would lead to fire and mercury release; and (b) the fraction of the route that is in a location where members of the public might be affected. Although this is unknown, these fractions are likely to be very small. Assuming that each of these fractions is 1 percent or less yields a compounded factor of 0.01 percent (or 0.01^2 = 1/10,000) which can then be applied to the frequencies in Table 2–14, reducing them to the vicinity of 1 to 2×10^{-6}/yr. The predicted frequency of accidents via ship is much smaller than for truck or rail transportation to the ports, with the exception of the very short rail trip from Somerville to New York.

The third transportation segment under the Sales Alternative involves the delivery of all the mercury from the port of destination to the mercury users. Lacking specific information about the location of mercury users, a reasonable assumption is made for the purpose of this report that the shipments from the destination port would be made entirely by truck over a 500-mi (805-km) trip. The total assumed destination truck mileage is 154,000 mi (247,832 km) (308 trips × 500 mi [805 km]).

Foreign truck accident rates are notably variable from place to place and for the purpose of this report are assumed to be twice as high as domestic truck accident rates (Barnas 2002). Conservatively assuming that the foreign trucking accident and fatality rates are two times the domestic rates, the total estimated frequency of accidents with fire and a release of mercury is 1.6×10^{-4}/yr. The total accident rate from the foreign transportation of the surplus mercury is listed in Table 2–15, assuming that all ground transportation is via truck.

Table 2–15. Summed Accident Frequencies for Delivery of Mercury from Storage Facility to Foreign End Users (yr^{-1})

Vessel Origin Port, Destination and Route	Domestic Truck Accident Frequency	Total Ocean Vessel Accidents Frequency	Foreign Truck Accident Frequency	Total Estimated Accident Frequency for Foreign Sales
New York to Amsterdam	7.3×10^{-6} to 1.1×10^{-4}	$\sim1.0\times10^{-6}$	1.6×10^{-4}	1.7×10^{-4} to 2.7×10^{-4}
New York to Bombay via Suez Canal	7.3×10^{-6} to 1.1×10^{-4}	$\sim2.0\times10^{-6}$	1.6×10^{-4}	1.7×10^{-4} to 2.7×10^{-4}
New York to Bombay via Panama Canal	3.7×10^{-4} to 4.6×10^{-4}	$\sim2.0\times10^{-6}$	1.6×10^{-4}	5.3×10^{-4} to 6.2×10^{-4}
San Francisco to Bombay	3.7×10^{-4} to 4.6×10^{-4}	$\sim2.0\times10^{-6}$	1.6×10^{-4}	5.3×10^{-4} to 6.2×10^{-4}

Note: Assumes 500 truck miles (805 truck kilometers) traveled from destination port. Also assumes that accidents are more frequent in the destination country; the rate for foreign truck accidents is twice the rate of domestic truck accidents.

The frequencies presented in Table 2–15 are all moderate; whereas, for the consolidation case in Table 2–9, the comparable frequencies are all low.

2.4 SUMMARY OF EVENT FREQUENCIES

Table 2–16 summarizes the analysis of event frequencies, which is an important precursor to the remaining portions of the risk assessment.

Table 2–16. Summary of Onsite And Offsite Frequency of Hazardous Events

Hazard	Activity	Postulated Scenario	Frequency of Release	Evaluated Further	Comments
Toxic	Onsite storage	Slow leak/release of liquid mercury	High	Yes	Requires failure of welded seam in older style flask.
Fire	Onsite storage	Building fire involving multiple flasks/pallets	Negligible	No	No ignition sources other than forklift fuel.
Fire	Onsite material handling	Fire involving forklift fuel system engulfs single pallet	Negligible (no action) Low (consolidation and sales)	No	Fire limited to single pallet by fire suppression system.
Fire/explosion nearby	All activities	Fire/explosion at nearby building impacts mercury containers	Negligible	No	No facilities located within 200 ft (61 m). Firewall separates mercury storage area from remainder of warehouse.
Wildfire	All activities	Wildfire consumes warehouse	Negligible	No	Although wildfires are common, fire monitoring, prevention and suppression systems eliminate likelihood of mercury release.

Table 2–16. Summary of Onsite And Offsite Frequency of Hazardous Events (Continued)

Hazard	Activity	Postulated Scenario	Frequency of Release	Evaluated Further	Comments
Kinetic	Onsite material handling	Single flask dropped during handling resulting in breach	Moderate (except High at Oak Ridge)	Yes	Single flasks not expected to be handled for 39 years after overpacking.
Kinetic	Loading	Single pallet dropped during loading resulting in breach	Moderate (no action) to High (consolidation and sales)	Yes	Requires failure of both flasks and overpack drums (where overpack is used).
Kinetic	Onsite material handling	Double pallet dropped during loading resulting in breach	Negligible	No	Requires failure of both flasks and overpack drums (where overpack is used).
Earthquake	All activities	Earthquake results in building damage and causes pallets and/or flasks to fall and spill	Moderate	Yes	Requires an earthquake and failure of flasks, overpack drums (if used), and fire suppression systems.
Weather	All activities	High winds or tornadoes result in roof failure and cause pallets and/or flasks to fall	Low (tornados) to Negligible (high winds)	Yes	Requires failure of both flasks and overpack drums (where applicable). Represented by earthquake scenario.
Weather	All activities	Lightning strike causes small building fire involving limited number of mercury containers	Negligible	No	Lightning strike as initiator of building fire not considered credible.
Weather	All activities	Snow load causes roof collapse resulting in mercury containers falling	Negligible	Yes	Requires failure of both flasks and overpack drums (where overpack is used). Represented by earthquake scenario.
Surface transportation	Onsite storage	Vehicle or train crash into building resulting in mercury container breach	Negligible	No	Concrete block construction precludes significant damage.
Surface transportation	Offsite transport	Truck or train crash during transportation of mercury with fire	Low (consolidation) Low (sales, rail) Moderate (sales, truck)	Yes	Impact breaches flasks, with spill and fire occurring after crash.
Surface transportation	Offsite transport	Truck or train crash with mercury spill (no fire)	Moderate	Yes	Impact breaches flasks with sudden evaporation
Surface transportation	Offsite transport	Truck or train crash with mechanically induced fatality	Low	Yes	Impact causes fatality
Surface/ocean transportation	Offsite transport	Truck, train, or oceangoing vessel crash with spill into waterbody	Negligible	No	Truck and rail travel near waterbodies is a very small fraction of miles traveled. Breach of shipping container, overpack drum (likely to be used here), and flasks during ocean transport very unlikely.
Aircraft crash	All activities	Aircraft crash into building resulting in fire, mercury container breach	Negligible	No	Limited target area given type of aircraft, flight vectors, and size of storage area within building.

2.5 OTHER TRANSPORTATION ELEMENTS AND ENVIRONMENTAL IMPACTS

Another element considered in the environmental impact of transportation operations associated with the Consolidated Storage Alternative is the volume or amount of air pollutants emitted. The EPA threshold for environmental significance is the emission of 100 tons (91 metric tons) or more of specific air pollutants within a designated clean air attainment area. None of the transportation activities envisioned under the Consolidated Storage Alternative exceeds the EPA threshold for carbon monoxide, particulate material, or nitrogen oxides in nonattainment or maintenance areas of 100 tons (91 metric tons) per year.

The rate at which air pollution is generated is dependent on the amount of fuel burned. The rate at which carbon dioxide is emitted is approximately 20 lbs (9.1 kg) of carbon dioxide per gallon of fuel burned (CDIAC 2002). Fuel consumption is based on the *Highway Statistics Table* VM-1 (FHA 1994).

- Fuel mileage average, commercial truck 6.0 mi (9.7 m) per gallon.
- Average rail fuel usage equals 233 ton-kilometers per gallon of fuel or 375 revenue ton-miles per gallon of fuel. Based on an average of 90 railcars per trainload, this translates to an average of 3.75 railcar miles per gallon of fuel, which would translate to an estimated 9 truck-miles per gallon (or approximately 50 percent greater fuel efficiency than over-the-road truck) based on data reported by *Association for American Railroads Environmental Facts at a Glance*. The fraction of the total cargo that is mercury in trains and ships is anticipated to be very small, and thus only a small fraction of the noted fuel consumption would be attributed to transporting the mercury.

It is also important to understand the amount of fuel used under each scenario because this could be fuel devoted to other enterprises or alternative goals. The estimated fuel use neither represents a significant portion of the nation's current fuel supply, fuel usage rates, nor is it enough to cause local fuel rate fluctuations or price spikes over the expected 1-yr duration of shipping. The estimated fuel usage is shown in Tables 2–17 through 2–19.

Table 2–17. Fuel Consumption for Consolidated Storage Transportation Activities

Consolidated Storage Location	Truck Miles	Total Truck Fuel (gallons[a])	Rail Miles	Total Rail Fuel (gallons[b])
New Haven, IN	141,533	23,589	88,128	23,501
Somerville, NJ	72,718	12,120	45,689	12,184
Warren, OH	104,536	17,423	70,015	18,671
Hawthorne, NV	770,816	128,469	414,849	110,626
Romulus, NY	117,400	19,567	75,634	20,169
Tooele, UT	616,478	102,746	351,373	93,699

[a] At 6 mi/gal.
[b] At 3.75 mi/gal.
Note: Total fuel = miles/fuel mileage average.

Table 2–18. Fuel Consumption for Sales Transportation Activities

	To Port of New York				To Port of San Francisco			
Sales Activities Location	Highway Miles	Total Truck Fuel (gallons[a])	Rail Miles	Total Rail Fuel (gallons[b])	Highway Miles	Total Truck Fuel (gallons[a])	Rail Miles	Total Rail Fuel (gallons[b])
New Haven, IN	25,342	4,224	15,166	4,044	88,854	14,809	46,754	12,468
Somerville, NJ	8,308	1,385	3,813	1,017	521,334	86,889	277,059	73,882
Warren, OH	16,158	2,693	10,484	2,796	97,683	16,281	50,192	13,385
Oak Ridge, TN	35,839	5,973	14,450	3,853	123,784	20,631	66,398	17,706

[a] At 6 mi/gal.
[b] At 3.75 mi/gal.
Note: Total fuel = miles/fuel mileage average.

Table 2–19. Fuel Consumption for Overseas Transportation Activities

Overseas Location	Truck Miles	Total Truck Fuel (gallons[a])
New York to Amsterdam	154,000	25,667
New York to Bombay via Suez Canal	154,000	25,667
New York to Bombay via Panama Canal	154,000	25,667
San Francisco to Bombay	154,000	25,667

[a] At 6 mi/gal.
Note: Total fuel = miles/fuel mileage average.

Other statistics used to determine average air pollution emissions (including carbon monoxide and oxides of nitrogen) are based on 1998 through 2000 models (EPA 2002b) and are listed below.

- Carbon monoxide = 10.33 g/mi for low altitude (roughly 500 ft [152 m] above mean sea level) and 17.47 g/mi for high altitude (roughly 5,500 ft [1,676 m] above mean sea level)
- Oxides of nitrogen = 6.49 g/mi for low and high altitude

All transportation is assumed to occur at low altitude, with the exception of transport to Hawthorne Army Depot, Utah Industrial Depot, and the Port of San Francisco. Trips made to those facilities are assumed to encounter high altitudes 25 percent of the time. This is shown in Tables 2–20 through 2–23, which also compares estimated transportation emissions of selected air pollutants and carbon dioxide into the environment. Vehicle emissions for foreign locations are considered to be similar to those produced domestically.

Table 2–20. Vehicle Emissions for Consolidation Transportation Activities

Consolidated Storage Location	Truck Highway Miles	Low Altitude Miles	High Altitude Miles	Rail Miles	Total Truck CO_2 (tons)	Total Rail CO_2 (tons)	Truck CO (tons)	Total Truck NO_x (tons)
New Haven, IN	141,533	141,533	NA	88,128	236	235	1.46	0.92
Somerville, NJ	72,718	72,718	NA	45,689	121	122	0.75	0.47
Warren, OH	104,536	104,536	NA	70,015	174	187	1.08	0.68
Hawthorne, NV	770,816	578,112	192,704	414,849	1,285	1,106	9.34	5.00
Romulus, NY	117,400	117,400	NA	75,634	196	202	1.21	0.76
Tooele, UT	616,478	462,358	154,119	351,373	1,027	937	7.47	4.00

Key: CO, carbon monoxide; CO_2, carbon dioxide; NA, not applicable; NO_x, nitrogen oxides.

Table 2–21. Vehicle Emissions for Sales Transportation Activities to Port of New York

Sales Activities at Port of New York	Truck Highway Miles	Low Altitude Miles	High Altitude Miles	Rail Miles	Total Truck CO_2 (tons)	Total Rail CO_2 (tons)	Truck CO (tons)	Total Truck NO_x (tons)
New Haven, IN	25,342	25,342	NA	15,166	42	40	0.26	0.16
Somerville, NJ	8,308	8,308	NA	3,813	14	10	0.09	0.05
Warren, OH	16,158	16,158	NA	10,484	27	28	0.17	0.10
Oak Ridge, TN	35,839	35,839	NA	14,450	60	39	0.37	0.23

Key: CO, carbon monoxide; CO_2, carbon dioxide; NA, not applicable; NO_x, nitrogen oxides.

Table 2–22. Vehicle Emissions for Sales Transportation Activities to Port of San Francisco

Sales Activities to Port of San Francisco	Truck Highway Miles	Low Altitude Miles	High Altitude Miles	Rail Miles	Total Truck CO_2 (tons)	Total Rail CO_2 (tons)	Truck CO (tons)	Total Truck NO_x (tons)
New Haven, IN	88,854	66,640	22,213	46,754	148	125	1.08	0.58
Somerville, NJ	521,334	391,001	130,334	277,059	869	739	6.32	3.38
Warren, OH	97,683	73,262	24,421	50,192	163	134	1.18	0.63
Oak Ridge, TN	123,784	92,838	30,946	66,398	206	177	1.50	0.80

Key: CO, carbon monoxide; CO_2, carbon dioxide; NA, not applicable; NO_x, nitrogen oxides.

Table 2–23. Vehicle Emissions for Overseas Transportation Activities

Overseas Activities	Truck Highway Miles	Low Altitude Miles	High Altitude Miles	Total Truck CO_2 (tons)	Truck CO (tons)	Total Truck NO_x (tons)
New York to Amsterdam	154,000	154,000	NA	257	1.59	1.00
New York to Bombay via Suez Canal	154,000	154,000	NA	257	1.59	1.00
New York to Bombay via Panama Canal	154,000	154,000	NA	257	1.59	1.00
San Francisco to Bombay	154,000	154,000	NA	257	1.59	1.00

Key: CO, carbon monoxide; CO_2, carbon dioxide; NA, not applicable; NO_x, nitrogen oxides.

Chapter 3
Human Toxicity Assessment for Mercury

In 1997, EPA conducted a comprehensive assessment of mercury toxicity as part of its Mercury Report to Congress (EPA 1997a). The report assessed the toxicity of elemental mercury, inorganic mercury (or mercury salts), and methyl mercury. Much of the information is also summarized on EPA's Integrated Risk Information System (IRIS: www.epa.gov/iris). In addition, the National Research Council completed a comprehensive assessment of the toxicity of methyl mercury in 2000 (NRC 2000). EPA revised its assessment of methyl mercury toxicity in July 2001, publishing revised oral reference doses (EPA 2002c). The following sections provide a brief overview of mercury toxicity in these three general forms.

3.1 TOXICITY OF ELEMENTAL MERCURY

The route of exposure (e.g., ingestion, dermal, inhalation) is an important consideration in assessing elemental mercury toxicity. Elemental mercury is poorly absorbed in the human gastrointestinal tract and does not, consequently, exhibit significant oral toxicity. In contrast, elemental mercury is readily absorbed through the lungs (estimated absorption is 75 to 85 percent) and is expected to account for 97 percent of the total dose of elemental mercury vapor absorbed by an individual. The remaining 3 percent is expected to be absorbed through the skin.

Once absorbed, elemental mercury is readily distributed throughout the body, crossing both the placental and blood-brain barriers. Subsequent oxidation by the hydrogen peroxidase-catalase pathway may cause the mercury to become irreversibly retained in body compartments such as brain tissue. Unconverted elemental mercury is eliminated via urine, feces, and expired air.

EPA (1997a) concluded that inhaled elemental mercury causes a range of adverse neurological effects at low exposure levels including:

- Tremors
- Emotional liability (changeable; irritability, excessive shyness, loss of confidence and nervousness)
- Insomnia
- Muscle weakness, twitching, and atrophy
- Headaches
- Polyneuropathy (a disease process involving a number of peripheral nerves)
- Impairment of cognitive function

According to EPA, at higher-level exposures, elemental mercury may result in adverse renal effects and pulmonary dysfunction. Effects of mercury exposure on renal function were observed in one study at concentrations that are consistent with those known to cause neurological effects. EPA also concluded that sufficient animal data are available to establish potential adverse reproductive and developmental effects. However, the data are insufficient to quantify the degree of the hazard.

Regarding the potential carcinogenicity of elemental mercury, EPA concluded that the available data does not support a classification as to human carcinogenicity. The available human epidemiological studies

have significant limitations and the data from the only available animal study is considered inadequate. The limited available data from genotoxicity studies do not support the existence of a carcinogenic effect.

3.2 TOXICITY OF INORGANIC MERCURY

In keeping with EPA practice, the toxicity of inorganic mercury is assessed based on the toxicity of mercuric chloride. In contrast to elemental mercury, as much as 20 percent of inorganic mercury salts are absorbed through the gastrointestinal tract. About 85 percent of inorganic mercury is eliminated in feces within a few days of ingestion. Dermal absorption of mercuric chloride was measured at 2 to 3 percent in guinea pigs. Mercury absorption from inhaled aerosols was measured at 40 percent in dogs.

Inorganic mercury does not distribute as readily throughout the body as elemental mercury. Inorganic mercury has a limited capacity to cross the blood-brain and placental barriers. The principal adverse effect of low-level exposures to inorganic mercury is kidney disease consequent to autoimmune glomerulonephritis (EPA 2002d). At higher levels, inorganic mercury exposures are associated with peripheral and motor neurotoxicity in addition to renal impairment. There is limited evidence indicating that inorganic mercury exposures may have adverse development effects as well.

EPA classifies mercuric chloride as a “possible human carcinogen” based on the absence of human data and limited evidence of carcinogenicity in rats and mice.

3.3 TOXICITY OF METHYL MERCURY

Methyl mercury is a highly toxic substance that is readily absorbed through the gastrointestinal tract (ATSDR 1999; EPA 2002c, 2002d). Once in the body, it readily passes into the adult and fetal brain where it accumulates and is subsequently converted to inorganic mercury. Consequently, the nervous system is considered to be the critical target organ system for methyl mercury toxicity. The nervous system of developing organisms is considered of special concern.

Chronic, low-dose exposures to methyl mercury in fish have been associated with subtle, neurotoxic endpoints in children, including poor performance on neurobehavioral tests of attention, fine motor function, visual-spatial abilities, and verbal memory. The effects of concern at high doses include mental retardation, cerebral palsy, deafness, blindness, speech impairments, and sensory and motor impairments. There is also evidence indicating that methyl mercury exposure can have adverse cardiovascular effects, possibly at exposure levels below those associated with neurological effects. There is additional evidence indicating that methyl mercury exposure may have adverse effects on the immune and reproductive systems. Based on “inadequate” data in humans and limited data in animals, EPA classifies methyl mercury as a “possible human carcinogen,” although there is no cancer slope factor available from EPA to assess cancer risks.

3.4 HUMAN RECEPTORS AND BENCHMARKS

This section describes the receptors that were chosen for the human health analysis and the benchmarks applied to the exposure point concentrations (EPCs).

3.4.1 Receptors

At each site, three receptors are considered—the public, facility workers, and collocated workers. The facility workers are those inside the storage warehouse. The collocated worker is someone who does not specifically work on the mercury itself, but is nearby. The public receptor is the closest offsite individual, often conservatively taken to be at the site boundary. The locations of the public receptor and the collocated worker are site-specific and are shown in Table 3–1.

Table 3–1. Distance to Receptor at Mercury Storage Locations

Facility	Description	Distance (m)
New Haven Depot[a]	South fence	150
Somerville Depot[b]	East fence	100
Warren Depot	East fence	60
Y–12	South fence	250
Hawthorne Army Depot	Nearest fence	3,700
PEZ Lake Development	Nearest fence	181
Utah Industrial Park	Nearest fence	406

[a] Collocated worker in depot offices is approximately 2,200 ft (671 m); a more conservative value of 500 ft (152 m) is used.

[b] Collocated worker in administrative office is approximately 2,000 ft (610 m); a more conservative value of 330 ft (101 m) is used.

3.4.2 Benchmarks

There are five benchmark quantities used in the human health analysis—

- Acute health effects among workers exposed to concentrations of mercury in air
- Acute health effects among members of the public exposed to concentrations of mercury in air
- Chronic health effects among workers exposed to concentrations of mercury in air
- Chronic health effects for the public exposed to concentrations of mercury in air
- Chronic health effects for the public exposed to concentrations of mercury deposited on soil

3.4.2.1 Workers – Acute Exposures

The National Institute for Occupational Safety and Health (NIOSH) IDLH (see Section 1.1.1) is an exposure concentration from which the worker can be expected to escape within 30 min in the event of a failure of respiratory equipment. For inorganic mercury, the IDLH is 10 mg/m^3, and this is chosen as the benchmark for acute worker exposures. There is also an IDLH of 2 mg/m^3 for organic mercury compounds, but for releases from storage facilities or transportation, mercury is released in elemental form; and there is no potential for it to convert to organic compounds of mercury until after it has been deposited.

3.4.2.2 Public Receptors – Acute Exposures

The benchmark for public receptors exposed to inorganic mercury is 0.2 ppm or 1.67 mg/m^3, which is the second-level ERPG-2 published by the AIHA. This is the maximum concentration in air below which it is believed that nearly all individuals could be exposed without experiencing or developing irreversible or

other serious health effects or symptoms that could impair their abilities to take protective action. As for the case of the worker, acute exposures to organic mercury are not considered.

3.4.2.3 Chronic Health Effects – Airborne Pathway

For evaluation of chronic effects related to exposures to mercury released from the stockpile via air, the value of 50,000 ng/m^3 was selected as the health-based benchmark for onsite workers. The general industry permissible exposure limit (PEL) for mercury vapor established by the Occupational Safety and Health Administration (OSHA) is 100,000 ng/m^3 (29 CFR 1910.1000). The PEL is a ceiling limit not to be exceeded at any time. The NIOSH recommended exposure limit (REL) is 50,000 ng/m^3 on a time-weighted-average (TWA) basis, with a ceiling limit of 100,000 ng/m^3. Referencing the 1992 American Conference of Governmental Industrial Hygienists (ACGIH), OSHA indicates that the ACGIH 8-hr TWA threshold limit value (TLV) for mercury vapor is 25,000 ng/m^3 (OSHA 2002). However, EPA indicates that the ACGIH 8-hr TWA threshold limit value is 50,000 ng/m^3 (EPA 1999a). The REL was selected as the benchmark rather than the PEL because the PEL is a ceiling limit, wherein the REL represents the more restrictive, longer-term limit. The uncertainty in the ACGIH value precluded its use as a benchmark.

The appropriate benchmark for offsite individuals is the EPA reference concentration of 300 ng/m^3. As explained in Appendix A, concentrations below this level are considered negligible.

3.4.2.4 Chronic Health Effects – Soil Pathway

For evaluation of chronic effects related to exposures to residual contamination in soil after deposition via air, the starting point is the *EPA Soil Screening Levels*. These are health-based values for total organic or inorganic mercury in soil. They are considered to be protective of ingestion exposures to the public.

In contrast to the case of inhalation exposures, there are no separate occupational standards for ingestion of mercury. Consequently, the same benchmarks for ingestion are applied to workers and the general public. Table 3–2 presents the health-based toxicity values for oral and inhalation exposures to mercury compounds established by EPA (EPA 2002a, 2002c, 2002d).

Table 3–2. EPA Toxicity Values for Mercury Compounds

Substance	RfD (μg/kg/d)	RfC (μg/m^3)
Elemental mercury	NA	0.3
Mercuric chloride	0.3	NA
Methyl mercury	0.1	NA

Key: NA, not applicable; RfC, reference concentration; RfD, reference dose.

RfDs and RfCs are based on the assumption that thresholds exist for certain toxic effects. For comparison purposes only, the elemental mercury RfC roughly equates to the methyl mercury RfD under the exposure assumption commonly used in EPA risk assessments (i.e., 20 m^3/day inhalation rate and a 154 lb [70-kg] body weight) (EPA 1997a).

Responses to accidental releases of mercury would be subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In 1996, EPA published guidance on deriving human-health-based soil screening levels (SSLs) for use in the Superfund program (EPA 1996a, 1996b). In general, SSLs represent concentrations below which no further study or action is warranted under CERCLA. As required by the statute, SSLs represent a level of contamination that is considered by EPA to be protective of human health.

The guidance established procedures for calculating generic and site-specific SSLs. EPA provides two generic SSLs for mercury, one for ingestion of mercury in soil (23 mg/kg) and one for inhalation of volatilized mercury (10 mg/kg). The former is based on the RfD for mercuric chloride while the latter is based on the RfC for elemental mercury. Both are based on conservative exposure assumptions for a child in a residential exposure setting. The value of 23 mg/kg was selected as the health-based benchmark for use in this analysis because it is conservatively based in terms of exposure assumptions, employs the lowest applicable EPA RfD as the applicable toxicity value, and is below the values considered protective of human health by EPA. The use of such a benchmark is a simplified approach that eliminates the need to explicitly account for frequency and duration of exposure as well as other applicable receptor characteristics because these factors are built into the benchmarks.

The benchmark used for evaluating human exposures is applied to the estimates of total mercury in soil. Consideration was given to using an adjusted SSL based on methyl mercury toxicity rather than mercuric chloride toxicity. At first glance, this would have resulted in a lower screening level. However, methyl mercury is unlikely to be released under the fire conditions analyzed here and divalent mercury is slow to transform into methyl mercury. Under these conditions the mass of mercury locally released to soil as methyl mercury is likely to be insignificant. Consequently, the value of 23 mg/kg was retained.

3.4.2.5 Summary of Human Health Benchmarks

The selected human health benchmarks for acute and chronic exposures to workers and the public are summarized in Table 3–3.

Table 3–3. Summary of Human Health Benchmarks

Medium	Exposure	Receptor	Benchmark	Source
Air	Acute	Worker	10 mg/m^3	NIOSH IDLH
		Public	1.67 mg/m^3	ACGIH ERPG-2 (2 ppm)
	Chronic	Worker	0.05 mg/m^3	NIOSH REL (8-hr TWA)
		Public	0.3 μg/m^3	EPA Reference Concentration
Soil	Chronic	Worker and public	23 μg/kg soil	EPA Soil Screening Level

Key: ACGIH, American Conference of Governmental Industrial Hygienists; ERPG-2, second-level Emergency Response Planning Guidelines; IDLH, immediately dangerous to life and health; NIOSH, National Institute for Occupational Safety and Health; REL, recommended exposure limit.

Different health-based benchmarks apply to site workers and offsite individuals due to the limited duration of occupational exposures (about 8 hours per day) as compared to the 24-hour-per-day duration of exposures assumed for the general public. The assessment is conducted by comparing the estimated concentrations in environmental media to the health-based criteria for inorganic and organic forms of mercury.

Chapter 4
Exposure Assessment and Human Risk Analysis

This chapter describes the methods used to calculate the exposures to human receptors for each alternative and provides estimates of the magnitude of the consequence associated with each exposure scenario. Ecological consequences are evaluated in Chapter 5. Table 2–16 summarizes the scenarios that remain after the frequency screening analysis in Chapter 2. Exposures are evaluated using modeled estimates of airborne and deposited concentration or EPCs at various receptor locations. The comparison of benchmarks and EPCs are then used to assign EPCs to high, moderate, low, or negligible consequence categories. Finally, the frequency (high, moderate, low, or negligible) of the exposure event is considered in conjunction with the consequence to reach a determination of risk (also high, moderate, low, or negligible) to the receptor.

4.1 SLOW LEAK DURING NORMAL OPERATING CONDITIONS

This pathway applies to any alternative or location in which the mercury is stored for an extended period of time. Exposures could arise during normal operating conditions from small amounts of elemental mercury vapor escaping from storage containers. Mercury vapor transported downwind could then be inhaled by site workers (at or nearby the stockpile) or nearby offsite individuals. Because the mercury escapes as elemental mercury vapor, virtually no deposition of mercury will occur so that mercury inhalation is the only exposure route of concern.

The most commonly used methods to estimate human exposure to airborne gases, vapors, and particles from individual sources are the Gaussian plume models. The Gaussian plume model used in this risk assessment is described in Appendix A.

In routine use, the Pasquill-Gifford model requires the rate of release of mercury from the containers, which is not available and is not readily estimated for slow leaks. However, the Pasquill-Gifford model can also be used to calculate "dilution factors" which describe the change in pollutant concentrations as a function of distance. If the pollutant concentration (C) at a baseline point (x_0, y_0, z_0) is known (or estimated) then the concentration at another point (x,y,z) can be estimated using the model as follows:

$$C(x,y,z) = C(x_0, y_0, z_0) \times \left[C_{est}(x,y,z) \Big/ C_{est}(x_0, y_0, z_0) \right]$$

Where $C_{est}(x,y,z)$ is the concentration at location (x,y,z) estimated using the model with a release rate of 1 mg/s and a wind speed of 1 m/s.

The ratio of the estimated initial upwind and projected downwind concentrations is the dilution factor. An important aspect of dilution factor method is that the estimated value does not depend on the release rate and wind speed assumptions. Because these are multiplicative factors in the Pasquill-Gifford model, they cancel out when the ratio is taken. The dilution factor depends solely on the location and the associated dispersion parameters values, and an assumed initial concentration at the baseline location.

The dilution factor method requires information about the magnitude and location of the initial concentration, receptor locations, and dispersion parameters as a function of location. As a worst-case for purposes of analysis, an initial upwind mercury concentration of 25,000 ng/m^3 is assumed to exist as a long-term average mercury concentration a short distance downwind of the building vent (see Section 6.1.1). This high concentration is very unlikely to occur at depots where the flasks have been

inspected, cleaned, and placed in overpack drums. This worst-case assumption is an upper tolerable threshold that is protective of anticipated activities (e.g., reflasking activities at year 39) and storage conditions (e.g., no overpacking) presuming that the air is monitored on a regular basis.

The horizontal distance of the initial location from the vent is set equal to the vertical height of the vent at each storage site. A shorter initial distance from the vent would result in greater projected dilution, as well as potentially violating certain aspects of the Gaussian plume model. A longer initial distance from the vent would not reflect the physical realities of dispersion as a function of downwind distance, since the concentrations are expected to decrease as the vapor moves downwind from the vent toward the initial modeled location. The assessment is inclined to overestimate downwind concentrations because the mercury concentrations inside the warehouses will rarely if ever exceed the limit of 25,000 ng/m^3, and then only for short periods of time because intervention to minimize the release would occur.

Estimates of the EPCs for elemental mercury vapor at each receptor location are presented in Table 4–1. The results for slow leaks of mercury vapor apply for all three alternatives—No Action, Consolidated Storage, and Sales. The EPCs are estimated for a vertical height of 5 ft (1.5 m), corresponding to the "breathing zone" of an average individual. These concentrations are based on Atmospheric Stability Class D with wind speed of 14.8 ft/s (4.5 m/s). This category is used to predict the chronic releases and long-term concentration averages. The averages used to estimate exposure occur over periods during which the weather conditions will cover the full range of what would be observed over time. Class D was selected as representative of those average weather conditions, and the predicted average concentration is also reasonable for average weather conditions.

As shown in the table, the unitless dilution factors used to estimate the EPCs are small, ranging from about 0.000055 to 0.0055. Consequently the EPCs, ranging from 1 ng/m^3 to 138 ng/m^3, are significantly attenuated from the initial concentration of 25,000 ng/m^3. These EPCs are negligible relative to the chronic benchmark of 50,000 ng/m^3 for the workers and the 300 ng/m^3 for public receptors.

The estimated EPCs for all onsite workers fall orders of magnitude below the specified benchmark into the negligible category for the severity of consequence. The EPCs for the offsite receptors (i.e., members of the public) are compared to a much more sensitive benchmark, and are tied directly to the nearest distance to the facility fence line (i.e., the closest hypothetical offsite receptor). The consequences are also negligible for all offsite receptors.

Elemental mercury is unlikely to deposit on the local meteorological scale (up to distances of about 6 mi [9.6 km] from its source) (see Appendix A). Beyond the local scale, the magnitude of mercury releases from the depot will be indistinguishable from mercury in the background. Local human health effects arising from slow leaks of mercury during normal operations are likely to be minimal because the slow leaks will be in the form of elemental mercury. The dry deposition velocity and the scavenging rate in rain for elemental mercury are essentially zero (EPA 1997b) and thus elemental mercury will not deposit locally. This issue is further discussed in Appendix A.

Table 4–1. Human Receptor Exposure Point Concentrations Due to Slow Leaks of Mercury Vapor

Site	Vent Height (ft)	Vent Height (m)	Receptor	Site	EPC Location (m)	Dilution Factor (Unitless)	Initial Concentration (ng/m^3)	EPC (ng/m^3)	Benchmark (ng/m^3)	Ratio
			Onsite worker							
New Haven	15	4.57		New Haven	150	0.0017	25,000	43	50,000	0.0009
Warren	16	4.88		Warren	60	0.0055	25,000	138	50,000	0.003
Somerville	16.5	5.03		Somerville	100	0.0036	25,000	90	50,000	0.002
Y–12	13	3.96		Y–12	250	0.00056	25,000	14	50,000	0.0003
Hawthorne Army Depot	35	10.7[a]		Hawthorne Army Depot	3,700	0.000049	25,000	1	50,000	0.00002
PEZ Lake Development	15	4.57		PEZ Lake Development	181	0.001279	25,000	32	50,000	0.0006
Utah Industrial Depot	4	1.22		Utah Industrial Depot	406	0.000023	25,000	0.6	50,000	0.00001
			Offsite individual							
				New Haven	150	0.0017	25,000	43	300	0.1
				Warren	120	0.0027	25,000	68	300	0.2
				Somerville	100	0.0036	25,000	90	300	0.3
				Y–12	960	0.000055	25,000	1	300	0.005
				Hawthorne Army Depot[b]	3,700	0.000049	25,000	1	300	0.004
				PEZ Lake Development[b]	181	0.001279	25,000	32	300	0.1
				Utah Industrial Depot[b]	406	0.000023	25,000	0.6	300	0.002

[a] Assumed vertical height (so site-specific data available).
[b] Assumed offsite location at the fence line.

Note: For the public, any concentration below 300 ng/m^3 is negligible, see Section 3.4.2.3. For the worker, consequence levels correspond to the following ratios:

>10 is a high consequence level
>1 and ≤10 are moderate consequence levels
>0.1 and ≤1 are low consequence levels
≤0.1 is a negligible consequence level

4.2 ONSITE ACCIDENTS

This section discusses the methods used to evaluate onsite accidents involving releases of mercury, and includes a simple spill, and a spill occurring in conjunction with a fire. Concentrations are projected for a range of distances from the source of contamination and are thus applicable to any given storage location. Site-specific factors are provided when appropriate.

4.2.1 Spill with No Fire

In Table 4–2, there are three scenarios of more-than-negligible event frequency that involve the spill of mercury at ambient temperature—single flask spill, single pallet spill, and earthquake spill. Exposures due to spills of mercury are based on evaporation from an exposed liquid pool under ambient conditions within the warehouse. Evaporation flux is based on parameters such as material vapor pressure and molecular weight, air velocity inside the building, pool temperature, and spill area as described in *Handbook of Chemical Hazard Analysis Procedures* (FEMA 1988). Spill area is estimated based on amount of mercury spilled or is limited by physical constraints such as the area of the catch tray. Spill area estimates are conservative for high specific gravity liquids such as mercury because the correlation used to estimate spill area is based on spills of more free-flowing liquids (FEMA 1988).

Table 4–2. Exposure Point Concentrations in Air and Human Benchmark Ratios for Accidental Spills at Mercury Stockpile

Event	Receptor	Receptor Location	EPC (mg/m^3)	Benchmark (mg/m^3)	Ratio	Consequence Level
Single flask spill	Facility worker	Within facility	0.16	10	0.02	Negligible
(All alternatives)	Onsite worker	60 m	0.016	10	0.002	Negligible
	Public	120 m	0.00451	1.67	0.003	Negligible
Single pallet spill	Facility worker	Within facility	0.84	10	0.08	Negligible
(All alternatives)	Onsite worker	60 m	0.0858	10	0.009	Negligible
	Public	120 m	0.024	1.67	0.01	Negligible
Earthquake spill	Facility worker	Within facility	4.24	10	0.4	Low[a]
(No Action Alternative)	Onsite worker	60 m	0.433	10	0.04	Negligible[a]
	Public	120 m	0.121	1.67	0.07	Negligible[a]
Earthquake spill	Facility worker	Within facility	11.8	10	1.2	Moderate[a]
(Consolidated Storage Alternative)	Onsite worker	60 m	1.3	10	0.13	Low[a]
	Public	120 m	0.35	1.67	0.21	Low[a]

[a] An earthquake of sufficient magnitude to cause building collapse and mercury release is also likely to cause fatalities to workers and the public.

Note: Consequence levels correspond to the following ratios:

>10 is a high consequence level
>1 and ≤10 are moderate consequence levels
>0.1 and ≤1 are low consequence levels
≤0.1 is a negligible consequence level

Involved workers will be trained to evacuate the area to minimize their exposure.

Given a spill of mercury inside a building, the liquid is expected to evaporate and the vapor vented from the building by prevailing winds entering at ground level through open doors. The release point is likely to be elevated at the roofline. A Gaussian plume dispersion model is used for the onsite receptor locations and for public receptor locations at the site boundaries (see Appendix A). Atmospheric Stability Class D is used with wind speed of 14.8 ft/s (4.5 m/s) as a simple analysis for this report. In principle, calculations should be performed over a range of weather conditions. Overall risk should be determined by plotting a cumulative frequency distribution of the consequences under certain weather conditions versus the likelihood of the weather conditions, or by calculating the weighted sum of the consequences. This weighted sum would be an average over many weather conditions, not just the worst-case. This report emulates that more complex approach by using clear and simple estimates based on average weather conditions, weighted by the total probability of occurrence of all weather conditions.

For workers in the immediate vicinity of the spill within the building, the airborne material is assumed to be dispersed instantaneously into a hemisphere 33 ft (10 m) in diameter. This is a conservative assumption because natural convection currents inside the building are likely to quickly dilute any airborne material into a larger volume. The worker walks through the hemisphere at a rate of 3.3 ft/s (1.0 m/s) for a maximum exposure time of 10 seconds. This time is based on professional judgment for trained workers to escape from the immediate vicinity of an accidental spill.

With regard to conditions inside the storage building, review of mercury inspection reports for the Warren Depot from December 1999 through June 2000 showed that the highest temperature recorded inside the warehouse was 74 °F (23 °C). A more limited set of readings from the New Haven Depot showed the highest recorded temperature of 76 °F (24.5 °C) during the period from September 1999 through

March 2000. The temperature assumed for the mercury evaporation model is 68 °F (20 °C), which is slightly lower than these readings for air temperature. Because mercury possesses a very large heat capacity, its temperature will lag behind that of the air in the warehouse.

Results of the analysis of human health related to the accidental onsite spill are shown in Table 4–2. For the single-flask and single pallet-spill, the EPCs are negligible both for workers and the public. For the earthquake spill under the No Action Alternative, the consequence for a worker in the immediate vicinity of the spill is low. This is mitigated by the fact that the IDLH applies to a tolerable exposure by a person for up to 30-min exposure time, so qualitatively there is some margin to expect that the exposure in a real-world situation would be much less for a person escaping a spill event. For the earthquake spill under the Consolidated Storage Alternative, the consequence for a worker in the immediate vicinity of the spill would be moderate, while the consequence level for the onsite worker and the public would be low. The consequences for the Consolidated Storage Alternative would be more severe than the No Action Alternative because a larger amount of mercury is at risk and assumed to be spilled.

4.2.2 Onsite Spill with Fire

The forklift fuel fire scenario envisions a spill of mercury with an ensuing fire, and the release of mercury into the atmosphere with subsequent transport downwind. Elemental mercury released as a result of such an accident is expected to remain airborne and transported far beyond the study area. Divalent mercury, which may be formed at high temperatures during such a fire, is expected to deposit significantly within the study area either as a result of dry deposition or rainfall scavenging (wet deposition). Once deposited, the mercury is expected to mix completely within the top 2 in (5.1 cm) of soil.

Fire characteristics, such as burn rate and toxic combustion gases, are dependent upon the fuel(s) being burned and contaminants present in the fuel. The exact characteristics of a fire in the warehouse are unknown. Therefore, the accident analysis must be based on bounding assumptions.

In the postulated fire, products of combustion at high temperature may cause overheating and collapse of the roof. This allows inflow of air (oxygen) to maximize combustion rates and allows the combustion products to rise vertically due to their buoyancy. The elevated plume is carried downwind and the combustion products diffuse away from the plume centerline, including downward towards the ground. Input parameters used to calculate emissions from a fire are presented in Table 4–3, which lists the values of various parameters for calculating downwind concentrations for a forklift fire on site. Appendix A, Section 2 discusses fire modeling and illustrates how these quantities are calculated for a similar scenario, the railcar fire.

In the immediate vicinity of the fire, convection currents and downdrafts can cause high concentrations of combustion product at ground level beneath the plume centerline. At greater distances, ground-level concentrations become small due to the higher plume elevation. Over flat terrain, ground-level concentrations increase with distance, reach a maximum, and then decrease. In comparison with non-buoyant plumes, buoyant plumes produce lower ground concentrations due to the elevation of the plume centerline.

For purposes of computing maximum mercury vapor concentrations, a downwind receptor is assumed to be located at the point of maximum concentration. Concentrations are estimated assuming Gaussian dispersion from a plume that rises 37 m (121 ft) above the ground. The value of 37 m (121 ft) shown in Table 4–3 was calculated as described in Section 2.1.1.3 of Appendix A. It is the predicted plume rise in Class D weather conditions arising from the fork lift truck fire with a rate of heat release of 5.2×10^{-4} cal/s as described in Section 2.1.1.1 of Appendix A. The EPCs are assumed to bound the concentrations at all

other downwind points away from the immediate vicinity of the fire. Due to entrainment, concentrations adjacent to the fire may be higher. However, such exposures are within the facility boundary and are likely to be limited since personnel will be required to evacuate the facility in the event of a fire.

Table 4–3. Parameters for Estimating Emissions of Mercury During an Onsite Fire

Parameter	Value
Molecular weight (MW)	200.6
Boiling point, F	674
T (boiling point), K	630
Vapor pressure at T	760
Wind speed (WS), m/s	4.5
Spill area (ft^2)	16
Spill area (m^2)	1.5
Fire area (ft^2)	16
Fire area (m^2)	1.5
Heat input (cal/s)	5.2×10^4
Quantity released (QR), lb/min	7.4
Release rate, mg/s	5.6×10^4
Release rate, mg/s/m^2	3.8×10^4
Minimum released quantity (lbs)	161
Plume rise (m)	37.1
Average wind speed (m/s)	4.76

This scenario envisions an accident that results in the breach of the forklift fuel cylinder resulting in a fire of the fuel and the wooden pallets containing the mercury flasks. The scenario assumes that mercury being carried on a pallet spills during the accident. Concurrently, the fire heats the spilled mercury causing its release into the atmosphere for as long as the supporting wooden pallet burns (estimated to burn for just over 20 min; see Appendix A). The assumptions and release rates for this process were presented above in Table 4–3. At the New Haven, Somerville, and Warren sites, the capacity of a pallet is 30 flasks, whereas at Y–12 the capacity of a pallet is 45 flasks. The more typical pallet size (30 flasks) is assumed to pertain to the Hawthorne Army Depot, PEZ Lake Development, and Utah Industrial Depot sites.

Generally, the release of liquid mercury and its subsequent volatilization into the atmosphere at ambient temperatures would result in a release of elemental mercury vapor. The presence of the fuel fire raises the possibility that the divalent form of mercury will be formed. It is conservatively assumed that all of the released mercury in a fire is divalent, thus maximizing the predicted deposition. (See Appendix A for more discussion.)

The forklift fuel fire scenario developed in the storage accident analysis is considered to represent a reasonable worst-case for the assessment of an onsite fire. The scenario was chosen from the onsite scenarios that have a higher than negligible event frequency because it represents the greatest potential threat of long-term consequences. The ingestion of soil contaminated with mercury represents the greatest plausible long-term human heath threat from accident-related mercury releases.

EPCs for airborne releases of mercury with deposition to soil, sediment, and surface water are presented in Table 4–4. These data are presented because many of them are used for the ecological risk assessment in Section 5 of this report.

Table 4–4. Exposure Point Concentrations for Airborne Releases of Mercury from Forklift Fuel Fire With Deposition to Soil, Sediment, and Surface Water

Dry Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
200	0.0186	0.0182	0.0004	0.0158	0.0028	0.0465	0.0395	0.0070	5.56×10^{-5}	2.58×10^{-4}
500	0.4611	0.4519	0.0092	0.3919	0.0692	1.1527	0.9798	0.1729	1.38×10^{-3}	6.40×10^{-3}
1,000	0.3221	0.3156	0.0064	0.2738	0.0483	0.8052	0.6844	0.1208	9.64×10^{-4}	4.47×10^{-3}
2,000	0.1318	0.1291	0.0026	0.1120	0.0198	0.3294	0.2800	0.0494	3.94×10^{-4}	1.83×10^{-3}
2,500	0.0951	0.0932	0.0019	0.0809	0.0143	0.2378	0.2021	0.0357	2.85×10^{-4}	1.32×10^{-3}
3,000	0.0724	0.0710	0.0014	0.0616	0.0109	0.1811	0.1539	0.0272	2.17×10^{-4}	1.01×10^{-3}
3,500	0.0574	0.0562	0.0011	0.0488	0.0086	0.1434	0.1219	0.0215	1.72×10^{-4}	7.97×10^{-4}
4,000	0.0468	0.0459	0.0009	0.0398	0.0070	0.1170	0.0994	0.0175	1.40×10^{-4}	6.50×10^{-4}
4,500	0.0391	0.0383	0.0008	0.0332	0.0059	0.0977	0.0830	0.0146	1.17×10^{-4}	5.43×10^{-4}

Wet Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
100	2.5564	2.5053	0.0511	2.1729	0.3835	6.3910	5.4323	0.9586	7.65×10^{-3}	3.55×10^{-2}
500	0.9645	0.9452	0.0193	0.8199	0.1447	2.4113	2.0496	0.3617	2.89×10^{-3}	1.34×10^{-2}
1,000	0.5601	0.5489	0.0112	0.4761	0.0840	1.4002	1.1902	0.2100	1.68×10^{-3}	7.78×10^{-3}
1,500	0.3476	0.3407	0.0070	0.2955	0.0521	0.8691	0.7388	0.1304	1.04×10^{-3}	4.83×10^{-3}
2,000	0.2403	0.2355	0.0048	0.2043	0.0360	0.6008	0.5107	0.0901	7.19×10^{-4}	3.34×10^{-3}
2,500	0.1787	0.1751	0.0036	0.1519	0.0268	0.4467	0.3797	0.0670	5.35×10^{-4}	2.48×10^{-3}
3,000	0.1396	0.1369	0.0028	0.1187	0.0209	0.3491	0.2967	0.0524	4.18×10^{-4}	1.94×10^{-3}
5,000	0.0688	0.0674	0.0014	0.0585	0.0103	0.1720	0.1462	0.0258	2.06×10^{-4}	9.55×10^{-4}
10,000	0.0249	0.0244	0.0005	0.0211	0.0037	0.0622	0.0528	0.0093	7.44×10^{-5}	3.45×10^{-4}

Key: Hg, mercury.

Table 4–5 presents the results of the analysis of exposures for onsite and offsite receptors via air resulting from an onsite fire. The consequence ratios all fall below the applicable benchmarks except for workers within the facility. For those workers, the consequences fall into the high category. Note that this is a very conservative assessment because, as described in Section 4.2.1, the worker is only exposed for only 10 seconds, whereas the benchmark applies to a 30-min exposure. The consequences to the public fall in the negligible-to-low category. As indicated by Table 2–16, the frequency and thus the risk estimate for workers and the public are negligible under the No Action Alternative due to low levels of activity with regard to the stockpile. Under the Consolidated Storage and Sales Alternatives the risk for workers at the facility is low frequency with high consequence, which translates to moderate risk while for the maximum exposed member of the public, low frequency and low consequence equals low risk.

Table 4–5. Exposure Point Concentrations in Air and Human Benchmark Ratios for Onsite Fire at Mercury Stockpile

Event	Receptor	Receptor Location	EPC (mg/m^3)	Benchmark (mg/m^3)	Ratio	Consequence Level
Forklift fire	Facility worker	Within facility	2,126	10	213	High
	Onsite worker	60 m	8×10^{-22}	10	8×10^{-23}	Negligible
	Public	120 m	2×10^{-5}	1.67	1×10^{-5}	Negligible
	Maximum	556 m	1.13	1.67	0.7	Low

Note: Involved workers will be trained to evacuate the area to minimize their exposure. Consequence levels correspond to the following ratios:

>10 is a high consequence level
>1 and ≤10 are moderate consequence levels
>0.1 and ≤1 are low consequence levels
≤0.1 is a negligible consequence level

Table 4–6 summarizes the results of the analysis of soil contamination arising from deposition to soil from the air. The maximum soil concentration arising from dry deposition was estimated to be 0.47 mg/kg which is about 2 percent of the human health based benchmark of 23 mg/kg established by EPA. The maximum EPC in soil occurs at 1,808 ft (551 m) from the fire.

Table 4–6. Distance to Locations Exceeding Human Health Criteria in Soil Due to Deposition During an Onsite Fire

Deposition Type	Maximum EPC in Soil (mg/kg)	Benchmark (mg/kg)	Ratio	Closest Downwind Distance (m) Where Soil Criteria Are Exceeded	Furthest Downwind Distance (m) Where Soil Criteria Are Exceeded
Dry	0.47	23	0.02	None	None
Wet	2.56	23	0.11	<100	<100

Note: Ratio is EPC at 328 ft (100 m) divided by the applicable benchmark.
Maximum air concentration: 1.13 mg/m^3 at 1,831 ft (558 m) (which is below the benchmark).
Maximum dry deposition soil concentration: 0.47 mg/kg at 1,808 ft (551 m).
Wet deposition soil concentration: 2.56 mg/kg at 328 ft (100 m).
Release rate: 5.59×10^4 mg/s.
Release height: 121.89 ft (37.15 m).
Wind speed 14.8 ft/s (4.5 m/s) at 33 ft (10 m).
Wind speed 15.62 ft/s (4.76 m/s) (averaged across release height).
Stability Class: D.
Key: EPC, exposure point concentrations.

For soil contamination arising from combined wet and dry deposition (i.e., that which might arise if the forklift fuel fire occurred during a rainstorm), the soil concentration arising from combined wet and dry deposition increases continually as the distance from the fire decreases. Limitations in atmospheric modeling capability preclude estimation of the soil concentrations due to wet deposition at distances less than about 328 ft (100 m). The results are expressed as the downwind distances where the health-based benchmark are exceeded, and thus points closer than 328 ft (100 m) are simply indicated as such (i.e., <100). The estimated soil mercury concentration arising from combined dry and wet deposition to soil at the minimum reportable distance of 328 ft (100 m) from the fire is 2.56 mg/kg. This indicates that any area of concern for soil contamination for humans would be this close or closer to the fire and would likely be cleaned up as part of the fire cleanup. The findings indicate that an onsite fire event is unlikely to produce adverse chronic human health effects related to exposure to soil located at least 328 ft (100 m) from the fire.

4.3 ACCIDENTAL OFFSITE TRANSPORTATION FIRE

The railcar or truck fire scenario envisions the release of mercury into the atmosphere and subsequent transport downwind. As was the case for the onsite fires, concentrations are projected for a range of distances from the source of contamination and are thus applicable to any accident location.

Elemental mercury released as a result of the accident is expected to remain airborne to be transported outside of the study area. Divalent mercury is expected to deposit significantly within the study area either as a result of dry deposition or rainfall scavenging (i.e., wet deposition). Once deposited, the mercury is expected to mix completely within the top 2 in (5.1 cm) of soil. Input parameters used to calculate emissions from an offsite fire are presented in Table 4–7 below.

Table 4–7. Parameters for Estimating Emissions of Mercury During an Offsite Fire

	Truck Fire	Railcar Fire
Molecular weight (MW)	200.6	200.6
Boiling point, F	674	674
T (boiling point), K	630	630
Vapor pressure at T	760	760
Wind speed (WS), m/s	4.5	4.5
Spill area (ft^2)	384	448
Spill area (m^2)	35.7	41.6
Fire area (ft^2)	384	590
Fire area (m^2)	35.7	54.8
Heat input (cal/s)	1.25×10^6	1.46×10^6
Duration of Pallet Fire/ Mercury Release(s)	762	1,308
Quantity released (QR), (lb/min)	177.6	207.2
Release rate, mg/s	1.3×10^6	1.6×10^6
Release rate, mg/s/m^2	3.8×10^4	3.8×10^4
Minimum released quantity (lbs)	3,869	4,514
Plume rise (m)	99	103
Average wind speed (m/s)	5.52	5.55

4.3.1 Offsite Truck Fire

Table 4–8 presents the estimated EPCs resulting from an accidental release of mercury with fire after an offsite truck accident and ensuing fire.

Table 4–8. Exposure Point Concentrations for Airborne Releases of Mercury from Offsite Truck Fire With Deposition to Soil, Sediment, and Surface Water

Dry Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
600	0.020	0.020	0.0004	0.017	0.003	0.050	0.043	0.0075	0.000060	0.00028
1,000	0.37	0.37	0.0075	0.32	0.056	0.93	0.79	0.14	0.0011	0.0052
1,500	0.81	0.79	0.016	0.69	0.12	2.0	1.7	0.30	0.0024	0.011
2,000	0.94	0.92	0.019	0.80	0.14	2.4	2.0	0.35	0.0028	0.013
2,500	0.92	0.90	0.018	0.78	0.14	2.3	2.0	0.34	0.0028	0.013
3,000	0.85	0.83	0.017	0.72	0.13	2.1	1.8	0.32	0.0025	0.012
3,500	0.77	0.75	0.015	0.65	0.12	1.9	1.6	0.29	0.0023	0.011
4,000	0.69	0.68	0.014	0.59	0.10	1.7	1.5	0.26	0.0021	0.010
4,500	0.62	0.61	0.012	0.53	0.093	1.6	1.3	0.23	0.0019	0.0086

Wet Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
100	53	52	1.1	45	7.9	132	113	20	0.16	0.74
500	11	10	0.21	9.1	1.6	27	23	4.0	0.032	0.15
1,000	5.8	5.6	0.12	4.9	0.86	14	12	2.2	0.017	0.080
1,500	4.4	4.3	0.088	3.7	0.66	11	9.3	1.6	0.013	0.061
2,000	3.6	3.5	0.072	3.1	0.54	9.0	7.7	1.4	0.011	0.050
2,500	3.0	3.0	0.060	2.6	0.45	7.5	6.4	1.1	0.0090	0.042
3,000	2.6	2.5	0.052	2.2	0.39	6.4	5.5	0.97	0.0077	0.036
5,000	1.5	1.5	0.031	1.3	0.23	3.8	3.3	0.57	0.0046	0.021
10,000	0.66	0.64	0.013	0.56	0.10	1.6	1.4	0.25	0.0020	0.0091

Key: Hg, mercury.

Table 4–9 shows that the maximum predicted airborne concentration is 2.27 mg/m^3. The acute human health effect for workers exposed to fires during consolidation by truck is low frequency with low consequence, or low risk. Under the Sales Alternative, the frequency increases to moderate and the consequence is low, also resulting in low risk. For the general public, the acute human health effect for exposures to fires during consolidation by truck is low frequency with moderate consequence, or low risk. Under the Sales Alternative, it is moderate frequency with moderate consequence, or moderate risk.

Table 4–9. Exposure Point Concentrations in Air and Acute Human Benchmark Ratios for Offsite Truck Fire

Event	Receptor	Receptor Location	EPC (mg/m^3)	Benchmark (mg/m^3)	Ratio	Consequence Level
Truck Fire	Offsite worker	2,162	2.27	10	0.2	Low
	Public	2,162	2.27	1.67	1	Moderate

Note: Maximum air concentration: 2.27 mg/m^3 at 7,094 ft (2,162 m). Consequence levels correspond to the following ratios:

>10 is a high consequence level

>1 and ≤10 are moderate consequence levels

>0.1 and ≤1 are low consequence levels

≤0.1 is a negligible consequence level

Involved workers will be trained to evacuate the area to minimize their exposure.

Table 4–10 presents results showing the EPC in soil at 328 ft (100 m) downwind from the truck fire, and the nearest and furthest downwind locations where soil concentrations could exceed the applicable benchmark for protection of human health.

Table 4–10. Distance to Locations Exceeding Human Health Criteria with Deposition to Soil During an Offsite Truck Fire

Deposition Type	Maximum EPC in Soil (mg/kg)	Benchmark (mg/kg)	Ratio	Closest Downwind Distance (m) Where Soil Criteria Are Exceeded	Furthest Downwind Distance (m) Where Soil Criteria Are Exceeded
Dry	0.94	23	0.04	None	None
Wet	53	23	2.3	<100	232

Note: Ratio is EPC at 328 ft (100 m) divided by the applicable benchmark. Maximum dry deposition soil concentration: 0.94 mg/kg at 6,946 ft (2,117 m).
Wet deposition soil concentration: 53 mg/kg at 328 ft (100 m).
Release Rate: 1.34×10^{6} mg/s.
Release height: 325.08 ft (99.08 m).
Wind speed 14.8 m/s (4.5 m/s) at 33 ft (10 m).
Wind speed 18.11 ft/s (5.52 m/s) (averaged across release height).
Stability Class: D.
Key: EPC, exposure point concentrations.

For the truck fire, the peak concentration via dry deposition to soil is 0.94 mg/kg (consequence ratio is 0.04 or negligible), which is well below the benchmark of 23 mg/kg. When there is wet deposition, the peak concentration in soil is 53 mg/kg (consequence ratio is 2 or moderate). Because the consequence for the exposures via dry deposition is negligible, the risk is also negligible regardless of event frequency. Exposures via wet deposition associated with consolidation activities results in low frequency with moderate consequence, or low risk per Figure 1–1. For wet deposition under the higher level of activity under the Sales Alternative the result is moderate frequency with moderate consequence and thus moderate risk per Figure 1–1.

Omitted from the risk estimates is the probability that it will actually be raining when the accident takes place, which on a national basis is likely to be about 32 percent (Rainfall Days 2002). Applying this factor to the moderate event frequencies in Table 2–15 (the largest of which is 6×10^{-4}/yr) reduces the event frequency (2×10^{-4}/yr) although it remains in the moderate category. It is noted that the rainfall days as provided apply to minimally measurable levels of precipitation (0.01 in [0.025 cm]), and as such is an overstatement of more significant amounts needed to thoroughly scavenge emissions from the air.

4.3.2 Offsite Railcar Fire

Table 4–11 presents the estimated EPCs resulting from an accidental release of mercury with fire after an offsite railcar accident and subsequent fire.

Table 4–11. Exposure Point Concentrations for Airborne Releases of Mercury from Offsite Railcar Fire with Deposition to Soil, Sediment, and Surface Water

Dry Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
600	0.0134	0.0132	0.0003	0.0114	0.0020	0.0336	0.0285	0.0050	4.02×10^{-5}	1.87×10^{-4}
1,000	0.3331	0.3264	0.0067	0.2831	0.0500	0.8328	0.7078	0.1249	9.97×10^{-4}	4.63×10^{-3}
1,500	0.8100	0.7938	0.0162	0.6885	0.1215	2.0250	1.7213	0.3038	2.42×10^{-3}	1.13×10^{-2}
2,000	0.9849	0.9652	0.0197	0.8372	0.1477	2.4622	2.0929	0.3693	2.95×10^{-3}	1.37×10^{-2}
2,500	0.9881	0.9683	0.0198	0.8399	0.1482	2.4703	2.0997	0.3705	2.96×10^{-3}	1.37×10^{-2}
3,000	0.9271	0.9085	0.0185	0.7880	0.1391	2.3177	1.9700	0.3477	2.77×10^{-3}	1.29×10^{-2}
3,500	0.8483	0.8313	0.0170	0.7210	0.1272	2.1207	1.8026	0.3181	2.54×10^{-3}	1.18×10^{-2}
4,000	0.7695	0.7541	0.0154	0.6541	0.1154	1.9238	1.6352	0.2886	2.30×10^{-3}	1.07×10^{-2}
4,500	0.6970	0.6831	0.0139	0.5925	0.1046	1.7426	1.4812	0.2614	2.09×10^{-3}	9.68×10^{-3}

Wet Deposition

Downwind Distance (m)	Hg in Dry Soil (mg/kg)	Inorganic Hg in Dry Soil (mg/kg)	Methyl Hg in Dry Soil (mg/kg)	Inorganic Hg in Wetland Soil (mg/kg)	Methyl Hg in Wetland Soil (mg/kg)	Total Hg in Sediment (mg/kg)	Inorganic Hg in Sediment (mg/kg)	Methyl Hg in Sediment (mg/kg)	Inorganic Hg in Surface Water (µg/l)	Methyl Hg in Surface Water (µg/l)
100	61.4631	60.2338	1.2293	52.2436	9.2195	153.6578	130.6091	23.0487	1.84×10^{-1}	8.54×10^{-1}
500	12.4004	12.1524	0.2480	10.5403	1.8601	31.0010	26.3508	4.6501	3.71×10^{-2}	1.72×10^{-1}
1,000	6.5818	6.4502	0.1316	5.5945	0.9873	16.4545	13.9863	2.4682	1.97×10^{-2}	9.14×10^{-2}
1,500	4.9727	4.8733	0.0995	4.2268	0.7459	12.4318	10.5670	1.8648	1.49×10^{-2}	6.91×10^{-2}
2,000	4.0829	4.0012	0.0817	3.4705	0.6124	10.2072	8.6761	1.5311	1.22×10^{-2}	5.67×10^{-2}
2,500	3.4380	3.3693	0.0688	2.9223	0.5157	8.5950	7.3058	1.2893	1.03×10^{-2}	4.78×10^{-2}
3,000	2.9410	2.8821	0.0588	2.4998	0.4411	7.3524	6.2495	1.1029	8.80×10^{-3}	4.08×10^{-2}
5,000	1.7668	1.7315	0.0353	1.5018	0.2650	4.4170	3.7545	0.6626	5.29×10^{-3}	2.45×10^{-2}
10,000	0.7660	0.7507	0.0153	0.6511	0.1149	1.9151	1.6278	0.2873	2.29×10^{-3}	1.06×10^{-2}

Key: Hg, mercury.

The railcar fire scenario developed in the transportation analysis is discussed in detail in Appendix A. This scenario envisions a railroad accident that results in the combustion of the pallets carrying the mercury to its new storage locations. The accident is assumed to breach a sufficient number of mercury containers to create an exposed area equal to the area of the pallets. This exposed mercury is assumed to be brought to its boiling point and to be released at the maximum rate consistent with the dynamics of boiling mercury. The analysis assumes that the mercury boils as long as the pallets are on fire. Human health consequences are presented in Table 4–12.

Table 4–12. Distance to Locations Exceeding Human Health Criteria With Deposition to Soil During an Offsite Railcar Fire

Deposition Type	Maximum EPC in Soil (mg/kg)	Benchmark (mg/kg)	Ratio	Closest Downwind Distance (m) Where Soil Criteria Are Exceeded	Furthest Downwind Distance (m) Where Soil Criteria Are Exceeded
Dry	0.94	23	0.04	None	None
Wet	61.5	23	2.67	<100	269

Note: Ratio is EPC at 328 ft (100 m) divided by the applicable benchmark. Maximum dry deposition soil concentration: 1.00 mg/kg at 7,359 ft (2,243 m). Wet deposition soil concentration: 61.5 mg/kg at 328 ft (100 m).

Release Rate: 1.57×106 mg/s.

Release height: 337.3 ft (102.8 m).

Wind speed 14.8 ft/s (4.5 m/s) at 33 ft (10 m).

Wind speed 18.213 ft/s (5.551 m/s) (averaged across release height).

Stability Class: D.

Key: EPC, exposure point concentrations.

Table 4–13 shows that the maximum predicted airborne concentration is 2.41 mg/m^3. The acute human health effect for workers exposed to fires during consolidation by rail is low frequency with low consequence, or low risk. Under the Sales Alternative, it is low frequency with low consequence, or low risk. For the general public, the acute human health effect for exposures to fires during consolidation by rail is low frequency with moderate consequence, or low risk. Under the Sales Alternative, it is low frequency with moderate consequence, or low risk.

Table 4–13. Exposure Point Concentrations in Air and Acute Human Benchmark Ratios for Offsite Railcar Fire

Event	Receptor	Receptor Location	EPC (mg/m^3)	Benchmark (mg/m^3)	Ratio	Consequence Level
Railcar Fire	Offsite worker	2,291	2.41	10	0.2	Low
	Public	2,291	2.41	1.67	1.4	Moderate

Note: Maximum air concentration: 2.41 mg/m^3 at 7,517 ft (2,291 m). Consequence levels correspond to the following ratios:

>10 is a high consequence level
>1 and ≤10 are moderate consequence levels
>0.1 and ≤1 are low consequence levels
≤0.1 is a negligible consequence level

Involved workers will be trained to evacuate the area to minimize their exposure.

For the railcar fire, the peak concentration via dry deposition to soil is approximately 1.00 mg/kg (consequence ratio is 0.04 or negligible), which is well below the benchmark of 23 mg/kg. The risk of exposure to mercury deposited to soil via dry deposition is negligible under any alternative or distance from the source. Wet deposition, under the Consolidated Storage Alternative, results in a concentration of 61.5 mg/kg at 328 ft (100 m) from the fire (consequence ratio is 3 or moderate). The closest valid distance for the estimated downwind concentration is 328 ft (100 m) (as noted in Section 4.2.2). The low frequency of rail crashes with mercury release and fire (see Table 2–16) and the projected moderate consequence of severity results in a risk estimate that is low per the risk matrix shown in Figure 1–1.

4.4 OFFSITE ACCIDENTAL TRANSPORTATION SPILL OF MERCURY WITH NO FIRE

For exposures occurring via air from a spill with no fire during a transportation accident, it is assumed that about 25 percent of the mercury is released. The release is a professional judgment for a reasonable release volume to apply under what would likely be widely differing conditions. The release is equivalent to 105 flasks of mercury per truckload (7,980 lbs [3,620 kg]) or 210 flasks per railcar (16,000 lbs [7,258 kg]). The downwind EPCs for mercury are shown in Table 4–14.

Table 4–14. Exposure Point Concentrations in Air for Spills Resulting from Offsite Transportation Accidents

Release Scenario	EPC in Immediate Area (mg/m^3)	IDLH Ratio	EPC at 100 Meters Downwind (mg/m^3)	ERPG-2 Ratio
Truck spill (no fire)	1.55	0.16	0.0649	0.06
Rail spill (no fire)	2.19	0.22	0.0914	0.09

Note: Release height: ground level. Wind speed 14.8 ft/s (4.5 m/s) at 33 ft (10 m). Stability Class: D.
Key: EPC, exposure point concentrations; IDLH, immediately dangerous to life or health.

The consequences in the immediate area of the spill fall well below the IDLH, and consequences for receptors 328 ft (100 m) downwind fall well below the ERPG-2. The resulting EPC/benchmark ratios are negligible and thus the risks associated with acute exposure to mercury vapor are also negligible. As

discussed previously, mercury vapor evaporating from a spill remains in the elemental form and does not deposit on the ground in the local area, so there is no complete local chronic exposure pathway.

4.5 TRUCKS OR RAILCAR ACCIDENT WITH MECHANICALLY INDUCED FATALITY

For the Consolidated Storage Alternative, from Table 2–16, the frequencies for truck or rail accidents are low. For the highest levels of activity anticipated under the Sales Alternative, the event frequency is moderate (see Table 2–16, this is actually a table for frequencies of accidents with fire and mercury release, but the frequencies of accidents with fatality are similar).

In general, accidents resulting in fatal crashes are not correlated with the type of cargo being transported. Thus, the risk of a fatality due to a "normal" traffic accident far exceeds the risk of a fatality from the accidental release of mercury. The number of miles traveled by road or rail to complete the consolidation or sales activities is only a small fraction of the total miles traveled per year transporting commodities in the United States.

4.6 SUMMARY

The results of the human health analysis summarized in Table 4–15 are applicable to any given storage location (i.e., on site), or any given location where an accident occurs (i.e., off site).

Table 4–15. Summary of Human Health Risks for Evaluated Scenarios

Scenario	Exposure Pathway and Intensity					
	Acute Inhalation for Facility Worker	**Acute Inhalation for Onsite Worker**	**Acute Inhalation for Public**	**Chronic Inhalation for Worker**	**Chronic Inhalation for Public**	**Soil Contamination**
No Action Alternative						
Slow leak on site	NA	NA	NA	Negligible	Negligible	NA
Single flask spill on site	Negligible	Negligible	Negligible	NA	NA	NA
Single pallet spill on site	Negligible	Negligible	Negligible	NA	NA	NA
Earthquake spill on site	Low	Negligible	Negligible	NA	NA	NA
Consolidated Storage Alternative						
Forklift fire on site	Moderate	Negligible	Negligible at fence line[a] Low at maximum EPC[b]	NA	NA	Negligible (≥100 m)
Earthquake spill on site	Moderate	Low	Low	NA	NA	NA
Offsite truck or rail release with fire	NA	NA	Low via truck Low via rail	NA	NA	Negligible if no rain, but moderate with rain
Offsite truck or rail spill with no fire	NA	NA	Negligible (≥100 m)	NA	NA	NA
Offsite truck or rail crash with fatality	NA	NA	NA	NA	NA	NA
Sales Alternative						
Forklift fire on site	Moderate	Negligible	Negligible at fence line[a] Low at maximum EPC[b]	NA	NA	Negligible (≥100 m)
Offsite truck or rail release with fire	NA	NA	Moderate via truck Low via rail	NA	NA	Negligible with no rain, but moderate with rain
Offsite truck or rail spill with no fire	NA	NA	Negligible (≥100 m)	NA	NA	NA
Offsite truck or rail crash with fatality	NA	NA	NA	NA	NA	NA

[a] "Public at fence line" refers to the closest fence line location which is assumed to be 394 ft (120 m) from the on-site fire (ranging from 328 ft (100 m) at the Somerville Depot to 12,139 ft (3,700 m) at the Hawthorne Army Depot.

[b] "Public at maximum EPC" refers to the location where maximum airborne exposure is expected; about 1,824 ft (556 m) from the on-site fire.

Note: Fatalities are not directly comparable to these health effects and are discussed in text.

Key: EPC, exposure point concentration; NA, not applicable.

Chapter 5
Ecological Risk Assessment

Ecological consequences are evaluated using the same modeled concentrations as those presented in Section 4. Potential ecological responses to mercury are related to selected measurement endpoints discussed in the *Draft Risk Assessment Plan for the Mercury Management Environmental Impact Statement*. This section first provides a general description of potentially toxic effects to ecological receptors from exposure to mercury. Then, the toxicity reference values (TRVs) for plants, earthworms, shrews, robins, hawks, aquatic biota, sediment biota, and herons are derived for mercury. The derivation of the media and receptor-specific benchmarks based on the TRVs is discussed next. Finally, the results of the comparison of estimated media concentrations against the ecological benchmarks are presented.

5.1 MERCURY ECOTOXICITY

Soil and surface water may become contaminated by airborne releases of mercury. Because mercury deposited onto soil or into water bodies is persistent, chronic exposure to contaminated soil and water is assumed. This assumption is conservative for accidental releases because spills are likely to be mitigated by cleanup operations. Exposure to mercury by inhalation in air or suspended particles is assumed to be negligible as explained in Section 5.4.1.

Elemental mercury released to the environment can be oxidized to ionic mercury by reactions with soil constituents. Elemental and ionic mercury under anaerobic conditions, such as in surface water and sediment, can be converted to methyl mercury. Mercury that may be released to terrestrial systems will be assumed to become ionic to some extent in the long term. Two percent of the mercury released to dry soil, and 15 percent of the mercury released to wetland soil and sediment is assumed to convert to methyl mercury (EPA 1999a). A partitioning equation was used to estimate the concentration of mercury leaching from sediment into the surface water. All mercury that can potentially be released to aquatic systems is assumed to become methyl mercury, which is a conservative measure because this is the most toxic form of mercury. Mercury investigations generally focus on aquatic rather than terrestrial ecosystems due to methylation and bioaccumulation of methyl mercury in aquatic systems. Animals primarily associated with aquatic food chains accumulate more mercury than those associated with terrestrial food chains. Methyl mercury biomagnifies in aquatic biota and, as a result, tends to occur at higher concentrations in higher trophic levels. Methyl mercury is the most toxic form of mercury to birds, mammals, and aquatic organisms.

Inorganic mercury accumulates to only a limited extent in plants and soil organisms and does not biomagnify in the organisms that feed on them. The effects of mercury on terrestrial receptors, according to EPA's Mercury Report to Congress (EPA 1997a), are listed below.

- In terrestrial plants, mercury can cause death as well as sublethal effects, such as decreased growth, root damage, hampered nutrient uptake, chlorophyll decline, and reduced photosynthesis.
- Earthworms exhibit effects that range from toxicity to complete mortality when exposed to inorganic mercury.
- In mammals, inorganic mercury is corrosive and may cause burning, irritation, salivation, vomiting, bloody diarrhea, upper gastrointestinal tract edema, abdominal pain, and hemorrhaging. Smaller animals are generally more susceptible to mercury poisoning than larger animals.
- In birds, sublethal effects of mercury include liver damage, kidney damage, neurobehavioral effects, reduced food consumption, weight loss, spinal cord damage, effects on enzyme systems,

reduced cardiovascular function, impaired immune response, reduced muscular coordination, impaired growth and development, altered blood and serum chemistry, and reproductive effects.

The effects of methyl mercury on aquatic receptors, according to EPA's Mercury Report to Congress (EPA 1997a), are listed below.

- In aquatic plants, mercury can cause death as well as sublethal effects such as premature aging. Growth inhibition, decreased chlorophyll content, decreased protein and ribonucleic acid content, inhibited catalase and protease activities, inhibited and abnormal mitotic activity, increased free amino acid content, discoloration of floating leaves, and leaf and root necrosis.
- The effects of mercury on fish include death, reduced reproduction, impaired growth and development, behavioral abnormalities, altered blood chemistry, impaired osmoregulation, reduced feeding rates and predatory success, and effects on oxygen exchange. The toxicity of mercury varies depending on the fish's physiological and behavioral characteristics, and the mercury concentration tends to increase in aquatic organisms as the trophic level in aquatic food webs increases.

5.2 TOXICITY REFERENCE VALUES

The TRVs used to derive the media and receptor-specific benchmarks are discussed below.

5.2.1 TRVs for Plants and Soil Invertebrates

Published TRVs for plants and earthworms are predominantly lowest observed adverse effect level (LOAEL) values determined for soil amended with chemical solutions at different concentrations (Efroymson et al. 1997a, 1997b). In most toxicity studies, no determination is made for the biological availability of the added constituents or of the total recoverable constituent (the type of information provided by the laboratory analysis of constituents in soil) in the test soil. Therefore, it is assumed that total recoverable constituents in soil found at the sites are 100 percent bioavailable and have the same toxicity as constituents added in laboratory toxicity tests. Mercury TRVs for plants and earthworms are presented in Table 5–1.

5.2.2 TRVs for Terrestrial Animals

The methods for assessing the potentially toxic effects of mercury to terrestrial animals are based on the derivation of a TRV. The TRVs are derived to represent conservative estimates of the mercury doses (mg/kg bw/day) that, if exceeded when exposed to an environmental medium, may produce toxic effects in ecological receptors exposed to that medium. Literature toxicity data are used by establishing data selection criteria so that TRVs are as relevant to the unit assessment endpoints as possible. Furthermore, the conservatism of the TRVs is reinforced by using the lowest available, appropriate toxicity values and modifying them by uncertainty factors when necessary. Toxicity values used as the basis for the TRVs were selected as described below. The source for most toxicity values used as TRVs is *Toxicological Benchmarks for Wildlife, 1996 Revision* (Sample et al. 1996).

In an effort to address uncertainties upfront in the Ecological Risk Assessment (ERA) process, the preferred toxicity test endpoint is the lowest appropriate chronic LOAEL for non-lethal or reproductive effects. LOAELs are appropriate for evaluating the risk to non-threatened and non-endangered receptor populations (Suter et al. 1994). When published LOAEL values are not available, LOAELs are estimated by multiplying published no observed adverse effects levels (NOAELs) by a factor of 10. If no NOAEL

values are available, the next preferred form of toxicity data for use in deriving a TRV is an LD_{50} (median lethal dose) or an LC_{50} (median lethal concentration). Values based on chronic studies are preferred. Studies are considered to provide chronic toxicity data if conducted for a minimum duration of 1 yr in mammals, 10 weeks in birds (Sample et al. 1996), or 7 days in fish or invertebrates. Studies shorter than 90 days in mammals, 18 days in birds, and 2 days in fish or invertebrates are considered acute. Studies longer than acute tests, but shorter than chronic tests, are considered subchronic. The derivation of mercury TRVs is shown for shrews, robins, hawks, and herons in Table 5–1.

Table 5–1. Mercury Toxicity Reference Values for Ecological Receptors

Receptor	Form of Mercury	TRV	Test Organism	Toxic Endpoint	Reference
Plants	Inorganic	0.3 mg/kg soil	Plants in soil	Unspecified toxicity	Efroymson et al. 1997a
	Methyl	No TRV	NA	NA	NA
Earthworms	Inorganic	0.1 mg/kg soil	Octochaetus pattoni	Survival and cocoon production	Efroymson et al. 1997b
	Methyl	2.5 mg/kg soil	Eisenia fetida	Survival and regeneration of segments	Efroymson et al. 1997b
Short-tailed shrew	Inorganic	27.7 mg/kg BW/day	Mink	Reproduction, estimated as NOAEL×10	Sample et al. 1996
	Methyl	0.34 mg/kg BW/day	Rat	LOAEL for reproduction	Sample et al. 1996
American robin	Inorganic	0.9 mg/kg BW/day	Japanese quail	LOAEL for reproduction	Sample et al. 1996
	Methyl	0.064 mg/kg BW/day	Mallard duck	LOAEL for reproduction	Sample et al. 1996
Red-tailed hawk	Inorganic	0.9 mg/kg BW/day	Japanese quail	LOAEL for reproduction	Sample et al. 1996
	Methyl	0.064 mg/kg BW/day	Mallard duck	LOAEL for reproduction	Sample et al. 1996
Great blue heron	Inorganic	0.9 mg/kg BW/day	Japanese quail	LOAEL for reproduction	Sample et al. 1996
	Methyl	0.064 mg/kg BW/day	Mallard duck	LOAEL for reproduction	Sample et al. 1996
Aquatic biota	Inorganic	1.3 µg/l	Aquatic biota	Tier II chronic value for inorganic mercury	Suter and Tsao 1996
	Methyl	0.0028 µg/l	Aquatic biota	Tier II chronic value for methyl mercury	Suter and Tsao 1996
Sediment biota	Inorganic	0.15 mg/kg sediment	Sediment-dwelling biota	NOAA ER-L	Jones, Suter, and Hull 1997
	Methyl	No TRV	NA	NA	NA

Key: LOAEL, lowest observed adverse effect level; NA, not applicable; NOAA ER-L, National Oceanic and Atmospheric Administration Effects Range - Low; NOAEL, no observed adverse effects levels; TRV, toxicity reference values.

5.2.3 TRVs for Aquatic Biota

For aquatic receptors, the preferred source of aquatic TRVs is *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision* (Suter and Tsao 1996). This document provides a compilation of aquatic toxicity values, including Federal ambient water quality criteria, derived Tier II values (secondary chronic and acute values), and chronic values from a variety of other governmental sources. Uncertainty factors (other than for use of a surrogate chemical) are not applied to TRVs from the above sources because the methods of their derivation already account for uncertainties. The preferred toxicity value for aquatic biota is the water quality criterion for mercury in freshwater. TRVs for inorganic and methyl mercury are also presented in Table 5–1.

Sediment is also evaluated for potential toxicity to aquatic receptors. The preferred source of sediment TRVs is *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment Associated Biota* (Jones, Suter, and Hull 1997). This document provides a compilation of sediment toxicity values, including EPA Sediment Quality Criteria for the Protection of Benthic

Organisms, derived sediment quality benchmarks for nonionic organics chemicals based on equilibrium partitioning, Washington State sediment quality standards for some ionic organic compounds, NOAA values from Long and Morgan (1991) and Long et al. (1995), and values from other governmental sources. NOAA Effects Range - Low (ER-L) values were used as the preferred sediment TRV for mercury (Long and Morgan 1991).

5.3 ECOLOGICALLY BASED BENCHMARKS FOR MERCURY

To expedite the evaluation of potential exposures, screening benchmarks for mercury in soil, surface water, and sediment were derived. For soil, the exposure dose was set equal to the TRV for each terrestrial receptor. Then the exposure equation was solved for the soil concentration, which became the soil screening value for each receptor. This procedure also was completed for exposure of great blue herons to mercury in surface water and sediment.

As previously discussed, media concentrations were calculated to determine screening benchmarks resulting in a Hazard Quotient (HQ) of 1 for each type of terrestrial receptor (lower trophic level and higher trophic level). The equations presented in the following sections were used to establish the screening benchmarks for the receptors exposed to soil, surface water, and sediment, and these are presented in Tables 5–2 (inorganic mercury) and 5–3 (methyl mercury).

Table 5–2. Ecological Screening Values for Inorganic Mercury

Receptor	TRV[a] (mg/kg BW/day)	SP[b]	Ip[c] (kg/day)	BAF_{inv}[d]	BCF[e]	Ia[f] (kg/day)	BAF_{mamm}[g]	Is[h] (kg/day)	Iw[i] (l/day)	BW[j] (kg)	UFF	Screening Value[k] (mg/kg or μg/l)
Plants	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.3
Soil invertebrates	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.1
Short-tailed shrew	27.7	0.18	0.0012	0.34	NA	0.008	13	0.0012	NA	0.017	1	110
American robin	0.9	0.04	0.061	0.34	NA	0.061	13	0.013	NA	0.080	1	2.0
Red-tailed hawk	0.9	NA	0	NA	NA	0.124	13	0	NA	1.13	0.001	1,619
Great blue heron, sediment	0.9	0.18	0	0.34	NA	0.009	NA	0	NA	2.39	1	736
Great blue heron, water	0.9	NA	NA	NA	3,530	0.422	NA	NA	0.045	2.39	1	1.4
Aquatic biota	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3
Sediment-dwelling biota	0.15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.15

[a] Toxicity reference value.
[b] Soil-to-plant transfer factor: to vegetative parts for shrew and heron; to reproductive parts for robin (Baes et al. 1984).
[c] Ingestion rate of plant tissue (EPA 1993).
[d] Soil-to-soil invertebrate transfer factor (HAZWRAP 1994).
[e] Water-to-tissue bioconcentration factor (EPA 1999a).
[f] Ingestion rate of animal tissue (EPA 1993).
[g] Food-to-tissue uptake factor for mammals and birds (HAZWRAP 1994).
[h] Ingestion rate of soil (EPA 1993).
[i] Ingestion rate of water (EPA 1993).
[j] Body weight (EPA 1993).
[k] Calculated by solving exposure equations for *Cs*, *Csed*, or *Cw* when *ED* = *TRV*.
Key: NA, not applicable; UFF, Unit Foraging Factor.

Table 5–3. Ecological Screening Values for Methyl Mercury

Receptor	TRV[a] (mg/kg BW/day)	SP[b]	Ip[c] (kg/day)	BAF_{inv}[d]	BCF[e]	Ia[f] (kg/day)	BAF_{mamm}[g]	Is[h] (kg/day)	Iw[i] (l/day)	BW[j] (kg)	UFF	Screening Value[k] (mg/kg or µg/l)
Plants	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	None
Soil invertebrates	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.5
Short- tailed shrew	0.34	0.137	0.0012	8.50	NA	0.008	13	0.0012	NA	0.017	1	0.08
American robin	0.064	0.137	0.061	8.50	NA	0.061	13	0.013	NA	0.08	1	0.010
Red-tailed hawk	0.064	NA	0	NA	NA	0.124	13	0	NA	1.13	0.001	6.86
Great blue heron, sediment	0.064	0.18	0	8.50	NA	0.0086	NA	0	NA	2.39	1	2.09
Great blue heron, water	0.064	NA	NA	NA	11,168	0.422	NA	NA	0.045	2.39	1	0.032
Aquatic biota	0.0028	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0028
Sediment-dwelling biota	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	None

[a] Toxicity reference value.
[b] Soil-to-plant transfer factor: to vegetative parts for shrew and heron; to reproductive parts for robin (EPA 1999a).
[c] Ingestion rate of plant tissue (EPA 1993).
[d] Soil-to-soil invertebrate transfer factor (EPA 1999a).
[e] Water-to-tissue bioconcentration factor (EPA 1999a).
[f] Ingestion rate of animal tissue (EPA 1993).
[g] Food-to-tissue uptake factor for mammals and birds (EPA 1999a).
[h] Ingestion rate of soil (EPA 1993).
[i] Ingestion rate of water (EPA 1993).
[j] Body weight (EPA 1993).
[k] Calculated by solving exposure equations for *Cs*, *Csed*, or *Cw* when *ED* = *TRV*.
Key: NA, not applicable.

5.3.1 Lower Trophic-Level Receptors (Short-Tailed Shrews and American Robins)

$$C_s = \frac{(BW*ED_{soil})}{[(SP*I_P) + (BAF_{inv}*I_a) + (I_s*ST)]}$$

where:

BW	=	Body weight (kg)
ED_{soil}	=	Soil exposure dose for terrestrial receptor (mg/kg/day)
C_s	=	Predicted concentration in soil (mg/kg)
SP	=	Soil-to-plant uptake factor (unitless); SP_v for shrews and SP_r for robins
I_p	=	Receptor-specific ingestion rate of plant material (kg/day)
BAF_{inv}	=	Constituent-specific bioaccumulation factor for transfer from soil to invertebrate tissue (kg soil/kg/tissue)
I_a	=	Receptor-specific ingestion rate of animal material (kg/day)
I_s	=	Receptor-specific ingestion rate of soil (kg/day)

ST	=	Bioavailability factor for constituents ingested in soil (assumed to be 1.0 for all constituents and receptors)

5.3.2 Terrestrial Higher Trophic Level Receptors (Hawks)

$$C_s = \frac{\left(\frac{(ED_{soil}*IR_{shrew}*BW)}{(BAF_{mammal}*I_{a(hawk)}*UFF)}\right)}{[(SP_v*I_{p(shrew)})+(BAF_{inv}*I_{a(shrew)})+(I_s*ST)]}$$

where:

C_s	=	Predicted concentration in soil (mg/kg)
ED_{soil}	=	Soil exposure dose for terrestrial receptor (mg/kg/day)
IR_{shrew}	=	Total food and soil ingestion rate by the shrew (kg/day)
BW	=	Body weight (kg)
BAF_{mammal}	=	Bioaccumulation factor of constituent ingested by the shrew (kg food/kg tissue), 13 for mercury
$I_{a(hawk)}$	=	Ingestion rate of animal material by the hawk (kg/day)
UFF	=	Unit foraging factor (unitless)
SP_v	=	Soil-to-plant uptake factor (kg soil/kg plant)
$I_{p(shrew)}$	=	Ingestion rate of plant material by the shrew
BAF_{inv}	=	Constituent-specific bioaccumulation factor for transfer from soil to invertebrate tissue (kg soil/kg/tissue)
$I_{a(shrew)}$	=	Ingestion rate of animal material by the shrew (kg/day)
I_s	=	Receptor-specific ingestion rate of soil (kg/day) for shrew
ST	=	Bioavailability factor for constituents ingested in soil (assumed to be 1.0 for all constituents and receptors)

5.3.3 Terrestrial Semi-Aquatic Receptor (Great Blue Heron) Exposed to Sediment

$$C_{sed} = \frac{(BW*ED_{sed})}{[(SP*I_P) + (BAF_{inv}*I_a)+(I_s*ST)]}$$

where:

C_{sed}	=	predicted concentration in sediment (mg/kg)
BW	=	Body weight (kg)
ED_{sed}	=	Sediment exposure dose for terrestrial receptor (mg/kg/day)
SP	=	Soil-to-plant uptake factor (kg soil/kg plant)
I_p	=	Receptor-specific ingestion rate of plant material (kg/day)
BAF_{inv}	=	Constituent-specific bioaccumulation factor (unitless)
I_a	=	Receptor-specific ingestion rate of sediment-dwelling animal material (kg/day)
I_s	=	Receptor-specific ingestion rate of sediment (kg/day)
ST	=	Bioavailability factor for constituents ingested in sediment (assumed to be 1.0 for all forms of mercury)

5.3.4 Terrestrial Semi-Aquatic Receptor (Great Blue Heron) Exposed to Surface Water

$$C_{sw} = \frac{(BW*ED_{sw})}{[I_{sw}+(BCF*I_a)]}$$

where:

C_{sw}	=	Concentration in surface water (mg/l)
BW	=	Body weight (kg)
ED_{sw}	=	Surface water exposure dose (mg/kg/day)
I_{sw}	=	Receptor-specific ingestion rate of surface water (l/day)
BCF	=	Constituent-specific water-to-tissue bioconcentration factor for prey (l/kg)
I_a	=	Receptor-specific ingestion rate of animal material (kg/day)

5.4 ECOLOGICAL RISK ANALYSIS

This section presents the estimated ecological health consequences associated with each of the management alternatives. These consequences are characterized by comparing the EPC estimates (presented in Section 4) with the applicable ecological health benchmarks (presented in Section 5.3).

Ecological consequences also were evaluated by calculating a ratio of the exposure concentration to benchmarks for ecological receptors. Also developed for this report is a qualitative indication (negligible, low, moderate, high) of the overall significance of the effect (see frequency and severity of consequences below). If the ratio was 20 or higher, a consequence level of high was assigned; if the ratio was between 10 and 20, a consequence level of moderate was assigned; if the ratio was between 1 and 10, a consequence level of low was assigned; and if the ratio was below 1, a consequence level of negligible was assigned. These indications are subsequently applied to the risk matrix presented in Figure 1–1.

In cases where the magnitude of the consequence is more than negligible, the overall risk is determined by combining the consequence (for a given exposure) with the estimated frequency of the release event (discussed in Table 2–16) using the three-by-three matrix illustrated in Figure 1–1. Using Figure 1–1, the risk is assigned to high, moderate, low, or negligible categories.

5.4.1 Slow Leaks and Spills from Storage Sites

This analysis applies to any of the storage locations under all three alternatives—No Action, Consolidated Storage, and Sales. The analysis is assumed to apply to all sites because there are no site-specific differences in the way spilled mercury would behave. Ecological risks associated with slow leaks during normal operations and accidental spills arise from the escape of mercury vapors from the containers during storage and handling. Generally, the release of liquid mercury results in its subsequent volatilization into the atmosphere in the form of elemental mercury vapor. The ingestion of soil contaminated with mercury represents the greatest, plausible, long-term threat from mercury releases. As discussed in Appendix A, deposition of airborne mercury is the primary mechanism of soil contamination. However, elemental mercury is not subject to significant atmospheric deposition, unlike divalent mercury. Although mercury vapor transported downwind could then be inhaled by ecological receptors at the site or nearby, the inhalation exposure route is generally insignificant relative to the major exposure pathway (i.e., ingestion) for ecological receptors.

Given the dispersion of mercury upon leaving the storage facility, exposures to ecological receptors would be minimal at most. As a result, risks to ecological receptors from slow leaks and spills are considered to be negligible at all storage sites.

5.4.2 Onsite Forklift Fire

In the event of a forklift accident at any of the storage facilities, the flasks may be breached causing a spill of mercury along with fuel. The primary release mechanism is driven by ignition of the fuel, resulting in the volatilization of a portion of the mercury, which is then entrained into smoke and subsequently deposited as divalent mercury. The potential for a fuel fire raises the possibility that the divalent form of mercury will be released. The risks associated with this pathway for the forklift fuel fire are discussed below. The analysis is assumed to apply to all sites because there are no site-specific differences in the way spilled mercury would behave during a fire.

Exposure concentrations, benchmark ratios, and consequence levels for ecological receptors exposed to divalent mercury after a forklift fire at 1,641 ft (500 m) (dry deposition) or 328 ft (100 m) (wet deposition) downwind from a storage facility are shown in Table 5–4. The calculated consequence levels cover the full range from negligible to high; however, the majority of exposures resulted in negligible consequence levels.

Table 5–4. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury Due to Onsite Forklift Fire

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil (mg/kg)	Concentration	0.452	0.009	2.505	0.051
		Benchmark	0.3	None	0.3	None
		Ratio	1.506	NA	8.351	NA
		Consequence level	Low	NA	Low	NA
Soil invertebrates	Dry soil (mg/kg)	Concentration	0.452	0.009	2.505	0.051
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	4.52	0.0037	25.053	0.020
		Consequence level	Low	Negligible	High	Negligible
Short-tailed shrew	Dry soil (mg/kg)	Concentration	0.452	0.009	2.505	0.051
		Benchmark	110	0.08	110	0.08
		Ratio	0.004	0.115	0.023	0.639
		Consequence level	Negligible	Negligible	Negligible	Negligible
American robin	Dry soil (mg/kg)	Concentration	0.452	0.009	2.505	0.051
		Benchmark	2	0.01	2	0.01
		Ratio	0.226	0.920	1.253	5.110
		Consequence level	Negligible	Negligible	Low	Low
Red-tailed hawk	Dry soil (mg/kg)	Concentration	0.452	0.009	2.505	0.051
		Benchmark	1,619	6.86	1,619	6.86
		Ratio	0.00028	0.001	0.0015	0.007
		Consequence level	Negligible	Negligible	Negligible	Negligible

Table 5–4. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury Due to Onsite Forklift Fire (Continued)

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Wetland soil (mg/kg)	Concentration	0.392	0.069	2.173	0.384
		Benchmark	0.3	None	0.3	None
		Ratio	1.306	NA	7.243	NA
		Consequence level	Low	NA	Low	NA
Soil invertebrates	Wetland soil (mg/kg)	Concentration	0.392	0.069	2.173	0.384
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	3.919	0.028	21.729	0.153
		Consequence level	Low	Negligible	High	Negligible
Short-tailed shrew	Wetland soil (mg/kg)	Concentration	0.392	0.069	2.173	0.384
		Benchmark	110	0.08	110	0.08
		Ratio	0.0036	0.865	0.020	4.794
		Consequence level	Negligible	Negligible	Negligible	Low
American robin	Wetland soil (mg/kg)	Concentration	0.392	0.069	2.173	0.384
		Benchmark	2	0.01	2	0.01
		Ratio	0.196	6.920	1.086	38.350
		Consequence level	Negligible	Low	Low	High
Red-tailed hawk	Wetland soil (mg/kg)	Concentration	0.392	0.069	2.173	0.384
		Benchmark	1,619	6.86	1619	6.86
		Ratio	0.00024	0.010	0.0013	0.056
		Consequence level	Negligible	Negligible	Negligible	Negligible
Benthic invertebrates	Sediment (mg/kg)	Concentration	0.980	0.173	5.432	0.959
		Benchmark	0.15	None	0.15	None
		Ratio	6.532	NA	36.215	NA
		Consequence level	Low	NA	High	NA
Great blue heron	Sediment (mg/kg)	Concentration	0.980	0.173	5.432	0.959
		Benchmark	736	2.09	736	2.09
		Ratio	0.0013	0.083	0.0074	0.459
		Consequence level	Negligible	Negligible	Negligible	Negligible
Aquatic biota	Surface water (mg/l)	Concentration	1.38×10^{-3}	6.40×10^{-3}	7.65×10^{-3}	3.55×10^{-2}
		Benchmark	1.3	0.003	1.3	0.003
		Ratio	0.0011	2.286	0.0059	12.679
		Consequence level	Negligible	Low	Negligible	Moderate
Great blue heron	Surface water (mg/l)	Concentration	1.38×10^{-3}	$6.40\times^{-3}$	$7.65\times^{-3}$	$3.55\times^{-2}$
		Benchmark	1.4	0.032	1.4	0.032
		Ratio	0.0010	0.200	0.005	1.109
		Consequence level	Negligible	Negligible	Negligible	Low

[a] Dry deposition and concentrations of divalent mercury at 1,641ft (500 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

The risk to each of the receptors after a forklift fire is shown in Table 5–5. This is based on the consequence levels in Table 5–4 and the frequency of forklift fires for the Consolidated Storage and Sales

Alternatives. The frequency of the scenario in the No Action Alternative is negligible so that the ecological risk is also negligible. The predicted frequency of forklift fires for the Consolidated Storage and Sales Alternatives is low (see Table 2–16). Table 5–6 shows that the levels of concern under the Consolidated Storage and Sales Alternatives range from low or negligible risk for most receptors to *situations of concern* (as seen in the key of the risk matrix Figure 1–1) for exposure of soil invertebrates to inorganic mercury in dry soil and wetland soil after wet deposition, for exposure of benthic invertebrates to inorganic mercury in sediment after wet deposition, and for exposure of the American robin to methyl mercury in wetland soil after wet deposition. Table 5–6 translates the results on Table 5–5 into the language used in the risk-based findings indicated by Figure 1–1, *situations of concern* and *situations of major concern*.

Table 5–5. Risk Levels for Exposure of Ecological Receptors to Mercury After a Forklift Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	Low	NA	Low	NA
Soil invertebrates	Dry soil	Low	Negligible	Moderate	Negligible
Short-tailed shrew	Dry soil	Negligible	Negligible	Negligible	Negligible
American robin	Dry soil	Negligible	Negligible	Low	Low
Red-tailed hawk	Dry soil	Negligible	Negligible	Negligible	Negligible
Plants	Wetland soil	Low	NA	Low	NA
Soil invertebrates	Wetland soil	Low	Negligible	Moderate	Negligible
Short-tailed shrew	Wetland soil	Negligible	Negligible	Negligible	Low
American robin	Wetland soil	Negligible	Low	Low	Moderate
Red-tailed hawk	Wetland soil	Negligible	Negligible	Negligible	Negligible
Benthic invertebrates	Sediment	Low	NA	Moderate	NA
Great blue heron	Sediment	Negligible	Negligible	Negligible	Negligible
Aquatic biota	Surface water	Negligible	Low	Negligible	Low
Great blue heron	Surface water	Negligible	Negligible	Negligible	Low

[a] Dry deposition and concentrations of divalent mercury at 1,641 ft (500 m) downwind (maximum concentration deposited).

[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

Table 5–6. Levels of Concern for Exposure of Ecological Receptors to Mercury After a Forklift Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	--	NA	--	NA
Soil invertebrates	Dry soil	--	--	Concern	--
Short-tailed shrew	Dry soil	--	--	--	--
American robin	Dry soil	--	--	--	--
Red-tailed hawk	Dry soil	--	--	--	--
Plants	Wetland soil	--	NA	--	NA
Soil invertebrates	Wetland soil	--	--	Concern	--
Short-tailed shrew	Wetland soil	--	--	--	--
American robin	Wetland soil	--	--	--	Concern
Red-tailed hawk	Wetland soil	--	--	--	--
Benthic invertebrates	Sediment	--	NA	Concern	NA
Great blue heron	Sediment	--	--	--	--
Aquatic biota	Surface water	--	--	--	--
Great blue heron	Surface water	--	--	--	--

[a] Dry deposition and concentrations of divalent mercury at 1,641 ft (500 m) downwind (maximum concentration deposited).

[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited). For the No Action Alternative, the frequency of release due to a forklift fire is negligible. For Consolidated Storage and Sales, the frequency of release due to a forklift fire is low.

Key: --, low risk; Concern, *situations of concern*, which corresponds to the moderate risk scenarios in Table 5–5.

Note that *situations of concern* exist only for wet deposition (that is, if it is raining during the fire). Because the simultaneous occurrence of a fire and rainfall for the duration of the fire is much less likely than either event alone, the frequency of wet deposition after a fire is lower than the expected frequency of fires assumed in Section 2.2.4. If it is assumed that wet deposition can occur only 10 percent of the time, the frequency of wet deposition after a forklift fire is negligible rather than low, and it is unlikely that a *situation of concern* would occur for deposition to dry soil. The frequency of deposition to a wetland or pond is even smaller than the frequency of deposition to dry soil because the wetland or pond would have to lie downwind from the fire, and it is unlikely that the wind blows continuously from the storage facility directly over a wetland or pond. Therefore, the conclusion that wet deposition after a forklift fire causes *situations of concern* is an extremely conservative conclusion.

In addition, risks were evaluated at the maximum modeled soil concentration. According to the data in Table 4–4, the soil concentration after wet deposition should decrease rapidly with distance downwind from the maximum location. That means that even if a fire and rain occurred at the same time, a *situation of concern* for soil invertebrates in dry soil and wetland soil would result for less than the nearest 1,641 ft (500 m) downwind. A *situation of concern* for songbirds like the American robin from deposition to wetland soil would be limited to the first 3,281 ft (1,000 m) downwind. For benthic invertebrates a *situation of concern* would result only if the pond where mercury is deposited is less than approximately 3,281 ft (1,000 m) downwind, and for aquatic biota, the pond would have to be less than 656 to 984 ft (200 to 300 m) from the fire.

Concentrations also decrease rapidly with distance from the centerline of the deposition zone, so the area contaminated above a level causing the *situation of concern* is small. The low to negligible probability that a fire would occur during a rain and the small area in which a *situation of concern* is predicted,

together with the negligible risk from spills without a fire, suggest that the ecological impact of potential accidents at the storage facility under the consolidated storage and sales alternatives would be very small.

5.4.3 Transportation Spills

Ecological risks associated with the Consolidated Storage Alternative or the Sales Alternative after a transportation accident arises from the vaporization of spilled mercury (after a spill) or the deposition downwind on soil or wetland sediments (after a fire). Thus, inhalation, direct contact and ingestion by ecological receptors could be of concern with one or both of the transportation accident scenarios. In the event of a spill, rapid cleanup is expected so that the only mercury released would be elemental. As discussed previously, the inhalation exposure route is generally insignificant relative to the major exposure pathway (i.e., ingestion). Thus, ecological risks are considered to be negligible for a transportation spill unless there is also a fire. In the case of a fire, as discussed previously, divalent mercury is formed and this can deposit on the ground or in water bodies, thereby presenting the potential for chronic exposures of ecological receptors.

5.4.3.1 Truck Crash/Fire Scenario

Exposure concentrations, benchmark ratios, and consequence levels for ecological receptors exposed to divalent mercury after a truck fire during transport under the Consolidated Storage and Sales Alternatives at 6,562 ft (2,000 m) (dry deposition) or 328 ft (100 m) (wet deposition) downwind are shown in Table 5–7. The calculated risk quotients and consequence levels ranged from negligible to high with the majority of consequence levels being negligible. Based on the consequence levels and low predicted frequency of a truck fire under the Consolidated Storage Alternative and moderate predicted frequency for the Sales Alternative (see Table 2–16), the matrix in Figure 1–1 was used to determine the risks shown in Table 5–8.

The level of concern for each of the receptors after a truck crash and subsequent fire under the Consolidated Storage and Sales Alternatives is shown in Table 5–9. This table shows that the levels of concern range from low risk to moderate risk (*situations of concern*) under the Consolidated Storage Alternative and from low risk to high risk (*situations of major concern*) under the Sales Alternative. The *situations of concern* (Consolidated Storage Alternative) and *situations of major concern* (Sales Alternative) result from exposure of plants to inorganic mercury in dry soil and wetland soil after wet deposition, soil invertebrates to inorganic mercury in dry soil and wetland soil after wet deposition, benthic invertebrates in sediment to inorganic mercury after wet deposition, for short-tailed shrew to methyl mercury in wetland soil after wet deposition, American robin to inorganic and methyl mercury in dry and wetland soil after wet deposition, and for aquatic biota and great blue heron to methyl mercury in surface water after wet deposition.

Table 5–7. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury Due to a Truck Fire

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil (mg/kg)	Concentration	0.922	0.019	51.918	1.060
		Benchmark	0.3	None	0.3	None
		Ratio	3.073	NA	173.061	NA
		Consequence level	Low	NA	High	NA

Table 5–7. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury Due to a Truck Fire (Continued)

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Soil invertebrates	Dry soil (mg/kg)	Concentration	0.922	0.019	51.918	1.060
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	9.22	0.008	519.2	0.424
		Consequence level	Low	Negligible	High	Negligible
Short-tailed shrew	Dry soil (mg/kg)	Concentration	0.922	0.019	51.918	1.060
		Benchmark	110	0.08	110	0.08
		Ratio	0.008	0.235	0.472	13.245
		Consequence level	Negligible	Negligible	Negligible	Moderate
American robin	Dry soil (mg/kg)	Concentration	0.922	0.019	51.918	1.060
		Benchmark	2	0.01	2	0.01
		Ratio	0.461	1.880	25.96	106.0
		Consequence level	Negligible	Low	High	High
Red-tailed hawk	Dry soil (mg/kg)	Concentration	0.922	0.019	51.918	1.060
		Benchmark	1619	6.86	1619	6.86
		Ratio	0.0006	0.003	0.032	0.154
		Consequence level	Negligible	Negligible	Negligible	Negligible
Plants	Wetland soil (mg/kg)	Concentration	0.800	0.141	45.031	7.947
		Benchmark	0.3	None	0.3	None
		Ratio	2.665	NA	150.103	NA
		Consequence level	Low	NA	High	NA
Soil invertebrates	Wetland soil (mg/kg)	Concentration	0.800	0.141	45.031	7.947
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	7.995	0.056	450.3	3.18
		Consequence level	Low	Negligible	High	Low
Short-tailed shrew	Wetland soil (mg/kg)	Concentration	0.800	0.141	45.031	7.947
		Benchmark	110	0.08	110	0.08
		Ratio	0.007	1.764	0.409	99.334
		Consequence level	Negligible	Low	Negligible	High
American robin	Wetland soil (mg/kg)	Concentration	0.800	0.141	45.031	7.947
		Benchmark	2	0.01	2	0.01
		Ratio	0.400	14.110	22.516	795
		Consequence level	Negligible	Moderate	High	High
Red-tailed hawk	Wetland soil (mg/kg)	Concentration	0.800	0.141	45.031	7.947
		Benchmark	1619	6.86	1619	6.86
		Ratio	0.0005	0.021	0.028	1.158
		Consequence level	Negligible	Negligible	Negligible	Low
Benthic invertebrates	Sediment (mg/kg)	Concentration	1.999	0.353	112.578	19.867
		Benchmark	0.150	None	0.150	None
		Ratio	13.325	NA	750.517	NA
		Consequence level	Moderate	NA	High	NA

Table 5–7. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury Due to a Truck Fire (Continued)

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Great blue heron	Sediment (mg/kg)	Concentration	1.999	0.353	112.578	19.867
		Benchmark	736	2.09	736	2.09
		Ratio	0.003	0.169	0.153	9.506
		Consequence level	Negligible	Negligible	Negligible	Low
Aquatic biota	Surface water (mg/l)	Concentration	2.82×10^{-3}	1.31×10^{-2}	1.59×10^{-1}	7.36×10^{-1}
		Benchmark	1.300	0.003	1.300	0.003
		Ratio	0.002	4.679	0.122	262.857
		Consequence level	Negligible	Low	Negligible	High
Great blue heron	Surface water (mg/l)	Concentration	2.82×10^{-3}	1.31×10^{-2}	1.59×10^{-1}	7.36×10^{-1}
		Benchmark	1.400	0.032	1.400	0.032
		Ratio	0.0020	0.409	0.114	23.000
		Consequence level	Negligible	Negligible	Negligible	High

[a] Dry deposition and concentrations of divalent mercury at 6,562 ft (2,000 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

Table 5–8. Risk Levels for Exposure of Ecological Receptors to Mercury After a Truck Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	Low/Low[c]	NA	Moderate/High[c]	NA
Soil invertebrates	Dry soil	Low/Low	Negligible	Moderate/High	Negligible
Short-tailed shrew	Dry soil	Negligible	Negligible	Negligible	Low/Moderate[c]
American robin	Dry soil	Negligible	Low/Low	Moderate/High	Moderate/High
Red-tailed hawk	Dry soil	Negligible	Negligible	Negligible	Negligible
Plants	Wetland soil	Low/Low	NA	Moderate/High	NA
Soil invertebrates	Wetland soil	Low/Low	Negligible	Moderate/High	Low/Low
Short-tailed shrew	Wetland soil	Negligible	Low/Low	Negligible	Moderate/High
American robin	Wetland soil	Negligible	Low/Moderate	Moderate/High	Moderate/High
Red-tailed hawk	Wetland soil	Negligible	Negligible	Negligible	Low/Low
Benthic invertebrates	Sediment	Low/Moderate	NA	Moderate/High	NA
Great blue heron	Sediment	Negligible	Negligible	Negligible	Low/Low
Aquatic biota	Surface water	Negligible	Low/Low	Negligible	Moderate/High
Great blue heron	Surface water	Negligible	Negligible	Negligible	Moderate/High

[a] Dry deposition and concentrations of divalent mercury at 6,562 ft (2,000 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).
[c] Low/low, low/moderate, or moderate/high refers to the risk for the Consolidated Storage Alternative and Sales Alternative. The risks for the latter case are higher because the frequency of truck fires is moderate for the Sales Alternative, but low for the Consolidated Storage Alternative (see Table 2–16). Negligible includes both scenarios.

Table 5–9. Levels of Concern for Exposure of Ecological Receptors to Mercury After a Truck Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	-- / --	NA	Concern[c] / major concern[d]	NA
Soil invertebrates	Dry soil	-- / --	--	Concern[c] / major concern[d]	--
Short-tailed shrew	Dry soil	--	--	--	-- / Concern[d]
American robin	Dry soil	--	-- / --	Concern[c] / major concern[d]	Concern[c] / major concern[d]
Red-tailed hawk	Dry soil	--	--	--	--
Plants	Wetland soil	-- / --	NA	Concern[c] / major concern[d]	NA
Soil invertebrates	Wetland soil	-- / --	--	Concern[c] / major concern[d]	-- / --
Short-tailed shrew	Wetland soil	--	-- / --	--	Concern[c] / major concern[d]
American robin	Wetland soil	--	-- / Concern[d]	Concern[c] / major concern[d]	Concern[c] / major concern[d]
Red-tailed hawk	Wetland soil	--	--	--	-- / --
Benthic invertebrates	Sediment	-- / Concern[d]	NA	Concern[c] / major concern[d]	NA
Great blue heron	Sediment	--	--	--	-- / --
Aquatic biota	Surface water	--	-- / --	--	Concern[c] / major concern[d]
Great blue heron	Surface water	--	--	--	Concern[c] / major concern[d]

[a] Dry deposition and concentrations of divalent mercury at 6,562 ft (2,000 m) downwind (maximum concentration deposited).

[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

[c] Level of Concern for the Consolidated Storage Alternative.

[d] Level of Concern for the Sales Alternative.

Note: Release of mercury due to a truck fire is low under the Consolidated Storage Alternative and moderate under the Sales Alternative.

Key: --, Low risk due to negligible frequency or severity of consequence; concern, *situations of concern*, corresponds to the moderate risk scenarios from Table 5–8; major concern, *situations of major concern*, corresponds to the high risk scenarios in Table 5–8.

Note that except for exposure of the American robin in wetlands and for benthic invertebrates, *situations of concern* exist only for wet deposition (that is, if it is raining during the fire). Because the simultaneous occurrence of a fire and rainfall for the duration of the fire is much less likely than either event alone, the frequency of wet deposition after a fire is lower than the expected frequency of fires shown in Tables 2–10 and 2–12. If it is assumed that wet deposition can occur only 10 percent of the time, the frequency of wet deposition after a truck crash with fire is negligible to low rather than low to moderate, and it is unlikely that a *situation of concern* would occur for deposition to dry soil. The frequency of deposition to a wetland or pond is even smaller than the frequency of deposition to dry soil because the wetland or pond would have to lie downwind from the fire, and it is not certain that the wind would be

blowing from the crash site directly over a wetland or pond. Therefore, although exposures would be high in the event of deposition to a wetland or pond, the low probability of the event makes it unlikely that harm would result from truck transportation under the consolidated storage and sales alternatives. Therefore, the conclusion that wet deposition after a fire causes *situations of concern* is an extremely conservative conclusion.

In addition, risks were evaluated at the maximum modeled soil concentration. According to the data in Table 4–8, the soil concentration after wet deposition should decrease with distance downwind from the maximum location. That means that a *situation of concern* for robins in a wetland and for benthic invertebrates in a pond after dry deposition would result at distances downwind of about 3,937 ft (1,200 m) to about 13,124 ft (4,000 m). In the case of wet deposition to dry soil, a *situation of concern* for soil invertebrates would exist for more than 16,405 ft (5,000 m) downwind. For other receptors, the distances would be lower (for example, about 8,203 ft [2,500 m] for plants and 4,922 ft [1,500 m] for songbirds). In the case of wet deposition to ponds and wetlands, however, a *situation of concern* would exist for several thousand meters downwind from the fire.

The low to negligible probability that a fire would occur during a rain and the limited area in which a *situation of concern* is predicted, together with the negligible risk from spills without a fire, suggest that the ecological impact of accidents during truck transport in the Consolidated Storage and Sales Alternatives is not likely to be of concern.

5.4.3.2 Railcar Crash/Fire Scenario

Exposure concentrations, benchmark ratios, and consequence levels for ecological receptors exposed to divalent mercury after a railcar crash/fire during transport for consolidation or sales at 6,562 ft (2,000 m) (dry deposition) or 328 ft (100 m) (wet deposition) downwind are shown in Table 5–10. The calculated risk quotients and consequence levels ranged from negligible to high with the majority of consequence levels being negligible. Based on the consequence levels and low predicted frequency of a railcar fire the Consolidated Storage and Sales Alternatives (see Table 2–16), the matrix in Figure 1–1 was used to determine the risks. The risk to each of the receptors after a railcar fire is shown in Table 5–11.

The level of concern for each of the receptors after a railcar crash and subsequent fire under the Consolidated Storage and Sales Alternatives is shown in Table 5–12. This table shows that the levels of concern range from low risk to moderate risk (*situations of concern*) under the Consolidated Storage and Sales Alternatives. The *situations of concern* result from exposure of plants to inorganic mercury in dry soil and wetland soil after wet deposition, soil invertebrates to inorganic mercury in dry soil and wetland soil after wet deposition, benthic invertebrates in sediment to inorganic mercury after wet deposition, for short-tailed shrew to methyl mercury in wetland soil after wet deposition, for American robin to inorganic and methyl mercury in dry soil and wetland soil after wet deposition, and for aquatic biota and great blue heron to methyl mercury in surface water after wet deposition.

Table 5–10. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury due to a Railcar Fire

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil (mg/kg)	Concentration	0.968	0.020	60.234	1.229
		Benchmark	0.3	None	0.3	None
		Ratio	3.228	NA	200.779	NA
		Consequence level	Low	NA	High	NA
Soil invertebrates	Dry soil (mg/kg)	Concentration	0.968	0.020	60.234	1.229
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	8.399	0.059	602.338	0.49
		Consequence level	Low	Negligible	High	Negligible
Short-tailed shrew	Dry soil (mg/kg)	Concentration	0.968	0.020	60.234	1.229
		Benchmark	110	0.08	110	0.08
		Ratio	0.019	4.631	1.187	15.36
		Consequence level	Negligible	Low	Low	Moderate
American robin	Dry soil (mg/kg)	Concentration	0.968	0.020	60.234	1.229
		Benchmark	2	0.01	2	0.01
		Ratio	0.484	1.980	30.117	122.930
		Consequence level	Negligible	Low	High	High
Red-tailed hawk	Dry soil (mg/kg)	Concentration	0.968	0.020	60.234	1.229
		Benchmark	1619	6.86	1619	6.86
		Ratio	0.0006	0.003	0.037	0.179
		Consequence level	Negligible	Negligible	Negligible	Negligible
Plants	Wetland soil (mg/kg)	Concentration	0.840	0.148	52.244	9.220
		Benchmark	0.30	None	0.3	None
		Ratio	2.800	NA	174.145	NA
		Consequence level	Low	NA	High	NA
Soil invertebrates	Wetland soil (mg/kg)	Concentration	0.840	0.148	52.244	9.220
		Benchmark	0.1	2.5	0.1	2.5
		Ratio	8.399	0.059	522.436	3.688
		Consequence level	Low	Negligible	High	Low
Short-tailed shrew	Wetland soil (mg/kg)	Concentration	0.840	0.148	52.244	9.220
		Benchmark	110	0.08	110	0.080
		Ratio	0.008	1.853	0.475	115.244
		Consequence level	Negligible	Low	Negligible	High
American robin	Wetland soil (mg/kg)	Concentration	0.840	0.148	52.244	9.220
		Benchmark	2	0.01	2	0.01
		Ratio	0.420	14.820	26.122	921.950
		Consequence level	Negligible	Moderate	High	High
Red-tailed hawk	Wetland soil (mg/kg)	Concentration	0.840	0.148	52.244	9.220
		Benchmark	1,619	6.86	1,619	6.86
		Ratio	0.0005	0.022	0.032	1.344
		Consequence level	Negligible	Negligible	Negligible	Low

Table 5–10. Exposure Concentrations, Consequence Levels for Ecological Receptors Exposed to Mercury due to a Railcar Fire (Continued)

			Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Parameter**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Benthic invertebrates	Sediment (mg/kg)	Concentration	2.100	0.371	130.609	23.049
		Benchmark	0.15	None	0.15	None
		Ratio	13.998	NA	870.727	NA
		Consequence level	Moderate	NA	High	NA
Great blue heron	Sediment (mg/kg)	Concentration	2.100	0.371	130.609	23.049
		Benchmark	736	2.09	736	2.09
		Ratio	0.003	0.177	0.177	11.028
		Consequence level	Negligible	Negligible	Negligible	Moderate
Aquatic biota	Surface water (mg/l)	Concentration	2.96×10^{-3}	1.37×10^{-2}	1.84×10^{-1}	8.54×10^{-1}
		Benchmark	1.3	0.003	1.3	0.003
		Ratio	0.0023	4.893	0.142	305.000
		Consequence level	Negligible	Low	Negligible	High
Great blue heron	Surface water (mg/l)	Concentration	2.96×10^{-3}	1.37×10^{-2}	1.84×10^{-1}	8.54×10^{-1}
		Benchmark	1.4	0.032	1.4	0.032
		Ratio	0.002	0.428	0.131	26.688
		Consequence level	Negligible	Negligible	Negligible	High

[a] Dry deposition and concentrations of divalent mercury at 8,203 ft (2,500 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

Table 5–11. Risk Levels for Exposure of Ecological Receptors to Mercury After a Railcar Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	Low	NA	Moderate	NA
Soil invertebrates	Dry soil	Low	Negligible	Moderate	Negligible
Short-tailed shrew	Dry soil	Negligible	Low	Low	Low
American robin	Dry soil	Negligible	Low	Moderate	Moderate
Red-tailed hawk	Dry soil	Negligible	Negligible	Negligible	Negligible
Plants	Wetland soil	Low	NA	Moderate	NA
Soil invertebrates	Wetland soil	Low	Negligible	Moderate	Low
Short-tailed shrew	Wetland soil	Negligible	Low	Negligible	Moderate
American robin	Wetland soil	Negligible	Low	Moderate	Moderate
Red-tailed hawk	Wetland soil	Negligible	Negligible	Negligible	Low
Benthic invertebrates	Sediment	Low	NA	Moderate	NA
Great blue heron	Sediment	Negligible	Negligible	Negligible	Low
Aquatic biota	Surface water	Negligible	Low	Negligible	Moderate
Great blue heron	Surface water	Negligible	Negligible	Negligible	Moderate

[a] Dry deposition and concentrations of divalent mercury at 8,203 ft (2,500 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).

Table 5–12. Levels of Concern for Exposure of Ecological Receptors to Mercury After a Railcar Fire—Consolidated Storage and Sales Alternatives

		Dry Deposition[a]		Wet Deposition[b]	
Receptor	**Medium**	**Inorganic Mercury**	**Methyl Mercury**	**Inorganic Mercury**	**Methyl Mercury**
Plants	Dry soil	--	--	Concern	--
Soil invertebrates	Dry soil	--	--	Concern	--
Short-tailed shrew	Dry soil	--	--	--	Concern
American robin	Dry soil	--	--	Concern	Concern
Red-tailed hawk	Dry soil	--	--	--	--
Plants	Wetland soil	--	--	Concern	--
Soil invertebrates	Wetland soil	--	--	Concern	--
Short-tailed shrew	Wetland soil	--	--	--	Concern
American robin	Wetland soil	--	--	Concern	Concern
Red-tailed Hawk	Wetland soil	--	--	--	--
Benthic invertebrates	Sediment	--	--	Concern	--
Great blue heron	Sediment	--	--	--	--
Aquatic biota	Surface water	--	--	--	Concern
Great blue heron	Surface water	--	--	--	Concern

[a] Dry deposition and concentrations of divalent mercury at 8,203 ft (2,500 m) downwind (maximum concentration deposited).
[b] Wet deposition and concentrations of divalent mercury at 328 ft (100 m) downwind (maximum concentration deposited).
Note: Frequency of release of mercury due to a railcar fire is low under both the Consolidated Storage and Sales Alternatives.
Key: --, low risk; concern, *situations of concern*, corresponds to the moderate risk scenarios in Table 5–11.

Note that *situations of concern* exist only for wet deposition (that is, if it is raining during the fire). Because the simultaneous occurrence of a fire and rainfall for the duration of the fire is much less likely than either event alone, the frequency of wet deposition after a fire is lower than the expected frequency of fires shown in Table 2–13. If it is assumed that wet deposition can occur only 10 percent of the time, the frequency of wet deposition after a rail crash with fire is negligible to low rather than low to moderate, and it is unlikely that a *situation of concern* would occur. The frequency of deposition to a wetland or pond is even smaller than the frequency of deposition to dry soil because the wetland or pond would have to lie downwind from the fire, and it is not certain that the wind would be blowing from the crash site directly over a wetland or pond. Therefore, although exposures would be high enough for a *situation of concern* in the event of deposition to a wetland or pond, the low probability of the event makes it unlikely that harm would result from rail transportation under the Sales Alternative. Therefore, the conclusion that wet deposition after a fire causes *situations of concern* is an extremely conservative conclusion.

In addition, risks were evaluated at the maximum modeled soil concentration. According to the data in Table 4–10, the soil concentration after wet deposition should decrease with distance downwind from the maximum location. That means that if a fire and rain occurred at the same time, a *situation of concern* for soil invertebrates in dry soil and wetland soil would result for nearly 32,810 ft (10,000 m) downwind. A *situation of concern* for songbirds like the American robin would be limited to the first 4,922 ft (1,500 m) downwind for deposition to dry soil, but concern would exist for more than 32,810 ft (10,000 m) from deposition to wetland soil. For benthic invertebrates a *situation of concern* would also result if the pond where mercury is deposited is less than 32,810 ft (10,000 m) downwind, and for aquatic biota, concern could exist for a pond less than 16,405 ft (5,000 m) from the fire.

The low to negligible probability that a fire would occur during a rain and the limited area in which a *situation of concern* is predicted, together with the negligible risk from spills without a fire, suggest that the ecological impact of accidents during rail transport in the Consolidated Storage and Sales Alternatives is not likely to be of concern.

Chapter 6
Uncertainty Assessment

This section describes uncertainties in the risk estimates and an indication of the magnitude and predominant direction of the uncertainty (i.e., whether the stated risk estimates tend to understate or overstate the risks).

6.1 CONTAMINANT SOURCE

The following discussion considers sources of contamination that might be expected under normal operating and accidental conditions.

6.1.1 Normal Operating Conditions

A principal assumption is the chemical form of mercury released. Mercury exists in three forms in the environment: elemental Hg^0 (metallic), Hg_2^{2+} (mercurous), and Hg^{2+}(mercuric). During normal storage it is highly unlikely that mercury will be released in a form other than elemental mercury vapor. Specific types of chemical reactions must occur to change metallic/liquid mercury into a mercurous or mercuric compound. One example is oxidation of metallic mercury into mercuric mercury in water in the presence of an oxidizer such as hydrogen peroxide. However, it is highly unlikely that these conditions will occur within the warehouse during normal operating conditions. Consequently, the uncertainty in the assessment of releases of elemental mercury vapor is considered minimal.

Air monitoring is conducted to detect leaks, and the conditions of normal storage together with the required worker safety procedures indicate that mercury concentrations inside the warehouses are unlikely to exceed the baseline concentration for other than a short period of time. In calendar year 2000, 52 measurements of mercury concentrations in air were made in the warehouse as part of the worker safety program at the Warren Depot. The concentration of mercury vapor exceeded the detection limit (about 1,000 ng/m^3) on only four occasions, with a maximum detected concentration of about 5,000 ng/m^3. At Somerville, mercury vapor was detected in 5 of 20 measurements at a maximum concentration of 17,000 ng/m^3. In all instances, the concentrations were below the limit of 25,000 ng/m^3 TLV (OSHA 2002) that is used in the risk assessment as a hypothetical and worst-case chronic upper limit for air within the warehouses. Further, the atmospheric processes mediating the transport of indoor air in the warehouse to the ambient air outside virtually ensure that the mercury concentration will not increase as the mercury is transported downwind. This claim is also supported by limited information from the Somerville Depot as well as the results of a Binghamton University study conducted at the Somerville Depot. In all cases the maximum concentrations were below the 25,000 ng/m^3. It is also notable that mercury concentrations measured outside the warehouse were nearly 1,000-fold lower than 25,000 ng/m^3.

Taken together, these findings indicate that it is highly unlikely that mercury vapor concentrations of 25,000 ng/m^3 would be reached or exceeded during long-term storage activities. As a consequence, the projected concentrations of mercury vapor are highly likely to be overstating actual conditions. More realistic assumptions based on better information would likely result in lower risk estimates.

6.1.2 Accidental Conditions

Although the mercury released into the atmosphere under a fire scenario would be partially in the form of elemental mercury and partially in the form of divalent mercury, this analysis implicitly assumes that all

of the mercury is in the divalent form. Under operating conditions that include stack emissions in the presence of environmental controls, EPA recommends phase allocations for mercury emissions of 20 percent vapor phase elemental mercury, 60 percent vapor phase divalent mercury and 20 percent particle phase mercury (EPA 1998). No information is available concerning the speciation of mercury resulting from sources involving combustion in the absence of emission controls. Therefore, because divalent mercury is assumed to be more susceptible to deposition processes than either elemental or particle mercury (EPA 1997b) and all forms of mercury are assumed to be equally as toxic as the most toxic form, the assumption that 100 percent of the mercury is released as divalent mercury represents a worst-case when considering deposition.

Assumptions are used to address the mercury release rate, the duration of the fire (and correspondingly, the mercury release and deposition flux durations), the chemical type of mercury released, and the effective release height. As much as 200 lb/min (91 kg/min) of mercury will be released into the atmosphere in the case of the railcar fire. This release rate estimate was derived using the methods recommended in EPA guidance on conducting the offsite consequence analyses for Risk Management Programs required under the Clean Air Act (EPA 1999b). As noted in this guidance, these methods produce worst-case estimates. As such, the release rate used in this analysis is more likely to result in an overstatement of the risks from a railcar accident than to understate them.

The duration of the fire was estimated using the methods recommended by the Nuclear Regulatory Commission (NRC) for conducting accident analysis of nuclear fuel cycle facilities (Ayer et al., 1988). As applied in this analysis, these equations tend to overestimate the rate of heat input into the rising contaminant plume and to underestimate the duration of the release. The overestimation of the rate of heat input into the rising contaminant plume tends to result in an overestimation of the effective release height, which tends to result in an underestimation of the dry deposition flux rate. The wet deposition flux rate is, however, largely insensitive to the effective release height. The noted underestimation of the release duration results tends to result in an underestimation of the total mass of mercury deposited through both dry and wet deposition processes. Overall, the NRC methods as applied in this analysis would tend to result in an understatement rather than an overstatement of risk.

The equation for estimating the effective release height (see Section A) is that recommended by the U.S. Army for use in chemical hazard prediction (Army 1980). The use of this equation is expected to have no identifiable biasing effect on the risk estimates.

Overall, the contaminant source assumptions are such that the analysis is more likely to overstate the risks than understate them.

6.2 RECEPTORS

This analysis estimates mercury concentrations in air, soil, surface water and sediment that could occur as a result from onsite and offsite fires. Several receptor-related assumptions were made in the analysis. Explicit assumptions were made concerning receptor locations, and implicit assumptions were also made. The analysis assumes that the mercury concentration estimated for each location represents the mercury exposure associated with a receptor nominally occupying that location. Over the short term, an individually identifiable location may be appropriate. Over the long-term, an individual's exposure represents an aggregate of the concentrations present in each of the numerous areas (or microenvironments) visited by the individual over time. EPA provides information on activity patterns including information on the amount of time spent "At Home" for men and women ages 18 to 64 years (EPA 1997c). According to EPA, men spend about 60 percent of their time at home, while women spend about 70 percent of their time there.

The generic soil screening level for mercury is based on exposure assumptions appropriate for a child 1 to 6 years of age (EPA 1996b). Thus, using the SSL in the derivation of the health-based benchmark results in the implicit assumption that the receptor of interest is a child. Moreover, because the assumed soil ingestion rate for children is higher than that of non-smoking adults while the assumed body weight is lower, child-based SSLs are lower than those of adults.

There is uncertainty about which organisms potentially exposed at the storage sites or in the environs of accidental releases are at most risk. If more sensitive receptors are present, then they may not be adequately addressed by the assessment endpoints evaluated in the ERA. The receptor species listed as potentially present at the unit are a limited subset of the species that may utilize the area to some extent for at least a portion of the year. The species evaluated in the ERA are considered to provide a conservative representation of the range of exposures that may be experienced by other species not evaluated.

It is noteworthy that EPA estimates the background mercury concentration in air to be about 1.6 ng/m^3 (EPA 1997a). This indicates two opposing conditions: that measurements taken at the warehouses could be confounded by background sources, and that the estimated concentrations of mercury in air are actually in addition to those already in the background. The noted assumptions are a source of significant uncertainty in the risk estimates but taken as a whole, they are believed to be overstated rather than understated.

6.3 ENVIRONMENTAL PATHWAYS

The modeling of atmospheric transport, transformation, and fate is a significant source of uncertainty in the risk estimates. In the case of elemental mercury, the uncertainties arise from the assumption that elemental mercury neither deposits nor transforms within the area addressed by this analysis. Also important is the assumption that the Pasquill-Gifford Gaussian plume model is appropriate for this analysis (especially when applied close to the release sources).

An important condition of the risk assessment is that releases of elemental mercury are not likely to deposit locally. The available information indicates that transformation of elemental mercury into other forms of mercury that are prone to deposition is unlikely. Discernible concentrations of the other forms of mercury locally (e.g., within 6.2 mi [10 km] of the warehouses) are thus unlikely. This assumption is well supported by EPA's Mercury Report to Congress (EPA 1997a). Homogenous gas phase transformation of elemental mercury is considered to be of little consequence even on a regional scale. Regionally significant heterogeneous reactions are likely to occur very slowly as a result of the low water solubility of elemental mercury (Bloxam 1995; EPA 1997a). As concluded by EPA (1997c):

> Global atmospheric circulation systems can take Hg^0 emissions from their point of origin and carry them anywhere on the globe before transformation and deposition occur… .[Elemental] mercury vapor is not thought to be susceptible to any major process of direct deposition to the earth's surface due to its relatively high vapor pressure and low water solubility. On non-assimilating surfaces elemental mercury deposition appears negligible…[and] this elemental mercury is expected to volatilize into the atmosphere.

Thus, even though some transformation and deposition of elemental mercury will inevitably occur, the available information indicates that on a local scale the magnitude of transformation and deposition of elemental mercury released as a result of normal operations is undoubtedly very small. Consequently, even though the transformation and fate assumptions may cause an understatement of the risks, the

magnitude of the understatement will also be very small. The significance of any such understatement is tempered by the significant assumptions made in the risk assessment that tend to overstate risks.

Numerous assumptions are implicitly made in employing a Gaussian plume model to estimate atmospheric pollutant concentrations and deposition rates. The implicit general assumptions are discussed in references addressing air pollution models such as Hanna, Briggs, and Hosker (1982) and Schulze (1991). Several specific assumptions of importance have been made in this analysis. These assumptions concern the selection of values or equations for wind speed, stability class, stability parameters, and deposition velocities.

The use of the single stability Class D to reflect long-term average conditions in the atmosphere is a common practice for initial screening analyses. The value for wind speed of 14.8 ft/s (4.5 m/s) used in this analysis is generally higher than the reported averages for selected locations in Indiana, New Jersey, and Ohio, as well as for Oak Ridge, Tennessee, shown below in Table 6–1. However, it is lower than the value of 16.4 ft/s (5 m/s) used for Stability Class D by EPA in its *Report to Congress* atmospheric mercury modeling (EPA 1997b). Consequently, this assumption is more likely to result in an understatement of risks rather than an overstatement.

Table 6–1. Wind Speed Ranges

State	Number of Locations	Annual Averages (m/s)	Minimum Monthly Averages (m/s)
Indiana	4	3.6 to 4.6	2.6 to 3.4
New Jersey	2	4.5 to 4.6	3.6 to 3.9
Ohio	8[a]	3.8 to 4.9	3.2 to 3.8
Tennessee	1[b]	2.0	1.6

[a] Includes data from the Greater Cincinnati Airport, which is located in Kentucky.
[b] Data from Oak Ridge, Tennessee.
Source: http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/avgwind.html.

The assumption that these equations apply to distances close to the source area is problematic because there is no information to validate the model under the assumption. Consequently, the model used in this analysis may cause significant uncertainty in the risk estimates close to the source, although in such a case it is not known whether the risk estimates are overstated or understated.

The analysis also explicitly assumes that the dry deposition velocity for divalent mercury is 1.1 in/s (2.9 cm/s) and that the rainfall-scavenging rate is 1.5×10^{-4} s^{-1}. According to EPA in its *Report to Congress* atmospheric mercury modeling for Stability Class D (EPA 1997b), the assumed dry deposition velocity lies in the upper end of the range of the available values. Regarding the rainfall scavenging rate, Hanna, Briggs, and Hosker (1982) note that this is a median value from 20 field experiments conducted by McMahon and Dennison. They indicate a range of 0.4×10^{-4} s^{-1} to 3×10^{-3} s^{-1}. They also state that: "The use of scavenging coefficients for wet removal modeling is probably best regarded as an order-of-magnitude estimation procedure" (Hanna, Briggs, and Hosker 1982). Furthermore, wind speeds and stability classes are themselves uncertain due to changes in weather conditions. Taken as a group, the direction of any resulting bias is indeterminate.

Intake from inhalation exposures is difficult to quantify for ecological receptors. However, intake via this route is likely to be minimal relative to intakes via ingestion. In the scenarios qualitatively evaluated in this ERA, ingestion was not evaluated because mercury is only expected to be in the elemental form and thus is unlikely to deposit on a local scale. Inhalation is typically a smaller contributor to risk than

ingestion. However, there is an increase in the uncertainty for the total risk encountered by leaving inhalation out and a likely but insignificant underestimate of total risk.

The EPCs in air are based on the concentration at the centerline of the plume. The concentration within the bulk of the plume area will likely be lower than at the centerline.

6.4 EFFECTS DUE TO EXPOSURE TO MERCURY

The limitations in toxicological testing and extrapolation of results from toxicological study populations to the general population, result in considerable uncertainty in determining the concentrations below which adverse effects are unlikely (e.g., Dourson, Felter, and Robinson 1996). However, the process of determining reference doses attempts to account for these uncertainties through the use of uncertainty and modifying factors. Consequently, it is unlikely that a reference concentration will understate toxicity. As noted by EPA, "the RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." Regarding the worker safety criteria, these criteria are regulatory in nature and are thus considered appropriate for screening worker safety risks.

Values for elemental mercury toxicity were used as the sole basis for evaluation of exposure to mercury vapor. The standard for mercury vapor is five-times higher than the value for organo-mercury alkyl compounds (OSHA 2002). However, use of the lower value would not change the results of the analysis. It is highly unlikely that any mercury vapor released under normal operating conditions would be transformed in a significant manner to any other form of mercury. EPA provides oral reference doses for mercuric chloride and methyl mercury (3×10^{-4} mg/kg/day and 1×10^{-4} mg/kg/day, respectively), but not elemental mercury (since it is primarily an inhalation hazard). Converting the inhalation reference concentration for elemental mercury to an equivalent oral reference dose yields a value of 9×10^{-5} mg/kg/day. Although this conversion may not be appropriate from a toxicological standpoint, it does serve to illustrate that reliance on elemental mercury alone as the basis for toxicological comparison does not appear to bias the risk results away from protection of human health.

Regarding the limitations in the toxicity data for mercury compounds, EPA classifies their confidence in the elemental mercury RfC as "medium". Inadequate quantification of exposure levels and lack of human or multi-species reproductive or developmental studies was cited by EPA as the reasons a rating of high could not be assigned (EPA 2002a). It is thus possible that the RfC understates (or overstates) the toxicity of elemental mercury. However, EPA's use of a 30-fold uncertainty factor in the derivation of the RfC makes it unlikely that the RfC is insufficiently conservative. In contrast, EPA classified their confidence in the mercuric chloride and methyl mercury reference doses as "high" in both cases. EPA identified the weight of evidence from the studies of the Brown Norway rat and the overall quality of the mercuric chloride toxicity database as the reasons supporting their assessment of confidence. The quality of the three epidemiological studies used to derive the methyl mercury reference dose together with consistent evidence from studies in monkeys were cited by EPA as supporting their confidence assessment. In addition, the available information indicates that even if mercuric chloride or methyl mercury is a carcinogen, they are unlikely to exhibit high carcinogenic potency.

The toxicity values used to assess short-term health effects related to exposures to mercury present uncertainties. The following discussion or uncertainty pertains to the ERPGs, but similar uncertainties exist for the IDLH values used to evaluate short-term effects to workers at the mercury storage facilities. The ERPG is a maximum airborne concentration to which most individuals could be exposed for up to 1 hour without irreversible serious health effects. In the following excerpt (taken from

http://www.bnl.gov/scapa/erpgpref.htm), the American Industrial Hygiene Association notes several key uncertainties in the level of protection provided:

> … ERPGs should not be expected to protect everyone but should be applicable to most individuals in the general population. In all populations there are hypersensitive individuals who will show adverse responses at exposure concentrations far below levels where most individuals normally would respond…they are estimates…of the thresholds above which there would be unacceptable likelihood of observing the defined effects. The estimates are based on the available data that are summarized in the documentation. In some cases where the data are limited, the uncertainty of these estimates is large.

The AIHA also notes uncertainty in the use of experiments on animals in developing the ERPGs for use with humans:

> In developing these ERPGs, human experience has been emphasized to the extent data are available. …More value is given to the more rigorously conducted studies, and data from short-term studies are considered to be more useful in estimating possible effects from a single 1-hr exposure.

Finally, AIHA notes that the timeframe (up to 1 hour) represented by the ERPG is somewhat arbitrary, based on professional judgment:

> This decision was based on the availability to toxicology information and a reasonable estimate for an exposure scenario. Users who may choose to extrapolate these values to other time periods are cautioned to review the documentation fully since such extrapolations tend to hold only over very limited time frames, if at all.

Although the acute toxicity values are uncertain (as are to some degree all toxicity values), they likely provide an adequate basis for the evaluation of acute health effects for most individuals who might be exposed to mercury via inhalation at the stockpiles (i.e., workers and the public). Based on the available information, the direction of the uncertainty (i.e., toward underestimation or overestimation of health effects) is not determined.

6.4.1 Effects

In calculating constituent intakes, conservative exposure factors are assumed in order to be protective of all potential receptors. Low-end estimates of body weights and high-end estimates of ingestion rates are assumed in order to model the highest potential dose to the receptor. Conservatism is also employed in estimating bioavailability, and the percent of contaminated plant and contaminated animal materials in the diet. The conservative exposure factors and exposure concentrations used provide confidence that calculated intakes are reasonably conservative estimates for receptor populations. Intakes from dermal and inhalation exposures are not quantifiable for ecological receptors. However, this does not significantly increase the uncertainty of the estimated total intake because, for most receptors, intakes via these routes are likely to be minimal relative to intakes via ingestion.

There is uncertainty associated with TRVs used in this ERA because the toxicity data are not site-specific. Limitations in toxicity values include variations in physiological or biochemical factors that may exist among species, behavioral and ecological parameters that may make species' sensitivity to a contaminant different from that of the test organism, and limited information on long-term effects on natural populations. In addition, most laboratory studies use highly bioavailable forms of chemicals during

toxicity related derivations. Since most chemicals in nature are bound or associated with inorganic matrices or organics, many are not as bioavailable as the forms used in the laboratory studies. The combination of maximum intakes and conservative TRVs provide confidence that the HQs resulting from the evaluation are conservative.

The TRVs for plants and earthworms are based on studies in which the receptors were maintained in soil to which the test compounds had been added. Because the concentration of biologically available mercury species is likely to be lower than the total concentration, the TRVs for plants and earthworms probably overstate the toxicity of inorganic mercury and methyl mercury to these receptors.

The TRV for mammals exposed to inorganic mercury is based on a study in which mink were fed mercuric chloride in the diet for 6 months, during which they had pups. A NOAEL of 1.0 mg/kg/day for reproductive success was reported. However, only one dose level was used in the study. Therefore, a higher dose might also have produced a NOAEL. The convention of multiplying the NOAEL by 10 to estimate a LOAEL is based on the observation that the LOAEL is ten-fold higher than the NOAEL in studies that use a series of ten-fold dilutions in the dose level. Therefore, 10 is an arbitrary conversion factor. However, since a LOAEL was not observed, the highest possible NOAEL is likely high enough that the toxicity of inorganic mercury is overstated by the assumptions used in this analysis. The TRV for mammals exposed to methyl mercury is based on a study in which rats were fed methyl mercury in the diet for 1 year, during which they had pups. A LOAEL of 0.16 mg/kg/day for viability of the pups was calculated by using an allometric (i.e., based on measurements of various body parts) equation for the food consumption rate. Therefore, there is some uncertainty in the actual dosage. Whether the LOAEL understates or overstates toxicity is indeterminate, but the effect on the analysis of risk is expected to be minor.

TRVs for mammals were scaled from LOAELs for the test species by the body weight of each receptor. The scaling factor is based on the principle that uptake and retention of chemicals are determined by metabolic rate, which is in turn related by body weight. Therefore, the same dose is expected to have quantitatively different toxic effects in different receptors. There is uncertainty that the scaling factors used are strictly accurate for each combination of test species and ecological receptor, and whether the calculated TRV overstates or understates toxicity is indeterminate. However, the effect on the analysis of risk is expected to be minor.

The TRV for birds exposed to inorganic mercury is based on a study in which Japanese quail were fed mercuric chloride in the diet for 1 year, during which they had offspring. A LOAEL of 0.9 mg/kg/day and a NOAEL of 0.45 mg/kg/day for reproductive success were calculated by using an allometric equation for the food consumption rate. Therefore, there is some uncertainty in the actual dosage. Whether the TRVs understate or overstate toxicity is indeterminate, but the effect on the analysis of risk is expected to be minor. The TRV for birds exposed to methyl mercury is based on a study in which mallard ducks were fed methyl mercury in the diet for three generations. A LOAEL of 0.064 mg/kg/day for reproductive success was observed. However, only one dose level was used in the study. Therefore, a lower dose might also have produced a LOAEL. As a result, the TRV for birds probably understates the toxicity of methyl mercury.

TRVs for aquatic biota are intended to protect most aquatic species and therefore likely overstate the toxicity of inorganic mercury and methyl mercury. The TRV for sediment biota is based on a correlation of observed adverse effects to sediment biota with concentrations of mercury in sediments that were contaminated by other pollutants as well. Because the concentration of biologically available mercury is likely to be lower than the total concentration and because other contaminants may have contributed to the observed toxicity, the TRV for sediment biota probably overstates the toxicity of inorganic mercury in sediment.

6.4.2 Summary

The risk estimates are believed to provide an adequate basis for health-protective decision-making. Taken together, the simplifying assumptions cause significant uncertainty in the final risk estimates. However, the predominant conservatism of most of the assumptions likely outweighs the biases caused by other assumptions. Uncertainty in the human and ecological risk characterization is a direct result of the conservative methodology employed. The conservative methodology and assumptions used in the exposure pathway selection, exposure assessment, and toxicity assessment are expected to overestimate, rather than underestimate, the potential for mercury to pose risk to assessment endpoints. By overestimating risk, the actual risk of the management alternatives considered is believed to be less than indicated by the numeric results presented in the risk assessment.

Chapter 7
Summary and Conclusions

An analysis was conducted of projected human and ecological health effects from exposure to mercury released during several management activities being considered in the MM EIS. Hypothetical releases were evaluated for slow releases and spills occurring at normal temperatures. Also considered were vapor phase release and deposition to soil resulting from hypothetical onsite and offsite accidents with fire, and transportation risks from hypothetically relocating the mercury stockpile for consolidation or sale. Risks were evaluated by estimating the frequency and the health consequences of the events, and applying a risk matrix to each of these (see Figure 1–1).

The following are conclusions with respect to the major findings of the human health and ecological risk assessment for the MM EIS. These conclusions should be tempered with the understanding that the analyses in this report are likely to overestimate the human health and ecological risks for the scenarios evaluated; furthermore, the definitions of risk used in the risk matrix presented in Figure 1–1 are more conservative than those used in many accident analyses; they typically consider the lack of a fatality or serious injury as an indication of low risk.

7.1 HUMAN HEALTH EFFECTS

The results of this analysis indicate that the risks associated with normal operations under the No Action Alternative are minimal largely because of the low level of activity associated with storage. The effects for onsite workers fall into the negligible category for severity of consequence. The effects for offsite receptors (i.e., members of the public) are based on a much more sensitive benchmark and depend on the distance to the facility fence line (i.e., the closest hypothetical offsite receptor). The consequences are low for an offsite receptor at the fence line at Warren and Somerville depots, and negligible at New Haven Depot, PEZ Lake Development, Y–12, Hawthorne Army Depot, and Utah Industrial Depot. These estimates are highly conservative because they are based on the presumption that the mercury concentration in the air venting from the warehouses is at a constant 25,000 $\mu g/m^3$. Another important assumption is that local human health effects from slow leaks of mercury during normal operations will be in the form of elemental mercury, which is unlikely to deposit locally.

Table 7–1 is presented to facilitate the summary discussion. For onsite accidents that do not result in fire under any alternative, all exposures at any of the facilities result in negligible risk with the exception of a spill due to an earthquake. An earthquake could result in a spill at normal temperature producing low-to-moderate acute human health risks for a worker in the immediate vicinity of the spill and negligible-to-low risk to the noninvolved worker and the public. Significant exposures to people beyond the immediate vicinity of the normal-temperature spill are unlikely as are lingering consequences after an earthquake, due to cleanup activities that would be anticipated in the short term.

In terms of risk, the Consolidated Storage and Sales Alternatives are distinguished from the No Action Alternative because they represent higher levels of activity. Spills and fires associated with these alternatives are more likely to occur due to the increased handling of the mercury on site and while transporting the mercury off site via truck, rail, or oceangoing vessel. Accident event frequencies are higher for truck accidents occurring under the Sales Alternative because travel occurs in both domestic and foreign territories. The consequence ratios used to assess releases occurring on site due to a forklift fuel and pallet fire under the Consolidated Storage and Sales Alternatives, all fall below the applicable benchmarks (i.e., negligible), except for workers in the immediate vicinity of the accident and the most exposed member of the public. For workers the consequences fall into the high category and the risks into the moderate category. The risk for the most exposed member of the public would be low. The risk

for onsite workers not in the immediate vicinity of the onsite fire and for most of the offsite public are negligible.

Table 7–1. Summary of Human Health Risks for Evaluated Scenarios

	Exposure Pathway and Intensity					
Scenario	**Acute Inhalation for Facility Worker**	**Acute Inhalation for Onsite Worker**	**Acute Inhalation for Public**	**Chronic Inhalation for Worker**	**Chronic Inhalation for Public**	**Soil Contamination**
No Action Alternative						
Slow leak on site	NA	NA	NA	Negligible	Negligible	NA
Single flask spill on site	Negligible	Negligible	Negligible	NA	NA	NA
Single pallet spill on site	Negligible	Negligible	Negligible	NA	NA	NA
Earthquake spill on site	Low	Negligible	Negligible	NA	NA	NA
Consolidated Storage Alternative						
Forklift fire on site	Moderate	Negligible	Negligible at fence line[a] Low at maximum EPC[b]	NA	NA	Negligible (≥100 m)
Earthquake spill on site	Moderate	Low	Low	NA	NA	NA
Offsite truck or rail release with fire	NA	NA	Low via truck Low via rail	NA	NA	Negligible if no rain, but moderate with rain
Offsite truck or rail spill with no fire	NA	NA	Negligible (≥100 m)	NA	NA	NA
Offsite truck or rail crash with fatality	NA	NA	NA	NA	NA	NA
Sales Alternative						
Forklift fire on site	Moderate	Negligible	Negligible at fence line[a] Low at maximum EPC[b]	NA	NA	Negligible (≥100 m)
Offsite truck or rail release with fire	NA	NA	Moderate via truck Low via rail	NA	NA	Negligible with no rain, but moderate with rain
Offsite truck or rail spill with no fire	NA	NA	Negligible (≥100 m)	NA	NA	NA
Offsite truck or rail crash with fatality	NA	NA	NA	NA	NA	NA

[a] "Public at fence line" refers to the closest fence line location which is assumed to be 394 ft (120 m) from the on-site fire (ranging from 328 ft (100 m) at the Somerville Depot to 12,139 ft (3,700 m) at the Hawthorne Army Depot.

[b] "Public at maximum EPC" refers to the location where maximum airborne exposure is expected; about 1,824 ft (556 m) from the on-site fire.

Note: Fatalities are not directly comparable to these health effects and are discussed in text.

Key: EPC, exposure point concentration; NA, not applicable.

Transportation accidents occurring off site under the Consolidated Storage or Sales Alternative could result in releases of mercury to the environment due to spills or fires. For offsite fires occurring during a truck accident under the Consolidated Storage Alternative, the projected result for acute effects to the public is low frequency with moderate consequence, or low risk. For offsite truck fires occurring under the higher level of activity under the Sales Alternative (i.e., truck transport occurs both in this country and in the destination country), the result is a moderate frequency with moderate consequence and thus

moderate risk for the public. For workers within the facility exposed to fires during the Consolidated Storage or Sales Alternative, the acute health effect frequency is moderate and the consequence is high, resulting in moderate risk.

For offsite fires occurring as a result of a railcar accident, the projected acute consequences for the public are somewhat greater, although the projected low event frequency and moderate severity of consequence result in a low risk for either the Consolidated Storage or Sales Alternative.

In the case of soil contamination resulting from deposition during a fire, the projected risks are negligible in the case of no rain, and moderate in cases when it is raining. In the case of spills with no resulting fire occurring during transportation off site, the projected acute human health risk is low for any receptor.

Accidents resulting in a mechanically induced fatality could occur during truck or rail transport. For the Consolidated Storage Alternative the frequency for such events is low. For the highest levels of activity anticipated under the Sales Alternative, the event frequency is moderate. It should be noted that accidents resulting in mechanically induced fatal crashes are not correlated with the cargo carried, rather they are tied to the number of miles traveled by road or rail to complete the consolidation or sales activities. Although it is possible that a mechanically induced fatality could occur during the Consolidated Storage or Sales Alternative, truck or rail traffic produced by these activities would be a very small fraction of the truck and rail traffic on the nation's roadways.

Accidents occurring at port under the Sales Alternative have the greatest potential for detrimental effects due to the increased handling while the cargo is onloaded and offloaded. The shallow waters and seabed at the port would likely contain significant marine life, as would the waters and seabed extending to the shallower portions of the continental margin. The density of the marine life is significantly lower in the deep ocean. It is important to note that any cargo released at port would likely be subjected to the most intensive and effective recovery and mitigation efforts. Once out to sea, recovery and mitigation efforts would become increasingly difficult. However, the accident frequency via oceangoing vessel is likely to be much smaller than that of truck transportation or rail transportation to the ports, or from the destination ports. Due to the low expected frequency, once the cargo is loaded onboard the vessel, subsequent accidents occurring on oceangoing vessels were considered to have negligible risk.

Wildfires are a possibility in the areas around the mercury storage locations. The dry conditions encountered in the summer months may lead to conditions prone to wildfires, and recent drought conditions have only exacerbated the situation. Although wildfires may occur, they are likely in more remote areas that are uninhabited. The high expected frequency for wildfires is countered by a negligible likelihood that the wildfire will actually consume any given warehouse and result in a release of mercury. First, the mercury storage warehouses are constructed with concrete floors, walls, and fire-resistant roofing. Second, the landscape is generally maintained in the warehouse areas such that vegetative fuel sources are minimal. Third, the facilities are all served by local emergency response services including fire departments.

7.2 ECOLOGICAL EFFECTS

Under any alternative, chronic consequences to ecological receptors for a slow leak or spill of elemental mercury during storage are negligible because the mercury would be contained within the storage building. Under the No Action Alternative, chronic consequences for an onsite fire during storage are negligible for ecological receptors. Therefore, risks are also negligible. Due to increased activity anticipated during the Consolidated Storage and Sales Alternatives, the frequency for onsite fire increases

to low. The chronic consequences for an onsite fire range from negligible to high and the overall risks range from low to moderate for soil invertebrates, benthic invertebrates, and robins.

Under the Consolidated Storage Alternative, chronic effects resulting from transportation accidents with resulting spills of mercury correlate with a projected negligible ecological consequence. However, offsite transportation accidents could involve a fuel fire and result in enhanced release of mercury to the environment. For a truck fire, the consequence levels ranged from negligible to high with a low projected frequency. For receptors with high consequence levels (plants, soil invertebrates, robins, benthic invertebrates, aquatic biota, and great blue herons), the overall risks (i.e., considering both frequency and consequence) were moderate (*situations of concern*). Under the Sales Alternative, the projected moderate frequency for a truck fire and for receptors with high consequence levels (plants, soil invertebrates, robins, benthic invertebrates, aquatic biota, and great blue herons) result in high overall risks (*situations of major concern*).

For fires occurring as a result of an offsite railcar accident, the consequence levels ranged from negligible to high. Under the Consolidated Storage Alternative, the low projected frequency for a railcar fire and the high consequence levels for certain receptors (plants, soil invertebrates, robins, benthic invertebrates, aquatic biota, and great blue herons) results in moderate overall risks (*situations of concern*). Under the Sales Alternative, the low projected frequency for a railcar fire and high consequence levels for certain receptors (plants, soil invertebrates, robins, benthic invertebrates, aquatic biota, and great blue herons) result in moderate overall risks (*situations of concern*).

When considering the projected frequency, consequence, and risk estimates, it is important to note that the situations of concern identified exist only if it is raining (roughly up to 10 percent of the time). If this is compounded with the unlikely event frequency of a forklift fire, it is possible but unlikely that a situation of concern would occur in general. Also, the wetland, pond, or other suitable habitat would have to lie downwind from the fire. Using the onsite fire as an example, during wet deposition events, a situation of concern for soil invertebrates in dry soil and wetland soil would exist up to 1,640 ft (500 m) downwind, for birds like the American robin it would be limited to the first 3,281 ft (1,000 m) downwind, for benthic invertebrates it would be limited to approximately 3,281 ft (1,000 m) downwind, and for aquatic biota the pond would have to be less than 656 to 984 ft (200 to 300 m) from the fire. Finally, concentrations at the deposition zone tend to decrease rapidly with distance from the centerline, so the affected area would be small. Taken together, these extremely conservative assumptions indicate that it is likely that the highest risk estimates (i.e., for wet deposition) may be overstated, meaning for example that the overall risks for receptors with high consequence levels might be better categorized under *situations of concern* rather than *situations of major concern*.

Chapter 8
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Appendix A
Atmospheric Dispersion and Deposition Models

1.0 THE GENERAL GAUSSIAN MODEL

This section describes the Gaussian model (as modified to take into account dry and wet deposition). The most commonly used methods to estimate human exposure to airborne gases, vapors, and particles from individual sources are the Gaussian plume models. These models represent a steady state average solution to the transport of pollutants arising from wind, turbulence, and other atmospheric forces (for example, see Hanna, Briggs, and Hosker 1982). These models have been modified to estimate the flux of contaminants from the atmosphere to land, water, and other surfaces arising from atmospheric deposition processes. Such processes include particle impaction and settling, as well as scavenging during rainstorms. The following equation describes the model used for the evaluation of both short- and long-term effects in this analysis:

$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left[\frac{-y^2}{2(\sigma_y)^2} - g(x)\right]\left(\exp\left[\frac{-((h-z))^2}{2(\sigma_z)^2}\right] + \exp\left[\frac{-((h+z))^2}{2(\sigma_z)^2}\right]\right)$$

$$g(x) = \sqrt{\frac{2}{\pi}}\frac{v_s}{U}\int_0^x \frac{1}{\sigma_z(y)}\exp\left[\frac{-h^2}{2(\sigma_z(y))^2}\right]dy + \frac{\Lambda x}{U}$$

$$F(x,y,0) = C(x,y,0)\left[v_s + \Lambda\sqrt{2\pi}\sigma_z(x)\exp\left[\frac{+h^2}{2(\sigma_z(x))^2}\right]\right]$$

where:

C(x,y,z):	Pollutant concentration at a location x meters downwind, y meters crosswind of the source, at a height of z meters (mg/m^3)
Q:	Pollutant release rate (mg/s)
σ_y:	Crosswind stability coefficient at location x meters downwind of the source (meters)
σ_z:	Vertical stability coefficient at location x meters downwind of the source (meters)
U:	Wind speed in the x direction (m/s)
h:	Effective release height of the source (including buoyant plume rise as appropriate) (m)
v_s:	Dry deposition velocity (m/s)
Λ:	The rainfall scavenging rate (1/s)
F(x,y,0):	Pollutant deposition flux rate at a location x meters downwind, y meters crosswind of the source, at ground level (mg/m^2/s)

1.1 STABILITY COEFFICIENTS

Formulae providing values for the dispersion parameters (σ_y and σ_z), as a function of distance (x) are available for each of the six Pasquill atmospheric stability classes. Briggs originally developed the most widely used equations in 1973 (Hanna, Briggs, and Hosker 1982), and provided formulas for σ_y and σ_z under open-country and urban conditions for each of the six stability classes. The following formulas for

open-country stability Class D were chosen as the most likely meteorological conditions to be present during the accidents:

$$\sigma_y = .08 \times x \times (1 + 0.0001 \times x)^{-1/2}$$

$$\sigma_z = 0.06 \times x \times (1 + 0.0015 \times x)^{-1/2}$$

The Briggs formulas were developed for use between 100 meters and 10 kilometers downwind of the source.

1.2 HEIGHT OF RELEASE

The height of release is dependent on the scenario being evaluated. For evaporation from pools, the release height is zero.

1.3 WET AND DRY DEPOSITION

This subsection describes the values of the dry deposition velocity and the rainfall scavenging rate that were used to determine how much mercury is deposited on the ground at any given location. The text below describes assumptions about how the mercury mixes with the soil.

1.3.1 Deposition Parameters

For releases of elemental mercury vapor, the dry deposition velocity and the scavenging rate are essentially zero (EPA 1997). For most of the scenarios identified in this risk assessment, mercury would in fact be released as elemental mercury and thus deposition pathways are not important.

In the case of fire scenarios, such as the onsite forklift fire or the offsite truck or rail fire, there is the possibility that mercury could be converted into a more reactive form with a significant dry deposition velocity. In practice, the mercury released into the atmosphere during a fire would partially be in the form of elemental mercury and partially in the form of divalent mercury. Under operating conditions that include stack emissions in the presence of environmental controls, the U.S. Environmental Protection Agency (EPA) (1998) recommends phase allocations for mercury emissions of 20 percent vapor phase elemental mercury, 60 percent vapor phase divalent mercury, and 20 percent particle phase mercury. No information is available concerning the speciation of mercury resulting from sources involving combustion in the absence of emission controls. Therefore, in this risk assessment, it is conservatively assumed that 100 percent of the mercury is released as divalent mercury because divalent mercury is more susceptible to deposition processes than either elemental or particle mercury (EPA 1997). This is an important assumption in the assessment of ecological risks.

For divalent mercury, a dry deposition velocity of 1.1 in/s (2.9 cm/s) was used, together with a rainfall-scavenging rate (Λ) of 1.5×10^{-4} s^{-1}. Use of this scavenging rate assumes that the entire height of the plume is located within the rainfall.

The basis for the choice of 1.1 in/s (2.9 cm/s) as a dry deposition velocity is shown in Table A–1, which presents the dry deposition velocities used by EPA in its *Report to Congress* (EPA 1997). As shown in this table, the assumed dry deposition velocity lies in the upper end of the range of the values presented. Regarding the scavenging rate, Hanna, Briggs, and Hosker (1982) note that this is a median value from 20 field experiments conducted by McMahon and Dennison. They indicate a range of 0.4×10^{-4} s^{-1} to

3×10^{-3} s^{-1}. They also state that: "The use of scavenging coefficients for wet removal modeling is probably best regarded as an order-of-magnitude estimation procedure" (Hanna, Briggs, and Hosker 1982).

Table A–1. Deposition Velocities for Divalent Mercury (cm/sec) for Various Types of Land Areas

Type of Land Area	Season				Annual Average
	Winter	Spring	Summer	Fall	
Water	1.09	0.98	0.92	1.00	1.00
Barren land	1.16	1.05	0.98	1.07	1.07
Range	1.89	1.49	1.67	1.78	1.71
Mixed agricultural/range	1.62	1.60	1.90	1.93	1.76
Agricultural	1.32	1.60	2.29	2.02	1.81
Rocky open areas	1.98	1.84	1.95	1.97	1.94
Non-forested wetland	2.02	1.85	1.91	1.88	1.92
Mixed forest/wetland	3.49	3.28	3.17	3.32	3.32
Coniferous forest	3.61	3.42	3.32	3.46	3.45
Deciduous forest	3.61	3.42	3.32	3.46	3.45
Urban	4.83	4.59	4.47	4.64	4.63

Source: EPA 1997.

1.3.2 Mercury Concentration in Soil

This model was used to determine the location and magnitude of the highest mercury deposition (or flux) to soil. The total mass of mercury deposited per unit area at that location was calculated as the mercury flux (in units of $mg/m^2/sec$) multiplied by the duration of plume passage. The mercury was assumed to mix completely within the top 2 in (5.1 cm) of soil, which, when multiplied by the soil density (1.8 g/cm^3) and scaled accordingly, yields soil concentration estimates (in units of mg/kg).

Note that mercury concentrations in soil that might arise from a combination of wet and dry deposition processes (e.g., during a rain storm) increase as the location of interest moves closer to the release location. However, due to fundamental modeling limitations, mercury concentrations in soil could not be reliably estimated at distances less than 328 ft (100 m) from the forklift fuel fire. Consequently, the closest location at which the mercury concentration in soil was estimated was 328 ft (100 m) from the fire.

2.0 MODELING FIRE EVENTS

As discussed above, it is only in the case of fire scenarios that deposition of mercury onto the ground is expected. Thus, the fire scenarios are important considerations with regard to chronic human health risk and ecological risk. The fires considered in this risk assessment include a forklift fire onsite and fires caused by truck or rail crashes offsite. This section illustrates the fire modeling employed by the authors by focusing on a railroad accident that results in the combustion of the pallets on a single railcar. The flasks are packed six to an overpack drum and five drums per pallet. Pallets will not be stacked for transport. The accident is also assumed to cause a breach in a sufficient number of mercury containers to create an exposed area equal to the area of the pallets. This exposed mercury is assumed to be brought to its boiling point and to release mercury at the maximum rate consistent with the dynamics of boiling mercury. The analysis assumes that the mercury boils as long as the pallets are on fire.

2.1 PARAMETERS OF INTEREST

The parameters of interest for long-term human health risk assessment are listed below.

- Heat output, area, and duration of the pallet fire
- Mercury release rate
- Effective release height
- Wind speed at the release height

The heat output and area of the fire are used to estimate the effective release height. The mercury release rate, effective release height, and wind speed at the release height are used in conjunction with the Gaussian model to estimate atmospheric mercury concentrations and mercury deposition flux rates to soil. The duration of the pallet fire determines the duration of the mercury deposition, which is then used to determine the mercury concentrations in the soil. The duration of the pallet fire and the mercury release rate determine the mass of mercury released into the atmosphere.

Table A–2 presents the values for the parameters determined in this analysis. The following sections detail the estimation of each parameter.

Table A–2. Estimated Values for Parameters of Interest in Railcar Fire Modeling

Parameter of Interest	Estimated Value
Pallet Fire Heat Output	1.46×10^6 cal/s
Pallet Fire Area (Railcar)	54.8 m^2
Duration of Pallet Fire/Mercury Release	1,308 s
Mercury Release Rate	1.56×10^6 mg/s
Plume Rise	103 m
Average Wind Speed	5.55 m/s

2.1.1 Pallet Fire Parameters

The dimensions of the railcar considered in this analysis are 59 ft (18 m) by 10 ft (3 m). Each pallet is 4 ft (1.2 m) by 4 ft (1.2 m). Therefore, the maximum number of pallets that can be loaded into the railcar is 28, 2 rows of 14 pallets each. Each unloaded pallet is assumed to weigh approximately 50 lbs (23 kg). Under these assumptions, the total mass of fuel available for combustion in the pallets is 1,400 lbs (635 kg). The area occupied by the pallets, and consequently the area of the fire is 448 ft^2 (41.6 m^2).

2.1.1.1 Pallet Fire Heat Output

The heat output of the pallet fire (dH_e/dt) for the railcar fire was estimated as follows. The rate of solids combusted in a fire was estimated as (Ayer et al. 1988):

$$\dot{M}_{Burned} = \frac{(\text{Heat flux generated}) \bullet A}{(\text{Heat absorbed/mass fuel vapor generated})}$$

The term A equals the area of the fire. The heat flux generated is the sum of the convective heat flux (18 kW/m^2 for wood) and the radiative heat flux (40 kW/m^2 for wood) minus the surface radiation heat

loss (16 kW/m^2 for wood) or 42 kW/m^2 for wood. The heat absorbed/mass fuel vapor generated for wood is 3.6 kW-s/g. The area of the fire is about 448 ft^2 (41.6 m^2). Accordingly:

$$\dot{M}_{Burned} = 42\ \text{kW/m}^2/3.6\ \text{kW-s/g} = 11.667\ \text{g/s-m}^2$$
$$11.667\ \text{g/s-m}^2 \times 41.6\ \text{m}^2 = 485.8\ \text{g/s}$$

At this rate of combustion, the pallet fire will last approximately 1,308 seconds or about 21.8 minutes. The heat output is calculated as:

$$dH_e/dt = \dot{M}_{Burned} \times THR \times EFF \times (1000/4.186)$$
$$dH_e/dt = 485.8\ \text{g/s} \times THR \times EFF \times (1000/4.186)$$

where:

THR: Theoretical heat release (18 kJ/g for wood)

EFF: Fraction of heat not lost to thermal radiation (0.7)

Consequently:

$$dH_e/dt = 485.8 \times 18 \times 0.7 \times (1000/4.186)$$
$$= 1.4623 \times 10^6\ \text{cal/s}$$

2.1.1.2 Mercury Release Rate

The equation used to estimate the mercury release rate is that specified by EPA for use in conducting the offsite consequence analyses for Risk Management Programs required under the Clean Air Act (EPA 1999). The equation, originally published in EPA's *Technical Guidance for Hazards Analysis* (EPA 1987), estimates the worst-case release from a toxic liquid at elevated temperatures as follows:

$$RR = (0.284 \times u^{0.78} \times MW^{2/3} \times A \times VP \times 453{,}600)/(82.05 \times T \times 60)$$

where:

RR: Release rate (mg/s)

u: Wind speed (m/s)

MW: Molecular weight

A: Surface area (ft^2)

VP: Vapor pressure (mm Hg)

T: Temperature of released substance (K)

The following assumptions were made in keeping with EPA guidance for estimating worst-case releases at the liquid boiling point:

u: 1.5 m/s

VP: 760 mm Hg (the vapor pressure of any liquid at its boiling point)

T: 630 °K (the boiling point of mercury)

In addition, the molecular weight of mercury was specified as 202.59 g/g-mole, and the area of the exposed mercury was assumed to be about 590 ft^2 (54.8 m^2).

Taken together, these assumptions yield a release rate (*RR*) for a railcar fire of about 1.56×10^6 mg/s. This equates to a total atmospheric mercury release of about 4,514 lbs (2,048 kg) for a 1,308-s (21.8-min) duration.

2.1.1.3 Effective Release Height

The effective release height was calculated using the following equations (U.S. Army 1980):

$$h = [6F/(U(h)\gamma^2 s)+(r/\gamma)^3]^{1/3} - r/\gamma$$

$$F = g(dH_e/dt)/(\pi\rho_a T_a c_p)$$

where:

h:	Effective release height, (m)
F:	Buoyancy parameter
g:	Gravitational acceleration (9.8 m/s^2)
dH_e/dt:	Rate of heat input to the plume • Forklift fire: 5.22×10^6 cal/s • Railcar fire: 1.4623×10^6 cal/s • Truck fire: 1.25×10^6 cal/s
ρ_a:	Standard density of air (1293 g/m^3)
c_p:	Specific heat of air (0.24 cal/g-K)
γ:	Entrainment coefficient (0.5 for uncontrolled fires)
T_a:	Ambient air temperature (289 K)
r:	Initial plume radius • Forklift fire: 0.668 m • Railcar fire: 4.176 m • Truck fire: 3.396 m
$U(h)$:	Average wind speed from ground to the plume rise elevation (m/s)
s:	Stability parameter (technically, the square of the Brunt-Vaisala frequency (-1.6×10^{-4} s^{-2})

This model assumes that the flow of air and combustion product are unimpeded.

The initial plume radius was calculated as the radius of a circle equal in area to the area of the burning pallets. The spill area of 448 ft^2 (41.6 m^2) corresponds to an initial plume radius of about 11.94 ft (3.64 m). As discussed above, the wind speed at 33 ft (10 m) was assumed to be 14.8 ft/s (4.5 m/s). This wind speed corresponds to the atmospheric stability associated with Pasquill-Gifford Class D. Based on

information provided in Hanna, Briggs, and Hosker (1982), the stability parameter (s) was assigned the value of 1.6×10^{-4} s^{-2}.

It is important to note that this equation does not explicitly relate the effective release height (*h*) to the other parameters because the average wind speed (an otherwise independent variable) is itself a function of *h*. Consequently, the equation was solved iteratively by successively calculating *h* and *U(h)* until successive estimates differed by less than 0.1 percent.

The average wind speed *(U)* was estimated by integrating the assumed vertical wind speed profile (*u(z)*) over the height of the rising plume and dividing by the height, i.e.,

$$U = (1/h)\int_0^h u(z)dz$$

The vertical wind speed profile was estimated using a power law equation for elevations up to 656 ft (200 m). The assumed characteristics of the railcar fire eliminated the need for considering elevations above 656 ft (200 m). The power law equation relating the wind speed at an elevation to the wind speed at 33 ft (10 m) is (Hanna, Briggs, and Hosker 1982):

$$u(z) = u(10)\times(z/10)^p$$

where:

$u(z)$	=	Wind speed at elevation z, m/s
$u(10)$	=	Wind speed at 10 m, m/s
z	=	Elevation above ground, m
p	=	A dimensionless exponent

Therefore:

$$U(h) = [u(10)/(p+1)]\times(h/10)^p \quad \text{for } h\leq 200 \text{ m}$$

The parameter *p* was assigned a value of 0.07 based on the assumed stability Class of D and information provided in Hanna, Briggs, and Hosker (1982).

The terms presented above yield an effective release height of about 122 ft (37.1 m) for the forklift fire, 338 ft (103 m) for the railcar fire, and 325 ft (99 m) for the truck fire.

2.1.1.4 Wind Speed at Plume Height

Using the power law equation discussed above, the average wind speed from the ground to the elevation of the plume rise was estimated to be 4.76, 5.55, and 5.52 m/s, respectively, for the forklift, railcar, and truck fire.

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