DOE/EIS-0200-F—
Vol. 4

FINAL
WASTE MANAGEMENT
PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT
for
Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste

Volume IV of V

Appendices E–I

U.S. Department of Energy
Office of Environmental Management
1000 Independence Ave.
Washington, DC 20585

HH

Appendix E

Radioactive and Hazardous Waste Transportation Risk Assessment

U.S. Department of Energy
Waste Management Programmatic Environmental Impact Statement

Contents

Tables

Figures

Foreword

This appendix presents a summary of the transportation-related human-health risk assessment conducted for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement (WM PEIS). It also provides references to more detailed sources of information for all waste types. The assessment of risks associated with the transportation of radioactive waste is described in Part I, the assessment for transportation of hazardous waste (HW) in Part II. The information presented in this appendix is supported by data in separate technical reports (ANL, 1996a-f), that is, transportation technical memoranda, which describe the transportation for offsite and onsite shipments of radioactive and hazardous wastes.

Transportation of radioactive waste and HW presents a risk to both crew members and members of the public. Part of this risk results from the nature of transportation itself, independent of the radioactive or hazardous characteristics of the cargo (for example, increased levels of pollution from vehicular exhaust and accidents during transportation); these risks can be viewed as "vehicle-related" risks. In addition, transportation of radioactive waste or HW may pose additional risk because of the characteristics and potential hazards of the material itself; these risks are considered to be "cargo-related" risks.

For radioactive materials, the cargo-related impacts on human health during transportation are caused by exposure to ionizing radiation during routine (for example, incident-free) transportation and during accidents. During routine operations, the external radiation field must be below limits specified in Federal regulations. During transportation-related accidents, human exposures may occur following release and dispersal of radioactive materials via multiple environmental pathways such as exposure to contaminated ground or contaminated air, or ingestion of contaminated food.

In contrast to radioactive materials, hazardous chemicals do not pose cargo-related risks to humans during routine transportation-related operations. Waste transportation operations are generally well regulated with respect to packaging, such that small spills or seepages during routine transport are kept to a minimum and do not result in exposures (for example, containers of liquids are surrounded by absorbent overpacking). Potential cargo-related health risks to humans can occur only if the integrity of a container is compromised during an accident (that is, a container is breached). Under such conditions, some toxic chemicals (such as chlorine gas) may cause an immediate health threat to exposed individuals.

In addition to acute health effects, cargo-related risk of excess cases of latent cancer from accidental chemical exposures has been estimated. The correlation of chemical dose with the induction of human cancer has traditionally been based on the linear/no-threshold hypothesis, similar to radioactive exposure. The treatment of carcinogenic effects of exposures resulting from accidental chemical releases has added uncertainty because the carcinogenic risk is estimated for short-term (1-hour) exposures. Lifetime risks less than 1 in 1 million have been considered negligible and are not estimated. The number of individuals experiencing an increased risk of cancer of 1 in 1 million or greater has been estimated, without attempting to estimate the precise risk for those in the category of greater than 1 in 1 million.

Health impacts from radioactive and hazardous materials are presented separately in Part I and Part II of this appendix. No attempt has been made (even in cases where both radioactive and hazardous components are present in the same materials) to add or compare the estimated risks for the two classes of contaminants. To understand and interpret the estimated health impacts presented in this appendix, readers must keep in mind the fundamental differences between radioactive and chemical contaminants discussed previously. The table on the following page summarizes the human health effects considered for the radioactive-waste and HW risk assessments in this appendix.

Endpoints Used for Human Health Effects: WM PEIS Transportation Risk Assessment [a]

Type of Human Health Effect	Nature of Health Effect	Radioactive Waste	HW
Vehicle-related effects: routine transportation			
Truck-emission-induced cancer fatality	Latent	✓	✓
Vehicle-related effects: accident			
Physical trauma fatality	Acute	✓	✓
Cargo-related effects: routine transportation			
Radiation-induced cancer fatality	Latent	✓	b
Radiation-induced cancer incidence	Latent	✓	b
Radiation-induced genetic effects	Latent	✓	b
Cargo-related effects: accident			
Potential life-threatening effects	Acute	c	✓
Potential for any adverse effects	Acute	c	✓
Cancer fatality	Latent	✓	d
Cancer incidence	Latent[e]	✓	✓
Genetic effects	Latent	✓	d

[a] Each check mark represents a quantitative measure of risk computed in this appendix. All end points are relevant to mixed waste because it contains both a radioactive and a hazardous component.
[b] No public exposure to the HW occurs during routine transportation.
[c] Threshold doses for radiological acute effects are generally in excess of 100 rem. Exposures from transportation-related activities (routine or accidents) have not been found to reach such a high dose level.
[d] Not applicable because of lack of scientific data to support the measure.
[e] For radioactive waste, the risk of cancer is expressed as the number of excess cases of cancer in the general population. For HW, the risk of cancer is expressed as the number of individuals in the general population experiencing an excess lifetime cancer risk of 1 in 1 million or greater.

Acronyms and Abbreviations

The following is a list of acronyms and abbreviations (including units of measure) used in this appendix.

Acronyms

ALOHA™	Areal Locations of Hazardous Atmospheres
Ames	Ames Laboratory
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
BCL	Battelle Columbus Laboratories
Bettis	Bettis Atomic Power Laboratory
BNL	Brookhaven National Laboratory
CFR	Code of Federal Regulations
CH	contact-handled
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
FEMP	Fernald Environmental Management Project
Fermi	Fermi National Accelerator Laboratory
FY	fiscal year
GTCC LLW	Greater-Than-Class-C low-level waste
Hanford	Hanford Site
HaWRAM	Hazardous Waste Risk Assessment Modeling
HEAST	Health Effects Assessment Summary Tables
HLW	high-level waste
HMIRS	Hazardous Materials Incident Reporting System
HQ	hazard quotient
HW	hazardous waste
ICRC	increased cancer risk concentration
INEL	Idaho National Engineering Laboratory
IRIS	Integrated Risk Information System
ITRI	Inhalation Toxicology Research Institute
KAPL-S	Knolls Atomic Power Laboratory (Schenectady)
KCP	Kansas City Plant
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LC_{50}	lethal concentration causing death in 50% of animals tested
LC_{LO}	lowest reported lethal concentration

LDR	land disposal restriction
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
MEI	maximally exposed individual
Mound	Mound Plant
NRC	U.S. Nuclear Regulatory Commission
NRF	Naval Reactor Facility
NTS	Nevada Test Site
ORISE	Oak Ridge Institute for Science and Education
ORR	Oak Ridge Reservation
PAEC	potential adverse effect concentration
Pantex	Pantex Plant
PEIS	Programmatic Environmental Impact Statement
PGDP	Paducah Gaseous Diffusion Plant
PIH	poison inhalation hazard
Pinellas	Pinellas Plant
PLC	potential lethal concentration
PORTS	Portsmouth Gaseous Diffusion Plant
PPPL	Princeton Plasma Physics Laboratory
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RFETS	Rocky Flats Environmental Technology Site
RH	remote-handled
RMI	Reactive Metals, Inc.
RTECS	Registry of Toxic Effects of Chemical Substances
SFEIS	Supplemental Final Environmental Impact Statement
SLAC	Stanford Linear Accelerator Center
SMAC	Shipment Mobility/Accountability Collection
SNL-CA	Sandia National Laboratories (California)
SNL-NM	Sandia National Laboratories (New Mexico)
SRS	Savannah River Site
STEL	short-term exposure level
TC_{LO}	lowest toxic concentration (lowest concentration causing any adverse effect)
TRUW	transuranic waste
TSCA	Toxic Substance Control Act
TSD	treatment, storage, and disposal
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant

WM	waste management
WVDP	West Valley Demonstration Project
YM	Yucca Mountain

Abbreviations

°C	degree(s) Celsius
d	day(s)
gal	gallon(s)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
L	liter(s)
m	meter(s)
m^3	cubic meter(s)
mi	mile(s)
mi^2	square mile(s)
mrem	millirem
ppm	part(s) per million
rem	roentgen equivalent man
s	second(s)
yr	year(s)

Appendix E—Part I
Radioactive Waste Transportation Risk Assessment

E.1 Introduction

Transportation is an integral component of the alternatives being considered for each type of radioactive waste in the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS). The types of radioactive waste considered in Part I are high-level waste (HLW), low-level waste (LLW), transuranic waste (TRUW), and low-level mixed waste (LLMW). For some alternatives, radioactive waste would be shipped among the DOE sites at various stages of the treatment, storage, and disposal (TSD) process. The magnitude of the transportation-related activities varies with each alternative, ranging from minimal transportation for decentralized approaches to significant transportation for some centralized approaches. The human health risks associated with transporting various waste materials were assessed to ensure a complete appraisal of the impacts of each PEIS alternative being considered.

This section provides an overview of the approach used in the PEIS to assess human health risks that may result from transporting radioactive waste. The assessment's scope, computer models used, important assumptions for each waste type, and methods for determining potential routes for transportation are discussed. The risk assessment results are summarized for all alternatives for each waste type. In addition, to aid in understanding and interpreting the results, specific areas of uncertainty are described, emphasizing how the uncertainties may affect comparisons of the alternatives. Finally, possible mitigative measures that could be implemented to reduce potential impacts are discussed.

Transportation of hazardous and radioactive materials, substances, and waste is governed by the U.S. Department of Transportation, the U.S. Nuclear Regulatory Commission (NRC), U.S. Environmental Protection Agency (EPA) regulations, and the Hazardous Materials Transportation Act. These regulations may be found in 49 CFR Parts 171-178, 49 CFR Parts 383-397, 10 CFR Part 71, and 40 CFR Parts 262 and 265, respectively.

The methods and assumptions used in the transportation-related radiological risk assessment were selected to ensure meaningful comparisons among programmatic-level alternatives. Therefore, this assessment uses a number of generic assumptions appropriate to the programmatic nature of the PEIS; for example, because a detailed consideration of every possible waste shipment would be impractical, representative physical and radiological characteristics were determined for each waste type. Similarly, conceptual transportation routes were selected to be consistent with current practice and applicable regulations, so that DOE can ensure that the waste is transported safely and will minimize the potential for adverse impacts to the public and environment. However, these may not be the actual routes that will be used in the future. Actual routes will be determined during the transportation planning process.

Transportation mode and routing decisions will be made on a site-specific basis during the transportation planning process. Sites can use the transportation analyses in this WM PEIS to make site-specific transportation decisions or, if necessary, conduct additional transportation analyses. DOE proactively works with states, regional entities, and carriers during large shipping campaigns to ensure that safe routing alternatives and safe havens are utilized.

Extensive studies of transportation risk assessment have been conducted for specific Federal actions (NRC, 1977a; DOE, 1986a; DOE, 1990a). However, care must be exercised when comparing the results of this PEIS transportation-related risk assessment with others. Although some alternatives in this PEIS may be similar to those analyzed in other studies, the results of other transportation risk assessments may differ for many reasons. In general, the other studies did not consider the range of programmatic alternatives being considered in this PEIS. Moreover, the other studies used assumptions and parameters specific to the actions being considered, which are not necessarily appropriate for this PEIS. In addition, revised radiation health risk conversion factors have been recommended (ICRP, 1991), and data on the projected waste inventory and on waste characterization have been revised and updated. Results of this PEIS are not intended to replace results of previous transportation risk assessments for ongoing or planned actions.

This section of the appendix should be read in conjunction with the technical reports describing the development of site-specific data on the waste inventory and characterization for each waste type (ANL, 1996g-k). Data on site-specific waste characterization are used for the transportation accident risk assessment but are not presented explicitly in this appendix. Similarly, the alternatives analyzed for each waste type are only summarized in Part I; detailed alternative definitions for each waste type are provided in the respective chapters of the PEIS for the waste type. The supporting technical reports prepared for each waste type contain detailed information on waste characterization, alternative definitions, and risk assessment results (ANL, 1996a,c-f). Revised site inventory estimates have become available, as discussed in Appendix I, since the original transportation analysis. Due to large changes in site inventory, radiological profiles, or waste treatment, the risk analysis involving selected sites has been updated. However, the transportation risk analysis has not been recalculated for all alternatives because the same trends among alternatives are expected to apply. Site-specific information in the site data sheets and the cumulative impacts have been updated, however.

E.2 Scope of Assessment

The scope of the PEIS transportation radiological risk assessment—including the alternatives, transportation-related activities, potential vehicle- and cargo-related impacts, receptors, and transportation modes considered—is described in this section. Additional details of the assessment are provided in the sections that follow.

E.2.1 Onsite Versus Offsite Transportation

The transportation risk assessment includes the onsite and offsite transportation of radioactive waste. Onsite transportation involves transporting waste between facilities within a DOE site's boundaries. Transfers of waste within a specific facility are not considered onsite shipments but are considered part of the normal facility operations. Offsite transportation refers to transporting waste between distinct sites, including parts of the routes that may be within the boundaries of the origin and destination sites.

Offsite transportation usually involves the shipment of potentially large quantities of radioactive waste moving through a changing landscape and potentially stopping at any place along a route (usually a major highway). To effectively describe this situation, models that use simplified assumptions and generalizations are used to estimate risk from offsite shipments. National average or typical values are chosen for variables such as road and track dimensions, vehicular speed, traffic density, weather conditions, and stop times; population densities are modeled as being uniformly distributed. Conversely, onsite transportation occurs at a fixed location, which allows for a site-specific analysis. The onsite risk assessment uses site-specific characteristics, such as local weather, nonuniform distributions of population, and data on agricultural productivity.

The human health risks associated with onsite transportation are generally much smaller than those from offsite transportation, largely because of the limited distances for onsite shipment, limited population densities along the routes, and limited average travel speeds (DOE, 1992b). Accordingly, the impacts of onsite transportation are not likely to contribute significantly to differences among the alternatives being considered. Therefore, for purposes of the PEIS, the onsite risk assessment has been limited to one representative site—the Hanford Site (Hanford). This site was selected primarily because it is relatively large and conducts activities for managing all waste types. The impacts calculated for the Hanford Site are believed to be typical of other large DOE sites and conservatively estimate the impacts expected for smaller sites. The risk assessment conducted for onsite transportation is intended to estimate the magnitude of potential risk for comparison with the risks of offsite transportation. The risk assessment also characterizes the typical site-specific transportation scenarios and impacts not encompassed in the offsite analysis.

E.2.2 WASTE TYPE-SPECIFIC ALTERNATIVES

The transportation risk assessment conducted for the PEIS estimates the human health risks associated with transporting radioactive waste for a large number of alternatives. In general, the PEIS alternatives are considered independently for each waste type and reflect decentralized, regionalized, and centralized approaches. For each waste type, several options, referred to as "cases," have been defined for each broad alternative. The individual cases differ in the numbers, locations, and types of TSD facilities being considered.

For the offsite transportation risk assessment, each specific case is defined as a set of pairs (origin and destination) representing shipping linkages among generator, treatment, and disposal sites. The number of origin-and-destination pairs varies among cases, ranging from a small number of pairs for decentralized cases to many pairs for centralized ones. Examples of the linkages for shipment in two sample cases are shown in Figures E–1 and E–2. Figure E–1 represents a decentralized LLW case involving 12 disposal sites. The sites that would not have the capability for disposal ship their wastes to a site that does. Figure E–2 represents a LLW centralized disposal case in which all sites would dispose of their wastes at a single site. Chapter 3 of the PEIS contains detailed descriptions of the alternatives for each waste type. The alternatives are summarized in the following paragraphs.

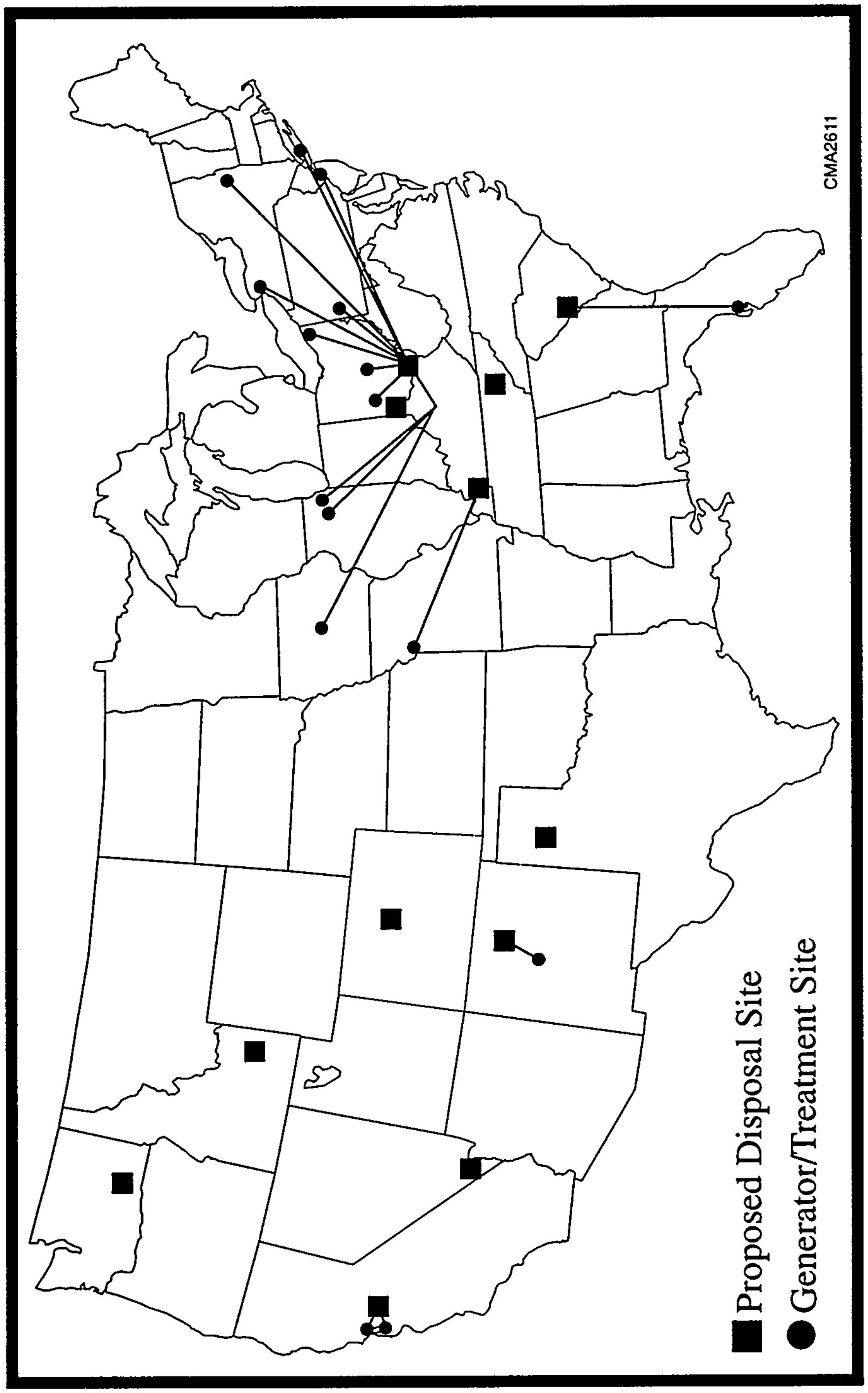

Figure E–1. Example of Shipping Linkages Among Generator, Treatment, and Disposal Sites for a LLW Decentralized Alternative.

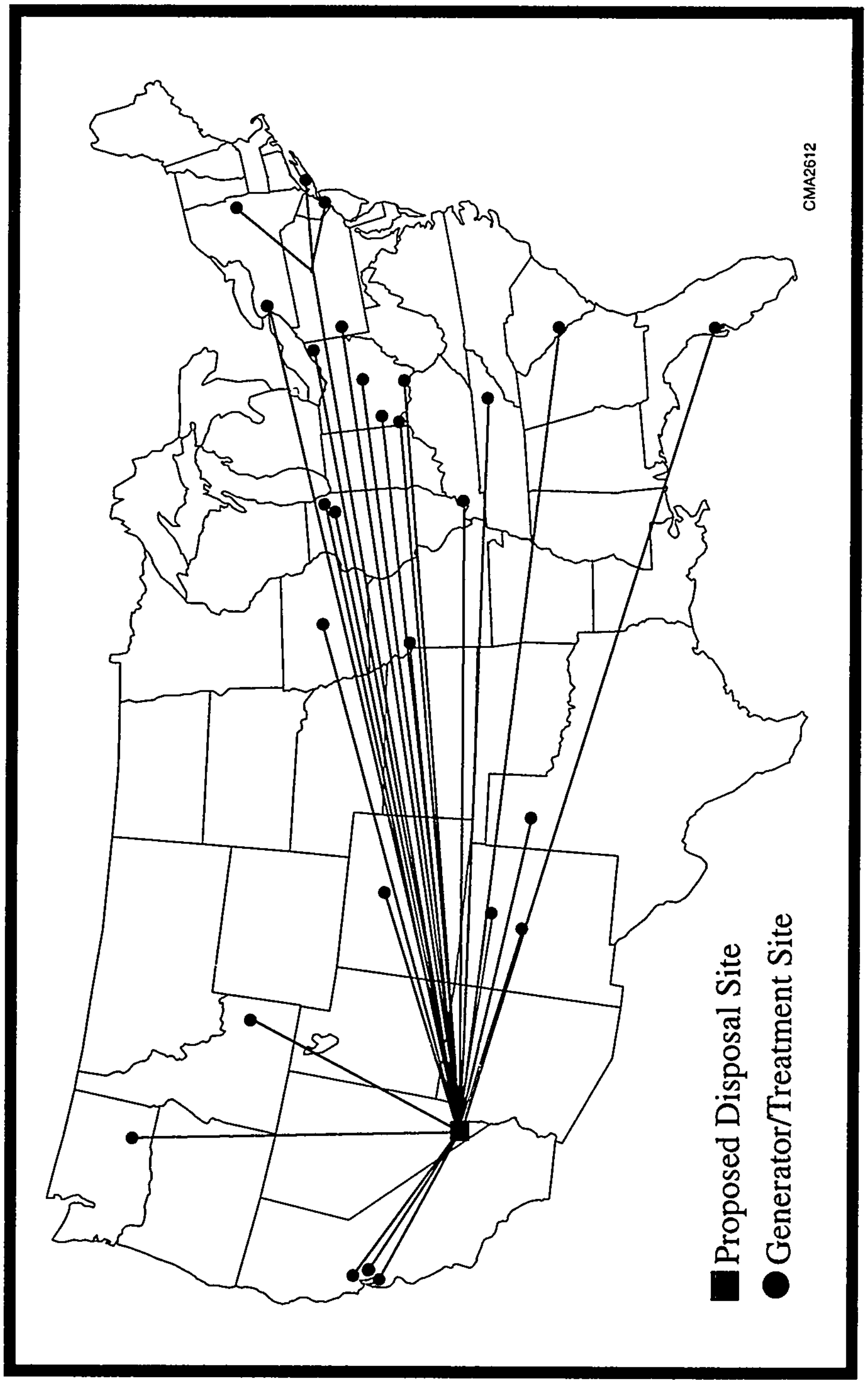

Figure E–2. Example of Shipping Linkages Among Generator, Treatment, and Disposal Sites for a LLW Centralized Alternative.

E.2.2.1 Alternatives for HLW

The generation, treatment, and management of HLW and the cases considered in the PEIS are described in detail in the HLW technical report (ANL, 1996g). In summary, canisters of vitrified HLW would be produced at the four DOE sites that have historically generated and currently store HLW and would be transported to a geologic repository for final disposal.

The analysis of HLW investigates storage options under the No Action, Decentralized, Regionalized, and Centralized Alternatives. For each of the latter three alternatives, two cases are analyzed. The first assumes the repository will open as scheduled in 2015, while the second case assumes the repository opens after 2015. The cases differ primarily in the location of interim canister storage before final disposal in a repository. For assessing the impacts of transportation, this PEIS assumes the repository to be located at the candidate site of Yucca Mountain in Nevada, which is the only site authorized by legislation for investigation. The alternatives are defined in Chapter 3 of the PEIS and are summarized as follows:

- *No Action.* Store HLW canisters on an interim basis at Hanford, the Savannah River Site (SRS), and the West Valley Demonstration Project (WVDP) in existing and approved interim storage facilities until acceptance of HLW canisters at a geologic repository. Store HLW at Idaho National Engineering Laboratory (INEL) in bin-sets as calcine or in tank farms as liquid HLW.
- *Decentralized.* Provide adequate interim HLW canister storage capacity at each of the four sites that would produce HLW canisters until acceptance of HLW canisters at a geologic repository.
- *Regionalized 1.* Transport HLW canisters from WVDP to SRS and provide adequate interim storage capacity for HLW canisters at Hanford, SRS, and INEL until acceptance of HLW canisters at a geologic repository.
- *Regionalized 2.* Transport the HLW canisters from WVDP to Hanford and provide adequate interim storage capacity for HLW canisters at Hanford, SRS, and INEL until acceptance of HLW canisters at a geologic repository.
- *Centralized.* Transport the HLW canisters from the WVDP, INEL and SRS to Hanford and provide adequate interim storage capacity for HLW canisters at Hanford until acceptance of HLW canisters at a geologic repository. Case 1 assumes the repository opens on time in the year 2015. Case 2 assumes the repository opens later and all HLW is stored temporarily at Hanford.

E.2.2.2 Alternatives for LLW

Transportation risks have been calculated for 14 LLW cases. The cases range from decentralized to centralized approaches to TSD. Case 1 represents the No Action Alternative. The number of disposal sites varies from 16 (decentralized disposal) to 1 (centralized disposal). Treatment options also vary from decentralized to centralized approaches. In general, sites without treatment or disposal capability would ship to the nearest site with such capability. The alternatives are defined in Chapter 3 of the PEIS and are summarized as follows:

- *No Action (Case 1).* All sites would treat LLW using existing, planned, and approved treatment facilities and dispose of LLW at the six current disposal sites in accordance with current arrangements.
- *Decentralized (Case 2).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at 16 sites (Argonne National Laboratory-East [ANL-E], Brookhaven National Laboratory [BNL], Fernald Environmental Management Project [FEMP], Hanford, INEL, Lawrence Livermore National Laboratory [LLNL], Los Alamos National Laboratory [LANL], the Nevada Test Site [NTS], Oak Ridge Reservation [ORR], Paducah Gaseous Diffusion Plant [PGDP], Pantex Plant [Pantex], Portsmouth Gaseous Diffusion Plant [PORTS], Rocky Flats Environmental Technology Site [RFETS], Sandia National Laboratories-New Mexico [SNL-NM], SRS, and WVDP).
- *Regionalized 1 (Case 3).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).
- *Regionalized 2 (Case 9).* Eleven Sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).
- *Regionalized 3 (Case 4).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearest of six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Regionalized 4 (Case 12).* Seven sites (Hanford, INEL, LANL, ORR, PORTS, RFETS, and SRS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Regionalized 5 (Case 19).* Four sites (Hanford, INEL, ORR, and SRS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).

- *Regionalized 6 (Case 5).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearer of two sites (Hanford and SRS).
- *Regionalized 7 (Case 6).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearer of two sites (NTS and SRS).
- *Centralized 1 (Case 7).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at one site (Hanford).
- *Centralized 2 (Case 8).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at one site (NTS).
- *Centralized 3 (Case 14).* Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (Hanford).
- *Centralized 4 (Case 14a).* Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (NTS).
- *Centralized 5 (Case 21).* One site (Hanford) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (Hanford).

E.2.2.3 Alternatives for TRUW

Transportation risks have been calculated for six TRUW alternatives. Each alternative is comprised of a case that deals with contact-handled TRUW (CH-TRUW) and a case that deals with remote-handled TRUW (RH-TRUW). The cases range from decentralized to centralized approaches to treatment and storage before final geologic disposal. In general, sites without treatment capability ship to the nearest site with such capability. The treatment options considered are (1) treatment that meets the Waste Isolation Pilot Plant (WIPP) waste acceptance criteria (WAC); (2) treatment to reduce gas generation using shredding, grouting, and nonsteel containers, resulting in waste that exceeds current WIPP-WAC requirements but does not meet land disposal restrictions (LDRs); and, finally, (3) treatment to a level that meets or exceeds LDR requirements. The transportation assessment assumes that all TRUW will ultimately be shipped to WIPP for disposal. The alternatives are defined as follows:

- *No Action (CH-TRUW Case 1, RH-TRUW Case 10).* Continue storing CH-TRUW at ANL-E, Hanford, INEL, LANL, Lawrence Berkeley Laboratory (LBL), LLNL, Mound Plant (Mound), NTS, ORR, PGDP, RFETS, SNL, SRS, and WVDP in accordance with current practices. Storage of RH-TRUW would continue at ANL-E, Hanford, INEL, LANL, and ORR in accordance with current practices. No transportation of waste is assumed.

- *Decentralized (CH-TRUW Case 4, RH-TRUW Case 11).* Ten sites (ANL-E, Hanford, INEL, LANL, LLNL, Mound, NTS, ORR, RFETS, and SRS) would treat CH-TRUW to meet the WIPP-WAC. Five sites (ANL-E, Hanford, INEL, LANL, and ORR) would treat RH-TRUW to WIPP-WAC. All treated TRUW would be disposed at WIPP.
- *Regionalized 1 (CH-TRUW Case 5, RH-TRUW Case 14).* Five sites (Hanford, INEL, LANL, RFETS, and SRS) would treat CH-TRUW to reduce gas generation. Two sites (Hanford and ORR) treat RH-TRUW to reduce gas generation. All treated TRUW would be disposed at WIPP.
- *Regionalized 2 (CH-TRUW Case 6, RH-TRUW Case 15).* Five sites (Hanford, INEL, LANL, RFETS, and SRS) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.
- *Regionalized 3 (CH-TRUW Case 8, RH-TRUW Case 15).* Three sites (Hanford, INEL, and SRS) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.
- *Centralized (CH-TRUW Case 9, RH-TRUW Case 15).* One site (WIPP) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.

E.2.2.4 Alternatives for LLMW

Transportation risks have been calculated for seven LLMW alternatives. The alternatives range from decentralized to centralized approaches to TSD. The number of disposal sites varies from 16 sites to 1. Treatment options also vary from decentralized to centralized approaches. In general, sites without treatment or disposal capability ship to the nearest site with such capability. The alternatives are defined in Chapter 3 of the PEIS and are summarized as follows:

- *No Action* (Case 1). Treatment and indefinite storage of LLMW generated in the future. No transportation occurs.
- *Decentralized (Case 2a).* Forty-nine sites treat LLMW to LDR levels, and 16 sites dispose.
- *Regionalized 1 (Case 4).* Eleven sites treat LLMW, and 12 sites dispose.
- *Regionalized 2 (Case 7).* Seven sites treat LLMW, and 6 sites dispose.
- *Regionalized 3 (Case 10a).* Seven sites treat LLMW, and 1 site disposes (NTS).

- *Regionalized 4 (Case 15)*. Four sites treat LLMW, and 6 sites dispose.
- *Centralized (Case 17)*. One site treats LLMW (Hanford), and 1 site disposes (Hanford).

E.2.3 DESCRIPTION OF TRANSPORTATION ACTIVITIES

The transportation risk assessment determines transportation-related risks by considering the total amount of waste shipped over each route for each alternative. The assessment considers waste currently stored or generated over the next 20 years. The assessment takes into account differences in the quantity and properties of wastes at each site. In addition, characteristics of the routes between sites are considered. For onsite transportation, most solid radioactive waste at the Hanford Site is assumed to be initially shipped to a central waste complex, regardless of possible offsite shipment for treatment or disposal. Therefore, the onsite transportation risks presented here apply equally to all alternatives. The onsite assessment is not intended to be used as a basis for comparison among alternatives.

The transportation risk assessment is limited to estimating the human health risks incurred during the actual transportation of waste for each alternative. The risks to workers or to the public during the loading, unloading, and handling of waste before or after shipment are considered as part of normal facility operations and are not included in the transportation assessment. Similarly, the transportation risk assessment does not address how increased levels of transportation may affect local traffic flow, noise levels, logistics, or infrastructure.

E.2.4 CARGO-RELATED IMPACTS (RADIOLOGICAL)

The cargo-related impacts on human health during the transportation of radioactive materials would be caused by exposure to ionizing radiation. For all cases, radiological risks (risks resulting from the radioactive nature of the waste) are assessed for routine (normal) transportation and for accidents. The radiological risk associated with routine transportation results from the potential exposure of people to low levels of external radiation near a loaded shipment. The radiological risk from transportation-related accidents lies in the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people through multiple exposure pathways, such as exposure to contaminated soil, inhalation, or the ingestion of contaminated food.

All radiologically related impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The dose of radiation calculated is the total effective dose equivalent (Title 10, Part 20, of the *Code of Federal Regulations* [10 CFR 20]), which is the sum of the effective dose equivalent from exposure to external radiation and the 50-year committed effective dose equivalent (ICRP, 1977) from exposure to internal radiation. Doses of radiation are calculated in units of roentgen equivalent man (rem) for individuals and in units of person-rem for collective populations.

The potential exposures to the public from transporting radioactive materials, either from routine operations or from postulated accidents, are usually at such a low dose that the primary adverse health effect is the potential induction of latent cancers (that is, cancers that occur years after the exposure). The correlation of radiation dose and human health effects for low doses has traditionally been based on what is called the "linear/no-threshold hypothesis," which has been described by various international authorities on protection against radiation. This hypothesis implies, in part, that even small doses of radiation have some cancer risk and that doubling the radiation dose means doubling the expected numbers of cancers. The types of cancer induced by radiation are similar to "naturally occurring" cancers and might be expressed at some point in the lifetime of the exposed individuals.

On the basis of the analyses presented in this appendix, transportation-related operations for all waste types are not expected to cause acute (short-term) radiation-induced fatalities or to produce immediately observable effects in exposed individuals. Acute radiation-induced fatalities occur at doses well in excess of 100 rem (ICRP, 1991), which generally would not occur for a wide range of transportation activities, including routine operations and accident conditions. (In general, individual acute whole-body doses in the range of 300 to 500 rem are expected to cause death in 50% of the exposed individuals within 30 to 60 days [ICRP, 1991].) For all severe accident scenarios analyzed, other short-term effects, such as temporary sterility and changes in blood chemistry, are not expected.

The radiological impacts discussed in this appendix are expressed as health risks in terms of the number of estimated latent cancer fatalities, the incidence of cancer, and the genetic effects in exposed populations for each alternative. The health risk conversion factors (expected latent health effects per dose absorbed) were derived from ICRP Publication 60 (ICRP, 1991).

E.2.5 VEHICLE-RELATED IMPACTS (NONRADIOLOGICAL)

In addition to the radiological risks posed by transportation-related activities, risks are also assessed for vehicle-related causes for the same routes for offsite transportation. These risks are independent of the radioactive nature of the cargo and would be incurred for similar shipments of any commodity. The vehicle-related risks are assessed for routine conditions and accidents. Vehicle-related risks during routine transportation are caused by potential exposure to increased vehicular exhaust emissions. The routine risks are primarily associated with travel in urban environments. The vehicle-related accident risk refers to the potential for transportation-related accidents that result in fatalities caused by physical trauma unrelated to the cargo. State-specific rates for transportation-related fatalities are used in the assessment. Vehicle-related risks are presented in terms of estimated fatalities for each alternative.

E.2.6 TRANSPORTATION MODES

Although radioactive waste can be transported by various modes, all shipments have been assumed to take place either by truck or rail. For each alternative, risks have been calculated separately for all truck and all rail options, although the actual shipping campaigns for a selected alternative may involve a combination of the two modes. Rail shipments are assumed to take place by regular freight train. Since the largest risk (fatalities) from rail transport is from the physical trauma due to accidents, the use of special or dedicated rail service would only reduce the overall risk by at most a factor of two for only those sites shipping enough waste to warrant dedicated shipment. Shipments by barge, though feasible for some sites, have not been explicitly considered because this mode of transportation is somewhat limited and has not been established as a major programmatic option for the PEIS assessment. Similarly, shipments by aircraft and other modes were not considered.

The assumption that waste would be shipped entirely by truck or entirely by rail has been made for calculational purposes. All DOE sites can ship waste by truck, but not all sites have readily available rail access. A review of the transportation facilities at 35 major DOE sites shows that 15 sites have onsite rail access: an additional 12 sites have access within 16 km (10 mi), and 8 more have access within 16 to 161 km (10 to 100 mi) of the site (Johnson, 1994). To ship by rail, sites that do not have direct rail access would likely ship waste by truck to the nearest rail siding, where the waste would be transferred to railcars. This type of shipment involving cargo transfer has not been considered in the risk assessment.

E.2.7 RECEPTORS

Transportation-related risks are calculated and presented separately for workers and members of the general public. The workers considered are truck and rail crew members involved in the actual transportation of waste. The public includes all persons who could be exposed to a shipment while it is moving or stopped en route. Potential risks are estimated for the collective populations of exposed people, as well as for maximally exposed individuals (MEIs). The collective population risk is a measure of the radiological risk posed to society as a whole by the alternative being considered. As such, the collective population risk is used as the primary means of comparing various alternatives.

E.3 Packaging and Representative Shipment Configurations for Radioactive Waste

Regulations that govern the transportation of radioactive materials are designed to protect the public from the potential loss or dispersal of radioactive materials, as well as from routine doses of radiation during transit. The primary regulatory approach for ensuring safety is by specifying standards for the packaging of radioactive materials.

Because packaging represents the primary barrier between the radioactive material being transported and exposure of the public and the environment to radiation, packaging requirements are an important consideration for the transportation risk assessment. Regulatory packaging requirements and the representative packaging and shipment configurations assumed for each type of radioactive waste considered in the PEIS are described in this section. The information about shipment configuration includes truck and railcar payload capacities for each waste type.

E.3.1 PACKAGING

Although several Federal and State organizations are involved in regulating the transportation of radioactive waste, the U.S. Department of Transportation (DOT) and the U.S. Nuclear Regulatory Commission (NRC) have primary regulatory responsibility. In addition, DOE has formalized agreements with the NRC and DOT to delineate responsibilities of each agency. All transportation- related activities must be in accordance with applicable regulations of these agencies specified in 49 CFR 173 and 10 CFR 71.

Packaging for transporting radioactive materials must be designed, constructed, and maintained to ensure that they will contain and shield their contents during normal transportation. For more highly radioactive material, the packaging must contain and shield their contents in severe accidents. The type of packaging used is determined by the radioactive hazard associated with the packaged material. The basic types of packaging required by the applicable regulations are designated as Type A, Type B, or "strong and tight" (generally for low specific-activity material).

Type A packaging must withstand the conditions of normal transportation without the loss or dispersal of the radioactive contents. "Normal" transportation refers to all transportation conditions except those resulting from accidents or sabotage. Approval of Type A packaging is achieved by demonstrating that the packaging can withstand specified testing conditions intended to simulate normal transportation. Type A packaging, typically a 0.21-m^3 (55-gallon [gal]) drum or standard waste box, is commonly used to transport wastes with low radioactivity levels. Type A packaging is routinely used in waste management for storage, transportation, and disposal. Type A packaging usually does not require special handling, packaging, or transportation equipment.

"Strong and tight" packagings may be used to transport certain low specific-activity materials (for example, mill tailings, uranium ore, natural uranium hexafluoride, and some LLW). Shipments of "strong and tight" packagings are excepted from certain packaging specifications and marking and labeling requirements but must still comply with many administrative controls. Functionally, "strong and tight" packagings are equivalent to Type A packaging because contents must not leak under normal transport conditions. Examples of "strong and tight" packages currently in use include steel drums, rectangular metal bins, and wooden boxes.

In addition to meeting the standards for Type A packaging, Type B packaging must provide a high degree of assurance that the package integrity will be maintained, even during severe accidents, with essentially no loss of the radioactive contents or serious impairment of the shielding capability. Type B packaging is required for shipping large quantities of radioactive material and must satisfy stringent testing criteria (specified in 10 CFR 71). The testing criteria were developed to simulate conditions of severe hypothetical accidents, including impact, puncture, fire, and immersion in water. The most widely recognized Type B packagings are the massive casks used for transporting highly radioactive spent nuclear fuel from nuclear power stations. Large-capacity cranes and mechanical lifting equipment are usually necessary for handling Type B packagings. Many Type B packagings are transported on trailers specifically designed for the package being used.

External radiation allowed to escape from a package must be below specified limits that minimize exposure of the handling personnel and the public. Most DOE waste shipments are handled only by the shipper and the receiver, an arrangement referred to as an "exclusive-use" shipment. For this type of shipment (regardless of the waste type or package), the dose rate for external radiation during normal transportation must be maintained below the following limits (49 CFR 173):

- Dose of 10 millirem per hour (mrem/h) at any point 2 m (6.6 ft) from the vertical planes projected by the outer lateral surfaces of the car or vehicle
- Dose of 2 mrem/h in any normally occupied position in the car or vehicle

Additional restrictions apply to radiation levels on the package surface; however, these restrictions do not affect the transportation-related radiological risk assessment. Representative external dose rates for each waste type are described in Section E.6.2.

For the purposes of risk assessment, specifying the actual package that will be used is unnecessary because all packagings of a certain type are designed to meet the same performance criteria; for instance, a 0.21-m^3 (55-gal) drum and a standard waste box, each designed to meet Type A packaging criteria, would be expected to behave similarly under routine transportation and accident conditions.

E.3.2 Representative Packaging and Shipment Configurations by Waste Type

To conduct the transportation risk assessment, assumptions must be made about the types of packaging, the transporting vehicles, and the shipment capacities used for future waste shipments. Certain assumptions, such as types of vehicles and their legal weight restrictions, are common to all waste types; however, the radiological and physical characteristics of waste types differ, so separate packaging assumptions must be made for each. In all cases, waste is assumed to be characterized, treated, packaged, and labeled in accordance with applicable regulations before shipment.

E.3.2.1 Offsite Transportation

For all waste types, transportation is assumed to be in certified or certified-equivalent packagings, and exclusive-use vehicles are assumed to be used. Legal-weight heavy-haul combination (tractor-trailer) trucks are assumed to be used for highway transportation. Typically, Type A packages are transported on common flatbed or covered trailers; Type B packages are generally shipped on trailers designed specifically for the packaging being used. For transportation by truck, the maximum payload weight is considered to be 19,958 kg (44,000 lb), based on DOT highway weight limitations and an average tractor-trailer weight of 16,329 kg (36,000 lb).

Regular freight-train service is assumed for the rail transportation. The use of special or dedicated train service was not considered in the analysis. For rail transportation, average payload weights for boxcars range from 45,359 to 68,039 kg (100,000 to 150,000 lb). A median payload weight of 54,431 kg (120,000 lb) has been assumed for this assessment.

The above shipment capacities for truck and rail were assumed to be reasonable based on current practice. In reality, truck and rail shipment capacities vary from shipment to shipment at a given site, depending on the characteristics of the waste, operational practices, and site regulations. Because of the programmatic nature of the PEIS, representative shipment capacities were assumed for each waste type based on current practices. For truck shipments, payloads were taken to be near the regulatory weight limit because the density of most waste is such that volume tends not to be limiting, and it is common practice to load trucks near the legal weight limit for economical reasons. On the other hand, railcar capacities are seldom limited by the weight restrictions of the railcar and can vary over a wide range depending upon the density of the material. Therefore, a “median” railcar capacity of 54,431 kg (120,000 lb) was assumed for calculational purposes because railcar weights are not normally distributed. In addition, the total risk remains relatively unchanged if the size of each shipment is changed. If the maximum payloads are used, the number of shipments is minimized, resulting in the least number of potential accidents, although the consequences are higher. Conversely, smaller payloads require more shipments, resulting in more potential accidents, each of lessor consequence.

As discussed previously, the packaging type is determined primarily by radiological characteristics of the waste material. For the purposes of risk assessment, representative packagings have been determined for each type of radioactive waste on the basis of average waste characteristics and currently accepted practice. In practice, packagings are selected on a case-by-case basis and may differ from the representative types presented here. Assumptions about packaging and shipment are discussed in this section and are summarized in Table E–1.

Table E–1. Representative Packaging and Shipment Assumptions for Radioactive Waste Types

Waste	Packaging	Shipment Capacity[a]
HLW	Type B: similar to the defense HLW cask	Truck cask = 1 canister; rail cask = 5 canisters
LLW	Type A: 208-L (55-gal) drums or standard waste boxes or strong and tight packaging	Assumed to be limited by vehicular weight restrictions; payload capacity: truck = 19,958 kg (44,000 lb) and rail = 54,431 kg (120,000 lb)
TRUW	Type B	Assumed to be limited by package volume restrictions
	CH = TRUPACT-II	3 TRUPACT-IIs per truck and 6 per railcar; payload capacity: truck = 8.4 m^3 (11 yd^3) and rail = 16.8 m^3 (22 yd^3)
	RH = RH-72B	1 RH-72B per truck and 2 per railcar; payload capacity: truck = 0.89 m^3 (1.2 yd^3) and rail = 1.8 m^3 (2.4 yd^3)
LLMW	Type A: 208-L (55-gal) drums or standard waste boxes or strong and tight packaging	Similar to LLW

Notes: CH = contact-handled waste; RH = remote-handled waste.
[a] Truck shipments are assumed to be legal weight. Truck payload capacities were calculated by assuming a 36,287-kg (80,000-lb) gross vehicular weight limit and a tractor-trailer weight of 16,329 kg (36,000 lb). Rail shipments are by regular freight service. The median railcar payload capacity was taken to be 54,431 kg (120,000 lb).

E.3.2.1.1 *HLW Shipments*

Canisters of vitrified HLW are assumed to be shipped in a Type B package similar to the "defense HLW cask" being developed for SRS. The number of canisters to be transported in a cask differs for the truck and rail modes. The truck cask is assumed to accept one HLW canister, and rail capacity is assumed to be five canisters (DOE, 1987a). In the future, DOE will likely develop a multiple-canister HLW truck cask to minimize the number of shipments for major shipping campaigns; however, because a multiple-canister cask does not yet exist, impacts were calculated by assuming that a single-canister cask would be used. If a multiple-canister cask were designed and used in the future, risks would be significantly less than those in this analysis.

E.3.2.1.2 *LLW Shipments*

All LLW is assumed to be transported in strong and tight or Type A packaging, such as 208-L (55-gal) drums or standard waste boxes. Suitable Type A packagings are readily available from commercial sources. The number of shipments from a specific site is calculated by projecting site-specific information about waste inventory (weight) and limitations on shipment capacity for each transportation mode. The effects of potential waste treatment, such as volume reduction or incineration, are reflected in changes in waste density. All shipments are assumed to be at the maximum weight limits for truck and rail shipments. On the basis of typical LLW densities, roughly 80 drums with a 208-L (55-gal) capacity each would be shipped per truck, and 300 per railcar.

E.3.2.1.3 *TRUW Shipments*

The radiological characteristics of TRUW require the use of Type B packaging. The DOE has agreed to have the NRC certify the containers used for CH-TRUW and RH-TRUW shipments as meeting Type B specifications (DOE, 1990a). Shipments of TRUW will essentially consist of a number of Type A packages within reusable certified Type B packages. The Type B packages are assumed to be the TRUPACT-II for CH-TRUW and the RH-72B for RH-TRUW.

The TRUPACT-II was certified as meeting the NRC regulations for Type B packaging in August 1989 (DOE, 1990a). The container is a cylinder with a flat bottom and domed top that is transported in an upright position. Each TRUPACT-II is approximately 2.4 m (8 ft) in diameter and 3.1 m (10 ft) in height. The TRUPACT-II was designed to maximize payload in volume and in weight. The usable volume of each TRUPACT-II is approximately 2.8 m^3 (3.7 yd^3) . The payload capacity of each TRUPACT-II is 3,300 kg (7,275 lb). Three TRUPACT-IIs are assumed to be transported per truck, and six per railcar. The total number of required shipments has been calculated on the basis of waste volume, which is 8.4 m^3 (11 yd^3) for truck shipments and 16.8 m^3 (22 yd^3) for rail shipments.

The RH-72B shipping cask is assumed to be used for all RH-TRUW shipments. The RH-72B is being designed to meet Type B packaging specifications and is a scaled-down version of the certified NuPac 125B cask (DOE, 1990a). (The NuPac 125B was used to transport core debris from the damaged Three Mile Island nuclear power station to INEL.) The RH-72B cask is approximately 3.7 m (12 ft) long with a diameter of 1.1 m (3.5 ft). The usable volume of each RH-72B is approximately 0.89 m^3 (1.2 yd^3). The payload capacity of each RH-72B is limited to 3,629 kg (8,000 lb). One RH-72B is assumed to be transported per truck, and two per railcar. The total number of required shipments has been calculated on the basis of waste volume, which is 0.89 m^3 (1.2 yd^3) for truck shipments and 1.8 m^3 (2.4 yd^3) for rail shipments.

E.3.2.1.4 *LLMW Shipments*

Shipment of LLMW is assumed to be similar to LLW. Shipments of LLMW would meet any additional requirements for characterization and labeling associated with the HW component. In addition, shipments of liquid waste would meet regulatory requirements specified for liquids; that is, packages would contain adequate absorbent material to absorb twice the volume of the transported liquid, or a leak-tight overpack would be used (10 CFR 71).

E.3.2.2 Onsite Transportation

The policy at the Hanford Site is to use certified packaging whenever practicable for transporting radioactive materials onsite (Mercado et al., 1992). Therefore, the packaging used for onsite transportation is assumed to be the same as that used for offsite transportation. If an alternative means of packaging is necessary, a concept of equivalent safety is maintained while achieving the same shipping results. Onsite transportation safety is attained through such measures as limiting vehicular speeds, appropriate traffic controls, or increasing shielding for crew members and distance from the package.

In addition, the public has access to a number of routes on the Hanford Site. Unless such routes are barricaded while radioactive waste is being transported, shipments must meet all pertinent Federal regulations pertaining to public highways. Stringent procedures are followed at the Hanford Site to ensure the safety of workers and the public, providing the same level of safety for onsite and offsite shipments (WHC, 1993).

E.4 Analysis of Truck and Rail Routing

As discussed previously and illustrated in Figures E–1 and E–2, each case can be defined as a set of origin-and-destination pairs representing shipping linkages among generator, treatment, and disposal sites. The calculation of the transportation risk for an alternative depends, in part, on the characteristics of the transportation routes between the origin and destination sites. Regulatory routing criteria and the methods used to determine conceptual truck and rail routes for the transportation risk assessment are described in this section.

E.4.1 Routing Regulations

The DOT routing regulations for public highways are prescribed in 49 CFR 177 (commonly referred to as HM-164). The objectives of the regulations are to reduce the impacts of transporting radioactive materials, to establish consistent and uniform requirements for route selection, and to identify the role of State and local governments in routing radioactive materials. The regulations attempt to reduce potential hazards by avoiding populous areas and by minimizing travel times. In addition, the regulations require that the carrier of radioactive materials ensure that the vehicle is operated on routes that minimize radiological risks, and that accident rates, transit times, population density and activity, time of day, and day of week are considered in determining risk.

A vehicle transporting a shipment of a "highway route controlled quantity" of radioactive materials is required by HM-164 to use the interstate highway system except when moving from origin to interstate or from interstate to destination, when making necessary repair or rest stops, or when emergency conditions make continued use of the interstate unsafe or impossible. Carriers are required to use interstate circumferential or bypass routes, if available, to avoid populous areas. Any State or Native American tribe may designate other "preferred highways" to replace or supplement the interstate system. Under its authority to regulate interstate transportation safety, DOT can prohibit State and local bans and restrictions as "undue restraint of interstate commerce." State or local bans can be preempted if inconsistent with HM-164.

The DOT has no railroad routing regulations specific to the transportation of radioactive materials. Routes are generally fixed by the location of rail lines, and urban areas cannot readily be bypassed.

E.4.2 REPRESENTATIVE TRANSPORTATION ROUTES

E.4.2.1 Offsite Transportation

The scope of this PEIS assessment involves every DOE site that generates, stores, or disposes radioactive waste. The transportation linkages among generator, treatment, and disposal sites depend on the type of waste and are defined explicitly for each case under consideration. For this PEIS, representative offsite truck and rail routes were determined for all possible pairs of origin and destination sites. Table E–2 gives the truck route distances between major DOE sites, and Table E–3 gives the rail route distances. The routes were selected to be consistent with existing routing practices and all applicable routing regulations and guidelines; however, because the routes were determined for the purposes of risk assessment, they do not necessarily represent actual routes that would be used to transport waste in the future.

The conceptual truck routes were determined by using the routing model HIGHWAY 3.1 (Johnson et al., 1993a), and INTERLINE 5.0 was used to determine the rail routes (Johnson et al., 1993b). For truck and rail transportation, the route characteristics most important to the radiological risk assessment include the total shipping distance between each origin-and-destination pair and the fractions of travel in rural, suburban, and urban zones of population density. The route selected determines the total potentially exposed population along a route and the expected frequency of transportation-related accidents. Because of the large number of unique origin-and-destination pairs considered for the PEIS alternatives, detailed route characteristics are provided in the technical reports prepared for each waste type (ANL, 1996a,c-f).

E.4.2.1.1 *HIGHWAY 3.1*

The HIGHWAY 3.1 computer program is used for predicting highway routes for transporting radioactive materials by truck within the United States. The HIGHWAY database is a computerized road atlas that describes at least 386,243 km (240,000 mi) of roads. This database includes a complete description of the interstate highway system and of all U.S. highways. In addition, most principal State highways and many local and community highways are identified. The code is updated periodically to reflect current road conditions and has been compared with reported mileages and observations of commercial trucking firms.

Routes are calculated within the model by minimizing the total impedance between origin and destination. The impedance is basically defined as a function of distance and driving time along a particular segment

Table E-2. Truck Route Distances (mi) Between Major DOE Sites[a]

	Ames	ANL-E	ANL-W	BCL	Bettis	BNL	Fermi	FEMP	Hanford	INEL	ITRI	KCP	KAPL-S	LBL	LLNL	LANL	Mound	NRF
Ames	0	351	1287	675	894	1206	341	611	1703	1287	1129	234	1163	1844	1853	1136	644	1287
ANL-E	351	0	1582	348	567	874	36	294	1998	1582	1333	520	831	2139	2148	1431	317	1582
ANL-W	1287	1582	0	1906	2125	2437	1572	1842	599	0	1177	1325	2393	963	972	1144	1875	0
BCL	675	348	1906	0	223	653	380	113	2322	1906	1463	650	626	2463	2472	1552	72	1906
Bettis	894	567	2125	223	0	506	599	312	2541	2125	1682	869	543	2682	2691	1771	291	2125
BNL	1206	874	2437	653	506	0	906	760	2853	2437	2113	1299	241	2994	3003	2201	721	2437
Fermi	341	36	1572	380	599	906	0	326	1975	1572	1359	519	863	2129	2138	1421	349	1572
FEMP	611	294	1842	113	312	760	326	0	2258	1842	1399	586	733	2399	2408	1488	49	1842
Hanford	1703	1998	599	2322	2541	2853	1975	2258	0	599	1593	1741	2809	875	894	1560	2291	599
INEL	1287	1582	0	1906	2125	2437	1572	1842	599	0	1177	1325	2393	963	972	1144	1875	0
ITRI	1129	1333	1177	1463	1682	2113	1359	1399	1593	1177	0	895	2085	1194	1154	111	1432	1177
KCP	234	520	1325	650	869	1299	519	586	1741	1325	895	0	1272	1881	1890	984	619	1325
KAPL-S	1163	831	2393	626	543	241	863	733	2809	2393	2085	1272	0	2950	2959	2174	694	2393
LBL	1844	2139	963	2463	2682	2994	2129	2399	875	963	1194	1881	2950	0	45	1274	2432	963
LLNL	1853	2148	972	2472	2691	3003	2138	2408	894	972	1154	1890	2959	45	0	1233	2441	972
LANL	1136	1431	1144	1552	1771	2201	1421	1488	1560	1144	111	984	2174	1274	1233	0	1521	1144
Mound	644	317	1875	72	291	721	349	49	2291	1875	1432	619	694	2432	2441	1521	0	1875
NRF	1287	1582	0	1906	2125	2437	1572	1842	599	0	1177	1325	2393	963	972	1144	1875	0
NTS	1520	1815	712	2078	2297	2670	1805	2014	1128	712	918	1428	2626	719	678	997	2047	712
ORISE	887	571	2077	399	586	808	603	299	2493	2077	1420	752	872	2592	2551	1509	335	2077
ORR	900	584	2048	412	563	821	616	312	2464	2048	1391	723	885	2563	2523	1480	348	2048
PGDP	629	385	1766	477	696	1115	417	409	2182	1766	1230	441	1099	2322	2327	1319	441	1766
Pantex	834	1038	1468	1168	1387	1817	1064	1104	1884	1468	313	600	1790	1485	1445	402	1137	1468
Pinellas	1481	1204	2617	1065	1252	1329	1236	965	3033	2617	1959	1293	1393	2945	2904	2048	1001	2617
PORTS	755	428	1986	84	265	689	460	173	2402	1986	1543	730	688	2543	2552	1632	152	1986
PPPL	1217	822	2448	546	398	189	854	635	2864	2448	2006	1192	291	3005	3014	2094	614	2448
RMI	751	419	1982	214	175	531	451	321	2398	1982	1673	860	416	2538	2547	1762	282	1982
RFETS	722	1017	716	1283	1500	1870	1005	1217	1132	716	483	631	1827	1283	1292	452	1250	716
SNL-NM	1120	1324	1168	1454	1673	2103	1350	1390	1584	1168	9	886	2076	1185	1145	102	1423	1168
SNL-CA	1853	2148	972	2472	2691	3003	2138	2408	894	972	1154	1890	2959	45	0	1233	2441	972
SRS	1175	892	2311	720	656	897	924	620	2727	2311	1653	987	961	2791	2750	1742	656	2311
SLAC	1885	2180	1004	2524	2723	3035	2167	2440	916	1004	1198	1939	2979	47	64	1294	2473	1004
WVDP	909	577	2140	372	257	492	609	479	2556	2140	1832	1018	314	2697	2706	1921	440	2140
WIPP	1301	1505	1759	1625	1813	2192	1531	1526	2175	1759	614	1067	2256	1509	1468	693	1561	1759
YM	1554	1849	746	2112	2331	2704	1839	2048	1162	746	952	1462	2660	753	712	1031	2081	746

Table E-2. Truck Route Distances (mi) Between Major DOE Sites[a]—Continued

	NTS	ORISE	ORR	PGDP	Pantex	Pinellas	PORTS	PPPL	RMI	RFETS	SNL-NM	SNL-CA	SRS	SLAC	WVDP	WIPP	YM
Ames	1520	887	900	629	834	1481	755	1217	751	722	1120	1853	1175	1885	909	1301	1554
ANL-E	1815	571	584	385	1038	1204	428	822	419	1017	1324	2148	892	2180	577	1505	1849
ANL-W	712	2077	2048	1766	1468	2617	1986	2448	1982	716	1168	972	2311	1004	2140	1759	746
BCL	2078	399	412	477	1168	1065	84	546	214	1283	1454	2472	720	2524	372	1625	2112
Bettis	2297	586	563	696	1387	1252	265	398	175	1500	1673	2691	656	2723	257	1813	2331
BNL	2670	808	821	1115	1817	1329	689	189	531	1870	2103	3003	897	3035	492	2192	2704
Fermi	1805	603	616	417	1064	1236	460	854	451	1005	1350	2138	924	2167	609	1531	1839
FEMP	2014	299	312	409	1104	965	173	635	321	1217	1390	2408	620	2440	479	1526	2048
Hanford	1128	2493	2464	2182	1884	3033	2402	2864	2398	1132	1584	894	2727	916	2556	2175	1162
INEL	712	2077	2048	1766	1468	2617	1986	2448	1982	716	1168	972	2311	1004	2140	1759	746
ITRI	918	1420	1391	1230	313	1959	1543	2006	1673	483	9	1154	1653	1198	1832	614	952
KCP	1428	752	723	441	600	1293	730	1192	860	631	886	1890	987	1939	1018	1067	1462
KAPL	2626	872	885	1099	1790	1393	688	291	416	1827	2076	2959	961	2979	314	2256	2660
LBL	719	2592	2563	2322	1485	2945	2543	3005	2538	1283	1185	45	2791	47	2697	1509	753
LLNL	678	2551	2523	2327	1445	2904	2552	3014	2547	1292	1145	0	2750	64	2706	1468	712
LANL	997	1509	1480	1319	402	2048	1632	2094	1762	452	102	1233	1742	1294	1921	693	1031
Mound	2047	335	348	441	1137	1001	152	614	282	1250	1423	2441	656	2473	440	1561	2081
NRF	712	2077	2048	1766	1468	2617	1986	2448	1982	716	1168	972	2311	1004	2140	1759	746
NTS	0	2180	2151	1864	1209	2720	2158	2620	2214	836	909	678	2414	739	2373	1365	46
ORISE	2180	0	10	333	1125	692	358	702	595	1383	1411	2551	369	2584	753	1410	2214
ORR	2151	10	0	304	1096	685	371	715	608	1354	1382	2523	379	2584	766	1381	2185
PGDP	1864	333	304	0	940	874	0	1009	687	1072	1226	2327	568	2359	845	1258	1903
Pantex	1209	1125	1096	940	0	1664	1248	1710	1378	774	304	1445	1358	1506	1537	308	1243
Pinellas	2720	692	685	874	1664	0	1024	1152	1261	1924	1950	2904	620	2969	1419	1762	2754
PORTS	2158	358	371	0	1248	1024	0	588	276	1361	1534	2552	540	2584	434	1632	2192
PPPL	2620	702	715	1009	1710	1152	588	0	528	1823	1997	3014	767	3046	489	2086	2654
RMI	2214	595	608	687	1378	1261	276	528	0	1415	1664	2547	726	2579	162	1822	2248
RFETS	836	1383	1354	1072	774	1924	1361	1823	1415	0	474	1292	1618	1324	1573	1067	868
SNL-NM	909	1411	1382	1226	304	1950	1534	1997	1664	474	0	1145	1644	1198	1823	605	943
SNL-CA	678	2551	2523	2327	1445	2904	2552	3014	2547	1292	1145	0	2750	64	2706	1468	712
SRS	2414	369	379	568	1358	620	540	767	726	1618	1644	2750	0	2820	1023	1524	2448
SLAC	739	2584	2584	2359	1506	2969	2584	3046	2579	1324	1198	64	2820	0	2738	1529	773
WVDP	2373	753	766	845	1537	1419	434	489	162	1573	1823	2706	1023	2738	0	1980	2407
WIPP	1365	1410	1381	1258	308	1762	1632	2086	1822	1067	605	1468	1524	1529	1980	0	1399
YM	46	2214	2185	1903	1243	2754	2192	2654	2248	868	943	712	2448	773	2407	1399	0

Notes: Ames = Ames Laboratory; ANL-E = Argonne National Laboratory-East; ANL-W = Argonne National Laboratory-West; BCL = Battelle Columbus Laboratories; Bettis = Bettis Atomic Power Laboratory; BNL = Brookhaven National Laboratory; Fermi = Fermi National Accelerator Laboratory; FEMP = Fernald Environmental Management Project; Hanford = Hanford Site; INEL = Idaho National Engineering Laboratory; ITRI = Inhalation Toxicology Research Institute; KCP = Kansas City Plant; KAPL-S = Knolls Atomic Power Laboratory (Schenectady); LBL = Lawrence Berkeley Laboratory; LLNL = Lawrence Livermore National Laboratory; LANL = Los Alamos National Laboratory; Mound = Mound Plant; NRF = Naval Reactor Facility; NTS = Nevada Test Site; ORISE = Oak Ridge Institute for Science and Education; ORR = Oak Ridge Reservation; PGDP = Paducah Gaseous Diffusion Plant; Pantex = Pantex Plant; Pinellas = Pinellas Plant; PORTS = Portsmouth Gaseous Diffusion Plant; PPPL = Princeton Plasma Physics Laboratory; RMI = Reactive Metals, Inc.; RFETS = Rocky Flats Environmental Technology Site; SNL-NM = Sandia National Laboratories (New Mexico); SNL-CA = Sandia National Laboratories (California); SRS = Savannah River Site; SLAC = Stanford Linear Accelerator Center; WVDP = West Valley Demonstration Project; WIPP = Waste Isolation Pilot Plant; and YM = Yucca Mountain.

[a] Truck routes generated by using the HIGHWAY 3.1 routing model (Johnson et al., 1993a).

Table E-3. Rail Route Distances (mi) Between Major DOE Sites[a]

	Ames	ANL-E	ANL-W	BCL	Bettis	BNL	Fermi	FEMP	Hanford	INEL	ITRI	KCP	KAPL-S	LBL	LLNL	LANL	Mound	NRF
Ames	0	329	1242	700	823	1365	291	717	1788	1242	1187	275	1126	1873	2018	1124	715	1242
ANL-E	329	0	1655	401	518	1066	49	412	2201	1655	1351	439	827	2549	2506	1288	416	1655
ANL-W	1242	1655	0	1942	2133	2607	1533	1907	658	0	1247	1238	2468	1102	1100	1179	1926	0
BCL	700	401	1942	0	280	855	427	135	2488	1942	1759	753	615	2573	2718	1696	65	1942
Bettis	823	518	2133	280	0	772	543	475	2611	2133	1857	943	533	2696	2840	1794	345	2133
BNL	1365	1066	2607	855	772	0	1088	984	3153	2607	2414	1518	239	3238	3383	2351	920	2607
Fermi	291	49	1533	427	543	1088	0	441	1971	1533	1356	453	853	2343	2341	1405	443	1533
FEMP	717	412	1907	135	475	984	441	0	2505	1907	1751	717	745	2590	2735	1688	69	1907
Hanford	1788	2201	658	2488	2611	3153	1971	2505	0	658	1793	1784	2914	986	973	1725	2472	658
INEL	1242	1655	0	1942	2133	2607	1533	1907	658	0	1247	1238	2468	1102	1100	1179	1926	0
ITRI	1187	1351	1247	1759	1857	2414	1356	1751	1793	1247	0	932	2177	1266	1222	104	1767	1247
KCP	275	439	1238	753	943	1518	453	717	1784	1238	932	0	1250	2016	2013	869	708	1238
KAPL-S	1126	827	2468	615	533	239	853	745	2914	2468	2177	1250	0	2999	3144	2122	680	2468
LBL	1873	2549	1102	2573	2696	3238	2343	2590	986	1102	1266	2016	2999	0	46	1354	2717	1102
LLNL	2018	2506	1100	2718	2840	3383	2341	2735	973	1100	1222	2013	3144	46	0	1326	2695	1100
LANL	1124	1288	1179	1696	1794	2351	1405	1688	1725	1179	104	869	2122	1354	1326	0	1704	1179
Mound	715	416	1926	65	345	920	443	69	2472	1926	1767	708	680	2717	2695	1704	0	1926
NRF	1242	1655	0	1942	2133	2607	1533	1907	658	0	1247	1238	2468	1102	1100	1179	1926	0
NTS	1674	2348	756	2374	2496	3039	1997	2391	1302	756	1065	1670	2800	860	1370	1169	2386	756
ORISE	956	651	2099	366	714	1221	679	331	2644	2099	1989	881	981	2890	2868	1926	301	2099
ORR	954	649	2055	393	903	1152	682	358	2601	2055	1749	838	957	2686	2831	1686	328	2055
PGDP	646	390	1699	581	816	1346	469	468	2245	1699	1539	482	1106	2490	2469	1476	564	1699
Pantex	809	972	1141	1381	1479	2035	977	1373	1686	1141	379	554	1807	1561	1534	483	1396	1141
Pinellas	1623	1319	2721	1151	1293	1585	1344	1116	3267	2721	2079	1503	1390	3278	3491	2183	1086	2721
PORTS	727	422	1975	91	429	921	451	207	2515	1975	1761	758	681	2767	2745	1698	156	1975
PPPL	1197	898	2507	655	400	410	924	938	2985	2507	2248	1289	214	3298	3276	2186	719	2507
RMI	717	418	2060	207	136	648	445	337	2505	2060	1769	842	408	2851	2829	1706	272	2060
RFETS	782	1194	738	1502	1692	2266	1016	1466	1284	738	572	778	2027	1320	1394	504	1485	738
SNL-NM	1187	1351	1247	1759	1857	2414	1356	1751	1793	1247	0	932	2177	1266	1222	104	1767	1247
SNL-CA	2018	2506	1100	2718	2840	3383	2341	2735	973	1100	1222	2013	3144	46	0	1326	2695	1100
SRS	1281	976	2407	740	947	1239	1001	774	2953	2407	2315	1161	1044	3192	3183	2252	744	2407
SLAC	1924	2536	1160	2947	2746	3289	2393	2641	1036	1160	1253	2073	3050	56	60	1357	2930	1160
WVDP	881	579	2123	370	244	549	603	631	2669	2123	1929	1033	309	2773	2898	1866	562	2123
WIPP	1115	1279	1447	1688	1785	2342	1284	1679	1993	1447	477	861	2114	1660	1633	581	1703	1447
YM	1674	2348	756	2374	2496	3039	1997	2391	1302	756	1065	1670	2800	860	1370	1169	2386	756

Table E–3. Rail Route Distances (mi) Between Major DOE Sites[a]—Continued

	NTS	ORISE	ORR	PGDP	Pantex	Pinellas	PORTS	PPPL	RMI	RFETS	SNL-NM	SNL-CA	SRS	SLAC	WVDP	WIPP	YM
Ames	1674	956	954	646	809	1623	727	1197	717	782	1187	2018	1281	1924	881	1115	1674
ANL-E	2348	651	649	390	972	1319	422	898	418	1194	1351	2506	976	2536	579	1279	2348
ANL-W	756	2099	2055	1699	1141	2721	1975	2507	2060	738	1247	1100	2407	1160	2123	1447	756
BCL	2374	366	393	581	1381	1151	91	655	207	1502	1759	2718	740	2947	370	1688	2374
Bettis	2496	714	903	816	1479	1293	429	400	136	1692	1857	2840	947	2746	244	1785	2496
BNL	3039	1221	1152	1346	2035	1585	921	410	648	2266	2414	3383	1239	3289	549	2342	3039
Fermi	1997	679	682	469	977	1344	451	924	445	1016	1356	2341	1001	2393	603	1284	1997
FEMP	2391	331	358	468	1373	1116	207	938	337	1466	1751	2735	774	2641	631	1679	2391
Hanford	1302	2644	2601	2245	1686	3267	2515	2985	2505	1284	1793	973	2953	1036	2669	1993	1302
INEL	756	2099	2055	1699	1141	2721	1975	2507	2060	738	1247	1100	2407	1160	2123	1447	756
ITRI	1065	1989	1749	1539	379	2079	1761	2248	1769	572	0	1222	2315	1253	1929	477	1065
KCP	1670	881	838	482	554	1503	758	1289	842	778	932	2013	1161	2073	1033	861	1670
KAPL-S	2800	981	957	1106	1807	1390	681	214	408	2027	2177	3144	1044	3050	309	2114	2800
LBL	860	2890	2686	2490	1561	3278	2767	3298	2851	1320	1266	46	3192	56	2773	1660	860
LLNL	1370	2868	2831	2469	1534	3491	2745	3276	2829	1394	1222	0	3183	60	2898	1633	1370
LANL	1169	1926	1686	1476	483	2183	1698	2186	1706	504	104	1326	2252	1357	1866	581	1169
Mound	2386	301	328	564	1396	1086	156	719	272	1485	1767	2695	744	2930	562	1703	2386
NRF	756	2099	2055	1699	1141	2721	1975	2507	2060	738	1247	1100	2407	1160	2123	1447	756
NTS	0	2530	2487	2131	1376	3153	2401	2871	2391	987	1065	1370	2839	862	2554	1475	0
ORISE	2530	0	40	632	1611	786	392	1176	575	1658	1989	2868	443	3103	889	1918	2530
ORR	2487	40	0	527	1371	797	442	760	600	1586	1749	2831	417	3031	889	1678	2487
PGDP	2131	632	527	0	1103	1056	495	1145	698	1220	1539	2469	714	2597	861	1410	2131
Pantex	1376	1611	1371	1103	0	1825	1382	1867	1387	465	379	1534	1937	1564	1551	307	1376
Pinellas	3153	786	797	1056	1825	0	1106	1207	1361	2280	2079	3491	485	3280	1568	2019	3153
PORTS	2401	392	442	495	1382	1106	0	838	279	1535	1761	2745	655	2651	585	1689	2401
PPPL	2871	1176	760	1145	1867	1207	838	0	511	2066	2248	3276	848	3121	426	2185	2871
RMI	2391	575	600	698	1387	1361	279	511	0	1619	1769	2829	920	2641	163	1705	2391
RFETS	987	1658	1586	1220	465	2280	1535	2066	1619	0	572	1394	1938	1377	1782	769	987
SNL-NM	1065	1989	1749	1539	379	2079	1761	2248	1769	572	0	1222	2315	1253	1929	477	1065
SNL-CA	1370	2868	2831	2469	1534	3491	2745	3276	2829	1394	1222	0	3183	60	2898	1633	1370
SRS	2839	443	417	714	1937	485	655	848	920	1938	2315	3183	0	3194	1223	2243	2839
SLAC	862	3103	3031	2597	1564	3280	2651	3121	2641	1377	1253	60	3194	0	2804	1662	862
WVDP	2554	889	889	861	1551	1568	585	426	163	1782	1929	2898	1223	2804	0	1858	2540
WIPP	1475	1918	1678	1410	307	2019	1689	2185	1705	769	477	1633	2243	1662	1858	0	1475
YM	0	2530	2487	2131	1376	3153	2401	2871	2391	987	1065	1370	2839	862	2540	1475	0

Notes: Ames = Ames Laboratory; ANL-E = Argonne National Laboratory-East; ANL-W = Argonne National Laboratory-West; BCL = Battelle Columbus Laboratories; Bettis = Bettis Atomic Power Laboratory; BNL = Brookhaven National Laboratory; Fermi = Fermi National Accelerator Laboratory; FEMP = Fernald Environmental Management Project; Hanford = Hanford Site; INEL = Idaho National Engineering Laboratory; ITRI = Inhalation Toxicology Research Institute; KCP = Kansas City Plant; KAPL-S = Knolls Atomic Power Laboratory (Schenectady); LBL = Lawrence Berkeley Laboratory; LLNL = Lawrence Livermore National Laboratory; LANL = Los Alamos National Laboratory; Mound = Mound Plant; NRF = Naval Reactor Facility; NTS = Nevada Test Site; ORISE = Oak Ridge Institute for Science and Education; ORR = Oak Ridge Reservation; PGDP = Paducah Gaseous Diffusion Plant; Pantex = Pantex Plant; Pinellas = Pinellas Plant; PORTS = Portsmouth Gaseous Diffusion Plant; PPPL = Princeton Plasma Physics Laboratory; RMI = Reactive Metals, Inc.; RFETS = Rocky Flats Environmental Technology Site; SNL-NM = Sandia National Laboratories (New Mexico); SNL-CA = Sandia National Laboratories (California); SRS = Savannah River Site; SLAC = Stanford Linear Accelerator Center; WVDP = West Valley Demonstration Project; WIPP = Waste Isolation Pilot Plant; and YM = Yucca Mountain.

[a] Rail routes generated by using the INTERLINE 5.0 routing model (Johnson et al., 1993b).

of highway. A special feature of the HIGHWAY 3.1 model is its ability to calculate routes that maximize the use of interstate highways. This feature allows the user to predict routes for shipping radioactive materials that conform to DOT transportation regulations, specifically HM-164. The population densities along a route are derived from 1990 census data from the U.S. Bureau of the Census. Rural, suburban, and urban areas are characterized according to the following breakdown: rural population densities range from 0 to 54 persons/km^2 (0 to 39 persons/mi^2); the suburban range is 55 to 1,284/km^2 (140 to 3,326/mi^2); and urban covers all population densities greater than 1,284/km^2 (3,326/mi^2).

E.4.2.1.2 *INTERLINE 5.0*

The INTERLINE 5.0 computer program is designed to simulate routing of the U.S. rail system. The INTERLINE database consists of 94 separate subnetworks and represents various competing rail companies in the United States. The database used by INTERLINE was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974. The database has been expanded and modified over the past two decades. The code is updated periodically to reflect current track conditions and has been compared with reported mileages and observations of commercial rail firms.

The INTERLINE 5.0 model uses a shortest route algorithm that finds the path of minimum impedance within an individual subnetwork. A separate method is used to find paths along the subnetworks. The routes chosen for this study used the standard assumptions in the INTERLINE model that simulate the process of selection that railroads would use to direct shipments of radioactive waste. For sites that do not have direct rail access, the rail siding nearest the site was used for routing. The population densities along a route are derived from 1990 census data. Rural, suburban, and urban areas are characterized according to the following breakdown: rural population densities range from 0 to 54 persons/km^2 (0 to 139/mi^2); the suburban range for population density is 55 to 1,284/km^2 (140 to 3,326/mi^2); and urban covers all population densities greater than 1,284/km^2 (3,326/mi^2).

E.4.2.2 Onsite Transportation

Most radioactive waste at the Hanford Site is shipped by truck. The routes for onsite transportation used for this analysis are typical of those used for shipping radioactive waste onsite at the Hanford Site (DOE, 1989). Because the Hanford Site maintains an extensive onsite railroad network, consideration of rail transport was included to maintain consistency with the analyses of offsite transportation. Rail routes were chosen to minimize distance traveled.

E.5 Methods for Calculating Transportation-Related Risks

The technical approach for conducting the transportation risk assessment was developed after a thorough and critical review of the literature and existing documentation in the National Environmental Policy Act for Federal actions involving transportation of radioactive materials. Consideration was also given to recent DOE commitments arising from litigation and public awareness. The approach selected uses several computer models and databases to determine risks for each case. The method for offsite assessment is discussed in Section E.5.1; the method for onsite assessment is discussed in Section E.5.2.

E.5.1 Offsite Transportation

The approach for offsite transportation risk assessment is summarized in Figure E–3 and discussed in detail in this section. For each case, risks are assessed for routine transportation and accidents. For the routine assessment, risks are calculated for the collective populations of potentially exposed individuals, as well as for the MEIs. The accident assessment consists of two components: (1) an accident risk assessment, which considers the probabilities and consequences of a range of possible transportation-related accidents, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences; and (2) an accident consequence assessment, which considers only the radiological consequences of the severe transportation-related accidents that are postulated to result in the largest releases of radioactive material.

The RADTRAN 4 computer code (Neuhauser and Kanipe, 1993) is used for routine and accident risk assessments to estimate the impacts to collective populations. RADTRAN 4 was developed by SNL-NM to calculate population risks associated with transporting radioactive materials by various means, including truck, rail, air, ship, and barge. The code has been extensively reviewed, updated, and used for transportation risk assessments since it was issued in the late 1970s.

The RADTRAN 4 calculations of population risk take into account the consequences and the probabilities of potential exposures. The collective population risk is a measure of the total radiological risk posed to

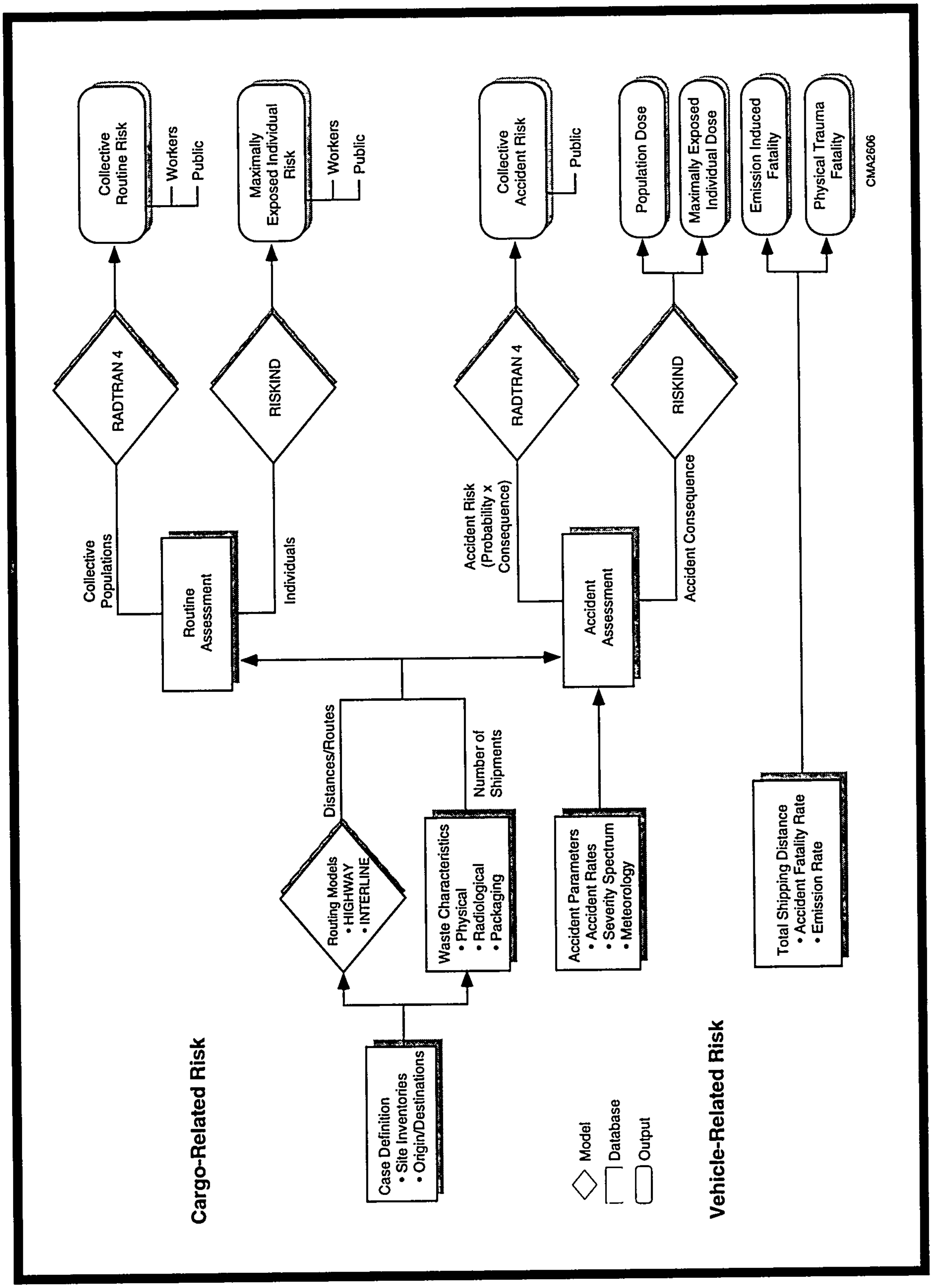

Figure E–3. Approach for the Offsite Transportation Radiological Risk Assessment.

society as a whole by the alternative being considered. The collective population risks are used as the primary means of comparing the various alternatives.

As a complement to the RADTRAN calculations, the RISKIND computer code (Yuan et al., 1993) is used to estimate scenario-specific doses to MEIs for routine operations and accidents and to estimate population impacts for the accident consequence assessment. The RISKIND computer code was developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups associated with transporting spent nuclear fuel. Minor modifications to the code were made for WM PEIS applications to accommodate shipments of all types of radioactive waste.

The RISKIND calculations are conducted for the WM PEIS to supplement the results for collective risk calculated with RADTRAN 4. Whereas the results for collective risk provide a measure of the overall risks of each case, the RISKIND calculations are meant to address areas of specific concern to individuals and subgroups of population. Essentially, the RISKIND analyses are meant to address hypothetical questions, such as, "What if I live next to a site access road?" or "What if an accident happens near my town?"

E.5.1.1 Routine (Incident-Free) Risk Assessment Method

E.5.1.1.1 *Collective Population Risk*

The radiological risk associated with routine transportation results from the potential exposure of people to low-level external radiation from loaded shipments. The maximum allowable external dose rates for exclusive-use shipments were presented in Section E.3.1.

For routine transportation, the RADTRAN 4 computer code considers all major groups of potentially exposed persons. The RADTRAN 4 calculations of risk for routine highway and rail transportation include exposures of the following population groups:

- *Persons Along the Route (Off-Link Population)*. Collective doses are calculated for all persons living or working within 0.8 km (0.5 mi) on each side of a transportation route. The total number of persons within the 1.6-km (1-mi) corridor is calculated separately for each route considered in the assessment.

- *Persons Sharing the Route (On-Link Population)*. Collective doses are calculated for persons in all vehicles sharing the transportation route. This group includes persons traveling in the same or the opposite direction as the shipment, as well as persons in vehicles passing the shipment.
- *Persons at Stops*. Collective doses are calculated for people who may be exposed while a shipment is stopped en route. For truck transportation, these include stops for refueling, food, and rest. For rail transportation, stops are assumed to occur for purposes of classification.
- *Crew Members*. Collective doses are calculated for truck and rail transportation crew members.

The doses calculated for the first three population groups are added generically to yield the collective dose to the public; the dose calculated for the fourth group represents the collective dose to workers. The RADTRAN 4 models for routine dose are not intended to be used for estimating specific risks to individuals.

The RADTRAN 4 calculations for routine dose are based on generically expressing the dose rate as a function of distance from a point source (Neuhauser and Kanipe, 1993). Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, source-receptor distance, duration of exposure, vehicular speed, stopping time, traffic density, and route characteristics such as population density. The RADTRAN manual contains derivations of the equations and descriptions of these parameters (Neuhauser and Kanipe, 1993). The values for many of the most important parameters are presented in Section E.6.

The collective routine risks are calculated for each specific alternative as follows. Each alternative is first defined as a set of origin-and-destination pairs. Representative highway and rail routes are determined for each unique pair, as described in Section E.4. The number of shipments transported across each linkage is then calculated for truck and rail modes by using estimated site-specific waste inventories and information on shipment capacity, which is in Section E.3. For shipments between each origin-and-destination pair, RADTRAN 4 is used to calculate collective risks to workers and the public on the basis of representative radiological and physical properties of the waste type being considered. The collective risks are then summed over the set of origin-destination pairs to estimate the collective routine risks associated with that case.

E.5.1.1.2 *Maximally Exposed Individual Risk*

In addition to assessing the routine collective population risk, the RISKIND model has been used to estimate risk to MEIs for a number of hypothetical exposure scenarios. The receptors include transportation crew members, departure inspectors, and members of the public exposed during traffic delays, while working at a service station, or while living near a DOE site.

The dose to each MEI considered is calculated with RISKIND for an exposure scenario defined by a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations of exposure are similar to those given in previous transportation risk assessments (DOE, 1987b; DOE, 1990a) and are presented in Section E.6. The scenarios are not intended to be exhaustive but were selected to provide a range of potential exposure situations.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the soil and air. The RISKIND model is used to calculate dose as a function of distance (millirems per hour) for stationary exposures and millirems per event (for moving shipments) from a waste shipment on the basis of the shipment dimensions. The code approximates the shipment as a cylindrical volume source; and the calculated dose includes secondary radiation-scattering contributions from buildup (scattering by waste contents), cloudshine (scattering by air), and groundshine (scattering by the ground). The dose rates calculated by using RISKIND have been shown to be comparable with output from existing shielding codes for various waste configurations. The RISKIND model produces realistic but conservative results. As a conservative measure, credit for potential shielding between the cask and the receptor is not considered, although RISKIND allows for shielding provisions.

E.5.1.1.3 *Vehicle-Related (Nonradiological) Routine Risk*

Vehicle-related health risks resulting from routine transportation may be associated with the transporting vehicles that generate air pollutants during waste shipment, independent of the nature of the shipment. The health endpoint assessed under routine transport conditions is the excess (additional) latent mortality caused by inhalation of vehicular exhaust emissions. A risk factor for latent mortality from pollutant inhalation, generated by Rao et al. (1982), is 1×10^{-7}/km (1.6×10^{-7}/mi) of truck travel in an urban area (1.3×10^{-7}/railcar-km for rail). This risk factor is based on regression analyses of the effect of sulfur dioxide and particulate releases from diesel exhaust on mortality. Excess latent mortality is assumed to be equivalent to cancer fatalities. Vehicle-related risks from routine transportation are calculated for each case by multiplying the total distance traveled in urban areas by the appropriate risk factor. Similar risk factors are not available for rural and suburban areas.

Risks are summed over the entire route and over all shipments for each alternative. This method has been used in several reports to calculate risks from routine transport of radioactive wastes (DOE, 1986b, 1987a, 1990a) and provides a convenient method of comparing the risks of routine transport for HW shipment alternatives and the risks of HW versus radioactive waste shipments under routine conditions. Lack of information for rural and suburban areas is an obvious gap in the data, although the risk factor would presumably be lower because total emissions from all sources in rural and suburban areas are lower.

E.5.1.2 Accident Assessment Method

E.5.1.2.1 *Radiological Accident Risk Assessment*

The risk analysis for potential accidents differs fundamentally from the risk analysis for routine transportation because occurrences of accidents are statistical. The accident risk assessment is treated probabilistically in RADTRAN 4. Accident risk is defined as the product of the accident consequence (dose) and the probability of the accident occurring. In this respect, the RADTRAN 4 code estimates the collective accident risk to populations by considering a spectrum of transportation-related accidents. The spectrum of accidents is designed to encompass a range of possible accidents, including low-probability accidents with high consequences and high-probability accidents with low consequences ("fender benders"). The results for collective accident risk can be directly compared with the results for routine collective risk because the former results incorporate the probabilities of accident occurrences.

The RADTRAN 4 calculation of collective accident risk employs models that quantify the range of potential accident severities and the responses of transported packages to accidents. The spectrum of accident severity is divided into a number of categories. Each category of severity is assigned a conditional probability of occurrence—that is, the probability that an accident will be of a particular severity if an accident occurs. The more severe the accident, the more remote the chance of such an accident. Release fractions, defined as the fraction of the material in a package that could be released in an accident, are assigned to each accident severity category on the basis of the physical and chemical form of the waste material. The models take into account the transportation mode and the packaging type being considered. The accident rates, the definition of accident severity categories, and the release fractions used in this analysis are discussed further in Section E.6.

For accidents involving the release of radioactive material, RADTRAN 4 assumes that the material is dispersed into the environment according to standard Gaussian diffusion models. For the risk assessment, default data for atmospheric dispersion were used, representing an instantaneous ground-level release and a small-diameter source cloud (Neuhauser and Kanipe, 1993). The calculation of the collective population dose after the release and dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud
- External exposure to contaminated soil
- Internal exposure from inhaling airborne contaminants
- Internal exposure from ingesting contaminated food

For the pathway of ingestion, State-specific food transfer factors, which relate the amount of radioactive material ingested to the amount deposited on the ground, were calculated in accordance with the methods described by NRC Regulatory Guide 1.109 (NRC, 1977b) and were used as input to the RADTRAN code. Doses of radiation from ingesting or inhaling radionuclides are calculated with standard dose conversion factors (DOE, 1988a-b).

The collective accident risk for each case is determined in a manner similar to that described for routine collective risks. Accident risks are first calculated for each unique origin-and-destination pair and then are summed over all pairs to estimate the total risk for the case. The accident risk assessment uses site-specific and waste type-specific radiological and physical waste characteristics, which are described further in Section E.6. In addition, the assessment uses route-specific information and accident rates derived for individual States.

E.5.1.2.2 *Radiological Accident Consequence Assessment*

The RISKIND code is used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents for each waste type. The RADTRAN 4 accident risk assessment considers the entire range of accident severities and their related probabilities, whereas the RISKIND accident consequence assessment focuses on accidents that result in the largest releases of radioactive material to the environment.

For each waste type, accident consequences are presented for a shipment of waste that represents the highest potential radiological risk if an accident occurs. This "maximum reasonably foreseeable accident" is identified for each waste type by screening the site-specific radiological waste characteristics (that is, activity concentrations) developed for this PEIS, taking into account the physical forms of waste and the relative hazards of individual radionuclides. For most waste shipments, the consequences of severe accidents would be less than those presented for the maximum reasonably foreseeable case. The accident consequence assessment is intended to provide an estimate of the maximum potential impacts posed by a severe transportation-related accident involving a particular waste type.

The severe accidents considered in the consequence assessment are characterized by extreme mechanical and thermal forces. In all cases, these accidents result in a release of radioactive material to the environment. The accidents correspond to those within the highest accident severity category, as described previously. These accidents represent low-probability high-consequence events. Therefore, accidents of this severity are expected to be extremely rare. However, the overall probability that such an accident could occur is dependent upon the potential accident rates for this severity category and the shipping distance for each case.

The RISKIND model was used to assess accident consequences for two reasons. First, its code can model the complex atmospheric (or site-specific) dispersion from severe accidents. The atmospheric dispersion is modeled as an instantaneous release by using standard Gaussian puff methods. In addition, because severe accidents routinely involve fires, modeling the potential radiological consequences takes into account physical phenomena resulting from the fire, such as buoyant plume rise. Second, RISKIND can estimate the dose to MEIs near an accident. RISKIND is used to determine the MEI's location on the basis of the atmospheric conditions assumed at the time of the accident and the thermal characteristics of the release.

For each waste type, the accident consequences are calculated for local populations and for MEIs. The population dose includes the population within 80 km (50 mi) of the accident site. The exposure pathways considered are similar to those discussed previously for the accident risk assessment. Although remedial activities after the accident (for example, evacuation or ground cleanup) would reduce the consequences, these activities were not considered in the consequence assessment.

Because predicting the exact location of a severe transportation-related accident is impossible, separate consequences are calculated for accidents occurring in rural, suburban, and urban zones of population density. Moreover, to address the effects of the atmospheric conditions existing at the time of an accident, two different atmospheric conditions are considered. The first case assumes neutral atmospheric conditions, and the second assumes stable conditions. Atmospheric conditions are discussed further in Section E.6.

E.5.1.2.3 *Vehicle-Related (Nonradiological) Accident Risk Assessment*

The vehicle-related accident risk refers to the potential for transportation-related accidents that directly result in fatalities that are not related to the shipment's cargo. This risk represents fatalities from mechanical causes. State-specific transportation fatality rates are used in the assessment and are discussed in Section E.6. Vehicle-related accident risks are calculated for each case by multiplying the total distance traveled in each State by the appropriate State rate for transportation-related fatalities. In all cases, the vehicle-related accident risks are calculated by using distances for round-trip shipment.

E.5.2 ONSITE TRANSPORTATION

The RISKIND computer code was used to calculate the routine and accident doses to MEIs and to collective onsite populations from onsite transportation at the Hanford Site. The RISKIND code allows for extensive use of site-specific data. Sitewide characteristics, such as weather data, nonuniform population densities, and surrounding agricultural productivity, are variable input parameters. In addition, the characteristics of receptors, such as shielding, intake rates, and location relative to the shipping route, can be specified.

E.5.2.1 Routine (Incident-Free) Risk Assessment Method

For routine conditions, RISKIND is used to calculate the dose and risk to specific individuals distinguished by their location relative to a shipment when it is stationary or moving. As a conservative assumption, potential shielding between the waste shipments and the receptor is not considered.

The following four groups of receptors are considered for the onsite routine risk assessment:

- Truck and rail crew members (crew dose)
- Workers near the transportation route (off-link worker population dose)

- Persons sharing the transportation route (on-link dose)
- Guards at the gates of individual facilities or at checkpoints along the route

The dose to the crew members is calculated by multiplying the distance traveled times the dose per kilometer calculated by RADTRAN 4 at the crew compartment. The dose rate in the crew compartment is limited to a value of 2 mrem/h by Federal regulations. RADTRAN 4 was used for estimating the dose to the crew to retain consistency with the offsite transportation assessment.

Onsite workers at the Hanford Site are located within well-defined facilities or work areas. All areas within 0.8 km (0.5 mi) on each side of the route were considered. RISKIND was used to calculate the population dose to each affected area by specifying the minimum distance from the route, the maximum distance from the route, and the average population density of that specific work area. The dose for each area was calculated while the shipment was immediately next to the area.

RISKIND was used to calculate the dose to individuals sharing the truck transportation route with waste shipments on the basis of the average vehicular occupancy and speed, road type, and one-way traffic densities. Members of the public, as well as workers, receive this dose because a section of a principal onsite route is over public-access roadways. No on-link dose was calculated for rail transportation because the tracks at the Hanford Site are used exclusively by Hanford; no parallel sets of tracks exist over the route.

For truck routes, the guard at the boundary of the shipping facility or the one at the checkpoint along the route is potentially the closest individual to the shipment outside of the loading facilities. This dose was calculated directly by using RISKIND.

E.5.2.2 Accident Consequence Assessment Method

For each waste type, the radiological accident consequences of the onsite transportation and its attendant health risks were calculated. The probabilities for onsite transportation accidents at Hanford Site (Wang et al., 1991) were used to estimate the likelihood of potential accidents and the associated maximum credible radioactive release for each waste type.

Doses to an MEI and to onsite and offsite populations are calculated by using RISKIND and parameters specific to Hanford. Doses include contributions from inhalation, cloudshine, and groundshine; no pathway for food ingestion has been considered for MEIs or for onsite worker populations. The food-ingestion pathway was considered only for offsite rural populations.

E.6 Input Parameters and Assumptions

The transportation risk assessment is designed to ensure—through uniform and judicious selection of models, data, and assumptions—that relative comparisons of risk among the various alternatives are meaningful. This goal is accomplished by uniformly applying to all alternatives the input parameters and assumptions common to each waste type. The principal input parameters and assumptions used in the transportation risk assessment are discussed in this section.

E.6.1 Waste Inventory and Characterization Data

The computational model WASTE_MGMT was developed at ANL-E to support the PEIS analyses of risks and costs (ANL, 1996l). Input to the model includes data on the waste inventory and on waste characterization at each DOE site, data on operations for the TSD facilities used for the wastes, and definitions of various alternatives. The sources and development of the model input data are described in the supporting technical reports specific to each waste type (ANL, 1996g-k).

One output of the model consists of the quantity, physical form, and radiological characteristics of the waste shipped between sites for each case. Table E–4 shows an example of output for an LLW case. The output presents part of a waste transportation data file that includes, for each origin- and-destination pair, the total quantity of waste shipped (both volume and mass), as well as the total activity (curies) of radionuclides in the waste being shipped. The effects of potential waste treatment, such as volume reduction or incineration, are considered in the model and are reflected in changes in waste density and activity concentrations. The WASTE_MGMT output files are used directly as input to the transportation risk assessment.

For each waste type, the physical forms of the waste are generally classified into a small number of categories, such as vitrified waste, liquid waste, metal waste, and heterogeneous solid waste. The package release fractions are developed according to the physical characteristics of the waste in each category.

Table E–4. Example of a Partial Argonne National Laboratory WASTE_MGMT Computational Model Output File Used as Input for the Transportation Radiological Risk Assessment[a]

Waste Stream LLW		
Origin Site AMES		
Destination	**Volume**	**Mass**
Site NTS	**m^3/yr 1.16E+01**	**kg/yr 2.99E+04**
	Radionuclide	Activity Ci/yr
	T1-208	4.50E-07
	Pb-212	1.19E-06
	Bi-212	1.19E-06
	Po-212	7.68E-07
	Po-216	1.19E-06
	Ra-224	1.19E-06
	Ra-228	7.12E-06
	Ac-228	7.12E-06
	Th-228	1.19E-06
	Th-231	6.86E-06
	Th-232	7.23E-05
	Th-234	8.79E-03
	Pa-234	9.01E-07
	Pa-234m	8.79E-03
	U-235	6.83E-06
	U-238	8.79E-03
	Pu-238	6.94E-04
	Pu-239	5.30E-05
	Pu-240	1.85E-04
	Pu-241	2.55E-02
	Am-241	1.06E-06
	Cm-242	1.48E-05
	Cm-244	5.30E-06

[a] A complete WASTE_MGMT output file contains the above shipment information for all origin-and-destination pairs for a given case. For illustrative purposes, only shipments between one origin and one destination are shown.

E.6.2 SHIPMENT EXTERNAL DOSE RATES

The dose (and, correspondingly, the risk) to populations and MEIs during routine transportation is directly proportional to the assumed external dose rate from the shipment. The Federal regulations for maximum allowable external dose rates for exclusive-use shipments are presented in Section E.3.1. The actual shipment dose rate is a complex function of the composition and configuration of shielding and containment materials used in the waste packaging, the geometry of the loaded shipments, and the characteristics of the waste material itself. The external dose rates assumed for each waste type are summarized in Table E–5 and are discussed in detail in the text. In practice, external dose rates vary not only from site to site and from waste type to waste type but also from shipment to shipment at a given site.

E.6.2.1 HLW Shipments

For HLW shipments, the external dose rate has been assumed to be equal to the regulatory limit of 10 mrem/h at 2 m (6.6 ft) for all shipments. The regulatory limit was assumed because extensive historical data for HLW shipments do not exist. In practice, the dose rates may range well below the regulatory limit assumed for this assessment. Therefore, assuming that the dose rates are equal to the regulatory limit provides a conservative estimate.

Table E–5. Shipment External Dose Rates for Each Waste Type

Waste Type	External Dose Rate
HLW[a]	10 mrem/h at 2 m (6.6 ft)
LLW[b]	1 mrem/h at 1 m (3.3 ft)
TRUW[c]	CH = 3 mrem/h at 1 m (3.3 ft) RH = 7 mrem/h at 1 m (3.3 ft)
LLMW	1 mrem/h at 1 m (3.3 ft)[d]

Notes: CH = contact handled waste; RH = remote-handled waste.
[a] Regulatory limit (10 CFR 71).
[b] Based on historical DOE LLW shipments as reported to the Shipment Mobility/Accountability Collection (Morris, 1993).
[c] Derived from DOE (1990a).
[d] Based on comparison of LLMW and LLW radiological characteristics.

E.6.2.2 LLW Shipments

For LLW shipments, the external dose rates from historical waste shipments were investigated by using the Shipment Mobility/Accountability Collection (SMAC) system (Morris, 1993). The SMAC database contains information about unclassified commercial freight shipments made by DOE and its contractors. The information available in the SMAC database is collected from site shipping and receiving documents. Available information for shipments of radioactive materials includes the types of material shipped, the number of packages in each shipment, shipment weights, external dose rates, and package isotopic inventories. Approximately two-thirds of all DOE unclassified shipments are estimated to be reported to the SMAC database.

Shipment information from the SMAC database was examined for fiscal years 1983 to the present (Morris, 1993). Information was provided for three general categories of radioactive material: irradiated fuel, "other" highway route controlled quantities, and LLW. (The material categories chosen were dictated by the format in which data are submitted and entered into the SMAC database and are not consistent with the definitions of waste types used in this PEIS.) Of the 15,000 LLW shipments recorded in the SMAC database, approximately 2,500 reported external dose rates. The average dose rate reported was approximately 1 mrem/h, measured at 1 m (3.3 ft) from the surface of a shipment. This value was used for future LLW shipments for the PEIS analysis.

E.6.2.3 TRUW Shipments

For TRUW shipments, external package dose rates have been derived from information in the Supplemental Final Environmental Impact Statement (SFEIS) for WIPP (DOE, 1990a). In the WIPP SFEIS, site-specific external package dose rates were presented for CH-TRUW and for RH-TRUW packages. For this PEIS, the average external dose rates were calculated by using the SFEIS values and were used for purposes of assessment. The average external package dose rates were calculated to be 3 mrem/h for CH-TRUW and 7 mrem/h for RH-TRUW at 1 m (3.3 ft).

E.6.2.4 LLMW Shipments

Because very limited data exists for historical LLMW shipments, and the fact that the radiological characteristics of LLMW were assumed to be similar to LLW for the PEIS, the external dose rate for shipments of LLMW was assumed to be the same as for the LLW shipments. As with LLW shipments, an average dose rate of 1 mrem/h measured at 1 m (3.3 ft) from the surface of a shipment was assumed for analysis purposes.

E.6.3 Population Density Zones

Three population density zones—rural, suburban, and urban—were used for the offsite population risk assessment. The fractions of travel in each zone were determined by using the HIGHWAY and INTERLINE routing models. The rural, suburban, and urban zones are assigned average population densities of 6/km^2 (15.5/mi^2), 719/km^2 (1,862/mi^2), and 3,861/km^2 (10,000/mi^2), respectively. These population densities are typical of rural, suburban, and urban environments (NRC, 1977a). Occurrence of the three population density zones is based on an aggregation of the 12 population density zones provided in the HIGHWAY and INTERLINE model outputs. For calculation purposes, information about population density was generated at the State level and used as RADTRAN input for all origin-and-destination pairs. For the onsite analysis, the population density of the Hanford Site was used.

E.6.4 Accident Rates

For calculating accident risks, vehicle accident involvement and fatality rates are taken from data provided in Saricks and Kvitek (1994). For each transport mode, accident rates are generically defined as the number of accident involvements (fatalities) in a given year per unit of travel of that mode in the same year. Therefore, the rate is a fractional value—the accident-involvement count is the numerator, and vehicular activity (total traveled distance) is the denominator. Accident rates are derived from multiple-year averages that automatically account for such factors as heavy traffic and adverse weather conditions. For assessment purposes, the total number of expected accidents or fatalities is calculated by multiplying the total shipping distance for a specific case by the appropriate accident or fatality rate.

For truck transportation, the rates presented in Saricks and Kvitek (1994) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are rigs composed of a separable tractor unit containing the engine and one to three freight trailers connected to each other and the tractor. Heavy combination trucks are typically used for shipping radioactive wastes. Truck accident rates are computed for each State on the basis of statistics compiled by the DOT Office of Motor Carriers for 1986 to 1988. Saricks and Kvitek (1994) present accident involvement and fatality counts, estimated kilometers of travel by State, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities (including crew members) are deaths attributable to the accident that occurred any time within 30 days of the accident.

Rail accident rates are computed and presented similarly to truck accident rates in Saricks and Kvitek (1994); however, for rail transport, the unit of haulage is the railcar. State-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1985 to 1988. Rail accident rates include both mainline accidents and those occurring in rail yards.

The accident assessment presented in this appendix uses separate accident rates for travel in rural, suburban, and urban population density zones in each State. Therefore, total accident risk for a case depends on the total distance traveled in various population zones in each State and does not rely on national average accident statistics. However, for comparative purposes, the national average truck accident rate presented in Saricks and Kvitek (1994) is 2.4×10^{-7} accidents/km (3.9×10^{-7} accidents/mi). The national average railcar accident rate is 5.6×10^{-8} accidents/km (9.0×10^{-8} accidents/mi). For the onsite accident assessment, accident probabilities at the Hanford Site were taken from Wang et al. (1991).

Note that the accident rates used in this assessment were computed using all interstate shipments, regardless of the cargo. Saricks and Kvitek (1994) point out that shippers and carriers of radioactive material generally have a higher-than-average awareness of transportation risk and prepare cargos and drivers for such shipments accordingly. This preparation should have the twofold effect of reducing component and equipment failure and mitigating the contribution of human error to accident causation. These effects were not considered in the accident assessment.

E.6.5 Accident Severity Categories

A method to characterize the potential severity of transportation-related accidents is described in a NRC report commonly referred to as NUREG-0170 (NRC, 1977a). The NRC method divides the spectrum of transportation accident severities into eight categories. Other studies have divided the same accident spectrum into 6 categories (Wilmot, 1981) and into 20 categories (Fischer et al., 1987); however, these studies focused primarily on accidents involving spent nuclear fuel shipments.

The NUREG-0170 scheme for accident classification is shown in Figure E–4 for truck transportation, and Figure E–5 for rail transportation. Severity is described as a function of the magnitudes of the mechanical forces (impact) and thermal forces (fire) to which a package may be subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range. The scheme for accident severity is designed to take into account all credible transportation-related accidents, including accidents with low probability but high consequences and those with high probability but low consequences.

Each severity category represents a set of accident scenarios defined by a combination of mechanical and thermal forces. A conditional probability of occurrence (that is, the probability that if an accident occurs, it is of a particular severity) is assigned to each category. The fractional occurrences for accidents by the accident severity category and the population density zone are shown in Table E–6.

Category I accidents are the least severe but the most frequent, whereas Category VIII accidents are very severe but very infrequent. To determine the expected frequency of an accident of a given severity, the conditional probability in the category is multiplied by the baseline accident rate. Each population density zone has a distinct baseline accident rate and distribution of accident severities related to differences in average vehicular velocity, traffic density, and other factors, including location—rural, suburban, or urban.

For the accident consequence assessment, the doses were assessed for populations and individuals by assuming an accident of severity Category VIII. This accident severity category represents the most severe accident scenarios, which would result in the largest releases of radioactive material. Accidents of this severity are extremely rare, occurring approximately once in every 70,000 truck or 100,000 rail accidents involving a radioactive waste shipment. On the basis of national accident statistics (Saricks and Kvitek, 1994), for every 1.6 km (1 mi) of shipment (loaded), the probability of an accident of this severity is 6×10^{-12} for shipment by truck and 1×10^{-12} for shipment by rail. For the PEIS waste alternatives (the largest estimated shipment mileage is 560 million mi for LLW), no accident of such severity is expected to occur.

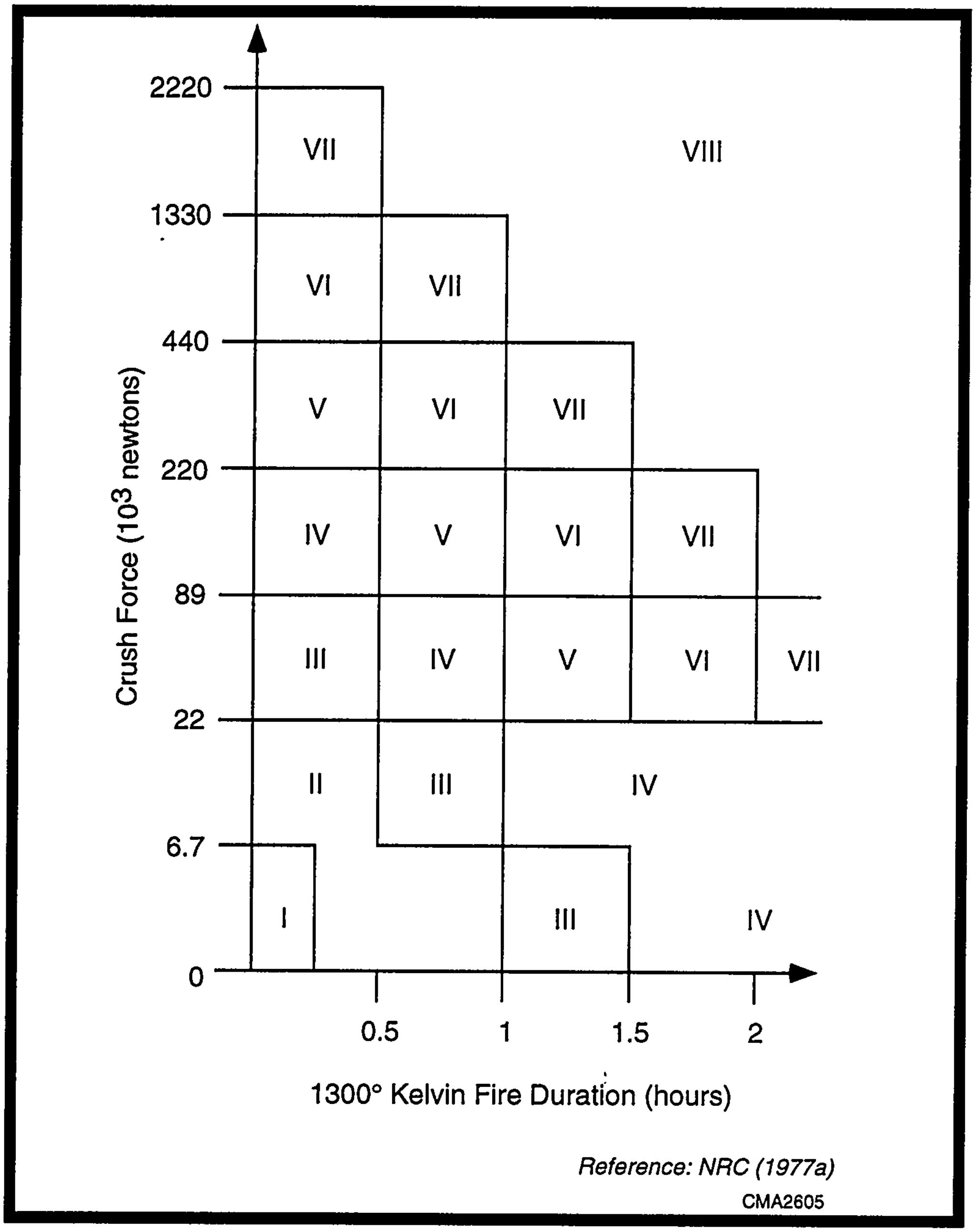

Figure E-4. Scheme for NUREG-0170 Classification by Accident Severity Category for Truck Accidents.

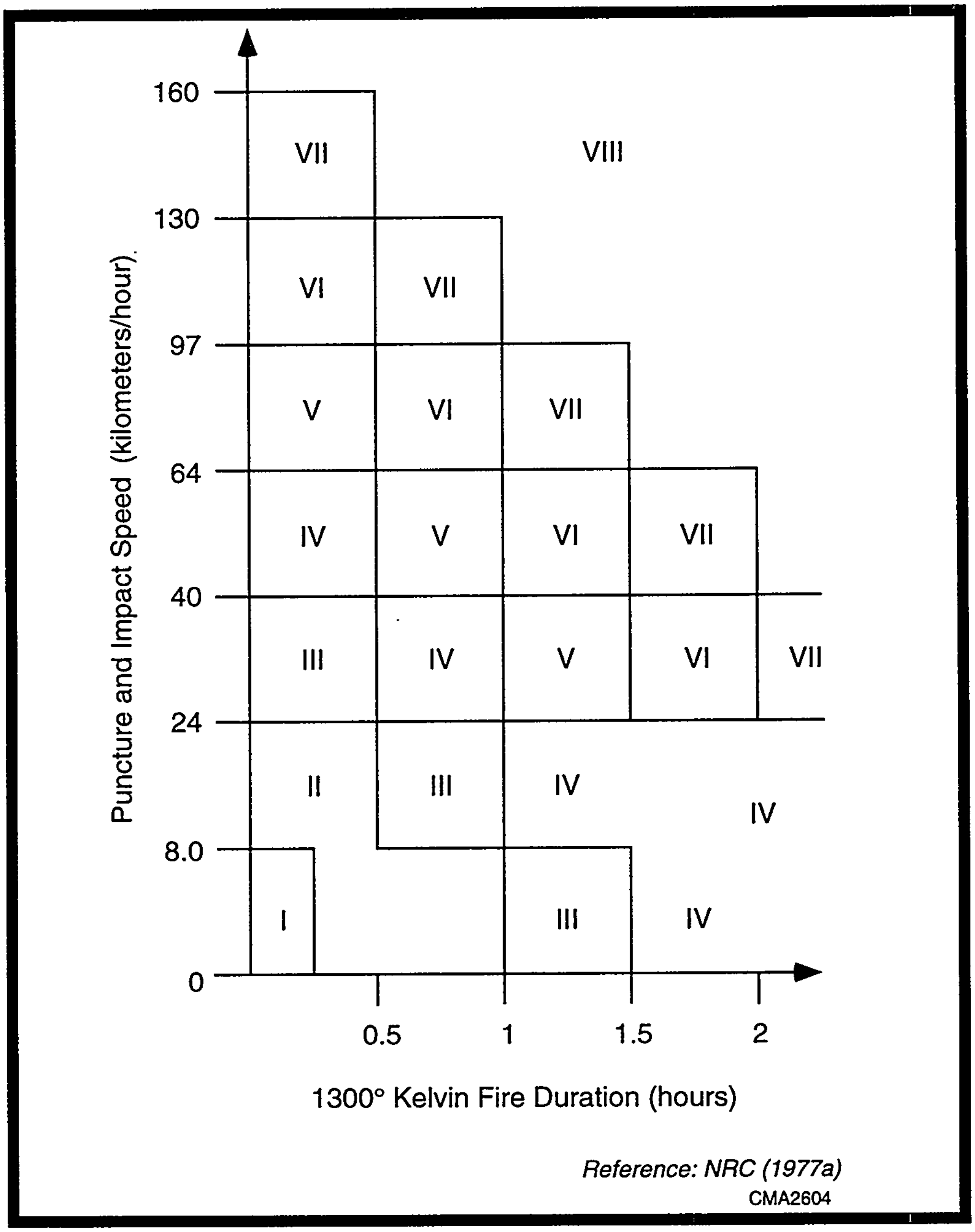

Figure E–5. Scheme for NUREG-0170 Classification by Accident Severity Category for Rail Accidents.

Table E-6. Fractional Occurrences for Accidents by Severity Category and Population Density Zone

Severity Category	Fractional Occurrence	Fractional Occurrence by Population Density Zone		
		Rural	**Suburban**	**Urban**
Truck				
I	5.5E-01	1.0E-01	1.0E-01	8.0E-01
II	3.6E-01	1.0E-01	1.0E-01	8.0E-01
III	7.0E-02	3.0E-01	4.0E-01	3.0E-01
IV	1.6E-02	3.0E-01	4.0E-01	3.0E-01
V	2.8E-03	5.0E-01	3.0E-01	2.0E-01
VI	1.1E-03	7.0E-01	2.0E-01	1.0E-01
VII	8.5E–05	8.0E-01	1.0E-01	1.0E-01
VIII	1.5E–05	9.0E-01	5.0E-02	5.0E-02
Rail				
I	5.0E-01	1.0E-01	1.0E-01	8.0E-01
II	3.0E-01	1.0E-01	1.0E-01	8.0E-01
III	1.8E-01	3.0E-01	4.0E-01	3.0E-01
IV	1.8E-02	3.0E-01	4.0E-01	3.0E-01
V	1.8E-03	5.0E-01	3.0E-01	2.0E-01
VI	1.3E–04	7.0E-01	2.0E-01	1.0E-01
VII	6.0E–05	8.0E-01	1.0E-01	1.0E-01
VIII	1.0E–05	9.0e-01	5.0E-02	5.0E-02

Source: NRC (1977a).

E.6.6 PACKAGE RELEASE FRACTIONS

Radiological consequences are calculated by assigning package release fractions to each accident severity category. The release fraction is defined as the fraction of the radioactive material in a package that could be released from that package during an accident of a certain severity. Release fractions take into account all mechanisms necessary to create release of radioactive material from a damaged package to the environment. Release fractions vary according to the package type and the physical form of the waste. Type B packagings are designed to withstand the forces of severe accidents and, therefore, have smaller release fractions than Type A packagings.

Package release fractions for accidents of each severity category are given in Table E–7 for the package types considered in this assessment. The values for release fractions were obtained from various sources, but all were derived on the basis of the methods described in NUREG-0170 (NRC, 1977a). Also important

Table E–7. Estimated Release Fractions for Shipping Packagings Under Various Accident Severity Categories

Severity Category	Estimated Release Fraction			
		Type B		
	Type A[a]	HLW Cask[a]	TRUPACT-II[b]	RH-72B[b]
Truck				
I	0	0	0	0
II	1.0E-02	0	0	0
III	1.0E-01	1.0E-02	8.0E–09	6.0E–09
IV	1.0E+00	1.0E-01	2.0E–07	2.0E–07
V	1.0E+00	1.0E+00	8.0E–05	1.0E–04
VI	1.0E+00	1.0E+00	2.0E–04	1.0E–04
VII	1.0E+00	1.0E+00	2.0E–04	2.0E–04
VIII	1.0E+00	1.0E+00	2.0E–04	2.0E–04
Rail				
I	0	0	0	0
II	1.00E-02	0	0	0
III	1.00E-01	1.0E-02	2.0E–08	2.0E–08
IV	1.00E+00	1.0E-01	7.0E–07	7.0E–07
V	1.00E+00	1.0E+00	8.0E–05	1.0E–04
VI	1.00E+00	1.0E+00	2.0E–04	1.0E–04
VII	1.00E+00	1.0E+00	2.0E–04	2.0E–04
VIII	1.00E+00	1.0E+00	2.0E–04	2.0E–04

[a] Values are for total material release fraction. To determine the amount of material dispersed in the environment, these values must be multiplied by the aerosolized and respirable fractions give in Table E–8 for the various physical waste forms.
[b] Values are for respirable release fraction.
Sources: NRC (1977a); DOE (1990a).

for the purposes of risk assessment are the fraction of the released material that can be entrained in an aerosol (that is, part of an airborne radioactive plume) and the fraction of the aerosolized material that is also respirable (of a size that can be inhaled into the lungs). These fractions depend on the physical form of the waste material. Most solid materials are difficult to release in particulate form and are, therefore, relatively nondispersible. Conversely, liquid or gaseous materials are relatively easy to release if the container is compromised in an accident. The aerosolized and respirable fractions for various physical forms of waste have been compiled in RADTRAN (Neuhauser and Kanipe, 1993) and are given in Table E–8. (Note that the release fractions for TRUW packages incorporate the aerosolized and respirable fractions on the basis of the characteristics of TRUW.)

Table E-8. Aerosolized and Respirable Material Release Fractions for Various Physical Waste Forms

Physical Waste Form	Aerosolized Fraction	Respirable Fraction
Vitrified waste (HLW)[a]	1.0E-06	5.0E-02
Activated metals (LLW)[a]	1.0E-06	5.0E-02
Heterogeneous solids (LLW, LLMW)[b]	1.0E-01	5.0E-02
Nonvolatile liquids (LLMW)	1.0E-01	5.0E-02
Volatile liquids (LLMW)	1.0E+00	1.0E+00

[a] Considered to behave as immobile material.
[b] Considered to behave as a loose powder.
Source: Neuhauser and Kanipe (1993).

E.6.7 ATMOSPHERIC CONDITIONS

Radioactive material released to the atmosphere is transported by the wind. The amount of dispersion, or dilution, of the radioactive material in the air depends on the meteorologic conditions at the time of the accident. Because predicting the specific location of an offsite transportation-related accident is impossible, generic atmospheric conditions were selected for the accident risk and consequence assessments.

For the accident risk assessment, neutral weather conditions were assumed; these conditions were represented by Pasquill stability Class D with a windspeed of 4 m/s (9 mi/h). Because neutral meteorologic conditions constitute the most frequently occurring atmospheric stability condition in the United States, these conditions are most likely to be present if an accident occurs involving a waste shipment. Observations at National Weather Service surface meteorologic stations from more than 300 U.S. locations indicate that on a yearly average, neutral conditions (represented by Pasquill Classes C and D) occur about half (50%) the time, while stable conditions occur about one-third (33%) of the time (Pasquill Classes E and F), and unstable conditions (Pasquill Classes A and B) occur about one-sixth (17%) of the time (Doty et al., 1976). The neutral category predominates in all seasons but is most prevalent (nearly 60% of the observations) during winter.

For the accident consequence assessment, doses were assessed under neutral atmospheric conditions (Pasquill Stability Class D with a windspeed of 4 m/s [9 mi/h] and stable conditions (Pasquill Stability Class F with a windspeed of 1 m/s [2.2 mi/h]). The results calculated for neutral conditions represent the most likely consequences, and the results for stable conditions represent a weather situation in which the least amount of dilution is evident with the highest air concentrations of radioactive material.

E.6.8 HEALTH RISK CONVERSION FACTORS

The health risk conversion factors used throughout this PEIS to estimate the number of expected cancer-caused fatalities, the incidence of cancer, and the serious genetic effects from radiological exposures were derived from ICRP (1991): 5.0×10^{-4} cases of fatal cancer per person-rem for members of the public, and 4.0×10^{-4} cases for workers; 1.7×10^{-3} cases of induced cancer per person-rem for members of the public, and 1.4×10^{-3} cases for workers; and 1.0×10^{-4} adverse genetic effects per person-rem for members of the public, and 6.0×10^{-5} adverse genetic effects for workers. Cancer-caused fatalities and cancer incidence are determined over the lifetimes of exposed populations. Genetic effects occur in descendants of the exposed population, and the estimates for these effects are based on the total dose to the reproductive organs. The genetic health risk conversion factors used in this analysis include all generations.

E.6.9 MAXIMALLY EXPOSED INDIVIDUAL EXPOSURE SCENARIOS

The risk to MEIs has been estimated for a number of hypothetical exposure scenarios for offsite transportation. The receptors include crew members, departure inspectors, and members of the public exposed during traffic obstructions (traffic jams), while working at a service station, or by living near a treatment, storage, or disposal site. The dose and risk to MEIs were calculated for particular distances and durations of exposure. The distances and durations of exposure for each receptor are similar to those used in previous transportation assessments (DOE, 1987b, 1990a). The scenarios for exposure are not intended to be exhaustive but were selected to provide a range of potential exposure situations. The assumptions for exposure scenarios are as follows:

- *Crew Members*. Truck and rail crew members are assumed to be occupational radiation workers and would be monitored by a dosimetry program. Therefore, the maximum allowable dose would be 5 rem/yr. As an administrative procedure, DOE limits doses to its workers to 2 rem/yr (DOE, 1992b).
- *Inspectors (Truck and Rail)*. Inspectors are assumed to be either Federal or State vehicle inspectors. Inspectors are not assumed to be monitored by a dosimetry program. An average exposure distance of 3 m (9.8 ft) and an exposure duration of 30 minutes are assumed.
- *Rail-Yard Crew Member*. A rail-yard crew member is not assumed to be monitored by a dosimetry program. An average exposure distance of 10 m (32.8 ft) and an exposure duration of 2 hours are assumed.
- *Resident (Truck and Rail)*. A resident is assumed to live 30 m (98 ft) from a site entrance route (truck or rail). Shipments pass at an average speed of 24 km/h (15 mi/h), and the resident is exposed

unshielded. Cumulative doses are assessed for each site on the basis of the number of shipments entering or exiting the site, with the assumption that the resident is present for 100% of the shipments.

- *Person in Traffic Obstruction (Truck and Rail).* A person is assumed to be stopped next to a waste shipment (because of traffic or other obstructions). The person is assumed to be exposed unshielded at a distance of 1 m (3.3 ft) for 30 minutes.
- *Person at Truck Service Station.* A person is assumed to be exposed at an average distance of 20 m (65.6 ft) for 2 hours. This receptor could be a worker at a truck stop.
- *Resident Near a Rail Stop.* A resident is assumed to live near a rail classification yard. The resident is assumed to be exposed unshielded at a distance of 200 m (656 ft) for 20 hours.

The largest uncertainty in predicting the dose to MEIs during transportation involves determining the frequency of exposure occurrence. This difficulty arises from uncertainties in future shipment schedules and route selection and from the inherent uncertainty in predicting the frequency of random or chance events; for example, it is conceivable that an individual may be stopped in traffic next to a shipment of radioactive waste, but it is difficult to predict how often the same individual would experience this event. Therefore, doses are assessed on a per-event basis for most receptors considered. To account for possible multiple exposures, ranges of realistic total doses are discussed qualitatively. One exception is the dose calculation for hypothetical residents living near an entrance route to a treatment, storage, or disposal site.

For these residents, total doses are calculated on the basis of the number of shipments entering or exiting each site for each PEIS alternative.

E.6.10 General RADTRAN Input Parameters

In addition to the specific parameters discussed previously, values for several general parameters must be specified within the RADTRAN code. These general parameters define basic characteristics of the shipment and traffic and are specific to the transportation mode. The user's manual for the RADTRAN code (Neuhauser and Kanipe, 1993) contains derivations and descriptions of these parameters. Table E–9 summarizes the general RADTRAN input parameters used in the transportation risk assessment.

Table E-9. General RADTRAN Input Parameters[a]

Parameter	Truck	Rail
Package type	Waste-type specific	Waste-type specific
No. of crew	2	5
Distance from source to crew (m)	3	152
Average vehicular speed (km/h)		
Rural	88	64
Suburban	40	40
Urban	24	24
Stop time (h/km)	0.011	0.033
No. of people exposed while stopped	25	100
No. of people per vehicle sharing route	2	3
Population densities (persons/km^2)		
Rural	6	6
Suburban	719	719
Urban	3,861	3,861
One-way traffic count (vehicles/h)		
Rural	470	1
Suburban	780	5
Urban	2,800	5

[a]Accident conditional probabilities are listed by severity category in Table E-6; accident release fractions are given in Table E-7.

Source: Neuhauser and Kanipe (1993).

E.6.11 Onsite Assessment Accident Location

The onsite transportation accident consequence was estimated for a potential accident occurring on the roadway or railroad adjacent to the 300 Area at the Hanford Site. This location would maximize exposure to worker populations onsite and to the public offsite. The highest accident severity category possible for each waste type was assumed to determine the amounts of radioactive material released.

E.7 Results of Risk Assessment

This section presents results of the transportation risk assessment for each of the four types of radioactive waste considered in the PEIS. For each waste type, results are presented for the alternatives summarized in Section E.2.2 and defined in detail in the waste type-specific chapters (Chapters 6 through 10). As stated previously, the number and location of potential treatment, storage, or disposal sites differs for each specific alternative, and the number of alternatives considered varies among waste types.

Although the method for risk assessment and important assumptions about assessment have been presented in detail previously, the following sections give a brief overview of the risk assessment process. This overview is intended to help readers interpret results as they are presented for each waste type.

For each waste type, the impacts of transportation are calculated in four areas: (1) collective population risks during routine conditions and accidents for each alternative, (2) risks to MEIs during routine conditions for each alternative, (3) consequences to individuals and populations after the most severe accidents involving release of radioactive material, and (4) onsite transportation risks. Each of these areas is described briefly.

Collective Population Risk. The collective population risk is a measure of the total risk posed to society as a whole by the alternative being considered. For the collective population risk assessment, the persons exposed are considered as a group, without specifying individual receptors. The collective population risk is used as the primary means to compare the various alternatives.

Collective population risks are calculated from vehicle- and cargo-related causes for routine transportation and accidents. Vehicle-related risks are independent of the shipment's cargo and include risks from vehicular exhaust emissions and traffic accidents (fatalities caused by physical trauma). Vehicle-related risks are presented in terms of estimated fatalities for each alternative.

For radioactive material, cargo-related risk refers to the risk posed by the radioactive nature of the material. The RADTRAN 4 model is used to calculate collective population risks for each alternative. The RADTRAN 4 calculations for population risk take into account the consequences and the probabilities of potential exposure-causing events (such as accidents). The accident risk values are referred to as "dose risk" because they incorporate the probabilities of a spectrum of accidents. The collective population risks are presented in terms of the total dose (person-rem) to workers and to members of the public for each alternative. The collective population risks are also presented in terms of estimated fatalities from latent cancer by using the ICRP Publication 60 (ICRP, 1991) health risk conversion factors described in Section E.6.8. Other health endpoints, such as the incidence of cancer and severe genetic effects, are not explicitly presented but can be calculated by multiplying the total doses by the appropriate conversion factors given in Section E.6.8.

Maximally Exposed Individuals During Routine Conditions. During the routine transportation of radioactive waste, specific individuals close to a shipment may be exposed to radiation. For each waste type, the RISKIND model has been used to estimate risk to these individuals for a number of hypothetical exposure-causing events. The receptors include transportation crew members, inspectors, and members of the public exposed during traffic delays, while working at a service station, or living near a DOE site. The assumptions about exposure are given in Section E.6.9. The scenarios for exposure are not meant to be exhaustive but were selected to provide a range of potential exposures.

For most individual receptors considered, doses are assessed and presented on a per-event basis. No attempt has been made to estimate the frequency of exposure-causing events, although the range of possible exposures is qualitatively discussed. However, one exception is the calculation of the dose to a hypothetical resident living near the entrance route to a treatment, storage, or disposal site. For these residents, cumulative doses are calculated on the basis of the total number of shipments entering or exiting each site for each alternative.

Accident Consequence Assessment. The RISKIND code is used to provide a detailed assessment of the consequences of the most severe transportation-related accidents for each waste type. The RADTRAN 4 collective accident risk assessment considers the entire range of accident severities and their related probabilities, whereas the RISKIND accident consequence assessment assumes that an accident of the highest severity category (Category VIII) has occurred. The consequences, in terms of committed dose (rem) and latent cancer fatalities, are calculated for exposed populations and individuals near an accident.

For each waste type, accident consequences are calculated for a waste shipment that represents the highest potential radiological risk if an accident occurs. The most hazardous waste is identified for each waste type by screening the site-specific characteristics for radiological waste (that is, activity concentrations) developed for the PEIS, by taking into account the physical forms of the waste and relative hazards of individual radionuclides. For most waste shipments, the consequences of severe accidents would be fewer than those presented for the most hazardous waste. Separate accident consequence calculations are not performed for each case for a given waste type. The accident consequence assessment is intended to provide an estimate of the maximum potential impacts posed by a severe transportation-related accident.

Onsite Assessment. The risk assessment conducted for onsite transportation is intended to provide an estimate of the magnitude of the potential onsite transportation risk for comparison with offsite transportation risks. For the PEIS, onsite transportation is defined as transportation of waste between facilities within the boundaries of a DOE Site. Transfers of waste within a specific facility are not considered onsite shipments but are part of the normal facility operations. (Offsite transportation refers to transporting waste between distinct sites, including parts of the routes that may be within the boundaries of the origin and destination sites.)

For purposes of the PEIS, the onsite risk assessment has been limited to one representative site—the Hanford Site. The Hanford Site was selected primarily because it is a relatively large site that conducts waste management activities for all waste types. The impacts calculated for the Hanford Site are believed to be typical of other large DOE sites and would conservatively bound the impacts expected for smaller sites. The routine risks presented for the Hanford Site are expected to be the same among alternatives for each waste type. This is because all radioactive waste is shipped to a centrally located processing facility regardless of final treatment/disposal, onsite or offsite.

E.7.1 HIGH-LEVEL WASTE

The generation, treatment, and management of HLW and the alternatives considered in the PEIS are described in detail in ANL (1996g). In summary, canisters of vitrified HLW are assumed to be produced at the four DOE sites that have historically generated and currently store HLW, and these canisters would be transported to a geologic repository for final disposal. Untreated HLW is transferred between facilities by a special pipeline system. Treated (vitrified) HLW will be stored in facilities in close proximity to the vitrification facilities. No significant onsite transportation of HLW is assumed to occur.

Transportation risks have been calculated for four HLW alternatives summarized in Section E.2.2. The six alternative cases differ primarily in the location for interim storage of canisters before final disposal in a geologic repository. For assessing the impacts of transportation, the PEIS assumes the location of the geologic repository to be at the candidate site of Yucca Mountain in Nevada, the only site currently authorized by legislation for investigation.

The analysis for transportation of HLW to a geologic repository for the Centralized Alternative is divided into Centralized Alternative 1 and Centralized Alternative 2. Centralized Alternative 1 for HLW refers to shipment to a geologic repository by 2015. Centralized Alternative 2 refers to shipment of HLW to a geologic repository later than 2015.

E.7.1.1 Shipment Summary

The number of canisters of vitrified HLW shipped varies from approximately 20,000 for the No Action Alternative to over 28,000 for the second case of the Centralized Alternative. The impacts of transportation have been calculated for shipping the entire estimated inventory of HLW canisters. However, the repository is expected to accept approximately 800 canisters per year when it becomes operational. Impacts have been calculated separately for all truck and rail modes of shipment.

The total number of shipments and the mileage for loaded shipments for each case are summarized in Table E-10 for truck shipments, and Table E-11 for rail shipments. For the six HLW cases, the total

Table E-10. Total Population Impacts of HLW Transportation for the WM PEIS Cases: Truck Mode

Parameter	Alternative[a]						
	No Action	Decentralized	Regionalized 1	Regionalized 2	Centralized 1	Centralized 2	Onsite[b]
Shipment summary							
Shipments	19,912	21,612	21,952	21,952	24,325	28,224	NA
Mileage (10^6 mi)	29.4	30.7	31.0	31.2	34.6	39.5	NA
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew[d]	2,600	2,720	2,750	2,760	3,050	3,460	NA
Routine public	3,520	3,670	3,710	3,730	4,120	4,690	NA
Accident[e]	0.68	0.684	0.680	0.688	0.725	0.760	NA
Latent cancer fatalities[f]							
Crew fatalities	1.0	1.1	1.1	1.1	1.2	1.4	NA
Public fatalities	1.8	1.8	1.9	1.9	2.1	2.3	NA
Vehicle-related[g]							
Emission fatalities	0.21	0.23	0.23	0.23	0.25	0.27	NA
Accident fatalities	1.8	1.9	1.9	1.9	2.1	2.3	NA
Total population health effects (fatalities)	4.8	5.0	5.1	5.1	5.7	6.3	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the WM PEIS.
[b] By definition, no onsite HLW shipments exist at the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Rail crew values are expected to range from impacts listed in this table (for dedicated shipments) to slightly higher than the truck crew impacts identified in the previous table. See Section E.7 for a more detailed explanation.
[e] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[f] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[g] Vehicle-related impacts are impacts independent of the shipment's cargo.

Table E-11. Total Population Impacts of HLW Transportation for the WM PEIS Cases: Rail Mode

Parameter	Alternative[a]						
	No Action	Decentralized	Regionalized 1	Regionalized 2	Centralized 1	Centralized 2	Onsite[b]
Shipment summary							
Shipments	3,983	4,323	4,391	4,391	4,866	5,646	NA
Mileage (10^6 mi)	6.68	6.93	7.04	7.03	7.70	8.74	NA
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	153	161	163	163	180	205	NA
Routine public	168	175	178	177	192	215	NA
Accident[d]	0.0215	0.0215	0.0208	0.0217	0.0234	0.0250	NA
Latent cancer fatalities[e]							
Crew fatalities	0.061	0.064	0.065	0.065	0.072	0.082	NA
Public fatalities	0.084	0.088	0.089	0.089	0.096	0.11	NA
Vehicle-related[f]							
Emission fatalities	0.041	0.043	0.043	0.043	0.046	0.050	NA
Accident fatalities	0.014	0.015	0.015	0.015	0.016	0.018	NA
Total population health effects (fatalities)	0.20	0.21	0.21	0.21	0.23	0.26	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the WM PEIS.
[b] By definition, no onsite HLW shipments exist at the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[e] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[f] Vehicle-related impacts are impacts independent of the shipment's cargo.

number of truck shipments ranges from 19,912 if the canisters from currently available storage are shipped directly to a repository (No Action Alternative) to about 28,224 if the repository opens after 2015 and all the canisters are consolidated at one site for interim storage (Centralized 2 Alternative). For rail transportation, the corresponding numbers of shipments range from about 3,983 to 5,646. The total mileage for loaded shipments ranges from about 47.3 to 63.6 million km (29.4 to 39.5 million mi) for truck transportation and from about 10.8 to 14.0 million km (6.7 to 8.7 million mi) for rail transportation.

For purposes of comparison, within the United States for the years 1986 to 1988, the average annual reported mileage for interstate truck shipments of all commodities was approximately 45.1 billion km (28 billion mi), and for train shipments approximately 48.8 billion railcar-km (30.3 billion railcar-mi) (Saricks and Kvitek, 1994). The entire number of HLW shipments for the Centralized 2 Alternative would thus represent less than 0.2% of the annual amount of truck and rail transportation activity within the United States.

E.7.1.2 Collective Population Risk Results

The results for collective risk assessment for HLW shipments are also summarized in Table E–10 for truck shipments and Table E–11 for rail shipments. The collective risk results are presented for shipment of the total estimated inventory of HLW canisters.

An examination of the results of the transportation risk assessment shows that differences in population risk among the various cases are dependent primarily on the number of shipments made and then on total shipping distances. The number of shipments and total shipping distance for each case is determined by the case definition (storage capacity, repository availability, shipment origin, and destination sites), the site-specific waste inventories (specifically waste volume and mass, which directly determine the total number of shipments), and the route distances among all pairs of origin and destination sites.

For truck transportation, the total estimated number of fatalities from radiological causes ranges from approximately 2.8 to 3.7. For rail transportation, the number of fatalities from radiological causes ranges from 0.15 to 0.19. In general, shipment by rail results in slightly lower doses to crew members and the public, primarily because of the reduced number of shipments. The vehicle- and cargo-related risks are comparable for truck shipments. The cargo-related risks are generally greater than the vehicle-related risks for rail transportation.

E.7.1.3 Maximally Exposed Individual Assessment

The estimated doses during routine transportation for each individual receptor considered (see Section E.6.9 for exposure assumptions) are presented in Table E–12 on a per-event basis. The total dose for repeated exposures can be estimated by multiplying the per-event dose by the number of exposure-causing events. The potential exists for significant individual exposures if multiple exposure-causing events occur. For example, the dose to a person stuck in traffic next to an HLW shipment for 30 minutes is estimated to be 11 mrem. If the duration of exposure were longer, the dose would rise proportionally. Therefore, conceivably, a person could receive a dose of approximately 30 to 50 mrem while stopped in traffic next

Table E–12. Estimated Routine Doses and Lifetime Risk of Fatal Cancer to MEIs From Shipments of HLW (per Exposure Event)[a]

Receptor[b]	Dose (rem)		Lifetime Risk[c]	
	Truck	Rail	Truck	Rail
Workers				
Crew member	d	d	d	d
Inspector	2.9E–03	2.9E–03	1.0E–06	1.0E–06
Rail-yard crew member	NA	1.3E–03	NA	5.0E–07
Public				
Resident	4.0E–07	4.0E–07	2.0E–10	2.0E–10
Person in traffic jam	1.1E–02	1.1E–02	6.0E–06	6.0E–06
Person at service station	3.1E–04	NA	2.0E–07	NA
Resident near rail stop	NA	1.3E–05	NA	7.0E–09

Note: NA = not applicable.
[a] The external dose rate is assumed to be 10 mrem/h at 2 m (6.6 ft) for all shipments.
[b] Receptor assumptions are described in Section E.6.9.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[d] The DOE administrative control level limits doses to DOE workers to 2 rem/yr.

to an HLW shipment. In addition, a person working at a truck service station could receive an increased dose if trucks used the same stops repeatedly. If a truck stop worker is present for 100 shipment stops (at the distance and duration given previously), the calculated dose would be approximately 30 mrem. Administrative controls could be instituted to control the location and duration of truck stops if multiple exposures were to occur routinely.

Table E–13 summarizes for each case the potential cumulative dose to a resident living along a site entrance route. The cumulative doses assume that a resident is present for every shipment entering or exiting a site and is unshielded at a distance of 30 m (98 ft) from the entrance route. The maximum cumulative dose would occur near the repository, except for the Centralized 2 case, because of the large number of shipments entering the site for all alternatives. The maximum total dose to this resident would be approximately 9 mrem for the all-truck case and 2 mrem for the all-rail case. For the Centralized 2 case where temporary storage of all HLW occurs at Hanford, the maximum total dose to a resident would be approximately 11 mrem for the all-truck case and 2 mrem for the all-rail case. The estimated dose to a resident would be well below the annual limit of 100 mrem specified for members of the public (DOE, 1990b).

Table E–13. Cumulative Routine Dose and Lifetime Risk to an MEI Living Along a Site Entrance Route for Shipments of HLW[a]

Alternative and Site	All Truck Total Shipments	All Truck Dose (rem)	All Truck Lifetime Risk[b]	All Rail Total Shipments	All Rail Dose (rem)	All Rail Lifetime Risk[b]
No Action						
Repository	19,912	8.0E–03	4E–06	3,983	1.6E–03	8E–07
Hanford	15,000	6.0E–03	3E–06	3,000	1.2E–03	6E–07
SRS	4,572	1.8E–03	9E–07	915	3.7E–04	2E–07
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08
INEL	0	0.0E+00	0E+00	0	0.0E+00	0E+00
Decentralized						
Repository	21,612	8.6E–03	4E–06	4,323	1.7E–03	9E–07
Hanford	15,000	6.0E–03	3E–06	3,000	1.2E–03	6E–07
SRS	4,572	1.8E–03	9E–07	915	3.7E–04	2E–07
INEL	1,700	6.8E–04	3E–07	340	1.4E–04	7E–08
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08
Regionalized 1						
Repository	21,612	8.6E–03	4E–06	4,323	1.7E–03	9E–07
Hanford	15,000	6.0E–03	3E–06	3,000	1.2E–03	6E–07
SRS	5,252	2.1E–03	1E–06	1,051	4.2E–04	2E–07
INEL	1,700	6.8E–04	3E–07	340	1.4E–04	7E–08
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08
Regionalized 2						
Repository	21,612	8.6E–03	4E–06	4,323	1.7E–03	9E–07
Hanford	15,680	6.3E–03	3E–06	3,136	1.3E–03	6E–07
SRS	4,572	1.8E–03	9E–07	915	3.7E–04	2E–07
INEL	1,700	6.8E–04	3E–07	340	1.4E–04	7E–08
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08
Centralized 1						
Repository	21,612	8.6E–03	4E–06	4,323	1.7E–03	9E–07
Hanford	20,426	8.2E–03	4E–06	4,086	1.6E–03	8E–07
SRS	4,572	1.8E–03	9E–07	915	3.7E–04	2E–07
INEL	1,700	6.8E–04	3E–07	340	1.4E–04	7E–08
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08
Centralized 2						
Hanford	28,224	1.1E–02	6E–06	5,646	2.3E–03	1E–06
Repository	21,612	8.6E–03	4E–06	4,323	1.7E–03	9E–07
SRS	4,572	1.8E–03	9E–07	915	3.7E–04	2E–07
INEL	1,700	6.8E–04	3E–07	340	1.4E–04	7E–08
WVDP	340	1.4E–04	7E–08	68	2.7E–05	1E–08

[a] The external dose rate is assumed to be 10 mrem/h at 2 m (6.6 ft). The resident is assumed to be present for all shipments that either enter or exit the Site. Shipments are assumed to pass at a distance of 30 m (98 ft) and an average speed of 24 km/h (15 mi/h).
[b] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.

E.7.1.4 Accident Consequence Assessment

Table E–14 presents results of the accident consequence assessment for HLW. As stated previously, the results are calculated for transportation-related accidents that result in the maximum release of radioactive material. The results were calculated for SRS HLW, which was found to result in the highest accident-related doses of the four types of site-specific HLW; however, all maximum accident-related doses for the

Table E–14. Estimated Consequences for the Most Severe Accidents Involving Shipments of HLW[a,b]

	Neutral Conditions[c]				Stable Conditions[d]			
	Population[e]		MEI[f]		Population[e]		MEI[f]	
Mode and Accident Location	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)
Truck								
Urban	4.2E+00	2.0E–03	3.4E–03	1.7E–06	3.4E+01	1.7E–02	1.2E–02	6.0E–06
Suburban	7.8E+01	4.0E–04	3.4E–03	1.7E–06	6.2E+00	3.1E–03	1.2E–02	6.0E–06
Rural	1.6E–02	8.0E–06	3.4E–03	1.7E–06	1.3E–01	6.5E–05	1.2E–02	6.0E–06
Rail								
Urban	2.1E+01	1.0E–02	1.7E–02	8.5E–06	1.7E+02	8.5E–02	6.0E–02	3.0E–05
Suburban	3.9E+00	2.0E–03	1.7E–02	8.5E–06	3.1E+01	1.6E–02	6.0E–02	3.0E–05
Rural	8.0E–02	4.0E–05	1.7E–02	8.5E–06	6.5E–01	3.3E–04	6.0E–02	3.0E–05

[a] The most severe accidents correspond to the highest NUREG-0170 accident severity category (Category VIII) (NRC, 1977a). Results are presented for HLW from SRS.
[b] Buoyant plume rise resulting from fire for a severe accident was included in the exposure model. One HLW canister is assumed to be breached in a truck accident; five canisters are assumed to be equally breached in a rail accident.
[c] Neutral weather conditions result in moderate dispersion and dilution of the released plume. Neutral conditions were considered to be Pasquill Stability Class D with a windspeed of 4 m/s (9 mi/h). Neutral conditions occur approximately 50% of the time in the United States.
[d] Stable weather conditions result in minimal dispersion and dilution of the released plume and thus are unfavorable. Stable conditions were taken to be Pasquill Stability Class F with a windspeed of 1 m/s (2.2 mi/h). Stable conditions occur approximately one-third of the time in the United States.
[e] Populations extend at a uniform population density to a radius of 80 km (50 mi) from the accident site. Population exposure pathways include acute inhalation; acute cloudshine; groundshine; resuspended inhalation; resuspended cloudshine; and ingestion of food, including initially contaminated food (rural only). No decontamination or mitigative actions are taken.
[f] The MEI is assumed to be at the location of maximum exposure. The locations of maximum exposure would be 160 m (525 ft) from the accident site under neutral atmospheric conditions and 400 m (1,312 ft) under stable atmospheric conditions. Individual exposure pathways include acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingested dose is considered.

four HLW types were within a factor of 5. The population doses are for a uniform population density within an 80-km (50-mi) radius of accidents in rural, suburban, and urban population density zones.

The location of the MEI after an accident is determined on the basis of atmospheric conditions and the buoyant characteristics of the released plume. The locations of maximum exposure are 160 m (525 ft) from the accident site for neutral conditions, and 400 m (1,312 ft) for stable conditions. The dose to the MEI is independent of the accident location. The maximum dose to an individual is approximately 60 mrem under stable weather conditions, which corresponds to a lifetime fatal cancer risk of 3×10^{-5}.

E.7.1.5 Onsite Assessment Results

As defined previously, no onsite transportation of HLW will occur at the Hanford Site. Therefore, no onsite transportation impacts have been calculated for the site.

E.7.2 LOW-LEVEL WASTE

The projected rate of LLW generation for each site, the waste characteristics, the potential treatments, and the alternatives considered in the PEIS are described in detail in the LLW technical report (ANL, 1996h). Transportation risks have been calculated for the 14 LLW alternatives summarized in Section E.2.2. The cases range from decentralized to centralized approaches to TSD. The number of disposal sites varies from 16 sites for decentralized disposal to 1 site for centralized disposal. Options for treatment also vary from decentralized to centralized approaches.

The PEIS considers current inventories of LLW plus 20 years of generation for all DOE Sites. All impacts are calculated as totals for the entire inventory of waste under consideration. The average annual risk can be estimated by dividing the summarized results by the duration of the shipping campaigns. For the No Action Alternative, shipments would be distributed uniformly over a 20-year period; however, for all other alternatives, shipments would occur uniformly over a 10-year period, with the assumption of a 10-year period to build TSD facilities. These timeframes are consistent with the assumptions used in the facility assessments for estimating throughputs.

E.7.2.1 Shipment Summary

The total number of shipments and the mileage for loaded shipments for each LLW case are summarized in Table E–15 for truck shipments, and Table E–16 for rail shipments. The estimated number of shipments and the total mileage for the various alternatives span a wide range. The total number of truck shipments ranges from approximately 24,420 for the Decentralized Alternative to about 264,000 shipments for the Centralized 4 Alternative. For rail transportation, the corresponding numbers of shipments range from 9,210 to 102,100. The total mileage for loaded shipments ranges from 13.9 to 906 million km (8.63 to 563 million mi) for truck transportation and from 5.6 to 360 million km (3.5 to 224 million mi) for rail transportation. The average annual number of shipments and mileage can be estimated by dividing the total results by a shipping duration of either 10 or 20 years.

For comparison, within the United States for the years 1986 to 1988, the average annual reported mileage for interstate truck shipments of all commodities was approximately 45 billion km (28 billion mi), and for train shipments approximately 48.8 billion railcar-km (30.3 billion railcar-mi) (Saricks and Kvitek, 1994). The estimated annual LLW shipments for the maximum transportation alternative would represent approximately 0.2% of the annual truck and rail transportation activity within the United States.

E.7.2.2 Collective Population Risk Results

The results for the collective risk assessment for the 14 LLW alternatives are also summarized in Table E–15 for truck shipments, and Table E–16 for rail shipments. The results for collective risk are presented for shipment of the current inventories plus the estimated generation of LLW for a period of 20 years.

Examination of the results of the transportation risk assessment shows that differences in population risk among the various cases are primarily dependent on total shipping distances. Thus, in general, centralized options predictably show larger transportation risks than regionalized or decentralized approaches because the centralized options involve greater transportation distances. The total shipping distance for each alternative is determined by the definition of the case (shipment origin and destination sites), site-specific waste inventories (specifically waste volume and mass, which directly determine the total number of shipments), packaging assumptions, and route distances among all pairs of origin and destination sites.

Table E–15. Total Population Impacts of Transportation of Current LLW Inventories Plus 20 Years of LLW Generation: Truck Mode

	Alternative[a]														
Impact	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Regional-ized 5	Regional-ized 6	Regional-ized 7	Central-ized 1	Central-ized 2	Central-ized 3	Central-ized 4	Central-ized 5	On-site[b]
Shipment summary															
Shipments	87,360	24,420	25,800	25,880	84,200	87,390	92,200	174,390	188,930	242,730	257,270	250,020	264,060	241,540	11,640
Mileage (10^6 mi)	166	8.63	9.31	9.19	38.1	36.9	63.8	124	125	563	505	530	478	560	0.27
Population impacts															
Cargo-related[c]															
Dose risk (person-rem)															
Routine crew	4,690	319	343	338	1,210	1,190	1,900	3,870	3,890	15,800	14,500	14,900	13,700	15,700	10.1
Routine public	5,620	335	362	357	1,340	1,310	2,180	4,350	4,410	18,700	17,200	17,700	16,300	18,700	0.224
Accident[d]	2.45	0.132	0.648	0.648	1.52	2.13	344	233	205	580	563	580	567	580	NA
Latent cancer fatalities[e]															
Crew fatalities	1.9	0.13	0.1	0.1	0.5	0.48	0.8	1.5	1.6	6.3	5.8	6.0	5.5	6.3	0.004
Public fatalities	2.7	0.17	0.2	0.2	0.7	0.66	1.1	2.3	2.2	9.7	8.6	9.1	8.4	9.3	0.0001
Vehicle-related[f]															
Emission fatalities	1.0	0.088	0.1	0.1	0.2	0.22	0.3	0.67	0.8	2.4	2.9	2.2	2.8	2.4	NA
Accident fatalities	10.8	0.43	0.5	0.5	2.6	2.5	4.4	8.7	9.0	35	35.1	33	34	35.0	NA
Total population health effects (fatalities)	16.4	0.8	0.9	0.9	4.0	3.9	6.6	13	13.6	53	52.4	50	51	53.0	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[e] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP, 1991).
[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

Table E–16. Total Population Impacts of Transportation of Current LLW Inventories Plus 20 Years of LLW Generation: Rail Mode

Impact	Alternative[a]														
	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Regional-ized 5	Regional-ized 6	Regional-ized 7	Central-ized 1	Central-ized 2	Central-ized 3	Central-ized 4	Central-ized 5	On-site[b]
Shipment summary															
Shipments	33,420	9,210	9,740	9,900	31,850	33,460	35,430	66,040	71,480	91,440	96,880	96,710	102,100	90,980	4,360
Mileage (10^6 mi)	69.9	3.50	3.74	3.78	17.2	16.6	25.3	51.4	54.4	224	219	218	212	223	0.122
Population impacts															
Cargo-related[c]															
Dose risk (person-rem)															
Routine crew[d]	388	41.1	43.7	44.2	163	166	208	405	433	1,190	1,190	1,190	1,180	1,190	1.38
Routine public	849	128	135	136	408	368	470	820	845	2,340	2,340	2,310	2,310	2,330	0
Accident[e]	1.03	0.0859	0.162	0.162	0.626	0.886	23.9	44.0	25.0	114	90.9	114	91.6	113	NA
Latent cancer fatalities[f]															
Crew fatalities	0.15	0.016	0.02	0.02	0.07	0.067	0.08	0.16	0.17	0.48	0.47	0.48	0.47	0.47	5.52×10^{-4}
Public fatalities	0.43	0.064	0.07	0.07	0.21	0.18	0.23	0.43	0.42	1.2	1.20	1.1	1.2	1.20	0
Vehicle-related[g]															
Emission fatalities	0.78	0.12	0.13	0.13	0.32	0.23	0.35	0.47	0.47	1.8	1.8	1.7	1.8	1.8	NA
Accident fatalities	0.15	0.0073	0.0078	0.0079	0.036	0.035	0.053	0.11	0.11	0.47	0.46	0.46	0.45	0.47	NA
Total population health effects (fatalities)	1.5	0.21	0.23	0.23	0.64	0.51	0.71	1.2	1.2	4.0	3.9	3.7	3.9	3.9	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Rail crew values are expected to range from impacts listed in this table (for dedicated shipments) to slightly higher than the truck crew impacts identified in the previous table. See Section E.7 for a more detailed explanation.
[e] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[f] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP, 1991).
[g] Vehicle-related impacts are impacts independent of the cargo in the shipment.

For truck transportation, the total estimated number of fatalities from radiological causes ranges from approximately 0.3 to 16. For rail transportation, fatalities from radiological causes range from 0.08 to 1.7. Shipment by rail results in lower doses to crew members and the public, primarily because of the reduced number of shipments involved. In general, for LLW shipments, the vehicle-related risks are greater than the associated cargo-related risks.

E.7.2.3 Maximally Exposed Individual Assessment

The estimated doses during routine transportation for each of the individual receptors considered (see Section E.6.9 for exposure assumptions) are presented in Table E–17 on a per-event basis. The total dose for repeated exposures can be estimated by multiplying the per-event dose by the number of exposures.

As noted previously for HLW shipments, the potential exists for significant individual exposures if multiple exposure-causing events occur during LLW shipments; for instance, the dose to a person caught in a traffic jam for 30 minutes next to a shipment is estimated to be 0.5 mrem. If the exposure is longer, the dose would rise proportionally. Therefore, it is conceivable that a person could receive a dose of between 2 to

Table E–17. Estimated Routine Doses and Lifetime Risk of Fatal Cancer to MEIs From Shipments of LLW (per Exposure Event)[a]

Receptor[b]	Dose (rem)		Lifetime Risk[c]	
	Truck	Rail	Truck	Rail
Workers				
Crew member	d	d	d	d
Inspector	1.5E–04	1.5E–04	6.0E–08	6.0E–08
Rail-yard crew member	NA	7.9E–05	NA	3.0E–08
Public				
Resident	1.6E–08	1.6E–08	8.0E–12	8.0E–12
Person in traffic jam	5.0E–04	5.0E–04	3.0E–07	3.0E–07
Person at service station	2.1E–05	NA	1.0E–08	NA
Resident near rail stop	NA	1.1E–06	NA	6.0E–10

Note: NA = not applicable.
[a] The external dose rate is assumed to be 1 mrem/h at 1 m (3.3 ft) for all shipments.
[b] Receptor assumptions are described in Section E.6.9.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[d] The DOE administrative control level limits doses to DOE workers to 2 rem/yr.

10 mrem while stopped in traffic next to an LLW shipment. In addition, a person working at a truck service station could receive an increased dose if trucks were to use the same stops repeatedly. If a truck-stop worker is present for 100 shipment stops (at the distance and duration given previously), the estimated dose is approximately 2 mrem. Administrative controls could be instituted to control the location and duration of truck stops if multiple exposures were to happen routinely. The probability of multiple exposures increases as the amount of waste transportation increases.

The potential cumulative dose to a resident living along a site entrance route is summarized in Table E–18 for the LLW alternatives. Doses were calculated for all DOE sites in each case; however, only the five sites sending or receiving the most shipments have been included in Table E–18. The cumulative doses assume that a resident is present for every shipment entering and exiting a site and is unshielded at a distance of 30 m (98 ft) from the roadway. The maximum cumulative dose would occur near centralized facilities because of the large number of shipments entering a single site; for instance, for the Centralized 2 Alternative, the maximum dose to a resident living near the NTS would be approximately 4 mrem for the all-truck case and 2 mrem for the all-rail case. The annual dose can be estimated by assuming that shipments would occur over a 20-year period for the No Action Alternative and over a 10-year period for all other cases. The estimated annual dose to a resident would be well below the annual limit of 100 mrem specified for members of the public (DOE, 1990b).

E.7.2.4 Accident Consequence Assessment

For the accident consequence assessment, the waste characteristics for each site were screened to determine the waste with the highest potential radiological consequences if a release were to occur. The LLW from the Argonne National Laboratory-West (ANL-W) site results in the highest transportation accident doses. The doses were highest primarily because the LLW from ANL-W contains a significant amount of cobalt-60, nearly 7,000 Ci per shipment. To comply with regulations in 10 CFR 71 for Type A packagings, the material would have to be shipped in many packages. In practice, such quantities likely would be shipped in Type B packages; however, for purposes of assessment, the ANL-W source term was used to conservatively estimate the impacts of potential LLW accidents.

As stated previously, the accident consequences were calculated for transportation-related accidents that result in the maximum release of radioactive material (accident severity Category VIII). The accident consequence results are presented in Table E–19. The population doses are for a uniform population

Table E-18. Cumulative Dose and Lifetime Risk to an MEI Living Along a Site Entrance Route for Shipments of LLW (Current Inventories Plus 20 Years of Generation)[a]

Alternative and Site[b]	All Truck			All Rail		
	Total Shipments	Dose (rem)	Lifetime Risk[c]	Total Shipments	Dose (rem)	Lifetime Risk[c]
No Action						
NTS	69,960	1.1E-03	6.0E-07	26,740	4.3E-04	2.0E-07
PORTS	33,440	5.4E-04	3.0E-07	12,740	2.1E-04	1.0E-07
Hanford	17,340	2.8E-04	1.0E-07	6,640	1.1E-04	6.0E-08
Pantex	13,740	2.2E-04	1.0E-07	5,440	8.8E-05	4.0E-08
RMI	7,300	1.2E-04	6.0E-08	2,740	4.4E-05	2.0E-08
Decentralized						
PORTS	23,320	3.7E-04	2.0E-07	8,760	1.4E-04	7.0E-08
RMI	7,680	1.2E-04	6.0E-08	2,870	4.6E-05	2.0E-08
KAPL-S	6,780	1.1E-04	6.0E-08	2,570	4.1E-05	2.0E-08
Mound	5,120	8.2E-05	4.0E-08	1,900	3.1E-05	2.0E-08
Bettis	3,730	6.0E-05	3.0E-08	1,410	2.3E-05	1.0E-08
Regionalized 1						
PORTS	24,820	4.0E-04	2.0E-07	9,330	1.5E-04	8.0E-08
RMI	7,680	1.2E-04	6.0E-08	2,870	4.6E-05	2.0E-08
KAPL-S	6,780	1.1E-04	6.0E-08	2,570	4.1E-05	2.0E-08
Mound	5,120	8.2E-05	4.0E-08	1,900	3.1E-05	2.0E-08
Bettis	3,730	6.0E-05	3.0E-08	1,410	2.3E-05	1.0E-08
Regionalized 2						
PORTS	24,380	3.9E-04	2.0E-07	9,260	1.5E-04	8.0E-08
RMI	7,610	1.2E-04	6.0E-08	2,850	4.6E-05	2.0E-08
KAPL-S	6,670	1.1E-04	5.0E-08	2,560	4.1E-05	2.0E-08
Mound	5,080	8.2E-05	4.0E-08	1,910	3.1E-05	2.0E-08
Bettis	3,660	5.9E-05	3.0E-08	1,400	2.3E-05	1.0E-08
Regionalized 3						
ORR	64,590	1.0E-03	5.0E-07	24,470	3.9E-04	2.0E-07
PORTS	33,440	5.4E-04	3.0E-07	12,740	2.1E-04	1.0E-07
LANL	18,400	3.0E-04	2.0E-07	6,910	1.1E-04	6.0E-08
Pantex	14,500	2.3E-04	1.0E-07	5,440	8.8E-05	4.0E-08
RMI	7,680	1.2E-04	6.0E-08	2,870	4.6E-05	2.0E-08
Regionalized 4						
ORR	58,210	9.4E-04	5.0E-07	22,310	3.6E-04	2.0E-07
PORTS	47,610	7.7E-04	4.0E-07	18,410	3.0E-04	2.0E-07
LANL	17,860	2.9E-04	1.0E-07	6,740	1.1E-04	5.0E-08
Pantex	14,180	2.3E-04	1.0E-07	5,370	8.6E-05	4.0E-08
RMI	7,520	1.2E-04	6.0E-08	2,860	4.6E-05	2.0E-08

Table E–18. Cumulative Dose and Lifetime Risk to an MEI Living Along a Site Entrance Route for Shipments of LLW (Current Inventories Plus 20 Years of Generation)[a]—Continued

Alternative and Site[b]	All Truck			All Rail		
	Total Shipments	Dose (rem)	Lifetime Risk[c]	Total Shipments	Dose (rem)	Lifetime Risk[c]
Regionalized 5						
ORR	63,430	1.0E–03	5.0E–07	24,170	3.9E–04	2.0E–07
PORTS	32,500	5.2E–04	3.0E–07	12,500	2.0E–04	1.0E–07
INEL	25,620	4.1E–04	2.0E–07	10,020	1.6E–04	8.0E–08
Pantex	13,830	2.2E–04	1.0E–07	5,380	8.7E–05	4.0E–08
LANL	11,750	1.9E–04	1.0E–07	4,640	7.5E–05	4.0E–08
Regionalized 6						
SRS	130,030	2.1E–03	1.0E–06	49,340	7.9E–04	4.0E–07
ORR	65,420	1.1E–03	5.0E–07	24,860	4.0E–04	2.0E–07
Hanford	44,360	7.1E–04	4.0E–07	16,700	2.7E–04	1.0E–07
PORTS	33,440	5.4E–04	3.0E–07	12,740	2.1E–04	1.0E–07
Pantex	14,500	2.3E–04	1.0E–07	5,440	8.8E–05	4.0E–08
Regionalized 7						
SRS	130,030	2.1E–03	1.0E–06	49,340	7.9E–04	4.0E–07
ORR	65,420	1.1E–03	5.0E–07	24,860	4.0E–04	2.0E–07
NTS	58,900	9.5E–04	5.0E–07	22,140	3.6E–04	2.0E–07
PORTS	33,440	5.4E–04	3.0E–07	12,740	2.1E–04	1.0E–07
Hanford	14,540	2.3E–04	1.0E–07	5,440	8.8E–05	4.0E–08
Centralized 1						
Hanford	242,730	3.9E–03	2.0E–06	91,440	1.5E–03	7.0E–07
SRS	68,340	1.1E–03	6.0E–07	25,400	4.1E–04	2.0E–07
ORR	65,420	1.1E–03	5.0E–07	24,860	4.0E–04	2.0E–07
PORTS	33,440	5.4E–04	3.0E–07	12,740	2.1E–04	1.0E–07
Pantex	14,500	2.3E–04	1.0E–07	5,440	8.8E–05	4.0E–08
Centralized 2						
NTS	257,270	4.1E–03	2.0E–06	96,880	1.6E–03	8.0E–07
SRS	68,340	1.1E–03	6.0E–07	25,400	4.1E–04	2.0E–07
ORR	65,420	1.1E–03	5.0E–07	24,860	4.0E–04	2.0E–07
PORTS	33,440	5.4E–04	3.0E–07	12,740	2.1E–04	1.0E–07
Hanford	14,540	2.3E–04	1.0E–07	5,440	8.8E–05	4.0E–08
Centralized 3						
Hanford	225,660	3.6E–03	2.0E–06	87,240	1.4E–03	7.0E–07
SRS	67,520	1.1E–03	5.0E–07	25,230	4.1E–04	2.0E–07
ORR	61,250	9.9E–04	5.0E–07	24,470	3.9E–04	2.0E–07
PORTS	47,440	7.6E–04	4.0E–07	18,350	3.0E–04	2.0E–07
LANL	36,640	5.9E–04	3.0E–07	14,400	2.3E–04	1.0E–07

Table E–18. Cumulative Dose and Lifetime Risk to an MEI Living Along a Site Entrance Route for Shipments of LLW (Current Inventories Plus 20 Years of Generation)[a]—Continued

	All Truck			All Rail		
Alternative and Site[b]	**Total Shipments**	**Dose (rem)**	**Lifetime Risk[c]**	**Total Shipments**	**Dose (rem)**	**Lifetime Risk[c]**
Centralized 4						
NTS	239,350	3.9E–03	2.0E–06	92,470	1.5E–03	7.0E–07
SRS	67,520	1.1E–03	5.0E–07	25,230	4.1E–04	2.0E–07
ORR	61,250	9.9E–04	5.0E–07	24,470	3.9E–04	2.0E–07
PORTS	47,440	7.6E–04	4.0E–07	18,350	3.0E–04	2.0E–07
LANL	36,640	5.9E–04	3.0E–07	14,400	2.3E–04	1.0E–07
Centralized 5						
Hanford	241,540	3.9E–03	2.0E–06	90,980	1.5E–03	7.0E–07
SRS	68,540	1.1E–03	6.0E–07	25,320	4.1E–04	2.0E–07
ORR	65,840	1.1E–03	5.0E–07	24,890	4.0E–04	2.0E–07
PORTS	32,500	5.2E–04	3.0E–07	12,500	2.0E–04	1.0E–07
Pantex	14,180	2.3E–04	1.0E–07	5,370	8.6E–05	4.0E–08

[a] The external dose rate is assumed to be 1 mrem/h at 1 m (3.3 ft) for all shipments. The resident is assumed to be present for all shipments that either enter or exit the site. Shipments are assumed to pass at a distance of 30 m (98 ft) and an average speed of 24 km/h (15 mi/h).
[b] For each alternative, only the five sites sending or receiving the most shipments are reported. All other sites have MEI doses less than those presented here.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.

density. The location of the MEI after an accident is determined on the basis of atmospheric conditions and buoyant characteristics of the released plume. The locations of maximum exposure from the accident site are 160 m (525 ft) for neutral conditions and 400 m (1,312 ft) for stable conditions.

The dose to the MEI is independent of the accident location. The maximum dose to an individual (approximately 7 rem for a rail accident under unfavorable weather conditions) has a potential lifetime fatal cancer risk of 4×10^{-3}.

The accident consequence results for LLW from ANL-W should be considered extremely conservative for most LLW shipments for a number of reasons. First, the LLW from ANL-W represents less than 1% by volume of the total LLW generated annually within DOE. Only about two truck shipments would be required each year to transport ANL-W waste to an offsite facility for treatment, storage, or disposal. Therefore, it is unlikely that a severe LLW accident would involve the LLW from ANL-W. Second, the

Table E-19. Estimated Consequences for the Most Severe Accidents Involving Shipments of LLW [a,b]

Mode and Accident Location	Neutral Conditions[c]				Stable Conditions[d]			
	Population[e]		MEI[f]		Population[e]		MEI[f]	
	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)
Truck								
Urban	8.3E+03	4.2E+00	7.7E-01	3.9E-04	6.7E+04	3.4E+01	2.6E+00	1.3E-03
Suburban	1.6E+03	8.0E-01	7.7E-01	3.9E-04	1.2E+04	6.0E+00	2.6E+00	1.3E-03
Rural	1.5E-01	8.0E-03	7.7E-01	3.9E-04	1.2E+02	6.0E-02	2.6E+00	1.3E-03
Rail								
Urban	2.2E+04	1.1E+01	2.1E+00	1.3E-03	1.8E+05	9.0E+01	7.0E+00	3.5E-03
Suburban	4.2E+03	2.1E+00	2.1E+00	1.3E-03	3.3E+04	1.7E+01	7.0E+00	3.5E-03
Rural	4.1E+01	2.0E-02	2.1E+00	1.3E-03	3.2E+02	1.6E-01	7.0E+00	3.5E-03

[a] The most severe accidents correspond to the highest NUREG-0170 accident severity category (Category VIII) (NRC, 1977a). Results are reported for LLW from ANL-W, which was found to result in the highest potential accident doses.
[b] Buoyant plume rise resulting from fire for a severe accident was included in the exposure model.
[c] Neutral weather conditions result in moderate dispersion and dilution of the released plume. Neutral conditions were taken to be Pasquill Stability Class D with a windspeed of 4 m/s (9 mi/h). Neutral conditions occur approximately 50% of the time in the United States.
[d] Stable weather conditions result in minimal dispersion and dilution of the released plume and are thus unfavorable. Stable conditions were taken to be Pasquill Stability Class F with a windspeed of 1 m/s (2.2 mi/h). Stable conditions occur approximately one-third of the time in the United States.
[e] Populations extend at a uniform population density to a radius of 80 km (50 mi) from the accident site. Population exposure pathways include acute inhalation; acute cloudshine; groundshine; resuspended inhalation; resuspended cloudshine; and ingestion of food, including initially contaminated food (rural only). No decontamination or mitigative actions are taken.
[f] The MEI is assumed to be at the location of maximum exposure. The locations of maximum exposure would be 160 m (525 ft) and 400 m (1,312 ft) from the accident site under neutral and stable atmospheric conditions, respectively. Individual exposure pathways include acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingested dose is considered.

accident dose results for LLW from ANL-W are at least a factor of 10 greater than those for LLW from other sites, primarily because of the cobalt-60 content of the ANL-W waste. The "average" accident consequences would be much less than those presented here.

E.7.2.5 Onsite Assessment Results

The onsite risks for LLW transportation at the Hanford Site are summarized in Table E-15 for truck transportation and in Table E-16 for rail transportation. The risks presented for the transportation crew include the dose to workers in areas along the shipping route. The total dose to workers close to the route is generally much less than the dose to the actual crew members involved in transporting the waste. Risks calculated for the public include persons sharing the transportation route with waste shipments. The MEI for routine conditions, besides crew members, was considered to be a guard at a facility gate or checkpoint along the route who is exposed to each shipment for 1 minute at a distance of 5 m (16.4 ft). The total dose to the guard for all shipments is estimated to be 30 mrem. Overall, the routine onsite shipment risks are much less than the offsite shipment risks for all cases considered.

In addition, the consequences of an onsite accident at the Hanford Site are summarized in Table E-20. For the accident consequence assessment, the characteristics of LLW from the Hanford Site were used. The

Table E-20. Results of Onsite Accident Consequence Assessment for the Hanford Site

	Onsite Population		Offsite Population		MEI	
Waste and Transport Mode	**Neutral Conditions**	**Stable Conditions**	**Neutral Conditions**	**Stable Conditions**	**Neutral Conditions**	**Stable Conditions**
Dose (person-rem)						
LLW						
Truck	7.6E-02	2.6E-01	9.0E-01	7.7E+00	7.7E-03	2.6E-02
Rail	2.0E-01	6.9E-01	2.4E+00	2.1E+01	2.1E-02	7.0E-02
CH-TRUW						
Truck	1.0E+01	3.6E+01	6.0E+00	5.2E+01	2.5E-01	8.4E-01
Rail	2.1E+01	7.0E+01	1.2E+01	1.0E+02	5.0E-01	1.7E+00
RH-TRUW						
Truck	2.1E+00	7.1E+00	1.2E+00	1.1E+01	5.0E-02	1.7E-01
Rail	4.1E+00	1.4E+01	2.4E+00	2.1E+01	1.0E-01	3.4E-01
LLMW						
Truck	4.5E+00	1.6E+01	8.1E+00	6.9E+01	1.1E-01	3.6E-01
Rail	1.2E+01	4.0E+01	2.1E+01	1.8E+02	2.8E-01	9.3E-01
Risk (latent cancer fatalities)						
LLW						
Truck	3.0E-05	1.0E-04	4.5E-04	3.8E-03	3.9E-06	1.3E-05
Rail	8.1E-05	2.8E-04	1.2E-03	1.0E-02	1.0E-05	3.5E-05
CH-TRUW						
Truck	4.2E-03	1.4E-02	3.0E-03	2.6E-02	1.3E-04	4.2E-04
Rail	8.2E-03	2.8E-02	5.9E-03	5.2E-02	2.5E-04	8.3E-04
RH-TRUW						
Truck	8.2E-04	2.8E-03	6.0E-04	5.3E-03	2.5E-05	8.4E-05
Rail	1.6E-03	5.6E-03	1.2E-03	1.1E-02	5.0E-05	1.7E-04
LLMW						
Truck	1.8E-03	6.2E-03	4.0E-03	3.5E-02	5.3E-05	1.8E-04
Rail	4.7E-03	1.6E-02	1.1E-02	9.0E-02	1.4E-04	4.6E-04

MEI is located at the position where maximum impacts would occur, similar to the offsite accident consequence assessment. An exposure of 2 hours was assumed for the population of onsite workers after an accident. The impacts on the offsite population were calculated by using the population distribution in the vicinity of the Hanford Site and by assuming a 1-year exposure duration.

E.7.3 TRANSURANIC WASTE

The projected rate for TRUW generation for each site, the waste characteristics, the potential treatments, and the cases considered in the PEIS are described in detail in the TRUW technical report (ANL, 1996i). Transportation risks have been calculated for five TRUW alternative cases summarized in Section E.2.2 (1 of the 6 alternatives does not involve waste transportation). The alternatives range from decentralized to centralized approaches to treatment and storage before final geologic disposal. The No Action Alternative does not involve transport of waste. The other alternatives each have CH-TRUW and RH-TRUW components. The transportation assessment assumes that all TRUW will ultimately be shipped to WIPP for disposal. The WM PEIS considers current inventories of TRUW plus 20 years of TRUW generation for all DOE sites. All impacts are calculated as totals for the entire waste inventory under consideration. The average annual risk can be estimated by dividing the summarized results by the duration of the shipping campaigns. For purposes of the PEIS, to estimate the sizes of potential facilities needed for treatment, the assumption has been made that waste would be shipped over a 10-year period. Previous assessments have assumed that TRUW would be shipped to WIPP over a 20-year period (DOE, 1990b). Transportation of TRUW for treatment, storage, and disposal is also analyzed in the DOE'S *Draft WIPP Disposal Phase Supplemental Environmental Impact Statement.*

E.7.3.1 Shipment Summary

The total number of shipments and the mileage for loaded shipments for each TRUW alternative are summarized in Table E–21 for truck shipments and Table E–22 for rail shipments. The total truck shipments range from approximately 18,640 to 23,900. For rail transportation, the corresponding numbers range from 9,360 to 12,010 shipments. The total distance for loaded shipments ranges from 55 to 69 million km (34 to 43 million mi) for truck transportation and from 26 to 34 million km (16 to 21 million mi) for rail transportation. The average annual number of shipments and mileage can be estimated by dividing the total results by a shipping duration of either 10 or 20 years.

Table E–21. Total Population Impacts of Transportation of Current TRUW Inventories Plus 20 Years of TRUW Generation: Truck Mode

Impact	Alternative[a]						
	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Central-ized	Onsite[b]
Shipment summary							
Shipments	0	23,900	21,680	18,640	20,600	21,640	206
Mileage (10^6 mi)	--	42.4	38.3	34.0	37.2	38.7	0.0047
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	--	3,650	3,270	2,890	3,160	3,310	11
Routine public	--	3,870	3,360	2,940	3,310	3,490	0.56
Accident[d]	--	9.80	8.98	8.98	11.8	8.93	NA
Latent cancer fatalities[e]							
Crew fatalities	--	1.5	1.3	1.2	1.3	1.3	0.0044
Public fatalities	--	1.9	1.7	1.5	1.7	1.7	0.00028
Vehicle-related[f]							
Emission fatalities	--	0.22	0.19	0.18	0.19	0.20	NA
Accident fatalities	--	3.0	2.7	2.4	2.6	2.7	NA
Total population health effects (fatalities)	--	6.6	5.9	5.2	5.7	6.0	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[e] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[f] Vehicle-related impacts are independent of the shipment's cargo.

For comparison, within the United States for the years 1986 to 1988, the average annual reported mileage for interstate truck shipments of all commodities was approximately 45 billion km (28 billion mi), and for rail shipments approximately 48.8 billion railcar-km (30.3 billion railcar-mi) (Saricks and Kvitek, 1994). The maximum estimated annual TRUW shipments would represent much less than 0.1% of the annual truck and rail transportation activity within the United States.

Table E-22. Total Population Impacts of Transportation of Current TRUW Inventories Plus 20 Years of TRUW Generation: Rail Mode

Impact	Alternative[a]						
	No Action	Decentralized	Regionalized 1	Regionalized 2	Regionalized 3	Centralized	Onsite[b]
Shipment summary							
Shipments	0	12,010	10,890	9,360	10,340	10,870	104
Mileage (10^6 mi)	--	20.3	18.2	15.8	17.4	18.4	0.0029
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew[d]	--	836	756	656	718	759	4.8
Routine public	--	1,130	978	821	907	1,010	0
Accident[e]	--	0.777	0.770	0.773	0.844	0.768	NA
Latent cancer fatalities[f]							
Crew fatalities	--	0.33	0.30	0.26	0.28	0.30	0.0019
Public fatalities	--	0.57	0.49	0.41	0.46	0.51	0
Vehicle-related[g]							
Emission fatalities	--	0.10	0.091	0.073	0.079	0.091	NA
Accident fatalities	--	0.043	0.037	0.033	0.036	0.039	NA
Total population health effects (fatalities)	--	1.0	0.92	0.78	0.86	0.94	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Rail crew values are expected to range from impacts listed in this table (for dedicated shipments) to slightly higher than the truck crew impacts identified in the previous table. See Section E.7 for a more detailed explanation.
[e] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[f] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[g] Vehicle-related impacts are independent of the shipment's cargo.

E.7.3.2 Collective Population Risk Results

The results for collective risk assessment for the TRUW alternatives are also summarized in Table E-21 for truck shipments and Table E-22 for rail shipments. The collective risk results are presented for shipment of the current TRUW inventories plus the estimated generation of TRUW for a period of 20 years.

Examination of the results of the transportation risk assessment shows that differences in population risk among the various cases are dependent primarily on total shipping distances. The total shipping distance for each alternative is determined by the definition of the case (shipment origin and destination sites), site-specific waste inventories (specifically waste volume and mass, which directly determine the total number of shipments), packaging assumptions, and the route distances among all pairs of origin-and-destination sites.

The total estimated number of fatalities from radiological causes ranges from approximately 2.7 to 3.4 for truck shipments. For rail transportation, fatalities from radiological causes range from 0.67 to 0.90. Shipment by the rail mode results in lower doses to crew members and the public, primarily because of the reduced number of shipments involved. In general, for TRUW shipments, the vehicle-related risks are comparable to the associated cargo-related risks.

E.7.3.3 Maximally Exposed Individual Assessment

The estimated doses during routine transportation for each individual receptor considered (see Section E.6.9 for exposure assumptions) are presented in Table E–23 for CH-TRUW, and in Table E–24 for RH-TRUW. The total dose for repeated exposures can be estimated by multiplying the per-event dose by the number of exposures.

Except for doses to crew members, all doses are presented for single exposures. Note that the potential exists for significant individual exposures if multiple exposure-causing events occur. For example, the dose to a person stopped in traffic next to a truck shipment of CH-TRUW for 30 minutes is estimated to be 5 mrem; if the exposure duration were longer, the dose would rise proportionally. Therefore, it is conceivable that a person could receive a dose of approximately 10 to 20 mrem while stopped in traffic next to a TRUW shipment. In addition, a person working at a truck service station could receive an increased dose if trucks used the same stops repeatedly. If a truck stop worker were present for 100 CH-TRUW shipment stops (at the distance and duration given previously), the estimated dose would be approximately 20 mrem. Administrative controls could be instituted to control the location and duration of truck stops if multiple exposures were to happen routinely. The probability of multiple exposures increases as the amount of waste transportation increases.

The cumulative dose to a resident living along a site entrance route is summarized in Table E–25 for each TRUW alternative. Note that each alternative involves both contact- and remote-handled shipments. Although doses were calculated for all DOE sites storing or generating TRUW, only data for the five sites

Table E-23. Estimated Routine Doses and Lifetime Risk of Fatal Cancer to MEIs From Shipments of CH-TRUW (per Exposure Event)[a]

Receptor[b]	Dose (rem)		Lifetime Risk[c]	
	Truck	Rail	Truck	Rail
Workers				
Crew member	d	d	d	d
Inspector	1.4E–03	1.4E–03	6.0E–07	6.0E–07
Rail-yard crew member	NA	1.5E–03	NA	6.0E–07
Public				
Resident	1.5E–07	3.0E–07	8.0E–11	2.0E–10
Person in traffic jam	4.7E–03	9.3E–03	2.0E–06	5.0E–06
Person at service station	1.9E–04	NA	1.0E–07	NA
Resident near rail stop	NA	2.1E–05	NA	1.0E–08

Note: NA = not applicable.
[a] The dose rate is assumed to be 3 mrem/h at 1 m (3.3 ft) from each package.
[b] Receptor assumptions are described in Section E.6.9.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[d] The DOE administrative control level limits doses to DOE workers to 2 rem/yr.

Table E-24. Estimated Routine Doses and Lifetime Risk of Fatal Cancer to MEIs From Shipments of RH-TRUW (per Exposure Event)[a]

Receptor[b]	Dose (rem)		Lifetime Risk[c]	
	Truck	Rail	Truck	Rail
Workers				
Crew member	d	d	d	d
Inspector	1.0E–03	1.0E–03	4.0E–07	4.0E–07
Rail-yard crew member	NA	1.1E–03	NA	4.0E–07
Public				
Resident	1.1E–07	2.3E–07	6.0E–11	1.0E–10
Person in traffic jam	3.6E–03	7.1E–03	2.0E–06	4.0E–06
Person at service station	1.5E–04	NA	8.0E–08	NA
Resident near rail stop	NA	1.5E–05	NA	8.0E–09

Note: NA = not applicable.
[a] Dose rate is assumed to be 7 mrem/h at 1 m (3.3 ft) from each package.
[b] Receptor assumptions are described in Section E.6.9.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.
[d] The DOE administrative control level limits doses to DOE workers to 2 rem/yr.

Table E–25. Cumulative Dose and Lifetime Risk to an MEI Living Along a Site Entrance Route for Shipments of TRUW (Current Inventories Plus 20 Years of Generation)[a]

	All Truck			All Rail		
Alternative and Site[b]	**Total Shipments**	**Dose (rem)**	**Lifetime Risk[c]**	**Total Shipments**	**Dose (rem)**	**Lifetime Risk[c]**
Decentralized						
WIPP	23,860	3.1E–03	2.0E–06	11,970	3.1E–03	2.0E–06
Hanford	10,260	1.2E–03	6.0E–07	5,140	1.2E–03	6.0E–07
INEL	5,970	8.7E–04	4.0E–07	2,990	8.7E–04	4.0E–07
SRS	2,370	3.6E–04	2.0E–07	1,190	3.6E–04	2.0E–07
ORR	1,910	2.1E–04	1.0E–07	970	2.2E–04	1.0E–07
Regionalized 1						
WIPP	20,080	2.5E–03	1.0E–06	10,060	2.6E–03	1.0E–06
Hanford	11,920	1.4E–03	7.0E–07	5,970	1.4E–03	7.0E–07
INEL	4,900	7.1E–04	4.0E–07	2,460	7.1E–04	4.0E–07
ORR	2,440	2.7E–04	1.0E–07	1,230	2.8E–04	1.0E–07
LANL	1,320	1.9E–04	1.0E–07	670	2.0E–04	1.0E–07
Regionalized 2						
WIPP	17,040	2.1E–03	1.0E–06	8,530	2.2E–03	1.0E–06
Hanford	11,830	1.3E–03	7.0E–07	5,930	1.4E–03	7.0E–07
INEL	4,250	6.1E–04	3.0E–07	2,130	6.1E–04	3.0E–07
LANL	1,030	1.5E–04	8.0E–08	520	1.5E–04	8.0E–08
ORR	990	1.1E–04	5.0E–08	500	1.1E–04	6.0E–08
Regionalized 3						
WIPP	17,030	2.1E–03	1.0E–06	8,520	2.2E–03	1.0E–06
Hanford	11,830	1.3E–03	7.0E–07	5,930	1.4E–03	7.0E–07
INEL	7,610	1.1E–03	6.0E–07	3,820	1.1E–03	6.0E–07
LANL	1,350	2.0E–04	1.0E–07	680	2.0E–04	1.0E–07
ORR	990	1.1E–04	5.0E–08	500	1.1E–04	6.0E–08
Centralized						
WIPP	20,500	2.6E–03	1.0E–06	10,290	2.7E–03	1.0E–06
Hanford	11,610	1.3E–03	7.0E–07	5,820	1.4E–03	7.0E–07
INEL	5,180	7.5E–04	4.0E–07	2,600	7.6E–04	4.0E–07
SRS	2,080	3.1E–04	2.0E–07	1,040	3.1E–04	2.0E–07
LANL	1,350	2.0E–04	1.0E–07	680	2.0E–04	1.0E–07

[a] The external dose rates are assumed to be 3 mrem/h at 1 m (3.3 ft) for CH-TRUW, and 7 mrem/h for RH-TRUW shipments. The resident is assumed to be present for all shipments that enter or exit the site. Shipments are assumed to pass at a distance of 30 m (98 ft) and an average speed of 24 km/h (15 mi/h).

[b] For each alternative, only the five sites sending or receiving the most shipments are reported. All other sites have MEI doses less than those presented here.

[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public.

sending or receiving the most shipments have been provided for each case in Table E–25. The cumulative doses assume that an unshielded resident is present at a distance of 30 m (98 ft) from the roadway for every shipment entering or exiting a site. In almost all cases, the maximum cumulative dose would occur near the WIPP disposal site. If all CH-TRUW and RH-TRUW were shipped to WIPP, the maximum dose to a resident would be less than 4 mrem for both truck and rail cases. The truck and rail doses are similar because the same number of packages would be shipped for each mode. The annual dose can be estimated by assuming that shipments would occur over either a 10- or 20-year period. The annual dose to a resident would be well below the annual limit of 100 mrem specified for members of the public through DOE orders (DOE, 1990b), as well as comparable NRC limits (10 CFR 20).

E.7.3.4 Accident Consequence Assessment

For the accident consequence assessment, the characteristics of contact- and remote-handled waste for each site were screened to determine the waste with the highest potential radiological consequences if a release were to occur during an accident. For CH-TRUW, waste shipments from LANL were found to result in the highest potential transportation accident doses. For RH-TRUW, shipments from the Hanford Site were found to result in the highest potential accident doses. The accident consequence results are presented in Table E–26 for contact-handled shipments and Table E–27 for remote-handled shipments. The population doses are for a uniform population density within an 80-km (50-mi) radius of accidents occurring in rural, suburban, and urban population density zones.

The location of the MEI after an accident is determined on the basis of atmospheric conditions and buoyant characteristics of the released plume. The locations of maximum exposure are 160 m (525 ft) from the accident site for neutral conditions, and 400 m (1,312 ft) from the accident site for stable conditions. The dose to the MEI is independent of the accident location. The maximum dose to an individual (approximately 34 rem for a RH-TRUW rail accident under unfavorable weather conditions) corresponds to a potential lifetime fatal cancer risk of 2×10^{-2}.

E.7.3.5 Onsite Assessment Results

The onsite risks for TRUW transportation at the Hanford Site are summarized in Table E–21 for trucks and Table E–22 for rail. The risks presented for the transportation crew include the dose to workers in areas

Table E–26. Estimated Consequences for the Most Severe Accidents Involving Shipments of CH-TRUW [a,b]

Mode and Accident Location	Neutral Conditions[c]				Stable Conditions[d]			
	Population[e]		MEI[f]		Population[e]		MEI[f]	
	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)	Dose (person-rem)	Risk (cancer fatalities)	Dose (rem)	Risk (cancer fatality)
Truck								
Urban	4.0E+03	2.0E+00	3.5E+00	1.8E–03	3.2E+04	1.6E+01	1.2E+01	6.0E–03
Suburban	7.4E+02	3.7E–01	3.5E+00	1.8E–03	5.9E+03	3.0E+00	1.2E+01	6.0E–03
Rural	6.5E+00	3.0E–03	3.5E+00	1.8E–03	5.2E+01	3.0E–02	1.2E+01	6.0E–03
Rail								
Urban	7.9E+02	4.0E+00	7.1E+00	3.6E–03	6.3E+04	3.2E+01	2.4E+01	1.2E–02
Suburban	1.5E+02	7.5E–01	7.1E+00	3.6E–03	1.2E+04	6.0E+00	2.4E+01	1.2E–02
Rural	1.3E+01	7.0E–03	7.1E+00	3.6E–03	1.0E+02	5.0E–02	2.4E+01	1.2E–02

[a] The most severe accidents correspond to the highest NUREG-0170 accident severity category (Category VIII) (NRC, 1977a). Results are reported for CH-TRUW from LANL.
[b] Buoyant plume rise resulting from fire for a severe accident was included in the exposure model. Three TRUPACT-IIs are assumed to be breached in a truck accident; six TRUPACT-IIs are assumed to be equally breached in a rail accident.
[c] Neutral weather conditions result in moderate dispersion and dilution of the released plume. Neutral conditions were taken to be Pasquill Stability Class D with a windspeed of 4 m/s (9 mi/h). Neutral conditions occur approximately 50% of the time in the United States.
[d] Stable weather conditions result in minimal dispersion and dilution of the released plume and are thus unfavorable. Stable conditions were taken to be Pasquill Stability Class F with a windspeed of 1 m/s (2.2 mi/h). Stable conditions occur approximately one-third of the time in the United States.
[e] Populations extend at a uniform population density to a radius of 80 km (50 mi) from the accident site. Population exposure pathways include acute inhalation; acute cloudshine; groundshine; resuspended inhalation; resuspended cloudshine; and ingestion of food, including initially contaminated food (rural only). No decontamination or mitigative actions are taken.
[f] The MEI is assumed to be at the location of maximum exposure. The locations of maximum exposure would be 160 m (525 ft) from the accident site under neutral atmospheric conditions, and 400 m (1,312 ft) for stable atmospheric conditions. Individual exposure pathways include acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingested dose is considered.

along the shipping route. The total dose to workers adjacent to the route is generally much less than the dose to the crew members involved in transporting the waste. Risks calculated for the public include persons sharing the transportation route with waste shipments. The MEI for routine conditions, besides crew members, was considered to be a guard at a facility gate or checkpoint along the route exposed to each shipment for 1 minute at a distance of 5 m (16.4 ft). The total dose to the guard from all shipments is estimated to be 61 mrem. Overall, the routine onsite shipment risks are much lower than the offsite shipment risks for all cases considered.

Table E–27. Estimated Consequences for the Most Severe Accidents Involving Shipments of RH-TRUW [a,b]

	Neutral Conditions[c]				Stable Conditions[d]			
	Population[e]		MEI[f]		Population[e]		MEI[f]	
Mode and Accident Location	**Dose (person-rem)**	**Risk (cancer fatalities)**	**Dose (rem)**	**Risk (cancer fatality)**	**Dose (person-rem)**	**Risk (cancer fatalities)**	**Dose (rem)**	**Risk (cancer fatality)**
Truck								
Urban	6.0E+01	3.0E-02	5.1E-02	2.6E-05	4.8E+02	2.4E-01	1.7E+01	8.5E-03
Suburban	1.1E+01	5.5E-03	5.1E-02	2.6E-05	8.9E+01	4.5E-02	1.7E+01	8.5E-03
Rural	1.0E-01	5.0E-03	5.1E-02	2.6E-05	8.3E+01	4.2E-04	1.7E+01	8.5E-03
Rail								
Urban	1.2E+02	6.0E-02	1.0E-01	5.0E-05	9.5E+02	4.8E-01	3.4E+01	1.7E-02
Suburban	2.2E+01	1.1E-02	1.0E-01	5.0E-05	1.8E+02	9.0E-02	3.4E+01	1.7E-02
Rural	2.1E-01	1.1E-04	1.0E-01	5.0E-05	1.7E+00	8.5E-04	3.4E+01	1.7E-02

[a] The most severe accidents correspond to the highest NUREG-0170 accident severity category (Category VIII) (NRC, 1977a). Results are reported for RH-TRUW from the Hanford Site.
[b] Buoyant plume rise resulting from fire for a severe accident was included in the exposure model. One RH-72B is assumed to be breached in a truck accident; two RH-72Bs are assumed to be equally breached in a rail accident.
[c] Neutral weather conditions result in moderate dispersion and dilution of the released plume. Neutral conditions were taken to be Pasquill Stability Class D with a windspeed of 4 m/s (9 mi/h). Neutral conditions occur approximately 50% of the time in the United States.
[d] Stable weather conditions result in minimal dispersion and dilution of the released plume and are thus unfavorable. Stable conditions were taken to be Pasquill Stability Class F with a windspeed of 1 m/s (2.2 mi/h). Stable conditions occur approximately one-third of the time in the United States.
[e] Populations extend at a uniform population density to a radius of 80 km (50 mi) from the accident site. Population exposure pathways include acute inhalation; acute cloudshine; groundshine; resuspended inhalation; resuspended cloudshine; and ingestion of food, including initially contaminated food (rural only). No decontamination or mitigative actions are taken.
[f] The MEI is assumed to be at the location of maximum exposure. The locations of maximum exposure would be 160 m (525 ft) and from the accident site under neutral atmospheric conditions, and 400 m (1,312 ft) for stable atmospheric conditions. Individual exposure pathways include acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingested dose is considered.

The consequences of an onsite accident at the Hanford Site are summarized in Table E–20. For the accident consequence assessment, characteristics of CH-TRUW and RH-TRUW from the Hanford Site were used. The MEI is located at the position where maximum impacts would occur, similar to the offsite accident consequence assessment. An exposure of 2 hours was assumed for the population of onsite workers after an accident. Impacts on the offsite population were calculated by using the population distribution near the Hanford Site and by assuming a 1-year exposure duration.

E.7.4 Low-Level Mixed Waste

The projected rate of LLMW generation for each site, the waste characteristics, the potential treatments, and the cases considered in the PEIS are described in detail in ANL (1996k). Transportation risks have been calculated for the LLMW alternatives summarized in Section E.2.2 (the No Action Alternative does not involve transportation of LLMW). The cases range from decentralized to centralized approaches to TSD. The number of disposal sites varies from 16 sites for decentralized disposal to 1 site for centralized disposal. Options for treatment also vary from decentralized to centralized approaches.

The PEIS considers current inventories of LLMW plus 20 years of generation for all DOE sites. All impacts are calculated as totals for the entire inventory of waste under consideration. The average annual risk can be estimated by dividing the summarized results by the duration of the shipping campaigns. For all alternatives, shipments would occur uniformly over a 10-year period, with the assumption of a 10-year period to build TSD facilities. These timeframes are consistent with the assumptions used in the facility assessments for estimating throughputs.

E.7.4.1 Shipment Summary

The total number of shipments and the mileage for loaded shipments for each LLMW alternative are summarized in Table E–28 for truck shipments, and Table E–29 for rail shipments. The estimated number of shipments and the total mileage for the various cases span a wide range. The total number of truck shipments ranges from approximately 490 for the Decentralized Alternative to about 11,000 shipments for the Regionalized 3 Alternative. For rail transportation, the corresponding numbers of shipments range from 360 to 4,540. The total mileage for loaded shipments ranges from 0.37 to 24 million km (0.23 to 15 million mi) for truck transportation and from 0.34 to 11 million km (0.21 to 6.8 million mi) for rail transportation. The average annual number of shipments and mileage can be estimated by dividing the total results by the shipping duration which is assumed to be 10 years in the WM PEIS.

For comparison, within the United States for the years 1986 to 1988, the average annual reported mileage for interstate truck shipments of all commodities was approximately 45 billion km (28 billion mi), and for train shipments approximately 48.8 billion railcar-km (30.3 billion railcar-mi) (Saricks and Kvitek, 1994). The estimated annual LLMW shipments for the maximum transportation alternative would represent less than 0.1% of the annual truck and rail transportation activity within the United States.

Table E-28. Total Population Impacts of Transportation of Current LLMW Inventories Plus 20 Years of LLMW Generation: Truck Mode

Impact	Alternative[a] Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Central-ized	Onsite[b]
Shipment summary							
Shipments	480	1,820	5,560	10,990	4,250	7,520	1,720
Mileage (10^6 mi)	0.25	0.59	2.57	14.9	2.89	13.5	0.051
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	8.22	20.4	80.3	429	84.1	374	1.49
Routine public	9.72	23.1	92.6	513	98.6	447	0.033
Accident[d]	1.09	2.23	15.4	26	15.9	148	NA
Latent cancer fatalities[e]							
Crew fatalities	0.0033	0.0083	0.032	0.17	0.033	0.15	0.00060
Public fatalities	0.0055	0.013	0.053	0.27	0.049	0.29	1.72×10^{-5}
Vehicle-related[f]							
Emission fatalities	0.0046	0.0085	0.024	0.10	0.015	0.054	NA
Accident fatalities	0.018	0.038	0.19	1.0	0.19	0.83	NA
Total fatalities	0.031	0.068	0.30	1.5	0.29	1.3	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[e] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP, 1991).
[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

E.7.4.2 Collective Population Risk Results

The results for the collective risk assessment for the LLMW alternatives are also summarized in Table E-28 for truck shipments, and Table E-29 for rail shipments. The results for collective risk are presented for shipment of the current inventories plus the estimated generation of LLMW for a period of 20 years.

Examination of the results of the transportation risk assessment shows that differences in population risk among the various cases are primarily dependent on total shipping distances. Thus, in general, centralized options predictably show larger transportation risks than regionalized or decentralized approaches because the centralized options involve greater transportation distances. The total shipping distance for each alternative is determined by the definition of the case (shipment origin and destination sites), site-specific

Table E–29. Total Population Impacts of Transportation of Current LLMW Inventories Plus 20 Years of LLMW Generation: Rail Mode

Impact	Alternative[a]						
	Decentralized	Regionalized 1	Regionalized 2	Regionalized 3	Regionalized 4	Centralized	Onsite[b]
Shipment summary							
Shipments	350	1,030	2,490	4,540	2,050	3,340	660
Mileage (10^6 mi)	0.23	0.48	1.37	6.76	1.57	6.46	0.026
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew[d]	1.97	4.98	12.9	41.3	12.5	36.6	0.206
Routine public	5.75	13.7	29.1	75.8	28.2	69.3	0.0024
Accident[e]	0.311	0.596	2.18	4.61	2.60	27.6	NA
Latent cancer fatalities[f]							
Crew fatalities	0.00081	0.0020	0.0052	0.017	0.0050	0.015	8.3×10^{-5}
Public fatalities	0.0031	0.0072	0.015	0.040	0.015	0.049	9.6×10^{-7}
Vehicle-related[g]							
Emission fatalities	0.0057	0.013	0.023	0.055	0.024	0.053	NA
Accident fatalities	0.00050	0.0010	0.0028	0.014	0.0032	0.014	NA
Total fatalities	0.010	0.023	0.046	0.13	0.047	0.13	NA

Note: NA = not applicable.
[a] Alternative definitions are summarized in Section E.2.2 and provided in detail in Chapter 3 of the PEIS.
[b] Onsite impacts are calculated for the Hanford Site.
[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.
[d] Rail crew values are expected to range from impacts listed in this table (for dedicated shipments) to slightly higher than the truck crew impacts identified in the previous table. See Section E.7
[e] Dose risk is a societal risk and is the product of accident probability and accident consequence.
[f] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP, 1991).
[g] Vehicle-related impacts are impacts independent of the cargo in the shipment.

waste inventories (specifically waste volume and mass, which directly determine the total number of shipments), packaging assumptions, and route distances among all pairs of origin and destination sites.

For truck transportation, the total estimated number of fatalities from radiological causes ranges from approximately 0.009 to 0.5. For rail transportation, fatalities from radiological causes range from 0.004 to 0.06. Shipment by rail results in lower doses to crew members and the public, primarily because of the reduced number of shipments involved. In general, for LLMW shipments, the vehicle-related risks are greater than the associated cargo-related risks.

E.7.4.3 Maximally Exposed Individual Assessment

The estimated doses during routine transportation for each of the individual receptors considered (see Section E.6.9 for exposure assumptions) are presented in Table E–30 on a per-event basis. The total dose for repeated exposures can be estimated by multiplying the per-event dose by the number of exposures.

As noted previously for HLW and LLW shipments, the potential exists for significant individual exposures if multiple exposure-causing events occur during LLMW shipments; for instance, the dose to a person caught in a traffic jam for 30 minutes next to a shipment is estimated to be 0.5 mrem. If the exposure is longer, the dose would rise proportionally. Therefore, it is conceivable that a person could receive a dose of between 2 to 10 mrem while stopped in traffic next to an LLMW shipment. In addition, a person working at a truck service station could receive an increased dose if trucks were to use the same stops repeatedly. If a truck-stop worker is present for 100 shipment stops (at the distance and duration given previously), the estimated dose is approximately 2 mrem. Administrative controls could be instituted to control the location and duration of truck stops if multiple exposures were to happen routinely. The probability of multiple exposures increases as the amount of waste transportation increases.

Table E–30. Estimated Routine Doses and Lifetime Risk of Fatal Cancer to MEIs From Shipments of LLMW (per Exposure Event)[a]

	Dose (rem)		Lifetime Risk[c]	
Receptor[b]	**Truck**	**Rail**	**Truck**	**Rail**
Workers				
Crew member	d	d	d	d
Inspector	1.5E–04	1.5E–04	6.0E–08	6.0E–08
Rail-yard crew member	NA	7.9E–05	NA	3.0E–08
Public				
Resident	1.6E–08	1.6E–08	8.0E–12	8.0E–12
Person in traffic jam	5.0E–04	5.0E–04	3.0E–07	3.0E–07
Person at service station	2.1E–05	NA	1.0E–08	NA
Resident near rail stop	NA	1.1E–06	NA	6.0E–10

Note: NA = not applicable.
[a] Dose rate is assumed to be 1 mrem/h at 1 m (3.3 ft) from an LLMW shipment.
[b] Receptor assumptions are described in Section E.6.9.
[c] Lifetime risk of fatal cancer based on ICRP Publication 60 (ICRP, 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public.
[d] The DOE administrative control level limits doses to DOE workers to 2 rem/yr.

The potential cumulative dose to a resident living along a site entrance route is summarized in Table E–31 for the LLMW alternatives. Doses were calculated for all DOE sites for each case; however, only the five sites sending or receiving the most shipments have been included in Table E–31. The cumulative doses assume that a resident is present for every shipment entering and exiting a site and is unshielded at a distance of 30 m (98 ft) from the roadway. The maximum cumulative dose would occur near regionalized or centralized facilities because of the large number of shipments entering a small number of sites; for instance, for the Regionalized 3 Alternative, the maximum dose to a resident living near the NTS would be approximately 0.2 mrem for the all-truck case and 0.06 mrem for the all-rail case. The annual dose can be estimated by assuming that shipments would occur over a 10-year period for all alternatives. The estimated annual dose to a resident would be well below the annual limit of 100 mrem specified for members of the public through DOE Orders (DOE, 1990b), as well as comparable NRC limits (10 CFR 20).

E.7.4.4 Accident Consequence Assessment

As stated previously, the accident consequences were calculated for transportation-related accidents that result in the maximum release of radioactive material (accident severity Category VIII). For these accidents, the assumptions were that all of the material in the shipment would be released from its packaging, that 10% would be entrained as an aerosol, and that 5% of the aerosol would be respirable.

During screening, the LLMW from the Paducah Gaseous Diffusion Plant (PGDP) was found to result in the highest transportation accident doses for the most severe accidents. The accident consequence results from RISKIND for LLMW shipments are presented in Table E–32. The population doses are for a uniform population density within an 80-km (50-mi) radius of accidents occurring in rural, suburban, and urban population density zones. The location of the MEI after an accident is determined on the basis of atmospheric conditions and the buoyant characteristics of the released plume. The locations of maximum exposure are approximately 160 m (525 ft) and 400 m (1,312 ft) from the accident site for neutral and stable weather conditions, respectively. The dose to the MEI is independent of the location of the accident. The maximum dose to an individual (approximately 5 rem for a rail accident under unfavorable weather conditions) has a potential lifetime fatal-cancer risk of 2.0E-03.

Table E-31. Cumulative Dose and Lifetime Risk to MEI Living Along a Site Entrance Route for WM LLMW Shipments (Current Inventories plus 20 Years of Generation)[a]

	All Truck			All Rail		
Alternatives and Site[b]	Total Shipments	Dose (rem)	Risk (Fatal Cancer)[c]	Total Shipments	Dose (rem)	Risk (Fatal Cancer)[c]
Decentralized						
LLNL	250	4.0E-06	2.0E-09	120	1.9E-06	1.0E-09
ETEC	110	1.8E-06	9.0E-10	40	6.4E-07	3.0E-10
NTS	100	1.6E-06	8.0E-10	40	6.4E-07	3.0E-10
SRS	90	1.4E-06	7.0E-10	90	1.4E-06	7.0E-10
PORTS	90	1.4E-06	7.0E-10	90	1.4E-06	7.0E-10
Regionalized 1						
FEMP	1,060	1.7E-05	9.0E-09	410	6.6E-06	3.0E-09
PORTS	820	1.3E-05	7.0E-09	440	7.1E-06	4.0E-09
ANL-E	450	7.2E-06	4.0E-09	180	2.9E-06	1.0E-09
LLNL	310	5.0E-06	3.0E-09	180	2.9E-06	1.0E-09
NTS	120	1.9E-06	1.0E-09	60	9.7E-07	5.0E-10
Regionalized 2						
LANL	2,610	4.2E-05	2.0E-08	1,020	1.6E-05	8.0E-09
RFETS	2,560	4.1E-05	2.0E-08	980	1.6E-05	8.0E-09
PORTS	2,260	3.6E-05	2.0E-08	960	1.5E-05	8.0E-09
ORR	1,660	2.7E-05	1.0E-08	650	1.0E-05	5.0E-09
ANL-E	450	7.2E-06	4.0E-09	180	2.9E-06	1.0E-09
Regionalized 3						
NTS	9,650	1.6E-04	8.0E-08	3,700	6.0E-05	3.0E-08
RFETS	2,560	4.1E-05	2.0E-08	980	1.6E-05	8.0E-09
PORTS	2,260	3.6E-05	2.0E-08	960	1.5E-05	8.0E-09
ORR	2,100	3.4E-05	2.0E-08	790	1.3E-05	6.0E-09
Hanford	1,690	2.7E-05	1.0E-08	710	1.1E-05	6.0E-09
Regionalized 4						
INEL	2,450	3.9E-05	2.0E-08	1,040	1.7E-05	8.0E-09
RFETS	1,990	3.2E-05	2.0E-08	740	1.2E-05	6.0E-09
ORR	1,480	2.4E-05	1.0E-08	740	1.2E-05	6.0E-09
PORTS	650	1.0E-05	5.0E-09	260	4.2E-06	2.0E-09
ANL-E	450	7.2E-06	4.0E-09	180	2.9E-06	1.0E-09
Centralized						
Hanford	7,520	1.2E-04	6.0E-08	3,340	5.4E-05	3.0E-08
RFETS	1,990	3.2E-05	2.0E-08	740	1.2E-05	6.0E-09
ORR	1,970	3.2E-05	2.0E-08	740	1.2E-05	6.0E-09
INEL	700	1.1E-05	6.0E-09	290	4.7E-06	2.0E-09
PORTS	650	1.0E-05	5.0E-09	260	4.2E-06	2.0E-09

[a] The external dose rate is assumed to be 1 mrem/h at 1 m (3.3 ft) for all shipments. The resident is assumed to be present for all shipments that enter or exit the site. Shipments are assumed to pass at a distance of 30 m (98 ft) and an average speed of 24 km/h (15 mi/h).
[b] For each alternative, only the five sites sending or receiving the most shipments are reported. All other sites have MEI doses less than those presented here.
[c] The risk of fatal cancer is calculated by using the ICRP Publication 60 (ICRP, 1991) health risk conversion factor of 5.0E-04 fatal cancers per person-rem for members of the public.

Table E–32. Estimated Consequences for the Most Severe Accidents Involving Shipments of WM LLMW[a,b]

Mode and Accident Location	Neutral Conditions[c]				Stable Conditions[d]			
	Population[e]		MEI[f]		Population[e]		MEI[f]	
	Dose (person-rem)	Risk (Cancer Fatalities)	Dose (rem)	Risk (Cancer Fatality)	Dose (person-rem)	Risk (Cancer Fatalities)	Dose (rem)	Risk (Cancer Fatality)
Truck								
Urban	6.0E+02	3.0E–01	5.3E–01	2.7E–04	4.75E+03	2.0E+00	1.8E+00	9.0E–04
Suburban	1.1E+02	6.0E–02	5.3E–01	2.7E–04	8.85E+02	4.0E–01	1.8E+00	9.0E–04
Rural	1.0E+00	5.0E–04	5.3E–01	2.7E–04	7.5E+00	4.0E–03	1.8E+00	9.0E–04
Rail								
Urban	1.62E+03	8.0E–01	1.4E+00	7.0E–04	1.283E+04	6.0E+00	4.8E+00	2.4E–03
Suburban	3.0E+02	2.0E–01	1.4E+00	7.0E–04	2.4E+03	1.0E+00	4.8E+00	2.4E–03
Rural	2.7E+00	1.0E–03	1.4E+00	7.0E–04	2.0E+01	1.0E–02	4.8E+00	2.4E–03

[a] The most severe accidents correspond to the highest NUREG-0170 accident severity category (Category VIII) (NRC, 1977a). Results are reported for WM LLMW from PGDP, which was found to result in the highest potential accident doses. The assumptions were that 100% of the radioactive material would be released from its packaging in an accident, that 10% of the release would be entrained in an aerosol, and that 5% of the aerosolized release would be respirable.

[b] Buoyant plume rise resulting from fire for a severe accident was included in the exposure model.

[c] Neutral weather conditions result in moderate dispersion and dilution of the released plume. Neutral conditions were taken to be Pasquill Stability Class D with a wind speed of 4 m/s (9 mi/h). Neutral conditions occur approximately 50% of the time in the United States.

[d] Stable weather conditions result in minimal dispersion and dilution of the released plume and are thus unfavorable. Stable conditions were taken to be Pasquill Stability Class F with a wind speed of 1 m/s (2.2 mi/h). Stable conditions occur approximately one-third of the time in the United States.

[e] Populations extend at a uniform population density to a radius of 80 km (50 mi) from the accident site. Population exposure pathways include acute inhalation; acute cloudshine; groundshine; resuspended inhalation; resuspended cloudshine; and ingestion of food, including initially contaminated food (rural only). No decontamination or mitigative actions are taken.

[f] The MEI is assumed to be at the location of maximum exposure. The locations of maximum exposure would be 160 m (525 ft) and 400 m (1,312 ft) from the accident site under neutral and stable atmospheric conditions, respectively. Individual exposure pathways include acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingested dose is considered.

E.7.4.5 Onsite Assessment Results

The onsite risks for LLMW transportation at the Hanford Site are summarized in Table E–28 for truck transportation and in Table E–29 for rail transportation. The risks presented for the transportation crew include the dose to workers in areas along the shipping route. The total dose to workers close to the route is generally much less than the dose to the actual crew members involved in transporting the waste. Risks calculated for the public include persons sharing the transportation route with waste shipments. The MEI for routine conditions, besides crew members, was considered to be a guard at a facility gate or checkpoint along the route who is exposed to each shipment for 1 minute at a distance of 5 m (16.4 ft). The total dose to the guard for all shipments is estimated to be 16 mrem. Overall, the routine onsite shipment risks are much less than the offsite shipment risks for all cases considered.

In addition, the consequences of an onsite accident at the Hanford Site are summarized in Table E–20. For the accident consequence assessment, the characteristics of LLMW from the Hanford Site were used. The MEI is located at the position where maximum impacts would occur, similar to the offsite accident consequence assessment. An exposure of 2 hours was assumed for the population of onsite workers after an accident. The impacts on the offsite population were calculated by using the population distribution in the vicinity of the Hanford Site and by assuming a 1-year exposure duration.

E.8 Uncertainties and Conservatism in Estimated Impacts

The sequence of analyses performed to generate estimates of radiological risk for transporting radioactive waste includes (1) determining waste inventory and characteristics at each site, (2) estimating shipment requirements, (3) determining route characteristics, (4) calculating radiation doses to exposed individuals (including estimating of environmental transport and uptake of radionuclides), and (5) estimating health effects. Uncertainties are associated with each step. Uncertainties exist in the way that the physical systems being analyzed are represented by the computational models; in the data required to apply the models (because of measurement errors, sampling errors, natural variability, or unknowns caused simply by the future nature of the actions being analyzed); and in the calculations themselves (for example, the approximation algorithms used by the computers).

In principle, one can estimate the uncertainty associated with each input or computational source and predict the resultant uncertainty in each subsequent set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final, or absolute, result.

However, conducting such a full-scale quantitative uncertainty analysis is often impractical and sometimes impossible, especially for actions to be initiated at an unspecified time in the future. Instead, the risk analysis is designed to ensure—through uniform and judicious selection of scenarios, models, and input parameters—that relative comparisons of risk among the various alternatives are meaningful. In the transportation risk assessment, this design is accomplished by uniformly applying input parameters and assumptions to all alternatives for each waste type. Therefore, although considerable uncertainty is inherent in the absolute magnitude of the transportation risk for each alternative, much less uncertainty is associated with the relative differences among the alternatives in a given measure of risk.

In the following sections, areas of uncertainty are discussed for each assessment step enumerated previously, with the exception of health effects. Special emphasis is placed on identifying whether the uncertainties affect relative or absolute measures of risk. Where practical, the parameters that most significantly affect the risk assessment results are identified, and quantitative estimates of uncertainty are provided. The uncertainties involved in estimating health effects from radiological doses are discussed in Appendix D.

E.8.1 Uncertainties in Waste Inventory and Characterization

The site-specific waste inventories and the physical and radiological waste characteristics are important input parameters for the transportation risk assessment. The potential amount of transportation for any alternative is determined primarily by the projected waste inventory at each site and assumptions about shipment configurations (packaging and shipment capacities). The physical and radiological waste characteristics are important in determining the amount of waste released during accidents and the subsequent doses to exposed individuals through multiple environmental exposure pathways.

The development of projected site-specific inventory and waste characterization data, including identification of uncertainties, is discussed in the reports prepared for each waste type. In general, the uncertainties in the data specific to the site and to the waste type may potentially affect the relative and absolute measures of transportation risk and are difficult to quantify. Precisely defining the impact of these uncertainties on the transportation risk analysis is difficult because of the large number of sites and alternatives and because of the inability to accurately quantify the uncertainty in waste characterization at each site.

The uncertainties in the waste characterization data will be reflected to some degree in the transportation risk results. If the waste inventories are consistently overestimated (or underestimated), the resulting transportation risk estimates will also be overestimated (or underestimated) by roughly the same factor. In terms of relative risk comparisons, if the uncertainty in one site inventory is large as compared with other site inventories, then the uncertainties may not be comparable among different alternatives, and meaningful relative risk comparisons are difficult. For example, if the inventory at Site A is overestimated as compared with other sites, the risk transportation assessment results will be unduly biased toward those alternatives that do not involve shipping Site A waste; however, the waste characterization data have been carefully developed by uniformly applying consistent methodologies and assumptions to the best available information. This approach is expected to limit the overall uncertainty in the data and the likelihood that the level of uncertainty varies significantly among sites. For comparative purposes among alternatives, the observed differences in transportation risks are believed to represent unbiased, reasonably accurate estimates from current information.

E.8.2 UNCERTAINTIES IN SHIPMENT CONFIGURATIONS

As stated previously, the amount of transportation required for each alternative is partly based on assumptions about the packaging and shipment configurations for each waste type. Representative shipment configurations have been defined for each waste type on the basis of either historical or probable future shipment capacities (for example, all truck shipments of LLW are assumed to be at the regulatory weight limit). In reality, the actual shipment capacities may differ from the predicted capacities so that the projected number of shipments and, consequently, the total transportation risk would change; however, although the predicted transportation risks would increase or decrease accordingly, the relative differences in risks among consolidation alternatives would generally remain unchanged.

E.8.3 UNCERTAINTIES IN ROUTE DETERMINATION

Conceptual routes have been determined between all pairs of origin and destination sites considered by the alternatives. The routes have been determined consistent with current guidelines, regulations, and practices but may not be the actual routes that will be used in the future. In reality, the actual routes may differ from the conceptual ones in terms of distances and total population along the routes. Moreover, because the assessment considers wastes generated over the next 20 to 30 years, the highway and rail infrastructures and the demographics along routes may change as a function of time. Although these effects have not been accounted for in the transportation assessment, it is not anticipated that these changes would significantly affect relative comparisons of risk among alternatives considered in the PEIS.

E.8.4 UNCERTAINTIES IN THE CALCULATION OF RADIATION DOSES

The models used to calculate radiation doses from transportation activities introduce additional uncertainty into the risk assessment process. Estimating the accuracy, or absolute uncertainty, of the risk assessment results is generally difficult. The accuracy of the calculated results is closely related to the limitations of the computational models and to the uncertainties in each of the input parameters that the model requires. The single greatest limitation facing users of RADTRAN, or any computer code of this type, is the scarcity of data for certain input parameters.

Uncertainties associated with the computational models are minimized by using state-of-the-art computer codes that have been extensively reviewed. However, because numerous uncertainties are recognized but are difficult to quantify, assumptions are made at each step of the risk assessment process that are intended to produce conservative results (that is, overestimate the calculated dose and radiological risk). Because parameters and assumptions are applied equally to all alternatives for a waste type, this model bias is not expected to affect the meaningfulness of relative comparisons of risk; however, the results may not represent risks in an absolute sense.

To understand the most important uncertainties and conservatisms in the transportation risk assessment, the results for all cases were examined to identify the largest contributors to the collective population risk. The results of this examination are discussed briefly in the following paragraphs.

For truck shipments, the largest contributors to the collective population dose were found to be, in decreasing order of importance: (1) incident-free dose to members of the public at stops; (2) incident-free dose to transportation crew members; (3) incident-free dose to members of the public sharing the route (on-link dose); (4) incident-free dose to members of the public living along the route (off-link dose); and (5) accident dose risk to members of the public. Approximately 80% of the estimated public dose was incurred at stops; 15% was incurred by the on-link population; and 5% was incurred by the off-link population. In general, the accident contribution to the total risk was negligible as compared with the incident-free risk.

For rail shipments, the largest contributors to the collective population dose were found to be the following (in decreasing order of importance): (1) incident-free dose to transportation crew members; (2) incident-free dose to members of the public living along the route (off-link dose); (3) incident-free dose to members of the public at stops; (4) incident-free dose to members of the public sharing the route (on-link dose); and (5) accident dose risk to members of the public. Approximately 70% of the estimated public dose was incurred by the off-link population; 25% was incurred by the population at stops; and 5% was incurred by the on-link population. As with truck shipments, the accident contribution to the total risk in general was negligible as compared with the incident-free risk.

As shown previously, incident-free transportation risks are the dominant component of the total transportation risk for both truck and rail modes. The most important parameter in calculating incident-free doses is the shipment external dose rate (incident-free doses are directly proportional to the shipment external dose rate). For calculational purposes, representative dose rates have been applied to each waste type because information is not available to predict shipment dose rates accurately on a site-by-site basis. The representative dose rates are based on historical shipments or waste type-specific data when possible and were selected to reflect the probable average dose rates of future shipments. In practice, the external dose rates will vary not only from site to site and waste type to waste type, but also from shipment to shipment at a given site; and the rates will range above and below the levels assumed for this assessment.

Finally, the single largest contributor to the collective population doses calculated with RADTRAN was found to be the dose to members of the public at truck stops. RADTRAN uses a simple point source approximation for truck stop exposures and assumes that the total stop time for a shipment is proportional to the shipment distance. The parameters used in the stop model were based on a survey of a very limited number of radioactive material shipments that examined various shipment types in different areas of the country (Madson and Wilmot, 1982). The assumption was made that stops occur as a function of distance, with a rate of 0.011 h/km; thus, for a 1,000-km (621-mi) trip, the total would be 11 hours of stops. The further assumption was made that an average of 25 people are exposed at a distance of 20 m (66 ft) at each stop. The population dose is directly proportional to the external shipment dose rate and the number of people exposed (25) and is inversely proportional to the square of the distance ($20 \times 20 = 400$). Based on the limited data available, the parameter values used in the assessment appear to be conservative; however, data do not exist to qualitatively assess the degree of conservatism in the stop dose model. As a practical matter, DOE could conceivably take steps to control the location, frequency, and duration of truck stops, if necessary to assure that the local population does not receive excessive exposure to radiation.

E.8.5 Uncertainties in the Comparison of Truck and Rail Transportation Modes

The transportation risk assessment results presented in the WM PEIS indicate that rail transportation poses a lower overall risk to workers and the public as compared with truck transportation of the same quantity of waste. However, it is important to recognize that although rail shipments were found to result in a smaller number of expected fatalities compared with truck shipments, in general the risks from transportation operations are small for both modes. Moreover, comparisons between truck and rail shipment risks need to consider the uncertainties inherent in the risk assessment process. As discussed above, in most cases the calculational uncertainties are difficult to quantify and, in fact, may not be the same between the truck and rail assessment assumptions. Some important issues that should be considered while comparing truck and rail shipment risks are discussed below.

In the WM PEIS, transportation risks were estimated for the shipment of all waste by (a) 100% truck and (b) 100% rail for each alternative and waste type. The intent of this approach was to bound the transportation impacts for any possible mix of truck and rail shipments, recognizing that both will likely take place in the future. Therefore, all facilities were assumed to have rail access. A review of the transportation capabilities at 35 major DOE sites indicated that 15 have direct rail access onsite, an additional 12 have access within 10 miles, and 8 more have access between 10 and 100 miles. For those sites lacking direct rail access, the risks associated with shipping waste by truck to a rail siding were not considered in detail in the WM PEIS assessment, although preliminary evaluations indicated that these activities are generally a small contributor to the overall transportation risk.

Although subject to calculational uncertainties, a number of factors contribute to the assessment results, indicating that rail shipments have lower impacts than truck shipments for the same alternative. These include:

- Rail shipments are larger than truck shipments (about three times larger) and thus require fewer total shipments. Consequently, impacts tend to be lower for rail because overall transportation impacts tend to be proportional to shipment mileage.
- On a per-shipment basis, rail shipments have lower radiological impacts than truck shipments. The radiological impacts from rail shipments tend to be lower than truck shipments because fewer members of the public are exposed during rail transport (primarily fewer people at stops and sharing the routes). In addition, crew members tend to be much farther from the radioactive material packages. However, the differences in radiological risk between the two modes for all

alternatives lies within the uncertainty from the estimates for the number and location of exposed persons in both cases.

Although rail impacts were found to be lower than truck impacts, a number of considerations were not specifically addressed in the representative assessment conducted for the purposes of the WM PEIS. First, rail shipments may require additional handling and preparation, especially for sites lacking rail access, which will contribute to the overall rail shipment risk. Second, rail shipments generally require a large inventory of waste to be cost-effective, and thus may not be a cost-effective option at smaller generating sites. Finally, rail operations in general are not as flexible and responsive to individual site needs and capabilities as truck operations.

E.9 Mitigative Measures

The DOE is committed to conducting all transportation-related activities in a manner protective of human health and safety. The hazards of transporting radioactive materials under both incident-free conditions and accidents are minimized by existing regulations. All activities related to transporting radioactive waste would be conducted according to applicable health-and-safety requirements of the Federal Government, States, and local jurisdictions, including requirements promulgated by DOT in 49 CFR.

Transportation planning integrates a wide range of expertise and requirements, including program engagement, material handling and packaging, transportation operations (traffic management), key governmental involvement, public information, environmental safety and health, and emergency preparedness. Where necessary, planning would be clarified in a Transportation Plan that would document the planned logistics for a shipping campaign. The focus of this plan would be operational; e.g., the handling, packaging, and transport of the waste through sequential steps resulting in the safe transport to a site. The plan would include organizational responsibilities of DOE, the shipper, corridor jurisdictions, and other Federal agencies. It would contain shipment schedules, transport mode, shipment route, emergency plan and contacts, and communication strategies.

Although detailed plans about waste transportation will not be prepared for major shipping campaigns until some future time, safety plans have been prepared for a program involving the transportation of TRUW to WIPP. The plans for WIPP can be considered as representative of those for future major DOE programs for waste transportation. The WIPP plans (DOE, 1990a) include provisions for the following:

- Vehicles and equipment with the best available mechanical safeguards, including personal protective equipment and speed limiters
- A facility for maintaining and inspecting equipment
- A safety program, including personnel training in safe work practices
- Stringent driver-training program and penalty provisions
- Accident and emergency training
- Constant-surveillance service for all loaded shipments
- Communications equipment and services

In reviewing the WIPP program activities, the National Academy of Sciences concluded that the "system proposed for transportation of TRUW waste to the WIPP is safer than that employed for any other hazardous material in the United States today and will reduce risk to very low levels" (DOE, 1990a).

In addition to these policies, DOE may impose administrative measures to control accumulated doses during specific circumstances. Examples of administrative controls would include requiring temporary lead shielding between loaded casks and service personnel, controlling the location and duration of service stops, and prohibiting transportation during inclement weather. These measures would ensure that all exposures are maintained below the regulatory dose limits specified in DOE Orders 5400.5 and 5480.11 (DOE, 1988c, 1990b), as well as comparable NRC limits (10 CFR 20) for members of the public and for workers.

For accidents, DOE has issued a series of orders specifying the requirements for emergency preparedness, including DOE Orders 5500.10, 5500.2B, 5500.3A, and 5500.4A (DOE, 1991a–c, 1992a). Each DOE site has also established an emergency management program, such as the one at the Hanford Site (WHC, 1994). Procedures and agreements among DOE, other Federal agencies, and State agencies are in place to allow for effective response by all appropriate parties if a severe accident should occur.

State and local police and fire departments have primary responsibility for responding to events that could endanger the health and welfare of their citizens. Most States maintain specialized teams capable of responding to hazardous materials incidents. Through the capabilities these teams currently possess for dealing with potential accidents involving other hazardous materials (e.g., hazardous chemicals), they should already have the capability to deal with most plausible accidents involving LLW and LLMW. Thus, additional training for LLW and LLMW would most likely be minimal. However, some states would require additional training to respond to potential radioactive hazards resulting from TRUW or HLW transportation accidents. Currently, to assist in planning and preparedness for an unlikely, but theoretically possible transportation emergency involving TRUW or HLW radioactive shipments, DOE does offer a variety of radiological emergency response resources and information to complement existing emergency preparedness programs, and will continue to maintain a comprehensive emergency management system, particularly for radiological emergencies. The emergency management system includes training courses, Regional Coordinating Offices, and DOE Radiological Assistance Program teams.

E.10 References

Part I

ANL. *See* Argonne National Laboratory.

Argonne National Laboratory. 1996a. *Risk Assessment for the On-Site Transportation of Radioactive Wastes for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by B.M. Biwer, F.A. Monette, and S.Y. Chen. ANL/EAD/TM-18. Argonne, IL.

Argonne National Laboratory. 1996b. *Risk Assessment for Transportation of Hazardous Waste and Hazardous Waste Components of Low-Level Mixed Waste and Transuranic Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.A. Lazaro, A.J. Policastro, H.M. Hartmann, A.A. Antonopoulos, D.F. Brown, W.E. Dunn, M.A. Cowen, Y.S. Chang, and B.L. Koebnick. ANL/EAD/TM-28. Argonne, IL.

Argonne National Laboratory. 1996c. *Risk Assessment for the Off-Site Transportation of High-Level Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by F.A. Monette, B.M. Biwer, and S.Y. Chen. ANL/EAD/TM-21. Argonne, IL.

Argonne National Laboratory. 1996d. *Supplemental Information Relating to Risk Assessment for the Off-Site Transportation of Transuranic Waste for the U.S. Department of Energy Waste Management Programmatic Waste Impact Statement* by F.A. Monette, B.M. Biwer, D.J. LePoire, and S.Y. Chen. ANL/EAD/TM-27. Argonne, IL.

Argonne National Laboratory. 1996e. *Supplemental Information Related to Risk Assessment for the Off-Site Transportation of Low-Level Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by F.A. Monette, B.M. Biwer, D.J. LePoire, and S.Y. Chen. ANL/EAD/TM-23. Argonne, IL.

Argonne National Laboratory. 1996f. *Supplemental Information Related to Risk Assessment for the Off-Site Transportation of Low-Level Mixed Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by F.A. Monette, B.M. Biwer, D.J. LePoire, M.A. Lazaro, A.A. Antonopoulos, H.M. Hartmann, A.J. Policastro, and S.Y. Chen. ANL/EAD/TM-35. Argonne, IL.

Argonne National Laboratory. 1996g. *High-Level Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by S.M. Folga, G. Conzelmann, J.L. Gillette, P.H. Kier, and L.A. Poch. ANL/EAD/TM-17. Argonne, IL.

Argonne National Laboratory. 1996h. *Low-Level Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.L. Goyette and D.A. Dolak. ANL/EAD/TM-20. Argonne, IL.

Argonne National Laboratory. 1996i. *Transuranic Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by K.J. Hong, T.J. Kotek, S.M. Folga, B.L. Koebnick, Y. Wang, and C.M. Kaicher. ANL/EAD/TM-22. Argonne, IL.

Argonne National Laboratory. 1996j. *Hazardous Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.A. Lazaro, A.A. Antonopoulos, M.P. Esposito, and A.J. Policastro. ANL/EAD/TM-25. Argonne, IL.

Argonne National Laboratory. 1996k. *Information Related to Low-Level Mixed Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by B.D. Wilkins, D.A. Dolak, Y.Y. Wang, and N.K. Meshkov. ANL/EAD/TM-32. Argonne, IL.

Argonne National Laboratory. 1996l. *WASTE_MGMT: A Computer Model for Calculation of Waste Loads, Profiles, and Emissions* by T.J. Kotek, H.I. Avci, and B.L. Koebnick. ANL/EAD/TM-30. Argonne, IL.

DOE. *See* U.S. Department of Energy.

Doty, S.R., B.L. Wallace, and G.C. Holzworth. 1976. *A Climatological Analysis of Pasquill Stability Categories Based on STAR Summaries*. April. Asheville, NC: National Climatic Center, National Oceanic and Atmospheric Administration.

Fischer, L.E., C.K. Chou, M.A. Gerhard, C.Y. Kimura, R.W. Martin, R.W. Mensing, M.E. Mount, and M.C. Wette. 1987. *Shipping Container Response to Severe Highway and Railway Accident Conditions*. NUREG/CR-4829. UCID-20733. Prepared by Lawrence Livermore National Laboratory. Washington, DC: Division of Reactor System Safety, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission.

ICRP. *See* International Commission on Radiological Protection.

International Commission on Radiological Protection. 1977. *Recommendations of the International Commission on Radiological Protection*. ICRP publication 26. Annals of the ICRP, vol. 1, no. 3. New York: Pergamon Press.

International Commission on Radiological Protection. 1991. *1990 Recommendations of the International Commission on Radiological Protection*. ICRP publication 60. Annals of the ICRP, vol. 21, nos. 1–3. New York: Pergamon Press.

Johnson, P.E., D.S. Joy, D.B. Clark, and J.M. Jacobi. 1993a. *HIGHWAY 3.1, An Enhanced Transportation Routing Model: Program Description, Methodology, and Revised User's Manual*. ORNL/TM-12124. March. Oak Ridge, TN: Oak Ridge National Laboratory.

Johnson, P.E., D.S. Joy, D.B. Clark, and J.M. Jacobi. 1993b. *INTERLINE 5.0, An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual*. ORNL/TM-12090. March. Oak Ridge, TN: Oak Ridge National Laboratory.

Madson, M.M., and E.L. Wilmot. 1982. *Truck Transportation of Radioactive Materials*. SAND-82-1952C. Albuquerque, NM: Sandia National Laboratories.

Mercado, J.E., J.G. Field, R.J. Smith, and O.S. Wang. 1992. *Alternative Risk-Based Criteria for Transportation of Radioactive Material on the United States Department of Energy Hanford Site*. WHC-SA-1385. Richland, WA: Westinghouse Hanford Co.

Neuhauser, K.S., and F.L. Kanipe. 1993. *RADTRAN 4, Volume II: Technical Manual*. SAND89-2370. Albuquerque, NM: Sandia National Laboratories.

NRC. *See* U.S. Nuclear Regulatory Commission.

Rao, R.K., E.L. Wilmot, and R.E. Luna. 1982. *Non-Radiological Impacts of Transporting Radioactive Material*. SAND81-1703. TTC-0236. Albuquerque, NM: Sandia National Laboratories.

Saricks, C. and T. Kvitek. 1994. *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight*. July. ANL/ESD/TM-68. Argonne, IL: Argonne National Laboratory.

U.S. Department of Energy. 1986a. *Environmental Assessment: Yucca Mountain, Nevada, Nuclear Waste Policy Act*. DOE/RW-0073. May. Washington, DC: Office of Civilian Radioactive Waste Management.

U.S. Department of Energy. 1986b. *Environmental Assessment: Deaf Smith County Site, Texas*. DOE/RW-0069. May. Washington, DC: Office of Civilian Radioactive Waste Management.

U.S. Department of Energy. 1987a. *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes*. DOE/EIS-0113. Dec. Richland, WA: Richland Operations Office.

U.S. Department of Energy. 1987b. *Analysis of Radiation Doses from Operation of Postulated Commercial Spent Fuel Transportation Systems*. DOE-CH/TPO-001. Nov. Richland, WA: Pacific Northwest Laboratory.

U.S. Department of Energy. 1988a. *External Dose Rate Conversion Factors for Calculation of Dose to the Public*. DOE/EH-0070. Washington, DC: Office of Environment, Safety, and Health.

U.S. Department of Energy. 1988b. *Internal' Dose Conversion Factors for Calculation of Dose to the Public*. DOE/EH-0071. Washington, DC: Office of Environment, Safety, and Health.

U.S. Department of Energy. 1988c. *Radiation Protection for Occupational Workers*. DOE Order 5480.11. Dec. 21. Washington, DC: Office of Environment, Safety, and Health.

U.S. Department of Energy. 1989. *Low-Level Burial Grounds Dangerous Waste Permit Application*. DOE/RL-88-20. Richland, WA: Richland Operations Office.

U.S. Department of Energy. 1990a. *Supplemental Environmental Impact Statement: Waste Isolation Pilot Plant*. DOE/EIS-0026-FS. Jan. Washington, DC.

U.S. Department of Energy. 1990b. *Radiation Protection of the Public and the Environment*. DOE Order 5400.5. Feb. 8. Washington, DC: Office of Environment, Safety, and Health.

U.S. Department of Energy. 1991a. *Emergency Categories, Classes, and Notification and Reporting Requirements*. DOE Order 5500.2B. April 30. Washington, DC: Director of Emergency Operations.

U.S. Department of Energy. 1991b. *Emergency Readiness Assurance Program*. DOE Order 5500.10. April 30. Washington, DC: Director of Emergency Operations.

U.S. Department of Energy. 1991c. *Planning and Preparedness for Operational Emergencies*. DOE Order 5500.3A. April 30. Washington, DC: Director of Emergency Operations.

U.S. Department of Energy. 1992a. *Public Affairs Policy and Planning Requirements*. DOE Order 5500.4A. June 8. Washington, DC: Office of Public Affairs.

U.S. Department of Energy. 1992b. *Environmental and Other Evaluations of Alternatives for Siting, Constructing, and Operating New Production Reactor Capacity*. DOE/NP-0014. Sept. Washington, DC: Office of New Production Reactors.

U.S. Nuclear Regulatory Commission. 1977a. *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*. NUREG-0170. Washington, DC.

U.S. Nuclear Regulatory Commission. 1977b. *Calculation of Annual Dose to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance With 10 CFR Part 50, Appendix I, Rev. 1*. Regulatory Guide 1.109. Washington, DC.

Wang, O.S., R.F. Carlstrom, G.A. Coles, and M.V. Schultz. 1991. *Risk Assessment of Intra-Area Transport of Radioactive Waste Using the TRUPACT-II Standard Waste Box*. WHC-SA-1276. Richland, WA: Westinghouse Hanford Co.

Westinghouse Hanford Co. 1993. *Hazardous Material Packaging and Shipping Manual*. WHC-CM-2-14. April. Richland, WA.

Westinghouse Hanford Co. 1994. *Emergency Plan*. WHC-CM-4-1. Jan. Richland, WA.

WHC. *See* Westinghouse Hanford Co.

Wilmot, E.L. 1981. *Transportation Accident Scenarios for Commercial Spent Fuel*. SAND80-2124. Albuquerque, NM: Sandia National Laboratories.

Yuan, Y.C., S.Y. Chen, D.J. LePoire, and R. Rothman. 1993. *RISKIND—A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel*. ANL/EAIS-6, Rev. 0. Feb. Argonne, IL: Argonne National Laboratory.

APPENDIX E—PART II
Hazardous Waste Transportation Risk Assessment

E.11 Introduction

Part II of this appendix considers risk from hazardous waste (HW) transportation and from the hazardous waste components of low-level mixed waste (LLMW) and transuranic waste (TRUW). These wastes are regulated under the Resource Conservation and Recovery Act (RCRA). Some waste types not covered by RCRA but regulated by the States or under the Toxic Substances Control Act (TSCA: 7 United States Code [USC] 136) are also included. The transportation of each waste type for treatment and ultimate disposal is an integral component of the alternatives being considered in the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS).

This appendix should be read in conjunction with the technical reports for HW, LLMW, and TRUW (ANL, 1996a-c), which present inventory characterization and waste load data for each major generator within the DOE complex. These data are used for the transportation risk assessment.

Section E.12 discusses the scope of the transportation risk assessment for HW and HW components of LLMW and TRUW. Section E.13 describes packaging requirements and the distinctions between requirements for HW and those for radioactive waste. Section E.14 describes the method for selecting the most likely transportation routes for use in the risk assessment. Section E.15 describes the analytical approach used for the transportation risk assessment. Modeling input parameters and assumptions are provided in Section E.16. Section E.17 presents the results of the transportation risk assessment for HW, LLMW, and TRUW. Section E.18 discusses sources of uncertainty in the assessment, focusing on areas that might affect comparisons among alternatives. Finally, Section E.19 suggests mitigative measures that could be implemented to reduce the risk of transporting HW and HW components of LLMW and TRUW.

E.12 Scope of Assessment

This section describes the scope of the PEIS transportation risk assessment, including the treatment, storage, and disposal (TSD) alternatives; transportation-related activities; onsite versus offsite assessments; potential vehicle- and cargo-related impacts; receptors; and transportation modes are considered. Subsequent sections provide additional details about the assessment.

E.12.1 ALTERNATIVES

HW. The HW transportation risk analysis is intended to provide input for decisions about the extent to which DOE should continue to rely on commercial facilities for treating and disposing of the nonaqueous portion of the hazardous waste stream. Four alternatives are considered: (1) No Action, (2) Decentralized, (3) Regionalized 1 (five TSD sites), and (4) Regionalized 2 (two TSD sites). The specific DOE and TSD sites associated with these alternatives are discussed in Section E.17. The HW technical report (ANL, 1996a) contains details about TSD technologies, HW inventory and generation, existing and planned capabilities for treating and storing HW, and waste loads by alternative.

TRUW. For TRUW, six alternatives are considered: (1) No Action, (2) Decentralized, (3) Regionalized 1, (4) Regionalized 2, (5) Regionalized 3, and (6) Centralized. See Section E.2.2.3 for detailed descriptions of these alternatives.

LLMW. For LLMW, seven alternatives are considered: (1) No Action, (2) Decentralized, (3) Regionalized 1, (4) Regionalized 2, (5) Regionalized 3, (6) Regionalized 4, and (7) Centralized. See Section E.2.2.4 for detailed descriptions of these alternatives.

E.12.2 DESCRIPTION OF TRANSPORTATION ACTIVITIES

As in Part I of this appendix, the radioactive waste transportation risk assessment, these HW assessments for HW and HW components of TRUW and LLMW are limited to estimating the human health risks during waste transport. The risks during waste loading, unloading, and handling before or after shipment are not included; nor do these assessments address possible impacts from increased transportation levels on local traffic flow, noise levels, logistics, or infrastructure.

E.12.3 ONSITE VERSUS OFFSITE TRANSPORTATION

The HW transportation risk assessment includes onsite and offsite transportation. These transportation types are as defined in Section E.2.1. To estimate onsite transportation risks, site-specific values are used (when available). Models that rely on simplifying assumptions and average values for many parameters, such as road dimensions, weather conditions, and population densities, are used to estimate risk from offsite shipments. As in the radiological transportation risk assessment, the Hanford Site (Hanford) was selected as representative of conservatively estimated impacts for onsite transportation risks and is used for comparison with offsite transportation risks. On-site analyses were not conducted for TRUW and LLMW. For both of these waste types, the low risks estimated for offsite transportation indicated that risks from onsite transportation would be negligible.

E.12.4 CARGO-RELATED IMPACTS (HAZARDOUS CHEMICAL WASTES)

Cargo-related impacts to human health during HW, TRUW and LLMW transportation come from exposure resulting from container failure and chemical release during an accident (a collision with another vehicle or road obstacle). Containers used for shipping HW have been specified by the U.S. Department of Transportation (DOT) and have been assumed to preclude any significant exposure of workers or the public during routine HW transport. Type A packaging for LLMW is also designed and maintained to ensure the containers will contain and shield their contents during normal transport. TRUW is packaged in TRUPACT-II containers (i.e., external containers into which 55-gal drums are placed for transportation), decreasing further the likelihood of release under routine conditions. Accordingly, no cargo-related impacts are associated with HW transport under routine (incident-free) conditions.

The risks from HW and HW component exposure during transportation accidents can be either acute (resulting in immediate injury or fatality) or latent (resulting in cancer that becomes evident after a latency period of several years). Population risks and risks to the maximally exposed individual (MEI) have been evaluated for transportation accidents. Two acute health endpoints—potential life-threatening effects and potential adverse effects—have been evaluated for assessing cargo-related population impacts from transportation accidents. The identification of chemicals in HW, TRUW, and LLMW with potential life-threatening effects was made by comparison with gaseous and liquid substances designated "poison inhalation hazard" (PIH) chemicals by DOT. Chemicals selected for the potential adverse effects analysis included PIHs and gaseous or liquid chemicals with inhalation toxicity values (reference concentrations) established by the U.S. Environmental Protection Agency (EPA, 1993a-b).

The acute effects evaluated are assumed to exhibit a threshold, nonlinear relationship with exposure; that is, some low level of exposure can be tolerated without inducing a health effect. Chemical-specific values for the potential life-threatening concentration (PLC) and potential adverse effect concentration (PAEC) were developed to estimate risks. All individuals exposed at these levels or higher are included in HW transportation risk estimates. Use of this type of population risk descriptor, which involves estimating the number of persons exposed above a specified conservatively estimated level, is recommended under EPA guidance (EPA, 1992). Figure E–6 presents a conceptual diagram of how PLC and PAEC values were derived. Additionally, to address MEIs, locations of maximum HW concentration were identified for shipments with the largest potential releases of individual HW components.

A latent health endpoint—"increased cancer risk"—has also been used to assess the cargo-related population impacts from accidents involving carcinogen releases. Traditionally, risk assessment for chemical carcinogens characterizes risk to the MEI (EPA, 1989a). The MEI assessment is included in this HW

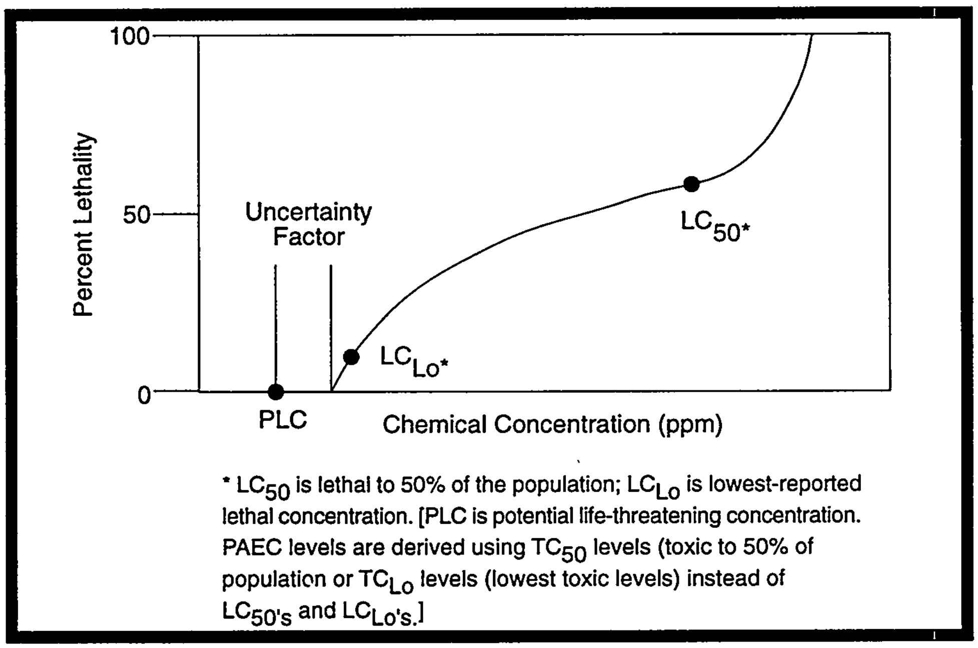

Figure E–6. Conceptualization of Threshold Health Effects.

transportation risk analysis (Section E.17.1.3). Additionally, for assessing risk to the general population, increased carcinogenic risk has been expressed as the number of individuals in the general population with an increased lifetime cancer risk of one in one million or greater, as recommended under EPA guidance for characterization of population risks (EPA, 1992). Cancer risks greater than one in one million have been designated as *increased cancer risk concentrations (ICRC) levels*. Overall population risk (in terms of number of excess cancers expected in the population) has not been calculated for HW as it was for radioactive waste because this calculation would require an estimate of average exposure levels in the population, while standardized cancer risk assessment methods address only MEIs. Therefore, characterizing population cancer risks associated with HW transportation as the number of individuals experiencing an increased risk of one in one million was deemed preferable. Cargo-related population cancer risks presented in this assessment cannot be directly compared with cancer risks for individuals.

Inhalation is the primary exposure route of concern for accidental release of HW, TRUW, and LLMW. Direct exposure to hazardous materials by other pathways, such as ingestion or dermal absorption, is possible, but these routes are expected to result in much lower exposure than the inhalation pathway doses. The likelihood of acute effects, such as those evaluated by using PLC and PAEC values, is much lower for the ingestion and dermal pathways than for inhalation. For HW, this assessment addresses inhalation of organic vapors and gases only: the potential for the public's exposure by inhalation of particulates is considered to be much lower than that for inhalation of vapors or gases because (1) DOE transports limited quantities of solids prone to particulate formation (for example, powders), so releases would be relatively small and would result only in small particulate clouds; (2) because particulates settle rapidly, exposure of the general population located 30 m (100 ft) farther from the release site would be minor because of low particulate concentrations; and (3) acute toxicity of inhaled particulates is lower than for vapors or gases in the DOE shipments for the same quantity released. Although some particulates are carcinogens (for example, cadmium salts), low exposure dose and duration make risks low compared with risks from vapors and gases. For LLMW, two types of exposures from solid wastes are also evaluated to maintain consistency with the radiological assessment. These are (1) volatile organic vapor emissions from contaminated spoils piles (i.e., solid waste spill on the ground); and (2) respirable aerosol fraction of organic substances from a solids spill direct to the atmosphere. Inorganic substances in LLMW were not assessed for the same reasons given above for HW. Evaluation of releases from solids was not conducted for TRUW because the bounding risk from release of organic liquids was minimal.

E.12.5 Vehicle-Related Impacts

For HW, vehicle-related risks (independent of a shipment's chemicals) are assessed for the same transportation routes as cargo-related impacts, for routine and accident conditions. Vehicle-related risks under routine conditions are the result of exposure to vehicle-exhaust emissions; risks are primarily associated with exposure in urban environments. Vehicle-related accident risks are fatalities and injuries resulting from direct physical trauma during an accident (not from exposure to released cargo). Fatality and injury rates specific to HW transportation are used in this assessment. For TRUW and LLMW, vehicle-related risks are presented in Part 1 of this appendix.

E.12.6 Transportation Mode

HW. The transportation risk assessment is based on shipping HW by truck from generators to TSD facilities. Shipments by rail, barge, and aircraft, although possible, have not been considered because none of these shipment modes were identified in the baseline case data. In addition, waste volumes accumulated at a site are generally small (onsite storage at DOE sites is generally limited to 90 days under RCRA, unless a Part B permit is obtained); the volume to be transported is not large enough to warrant rail or barge transportation.

TRUW and LLMW. Both truck and rail transport were assessed for TRUW and LLMW. The assessments for truck and rail shipments used the same methods and accident statistics as were used for the radiological assessment.

E.12.7 Receptors

In general, risks from HW, TRUW, and LLMW transportation are calculated for members of the public. Risks to the MEI are also presented. Potential risks are estimated for the collective populations of exposed people, as well as for MEIs. The collective population risk is a measure of the radiological risk posed to society by the alternative being considered, and it is the primary means of comparing various alternatives.

E.13 Waste Packaging

Regulations that govern the transportation of hazardous materials are designed to protect the public from the potential dispersal of hazardous materials. The specification of standards for packaging hazardous materials is the primary regulatory approach for ensuring the public's safety.

The packaging requirements for a specific hazardous material are determined by the level of hazard the material would present as a result of an accidental release. In the "Hazardous Materials Table" (Title 49, Part 172.01, of the *Code of Federal Regulations* [CFR]), which lists more than 4,000 chemicals in alphabetical order by proper shipping name, column 8 supplies a reference number to a part of 49 CFR 173. The part specified describes shipping requirements for a particular chemical.

Container acceptability is determined by performance-based tests (e.g., drop strength, leak resistance, hydrostatic pressure, stacking, and vibration) (49 CFR 173). A wide range of performance levels is required because of the broad spectrum of hazard levels presented by different hazardous materials.

Radioactive waste types generally have more rigorous containment requirements than HW. Most low-level waste (LLW) and LLMW can be shipped in Type A containers, typically 0.21-m^3 (55-gal) drums. The DOT and U.S. Nuclear Regulatory Commission (NRC) performance specifications for Type A radioactive waste containers are comparable to the DOT requirements for HW containers. Most other radioactive wastes considered in this PEIS (HLW and TRUW) require Type B containers, which are subject to far more rigorous requirements than Type A containers. Examples of testing include a 9-m (30-ft) drop test (regardless of size and weight of container), a 15-m (50-ft) water immersion over an 8-hour period, and a 30-minute exposure to a radiation environment at or above 802°C (1,475°F) and emissivity coefficient of at least 0.9.

The NRC data summarized in Section E.6.5 (Tables E–6 and E–7) and DOT-reported data on release probability during an accident (Harwood and Russell, 1990) can be used to compare the containment performance differences between Type B containers and typical containers used for HW. The data show that the probability of a release from a Type B container resulting from an accident would be less than 9% and that, if a release occurs, less than 1% of the total shipment quantity would be released. These estimates are considered to be extremely conservative (i.e., overestimates of potential release amounts). The DOT data, based on 1985–86 data involving liquid hazardous material spills from truck accidents in the State of Missouri, show that the probability of a liquid hazardous material in bulk containment being released as the result of an accident is estimated to be 18.7% and that, if a release occurred, the average percentage of total cargo released would exceed 16%.

E.14 Routing Analysis

The HIGHWAY 3.1 computer program (described in Section E.4.2.1.1) was used for predicting the most likely truck route for each shipment of HW assessed. The HIGHWAY model provides the number of miles each route passes through various population density areas and provides estimates of population densities along each segment of routes of interest. In generating estimates of risk, the midpoint of the population density given by the HIGHWAY code for each route segment was used.

For the potential life-threatening endpoint under the No Action Alternative, transporters were contacted to determine the actual routes for each shipment. For the potential adverse effect and increased carcinogenic risk endpoints and for all four alternatives, HIGHWAY was used to determine the most likely route by constraining the routing to maximize interstate highway use. The INTERLINE 5.0 model was used for determining rail routes for LLMW and TRUW (see Section E.4.2.1.2 for details).

E.15 Methods for Computing Transportation Risk

This section describes methods for computing risks associated with two types of transportation conditions—routine operations and accident conditions—involving the vehicle and its cargo. The routine risk estimated is solely the vehicle-related risk from inhalation of vehicle emissions; no cargo-related risk would exist because of the assumption that potential seepage would be contained. The accident risks include cargo-related risks from inhalation of a hazardous chemical (in the case of a ruptured waste container) and vehicle-related risks from the physical trauma of a traffic accident. The risk computation for routine operating conditions involves only two parameters: a risk factor for urban vehicle exhaust exposure and the distance transported in an urban area. In addition to risks to the general population, risks to the MEI from the most hazardous chemical shipment are also assessed for accident conditions. A technical support document by ANL (1996d) contains a more detailed discussion of this method.

The cargo-related health risk to the public (expressed as the number of individuals likely to experience an adverse health effect) from transporting a specific HW is computed for each segment of the rural, urban, or suburban population zone associated with a specific shipment route. The total risk is obtained by summing the risks for each shipment over a period of interest. This approach for determining risk from transporting HW and HW components of TRUW and LLMW is similar to the procedure for performing radiological transportation risk calculations described in Part I of this appendix. The differences in approach are principally the applied consequence assessment models and model input assumptions, and the health criteria used to compute the hazard zones (population areas at risk). These differences and the principal areas of similarity are highlighted in the following sections for the offsite and onsite risk assessment methodologies.

E.15.1 OFFSITE TRANSPORTATION

The offsite transportation risk assessment approach for routine operations and accident conditions is summarized in Figure E–7 and discussed in detail in the following sections. Section E.16.5 describes the development of health risk criteria used in this assessment.

E.15.1.1 Routine Risk Assessment Method (Vehicle-Related Risks)

The HW assessment calculates only vehicle-related routine risk, because no significant health concerns can be identified for cargo-related routine operations. The estimation of routine risks from vehicle exhausts is based on an empirical correlation linking latent inhalation mortality risk to vehicle mileage (the methods are the same as those described in Section E.5.1.1.3 of the radiological assessment).

Risks from routine transportation may be calculated by multiplying the number of kilometers traveled in urban areas by the appropriate risk factor for each HW shipment. This calculation enables the comparison of total risk of routine transport for the baseline case and the various alternatives. Routine risk for HW is presented in Section E.17, whereas routine risks for TRUW and LLMW are presented in Part I of this appendix.

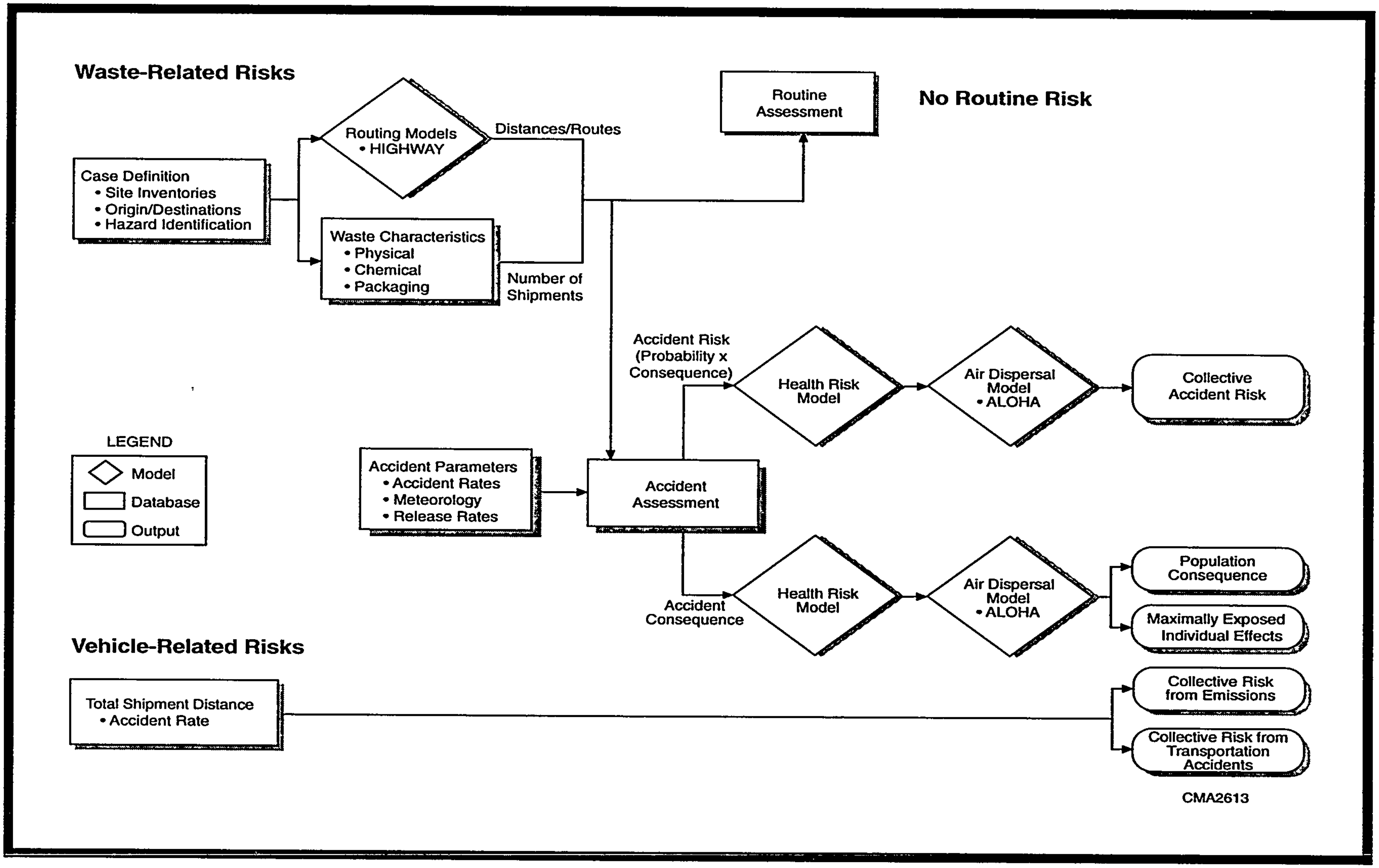

Figure E–7. Components of the Transportation Risk Assessment Method for HW and HW Components of TRUW and LLMW.

E.15.1.2 Accident Risk Assessment Method

E.15.1.2.1 *Cargo-Related Risks*

HW. The risk assessment for HW transportation accidents considers historical hazardous material truck traffic data, including accident probabilities, cargo release likelihoods given an accident, and consequences of a range of possible transportation accidents. These accidents include low-probability accidents with high consequences and high-probability accidents with low consequences. The need to evaluate the consequences from the most severe hypothetically postulated HW transportation accident (instantaneous release of entire cargo contents), consistent with the assumptions used for the most severe radioactive accidental release, is considered. As discussed in Section E.5.1, the consequence assessment for routine and accident radioactive waste transportation conditions are computed with the RADTRAN 4 (collective populations risks) and RISKIND (individual or population subgroup risks) models (Neuhauser and Kanipe, 1993; Yuan et al., 1993). Hazardous waste transportation accident consequence assessment relies on the Areal Locations of Hazardous Atmospheres ALOHA™ model (version 5.1) (Reynolds, 1992) for the collective population and individuals. The model is a widely applied code EPA often used to help emergency field personnel implement emergency response measures.

The main differences between the ALOHA™ and the RADTRAN 4/RISKIND computer models are in the approaches for determining the source-term (chemical or radionuclide release rate or fraction), transport and dispersion, and exposure duration. The ALOHA™ model has a built-in source-term algorithm for computing the rate, quantity, and type of atmospheric release of a hazardous air pollutant, including pool evaporation from a volatile organic liquid spill. The model can handle computations for frequently encountered accidental releases from ruptured tanks, drums, and pipes. ALOHA™ incorporates a chemical data library of physical and chemical properties (such as vapor pressure, boiling point, and molecular weight) for several hundred chemical compounds. These properties, along with container content input, such as the container geometry and rupture characteristics (hole size, for example), are used by ALOHA™ to compute chemical release rate and duration. Radionuclide release quantities for RADTRAN 4 and RISKIND are not computed by the models but are specified as release fraction input parameters. With these models, release fractions (defined as the fraction of material in a package that could be released in an accident) are assigned to each accident severity category according to the waste material's physical and chemical form. Both models assume instantaneous releases.

All three models assume that plume transport and diffusion approximate Gaussian distribution in the atmosphere. The ALOHA™ model simulates atmospheric transport and dispersion of the released substance as either a neutrally buoyant (or passive) plume or a slumping dense gas plume. In the ALOHA™ model, the selection of plume type (passive or heavy gas) from a near-surface release depends primarily on the relative density of the released toxic vapor (vapor or gas density to atmospheric density) and the ambient windspeed. Either continuous or intermittent releases and dispersion in rural or urban atmospheres can be simulated. The RADTRAN 4 and RISKIND models are limited to passive plume dispersion from instantaneous releases; these models are not designed to simulate transport and dispersion from dense gas releases commonly associated with HW chemicals. The ALOHA™ model does not account for the thermal buoyancy generated from fire plumes. Because severe accidents routinely involve fires, the RISKIND model was designed to take into account physical phenomena from the fire, such as buoyant plume rise. The risks associated with HW transportation accidents involving fire and water immersion are now being assessed with models or approaches appropriate to these conditions. These assessments will address risk associated with fire combustion products and water reaction chemistry.

Once the release and plume characteristics are computed, ALOHA™ establishes the plume hazard area or "footprint" (ground areal plume coverage with chemical concentrations greater than or equal to health criteria concentrations). Health criteria values are concentrations in air corresponding to the potential life-threatening effect, increased cancer risk, and any adverse health effect endpoints. This footprint is used to estimate the consequences of population exposure along the transportation route. No consequences are assumed within 30 m (98 ft) of the accident because homes are not likely to be located less than 30 m (100 ft) from the center of the highway. The ALOHA™-computed hazard areas, along with the chemical-specific health criteria concentration values and estimated exposure durations, are used to estimate acute and latent health effects from inhalation. In comparison, the consequences estimated by RADTRAN 4 or RISKIND, along with health risk conversion factors, are used to compute latent cancer fatalities, cancer incidence, and serious genetic effects from inhalation and ingestion by exposed populations. The supporting technical report by ANL (1996a) provides further description of the ALOHA™ model and modeling assumptions.

TRUW. Since only liquid or gaseous hazardous components of TRUW required evaluation, the methods used to calculate cargo-related risks were identical to those used for HW.

LLMW. The LLMW consequence assessment for HW assumes organic liquid spills and particulate releases are instantaneous as liquid and solid (as respirable fraction) aerosols. The methods used to calculate cargo-related risks for the liquid or gaseous hazardous components of LLMW were identical to those used for HW. For particulates, release fractions are estimated with the approach used for radionuclide releases (described in Section E.6.6). One additional source term is estimated for contaminated solids (containing volatile organic compounds) spilled on the ground. The emission rate is calculated with a standard evaporative gaseous emissions model (EPA, 1988). The emission rates are used in the ALOHA™ code to provide hazard zones ("footprints"). Details are provided in the Supplemental Information document for LLMW (ANL, 1996e).

E.15.1.2.2 *Vehicle-Related Risks*

The risk assessment also provides an estimate of injury or fatality to truck crew members and the public as a result of physical trauma from vehicle collisions. This risk is assessed by combining data on U.S. annual deaths and injuries occurring from hazardous materials transportation accidents with total miles traveled by hazardous materials transport vehicles (DOC, 1987). The death and injury rates (unit risks) derived from these data are 9.56×10^{-9} fatalities/km (1.53×10^{-8}/mi) traveled and 6.25×10^{-8} injuries/km (1.0×10^{-7}/mi) traveled.

The risk of collision death or injury from transporting HW for each route segment is calculated as the product of the number of kilometers traveled and the unit risk factors. Risks are summed over the entire route and over all shipments for each alternative. Vehicle-related risks for TRUW and LLMW are presented in Part I of this appendix.

E.15.2 ONSITE TRANSPORTATION

The approach used for offsite HW transportation risk calculations was also used to estimate onsite accident risks to collective populations and the MEI. The Hanford Site was selected as a large representative DOE site for estimating the magnitude of the onsite transportation risk for hazardous and radioactive waste. The assessment requires extensive use of site-specific routing and worker population data. Sitewide characteristics such as meteorologic data and building-specific worker population densities are variable input parameters. In addition, receptor characteristics such as intake rate and location relative to the shipment route can be specified.

The three groups of receptors considered for the onsite routine risk assessment are as follows:

- Workers near the transport route (worker population dose)
- Guards at the gates of individual facilities or at checkpoints along the route
- General public near a gate (offsite collective population)

For each shipment, onsite transport HW accident consequences and the attendant health risks were calculated. The same accident and release probabilities used for the offsite risk calculations were used for the onsite risk estimates at the Hanford Site.

Based on results of the off-site analysis for TRUW and LLMW, risks from on-site transportation for these waste types would likely be very small, and were therefore not quantified.

E.16 Input Parameters and Assumptions

E.16.1 Waste Inventory and Characterization Data

HW. The HW risk assessment modeling (HaWRAM) database was developed to support the WM PEIS transportation and technology analysis (Lazaro et al., 1994). The database was developed primarily as a tool to provide the modeling parameters identified below:

- Chemical name, its United Nations or North American identification number, and classification; that is, whether the chemical is a PLC, PAEC, or ICRC chemical
- Physical-chemical state (liquid, solid, or gas/vapor) of waste container contents
- Chemical composition and physical-chemical characteristics
- Container type (metal or fabric drum)
- Container size (0.21-m^3, 0.11-m^3, or 19-L [55-, 30-, or 5-gal] drum), number of containers in shipment, and total quantity of waste in containers shipped
- Shipment date and EPA and State manifest numbers
- Generator name, EPA identification number, and location
- TSD facility name, EPA identification number, and location

The HaWRAM database contains waste inventory and characterization data for each DOE site, operations data for the facilities used for TSD of the wastes, and definitions of the various alternatives. The development of the HaWRAM database is described by ANL (1996a,c).

The HaWRAM database was designed to provide the following:

- Quantities of offsite HW shipments, key physical-chemical HW characteristics, and treatment technologies commercial TSD facilities used
- Data, such as chemical name, container size, chemical state, and chemical hazard designation, required to carry out a transportation risk assessment under current as well as future conditions
- Data for determining the degree and type of onsite versus offsite treatment at commercial facilities
- Data on "as-generated" or "operational" HW from industrial-type processes or laboratory research versus "remediation" HW from decommissioning or Superfund cleanup

Hazardous waste is defined under RCRA as waste either exhibiting certain standard characteristics (ignitability, corrosivity, reactivity, or toxicity) or listed under RCRA Subpart D (40 CFR 261.31). Subpart D lists approximately 800 waste categories and several hundred individual constituents as hazardous waste; however, many of these wastes are solids or nonvolatile liquids whose potential to become airborne under accident conditions is insufficient for significant exposure of the general public. Therefore, the substances evaluated for the WM PEIS transportation risk assessment were limited to those appropriate for the health endpoint being assessed, as detailed below.

For accident conditions, three health endpoints were evaluated: potential for life-threatening effects, potential for any adverse effects, and increased cancer risk. For evaluation of the potential life-threatening effects endpoint, analyses were conducted for shipments containing substances designated by DOT as PIH chemicals (criteria for PIH designation are detailed in Section E.16.5.1). Potential life-threatening concentration values were developed for estimating the risks for this endpoint. In the evaluation of potential for any adverse effects, both PIH substances and substances that may result in less severe adverse health effects on exposure were evaluated. Potential adverse effect concentration values were developed for estimating the risks for this endpoint. Increased cancer risks concentration values were developed to assess risks from substances for which sufficient evidence of carcinogenicity exists in humans or animals. Increased cancer risk concentration values were expressed as the concentrations associated with an increased lifetime cancer risk of one in one million for members of the public.

For fiscal year (FY) 1992, the HaWRAM database identifies the shipment by DOE of 48 substances to be evaluated under the potential life-threatening effects endpoint, 85 substances evaluated under the potential for any adverse effects endpoint, and 32 substances evaluated under the increased cancer risk endpoint. This constituted cargo-related risk evaluations of approximately 285 of the 1,712 shipments; however, evaluation of these shipments for the three stated health endpoints was considered to adequately represent inhalation hazards associated with collisions, because releases of less hazardous substances from other shipments are unlikely to result in a health risk to the general population. The potentially lethal concentrations (PLC), potentially adverse effects concentration (PAEC), and increased cancer incidence effects (ICRC) values were developed for the WM PEIS risk assessment (Hartman et al., 1994). These values were derived by using toxicologic data and risk evaluation methods for emergency planning available from the EPA and other sources (EPA, 1986; EPA et al., 1987; DOT, 1993b; National Research Council, 1993).

TRUW and LLMW. Reports have been prepared describing the TRUW and LLMW inventories and characteristics at each DOE site (ANL, 1996b,c). These reports were used as the primary source of information for the transportation assessment. The majority of information on the hazardous-chemical compositions is derived from site-specific (process) operational knowledge. All TRUW is assumed to be radioactive material mixed with other chemical substances and divided into a number of waste-stream categories (e.g., aqueous wastes, organic liquids, contaminated soils). Concentrations of hazardous chemical constituents for each of these categories were estimated (ANL, 1996b). For LLMW, classification into waste-stream categories was also conducted to facilitate the assessment (e.g., aqueous liquids, organic liquids, solid process residues; ANL, 1996b).

Organic liquid and solid hazardous waste components with significant volatilization potential and inhalation toxicity values (i.e., slope factors or reference concentrations) available from the EPA were evaluated. The same health risk endpoints as for HW were considered, although for some health endpoints, zero risk was calculated (e.g., the potential for life-threatening effects endpoint for both TRUW and LLMW was zero, because no substances in the respective inventories were identified as PIH chemicals.)

E.16.2 Population Density Zones

The same three population density zones (rural, suburban, and urban) used in the radiological risk assessment (Section E.6.3) were used for the offsite population risk assessments. As for the radiological risk assessment, the onsite analysis used population densities for the Hanford Site and the town of Richland, Washington.

E.16.3 TRUCK ACCIDENT AND RELEASE PROBABILITIES

A cross-classification study conducted in California (Graf and Archuleta, 1985) and cited in a Midwest Research Institute document (Harwood and Russell, 1990) provided the only data available on accident rates by highway type (rural freeway, rural nonfreeway, or urban freeway) and truck configuration (single unit, single combination, or double combination). Because HWs in the DOE complex are shipped mainly by 0.21-m^3 (55-gal) drum or smaller containers, single-unit trucks will likely be the predominant truck type used; therefore, accident rates for single-unit trucks were used in this assessment. Also, because an accident rate for suburban freeways was required, the average of the rural and urban freeway rates was used. Rates used in the analysis (per million kilometers of truck travel) were as follows: rural freeway, 0.35; rural nonfreeway, 0.42; suburban freeway, 0.49; and urban freeway, 0.63 (0.56, 0.68, 0.79, and 1.01, respectively, per million miles). Rural nonfreeway rates were used for the small route segments from facilities to freeways.

Some states maintain more comprehensive and better monitored hazardous materials incident data than can be found in corresponding national data from DOT sources; for example, the State of Missouri's highway patrol accident reports contain data identifying whether each vehicle involved in an accident was carrying hazardous materials, what type or types of materials were carried, and whether a toxic substance was released. This format permits accurate classification of accidents by hazardous material cargo type. Missouri is one of only three states to incorporate all of these items in their reports. Because Missouri was considered the most representative (nearest the midpoint of the Nation), the data from Missouri, as cited in Harwood and Russell (1990), were used as the basis for estimating the probability of a toxic substance release after an accident. The probabilities used were 0.072 for gases in bulk and 0.187 for liquids in bulk.

In addition to these accident and release probabilities, an estimate is needed of the likely number of containers and the quantity of chemicals to spill from them as the result of a vehicle accident. An algorithm was developed to account for multiple chemicals in containers, percentage of containers in a shipment expected to be breached in an accident, and average quantity released per container. This algorithm provided the estimate of the amount spilled from the total quantity reported on HW manifest sheets (an HW tracking form mandated by Federal and, in most cases, State law for all offsite shipments of HW). The quantity of the chemical of interest per container was assumed to be equal to the total quantity in each container divided by the number of chemicals in the container (specific concentration levels were generally unavailable). This quantity was multiplied by the appropriate assumption for percent spilled and by the number of containers assumed to be breached. Data on percent spilled and number of containers breached were specific to container type (metal, plastic, glass, pressurized, or other) and size and were based on statistics from the Hazardous Materials Incident Reporting System (HMIRS) database (DOT, 1993a).

E.16.4 Atmospheric Conditions

The meteorologic input to the ALOHA™ model assumes neutral stability (Pasquill Stability Class D, daytime) with moderate to overcast solar insolation, ambient temperature of 35°C (95°F), and a windspeed of 4 m/s (13.12 ft/s). Because neutral meteorologic conditions are the most frequently occurring atmospheric stability conditions in the United States, these conditions are most likely to prevail in the event of a transportation spill of a hazardous chemical or radioactive waste shipment (Part I, Section E.6.7, contains assumptions for radioactive waste exposure modeling). On the basis of observations from National Weather Service surface meteorologic stations at more than 300 locations in the United States, on an annual average, neutral conditions occur about 50% of the time, while stable conditions (represented by Pasquill Stability Classes E and F) occur about 33% of the time, and unstable conditions (represented by Pasquill Stability Classes A and B) occur about 17% of the time (NOAA, 1976). Regionally, neutral conditions are less prevalent in the arid Southwest and most prevalent in the Midwest and Northeast. The neutral category predominates in all seasons, but most frequently in the winter (nearly 60% of the observations). Neutral stability is conservative for the daytime, when most accidents occur. In its *1993 Emergency Response Guidebook* (DOT, 1993b), DOT employs neutral stability and 4.5-m/s (14.76-ft/s) windspeed for the meteorology for all transportation accidents. Although most conservative meteorological conditions, such as Class F stability and windspeed of 1.5 m/s (4.92 ft/s), should be conservative for both day and night, DOT's position when developing the Initial Isolation and Protective Action Distances was to avoid multiplying conservative assumptions. This position was also adopted for modeling chemical exposure in this assessment.

E.16.5 Health Risk Criteria

For predicting inhalation hazards associated with accidental releases, the ALOHA™ model can be applied to calculate the health consequence area by predicting the HW plume area resulting from an accident. Plume concentrations corresponding to appropriate health endpoints are required. Human health risk endpoints addressed in this assessment include the potential for life-threatening effects (evaluated using PLC values), potential for reversible or irreversible adverse effects (evaluated using PAEC values), and potential for increased cancer incidence effects (evaluated using ICRC values). The calculated risks correspond to the endpoint being assessed.

The goal of identifying PLC, PAEC, and ICRC values is to estimate the minimum concentration that could induce an adverse health effect. This minimum level is used in the ALOHA™ model to estimate the plume area with an air concentration at that level or higher. The total population exposed is assumed to be at risk for the health effect. Of the population at risk (the population within the plume), those exposed to the highest concentrations will be most likely to experience the health effect. The collective population risk calculations identify the number of individuals in the population at risk but do not differentiate the risk for individuals within the plume area. The analysis for MEI receptors addresses the highest estimated exposure levels.

E.16.5.1 Potential Life-Threatening Concentration Values

The potential for life-threatening health effects is assessed for specific HW components designated as PIHs by DOT (49 CFR 173.115, 173.132-133). These substances are assigned protective action distances in the DOT *1993 Emergency Response Guidebook* commonly used by hazardous materials incident response personnel (DOT, 1993a). Only liquids and gases are designated as PIH substances. Two criteria must be met for designation as a PIH: (1) high toxicity, based on the concentration of a chemical gas or vapor at which 50% of the test animals die, known as LC_{50}; and (2) for liquids, medium to high volatility. Potential life-threatening concentration values were derived for all PIH substances in the HW FY 1992 shipment inventory considered the baseline case for the No Action Alternative. These resulted in PLC values for approximately 50 chemicals. No PIH chemicals were identified in the TRUW or LLMW inventories.

Potential life-threatening concentration values are air concentrations of HW above which exposed persons are at risk for potential life-threatening health effects when exposed for the associated exposure duration. Potential life-threatening concentration values are input to the ALOHA™ code to estimate "PLC-areas at risk" (areas that equal or exceed the PLC air concentration). In deriving PLC values, three main issues must be addressed: (1) selection of toxicity values, (2) selection of appropriate uncertainty factors, and

(3) exposure duration adjustment. These issues are discussed in detail in the technical support document (ANL, 1996a) and are summarized below.

E.16.5.1.1 *Toxicity Value Selection*

Toxicity data were obtained from one of two sources: (1) the Registry of Toxic Effects of Chemical Substances (RTECS) database (NIOSH, 1992), or (2) *Dangerous Properties of Industrial Materials* (Lewis and Sax, 1992). Two possible toxicity values for estimating potential human life-threatening health effects are the LC_{50}, defined above, and the human LC_{LO} defined as the lowest reported concentration of gas or vapor that has caused death in humans.

In this assessment, the lower of either (a) the lowest available human LC_{LO} value divided by an uncertainty factor of 3 or (b) the LC_{50} value for the most sensitive tested mammalian species divided by an uncertainty factor of 10 was selected as the primary toxicity value for deriving PLCs. For substances with no available LC_{50} or human LC_{LO} value, the lowest mammalian LC_{LO} value was substituted for the LC_{50} value. In the absence of either value, a short-term exposure level (STEL) for occupational exposures was multiplied by 15 to derive the PLC value, based on methods similar to those used to derive "Level of Concern" values (EPA et al., 1987). The toxicity value selection was restricted to data with associated experimental exposure times between 5 minutes and 6 hours. Experimental data with exposure times less than 5 minutes are difficult to reproduce, and data with exposure times greater than 6 hours would be inappropriate for evaluating acute health effects.

E.16.5.1.2 *Uncertainty Factor Selection*

The EPA uses uncertainty factors to allow for imprecision in deriving reference doses (RfDs) for hazardous chemical substances (EPA, 1989a). For this assessment, an uncertainty factor of 3 (approximate logarithmic mean of 1 and 10) was selected on the basis of limited EPA guidance (EPA, 1980; 1989a). To correct for variations in susceptibility among individuals in the human population, LC_{LO} values were reduced by an uncertainty factor of 3. Values for LC_{50} or mammalian LC_{LO} were reduced by an uncertainty factor of 10 (3 to correct for interspecies extrapolation and 3 to account for variations in human susceptibility—rounded from 9 to 10 for simplicity).

E.16.5.1.3 *Exposure Duration Adjustment*

The ALOHA™ code used to estimate the PLC areas at risk for transportation accidents also computes estimates of release duration. These estimates range from 1 to 60 minutes. Longer duration releases are reported as "greater than 60 minutes." The ALOHA™ model limits the puff release (forcible emission) duration to periods of 1 hour or less.

Reported LC_{LO} and LC_{50} values are associated with experimental exposure times. The estimated duration of releases computed with the ALOHA™ code are used to scale LC_{LO} or LC_{50} values in the literature from experimental exposure times to the estimated duration of exposures. Either a linear or exponential function can be assumed in scaling literature-reported toxicity values to the appropriate exposure duration. The scaling assumption resulting in the lowest PLC value was used in this assessment.

In calculating accident risks for the potential life-threatening endpoint, the assumption is that the entire population living within the PLC area at risk could experience life-threatening health effects from the exposure. This assumption is conservative because the PLC values have incorporated uncertainty factors to account for sensitive human subpopulations. Greater detail on the derivation of PLC values, the PLC values for all PIH substances contained in the HW shipping inventory, and comparisons with other available emergency planning criteria, are included in the technical support document (ANL, 1996d). Potential life-threatening concentration values and supporting information for some representative high-risk substances are presented in Table E–33.

E.16.5.2 Potential Adverse Effect Concentration Values

To estimate the occurrence probability of less severe effects, values were also developed to estimate air concentrations of HW components above which exposed persons are at risk of any adverse effect (PAEC values). Any-adverse-effect concentration values were derived for all PIH substances shipped by DOE waste generators in FY 1992 and for other substances (in either HW, LLMW, or TRUW shipment inventories) with inhalation RfDs available from the EPA (approximately 90 substances). As in the derivation of PLC values, the derivation of PAEC values requires selection of toxicity values, selection of uncertainty factors, and exposure duration adjustment, which are discussed below.

Table E-33. Values for PLC, PAEC, and ICRC for Representative Substances

Substance	Toxicity Value (ppm)	Time/Species/ Effect/Reference[a]	Inhalation RfD (mg/kg/d)[b]	Inhalation Unit Risk ($\mu g/m^3)^{-1}$	VSD (mg/m^3)	Health Risk Criterion (ppm) (15 min)	Health Risk Criterion (ppm) (30 min)	Health Risk Criterion (ppm) (60 min)
PLC Values								
Arsine[c]	1.3E+02	30 min/rat	NA	NA	NA	1.9E+01	1.3E+01	6.6E+00
Chlorine	1.4E+02	1 h/mouse	NA	NA	NA	2.7E+01	1.9E+01	1.4E+01
Hydrogen fluoride[c]	5.0E+01	30 min/human/ LC_{LO}/Lewis & Sax	NA	NA	NA	2.4E+01	1.7E+01	8.3E+00
Hydrogen selenide	6.1E+00	1 h/rat/LC_{LO}	NA	NA	NA	1.2E+00	8.6E-01	6.1E-01
Nitrogen dioxide	3.0E+01	1 h/guinea pig	NA	NA	NA	6.0E+00	4.2E+00	3.0E+00
PAEC Values								
Acrolein[d]	8.7E-06	2 wk-7 yr/ human/RfC/IRIS or HEAST	5.71E-06	NA	NA	1.5E-03	7.4E-04	3.7E-04
Hydrogen chloride[d]	4.7E-03	2 wk-7 yr/ human/RfC/IRIS or HEAST	2.00E-03	NA	NA	8.0E-01	4.0E-01	2.0E-01
Hydrogen fluoride	1.2E+02	1 min/human TC_{LO}/cough, irritation	NA	NA	NA	8.2E-01	4.1E-01	2.0E-01
Hydrogen selenide	6.1E+00	1 h/rat/LC_{LO}	NA	NA	NA	1.2E-02	9.0E-03	6.0E-03
Phosgene	4.4E+02	10 min/mouse/ LC_{50}	NA	NA	NA	3.0E-01	1.5E-01	7.0E-02
1,1,1-Trichloroethane[d]	1.8E-01	2 wk-7 yr/ human/RfC/IRIS or HEAST	NA	NA	NA	3.1E+01	1.6E+01	7.8E+00
ICRC Values[e]								
Chloroform	NA	NA	NA	2.3E-05	4.3E-05	NA	NA	5.5E+00
Dichloroethylene	NA	NA	NA	5.0E-05	2.0E-05	NA	NA	3.1E+00
Dichloromethane	NA	NA	NA	4.7E-07	2.1E-03	NA	NA	3.8E+02

Notes: NA = not applicable; $(\mu g/m^3)^{-1}$ = reciprocal micrograms per cubic meter; VSD = virtually safe dose = 10^{-6} (inhalation unit risk ×1,000 µg/mg).
[a] For PLC derivation, toxicity value is LC50 unless otherwise noted. For PAEC derivation, toxicity value is RfC obtained from EPA's IRIS database (EPA, 1993b) or EPA's HEAST (EPA, 1993a). Other toxicity values were obtained from the RTECS database (NIOSH, 1992), except when Lewis and Sax (Lewis and Sax, 1992) are listed.
[b] Inhalation RfD (in milligrams per kilogram per day) = [(toxicity value × molecular weight) /24.5] × (20 m^3/d ÷ 70 kg).
[c] Exponential scaling used for 15-min PAEC; linear scaling used for 60-min PAEC.
[d] Indicates that chronic RfC was adopted as subchronic RfC; value may be conservative.
[e] ICRC value = VSD × 24 h/d × 365 d/yr × 70 yr × 24.5/molecular weight (per National Research Council, 1986, 1993).

E.16.5.2.1 *Toxicity Value Selection*

Inhalation RfDs and reference concentrations (RfCs) developed by EPA were selected as the most applicable toxicity values for deriving PAEC values. An inhalation RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects (EPA, 1989b). Subchronic RfC values, applicable to exposure durations of 2 weeks to 7 years, are used when available. Otherwise, chronic RfC values are used; these values are most likely conservative, tending to overestimate risk. The RfD in milligrams per kilogram per day is derived from the RfC in milligrams per cubic meter. The EPA Integrated Risk Information System (IRIS) database and Health Effects Assessment Summary Tables (HEAST) have been used to obtain current RfC values (EPA, 1993a,b).

Many PIH substances did not have available RfC values. For these substances, toxicity data, such as values for the lowest toxic concentration (TC_{LO}), were obtained from either NIOSH (1992) or Lewis and Sax (1992). Toxicity values were selected in a hierarchical fashion analogous to that used to estimate PLC values. In the absence of an RfC, the lowest human TC_{LO} value, or the lowest concentration causing any adverse effect, was selected as the most appropriate toxicity value for PAEC derivation. When human TC_{LO} values were unavailable, the following toxicity values from the literature were used (in decreasing order of preference): (1) lowest mammalian TC_{LO} values, (2) lowest human LC_{LO} values, (3) lowest LC_{50} values, (4) lowest mammalian LC_{LO} values, and (5) the STEL value. As with the PLC data, the toxicity value selection for PAEC values was restricted to data with associated experimental exposure times of between 5 minutes and 6 hours.

E.16.5.2.2 *Uncertainty Factor Selection*

For substances with available RfC values, application of uncertainty factors was unnecessary because the appropriate factors are already incorporated into the RfC value (EPA, 1993a,b). Where use of other toxicity values was necessary, uncertainty factors were selected following the rationale EPA used in deriving RfC values (EPA, 1989a): (1) human TC_{LO} divided by 10 (for sensitive subpopulations); (2) mammalian TC_{LO} divided by 100 (10 for sensitive subpopulations and 10 for extrapolation from animal data to humans); (3) human LC_{LO} divided by 100 (10 for sensitive human subpopulations and 10 for extrapolation of lethality data to estimate sublethal effects); (4) LC_{50} or mammalian LC_{LO} divided by 1,000 (10 for sensitive human subpopulations, 10 for extrapolation from animal data to humans, and 10 for extrapolation of lethality data to estimate sublethal effects); and (5) the STEL value divided by 3 (for sensitive human subpopulations).

E.16.5.2.3 *Exposure Duration Adjustments*

For substances for which RfC values are available, the equation used to estimate PAEC values was based on EPA methods for estimating inhalation exposures and acceptable air concentrations of noncarcinogenic contaminants (EPA, 1989a, 1991). Details about the parameter values chosen are given in supporting documentation (ANL, 1996a).

For substances for which no RfC values are available, the exposure duration adjustment is identical to that used in generating PLC values: the exposure duration adjustment (linear or exponential) resulting in the lowest PAEC value was used in modifying toxicity values to derive PAECs.

In calculating accident risks for the endpoint presented as any adverse effect, the assumption is that the entire population living within the PAEC area at risk would experience some adverse effect from the exposure. Again, this assumption is conservative because the PAEC values have incorporated uncertainty factors to account for sensitive human subpopulations. The equation used to estimate PAECs and the computed PAEC values, along with comparisons with other available emergency planning criteria, are discussed in the technical support document (ANL, 1996d). The PAEC values and supporting information for some representative high-risk substances are presented in Table E–33.

E.16.5.3 Increased Cancer Risk Concentration Values

Hazardous chemical waste transported from DOE facilities may also be evaluated for possible increased cancer risk in exposed individuals. Values were developed to estimate the air concentrations of carcinogenic HW components above which exposed persons have an increased carcinogenic risk of one in one million or higher. These values were termed ICRC values. The risk level of one in one million was selected to represent the level below which increased risk is considered negligible.

An ICRC value was derived for each HW, TRUW, LLMW substance that met the following criteria: (1) the substance is classified as a known, probable, or possible human carcinogen (EPA, 1993a,b); (2) the substance has an EPA inhalation unit-risk value; and (3) the substance is volatile enough to present significant potential for exposure of the public. Increased cancer risk concentration values were derived for approximately 25 carcinogens. Several inorganic and organic substances were not evaluated because they are solids under ambient conditions or because the potential to volatize is minimal (for example, lindane, arsenic, beryllium, and cadmium).

The method used to generate ICRC values is that recommended by the National Research Council (1986, 1993). Because the estimation of increased cancer risk for exposure periods of less than 1 hour is highly uncertain, ICRC values were generated only for an assumed 1-hour exposure. Exposures were averaged over a 70-year lifetime. In calculating risks for individual accidents, the assumption was made that the entire population living within the ICRC area at risk would experience an increased cancer risk of one in one million or higher. The equation used to estimate ICRCs and the computed ICRC values are discussed in the technical support documents (ANL, 1996c-e). Table E–33 presents increased cancer risk concentration values and supporting information for some representative high-risk substances.

Population at Risk. The cargo-related population risk is calculated by estimating the minimum concentration level that could induce the adverse health effect of interest for each endpoint (potential life-threatening effects, any adverse effects, or increased cancer risk). This minimum level is used in the ALOHA™ model to estimate the plume area with an air concentration at that level or higher. The HIGHWAY 3.1 and INTERLINE 5.0 models then provides population density estimates for the plume areas in rural, suburban, or urban areas. Of the population at risk, those exposed to the highest concentrations would be most likely to experience the health effect, but the method does not differentiate the risk for individuals within the plume area. The evaluation of MEIs is intended to address the question of what maximum exposure levels could be and what health effects could be associated with those levels. To evaluate the MEI for each health endpoint, the primary factors considered were a combination of chemical potency, quantity released, and dispersion, as reflected by the exposed areas output from the ALOHA™ model (Section E.17.1.3 provides details). The MEI was considered to be located at the point of highest chemical concentration accessible to the public. This location was modeled to be 30 m (100 ft) from the release point (the assumed closest distance of a residence from the middle of the roadway). Although for each endpoint, many shipments of each chemical may be included in the database, only the shipment resulting in the highest chemical concentration is evaluated for the MEI.

E.17 Risk Assessment Results

E.17.1 HAZARDOUS WASTE

E.17.1.1 Hazardous Waste Alternatives

Transportation impacts associated with the four HW alternatives are analyzed to provide input for decisions about the extent to which DOE should continue to rely on commercial facilities for treating and disposing of the nonaqueous part of the hazardous waste stream. The analyzed HW alternatives are (1) No Action; (2) Decentralized (optimize commercial facility selection for 11 DOE sites, and use the limited existing and approved treatment capacity at three to five sites); (3) Regionalized 1 (five DOE TSD sites, including three TSD hubs or host sites); and (4) Regionalized 2 (two DOE TSD hubs or host sites). Hazardous waste from 11 DOE sites representing approximately 90% of the HW generation in the DOE complex was analyzed. The HW inventories and the HW alternatives for these facilities are described further in ANL (1996a).

Hazardous waste management under the *No Action Alternative (current baseline conditions)* would continue to use existing and approved TSD facilities (for example, primarily wastewater treatment) at the DOE sites, while most of the nonaqueous (nonwastewater) waste stream would be shipped offsite to permitted commercial facilities.

Under the *Decentralized Alternative (optimal conditions)* the no action activities would continue with an "optimized" use of DOE facilities and commercial vendors. This optimization would occur through eliminating brokering (consolidating HW with a broker from more than one generator before shipment for TSD) and by strategically selecting commercial TSD facilities by waste treatment group capability and proximity to the largest generators. These actions would limit the number of commercial facilities storing, brokering, treating, and disposing DOE HW and would select commercial TSDs as close to the principal generators as practical. Hazardous waste brokering, sometimes at several broker locations, can significantly increase the transportation miles of the original HW, depending on when and where consolidation occurs. Figure E-8 illustrates shipment routes for the Decentralized Alternative. Except for wastes to be incinerated (approximately 15% of the total generated organic HW) and destroyed through use as a fuel-waste (approximately 12% of the total organic generated HW) at Idaho National Engineering Laboratory (INEL),

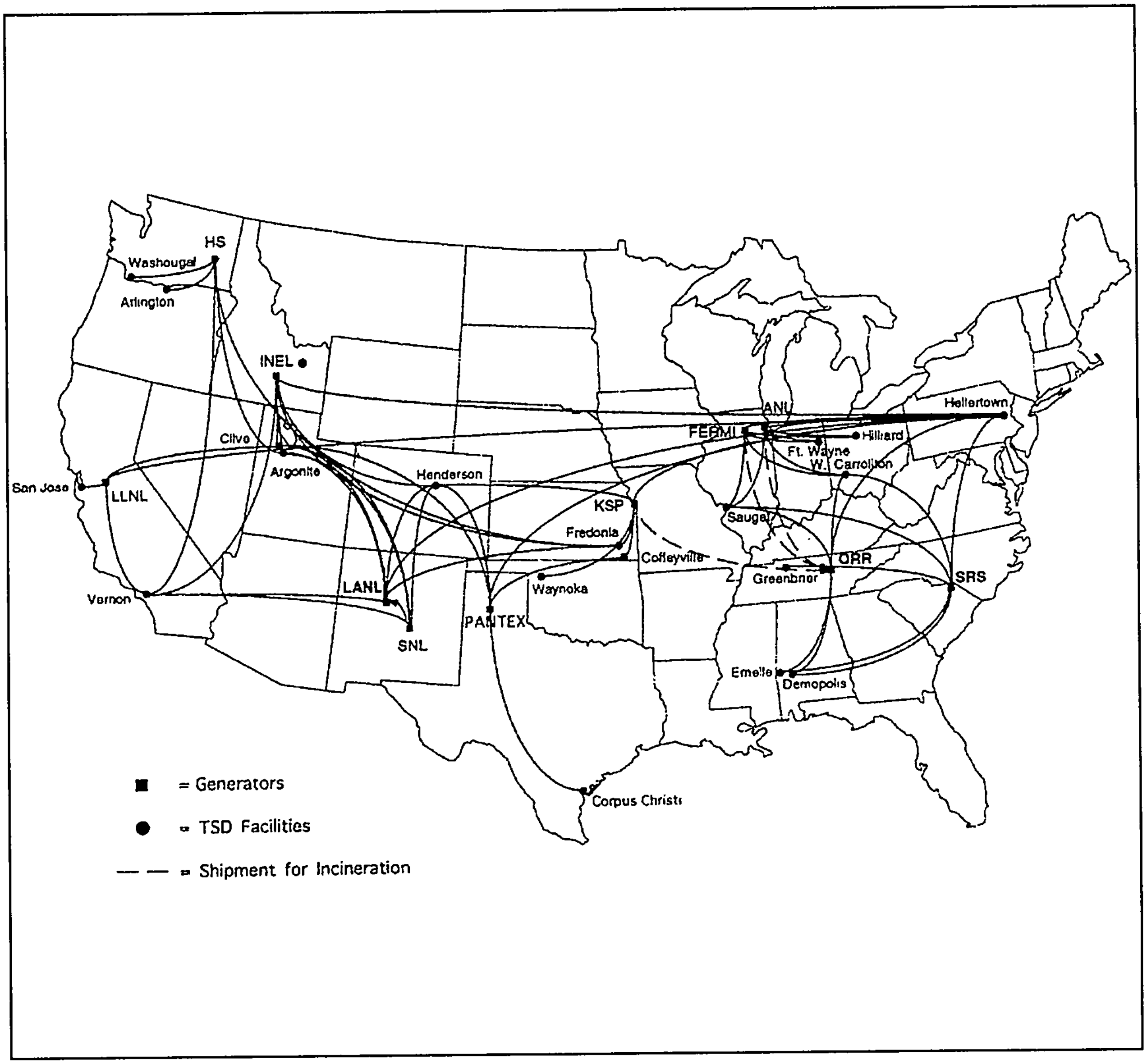

Figure E–8. Decentralization Alternative—Offsite HW Shipments From DOE Sites to Commercial TSD Facilities and to LANL and ORR for Limited Incineration.

Oak Ridge Reservation (ORR), and the Savannah River Site (SRS), most of the HW generated by the other eight DOE sites included in this analysis would be sent to commercial TSD facilities.

The *Regionalized 1 Alternative* would continue no action, except that approximately 50% of nonaqueous HW generated by the core sites would be treated at five treatment hubs or home facilities—Hanford, INEL, LANL, ORR, and SRS. Hazardous waste not treated at these sites and the residual treated waste from these sites would be sent to commercially licensed facilities for treatment and disposal. Under this alternative, HW shipments would occur as follows: Pantex and Sandia National Laboratories (SNL) to the LANL hub; Lawrence Livermore National Laboratory (LLNL) to the Hanford Site hub; and the Kansas City Plant (KCP), Argonne National Laboratory-East (ANL-E), and Fermi National Accelerator Laboratory (FERMI) to the ORR hub. INEL and SRS would serve as home TSDs only for their own generated HW. The remaining smaller generators would ship to permitted commercial TSD facilities. Figure E-9 shows the transportation routes computed for the Regionalized 1 Alternative.

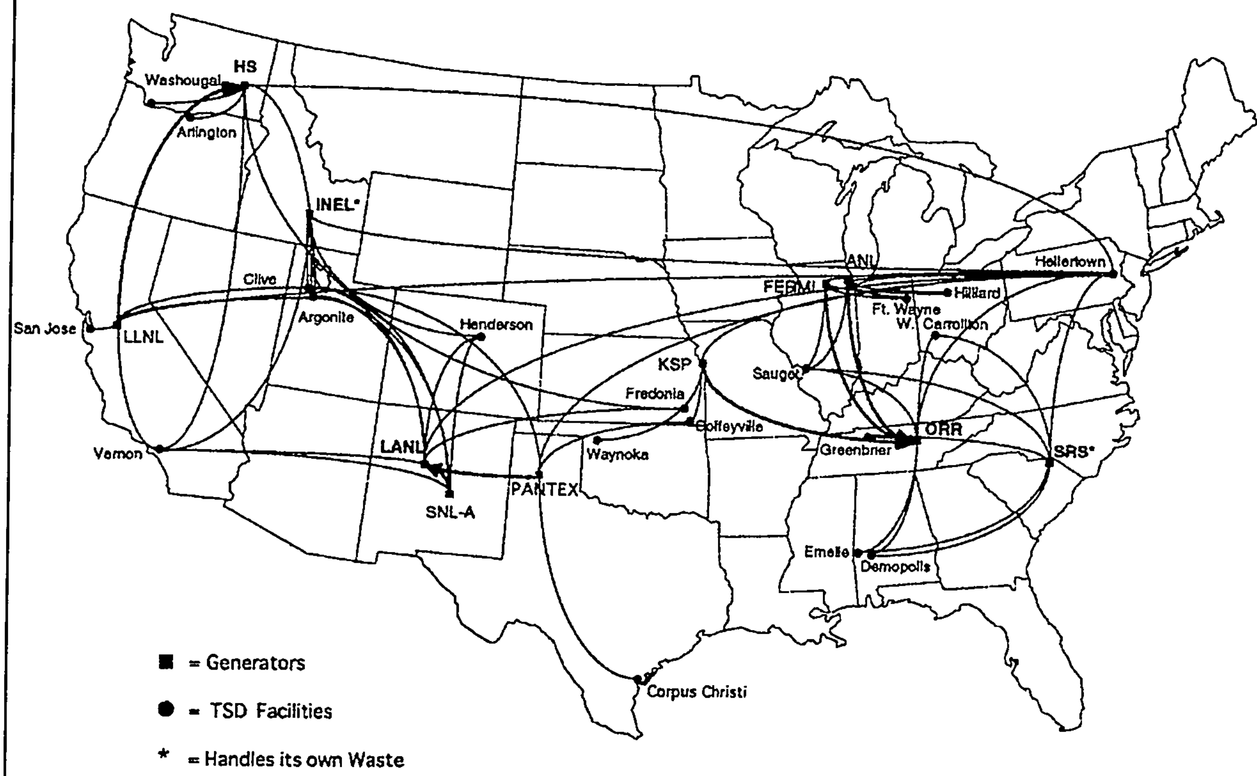

Figure E-9. Regionalized 1 Alternative—Offsite HW Shipments From DOE Sites to Three DOE Treatment Hubs (Hanford, LANL, and ORR) and to Commercial TSD Facilities.

The *Regionalized 2 Alternative* would continue no action, except that approximately 90% of the total nonwastewater HW generated by core sites (including all organic HW) would be treated at two treatment hubs (INEL and ORR). All remaining HW would be packed and shipped to a limited number of permitted commercial TSD facilities. Under this alternative, shipments of HW would be as follows: Hanford, LANL, Pantex, SNL, and LLNL to the INEL hub; and KCP, ANL-E, Fermi, and SRS to the ORR hub. Figure E-10 illustrates the transportation routes computed for the Regionalized 2 Alternative.

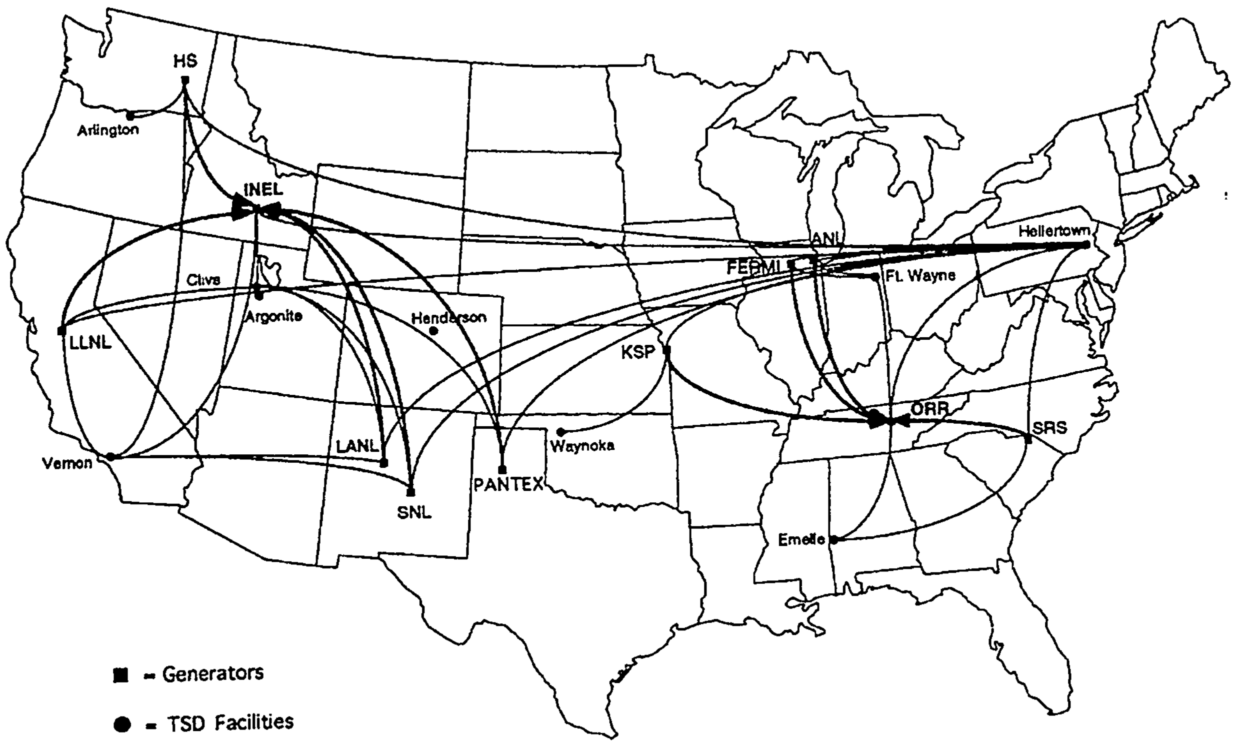

Figure E-10. Regionalized 2 Alternative—Offsite HW Shipments From DOE Sites to Two Treatment Hubs (INEL and ORR) and to Commercial TSD Facilities.

For each alternative, vehicle-related and cargo-related risks are calculated for onsite and offsite transportation of HW. Cargo-related risks from accident conditions are computed for chemical exposure of onsite and offsite populations and for the MEI. Vehicle-related risks are quantified for death and injury from collisions and for latent cancer mortality caused by inhalation of vehicle exhausts. The collective risk for each alternative is computed and reported below on an annual basis for the respective estimated HW shipment inventories. Shipments of HW to commercial and DOE hub TSD facilities are assumed to occur over 20 years. The average shipment period duration risk can therefore be calculated by dividing the results provided in the following tables by 20.

E.17.1.2 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation)

The assessment of transportation accident impacts associated with exposures to chemical releases are quantified in terms of risks to onsite and offsite populations for the three health endpoints described in Section E.16.5. Inhalation exposure risks from chemical releases in onsite and offsite HW transportation accidents are quantified for the four HW alternatives. The risks are expressed as the potential number of expected adverse health effects (such as fatalities, reversible or irreversible organ or tissue damage, and individuals with an increased cancer risk of one in one million or higher) for each alternative and as a relative risk as compared with the No Action Alternative. A detailed description of the HW shipment inventory for each alternative is in ANL (1996a).

The collective annual population risks to the general public and onsite workers for onsite and offsite HW transportation, under each alternative, are presented in Table E–34. The approximate shipping routes are shown in Figures E–8 through E–10. The technical support document (ANL, 1996a) should be consulted for more detailed information (such as risks by generator, by shipment, and by chemical). Under the current system (No Action Alternative), HW is often brokered. Brokering is not assumed to occur under any but the No Action Alternative. Data on final destination of brokered HW were generally unavailable for the assessment of shipments evaluated for the potential adverse effects and cancer endpoints. Brokering data were incorporated only for shipments evaluated for the potential lethality endpoint.

Table E–34. Population Impacts Summary for Each HW Alternative for a 20-Year Period[a]

Shipment Data and Population Risks	Alternatives			
	No Action	Decentralized	Regionalized	Regionalized 2
Shipment Summary				
Number of shipments				
PIH cargo	1,000	1,000	2,000	1,000
Carcinogenic waste	3,000	4,000	5,000	3,000
Adverse effect waste	6,000	7,000	8,000	6,000
Other waste[b]	34,000	41,000	50,000	34,000
All waste categories[c]	34,000	41,000	50,000	34,000
Distance (km × 10^6)[d]				
Other waste[b]	31.5	31.3	55.7	30.0
PIH cargo	2.3	1.3	0.8	1.6
Carcinogenic waste	6.3	3.9	7.3	5.6
Adverse effect waste	13.00	8.9	16.5	11.8
All waste categories[c]	31.5	31.3	55.7	30.0
Population Risks[e] (number of individuals potentially affected)				
Cargo-related[f]				
Potential life-threatening health effects	0.146	0.057	0.056	0.076
Concerns for potential cancer incidents	2.2	1.2	2.5	2.1
Potential adverse health effects	78	49	86	60
Vehicle-related				
Physical trauma impacts[g]				
Accident fatalities	0.302	0.274	0.533	0.287
Accident injuries	1.972	1.793	3.480	1.874
Vehicle exhaust-related fatalities[h]	0.117	0.102	0.180	0.102

[a] Risks, number of shipments, and travel distances are for the total shipment duration (20 years). To obtain the annual values, divide risks, shipments, and distances by 20.
[b] Other waste is RCRA waste that did not meet the toxicity criteria for evaluation in this assessment (Section E.16.5).
[c] Total shipments and distances are less than the sum of the shipments and distances by cargo type because several waste types are generally shipped together.
[d] Distances reflect nonempty truck shipment distance multiplied by 2 to account for return of trucks with empty cargo. As a result, distance may be overestimated.
[e] Cargo-related and vehicle-related risks cannot be added because of the disparity in calculation methods and meaning of endpoints.
[f] Cargo-related risks refer to the number of people affected, computed from the product of the probability of accidental release times the number of people exposed to the health criteria concentration.
[g] Physical trauma impacts are based on total distance traveled carrying DOE HW.
[h] Vehicle exhaust impacts are based on total urban kilometers traveled by trucks carrying DOE HW in all four categories.

E.17.1.2.1 *Potential Life-Threatening Effects*

The data in Table E–34 show the relative risk of potential life-threatening effects among alternatives from transporting HW involving a PIH chemical spill. This table indicates that, among the alternatives evaluated, the No Action Alternative tends to indicate a higher risk of 45 to 50%. Risks under the Decentralized and Regionalized Alternatives are lowest, approximately 40% of those under the No Action Alternative.

The risk of life-threatening effects from offsite HW shipments under the No Action Alternative is generally approximately two or more times greater than the risks for other alternatives. The average shipment distances for containers with PIH chemicals for each alternative are approximately 2,380 km (1,480 mi) for No Action, 1,320 km (820 mi) for Decentralization, 400 km (250 mi) for Regionalized 1, and 1,600 km (994 mi) for Regionalized 2. More than 50% of the potential life-threatening effects risk under the No Action Alternative is contributed by about 8% of the HW shipments that contain PIH chemicals (5 of 63 PIH shipments). This same relationship is also true for the other three alternatives. The reduced risk under these alternatives is a direct result of shortening the shipment transportation distances. The specific chemicals in the five waste truckloads that contribute to most of the chemical inhalation risk are two shipments of arsine (0.03 m^3 [8 gal]), two shipments of hydrogen fluoride (0.06 m^3 [17 gal]), and one shipment of hydrogen selenide (3.8 L [1 gal]). The atmospheric transport and dispersion from the release of all five truckloads of these three chemicals was modeled as a negatively buoyant heavy or dense vapor plume. As the analysis indicates, these chemicals could present a significant but relatively small risk over the 20-year shipment duration.

E.17.1.2.2 *Any Adverse Effects*

For the any-adverse-effects endpoint, risks are highest under the No Action and Regionalized Alternatives; these risks are about 60 to 80% greater than risks under the Decentralized and Regionalized 2 Alternatives (Table E–34). The average transportation distances for shipments containing compounds with PAEC values are approximately 2,166 km (1,346 mi) for No Action, 1,271 km (790 mi) for the Decentralized Alternative, 2,062 km (1,282 mi) for Regionalized 1, and 1,967 km (1,222 mi) for Regionalized 2. More than 50% of the any-adverse-effects risk under the No Action Alternative is contributed by less than 13% of the shipments involving any-adverse-effect chemicals (36 of 285 shipments). This relationship also holds approximately true for the other three alternatives. The specific chemicals in these waste shipments that contribute most of the any-adverse-effect risk are 26 shipments of hydrogen chloride (30 containers;

3.05 m^3 [800 gal]), 8 shipments of hydrogen fluoride (9 containers; 0.81 m^3 [215 gal]), 1 shipment of acrolein (1 container; 3.8 L [1 gal]), 1 shipment of hydrogen selenide (1 container; 3.8 L [1 gal]), and 1 shipment of phosgene (1 container; 3.8 L [1 gal]). Atmospheric transport and dispersion were modeled as a negatively buoyant heavy or dense vapor plume for all but the acrolein shipment. The acrolein spill was modeled as a passive neutrally buoyant vapor plume. As the analysis indicates, these chemicals are substances that could present a significant risk of adverse effects if an accidental release occurred during truck transportation.

E.17.1.2.3 *Increased Carcinogenic Risk*

The average distance of waste container shipments with carcinogenic chemicals (or compounds with an ICRC value) for each alternative is approximately 2,100 km (1,305 mi) for No Action, 975 km (606 mi) for the Decentralized Alternative, 1,460 km (907 mi) for Regionalized 1, and 1,867 km (1,160 mi) for Regionalized 2. More than 50% of the carcinogenic risk under the No Action Alternative is contributed by less than 7% of the shipments of HW containing carcinogenic chemicals (7 of the 169 shipments). This relationship also holds approximately for the other three alternatives. The reduced cancer risk under the Decentralized Alternative is a direct result of lessening the shipment transportation distance. The specific chemicals in the seven waste shipments that contribute to most of the total risk are five shipments of dichloroethylene (six containers; 363.4 L [96 gal]) and two tanker shipments of chloroform 27.8 m^3 [7,342 gal]). The atmospheric transport and dispersion of these chemicals were modeled as passive, neutrally buoyant vapor plumes. As the analysis indicates, these chemicals could present an increased cancer risk of one in one million or higher to the general population if an accidental release occurred during truck transportation.

E.17.1.2.4 *Discussion*

As indicated in Table E-34, with respect to potential life-threatening health effects, the No Action Alternative results in the greatest number of kilometers traveled and, thus, the highest cargo-related population risk. For the other health endpoints, the No Action Alternative does not result in the highest number of miles traveled or the highest risks; however, the mileage estimates under the No Action

Alternative for the increased-cancer-risk and any-adverse-effects endpoints may be underestimated, because information on brokering was unavailable for shipments evaluated for those endpoints.

The Regionalized 2 Alternative results in higher potential life-threatening risks than the Regionalized 1 Alternative; however, with respect to the increased-cancer-risk and any-adverse-health-effects endpoints, the Regionalized 1 Alternative has greater risk. In all cases, the higher risks are associated with a greater number of kilometers traveled. The Regionalized 1 Alternative has five DOE treatment sites and nine supporting commercial sites (five west and four east of the Mississippi River). The Regionalized 2 Alternative includes two DOE sites and 21 commercial sites; however, the key factor here is that approximately 50% of the HW for the Regionalized 1 Alternative would be treated at commercial sites and 50% at DOE sites. For the Regionalized 2 Alternative, 90% of the waste is to go to only two sites (the DOE locations); the remaining 10% of the waste is to be sent, as needed, to the commercial sites.

The explanation for why risk is greater under the Regionalized 1 Alternative than under the Regionalized 2 Alternative (for carcinogenic and any-adverse-health-effects endpoints) lies in the distance trucks travel and how full they would be with DOE waste. In the analysis, more trucks are needed to ship HW under the Regionalized 1 Alternative because the waste typically must be split between commercial and DOE treatment. A shipment was considered a DOE shipment even if the truck was only partially loaded with DOE waste; however, for the Regionalized 2 Alternative, trucks can be loaded closer to capacity, reducing the number of shipments and transportation distance because so much of the waste is going to the same place (to either of the two DOE Regionalized 2 treatment hubs). The 90-day maximum on storage at DOE sites is the reason that full truckloads of waste are unlikely to leave DOE sites for treatment. Once the 90-day period is over, the waste must be moved offsite for treatment. Full trucks are more the exception than the rule, considering the various treatments possible for that waste. The exception is for the PIH chemicals. Although fewer shipments are required under the Regionalized 2 Alternative for PIH chemicals, the greater distance to centralized hubs is likely the cause of higher risks.

Current practice is for a DOE site to be one of a number of loading stops for a commercial transporter. The use of fully loaded, dedicated trucks going to a centralized location is an expensive alternative not considered realistic. This usage is certainly not common practice for DOE at this time. In addition, the requirement that a waste container not be stored for more than 90 days also argues for the current commercial pickup procedure, which allows for a larger number of shipments spread out over the year and avoids waste accumulation. If DOE-dedicated trucks were used for the Regionalized 1 and Regionalized 2

Alternatives, the total truck distance traveled would likely be lower for the Regionalized 1 Alternative because travel distance would be less for most shipments.

E.17.1.3 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation) for the MEI

E.17.1.3.1 *Potential Life-Threatening Effects*

The ALOHA™-computed hazard zones for PIH chemicals are given in Table E–35. A hazard zone is the distance from the release point within which life-threatening health effects may occur. Hazard zones are presented for PIH chemicals shipped by DOE with ALOHA™-modeled releases that would result in potentially lethal plumes. Poison inhalation hazard chemicals shipped in small quantities and for which spills would not result in a potentially lethal plume are not listed.

Table E–35. Hazard Zones for Potential Life-Threatening Risks to an MEI

Chemical Name	Hazard Zone[a] (m)	Number of Annual Shipments	Chemical Name	Hazard Zone[a] (m)	Number of Annual Shipments
Ammonia	93	5	Nitric acid, fuming	67	2
Arsine	719	4	Nitric oxide	137	1
Boron trifluoride	238	1	Phosgene	39	2
Bromine	39	2	Phosphine	203	2
Carbon monoxide	76	4	Sulfur dioxide	122	1
Chlorine	305	10	Titanium tetrachloride	40	1
Hydrogen fluoride	626	5			
Hydrogen sulfide	207	8	Nickel carbonyl	227	2

[a] Hazard zone indicates the distance from the release point within which life-threatening health effects may occur.

E.17.1.3.2 *Any Adverse Effects*

Poison inhalation hazard chemicals were not included in the exposure assessment of the MEI for the potential adverse effects endpoint because the appropriate endpoint for MEI receptors is potential lethality, which was addressed under Section E.17.1.3. ALOHA™ was used to estimate the chemical concentration and exposure duration for the MEI for the non-PIH chemicals. A standard risk equation was used (EPA, 1989b). Consistent with the chemical-specific accident risks for the public for this endpoint, parameters for a 6-year-old child were used: body weight of 21 kg (46.3 lb) and moderate activity inhalation rate of 0.033 m^3/min (EPA, 1989a). These values were compared with EPA RfD values by generating a hazard quotient (HQ) (daily intake/RfD) for each chemical. An HQ greater than 1 indicates that an adverse effect for the MEI is likely. Note that the level of concern associated with exposure to these compounds does not increase linearly as HQ values exceed 1. In other words, HQ values do not represent a probability or a percentage. One may conclude that, as the HQ value above 1 increases, greater concern exists about potential adverse effects; however, assuming that an HQ value of 10 indicates that adverse health effects are 10 times more likely to occur than for an HQ value of 1 is incorrect.

Results are shown in Table E-36. Only the HQ for trichlorofluoromethane is less than 1. The other HQs range from 1.9 (for dichlorodifluoromethane) to about 29,000 (for mercury). Thus, an accidental release of any of these substances would potentially result in adverse effects for receptors at the MEI location. Because of uncertainties and conservatism associated with using EPA RfD values to evaluate single, brief exposures, the assumption may be made that the risk of adverse effects is minimal for substances with HQ values between 1 and 10. Therefore, the greatest potential for adverse effects to the MEI is associated with accidental release of the following substances: 1,1,1-trichloroethane, acrylonitrile, carbon disulfide, carbon tetrachloride, chloroform, epichlorohydrin, hexane, mercury, methylene chloride, methyl isobutyl ketone, propylene oxide, toluene, triethylamine, and vinyl acetate.

E.17.1.3.3 *Increased Carcinogenic Risk*

For the 10 carcinogens of greatest concern, risks to the MEI were calculated on the basis of potency, quantity released, and dispersivity, as reflected by exposed areas output from the ALOHA™ model. Of the carcinogens DOE shipped under the No Action Alternative, only two (benzene and vinyl chloride) are

Table E-36. Any Adverse Effects Risk to an MEI

Chemical	Concentration at MEI Location (ppm)	Exposure Time (min)	Intake (mg/kg/d)	RfD (mg/kg/d)	HQ
Acetonitrile	3.0E+02	25	1.4E+00	1.4E-01	1.0E+01
Acrylonitrile	2.6E+02	20	1.3E+00	5.7E-04	2.3E+03
Acrylic acid	2.5E+01	60	5.0E-03	8.6E-04	5.8E+00
Aniline	9.0E+01	60	2.3E-02	2.9E-03	7.9E+00
Carbon disulfide	2.5E+02	10	8.7E-01	2.9E-03	3.0E+02
Carbon tetrachloride	1.4E+02	20	2.0E+00	1.7E-02	1.2E+02
Chloroform	7.0E+03	20	7.7E+01	1.1E-02	7.0E+03
Chloromethane	1.2E+04	2	5.3E+00	2.6E+00	2.0E+00
Dichlorodifluoro-methane	1.0E+03	2	1.1E+00	5.7E-01	1.9E+00
Epichlorohydrin	8.0E+00	60	2.0E-01	2.9E-03	6.9E+01
Hexane	1.8E+02	10	6.9E-01	5.7E-02	1.2E+01
Mercury	4.5E+01	60	2.5E+00	8.6E-05	2.9E+04
Methylene chloride	2.0E+04	10	7.8E+01	8.6E-01	9.1E+01
Methyl ethyl ketone	1.2E+03	25	9.9E+00	2.9E+00	3.4E+01
Methyl isobutyl ketone	5.5E+02	60	1.5E+01	2.3E-01	6.5E+01
Nitrobenzene	1.1E+00	60	3.6E-02	5.7E-03	6.3E+00
Propylene oxide	3.1E+02	2	1.7E-01	8.6E-03	2.0E+01
Toluene	6.5E+02	55	1.5E+01	1.1E-01	1.4E+02
Trichlorofluoromethane	1.3E+03	2	1.6E+00	2.0E+00	8.0E+01
1,1,1-Trichloroethane	1.0E+04	20	1.2E+02	2.9E-01	4.1E+02
Triethylamine	1.5E+01	15	1.0E-01	2.0E-03	5.0E+01
Vinyl acetate	1.4E+02	20	1.1E+00	5.7E-02	1.9E+01

ranked in carcinogen Class A (known human carcinogens). These two chemicals were included in the MEI evaluation.

ALOHA™ was used to estimate the carcinogen concentration and duration of exposure for the MEI. A standard risk equation and standard assumptions for inhalation rate (0.014 m^3/min and body weight of 70 kg [approximately 155 lb]) were used in calculating risks (EPA, 1989b). Risks ranged from 7×10^{-6} to 2.1×10^{-4} and are presented in Table E-37. All except one are within a risk range generally considered acceptable for HW sites. The risk of 2.1×10^{-4} was for hydrazine, a chemical shipped 12 times under the

Table E–37. Lifetime Increased Carcinogenic Risk to an MEI

Chemical	Concentration at MEI Location (ppm)[a]	Exposure Time (min)	Intake (mg/kg/d)[b]	Slope Factor $(mg/kg/d)^{-1}$	Cancer Incidence Risk to MEI
1,2-Dibromoethane	1.0E+01	60	3.6E–05	7.7E+01	2.8E–05
1,3-Butadiene	4.5E+02	2	1.6E–05	9.8E–01	1.5E–05
Acrylonitrile	2.5E+02	20	8.5E–05	2.4E–01	2.0E–06
Benzene	6.0E+02	20	3.0E–04	2.9E+02	8.7E–06
Ethylene oxide	5.55E+02	5	3.9E–05	3.5E–01	1.4E–05
Formaldehyde	8.15E+03	2	1.6E–04	4.6E–02	7.1E–06
Hydrazine	2.0E+01	60	1.2E–05	1.7E+01	2.1E–04
Tetrachloroethane	5.0E+01	60	1.6E–04	2.0E–01	3.3E–05
Vinyl chloride	1.85E+03	2	3.4E–05	2.9E–01	2.2E–05
Vinylidene chloride	1.25E+03	2	7.7E–05	1.8E–01	1.4E–05

[a] MEI is assumed to be located 30 m (100 ft) from release point.
[b] Adjusted to short-term exposures.

No Action Alternative; therefore, increased carcinogenic risk for the MEI is insignificant for all carcinogens except hydrazine; however, note that several of these carcinogens (specifically, acrylonitrile, ethylene oxide, and formaldehyde) are severe irritants and would be expected to result in eye and respiratory irritation to the MEI at the modeled dose levels.

E.17.1.3.4 *Accident and Routine Vehicle-Related Transportation Risks*

The risk of fatality and injury under each alternative is directly proportional to the number of miles traveled. For this reason, risks of the Decentralized, Regionalized, and Regionalized 2 Alternatives are approximately one-half those of the No Action Alternative. These risks may be refined to reflect fatality and injury rates specific to urban, suburban, and rural roadways as these data become available. The risks of fatalities and injuries from collisions occurring during HW transport are reported in Table E–34 for each alternative.

The routine vehicle-related risks associated with truck emissions are directly proportional to the number of miles traveled in urban areas for each alternative: the alternative with the most miles through urban areas has the greatest risk. The collective annual population risks (to the public and workers) from onsite and offsite HW transportation under routine nonaccident conditions are reported for each alternative in Table E–34. The data clearly show that routine risk estimates are linearly dependent on only one variable, total HW transportation distance. Truck shipments of HW through urban areas are 40 to 55% more frequent under the Regionalized 1 Alternative than under the other alternatives.

E.17.2 TRANSURANIC WASTE

E.17.2.1 TRUW Alternatives

See Section E.2.2.3 for a detailed description of the six TRUW alternatives.

E.17.2.2 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation)

Organic liquids constituted the TRUW waste stream class which would present the greatest risk to the public in terms of hazardous waste impacts if a transportation accident occurred. Therefore, this case was studied in detail for both truck and rail transportation modes. For truck mode, the results revealed that the footprint area for the work-case shipment was within 30 m (98 ft) of the roadway, where no residents were assumed to live. This was true for both the "any adverse effects" and "increased carcinogenic risk health" endpoints. Recall that no substance evaluated for the potentially-life threatening endpoint was included in the TRUW inventory. Since the most hazardous shipment was assessed, all other shipments would also result in zero population risks. Similarly, the plume footprint area for the most hazardous rail mode shipment was also within 30 m (98 ft) of the roadway, so the population risk was zero. Therefore, the population risk for both transportation modes under all alternatives was zero, primary due to TRUW transportation in TRUPACT-II containers.

E.17.2.3 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation) for the MEI

Truck Mode. The impacts to the MEI are the same for all alternatives under the truck transport mode since each alternative involves transport of organic liquids via truck or rail, and the MEI for each alternative is assumed to be located 30 m (98 ft) from the roadway. The MEI calculations were performed using assumptions and methods consistent with those presented above for hazardous waste. The carcinogenic risks and risks for any adverse effect are presented in Tables E–38 and E–39. The potential life-threatening effects endpoint was not assessed, because no PIH substances were included in the TRUW inventory. The risks to the MEI are very small but are nonzero. The risks shown are consistent with the result of zero population risks, because only carcinogenic risks of 10^{-6} or greater or hazard quotients of 1 or greater would result in a population risk that is reported in this assessment.

Rail Mode. The railcar accident release rates are twice the truck accident rates, because the railcars have a TRUPACT-II capacity of six (versus a truck capacity of 3). Therefore, the carcinogenic risks and risks for any adverse effects presented in Tables E–40 and E–41 are twice the risks presented for truck mode. The hazard quotient to the MEI from carbon tetrachloride is 1.06. This hazard quotient indicates a very borderline potential for any adverse effects (potential for effects is considered unlikely for hazard quotients

Table E–38. Lifetime MEI Carcinogenic Risks for Mixed TRUW—Truck Mode

Chemical Name	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation Air Intake (mg/kg/d)	Slope Factor $(mg/kg/d)^{-1}$	Carcino-genic MEI Risk
Carbon tetrachloride	2.15E–01	60	6.34E–07	5.25E–02	3.3E–08

Table E–39. MEI Hazard Quotients for Adverse Effect Endpoint for Mixed TRUW—Truck Mode

Chemical Name	Molecular Weight	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation Air Intake (mg/kg/d)	Inhalation RfD $(mg/kg/d)^{-1}$	Hazard Quotient Risk
1,1,1-trichloroethane	133.42	5.86E–01	60	2.1E–02	2.9E–01	7.52E–02
Carbon tetrachloride	153.82	2.15E–01	60	9.1E–03	1.7E–02	5.30E–01
Freon 113	187.38	1.85E–01	60	9.5E–03	8.6E+00	1.11E–03

Table E-40. Lifetime MEI Carcinogenic Risks for Mixed TRUW—Rail Mode

Chemical Name	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation Air Intake (mg/kg/d)	Slope Factor $(mg/kg/d)^{-1}$	Carcino-genic MEI Risk
Carbon tetrachloride	4.3E-01	60	6.34E-07	5.25E-02	6.6E-08

Table E-41. MEI Hazard Quotients for Adverse Effect Endpoint for Mixed TRUW—Rail Mode

Chemical	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation Air Intake (mg/kg/d)	Inhalation RfD (mg/kg/d)	Hazard Quotient
1,1,1-trichloroethane	1.17E+00	60	2.1E-02	2.9E-01	1.50E-01
Carbon tetrachloride	4.30E-01	60	9.1E-03	1.7E-02	1.06E+00
Freon 113	3.70E-01	60	9.5E-03	8.6E+00	2.22E-03

less than 1). As a general guideline, the assumption may be made that the risk of adverse effects in minimal for substances with HQ values between 1 and 10, due to the uncertainties and conservatism associated with the use of EPA RfD values to evaluate single, brief exposures. Therefore, adverse effects due to carbon tetrachloride exposure would be unlikely unless the MEI receptor was extremely sensitive with respect to chemical exposures.

Accident and routine vehicle-related risks from transportation of TRUW are presented in Part I.

E.17.3 Low-Level Mixed Waste

E.17.3.1 LLMW Alternatives

See Section E.2.2.4 for a detailed description of the six LLMW alternatives. In summary, the alternatives assessed for the HW component of LLMW consist of the following:

- Decentralized (49 sites treat contact-handled waste [CH]; 16 sites dispose)
- Regionalized 1 (11 sites treat CH; 12 sites dispose)

- Regionalized 2 (7 sites treat CH; 6 sites dispose)
- Regionalized 3 (7 sites treat CH; 1 site disposes)
- Regionalized 4 (4 sites treat CH; 6 sites dispose)
- Centralized (1 site treats and 1 site disposes of CH

Under all alternatives, remote-handled waste would be treated and disposed of at four sites. The No Action Alternative does not involve HW transportation risks, and thus is not discussed here.

E.17.3.2 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation)

The collective cargo-related population risks to the general public for 10 years of off-site WM transportation are summarized in Table E-42 for truck transport mode and in Table E-43 for rail transport mode. The potential life-threatening effects endpoint was not assessed, because no PIH substances were included in the LLMW inventory.

The potential population risks involving liquid waste shipments by trucks and railcars are attributed to the direct release of aerosolized liquid droplets. Truck-accident increased cancer risk and any adverse effect risk from aerosolized liquid droplets are highest for highway shipments under the Centralized Alternative, Severity Category IV. Railcar-accident risks from aerosolized liquid droplets are also highest for rail shipments under the centralized alternative and the same severity category.

The potential population risks involving solid waste shipments by trucks and railcars are attributed to evaporative organic vapor emissions from a waste spoils-pile ground spill and to the direct release of respirable particulates from an overturned vehicle or a ruptured container (or both). Both truck and railcar accident risks from evaporative and from respirable particulate releases are found to be zero for all of the cases.

Table E-42. Summary of Cargo-Related Population Risks[a] for WM (10-Year Period)[b] LLMW Shipments by Highway

	LLMW Treatment Options					
Population Risks	**Decen-tralized**	**Region-alized 1**	**Region-alized 2**	**Region-alized 3**	**Region-alized 4**	**Centralized**
Shipment summary						
Number of shipments	5.00E+01	6.30E+02	1.23E+03	1.18E+03	2.49E+03	5.13E+03
Distance (km)	4.73E+04	3.23E+05	5.00E+05	4.44E+05	8.27E+05	2.33E+06
Liquid wastes						
Potential for increased cancer incidence						
Severity Categories I	0	0	0	0	0	0
Severity Categories II	0	0	0	0	0	0
Severity Categories III	0	5.98-07	2.54E-04	2.54E-04	2.61E-04	3.08E-04
Severity Category IV[c]	*2.49E-07*	*3.90E-06*	*3.42E-04*	*3.42E-04*	*3.53E-04*	*4.30E-04*
Severity Category V	3.42E-08	4.89E-07	4.39E-05	4.39E-05	4.54E-05	5.55E-05
Severity Category VI	9.76E-09	1.16E-07	1.10E-05	1.10E-05	1.14E-05	1.41E-05
Severity Category VII	4.99E-10	7.08E-09	6.44E-07	6.44E-07	6.67E-07	8.21E-07
Severity Category VIII	6.30E-11	7.30E-10	7.09E-08	7.09E-08	7.38E-08	9.20E-08
Potential adverse health effects						
Severity Categories I	0	0	0	0	0	0
Severity Categories II	0	1.39E-06	8.01E-04	8.01E-04	8.09E-04	9.28E-04
Severity Categories III	0	8.28E-06	9.21E-04	9.21E-04	9.50E-04	1.22E-03
Severity Category IV[c]	*1.53E-06*	*1.98E-05*	*1.33E-05*	*1.32E-03*	*1.37E-03*	*1.67E-03*
Severity Category V	2.10E-07	2.51E-06	1.70E-04	1.70E-04	1.76E-04	2.15E-04
Severity Category VI	6.01E-08	6.07E-07	4.26E-05	4.25E-05	4.42E-05	5.45E-05
Severity Category VII	3.07E-09	3.65E-08	2.50E-06	2.49E-06	2.59E-06	3.18E-06
Severity Category VIII	3.88E-10	3.86E-09	2.75E-07	2.75E-07	2.87E-07	3.57E-07
Solid wastes (volatile-organic-contaminated soil/debris evaporative releases)						
Potential for increased cancer incidence	0	0	0	0	0	0
Potential adverse health effects	0	0	0	0	0	0
Solid wastes (respirable contaminated aerosol releases)						
Potential for increased cancer incidence	0	0	0	0	0	0
Potential adverse health effects	0	0	0	0	0	0

[a] Cargo-related risks refer to the number of people affected and were computed from the product of the probability of accidental release times the number of people exposed to the health criteria concentration.
[b] Risks and travel distances are for the total shipping duration (10 years). To obtain the annual values, the risks and distances must be divided by 10.
[c] Values in italics present the highest risk for a specific risk category.

Table E–43. Summary of Cargo-Related Population Risks[a] for WM (10-Year Period)[b] LLMW Shipments by Railway

Population Risks	LLMW Treatment Options					
	Decentralized	Regionalized 1	Regionalized 2	Regionalized 3	Regionalized 4	Centralized
Shipment summary						
Number of shipments	5.00E+01	5.30E+02	8.10E+02	7.60E+02	1.32E+03	2.34E+03
Distance (km)	3.88E+04	3.65E+05	5.76E+05	5.17E+05	9.15E+05	2.46E+06
Liquid wastes						
Potential for increased cancer incidence						
Severity Categories I	0	0	0	0	0	0
Severity Categories II	0	0	2.42E–05	2.42E–05	2.42E–05	2.42E–05
Severity Categories III	0	1.84E–07	*9.05E–05*	*9.05E–05*	*9.24E–05*	*1.12E–04*
Severity Category IV	*9.84E–08*	*1.03E–06*	7.42E–06	7.41E–05	7.60E–05	9.19E–05
Severity Category V	7.56E–09	7.51E–08	5.36E–08	5.35E–06	5.50E–06	6.70E–06
Severity Category VI	3.82E–10	3.41E–09	2.38E–07	2.38E–07	2.46E–07	3.04E–07
Severity Category VII	8.53E–11	8.66E–10	7.22E–08	7.21E–08	7.42E–08	8.90E–08
Severity Category VIII	1.57E–11	1.26E–10	9.62E–09	9.60E–09	9.98E–09	1.24E–08
Potential adverse health effects						
Severity Categories I	0	0	0	0	0	0
Severity Categories II	0	1.41E–07	1.38E–04	1.38E–04	1.38E–04	1.55E–04
Severity Categories III	0	3.13E–06	*4.08E–04*	*4.08E–04*	*4.17E–04*	*4.92E–04*
Severity Category IV	*4.41E–07*	*4.71E–06*	2.92E–04	2.91E–04	2.99E–04	3.64E–04
Severity Category V	3.39E–08	3.44E–07	2.11E–05	2.11E–05	2.17E–05	2.65E–05
Severity Category VI	1.17E–09	1.57E–08	9.38E–07	9.37E–07	9.69E–07	1.20E–06
Severity Category VII	3.82E–10	3.95E–09	2.84E–07	2.84E–07	2.92E–07	3.52E–07
Severity Category VIII	7.01E–11	5.88E–10	3.79E–08	3.78E–08	3.93E–08	4.91E–08
Solid wastes (volatile-organic-contaminated aerosol releases)						
Potential for increased cancer incidence	0	0	0	0	0	0
Potential adverse health effects	0	0	0	0	0	0
Solid wastes (respirable contaminants aerosol releases)						
Potential for increased cancer incidence	0	0	0	0	0	0
Potential adverse health effects	0	0	0	0	0	0

[a] Cargo-related risks refer to the number of people affected and were computed from the product of the probability of accidental release times the number of people exposed to the health criteria concentration.
[b] Risks and travel distances are for the total shipping duration (10 years). To obtain the annual values, the risks and distances must be divided by 10.
[c] Values in italics present the highest risk for a specific risk category.

E.17.3.3 Cargo-Related Accident Transportation Risks (Chemical Dose Through Inhalation) for the MEI

With regard to MEI risk evaluation, the increased cancer risk and any adverse effects endpoints are summarized in Tables E–44 and E–45. The methods used to estimate risks to the MEI were the same as those used for HW outlined in Sections E.17.1.3.2 and E.17.1.3.3 above. The risk calculations are based on the maximum ambient concentrations at 30 m (98 ft) from the release point for all shipments for a single

Table E-44. Lifetime Increased Cancer Risk to an MEI for LLMW Transportation

Transportation Mode	Release Mode	Chemical Name	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation[a] Air Intake (mg/kg/d)	Slope Factor $(mg/kg/d)^{-1}$	Cancer Incidence Risk to MEI
Highway	Liquid aerosol (direct)	Dichloromethane	1.22E+00	60	1.99E-06	1.65E-03	3.3E-09
		Dichloroethane	7.21E-01	60	1.37E-06	9.10E-02	1.2E-07
		Tetrachloroethene	1.15E+01	60	3.66E-05	5.95E-03	2.2E-07
		Benzene	1.28E+03	60	1.92E-03	2.91E-02	5.6E-05
	Vapor spoils pile (Superfund)	Dichloromethane	2.51E-03	60	4.09E-09	1.65E-03	6.7E-12
		Dichloroethane	1.69E-03	60	3.21E-09	9.10E-02	2.9E-10
		Tetrachloroethene	6.59E-04	60	2.10E-09	5.95E-03	1.2E-11
		Benzene	8.05E-03	60	1.21E-08	2.91E-02	3.5E-10
	Particulate (severity Category II)	Dichloromethane	5.28E-03	60	8.60E-09	1.65E-03	1.4E-11
		Dichloroethane	2.31E-03	60	4.38E-09	9.10E-02	4.0E-10
		Tetrachloroethene	2.47E-02	60	7.86E-08	5.95E-03	4.7E-10
		Benzene	8.09E-02	60	1.21E-07	2.91E-02	3.5E-09
	Particulate (severity Category III)	Dichloromethane	5.28E-02	60	8.60E-08	1.65E-03	1.4E-10
		Dichloroethane	2.31E-02	60	4.28E-08	9.10E-02	4.0E-09
		Tetrachloroethene	2.47E-01	60	7.86E-07	5.95E-03	4.7E-09
		Benzene	8.09E-01	60	1.21E-06	2.91E-02	3.5E-08
	Particulate (severity Categories IV-VIII)	Dichloromethane	5.28E-01	60	8.60E-07	1.65E-03	1.4E-09
		Dichloroethane	2.31E-01	60	4.38E-07	9.10E-02	4.0E-08
		Tetrachloroethene	2.47E+00	60	7.86E-06	5.95E-03	4.7E-08
		Benzene	8.09E+00	60	1.21E-05	2.91E-02	3.5E-07
Railroad	Liquid aerosol (direct)	Dichloromethane	1.57E+01	60	2.56E-05	1.65E-03	4.2E-08
		Dichloroethane	7.27E+00	60	1.38E-05	9.10E-02	1.3E-06
		Tetrachloroethene	2.33E+01	60	7.41E-05	5.95E-03	4.4E-07
		Benzene	3.22E+03	60	4.82E-03	2.91E-02	1.4E-04
	Vapor spoils pile (Superfund)	Dichloromethane	2.51E-03	60	4.09E-09	1.65E-03	6.7E-12
		Dichloroethane	1.69E-03	60	3.21E-09	9.10E-02	2.9E-10
		Tetrachloroethene	6.59E-04	60	2.10E-09	5.95E-03	1.2E-11
		Benzene	8.05E-03	60	1.21E-08	2.91E-02	3.5E-10
	Particulate (severity Category II)	Dichloromethane	5.28E-03	60	8.60E-09	1.65E-03	1.4E-11
		Dichloroethane	2.31E-03	60	4.38E-09	9.10E-02	4.0E-10
		Tetrachloroethene	2.47E-02	60	7.86E-08	5.95E-03	4.7E-10
		Benzene	8.09E-02	60	1.21E-07	2.91E-02	3.5E-09
	Particulate (severity Category III)	Dichloromethane	5.28E-02	60	8.60E-08	1.65E-03	1.4E-10
		Dichloroethane	2.31E-02	60	4.38E-08	9.10E-02	4.0E-09
		Tetrachloroethene	2.47E-01	60	7.86E-07	5.95E-03	4.7E-09
		Benzene	8.09E-01	60	1.21E-06	2.91E-02	3.5E-08
	Particulate (severity Categories IV-VIII)	Dichloromethane	5.28E-01	60	8.60E-07	1.65E-03	1.4E-09
		Dichloroethane	2.31E-01	60	4.38E-07	9.10E-02	4.0E-08
		Tetrachloroethene	2.47E+00	60	7.86E-06	5.95E-03	4.7E-08
		Benzene	8.09E+00	60	1.21E-05	2.91E-02	3.5E-07

[a] Adjusted to short-term exposures.

Table E-45. Any Adverse Effects Risk to an MEI for LLMW Transportation

Transportation Mode	Release Mode	Chemical Name	Concentration at MEI Location (ppm)	Exposure Time (min/d)	Inhalation Air Intake (mg/kg/d)	RfD (mg/kg/d)	HQ
Highway	Liquid spill	Dichloromethane	1.22E+00	60	2.9E-02	8.6E-01	3.33E-02
		1,1,1-Trichloroethane	7.21E-01	60	2.6E-02	2.9E-01	9.25E-02
		Freon 113	1.15E+01	60	5.9E-01	8.6E+00	6.90E-02
		Toluene	1.28E+03	60	3.2E+01	1.1E-01	2.84E+02
	Spoils pile vapor (Superfund)	Dichloromethane	2.51E-03	60	5.9E-05	8.6E-01	6.84E-05
		1,1,1-Trichloroethane	1.69E-03	60	6.2E-05	2.9E-01	2.17E-04
		Freon 113	6.59E-04	60	3.4E-05	8.6E+00	3.95E-06
		Toluene	8.05E-03	60	2.0E-04	1.1E-01	1.78E-03
	Particulate (severity Category II)	Dichloromethane	5.28E-03	60	1.2E-04	8.6E-01	1.44E-04
		1,1,1-Trichloroethane	2.31E-03	60	8.5E-05	2.9E-01	2.96E-04
		Freon 113	2.47E-02	60	1.3E-03	8.6E+00	1.48E-04
		Toluene	8.09E-02	60	2.0E-03	1.1E-01	1.79E-02
	Particulate (severity Category III)	Dichloromethane	5.28E-02	60	1.2E-03	8.6E-01	1.44E-03
		1,1,1-Trichloroethane	2.31E-02	60	8.5E-04	2.9E-01	2.96E-03
		Freon 113	2.47E-01	60	1.3E-02	8.6E+00	1.48E-03
		Toluene	8.09E-01	60	2.0E-02	1.1E-01	1.79E-01
	Particulate (severity Categories IV-VIII)	Dichloromethane	5.28E-01	60	1.2E-02	8.6E-01	1.44E-02
		1,1,1-Trichloroethane	2.31E-01	60	8.5E-03	2.9E-01	2.96E-02
		Freon 113	2.47E+00	60	1.3E-01	8.6E+00	1.48E-02
		Toluene	8.09E+00	60	2.0E-01	1.1E-01	1.79E+00
Railroad	Liquid spill	Dichloromethane	1.57E+01	60	3.7E-01	8.6E-01	4.28E-01
		1,1,1-Trichloroethane	1.29E+02	60	4.7E+00	2.9E-01	1.66E+01
		Freon 113	7.65E-02	60	3.9E-03	8.6E+00	4.59E-04
		Toluene	2.68E+03	60	6.8E+01	1.1E-01	5.94E+02
	Spoils pile vapor (Superfund)	Dichloromethane	2.51E-03	60	5.9E-05	8.6E-01	6.84E-05
		1,1,1-Trichloroethane	2.87E-03	60	1.1E-04	2.9E-01	3.68E-04
		Freon 113	2.98E-05	60	1.5E-06	8.6E+00	1.79E-07
		Toluene	2.04E-03	60	5.2E-05	1.1E-01	4.52E-04
	Particulate (severity Category II)	Dichloromethane	5.28E-03	60	1.2E-04	8.6E-01	1.44E-04
		1,1,1-Trichloroethane	3.85E-02	60	1.4E-03	2.9E-01	4.94E-03
		Freon 113	9.64E-04	60	5.0E-05	8.6E+00	5.78E-06
		Toluene	7.34E-02	60	1.9E-03	1.1E-01	1.63E-02
	Particulate (severity Category III)	Dichloromethane	5.28E-02	60	1.2E-03	8.6E-01	1.44E-03
		1,1,1-Trichloroethane	3.85E-01	60	1.4E-02	2.9E-01	4.94E-02
		Freon 113	9.64E-03	60	5.0E-04	8.6E+00	5.78E-05
		Toluene	7.34E-01	60	1.9E-02	1.1E-01	1.63E-01
	Particulate (severity Categories IV-VIII)	Dichloromethane	5.28E-01	60	1.2E-02	8.6E-01	1.44E-02
		1,1,1-Trichloroethane	3.85E+00	60	1.4E-01	2.9E-01	4.94E-01
		Freon 113	9.64E-02	60	5.0E-03	8.6E+00	5.78E-04
		Toluene	7.34E+00	60	1.9E-01	1.1E-01	1.63E+00

Note: RfD = inhalation reference dose.

truck or railcar accident predicted by the ALOHA™ model on a chemical-specific basis. As indicated in Table E–44, carcinogenic risks for all chemicals are between 1.2×10^{-11} and 1.4×10^{-4}.

All except one for the liquid shipment assessed (both by truck and rail) are lower than or within a risk range generally considered acceptable for HW sites (i.e., 10^{-6} to 10^{-4}). The carcinogenic risks of 5.6×10^{-5} for truck shipment and 1.4×10^{-4} for railcar shipment were for LLMW classified as soluble hydrocarbon. As a conservative assumption and to facilitate calculations, soluble hydrocarbon waste was assumed to be the carcinogenic substance benzene. The risks presented for this waste category are probably overestimated, because it is highly unlikely that the soluble hydrocarbons are actually composed of pure benzene. However, more data on the composition of the material would be required to refine the risk estimate. Adverse effects are considered possible for substances with associated hazard quotient values greater than 1. As shown in Table E–45, HQs are greater than 1 for the liquid shipment assessed (both by truck and rail), and for solid-waste truck and rail shipments of toluene under accident severity categories IV through VIII. Thus, accidental release involving any of these shipments would have a potential to result in adverse effects for receptors at the MEI location.

Increased cancer risks and any adverse effects risks are also presented in the technical support document by alternative (ANL, 1996e).

E.18 Uncertainty

The consecution of analysis leading to estimates of transportation risk for HW and HW components of TRUW and LLMW has the following major components: (1) computation of transportation routes; (2) development of health effects criteria; (3) selection of appropriate truck accident, toxic chemical release, and ruptured container probabilities; (4) quantitative estimation of source terms and atmospheric transport and dispersion; (5) calculation of exposure areas exceeding health endpoint specific chemical concentration levels; and (6) estimation of worker, general population, and MEI risks. Various levels of uncertainty are associated with each of these components. Uncertainties exist in the way the physical systems being analyzed are represented by the computational models, in the data required to exercise the models (due to measurement errors, sampling errors, natural variability, or unknowns simply due to the future nature of the actions being analyzed), and in the calculations themselves (for example, empirical data inherent in the model structure and the theoretical assumptions incorporated in the model). The errors in data used as input to the model or models applied to compute risk can be referred to as *parameter uncertainty*. Errors in the model algorithm or empirical data incorporated in the model can be referred to as *model uncertainty*.

In principle, one can estimate the uncertainty associated with each model input data parameter, each model empirical parameter, and each model theoretical assumption, and predict the resultant uncertainty in each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final result (that is, human health risk); however, conducting such a full-scale quantitative uncertainty analysis is often impractical because of the lack of actual data (for example, field measurements), which does not permit development of the necessary probability distributions needed to quantify uncertainty in every parameter. This is especially true for actions to be taken in the future; however, one can typically assume that the accuracy of Gaussian model predictions of maximum ground level concentrations, such as those from ALOHA™, are within a factor of 3 of corresponding field observations (Turner, 1994). The remainder of the error inherent in the risk calculations is in parameter uncertainty. Three main types of parameter uncertainty exist: random error resulting from data entry or reporting, systematic error induced from biases in data collection and analysis procedures, and errors resulting from variability over time and space (that is, meteorology or waste volumes). Certain key model input parameters can be identified for analysis that should capture the most significant contributors associated with parameter uncertainty and, when combined with model uncertainty, to the overall uncertainty in the risk assessment. These parameters come from the following six areas:

- *Meteorologic conditions* (for example, windspeed and direction, atmospheric stability, relative humidity, and ambient temperature) at the time of the accident
- *Number of shipments* of hazardous chemicals, which depends on the accuracy of the total annual shipment inventory and its variation from year to year
- *Release amounts* from any given accident caused by impact physics (the vehicle's speed, collision type, and number of vehicles involved), the location of the container rupture, and the number and contents of ruptured containers
- Hazardous material truck *accident rates* and the *release probability*, given an accident
- *Population density* in the vicinity of the accident
- *Health criteria* and extrapolation to humans, including the adjustment of each health criterion to the actual exposure time of the human to the vapor plume

Estimates of the potential range of uncertainty or variability in the absolute HW risk can be made by varying these parameters independently within probable parameter error bands or known variability bands. Although not a quantitative uncertainty analysis, this type of sensitivity analysis is useful in providing some semiquantitative estimate of potential absolute uncertainty in the risk estimates associated with each parameter. To do this, the data used to estimate the risk of potential life-threatening effects discussed in Section E.17.1.2.1 of this appendix were used to carry out a sensitivity analysis to estimate potential parameter error bands. Because the risk estimate results from these data show that more than 50% of the risk for potential life-threatening effects under the No Action Alternative is contributed by a small fraction of the total shipments (5 of 63 PIH shipments), a sensitivity analysis using these data should provide a reasonable estimate of the magnitude of parameter error bands. The specific chemicals in the five waste truckloads that contribute to most of the chemical-inhalation potential life-threatening risk are two shipments of arsine (0.03 m^3 [8 gal]), two shipments of hydrogen fluoride (0.06 m^3 [17 gal]), and one shipment of hydrogen selenide (3.8 L [1 gal]). The atmospheric transport and dispersion from the release of all five truckloads of these three chemicals were modeled as a negatively buoyant heavy or dense vapor plume.

The first parameter examined was meteorologic conditions. Although random error (error of data collection and reporting) and systematic error (error of instrument calibration) are associated with this parameter, uncertainty associated with meteorologic variability should produce variability bands that overlap the smaller error bands associated with random and systematic error. Windspeed, atmospheric stability, and ambient temperature were varied to estimate the risk associated with meteorologic variability for the top six HW shipments contributing more than 50% of the risk. Windspeeds were varied from 1 to 20 m/s (2.2 to 45 mi/h) for conditions of daytime neutral stability (stability Class D) with 35°C (95°F) and 10°C (50°F) ambient temperatures and were varied from 2 to 5 m/s (4.5 to 11 mi/h) for nighttime stable (stability Classes E and F) conditions with 20°C (70°F) and -9°C (15°F) ambient temperatures. The PEIS risk assessment assumed 4-m/s (9-mi/h) winds, neutral stability, and an ambient temperature of 35°C (95°F). This parameter variability produces a risk uncertainty varying from approximately a factor of 3 smaller to approximately a factor of 11 larger. Risk standard deviations range from 4.3×10^{-4} (for the arsine shipment) to 2.0×10^{-2} (for the hydrogen selenide shipment).

The uncertainty in the number of shipments per year depends on the accuracy of reported manifested waste volume inventory of PIH, ICRC, and PAEC chemicals and the year-to-year variability in shipping these chemicals. Although risk is linear with transportation miles, the number of shipments is not linear with manifested waste volumes. With the assumption that a fully implemented waste minimization program would offset any positive bias in the waste inventory, a 20% reduction in volume could lead to 5% fewer shipment miles.

The release amount depends on many factors, such as the vehicle's speed at impact, the position and quantity of drums in the truck, and the truck type. Preliminary sensitivity analysis indicated that variations in these factors can lead up to a factor of 10 difference in risks for a single route.

Release probabilities have an approximately linear relationship to risk. The same six routes and chemicals mentioned previously were analyzed for transportation risk by using 20% more or less than the probabilities used in actual risk analysis. Risk results appeared to be linearly related because 20% higher probabilities led to an approximately 20% higher risk.

Changing the health criteria (for lethality) to 0.1 to 10 times the value used in the risk assessment led to dramatic changes in the risk. Typically, changes in the risk between 1 and 2 orders of magnitude resulted along any one route of the six tested. Errors of 0.1 to 10 are possible for the health criteria for different chemicals, but that range likely covers any reasonable error in estimation of that health criterion. Some cancellation of errors is likely as the risk from many routes and chemicals is summed to provide the total risk for a specific alternative; however, the risk from the top 10% of the routes with the greatest risk likely dominates this summation process.

Looking at the individual contributors to risk uncertainty is useful from a modeler's perspective for gaining insight on the weaknesses and strengths of a particular modeling analysis. However, it would be more useful from a decision maker's perspective to have some estimate of the overall uncertainty in the computed risk estimate. To do this, a risk estimate model that provides both deterministic and probabilistic estimates was employed (Policastro et al., 1995). The results from this exercise show an approximately 98.6% probability that after 20 years of hazardous waste shipments, no people would suffer potentially life-threatening health effects. The deterministic prediction of risk for the 20-year period, 3.48×10^{-3} people suffering potentially life-threatening health effects, was found to be at the 99.5th percentile of the probability distribution.

The transportation risk assessment is designed to ensure—through uniform and judicious selection of scenarios, models, and input parameters—that relative comparisons of risk among the various alternatives are meaningful because the errors in each alternative evaluation repeat themselves in the same way. Because the uncertainty is in the absolute risk estimates; for example, the potential number of fatalities, relying on the relative risk comparisons among alternatives normalizes this uncertainty and therefore reduces the level of uncertainty in the comparative results. In the transportation risk assessment, input parameters and assumptions are uniformly applied to all HW alternatives. Therefore, although considerable uncertainty is inherent in the absolute magnitude of the transportation risk for each alternative, much less uncertainty is associated with the relative differences among the alternatives in a given measure of risk.

E.18.1 Counterposing or Reinforcement of Errors (Absolute Uncertainty)

The previous discussion describes the major sources of parameter and model uncertainty in the HW risk analysis calculations and the ranges of likely uncertainty in those parameters and models used. For some parameters, an estimate of the possible risk value range for a 1.6-km (1-mi) segment due to the parameter range was given as well; however, the total risk calculated for a specific alternative (and health endpoint) is actually the sum of the risk values computed for each of the many 1.6-km (1-mi) segments encompassing the many routes traveled by the many HW shipments for that alternative (No Action, Decentralized, Regionalized 1 or 2). The computed risk is the summation of the predicted risk for each mile in the routing. There is some error in the risk prediction for each mile. There would be some degree of cancellation of errors during this risk summation process (risk for some miles being overestimated and for others being underestimated), unless there is a systematic overprediction or underprediction of the risk at each mile. That possibility is not expected because the most accurate value was chosen for component of risk in the risk calculation for each single mile. The interplay of uncertainties by parameter and assumption could be estimated only by using a detailed probabilistic risk assessment approach, which was not taken in this appendix. Recognizing that some error cancellation and actually some error reinforcement do occur is key to understanding the uncertainty in the final or total risk numbers computed. The effect of the combined set of parameter and model errors is estimated to be within plus or minus one order of magnitude for the total risk numbers presented for a specific alternative and endpoint.

E.18.2 Relative Uncertainty

Although the absolute uncertainty may seem large from the previous discussion, the relative uncertainty is most important, and that uncertainty is believed to be sufficiently small to allow reliance on the management conclusions that result from comparing differences in the risk predictions among the alternatives. Relative uncertainty is the uncertainty in the difference between pairs of alternatives. Because a risk value is computed for each of the four alternatives (and same endpoint) by using exactly the same methods, models, and parameter values, differences in the results should be caused by meaningful differences in the structure of the alternatives; for example, with one alternative, more miles may be covered by HW shipments than another. This relative risk is believed to be smaller than the actual differences in risk values from the various alternatives; for example, if the risk from the Regionalized 2 Alternative is greater than the risk from the No Action Alternative, the behavior—of Regionalized 2 being larger than No Action—is believed to be accurate, although the actual risk numbers computed may each contain significant error. The accuracy of these statements about relative risk are critical to the meaning of the risk analyses in this PEIS.

E.19 Mitigative Measures

When transporting HW and LLMW, DOE follows all applicable regulations of DOT and EPA, such as using absorbent overpacking to prevent liquid releases, using placards, preparing manifests, and employing licensed transporters. For each named chemical, the CFR identifies permissible containers for transporting that chemical. The containers are ranked based on their sturdiness and the hazard class of the chemical to be transported. These regulations are designed to minimize the risks of transporting HW and to allow for rapid mitigative action in the event of an accidental release.

The DOE may consider additional measures to further minimize risks associated with HW and LLMW transportation. Examples include rerouting shipments through low-population density areas, pretreating the more dangerous chemicals at DOE sites, or substituting for the chemicals that lead to the greatest risk. Where possible, the potential decrease in risk that could be achieved through using rail transport may also be investigated.

E.20 References

Part II

ANL. *See* Argonne National Laboratory.

Argonne National Laboratory. 1996a. *Hazardous Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.A. Lazaro, A.A. Antonopoulos, M.P. Esposito, and A.J. Policastro. ANL/EAD/TM-25. Aug. Argonne, IL.

Argonne National Laboratory. 1996b. *Information Related to Low-Level Mixed Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by B.D. Wilkins, D.A. Dolak, Y.Y. Wang, and N.K. Meshkov. ANL/EAD/TM-32. Argonne, IL.

Argonne National Laboratory. 1996c. *Transuranic Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by K.J. Hong, T.J. Kotek, S.M. Folga, B.L. Koebnick, Y. Wang, and C.M. Kaicher. ANL/EAD/TM-22. Argonne, IL.

Argonne National Laboratory. 1996d. *Risk Assessment for Transportation of Hazardous Waste and Hazardous Waste Components of Low-Level Mixed Waste and Transuranic Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.A. Lazaro, A.J. Policastro, H.M. Hartmann, A.A. Antonopoulos, D.F. Brown, W.E. Dunn, M.A. Cowen, Y.S. Chang, and B.L. Koebnick. ANL/EAD/TM-28. Argonne, IL.

Argonne National Laboratory. 1996e. *Supplemental Information Related to Risk Assessment for the Off-site Transportation of Low-Level Mixed Waste for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by F.A. Monette, B.M. Biwer, D.J. LePoire, M.A. Lazaro, A.A. Antonopoulos, H.M. Hartmann, A.J. Policastro, and S.Y. Chen. ANL/EAD/TM-35. Argonne, IL.

DOC. *See* U.S. Department of Commerce.

DOT. *See* U.S. Department of Transportation.

EPA. *See* U.S. Environmental Protection Agency.

Graf, V.D., and K. Archuleta. 1985. *Truck Accidents by Classification*. FHWA/CA/TE-85. Jan. California Department of Transportation.

Hartmann, H.M., A.J. Policastro, and M.A. Lazaro. 1994. "Hazardous Waste Transportation Risk Assessment for the Environmental Restoration and Waste Management Programmatic Environmental Impact Statement—Human Health End Points." Paper presented at symposium, Waste Management '94. University of Arizona, Feb. 27-March 3, Tucson, AZ.

Harwood, D.W., and E.R. Russell. 1990. *Present Practices of Highway Transportation of Hazardous Materials*. FHWA/RD-89/013. May. McLean, VA: Midwest Research Institute for Federal Highway Administration, Office of Safety and Traffic Operations.

Johnson, P. (Oak Ridge National Laboratory, Oak Ridge, TN). Personal communication, Jan. 24, 1994.

Lazaro, M.A., P.W. Stoll, A.J. Policastro, A.A. Antonopoulos, H.M. Hartmann, B. Koebnick, and M. Dovel. 1994. *Hazardous Waste Database: Waste Management Policy Implications for the U.S. Department of Energy's Environmental Restoration and Waste Management Programmatic Environmental Impact Statement*. Paper presented at symposium, Waste Management '94. University of Arizona, Feb. 27-March 3, Tucson, AZ.

Lewis, R.J., and N.I. Sax. 1992. *Sax's Dangerous Properties of Industrial Materials*. 8th ed. New York: Van Nostrand Reinhold.

Morris, R. (Science Applications International Corp.). Personal communication, Dec. 9, 1993.

National Institute of Occupational Safety and Health (NIOSH). 1992. *Registry of Toxic Effects of Chemical Substances (RTECS)*. Database. Cincinnati, OH.

National Oceanic and Atmospheric Administration (NOAA). 1976. *A Climatological Analysis of Pasquill Stability Categories Based on STAR Summaries*. Asheville, NC: National Climatic Center. April.

National Research Council. 1986. *Criteria and Methods for Preparing Emergency Exposure Guideline Level (EEGL), Short-Term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL) Documents*. Committee on Toxicology. Washington, DC: National Academy Press.

National Research Council. 1993. *Guidelines for Developing Community Emergency Exposure Levels for Hazardous Substances*. Committee on Toxicology. Washington, DC: National Academy Press.

Neuhauser, K.S., and F.L. Kanipe. 1993. *RADTRAN 4, Volume II: Technical Manual*. SAND89-2370. Aug. Albuquerque, NM: Sandia National Laboratories.

NIOSH. *See* National Institute of Occupational Safety and Health.

NOAA. *See* National Oceanic and Atmospheric Administration.

Policastro, A.J., et al.1995. "Hazardous Waste Transportation Risk Assessment: Benefits of a Combined Deterministic and Probabilistic Monte Carlo Approach in Expressing Risk Uncertainty." Paper presented at symposium, Waste Management '95. Feb. 26-Mar. 2. Tucson, AZ.

Reynolds, R.M. 1992. *ALOHA™ (Areal Locations of Hazardous Atmospheres) 5.0: Theoretical Description*. NOAA-TM NOS ORCA-65. Aug. Seattle, WA: National Oceanic and Atmospheric Administration.

Turner, D.B. 1994. *Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modeling*. 2d ed. Boca Raton, FL: CRC Press.

U.S. Department of Commerce. 1987. *Truck Inventory and Use Survey*. Washington, DC: Bureau of the Census.

U.S. Department of Transportation. 1993a. *Hazardous Materials Information Reporting System Database*, Washington, D.C. Research and Special Programs Administration.

U.S. Department of Transportation. 1993b. *The 1993 Emergency Response Guidebook.* DOT P 5800.5. Washington, DC: Research and Special Programs Administration.

U.S. Environmental Protection Agency. 1980. *Water Quality Criteria Document: Availability. Federal Register* 45:79353. November 28.

U.S. Environmental Protection Agency. 1986. *Guidelines for Carcinogenic Risk Assessment. Federal Register* 51:33992-34003. September 24.

U.S. Environmental Protection Agency. 1988. *Superfund Exposure Assessment Manual.* EPA/540/1-68/001. April. Washington DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1989a. *Exposure Factors Handbook.* EPA/600/8-89/043. July. Washington, DC: Office of Health and Environmental Assessment.

U.S. Environmental Protection Agency. 1989b. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual* (Part A, Interim Final). EPA/540/1-89/001. Dec. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1991. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals.* EPA/540/R-92/003. Dec. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1992. "Guidance of Risk Characterization for Risk Managers and Risk Assessors." Memorandum from F. Henry Habicht II, Deputy Administrator to Assistant and Regional Administrators. February 26.

U.S. Environmental Protection Agency. 1993a. *Health Effects Assessment Summary Tables (HEAST), Annual FY 1993.* OERR 9200.6-303 (92-1). March. Washington, DC: Office of Emergency and Remedial Response.

U.S. Environmental Protection Agency. 1993b. *Integrated Risk Information System (IRIS)*. Database. Washington, DC: Office of Emergency and Remedial Response. Accessed October 1993.

U.S. Environmental Protection Agency, Federal Emergency Management Agency, and U.S. Department of Transportation. 1987. *Technical Guidance for Hazards Analysis — Emergency Planning for Extremely Hazardous Substances*. Appendix D. Washington DC: Office of Emergency and Remedial Response.

Yuan, Y.C., S.Y. Chen, D.J. LePoire, and R. Rothman. 1993. *RISKIND—A Computer Program for Calculating Radiological Consequences and Health Risks From Transportation of Spent Nuclear Fuel*. ANL/EAIS-6, Rev. 0. Feb. Argonne, IL: Argonne National Laboratory.

Appendix F

Treatment and Storage Facility Accidents

U.S. Department of Energy
Waste Management Programmatic Environmental Impact Statement

Contents

Tables

Figures

Acronyms and Abbreviations

The following is a list of acronyms and abbreviations (including units of measure) used in this appendix.

Acronyms

ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
ARF	airborne release fraction
BTX	benzene, toluene, and xylene
Cd	cadmium
CFR	Code of Federal Regulations
CH	contact-handled
CIF	Consolidated Incineration Facility
CO_2	carbon dioxide
CPC	Chemical Process Cell
Cr	chromium
DBE	design-basis earthquake
DF	damage fraction
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DST	double-shell tank
DWPF	Defense Waste Processing Facility
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ER	environmental restoration
FEMP	Fernald Environmental Management Project
FY	fiscal year
GDC	general design criterion
GTCC	Greater-Than-Class-C
GWSB	Glass Waste Storage Building

^3H	tritium
Hanford	Hanford Site
HCl	hydrogen chloride
HEPA	high-efficiency particulate air
HFEF	Hot Fuel Examination Facility
Hg	mercury
HLW	high-level waste
H_2O	water
HW	hazardous waste
HWSF	hazardous waste storage facility
HWVP	Hanford Waste Vitrification Plant
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LDR	land disposal restriction
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LPF	leak path factor
MAR	material at risk
MEI	maximally exposed individual
NEPA	National Environmental Policy Act
NH_3	ammonia
NH_4	ammonium
NO_x	nitrogen oxides
NPH	natural phenomena hazards
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PC	performance category
PEIS	Programmatic Environmental Impact Statement
PGDP	Paducah Gas Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
PIH	poison inhalation hazard

PREPP	Process Experimental Pilot Plant
PSAR	Preliminary Safety Analysis Report for the Retrieval of Transuranic Waste
RARF	respirable airborne release fraction
RCRA	Resource Conservation and Recovery Act
RF	respirable fraction
RFETS	Rocky Flats Environmental Technology Site
RH	remote-handled
RWMC	Radioactive Waste Management Complex
SAR	safety analysis report
SCC	secondary combustion chamber
SCT	shielded canister transport
SO_2	sulfur dioxide
SQUG	Seismic Qualification Users Group
SRS	Savannah River Site
SWEPP	Solid Waste Experimental Pilot Plant
TC	treatment code
TRF	total release fraction
TRUW	transuranic waste
TSA	Transuranic Storage Area
TSD	treatment, storage, and disposal
WAC	waste acceptance criteria
WCSF	Waste Canister Storage Facility
WERF	Waste Experimental Reduction Facility
WIPP	Waste Isolation Pilot Plant
WM	waste management
WRAP	Waste Receiving and Processing Facility
WVDP	West Valley Demonstration Project

Abbreviations

atm	atmosphere(s)
°C	degree(s) Celsius
Ci	curie(s)
cm	centimeter(s)
cm^3	cubic centimeter(s)
°F	degree(s) Fahrenheit
ft	foot (feet)

ft^2	square foot (feet)
ft^3	cubic foot (feet)
g	gravity (acceleration due to)
gal	gallon(s)
h	hour(s)
kg	kilogram(s)
kPa	kilopascal(s)
lb	pound(s)
m	meter(s)
m^3	cubic meter(s)
mi	mile(s)
mm	millimeter(s)
mol	mole(s)
MPa	megapascal(s)
PE-Ci	Pu-239-equivalent curies
psig	pound(s) per square inch gauge
yr	year(s)

APPENDIX F
Treatment and Storage Facility Accidents

F.1 Introduction and Overview

F.1.1 SUMMARY

This appendix documents the methodology, computational framework and results for facility accident analyses performed for the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS). The methodology is in compliance with the most recent DOE EIS guidance (DOE, 1993a) in that it considers the spectrum of accident sequences that could occur in activities covered by the WM PEIS and uses a graded approach emphasizing the risk-dominant scenarios to facilitate discrimination among the various WM PEIS alternatives. The main goal of the accident analysis is to provide results that allow reliable estimates of the relative risks among the alternatives rather than reliable values of absolute impact. The relative risk provides a sufficient basis for discriminating among alternatives. In the analysis of accident sequences, the accident models have been systematically applied to approximate the key source term parameters as functions of (1) the phenomenology and severity of the accident, (2) the process parameters, (3) the characteristics of the facility, and (4) the properties of the waste types. Uncertainties in data have been treated in a consistent manner to enhance the value of the relative risk comparisons.

The output of the facility accident analyses is consists of identification of the accidents potentially important to human health risk for each waste type, an assessment of the frequencies of these accidents, and an evaluation of the radiological and chemical source terms resulting from these accidents. A radiological source term is defined by specifying the amount (in curies) of each radionuclide released during an accident. Release is conservatively assumed to be instantaneous.

A chemical source term is defined by specifying the rate and duration of release for each toxic chemical released during an accident. The frequencies of the accidents and the results of the source term evaluation are provided as input to the WM PEIS for calculations of the human health and risk impacts.

Numerous DOE waste management sites were analyzed in this study. However, generic DOE facility characteristics were assumed in developing the accident sequences for all sites. Facility waste inventories assumed for each DOE site were derived from the storage inventories, generation rates, and treatment throughputs developed in the WM PEIS. Site safety documentation was used to help identify the frequencies and potential risk importance of extreme events such as seismic or tornadic events or aircraft crash events. Existing facility documentation and accident data were used only for general guidance in source term development; thus, the accident analyses herein may not necessarily duplicate the results produced in individual site environmental impact statements (EISs) or safety analysis reports (SARs) in which specific facilities are assessed.

The accident sequences analyzed were selected for their potential importance relative to human health effects. In light of the lack of specific process and facility design information, the analyses focused on accidents with the potential for airborne releases to the atmosphere. Although disposal alternatives are included in the WM PEIS waste management options, the details of ultimate disposal are not addressed. Consequently, accidents were not developed for this phase of waste management.

F.1.2 Scope and Objectives

The WM PEIS addresses strategic alternatives for management of five different types of waste in the DOE complex: high-level waste (HLW), transuranic waste (TRUW), low-level waste (LLW), low-level mixed waste (LLMW), and hazardous waste (HW). For each waste type, four alternatives or strategies have been analyzed for treatment, storage, and disposal (TSD): (1) no action, where existing sites will generally store and treat their own wastes consistent with currently approved plans; (2) centralization, where from one to a few DOE sites will be used to treat, store, and dispose of a given waste type from the entire DOE complex; (3) regionalization, where several sites distributed throughout the country will be used to treat, store, and dispose of that waste type for their geographic regions; and (4) decentralization, where regionalization is extended to include more sites. Alternatives for consolidation of waste involve both existing and conceptual-design facilities at the DOE sites. Moreover, a number of waste treatment technologies and storage options are assessed for each type of waste.

The most recent guidance (DOE, 1993a) from the Office of National Environmental Policy Act (NEPA) Oversight within the DOE calls for consideration of the spectrum of accident scenarios that could occur in activities being evaluated. This guidance also calls for a graded approach in which risk-dominant scenarios are emphasized. Determination of risk dominance requires assessment of both the likelihood and the severity of plausible accident scenarios that could present a significant health hazard to either the workforce or the public. The spectrum of accident scenarios includes all accidents important to risk, from low-frequency events with potentially high consequences (as typified by accident sequences associated with severe natural phenomena, such as earthquakes) to relatively high-frequency events with very low consequences (as typified by routine industrial accidents).

The broad scope of the WM PEIS and the recent NEPA guidance result in a very large number of combinations of possible TSD options, existing or new facilities, and related possible accident scenarios to be evaluated for assessing management alternatives for each waste type. Accordingly, one obvious objective of the methodology for accident analysis was the development of a screening methodology that would enable focus on the risk-dominant sites and facilities for the storage and treatment operations and for waste consolidation.

A second objective was to develop a methodology for accident analysis that would allow sufficient discrimination of risk impacts among the various options and alternatives to support the WM PEIS decision-making process. Although the method must provide reasonable estimates of the risk impacts associated with each alternative, providing reliable estimates of the relative risks among the alternatives is more important. To accomplish these goals, the accident models must be adequate to approximate the key source term parameters as a function of the phenomenology and severity of the accident, the process parameters, the characteristics of the facility, and the properties of the waste types. Although developing all accidents in detail is not necessary, systematically applying the underlying approximate models is necessary. Many of the uncertainties in the data that are reflected in estimates of absolute risk tend to be canceled in estimates of relative risk. Thus, systematic application of the models is required to provide a sufficient and scrutable basis for estimating relative risk and discriminating among alternatives.

A consistent database must also be applied. Current safety analyses, environmental assessments, and EISs provide much site-specific information, but they have been developed over many years as the underlying technology base and the related regulatory guidance have improved. The scope and supporting levels of detail in site safety reports vary widely. Thus, a third objective was to support the data requirements for the implementation of the computational framework by appropriately combining existing data and documentation on the safety of facilities with the most recent guidance on accident modeling.

The last objective was to provide an automated capability to facilitate the overwhelming number of calculations in the accident analysis that are required to provide relative risk for the many combinations of process technology, facility selection, and site consolidation strategies for each waste type. The purpose is not only to provide baseline accident frequency and source term estimates, but also to provide a capability for sensitivity analysis that can be used in the review process. Accident frequencies, radiological and chemical release source terms, and health effects on various populations are all sensitive to waste throughput. Accordingly, the computational packages for the accident analysis and the databases (storing the data on the waste inventories) have been be integrated among themselves and with the computer codes for health effects to allow accident risk to be characterized as a function of the throughput for a given waste type and facility.

F.1.3 ANALYTIC APPROACH

To meet these objectives, an integrated approach was developed, which included the following interrelated elements: (1) selection of operations and related facility configurations across the DOE complex that have potentially hazardous inventories of radioactive or chemically toxic wastes when considering facilities' vulnerabilities and demographics; (2) development and evaluation of a uniform set of the risk-dominant accident sequences; and (3) determination of the compositions of radiologically or chemically hazardous source terms predicted to be released during the sequences. A personal-computer-based computational framework and database (WASTE_ACC) have been developed to automate these elements and to provide source term input for the analyses of health effects to the general public and to the workforces (ANL, 1996d). This assessment is discussed elsewhere (see WM PEIS Appendix D).

The other important elements in assessing risk include (1) development or integration of existing site-specific demographics and meteorologic data into calculation of site-specific unit risk factors and (2) assessment of the radiological or toxicological consequences of accident releases to the general public and to the occupational workforces by (combining the source term and unit risk information).

Figure F.1-1 illustrates the integration of these elements into a systematic approach for performing risk impact analysis. The WM PEIS waste management alternatives encompass siting options for storing and treating each waste type before disposal. The volume and radionuclide composition of each waste stream is tracked in a relational database as the waste is processed and finally disposed of. Details of the method

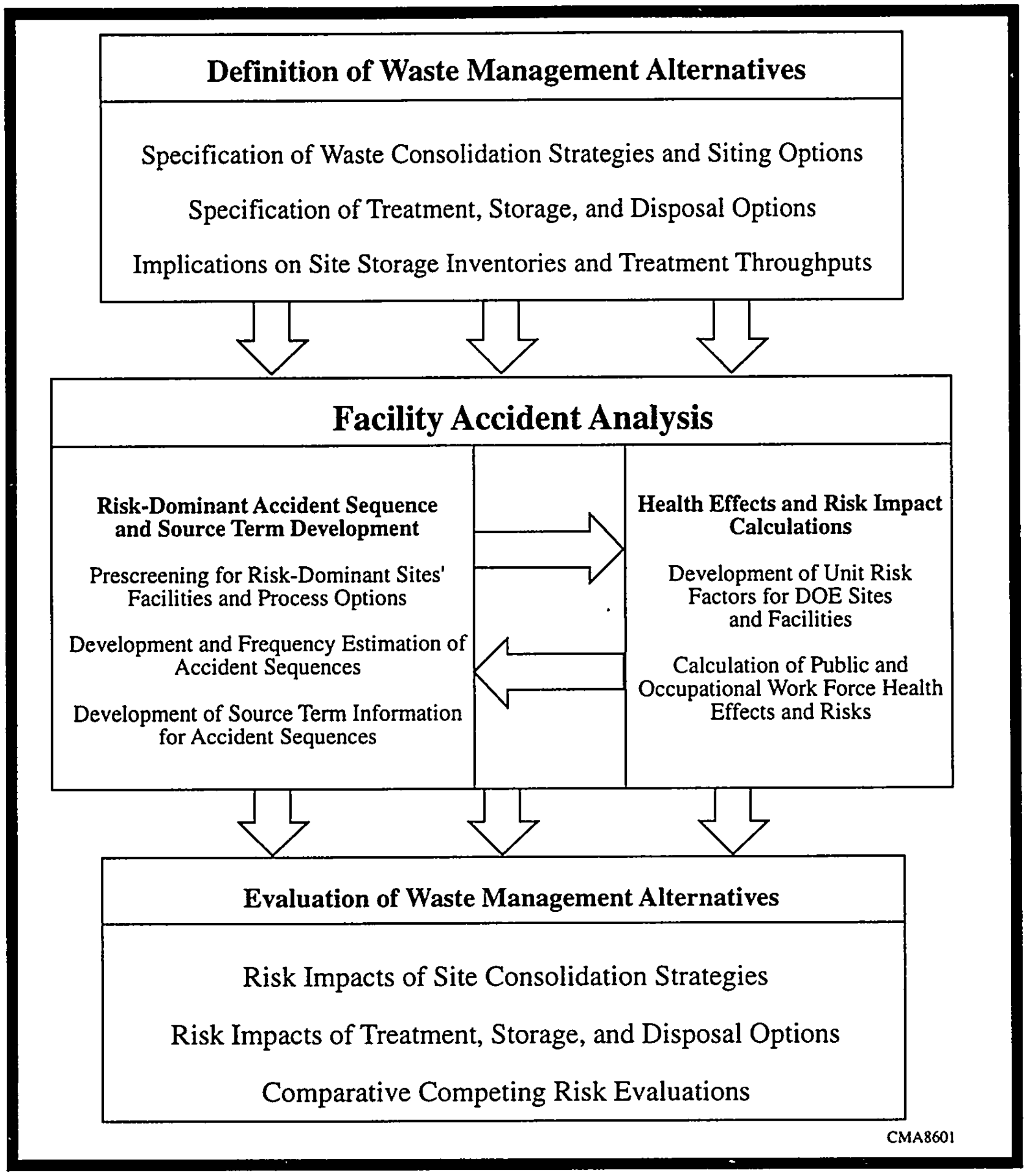

Figure F.1–1. Overview of Facility Accident Analysis Interactions for the WM PEIS.

and computational framework developed to link these elements for the accident analysis are described in Section F.2, with the remainder of this appendix discussing the accident analyses, leading to source term generation, for each waste type. The source terms for all accidents analyzed are provided in the technical support document (ANL, 1996a).

F.1.4 ORGANIZATION OF APPENDIX

Section F.2 describes the overall method and computational framework utilized in the WM PEIS accident analysis. The section also describes the use and integration of generic and site-specific accident analysis data, waste stream inventory data, storage and treatment process characterizations, and site and facility demographic information.

Calculations with currently projected waste generation rates, storage inventories, and treatment process throughputs have been performed. Specific source term results are presented in this report for each of the waste streams in the WM PEIS in Sections F.3 through F.7. Frequencies and source term parameters are presented for each of the major DOE sites for various analysis cases for each waste stream. Key assumptions in the development of the source terms are identified. The compilations of the chemical and radiological source terms for all of the accidents are provided in the report by ANL (1996a).

The listed references include DOE orders and standards, U.S. Nuclear Regulatory Commission (NRC) regulations, and NEPA documentation, as well as technical reports developed in support of this regulatory guidance. The reference section also includes site-specific safety analysis and environmental impact documentation and related supporting technical reports that were used in support of the WM PEIS accident analysis.

F.2 Methodology and Computational Framework for Accident Analysis

F.2.1 OVERVIEW

This section describes the methodology and computational framework for the facility accident analysis for the WM PEIS. Figure F.2–1 illustrates the major components and related input and output of data from the facility accident analysis and presents an overview of the interactions of the analysis with other elements of the WM PEIS. Implementation of this analysis framework included selection and development of the accident sequences and associated source terms. Unit risk factors developed as part of the WM PEIS effort were used to screen accident sequences for risk dominance. A unit risk factor is the consequence associated with a unit release of a radionuclide to the environment from a facility at a given site for a given receptor.

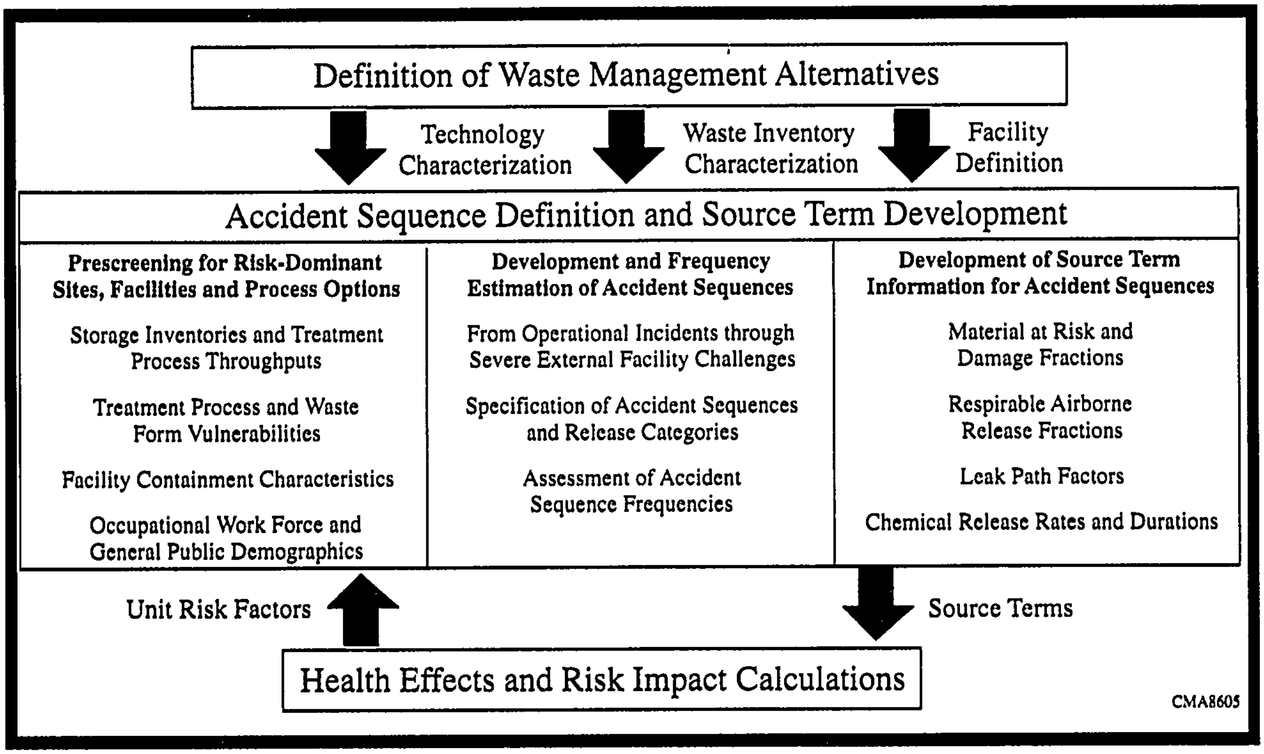

Figure F.2–1. Major Components and Related Input and Output of Data for Facility Accident Analysis.

Section F.2 is organized to reflect the integrated approach depicted in Figure F.2–1. Section F.2.2 sets forth the underlying assumptions of the analysis. Sections F.2.3 through F.2.5 explain how the elements are applied to the WM PEIS accident analysis. The general discussion in the sections is applicable to the overall WM PEIS accident analyses for all waste types. Sections F.2.6 and F.2.7 discuss the general modeling assumptions and the data used to evaluate the frequencies for the various accidents and to determine the appropriate source terms for specific accidents, facilities, and waste types. Sections F.2.8 and F.2.9 discuss the calculation of source term estimates and the uncertainties inherent in the analysis, respectively.

F.2.2 General Assumptions Applied in the Analysis

A limited set of general assumptions were applied in the analysis. These assumptions and the bases for using them are discussed below.

In the analysis, it was assumed that all facilities will be considered per local building codes, including earthquake/seismic codes. Treatment facilities were assumed to be designed to Hazard Category 2 requirements (generally to Performance Category [PC] 3 for seismic criteria). Figure F.2–2 summarizes the relationships of the Hazard Categories and the Performance Categories. In some cases, it is possible that treatment facilities would be designed to the less stringent Hazard Category 3 requirements (and accordingly to Performance Category 2 for severe natural phenomena). While such facilities would be designed to less stringent design requirements, it is also true that in the Safety Analysis Report process, it would be necessary to demonstrate that accidents at such facilities have no impact on offsite personnel and only limited to minor impact to onsite workers. Hence, it was concluded that the more conservative approach was to assume that the facilities were designed to Hazard Category 2 requirements where there would be a greater impact to the onsite workers in the event of accidents, were they to occur.

Generally in this Appendix for the analysis associated with storage of existing waste material, specific accident analyses were not performed. That decision was based on the underlying assumption in the PEIS analysis that all the sites will continue to accumulate, or at least not reduce, waste inventories for roughly the next 10 years, at which time complexwide treatment will begin. Thus all sites will be at their maximum inventory in about 10 years, at which time the potential for release will be maximum. This assumption is independent of the existing inventory. Thus, detailed analysis would not assist in discriminating among the alternatives.

F.2.3 Selection of Risk-Dominant Operations, Facilities, and Related Types of Accidents

A review and screening were performed to focus the analysis of the large number of processes and facility configurations possible within the WM alternatives such that only those configurations with accidental radiological or chemical releases potentially important to overall risk were treated in detail. This approach assisted in illuminating the factors that provide reasonable discrimination among the alternatives. This section describes the process of screening and then describes the three classes of accidents selected for analysis: (1) general handling accidents, (2) accidents at storage facilities, and (3) accidents involving treatment processes and facilities.

F.2.3.1 Categorization and Screening

Waste management activities fall within three operational regimes: (1) current or pretreatment storage, which includes placement in and retrieval from storage and transfer to facilities for pretreatment or

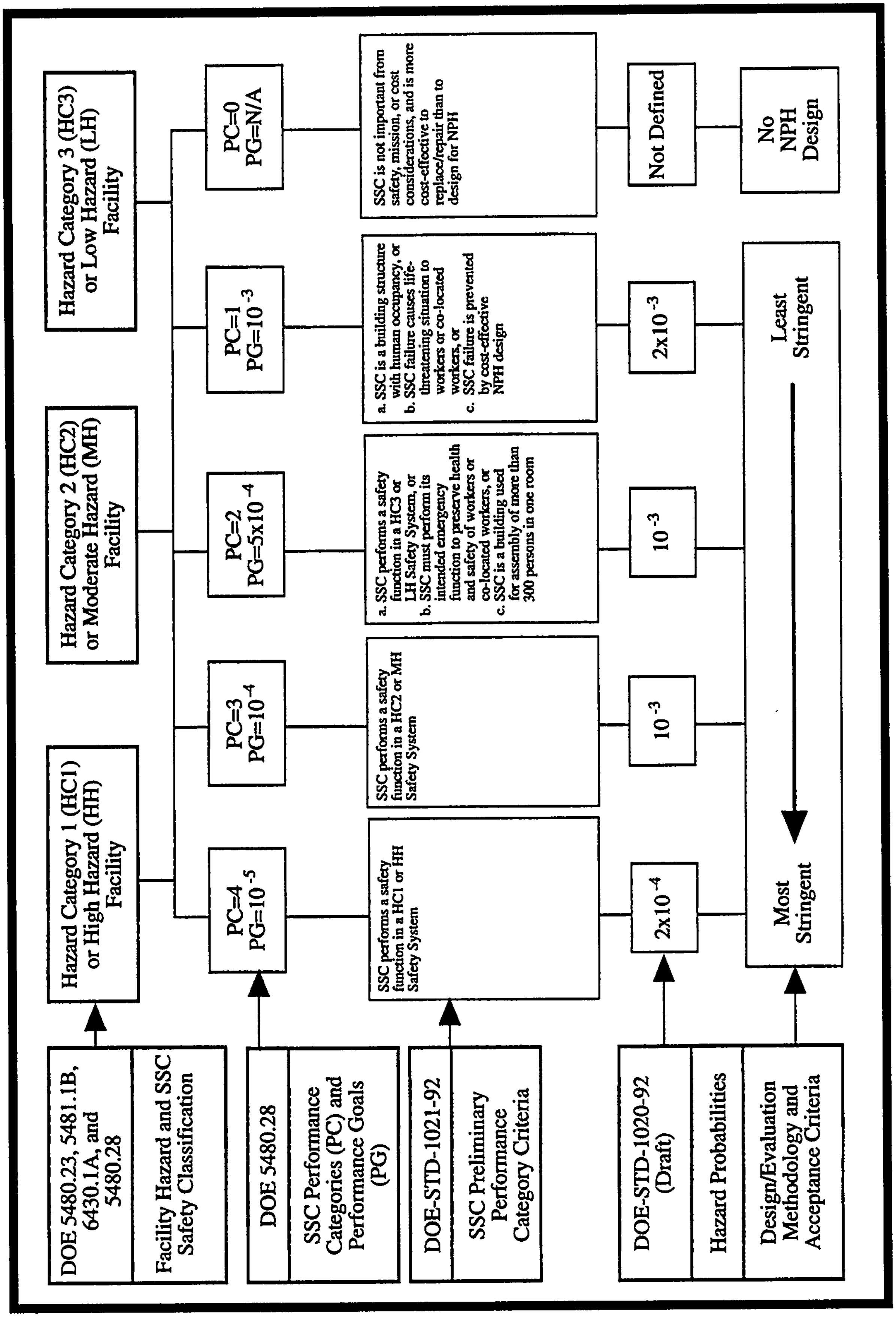

Figure F.2-2. DOE Performance Goals for Hazard Category 1, 2, and 3 Facilities.

treatment; (2) processing, which includes pretreatment (which applies only to HLW) and treatment; and (3) interim or predisposal storage. Because of the more stable nature of wastes in their final forms before disposal, the last operational regime was judged to pose a much smaller risk than current storage and processing. As a result, among the waste types, accidents affecting storage before final disposal were analyzed only for HLW.

The inventories in storage, the throughputs for treatment, and the sizing of the facility are all functions of the alternatives being investigated by the WM PEIS. Criteria were developed to help identify and classify potentially risk-dominant facilities and operations for each waste stream by their characteristics with respect to accidental radiological or chemical releases. These criteria included the amount and composition of the material at risk (MAR); the vulnerability of this material to airborne releases; the containment characteristics of the facility; and the demographics of the site/facility and the general population.

Review of the operations and facilities led to the establishment of three broad classes of accidents as determined by their release characteristics and the facilities and populations affected. These classes are (1) general handling accidents involving a breach of the waste packaging, (2) accidents at storage facilities, and (3) accidents involving treatment (or pretreatment) processes and facilities. Within these classes, individual operations or facilities were then reviewed to better define potentially risk-dominant operations or facility configurations.

Only airborne releases were considered based on evidence in existing DOE safety analyses that airborne pathways dominate the accident consequences and drive the facility risks. Releases to surface runoff or to groundwater cause longer term effects and are not a strong indicator or discriminator of the risk associated with the WM PEIS alternatives. The only reasonable threats that could cause immediate and appreciable effects via nonairborne pathways are criticalities involving the various waste types. However, facilities handling materials with high fissile content will have rigorous procedures and checks to prevent inadvertent criticalities. Regulations require that facilities and processes used to handle fissile materials be designed so that at least two separate events must occur before a condition exists that could result in a criticality, which would be a highly improbable event. As such, releases via nonairborne pathways are not considered.

The following factors were included in the screening process to arrive at risk dominant accident sequences for derived analysis.

Amount and Composition of MAR. Each alternative for waste consolidation discussed in the WM PEIS implicitly defines pretreatment and posttreatment inventories and throughputs for treatment of each waste type at each DOE site. Specification of the storage inventories and treatment throughputs by volume, by physical and chemical form, and by radionuclide or chemical composition of the wastes was obtained from the WM database (ANL, 1996b). Accordingly, for each alternative and each waste type, the DOE sites were ranked by relative radiological hazard to determine those sites and waste types presenting the greatest risk. A similar ranking was performed to determine sites with the greatest chemical inventories for each waste type (chemical accidents during treatment that could not be correlated with waste inventories or throughputs were not analyzed). These rankings led to the reduction in the number of analyses for any given waste type so they were focused on sites with sufficient inventories to justify development of distinct source terms.

Vulnerability of MAR. Another focus of the screening was the vulnerability of the MAR to potential fire or explosion accident sequences. The physical and chemical stability of the waste was reviewed to preclude unnecessary analysis of storage or process operations involving highly stable wastes that would require extremely severe and improbable conditions to attain significant airborne releases. The packaging of the wastes and the overall configuration of the containment facility were also reviewed.

Characteristics of Facility Containment. Facilities considered in the WM PEIS range from outdoor storage pads which provide no containment to facilities that have the structural capability to withstand the forces from significant natural phenomena. The containment characteristics of the existing or proposed facilities were judged by their hazard category or natural phenomena hazards (NPH) PC and the corresponding structural capabilities. Hazard category and NPH PC are discussed and defined in Section F.2.6.1.

Demographics. The hazard to the workforce is directly related to the radiological or chemical inventory involved in the accident, the number of workers affected, and the proximity of these workers to the point of release. Consideration of work force populations and their locations helped provide initial identification of those processes and facilities that would potentially dominate the risk to the worker population. The demographics for the general public were included as an input to the development of the health effects and risk impact analysis but were not specifically used to select accidents.

F.2.3.2 General Handling Accidents

General handling accidents were selected as a distinct class because hands-on operational accidents are expected to dominate the radiological and chemical risks to workers due to the relatively high frequency of such accidents and the proximity of the workers to any release. Such operations include handling in storage and staging areas, packaging and unpackaging, movement of waste within treatment facilities, and some treatment operations. These operations are prone to mechanical stresses in industrial accidents such as drops and spills of a container or punctures by a forklift. The resulting breaches in a container can be shown to lead to insignificant airborne releases relative to those releases involving fires or explosions. As a result, these handling accidents usually constitute little hazard to the general public.

F.2.3.3 Storage Facility Accidents

Accidents at storage facilities were selected as a separate class because they potentially involve large quantities of MAR. Moreover, many storage facilities provide little or no formal containment or containment that would likely be breached in the event of severe thermal or structural challenges; severe accidents (such as fires) in a storage area may result in a significant risk to onsite personnel and the general population for many DOE sites.

In addition to potential importance to risk, two other criteria were used to determine which storage facilities and related accidents should be analyzed or reviewed: (1) their potential for discriminating among PEIS alternatives and (2) quantity and quality of information available for input to analysis. As a result, storage prior to treatment of LLMW, LLW, and TRUW was not analyzed because the results will not help to discriminate among alternatives. This is a result of the underlying assumption used in the PEIS analyses that all sites will accumulate or at least not reduce their waste inventories for roughly 10 years, at which time complexwide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases), independent of alternative in about ten years. Nevertheless, because recent DOE safety or NEPA information on storage facility accidents provides guidance on the potential risk impacts applicable to LLW, LLMW, and TRUW storage, the information will be discussed in the appropriate sections for these waste steams.

Calculations of the cost and risk impacts for current storage of HLW are not within the scope of the PEIS, and as a result, no analyses have been performed. However, the storage of vitrified HLW was analyzed because it could be a factor in discriminating among alternatives for HLW management. For the other waste streams, accidents were not analyzed for storage facilities housing solidified, vitrified, or otherwise highly stable wastes prior to disposal because of their low potential for risk-significant releases.

Finally, the characteristics of current or pretreatment storage for hazardous wastes do vary by alternative. Thus, HW storage accidents have been generically analyzed and will be discussed.

F.2.3.4 Treatment Facility Accidents

Accidents involving treatment processes and facilities were identified as a separate class of accidents. Unlike storage accidents, where the overriding concern relates to the large amount of MAR, treatment introduces different safety considerations such as the joint presence of high temperatures and pressures, combustible materials, and feed lines for natural gas or fuel. Moreover, the MAR may not only involve substantial inventories but the MAR may be highly concentrated toxicological or radiological materials that pose a threat to both the immediate workforce of the facility and the populations surrounding the facility. The facilities for treatment typically have containment structural design and filtration capabilities commensurate with these hazards.

Treatment operations were reviewed, and many were excluded from detailed investigation on the basis of the absence of sufficient radiological and hazardous material concentrations or lack of sufficient mechanistic stresses and energies capable of creating significant airborne releases. These operations included evaporative processes and solidifying operations such as grouting and cementation (EG&G, 1992a,b). In general, benign operations, such as packaging and nonthermal size-reduction activities (including shredding, compaction, and supercompaction), were excluded from large-scale accident consideration. Technologies for mercury (Hg) separation were excluded because of their relatively low-energy operating characteristics. Thermal desorption of residues, sludges, and resins or of debris wastes involves combustible material; however, the process was excluded because it operates at lower temperatures and pressures than incineration, and the output product is much less dispersible than the ash from incineration.

Other high temperature or pressure processes were more closely reviewed in light of the potential energy source for dispersing airborne radioactive or toxic material and for challenging a facility's integrity and capability for filtration. Similarly, operations involving or being performed in the presence of combustible materials or involving feed lines of natural gas or fuel were reviewed in light of the potential for ignition and subsequent fire or explosions. Thus, thermal or heat-accumulating processes (such as fractionation by using ion-exchange columns, metal melting, incineration, wet-air oxidation, and vitrification) were identified for their potential for major airborne release.

These processes are discussed below.

Ion Exchange. Ion exchange is a standard technology for removing dissolved ionic material, radionuclides, and toxic pollutants from solution. Ions in an aqueous phase displace complementary ions from ion-exchange sites on the surface of an insoluble support material. Depleted resins are removed, replaced, or regenerated. Regeneration involves displacing contaminant ions with fresh complementary ions by washing with acid or base solution. The dominant accident considered in the literature is an explosion of the ion-exchange column, where self-heating of the ion-exchange resin results in fire or explosion, with attendant discharge of the radionuclide-loaded resin to the surroundings as a radioactive and chemically toxic aerosol. Some of the conditions causing self-heating of the resin include introduction of a solution with a high concentration of nitric acid (which would result in a highly exothermic reaction), column overloading, drying out of the resin in the column, resulting in high column temperatures (leading to ignition) (Ayer et al., 1988). Analysis shows that these accidents have no impact on the operation of the ventilation system of the facility (Mishima et al., 1986).

Metal Melting. Metal melting is used to prepare, melt, and cast incoming scrap ferrous and nonferrous bulk metals. The incoming metal is shredded and transported to a furnace where it is melted and cast as ingots. Any combustible material in the incoming feed is thermally destroyed in a secondary combustion chamber. Highly radioactive materials tend to collect in the slag, which is skimmed from the top of the melt and cast into crucible molds. The cast slag is stored before final disposal, and the cast metal is sent to a fabrication plant for reuse into overpack containers and shielded caskets. The accident of concern is overpressurization and rupture of the combustion chamber with dispersal of the contents, particularly the radioactive slag.

Incineration. Incineration is a means of reducing the volume of combustible solid waste and destroying organic waste. Key characteristics of the incineration process with implications for potential airborne release include high temperature, the presence of combustible materials, the potential for rupture of the vessel, elevated concentrations of radioactivity in the ash byproduct, and the high dispersibility of the ash. Because incineration often results in a volume reduction factor of roughly 100, the ash byproduct could have a concentration of radionuclides roughly 2 orders of magnitude greater than the input feed waste. Accidents of concern for an incineration facility include explosions of the incinerator or fires involving the feedstock, ash residue, or residues in the filtration system. Feedstock fires may pose a toxicological risk for mixed wastes because of the relatively high concentrations of organic materials.

Wet-Air Oxidation. Wet-air oxidation is the aqueous-phase oxidation of suspended organic substances using elevated temperatures and pressures. Water (H_2O) catalyzes oxidation so that reactions proceed at much lower temperatures (175–340 °C than are required for oxidation in open-flame combustion such as incineration. Although the pressures (2–20 MPa) are higher than those in other thermal treatment processes, the MAR is more dilute and is in an aqueous noncombustible liquid form. Rupture of the oxidation vessel followed by a pressurized release is considered plausible but was judged to be relatively insignificant in terms of radiological risk to the public or to occupational workforces. Potential accident impacts are enveloped by incineration, a competing technology.

Vitrification. In vitrification, prepared wastes are mixed with glass-forming materials and transferred to the melter that melts the material at a nominal temperature of 1,150 °C. The final product of vitrification is a molten borosilicate glass. The key accident in vitrification processes identified in the WIPP SEIS-II (DOE, in preparation) is rupture of a vessel from a steam explosion due to the interaction of molten glass with water. This accident could affect the integrity of the cell in which the equipment is located. There is also the potential for shrapnel formation, and damage to the off-gas filtration units and to adjacent areas of the facility. The serious nature of this accident indicates it is the risk-dominant vitrification accident for the involved workforce. Other vitrification-related accidents considered in the WIPP SEIS-II include failure of a drum containing vitrified treated waste and a beyond-design-basis earthquake with resultant collapse of the waste treatment facility.

A comparison of the characteristics of the identified treatment processes led to the selection of incineration as the technology most likely to dominate risk to site workers and to the surrounding general populations for LLW, LLMW, TRUW, and HW. As discussed previously, the characteristics of radioactive release from wet-air oxidation are clearly enveloped by those for incineration, a competing technology. Nevertheless, because some of the treatment trains for LLMW sites have greater volumes of waste to be treated by wet-air oxidation than by incineration, source terms were developed for tank ruptures with pressurized releases from wet oxidation processes.

Although accidents with fractionation and with vitrification may be important in assessing pretreatment or treatment operations for HLW, these accidents do not affect WM PEIS decisions with respect to HLW alternatives. Vitrification of LLW incineration ash, of sludges and resins, or of wastes resulting from HLW partitioning is a process comparable to incineration in terms of temperature, potential for pressurization, and the combustible-material hazards. Dispersibility of the feedstock would be equivalent to dispersal of the feedstock for incineration, and the forms of the vitrification material (molten and solidified borosilicate glass) would be less dispersible by several orders of magnitude than ash from a kiln or from a secondary combustion chamber (SCC). Similarly, the dispersibility of the contents of the radioactive slag in metal melting is also very low relative to the ashes in the incineration process.

In summary, source term analyses for treatment operations were generally focused on incineration accidents. Accidents associated with other types of treatment were generally not considered because of the low vulnerability and dispersibility of MAR as discussed above. Further, the throughputs for the other treatment processes are generally low compared with incineration.

F.2.4 Development of Risk-Dominant Accident Sequences

This part of the analysis involved the development of a framework that would accommodate the spectrum of accidents possible over the range of DOE facilities managing the different waste types. Orders, standards, and other regulatory guidance from the DOE, the NRC, and the U.S. Environmental Protection Agency (EPA), as well as key supporting documents, were reviewed to identify the spectrum of accidents, accident initiators, and potential releases routinely evaluated in safety analyses. The DOE *Defense Programs Safety Survey Report* (Pinkston, 1993) and other internal DOE reports related to the Idaho National Engineering Laboratory (INEL) and spent fuel EIS were also reviewed to provide guidance for the selection and evaluation of accidents. Finally, recent SARs and other facility-specific analyses were reviewed for applicability to both specific facilities and related generic facilities.

Probabilistic risk assessment techniques were used to structure the computational framework for operational events and to track the progression of accidents for external events. Potential accident initiators were first reviewed and grouped into categories for analysis of subsequent accident progression (see Section F.2.4.1). A generic set of accident sequences was then developed to follow the progression of accidents into various source term categories organized by release characteristics and severity levels (see Section F.2.4.2). Nuclear criticality events were considered independently (see Section F.2.4.3).

F.2.4.1 Selection and Categorization of Accident Initiators

The selection of accident initiators was based primarily on the expected importance to human health risk of the potential radiological or chemical releases. Populations at risk include the workforce in the facility where the accident occurs, the population onsite, and the general population surrounding the site. In general, operational safeguards and equipment are in place to ensure that the impacts on the public health of all events are extremely limited, except in the most severe (and unlikely) accident situations. Higher frequency operational events, such as spills or drops, are expected to dominate the risks to workers, but the limited amount of material generally ensures that such events contribute little risk to public health. The less-frequent severe accidents have large inventories at risk, and the potential exists for breaching multiple containment barriers and filtering systems and disrupting standard emergency procedures. As a result, the low frequency of such accidents is offset by their larger consequences; typically, severe accidents are predicted to dominate overall risks to public health. With different populations at risk, a spectrum of accidents covering a wide range of frequencies and expected consequences must be considered. The accidents considered meet the "reasonably foreseeable" criteria recommended by DOE (DOE 1993a).

To facilitate subsequent analyses, all generic accident initiators were first categorized on the basis of the nature of the initiator and the potential magnitude of releases. These categories included (1) operational events initiated from within the facility (internal events) and (2) external challenges to the facility. Internal events were subdivided to account for mechanically induced breaches of waste containers, fires, and explosions—all resulting from human errors, equipment failures, or industrial accidents internal to the facility. The external events were subdivided to consider accidents from (1) generally man-made events, such as aircraft crashes and fires and explosions onsite or at adjacent facilities, and (2) potentially catastrophic natural phenomena (for example, earthquakes, extreme winds or tornadoes, floods, and volcanoes) with likely implications for other facilities at the site.

These accident initiator categories were then mapped into the risk-dominant WM operations or facility configurations identified in Section F.2.3. The screening process used to compare the process and facility characteristics with generic accident consideration is illustrated in Figure F.2-3. Table F.2-1 shows the matrix of accident categories analyzed.

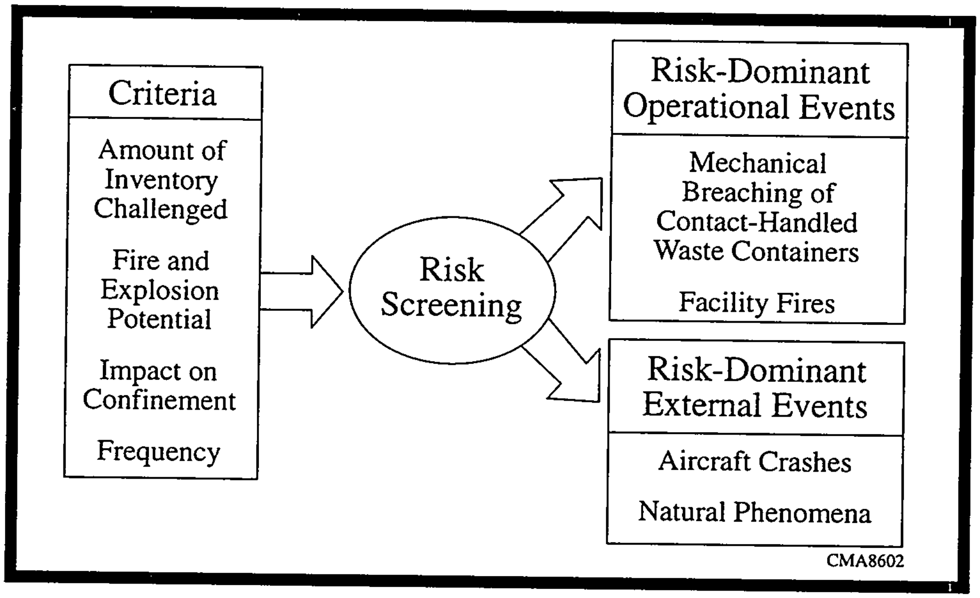

Figure F.2-3. Screening of Risk-Dominant Accident Sequences.

Table F.2-1. Risk-Dominant Accident Initiator Categories for WM Operations and Facilities

Function or Operation	Containment Characteristics of Facility	Internal Operational Accidents: Operational Breaches of Waste Packaging	Internal Operational Accidents: Operating Fires or Explosions	External Challenges to Facility: Man-Made	External Challenges to Facility: Natural Phenomena
General waste-handling operations	Not relevant	X[a]	X	-[b]	-
Large-scale storage	Less than Hazard Category 2[c]	Included above	X	X	X
Treatment or pretreatment	Hazard Category 2	Included above	X	X	X

[a] X = risk-dominant accident initiator.
[b] - = not applicable.
[c] See Figure F.2-2 for definitions of hazard categories.

Finally, the accident sequences emerging from the initiators were classified by the frequency categories traditionally considered in safety documentation (Table F.2-2). Although the descriptive terminologies of these categories have changed through the years in safety documentation, the frequency ranges remain the same. Risk-dominant accident sequences from each of the frequency ranges shown were assessed in a manner consistent with the recent NEPA (DOE, 1993a) guidance, in light of their potential for affecting different populations; however, accident initiators leading to sequences with nominal frequencies less than 1.0E-06/year (yr) were generally ignored unless (1) the predicted consequences were so high that the risk (product of frequency and consequence) was likely to be dominant or (2) the uncertainty in the estimated frequency of the sequence was so large that a significant chance existed that

Table F.2–2. Frequency Categories Traditionally Considered in Safety Documentation

Frequency Category[a]	Frequency (yr^{-1})	Definition
Likely	>1.0E−02	May be expected to occur once or more during the lifetime of the facility.
Unlikely	1.0E−02 to 1.0E−04	Not expected but may occur during the lifetime of the facility.
Extremely unlikely	1.0E−04 to 1.0E−06	Will probably not occur during the lifetime of the facility.
Not credible	<1.0E−06	Has extremely low probability of occurring.

a Although the descriptive terminologies of these categories have changed through the years in safety documentation, the frequency ranges remain the same.

the true frequency was greater than 1.0E−06/yr. The final risk-dominant accident sequences selected were at or near the maximum reasonably foreseeable accidents.

Qualitative descriptions of the types of events comprising the accident initiator categories are found in Table F.2–3. Surrogate accident initiators were defined for the aforementioned subcategories of internal accidents on the basis of their expected frequency, dominant accident stress mechanisms, and potential consequences. Accident initiators were assigned frequencies appropriate to the process and facility configuration being evaluated, as reflected in the most recent safety documentation for DOE facilities managing nuclear waste and HW.

External event initiators for man-made challenges include impacts of aircraft and fires or explosions in adjoining or nearby facilities that would challenge the primary facility. Although the expected frequency of an aircraft impact is intuitively very low for most DOE facilities, certain facilities are located relatively close to airports or are in or near flight patterns for commercial, regional, or military airports. For these sites, aircraft crashes with attendant fires or explosions involving aviation fuel could dominate public risk. Impacts from small and large aircraft will have different frequencies and consequences and are considered independently. Frequencies for air crashes were derived (Appendix F of ANL [1996a]) for each site from either site-specific documentation or generic guidance, depending on the proximity to airports and the exposure to flight patterns. In general, derived frequencies of aircraft crashes were well below 1.0E−06/yr. Frequencies for fires and explosions were generally derived from generic data. Appendix C of ANL (1996a) summarizes fire and explosion information used for guidance. Natural phenomena considered as external accident initiators included earthquakes, floods, extreme winds or tornadoes, and volcanic activity;

Table F.2–3. Descriptions of Accident Initiators

Internal Operational Events (Generally with No Public Health Consequences)

Representative Industrial Accidents

Breach of primary containment of waste by an operational event, such as a handling accident, vehicular impact, improper system operation, system malfunction, or component failure, or resulting from failure of a support system such as a loss of power. Breach of containment by a small fire or process explosions originating inside the facility are included. Large-scale fires from industrial accidents are also considered, independent of large-scale fires and explosions that challenge the facility from outside and which are treated separately. To the extent possible, initiation frequencies are taken or derived from information in the SARs or supporting documentation. Frequencies of fires and explosions accompanying or subsequent to the breach are based on the combustibility of involved materials or the presence of combustible materials within the facility and are conditioned on the frequencies of events precipitating the accident sequence.

Severe External Challenges to the Facility (Other Than Catastrophic Natural Phenomena)

Fire or Explosion

A fire or explosion originating outside the facility challenges the facility. Examples of initiators include explosions of fuel or volatile chemical tanks or trucks and fires impacting nearby facilities, fires in adjoining facilities, explosions of natural gas or process chemical lines or tanks, and naturally caused fires, such as prairie fires. If the facility is breached, concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility.

Impact of Aircraft

An aircraft or major aircraft component (engine) impacts the facility. If the facility is breached, concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility. The initiating frequency of impact reflects missiles posing a credible threat to secondary confinement and primary containment. Impacts from small and large aircraft will have different frequencies and consequences and are considered independently.

Catastrophic Challenges to the Site and Facility from Natural Phenomena

Earthquake

An earthquake exceeding the design basis for the facility occurs. Concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility.

Flood

A flood exceeding the design basis for the facility occurs. Concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility. Because subsequent significant airborne releases are both implausible and enveloped in magnitude by airborne releases resulting from other natural phenomena in the same frequency range, airborne source terms for flooding are not developed in this report. Dominance by airborne releases is especially true since liquid HLW storage is not included in the analysis.

Extreme Winds or Tornado

Extreme winds or tornadoes exceeding the design basis for the facility occur. Concurrent (common cause) or subsequent accident events challenge the waste-containment barriers within the facility.

Volcanic Activity

A volcanic eruption occurs, with ashfall or lava flow (or both). Breach of primary containment may be caused by an operational accident or malfunction due to loss of power or by impacts of structural failure due to heavy ashfall or lava flow. Concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility. Because volcanic activity is of concern at very few sites and because potential subsequent source term releases are enveloped either by analogous releases following other natural phenomena in the same frequency range or by the effects of the eruption itself, source terms from volcanic activity are not developed in this report.

Criticality

Nuclear Criticality

A nuclear criticality occurs within a storage facility or process vessel. Concurrent (common cause) or subsequent accident events challenge the primary waste-containment barriers within the facility.

however, source terms were not developed for catastrophic flooding accidents because subsequent significant airborne releases are both implausible and enveloped in magnitude by airborne releases resulting from other catastrophic natural phenomena in the same frequency range. This is especially true since liquid HLW storage is not included in the analysis.

Source terms were also not developed for volcanic activity because such activity is believed to pose a credible threat to WM facilities at only three major sites, the Hanford Site (Hanford), Los Alamos National Laboratory (LANL), and INEL. Eruption of the active volcanoes near Hanford or LANL would only result in ashfall, the potential effects of which are overwhelmed by analogous effects for earthquakes in the same frequency category. Although INEL is considered vulnerable to lava flow, the airborne releases of radiological waste are expected to be comparable to those from large-scale facility fires. Thus, for the analyses herein, seismic events are analyzed as an enveloping scenario for floods and most volcanic activities, and large-scale facility fires envelop the lava flow accidents at INEL.

Seismic events are also used as the surrogate initiator for extreme winds or tornadoes, with the overriding reason being that standard atmospheric dispersion modeling would predict much greater dispersion (and hence, greatly reduced airborne concentrations) for high wind conditions than for the stable wind conditions assumed to be present during earthquakes. Existing analyses in U.S. Department of Energy (DOE) SARs and in the DOE *Defense Programs Safety Survey Report* (Pinkston, 1993) show that seismic events generally bound the risks of winds or tornadoes, including the risks from wind-driven projectiles. With respect to such projectiles, unpublished preliminary analyses for TRUW drums stored on outdoor pads at the Savannah River Site (SRS) suggest that damage from projectiles could exceed damage caused by seismic events, primarily because of the stability of the drum-stacking arrangement and the lack of protection against projectiles. To appropriately bound potential damage by projectiles to unprotected outdoor storage areas, the damage for seismic events in the WM PEIS analysis is conservatively defined to have higher damage ratios than those used in the aforementioned SRS report in order to envelop the damage caused by high winds or wind-driven projectiles.

Frequencies of occurrence for natural phenomena were generally taken from DOE design and evaluation guidance regarding natural phenomena (see Appendix E of ANL [1996a]); however, the frequencies of loss of integrity of a facility from the challenges of natural phenomena were determined in accordance with DOE facility NPH design performance goals, as discussed in Section F.2.6.1.

F.2.4.2 Specification and Evaluation of Accident Sequences

For the internal accident initiators defined in Table F.2-3, the plausible accident scenarios and the associated frequencies were based on existing accident analyses in SARs and EISs for DOE facilities. These existing analyses for DOE facilities with WM activities constitute a significant resource of information on accident assessment, and many of the analyses have been reviewed by peers and approved by the DOE. These analyses included scenarios that are very similar to those needed for the WM PEIS. They are a plausible source for estimating accident frequencies. In many cases, the existing analyses included probabilities for failure that were based on experience or on data on plant failures. The use of existing scenario frequencies precluded the need to estimate numerous event tree conditional probabilities for equipment failures and human errors that constitute the accident sequences.

High and low frequency estimates were taken from existing accident analyses with accident initiators, facility types, hazardous material types, and circumstances similar to accidents considered in the WM PEIS evaluation. The frequency selected for the WM PEIS evaluation was based on the overall similarity of the existing analysis to the analysis in question. In some cases, adjustments were made to include or remove frequency contributions from preventive and mitigative features that may or may not be included in the WM PEIS alternative. In most cases, the frequencies used in the WM PEIS were on the conservative side of the frequencies reported in existing analyses, as discussed in Section F.2.7.

For the external initiators, the analyses from existing SARs and EISs were sparse and often outdated. Because external events are rare, the facilities have no experience with direct impact of external forces or experience such as that of the Nuclear Utility Seismic Qualification User's Group (SQUG); therefore, analysis on the basis of experimental data could not be achieved. Event trees were developed to project the progression of the accidents associated with external initiators through plausible generic sequences. The extent of any release is a function of (1) the accident-related stresses affecting and rendering airborne the material involved in the accident and (2) the response of the containment barriers and filtration systems (if any). Accident stress mechanisms can be categorized as mechanical, fire-driven, or explosion-driven mechanisms. Branches of event trees were specifically defined to delineate fire and explosion categories for which experimental information is available to support the associated estimates of the release fraction.

The containment response is a function of the structural strength and operational status and efficiency of the buildings, equipment, and materials providing containment or filtering (or both), as well as the emergency response capabilities of the mitigative systems and relevant personnel. Accordingly, event tree branches were similarly defined to incorporate the key containment responses affecting the amount of airborne activity released to the atmosphere. This structuring of the event trees to incorporate stresses and responses of containment allowed a step-by-step characterization of the likelihood of the sequence and the magnitude of the release as the accident sequence progressed.

The accident sequences were developed and analyzed for accident categories applicable to facilities. They (1) provide a uniform treatment of accident analysis to a wide range of facilities with similar design characteristics across the DOE complex and (2) reduce the number of actual analyses performed to a manageable level. To implement this approach, existing facilities were generally mapped into a DOE-STD-1027-92 Hazard Category (DOE, 1992b) (see Section F.2.6.1) and into DOE-STD-1021-93 facility NPH PCs (DOE, 1993b). In general, conceptual treatment process facilities were assumed to be Hazard Category 2. A no-confinement category was assigned to concrete pads used for packaged storage, weather protection sheds, Butler buildings, and facilities providing no real barriers to release, up to and including general-use buildings. This treatment is appropriate for catastrophic releases and conservative for more benign sequences.

A generic matrix of release characteristics was then developed as a function of the event tree branches to facilitate the tracking of potential source terms through the accident sequences. This approach enabled the determination of the fractional release of each radionuclide or toxic chemical in the original inventory (the airborne release fraction [ARF]) at each point in the progression of the accident. Each accident sequence is then terminated in a generic release category. This approach adapts the source term treatment used in the DOE *Defense Programs Safety Survey Report* (DOE, 1993e) to accident progression analysis (see Section F.2.4). The approach also allows the evaluation of contributions from both the accident initiation and the subsequent accident sequence steps in determining the overall ARF.

The final step in evaluation involved the integration of the radionuclide or chemical compositions of the waste process inventories of MARs in the accidents with the accident data to derive the source terms. Preliminary estimates of the effects on health were obtained by combining the information on source term with the unit risk factors for each site. With this information, a reduced set of risk-dominant source terms covering the plausible frequency spectrum was developed for final calculations on health effects and risk.

F.2.4.3 Nuclear Criticality

On the basis of existing safety analyses, criticalities are judged to be incredible for LLW and LLMW storage, treatment, and post-treatment storage. The safety analysis of the consolidated incineration facility (CIF) at the SRS (Du Pont, 1987) considered nuclear criticality as implausible on the basis of design basis feedstocks and as incredible on the basis of the large number of independent operator errors and other failures necessary to introduce an unsafe quantity of fissile material into the incinerator and processes. The numerous combinations of failures in the waste packaging, classification, and handling processes required to both introduce sufficient fissile material into an LLW or LLMW storage or process facility and create a critical geometry or arrangement of the waste storage arrays simply rule out a credible criticality before or after treatment for these waste types. Because the WM PEIS addresses only the shipping and interim storage options related to canisters of vitrified HLW, for which no plausible mechanisms exist to achieve criticality, source term analysis for HLW criticality is not warranted.

A nuclear criticality in a TRUW solid-waste storage-and-handling facility (for example, Waste Receiving and Processing Facility [WRAP] Module 2 and the Radioactive Waste Management Complex [RWMC] [EG&G, 1993b]) is also judged to be incredible because of the low density and inventory of fissile material in the solid wastes, coupled with the dispersed geometry. Nuclear criticality can be conceived in some aqueous processing alternatives, depending on the dissolution of fissile material in the throughput of the process, the design of the vessel, and the flowsheet parameters (see Appendix C of ANL [1996a]); however, this criticality would require numerous breakdowns of administrative and accountability controls or unforeseen design deficiencies in the processing system (or both).

The DOE requires specific analyses to estimate the frequency of criticality for such processes. If the analysis indicates credibility ($>1.0E-06$/yr), the DOE then requires specific design provisions to preclude or mitigate the effects. With these safeguards in place, accidents of nuclear criticality have been ruled out as not being sufficiently important to risk to justify source term analysis for TRUW and are not discussed further in this chapter.

F.2.5 Development of Source Terms for Accident Sequences

F.2.5.1 Radiological Source Terms

The method used to estimate radiological source terms is similar to that used in the DOE *Defense Programs Safety Survey Report* (Pinkston, 1993). The source term associated with each accident is the product of four factors that vary for each radionuclide within the inventory affected by the accident:

$$source\ term = MAR \times DF \times RARF \times LPF \ , \qquad \text{(F.2–1)}$$

where

MAR = material at risk,

DF = damage fraction,

$RARF$ = respirable airborne release fraction, and

LPF = leak path factor.

Figure F.2–4 illustrates the evolution and development of the source term components from accident initiation through delivery to the atmosphere. While the disaggregation of the source term into these components broadly follows the treatment used in the DOE *Defense Programs Safety Survey Report* (Pinkston, 1993), the treatment of the components has been extended as discussed in Section F.2.4.2 to allow the tracking of these parameters at each point in the accident sequence.

All accident sequences culminated in fractional release categories defined to accommodate the various combinations of generic sets of DF, RARF, and LPF. The source term total release fraction (TRF) is defined as

$$TRF = DF \times RARF \times LPF \qquad \text{(F.2–2)}$$

and provides the fraction of each radionuclide or toxic material in the MAR that escapes the confinement and is available for atmospheric transport. This term, multiplied by the MAR, provides the source term used in the calculations of health effects and risk (see Section F.2.4).

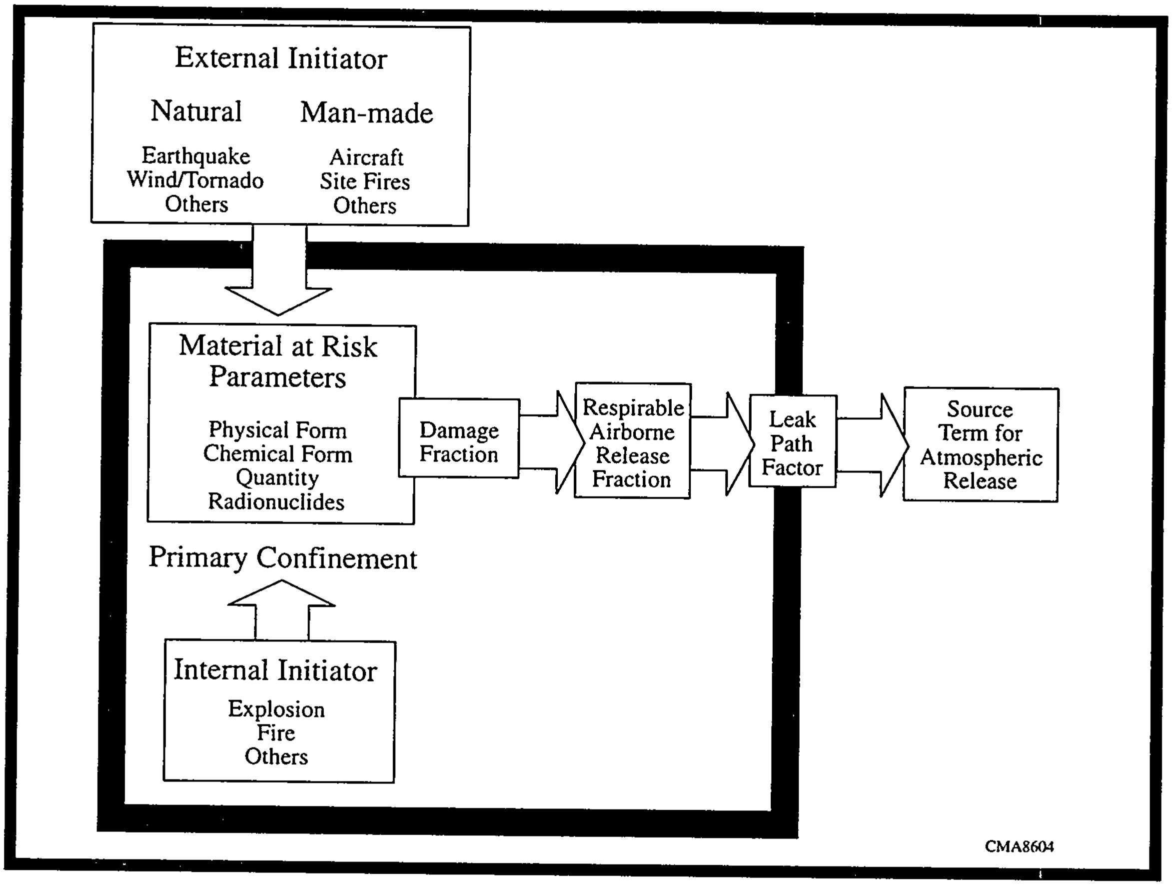

Figure F.2–4. Conceptual Flow Diagram for Source Term Development.

F.2.5.1.1 *Material at Risk and Damage Fraction*

The MAR is the total inventory of waste in a facility or particular operation with the potential of being impacted. The MAR is a function not only of the configurations of the process and facility but also of the severity of the accidents challenging the process or facility; for example, catastrophic accident initiators such as earthquakes clearly have the potential to affect greater inventories of waste than do industrial accidents and thus have greater MARs.

The DF refers to the fraction of MAR involved in the accident sequence and actually susceptible to airborne release. The DF is a function of the severity of the initiator and is generally small for operational events and larger for more severe events, such as external challenges to a facility from natural phenomena. The DF is also a function of the process and facility characteristics and of the subsequent phenomena encountered in the accident sequence, such as fires or explosions that have the capability of challenging or propagating to additional inventories of the MAR. More benign sequences without such mechanisms have sequence DFs that are zero or very small. Damage fractions were assigned as a function of the severity of the accident sequence, the physical and chemical forms of the MAR, and the vulnerability of the containment of the MAR.

F.2.5.1.2 *Respirable Airborne Release Fraction*

The ARF is the fraction of the potentially available inventory of the radionuclides rendered airborne at the point of the accident. The ARF is a joint function of the original physical form of the waste and the accident mechanisms and concomitant stresses acting to create airborne materials. The airborne release of radioactive materials depends on the ability of an accident sequence to overcome the barriers between the radioactive material and the ambient environment and to subdivide and suspend the radioactive material. Liquids or solids must be either fragmented or deagglomerated and suspended. All materials in the gaseous state (noncondensable gases and vapors under ambient conditions) were assumed to be transportable and respirable. The ARF is also a function of the physical or chemical properties of the individual radionuclides or chemical species. The respirable fraction (RF) for particulates is conservatively defined as the fraction of particulates with aerodynamic equivalent diameters below 10 μm. The aerodynamic equivalent diameter is that of a sphere of a material, with a density of 1 g/cm^3, that will have the same terminal velocity as the particle.

Many experiments and analyses have been conducted to provide both bounding ranges and best estimates of the release fractions of various radionuclides as a function of their chemical and physical form under a variety of accident stresses. The RARFs used in the accident sequences herein were derived by multiplying the ARF and RF for the applicable stress provided in DOE-HDBK-3010-94 (DOE, 1994b), which examines experimental data for the airborne release of materials under five types of stress: (1) explosions (shock and blast effects), (2) fires, (3) venting of pressurized liquids and powders (or venting of pressurized volume above solids), (4) crush-impact (either fragmentation by the impact of a falling hard unyielding object or the impact of a falling material on a hard unyielding surface), and (5) aerodynamic entrainment or resuspension. Where ARFs and RFs were unavailable for the type of material or the level of stress, values were derived by assessing the effect of some characteristic of the initiator or materials involved (for example, the effect of viscosity on the fragmentation and suspension of liquids in free-fall spill or pressurized release).

Matrices were developed for each waste type to account for the physical and chemical characteristics of the MAR by mapping the treatability categories into the physical forms for which airborne release data were developed. These matrices and results for the RARFs developed for the various physical forms of waste encountered in DOE waste management as a function of the stresses encountered in the potential accident sequences are shown in ANL (1996a). This treatment allows the analyses of the stresses encountered in the initiating events and the accident sequences to be evaluated independently, which, in turn, allows the step-by-step generation buildup of the source term to be tracked and integrated with the response of the protection systems to facilitate calculations of health effects for both the occupational workforce and the public.

F.2.5.1.3 *Leak Path Factor*

The LPF is the fraction of the airborne inventory that passes through the containment barriers and filters to the atmosphere. The LPF is a function of the physical form of the nuclide being released, the susceptibility of the nuclide to removal or reduction phenomena (such as precipitation or agglomeration) and to subsequent capture within the containment walls or filtering systems, and the effectiveness of the filtration systems in place. In-containment transport and filter effectiveness can be heavily dependent on the accident sequence, as well as on the structural characteristics and physical design of the facility. The LPFs were assigned on the basis of the integrity of the containment (if any) and the functionality of filtration systems in the facilities for the accident sequences. The more severe accident sequences generally involved breach of confinement, for which a conservative LPF of unity was assigned. Appendix D of ANL (1996a) provides LPFs as a function of the effectiveness of the filters used in DOE facilities and the intracontainment transport properties of gases and particulates.

F.2.5.2 Chemically Hazardous Source Terms

Chemical source terms were specifically developed for two waste types: HW and LLMW. All accidents were divided into three general categories, each having subcategories and including sublethal and lethal exposure concentrations:

- Spills resulting in partial vaporization of the waste ("spill only")
- Spills followed by ignition of the waste ("spill plus fire")

- "Other event combinations"
  - Spills followed by ignition of the waste and an induced explosion in a waste container ("spill plus fire plus explosion")
  - Facility fires resulting in a waste container breach ("fire only")
  - Mechanical failure of a compressed gas container resulting in an explosion ("spill and explosion")
  - Explosion from exposure of reactive material to air followed by fire ("fire and explosion")

The MAR and DF for the various chemical accident sequences were based on the same considerations as discussed for the radiological accidents.

In general, these accidents involve chemical or physical change in materials affected by the initial incident. The chemical and physical properties of the MAR were reviewed, and toxic gaseous products were identified for the accident sequences. The masses of these products were estimated from the mass of the reactants and the stoichiometry of the reactions. Rates of releases were generally estimated by assuming exponential decay with time. Obviously, the exact course of an accident is shaped by a multitude of factors, including (but not limited to) temperature, humidity, pooling versus spreading of spills, the exact composition or concentration of reactive materials (often unknown), and the proximity and nature of nearby reactive materials (including packaging, shelving, and flooring). The details on the selection of the accident scenarios, on the chemistry involved in their progress, and on the estimation of the rates of release of the toxic gases are provided in the sections for HW and LLMW (Sections F.6 and F.7).

F.2.6 GENERAL FACILITY MODELING AND INVENTORY ASSUMPTIONS

As discussed in Section F.2.3.1, the accidents considered in the WM PEIS accident analysis include general handling accidents, storage facility accidents, and accidents involving treatment processes or facilities. To appropriately evaluate these accidents, descriptions and assumptions concerning the design and configuration of facilities must be established. This section discusses the generic DOE design and performance criteria and the design aspects and associated modeling assumptions that are the basis for the accident evaluation.

F.2.6.1 DOE Design and Performance Criteria

To understand how the facilities for TSD operations are affected by the various accident initiators discussed in Section F.2.4.1, an understanding of how DOE facilities are designed and evaluated is necessary. The DOE has established general design criteria (GDCs) for all types of facilities in DOE Order 6430.1A (DOE, 1989). The GDCs in DOE Order 6430.1A provide the minimum requirements for the design, construction, and maintenance of facilities, and these GDCs must be followed for all new construction, including modifications of facilities. For facilities constructed before 1989 (the year when the order was approved), similar predecessor GDCs were used, but compliance was less strictly enforced and the GDC were somewhat less stringent and specific. However, in the last few years, great emphasis has been placed on achieving compliance through facility upgrades or demonstrating that noncompliance with a particular GDC does not cause undue risk. An implied assumption exists throughout the WM PEIS accident analysis that WM facilities involved in all of the alternatives conform to an acceptable design pedigree (such as control system redundancy or natural phenomena resistant design) for structures, systems, and components that perform a safety function. An acceptable design pedigree is established using the "graded approach" concept for design.

The "graded approach" for facility design, as applied by DOE Order 6430.1A and other DOE orders and standards, is a particularly important design concept that affects the results and assumptions in the WM PEIS accident analysis. The graded approach is a common sense concept that the design pedigree, as well as the operational maintenance and surveillance, for structures, systems, and components should be commensurate with the importance that the structures, systems and components have with respect to the protection of the onsite workers, the public, and the environment. To achieve the appropriate design pedigree and to select appropriately stringent criteria from DOE Order 6430.1A, the DOE classifies facilities by using criteria in DOE Standard DOE-STD-1027-92 (DOE, 1992b). This standard categorizes nuclear facilities into hazard categories 1, 2, or 3 on the basis of the effects of unmitigated releases of hazardous materials. Category 1 facilities are the most hazardous and are considered to have the potential to cause significant offsite effects. Category 3 facilities are the least hazardous and do not have the potential to cause offsite effects or more than minor onsite effects. Analogous categories for nonnuclear facilities (no radiological hazards) are also established and are referred to as high-, moderate-, or low-hazard facilities.

It is reasonable to assume that the safety significant aspects of the facility design (i.e., those that may affect the PEIS analysis) comply with the GDC since compliance must be demonstrated as part of the authorization basis for facility operations. As such, noncompliant features that may threaten the safety envelope documented in the authorization basis are reviewed for their safety impact and modifications and retrofits are made as necessary. The GDC are also considered in the safety review of design changes to ensure that compliance is achieved, and the authorization basis is maintained. Facility compliance to the GDC ensures the facility safety envelope is maintained and assuming GDC compliance for the PEIS accident analysis is reasonable and justified.

An assumption or assertion that a facility is in a particular hazard category implies that the facility has a design pedigree commensurate with the level of risk posed by the facility. However, the assumption of a higher design pedigree does not in itself ensure that risks to the public and workers are appropriately controlled. The assumption of a design pedigree simply implies that structures, systems, and components are designed to prevent accidents or to mitigate the consequences of accidents. The assessment that risks are adequately controlled is documented in safety analysis documentation that uses risk-based methods to demonstrate that appropriate programmatic functions and controls are used in concert with the facility design to achieve acceptable risk performance.

To achieve a performance goal of not exceeding a certain annual probability of loss of function in a facility, the facility (and related structures, systems, and components) must be designed to withstand a certain magnitude of hazard (the design basis natural phenomena event). Report UCRL-15910 (Kennedy et al., 1990) provides guidelines for selecting the natural phenomena design basis and the maximum acceptable annual probability of exceedance of the hazard to achieve a predetermined performance goal for a facility. In the WM PEIS, a facility of a particular hazard category is assigned a performance goal as defined in DOE-STD-1021-93 (DOE, 1993b). The design basis hazard magnitude for earthquakes and winds corresponding to the hazard annual probability of exceedance (listed in UCRL-15910) is obtained from site-specific hazard curves reported in the Natural Phenomena Hazards Modeling Project (Coats and Murray 1984). For example, for a Hazard Category 2 facility, the performance goal is 1.0E–04 (for loss of function), and based on UCRL-15910, the recommended maximum annual probability of exceedance of a seismic hazard to meet such a performance goal is 1.0E–03. Thus, for a given site such as Argonne National Laboratory-East (ANL-E), the peak ground acceleration corresponding to an annual probability of exceedance of 1.0E–03 is 0.12 g (Coats and Murray, 1984), where *g* is the gravity acceleration. Therefore, a Hazard Category 2 facility at ANL-E with a 0.12 g seismic design basis has an annual probability of exceedance (beyond seismic design basis) of 1.0E-03 and an annual probability of loss of function of 1.0E-04 (beyond performance goal).

Figure F.2–2, abstracted from DOE-STD-1021-93 (DOE, 1993b), depicts the performance goals of 1.0E–05, 1.0E–04, and 5.0E–04 assumed herein to represent frequencies of facility containment failure under challenge from natural phenomena for Hazard Category 1, 2, and 3 buildings, respectively. This figure also shows the relationship between the criteria of resistance to natural phenomena and the PCS and performance goals. The DOE orders and standards to implement the use of these criteria, including DOE Orders 5480.23 (DOE, 1993d), 5481.1B (DOE, 1987), 6430.1A (DOE, 1989) and 5480.28 (DOE, 1993c; formerly 5480.NPH), are also shown. The primary DOE standards for performing structural design and evaluation with respect to natural phenomena resistance are DOE-STD-1021-93 (DOE, 1993b) and DOE-STD-1020-94 (DOE, 1994a), formerly UCRL-15910 (Kennedy et al., 1990).

In general, the facility categories referenced in the WM PEIS analysis refer to the hazard category that is established by using criteria from DOE-STD-1027-92 (DOE, 1992b). Most of the facilities considered in the WM PEIS alternatives are Hazard Category 2 or 3 or general-use facilities. Treatment facilities were assumed to be Hazard Category 2 for accident analyses. Storage facilities were conservatively assumed to have no containment.

F.2.6.2 Storage Facility Accidents

LLW, LLMW, and TRUW. The underlying assumption used in the PEIS is that all sites will accumulate or at least not reduce these waste inventories for roughly ten years at which time complexwide treatment will begin. Thus all sites will achieve their maximum inventories (leading to maximum potential releases), independent of alternative in about 10 years. This condition applies to all analysis of storage facility accidents and offers no discrimination. Hence accidents during current storage of LLMW, LLW, and TRUW were not analyzed. However, to provide guidance on the likely impacts of storage facility accidents, a review of recent DOE NEPA guidance or safety documentation is provided in the individual sections for LLMW, LLW, and TRUW. Although not relevant in the discrimination of PEIS alternatives, this guidance facilitates qualitative comparisons of the relative impacts of storing wastes in their current form versus treating these wastes prior to disposal.

Current storage for these waste streams is accomplished in a variety of ways. Low-level waste is generally packaged in drums or containers and stored on outdoor concrete or asphalt pads or in weather-protective sheds pending treatment or shallow land disposal. Low-level mixed waste is generally packaged in drums or containers and stored in Resource Conservation and Recovery Act (RCRA)-compliant weather-protective sheds pending treatment. Transuranic waste is generally packaged in drums or containers and stored in concrete structures, in weather-protective sheds, in earthen berms, or in below-grade caissons (remote-handled [RH] TRUW). Most contact-handled (CH) TRUW, which dominates the total TRUW inventories, is stored in facilities with minimal containment, although DOE sites are moving toward qualified TRUW storage.

High-Level Waste. Most DOE HLW is stored in large underground tanks at Hanford and Savannah River with much smaller amounts stored at INEL and West Valley. Because calculation of the cost and risk impacts of current storage of HLW is not within the scope of the PEIS, no analyses of these storage facilities were performed. However, the storage of vitrified HLW was analyzed because it could be a factor in discriminating among alternatives for HLW management. These analyses are described in the section on HLW.

Hazardous Waste. Hazardous waste is generally packaged in 55-gal drums and stored in RCRA-compliant staging areas or weather protection sheds before offsite shipment for commercial treatment and disposal.

A HW storage facility (HWSF) typically has over 100 different chemicals, which may include chlorinated solvents, acids, bases, photographic chemicals, ignitable solids and liquids, compressed gases, metallic salts, lab-packed wastes, polychlorinated biphenyls, asbestos, and other regulated wastes. With explosives generally prohibited, the potential hazardous characteristics include volatility, flammability, dispersibility, and toxicity; and the HW is characterized and segregated on the basis of toxicity, corrosivity, reactivity, and ignitability. Most HWSFs have containment berm areas and individual storage cells that permit waste segregation according to RCRA and EPA criteria; some HWSFs have the capability of fire detection and suppression, and some have forced ventilation.

Because of the great diversity of storage facility designs among the DOE sites, a generic facility configuration with design characteristics such as storage arrays and segregation (as illustrated in Figure F.2–5) was assumed in the analyses. No credit was taken for containment or filtration.

F.2.6.3 Treatment Facility Accidents

The configuration of the generic treatment facility for the WM PEIS accident analysis consists of a series of linked process modules, each providing a specific treatment process. Modules providing common service

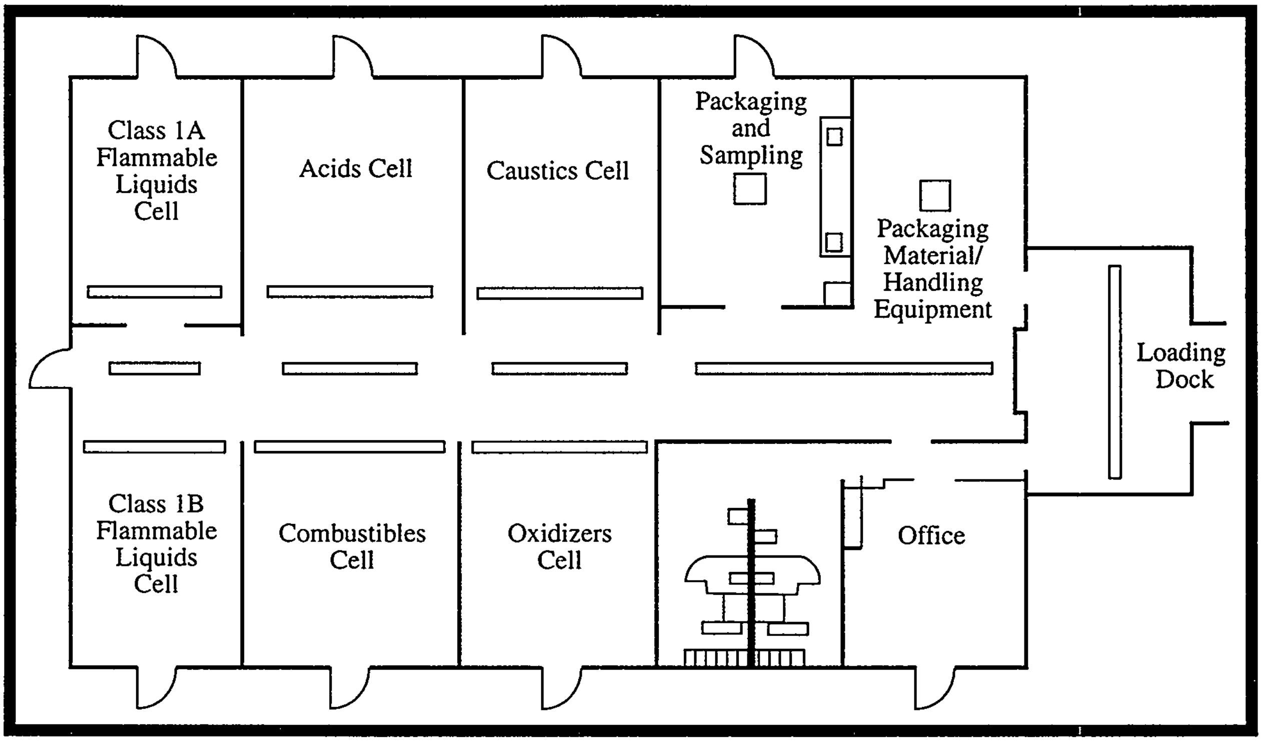

Figure F.2–5. Typical Design for Hazardous Waste Storage Facility.

to the process modules consist of (1) front-end support, providing waste receipt and lag storage; (2) treatment receiving and inspection; (3) container opening, dumping, and sorting; (4) certification and shipping; and (5) back-end interim storage before disposal. Process modules consist of specific treatment operations and process support services. The treatment facility is assumed to consist of process trains for both RH and CH operations, with similar unit operations, differing only in the degree of shielding and the degree of contact operations and maintenance. The RCRA contaminant removal technologies entail modules for (1) sorting and segregation (for example, before incineration); (2) removal or destruction of aqueous organics before evaporation; (3) metal removal; (4) metal recovery; (5) Hg removal and recovery; and (6) stabilization of various waste constituents by immobilization, conversion to stable forms, or removal.

As discussed in Section F.2.3.4, a generic incineration facility was selected for the evaluation of LLW, LLMW, and TRUW accidents. The RH and CH incineration portions of the facility shown in Figure F.2–6 have the following general functional areas: a receiving, storage, and feed area; the incinerator area, housing the rotary kiln and an off-gas secondary combustion chamber; an incinerator off-gas treatment area; a liquid treatment area; a solidification area (when cement solidification is applied to the ash); and facility and process exhaust air treatment, including the high-efficiency particulate air (HEPA) filtration systems.

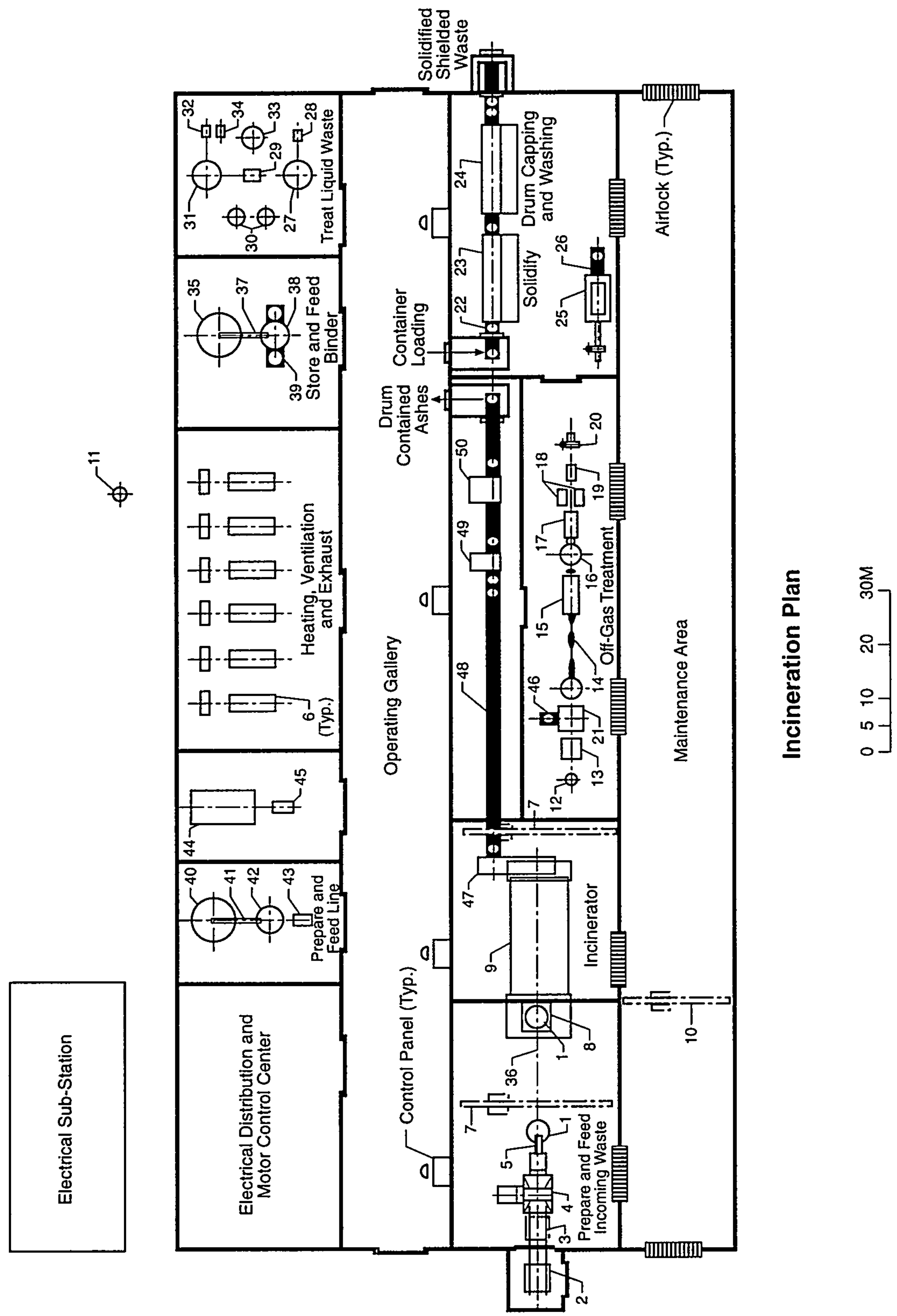

Figure F.2-6. Plan View of Incinerator Facility (See key on following page.)

Figure F.2–6. Key to Equipment.

1 = Waste Transfer Bin
2 = Incoming Waste Bin
3 = Skip
4 = Shredder 2 With Feed Hopper, Dust Hood, and Hydraulic Ram
5 = Auger Feeder
6 = HEPA Filter and Fan
7 = Underhung Crane in Enclosed Process Area
8 = Feed Bin
9 = Incinerator
10 = Underhung Crane in Enclosed Maintenance Area
11 = Stack
12 = Afterburner
13 = Cooler
14 = Double Venturi
15 = Condenser
16 = Mist Eliminator
17 = Reheater
18 = Double HEPA Filters
19 = Final HEPA filter
20 = Interior Decontamination Fan
21 = Ceramic Bag Filter
22 = Drum Staging Conveyer (Powered Roll)
23 = Solidification System
24 = Drum Capping and Washing System
25 = Dust Collector, Fan, and HEPA Filter
26 = Drum Staging Conveyor (Powered Roll)
27 = Receiving Tank
28 = Pump
29 = Filter
30 = Ion Exchange
31 = Treated Waste Tank
32 = Pump
33 = Sludge Tank
34 = Pump
35 = Storage Bin
36 = Bin Hoist
37 = Conveyor
38 = Day Bin
39 = Drum Staging Conveyor (Gravity)
40 = Lime Silo
41 = Screw Conveyor
42 = Mixing Tank With Mixer
43 = Feed Pump
44 = Chiller
45 = Circulation Pump
46 = Drum Staging Conveyor (Powered Roll)
47 = Drag Conveyor
48 = Drum Staging Conveyor (Powered Roll)
49 = Capping Device
50 = Washing Device

The receiving and storage area contains waste in various (but mostly solid) physical forms. Waste is fed to the incinerator after preparation (sorting or shredding, or both, as required). All combustible materials are destroyed, leaving a solid (ash) residue. The ash is generally solidified or packaged (or both) before transportation and disposal.

Incineration off-gas treatment includes a condenser and fume scrubber and generates a liquid waste stream of condensate and spent gaseous scrubber solution. In the liquid treatment area, dissolved and suspended solids are removed, liquid residue is prepared for immobilization, and treated wastewater is recycled to the system. In the solidification system, the sludge from the liquid residue and the ash resulting from the incineration are mixed with concrete and immobilized. Waste in the other areas is in the form of ash. In the CIF at the SRS, wet ash is found in all ash areas except the two combustion chambers (Du Pont, 1987). Dry ash is generated in other DOE incinerators and, because of its greater dispersibility, is assumed here for source term development.

The incineration facility also produces a residual gaseous waste stream. The incinerator off-gas treatment unit is designed to remove particulates, sulfur dioxide (SO_2), hydrogen chloride (HCl), and nitrogen oxides (NO_x). Acid gases are typically removed by scrubbing. Radioactivity and some toxic metals are released directly in off-gas as volatilized compounds and radionuclides (iodine, ruthenium, and cesium) or radioactive gases (carbon dioxide [CO_2], H_2O, and SO_2 formed with carbon-14, tritium [^3H], and sulfur-35, respectively). Some fission products are also released indirectly in combination with particulates that are removed by off-gas scrubbing and filtering.

Detailed modeling of facilities was beyond the scope of the WM PEIS. Accordingly, a treatment facility with generic confinement characteristics defined previously was used to assess accidents to envelop the releases from accidents in the treatment process. A DOE Hazard Category of 2 and the associated performance requirements on its systems were assumed. Double-HEPA-filtration structures, systems, and components were assumed to be in place. The waste inventory at the time of the accident was based on the facility throughput at each site and included unique volumetric inventories and physical, chemical, and radiological compositions for each site for each alternative.

F.2.7 EVALUATION OF SOURCE TERM PARAMETERS AND FREQUENCIES

This section discusses the development of the frequency and source term data generally used across the waste types. The evaluation of the frequencies and source term parameters required not only generic data applicable to broad classes of accidents but also data specific to the various waste types to account for differences in the physical and chemical forms, the packaging used as primary containment, and the facilities used to store or treat that waste type. The final selection of data used for facility accidents for each waste type is discussed in further detail in the chapters describing the analyses for that waste type (Sections F.3 through F.7).

After the generation of these data, a number of new or previously unavailable accident analyses addressing facility accidents were obtained. These accident analyses were performed in support of recently published DOE SARs and EISs. Another new document of particular relevance that has recently been published is the new DOE Standard DOE-HDBK-3010-94 (DOE, 1994b) on RARFs, which provides the latest RARF values published by DOE for use in accident analysis. These latest values supersede some of the RARF values used herein. These reports have been reviewed to determine whether they would significantly affect the source term calculations or frequency assignments developed herein. It was concluded that the Draft WM PEIS accident calculations lead to somewhat more conservative releases than would be calculated using the most recent DOE guidance; consequently, values in this Appendix have generally not been revised for the Final WM PEIS.

F.2.7.1 General Handling Accidents

The dominant contributor to worker risk from radiological or chemically hazardous releases for general handling accidents is expected to result from mechanical breaches of waste containers. This expectation stems from the relatively high frequency of such occurrences and the proximity of the worker to the point of release in such operational incidents. Handling accidents include container breaches caused by package drops, by forklift or other vehicular impacts, by crane drops or crushing, and by overpressurization. The use of heavy equipment poses a potential for damage to waste packages either because of package handling or inadvertent collisions. For many facilities, such as WRAP (DOE, 1991b) at Hanford and the RWMC (EG&G, 1993b) at INEL, cranes are used to move drums and boxes, with the height of movement generally exceeding the nominal 1.2-m height design specification for drum integrity in the event of a drum drop (Type A package; Code of Federal Regulations [49 CFR Part 173]). In all facilities, crushing of drums or boxes caused by impact with trucks, forklifts, and other equipment is possible. Although one waste container would generally be breached in an accident, rupture of multiple containers could occur in instances when several containers are handled at a time.

Handling accidents during treatment processes entail minor hazards to the operating staff. Hazards include puncture wounds during waste sorting, minor contamination from glove failures, and minor spreads of contamination from treatment equipment pressurization failure events and from off-gas treatment confinement failures (corrosion, gasket failures, etc.). The risk from exposure to radiation from these operational incidents is judged to be enveloped by the analysis for general handling accidents.

The frequencies for chemical spills involving HW or LLMW are derived by using site-specific inventories of individual representative chemicals, along with the assumptions identified previously on the frequencies of breach per operation. Conditional probabilities of fire or explosion of chemically reactive or combustible chemicals are also developed. These discussions are included in the sections on HW and LLMW accident analyses (Sections F.6 and F.7).

Evaluation of Source Term Parameters. For fall or crush damage scenarios in operations with stacked arrays, the MAR will generally vary from one to four packages, depending on the method of stacking and the arrangement of the array. Storage packages are typically (1) Type A (49 CFR Part 173) plastic-lined, carbon steel 55-gal drums; (2) plastic-lined wooden boxes (120 cm × 120 cm × 210 cm or 60 cm × 120 cm × 210 cm); (3) TRUPACT-II standard waste boxes (metal boxes measuring 120 cm × 120 cm × 210 cm; or (4) ST-5 metal boxes (120 cm × 120 cm × 180 cm). The Waste Isolation Pilot Plant (WIPP) final SAR (DOE, 1990b) and the WIPP SEIS-II (DOE, 1996) assume that 25% of the package contents are spilled (that is, a DF of 2.5E-01) for events dislodging the drum lid and that 10% of the waste package contents are spread by events where there is an inadvertent puncture by forklift tines.

In the majority of handling accidents or hands-on processing incidents, the MAR would be limited to a single package. For more severe sequences involving an array of several containers being dropped or impacted in a single accident, the MAR would depend on the configuration but would be limited to the maximum number of packages in the array. Because the accident releases of greatest overall risk to the workforce involve single-drum handling operations where the worker is in contact with or very near to a breached package, a MAR of one drum is specified to calculate source terms for general handling accidents for all waste types.

The DF of the MAR subjected to spill, crush-impact, or overpressurization would depend on the location of the breach, the physical form of the MAR, and the severity of the accident stress. Liquids and volatiles would be free to flow out of a breached container, whereas most solid material would remain inside. Breached containers of LLW, LLMW, and TRUW are assumed to hold solid wastes, with a single-container DF of 2.5E-01. Breached containers of HW are assumed to hold liquid, with a single-container DF of 1.0E+00 for the representative handling accidents analyzed herein. The physical composition of the MAR in storage was defined by volume weighting the treatability category inventories at each site.

Evaluation of Frequencies. Numerous frequency estimates for waste package breaches in a facility are reported, although facility inventories are generally not reported in existing safety analyses. The SAR for the RWMC (EG&G, 1993b) estimates an annual frequency[i] of external drum breach of 1.4E+00/yr per facility. The EIS for new production reactor capacity (DOE, 1991a) estimates a total annual frequency of externally induced drum breaches of 2.0E-02/yr and a rate of vehicular crashes of 1.8E-02/yr. Published joint probabilities for a drop from a crane and for the drum or container to breach range from 1.2E-01 to 8.0E-02/yr per facility. The various WRAP studies (DOE, 1991b,c; WHC, 1991a,b) assume that 10% of dropped containers are breached. A low value (8.0E-02/yr) has been estimated for damaging packages during loading drums into TRUPACT containers, which is similar to an estimate for breaching drums during ATMX railcar loading (1.1E-01/yr) and the value of 1E-02/yr applied in the WIPP SEIS-II (DOE, 1996). A higher value of 1.2E-01/yr was estimated for damage during the retrieval and restorage of buried TRUW drums and boxes at INEL (DOE, 1992a). This value is assumed to be more applicable to TRUW because of the large number of package movements required in the operations of the storage facilities. A frequency of 7.5E-02/yr has been estimated for puncturing up to two packages with forklift tines or, in some fashion, damaging one or more waste packages during heavy equipment operation (for example, dislodging the top tiers of a four-package-high array).

The approach used herein was to develop an estimate of the frequency of mechanical breaches for general handling operations on a per-operation basis, with an operation defined as picking up, moving, and setting down a container. The SAR for the HWSF (EG&G, 1990) uses an estimated frequency of one drum breached per 10,000 operations, on the basis of analyses at the Rocky Flats Environmental Technology Site (RFETS). A fault tree analysis of container rupture at the HWSF resulted in a probability of 3.0E-03 of an operation error, with a conditional probability between 2.0E-03 and 1.0E-02 for drum breach after an impact, depending on the type of container, or 1.0E-01 for drum piercing. Although several handling errors are considered, this analysis leads to a frequency of rupture between 6.0E-01 and 3.0E+00 for every 10,000 operations. The WIPP fire hazards analysis (Westinghouse Electric Corp., 1991) used a frequency of 5.0E-05 failures per forklift operation when a crew of two is performing the handling operations. A value of 1.5E-04 accidents per forklift operation, with a conditional probability of 2.5E-01 for drum rupture, leading to a breach frequency of 0.4E-04, was used in a probabilistic safety analysis of a Los Alamos National Laboratory (LANL) facility (Sasser, 1992). The LLMW systems analysis (EG&G, 1992c, 1993a) used a value of 1.0E-03 drum breaches per operation but included very minor breaches and spills. Finally, analysis of actual event data at the Savannah River Site (SRS) resulted in a forklift drum drop probability of 5.0E-05 per operation and a drum piercing probability of 3.0E-05 per operation (WSRC, 1994).

On the basis of all of these studies, a probability of 1.0E-04 per operation for significant drum breaches consistent with the aforementioned estimates of source term parameters was used in the analysis herein. To apply this operational failure probability to storage area facilities, residency times in the interim storage area, which vary greatly, must be considered. Most areas are simply staging areas for treatment or disposal operations. Generally, for such staging areas, two handling operations would occur, one for receiving and one for removal. Thus, the expected annual frequency (f_{mb}) of a container breach for waste product x caused by a handling accident is

$$f_{mb} = 0.0002 \times n_x \ , \qquad \text{(F.2-3)}$$

where n_x is the number of waste containers of waste product x received annually. To convert this value to a throughput number, a conservative assumption was made that the complete inventory turns over each year. Then the expected annual frequency of significant mechanical breaches is given by

$$f_{mb} = 0.0002 \times N \ , \qquad \text{(F.2-4)}$$

where N is the capacity of the facility in number of drums.

The previous frequency estimate should envelop frequencies for breach of postprocessing storage containers that contain immobilized residues from treatment. With the exception of potential gas generation and pressure buildup, no significant breach mechanisms are present. For miscellaneous TRUW solids, the SAR for the RWMC (EG&G, 1993b) includes a facility frequency estimate of 2.1E-02 events per year for severe internal stresses, such as a hydrogen pressure buildup from radiolysis of cellulose material or other gas-generating mechanisms. Thus, the operational estimate of Equation F.2-4 envelops this facility estimate.

The frequencies for container damage internal to a treatment facility would also be expected to be lower than those for lag storage because of the significantly lower inventory of drums and reduced drum vulnerability during handling. The estimate for metal-box drop and breach was 1.0E-02/yr for WRAP Module 2 (DOE, 1991c). A value of 3.8E-02/yr is estimated for the crane-drop scenario for the WRAP Module 1 facility (WHC, 1991a). For processing facilities, fewer drums and other packages are handled per year than would be the case for the range of potential operations of the lag storage areas (for example, consolidation of the contents of a number of waste pads onto a new pad). Furthermore, the operating conditions internal to a processing facility are superior to those for outside pads in terms of equipment reliability and working environment.

An approach similar to that discussed previously is used for estimating container breaches from operational events involving canisters of vitrified HLW. The glass product is noncombustible, and the stainless steel canister used as a container for the glass offers a high degree of protection from external incidents (for example, the HLW canisters are designed to be dropped from a height of 9 m without loss of integrity). Beyond 9 m, the integrity of the canisters is uncertain (for example, the maximum height that a Hanford canister can drop in a storage facility is 13 m). Canisters are probably most vulnerable to damage during transfer from the onsite canister transporter into the vault tube (Braun et al., 1993). On the basis of this observation, the only accident analyzed for the glass storage facility is an operational event involving the crush-impact of a glass canister. Given that a simple drop of a canister (from a height less than 9 m) would not result in a breach, canister rupture would require the drop of a heavy structure (for example, a crane or concrete cover) on top of a canister during handling.

The estimated frequency for a canister breach for the Hanford glass storage facility, which would handle approximately 370 canisters, is 4.0E-03/yr (Braun et al., 1993). By assuming that the annual frequency of a canister breach depends on the number of canisters, which is taken to be equal to the annual rate of canister production, the frequency for an HLW breach (f_{HLW}) is

$$f_{HLW} = 0.004/370 = 0.00001/canister. \qquad \text{(F.2–5)}$$

Thus, the frequency for canister break at SRS is approximately 4E-03/yr on the basis of an annual production rate of 410 canisters per year. The West Valley Demonstration Project (WVDP) will handle approximately 100 canisters per year, and the annual frequency for canister break is therefore 1.0E-03/yr. The preliminary design at Hanford assumes a production rate of 890 canisters per year, leading to a frequency of 9.0E-03/yr.

The frequencies for chemical spills involving HW or LLMW are derived by using site-specific inventories of individual representative chemicals, along with the previously identified assumptions on frequencies of breach per operation. Conditional probabilities of fire or explosion of chemically reactive or combustible chemicals are also developed. These discussions are included in the sections on HW and LLMW accident analyses.

F.2.7.2 Storage or Staging Area Accidents

The major concern with storage and some staging facilities is the large inventory of waste in a centralized area and releases during accidents involving fires or explosions. The sections that follow summarize the accident types considered that would affect either dedicated storage areas or areas for staging waste prior to treatment. The discussion is generic in that it is not tied to a specific treatment process or waste type. The final determination of source term parameters for HW storage accidents is discussed in the section addressing that waste type. Both internally initiated accident sequences and external events were taken into account.

F.2.7.2.1 *Internally Initiated Fires*

Internally generated facility fires generally occur because of ignition of fuel sources, combustion of rubbish, or spontaneous combustion of the contents of a waste package. Combustible or flammable fuel sources include diesel fuel or gasoline for tractors, trucks, or other vehicles and natural gas or fuel supplies. Combustible rubbish fires generally result from poor housekeeping and are probably the principal cause of minor facility fires. Spontaneous combustion of the contents of a waste package has been reported (DOE, 1990a) but is considered unlikely.

Design and operational safeguards are in place to prevent propagation from a localized source (such as a single package or drum or a rubbish pile) to a much larger inventory. Packages for combustible materials are either steel drums, fire-resistant boxes, or fire-protected shipping containers. Moreover, sites are generally bound by the RCRA to segregate storage by waste form compatibility and RCRA category; therefore, combustibles are segregated. Finally, most facilities have fire detection and suppression capabilities from fire-watch or operator surveillance, automatic sprinkler systems, fire barriers, or onsite fire department response (or some combination of these types of protection). As a result, fires can be categorized as either local fires involving very limited inventories of wastes or, at the other end of the spectrum, as major facility fires induced by forces that provide a source of fuel (such as gasoline) and that also disable or overwhelm any available safeguards. Accidents affecting staging-area waste packages can generally be enveloped by those affecting storage areas because of the similarity of the primary containment (packaging) and are included herein.

Evaluation of Source Term Parameters. The MAR in all fire scenarios is limited to the waste exposed to the fire, which depends on the facility configuration and the detection of and response to the fires. The DF is a strong function of the packaging and the physical form (and combustibility) of the MAR. Two categories of fires were considered: waste-container fires and facility fires. The former category was assumed to have a MAR equivalent to the contents of a single 55-gal drum and to have a DF of 1.0E+00. This DF is conservative relative to the value of 0.1 applied in the WIPP SEIS-II (DOE, 1996). The representative fire in a storage facility was assumed to encompass the spectrum of undetected or unsuppressed fires, and the entire facility's inventory of waste was assumed to constitute the MAR. A DF of 1.0E-01 was assumed as a generic value to account for segregation and separation of waste packages in the facility and for the nature of the waste packaging as described previously.

Evaluation of Frequencies. Reported fire-initiator frequencies for drum storage (DOE, 1990b; Salazar and Lane, 1992; EG&G, 1993b) for operationally related events range from 1.0E-03/yr to 2.0E-04/yr. The higher value is estimated for general miscellaneous combustibles. The lower value is also fairly typical of estimates for scenarios involving ignition of leaking fuel or natural gas. Because some references distinguish between operationally generated waste and the packaged waste being stored, the upper value is probably associated with poor housekeeping. For fire initiating in a waste package, frequencies on the order of 9.2E-04/yr have been reported for the RWMC (EG&G, 1993b), with a value of 1E-04/yr reported in the WIPP SEIS-II (DOE, 1996). This range of values is inferred to apply to storage situations involving minimal intervention by operators. Fire frequencies associated with fuel from transport vehicles, cranes, and forklifts range from 3.3E-03/yr to 8.3E-04/yr for initiation (Davis and Satterwhite, 1989; EG&G, 1993b). Fires resulting from subsequent ignition upon violent breach of TRUW drums can be envisioned because of hydrogen buildup from alpha activity in contact with cellulose material (DOE, 1990a). Although frequencies for waste-package damage scenarios have been estimated, conditional probabilities for ignition and fire following package breach have not been reported, but would be higher for TRUW than for LLW and LLMW, for which hydrogen buildup is much less likely.

Because of the relative infrequency of a single-container fire and the much greater consequences of fully developed facility fires, only the latter were analyzed for source term development for the WM PEIS. The estimated annual frequency is 1.0E-04/yr for a fully developed facility fire in the absence of treatment process operations. (See also section on treatment facility fires.) This frequency is the product of a generic facility fire frequency of 1.0E-02/yr and a fire suppression system failure probability of 1.0E-02 (DOE, 1982). This value is consistent with existing documentation and is judged to be reasonable in light of the existing preventive and mitigative safeguards discussed previously.

F.2.7.2.2 *Internally Initiated Explosions*

Explosion scenarios for packaged wastes can be postulated for LLMW, TRUW, and HW. Most LLMW accident analyses focus on storage of miscellaneous organic liquid waste (for example, benzene at the SRS [WSRC, 1994]), where blankets of inert gas serve to preclude ignition and detonation. Most TRUW analyses focus on the accumulation of hydrogen or methane from radiolysis of organics, with subsequent ignition and detonation. Inadvertent chemical reactions are considered for HW but should be unlikely because waste sorting and segregation at the point of generation act to preclude combining reactive materials and oxidants. Storage activities are generally not climate controlled, but heating gas is a candidate source for explosion where some control is maintained. Postprocessing storage is less of a problem than pretreatment storage because of the greater stability of the final forms (for example, grout).

Damage to packages from an explosion is governed by projectile behavior and the location and configuration of the package. One type of array is a four-tier-high stack of two pallets, each holding a two-drum-high, tightly packed array of four drums (Salazar and Lane, 1992). Here, the number of drums that could be directly affected by projectile impact would be five, although the array could be toppled, or other ancillary damage (for example, to adjacent arrays) could be envisioned. A similar rationale applied to waste boxes would indicate two affected adjacent boxes.

Evaluation of Source Term Parameters. The MAR for an explosion would generally be limited to a single package because very little explosive energy is typically associated with currently generated wastes, and extrapolation of scenarios to include high-energy projectiles is difficult. The DF for explosions internal to a container would be 1.0E+00 (that is, the entire contents of the package are assumed to be affected). This damage is judged to conservatively envelop any projectile damage to nearby packages. For external explosions, projectile damage to a waste package is similar to puncture of a package, and a damage ratio of 2.5E-01 or 1.0E+00 would be expected, depending on whether the contents are solid or liquid.

Evaluation of Frequencies. The WRAP Module 1 at Hanford (WHC, 1991b) considered various potential explosions for CH TRUW and LLW operations and assigned a frequency range of 1.0E-06/yr to 1.0E-04/yr for a drum exploding because of hydrogen buildup during storage in the shipping and receiving area (after receipt). Presumably, the hydrogen resulted from radiolytic decomposition of H_2O or hydrocarbons, which is plausible for TRUW but unlikely for LLMW. A glove box sorting area explosion frequency of 6.3E-05/yr was estimated for opening a RH TRUW drum containing a hydrogen-air mixture with failure to vent, failure to detect, and ignition.

Because of the relative infrequency of single-container explosions, and the lack of any known large-scale explosions, radiological source terms for explosions in storage and staging areas for other than hazardous waste were not judged sufficiently important to risk to justify source term development. Process explosions, however, were analyzed as discussed in the section on treatment facility accidents (Section F.2.7.3).

F.2.7.2.3 *External Event Accident Sequences*

External event challenges are important to the human health risk insofar as these challenges have the potential to create fires or explosions that can disperse and render airborne radioactive waste materials. As discussed in Section F.2.4.1, plausible external accident initiators leading to direct fire and explosion scenarios include impacts from military, general aviation, or commercial aircraft; impacts from large trucks carrying fuel or chemicals; and fuel or process chemical fires and explosions in nearby facilities or storage tanks. Natural phenomena such as earthquakes can cause natural gas, fuel, or process chemical fires and explosions in nearby facilities. The severity of such phenomena makes mitigation by onsite fire brigades very unlikely.

Event trees described by ANL (1996a) are used to model the accidents caused by external events and to project the progression of the accidents through plausible generic sequences. The event tree methods are based on accepted probabilistic risk assessment methods and are consistent with methods prescribed by the NRC, the American Institute of Chemical Engineers (1989), and the DOE. Accident sequences are developed for aircraft impacts (small aircraft and large aircraft are considered separately) and seismic events. As discussed in Section F.2.4.1, the safety impacts of aircraft accidents envelop impacts for other man-made severe external challenges, and the damage and safety impacts from seismic events generally envelop effects from other natural phenomena. These accident initiators and the associated accident sequences are developed for the designs for the generic facilities described in Section F.2.6. The results are covered in the following sections on specific waste types.

F.2.7.3 Treatment Facility Accidents

The major concern with treatment facilities involves fire- or explosion-driven releases of process inventories that are often much more concentrated than the inventories of waste in current storage or in staging areas. This section primarily summarizes internal event-initiated treatment process accident types and discusses the associated source term and frequency data used for the analyses. However, external event sequences were also analyzed using event trees in ANL (1996a) to structure and facilitate the evaluation. Results for both internal and external events are shown in the individual sections for each waste type (Sections F.3 through F.7).

F.2.7.3.1 *Treatment Process Incidents*

In general, the processes of the generic treatment facility described in Section F.2.6.3 entail minor hazards to the operating staff, including puncture wounds during waste sorting, minor contamination from glove failures, and minor spread of contamination from the events involving treatment equipment pressurization, spills, and off-gas treatment confinement failures (corrosion, gasket failures, etc.). Such minor operational incidents in treatment have been folded into general handling accidents analysis and, as a result, are not discussed further.

F.2.7.3.2 *Off-Gas System Failures*

Potential onsite and offsite effects may result from failure of the off-gas treatment system to perform as designed or from introduction, into the off-gas treatment, of species for which the treatment steps are ineffective (for example, noble gases, volatile radionuclides such as ^{3}H, or high-temperature conversion of dichlorodifluoromethane [HALON] to phosgene); but off-gas events tend to be minor because of dilution due to a high gas sweep rate and the inertness of the off-gas constituents relative to the chemically reactive or hazardous materials given off during facility fires and explosions. The onsite and offsite risks from such accidents are enveloped by potential facility fires or explosions that involve releases of chemically reactive materials or radionuclides that have extended residence times in the body. Thus, these events are not considered further.

F.2.7.3.3 *Treatment Process Vessel Releases*

Aqueous processes to remove RCRA contaminants entail short-term storage in tanks, transfer pumps, vessels, pipelines, and reaction vessels. Because most sites have some capability to reduce volume and to immobilize or to dispose of low-activity liquid wastes, long-term storage of these liquid wastes is limited to specific situations, such as the LLMW stored in tanks at Hanford. Nevertheless, rupture or failure of these tanks could arise from corrosion, internal stress, or external impact. More severe events can also be conceived, such as hoop stress failure from severe overpressurization (for example, vapor-space gas detonation from ignition of radiolytically generated hydrogen or benzene vapor), with subsequent fires or explosions; however, both frequencies and consequences for such severe events should be extremely low for all radioactive waste types except possibly HLW. Because tank storage of HLW is not included in the evaluation of the WM PEIS alternatives, such accidents are not addressed here.

On the basis of inventories of the various waste types and identified treatment technologies, wet-air oxidation of LLMW was selected as a potentially risk-dominant process with vessel breach the accident of concern. However, details of the process and related system descriptions were inadequately specified in the WM PEIS to allow detailed accident analyses. As a result, source terms for wet-air oxidation were analyzed by using MAR and facility containment parameters consistent with those used to analyze accidents involving incineration facilities (discussed subsequently). This approach allows an order of magnitude scoping of the risks of wet-air oxidation process accidents and provides a reasonable relative risk comparison with incineration accidents. The MAR was assumed to be the entire contents of the vessel (DF = 1.0E+00), which was assumed to hold 1% of the annual wet-air oxidation throughput at the site. The radiological composition at each site for each alternative was obtained from the WM database (Avci et al., 1994). An earthquake was the only plausible accident capable of rupturing the process vessel and at the same time defeating the facility containment integrity and filtration systems. For conservatism, the airborne release was assumed to be pressurized, with RARFs chosen accordingly.

F.2.7.3.4 *Treatment Facility Fires*

Two categories of fires at treatment facilities have been considered: (1) operation-specific fires developed from consideration of the characteristics of a particular treatment technology or the related process and facility characteristics, and (2) generic fires. Existing onsite safety documentation has been reviewed to develop the source terms and frequencies associated with plausible accident sequences for the first category, which includes fires in incinerator facilities. The CIF analysis (Du Pont, 1989) treats the fire initiator potential of the incinerator system as governed by the nature of the feedstocks and attributes the initiation of fire to (1) spontaneous combustion of solid waste in lag storage or (2) ignition of contaminated organic liquids in storage. The Waste Experimental Reduction Facility (WERF) (EG&G, 1993b) analysis considered a fire in the baghouse of the filtration system. Both analyses were used to define a reference scenario, as discussed subsequently.

Facility or facility operations characteristics other than those associated with the treatment process can clearly be correlated with the occurrence of fire. These characteristics include the presence of highly combustible materials (or materials that can undergo spontaneous combustion, such as dried tetraphenylborate salts), the existence of activities involving these materials (such as machining of pyrophorics), maintenance activities (such as welding) that involve fuel and ignition sources, and building support systems such as the heating and electrical distribution systems (especially switchgear). The assumption is that these characteristics are reflected in the generic database used to establish the generic data on fire frequency. Site-specific analyses include ignition of the contents of a breached drum and general room fires (Salazar and Lane, 1992). In general, existing LLW and TRUW safety analyses seem to focus less on facility fires than on other accidents; for example, analyses for the various Hanford WRAP modules mention but do not analyze fires. The WIPP SEIS-II (DOE, 1996) analysis considered a scenario in which a single TRUW drum was postulated to erupt into flames as it was opened but before it was emptied onto a conveyor belt for sorting. Engineering judgment, which is based, in part, on the information developed herein and largely presented in Appendix C of ANL (1996a), has been used to assign reasonable source term and frequency parameters to generic facility fires.

Evaluation of Source Term Parameters. The representative incineration facility fire used to envelop radioactive releases is based largely on information for the Waste Experimental Reduction Facility (WERF) (EG&G, 1993b). The assumption that a fire starts in the baghouse of the filtration system and propagates to the HEPA filters is plausible because of the high temperatures of the material entering the baghouse. The fire causes the housing seals to fail on the baghouse and the filters, yielding a direct release of fly ash to the atmosphere. The total ash inventory accumulated in the baghouse and the HEPA filters is assumed to constitute the MAR. It has been assumed that the ash fed to the baghouse during the fire, if the facility has not shutdown, is a small fraction of the ash accumulated in the baghouse, and it is therefore neglected in the calculations. The MAR was estimated by averaging the fractions of the total facility ash inventories in the CIF and the Process Experimental Pilot Plant (PREPP) actually present in the baghouse and HEPA filters, a value of roughly 3.0E-02 (Du Pont, 1989). All of the baghouse and HEPA filter ash was assumed to be affected by the fire, resulting in a DF of 1.0E+00. Any subsequent explosions of accumulated waste ready to be incinerated were judged to be enveloped by the dispersion of ash. A more detailed description of the external events analyses can be found in the report by ANL (1996a).

The representative incineration facility fire for HW used to envelop hazardous releases assumes that the fire engulfs the feedstock. For further information, refer to the HW analysis.

Evaluation of Frequencies. Fire frequencies for production operations are based on occurrences in the SRS data bank for the operations in the SRS 200 Area and on other industrial experience. The frequency of spontaneous ignition of accumulated combustibles (poor housekeeping) is 5.0E-01/yr if (1) pyrophorics or (2) nitric acid and cellulose are available. The CIF analysis (Du Pont, 1989) assigned a value of 2.6E-02/yr for fire initiation in the lag storage area for cardboard boxes, on the basis of general experience with spontaneous combustion for F and H Canyon operations. The SAR for the CIF also addressed the possibility of a fire involving waste organic feedstock (5.0E-03 per tank per year, with three tanks). Maintenance activities, depending on the circumstances (confined space welding, use of greenhouses, etc.), initiate fires with a frequency of 3.0E-01/yr to 2.0E-01/yr. Fires from electrical shorts have similar frequencies. The expected frequency for a process-related fire in a canyon facility has been estimated to be 1.5E-02/yr on the basis of experience in the SRS's F and H Canyons (WSRC, 1994).

Analysis of actual event data at the SRS indicates a failure probability for manual fire suppression of 1E-01 to 5E-01 per demand, assuming the fire is detected (Benhardt and Held, 1994). Most SARs use a reasonably conservative value of 1E-02 per demand for failure of automatic fire suppression systems on the basis of the DOE study (DOE, 1982). More recent analyses of Hazard Category 2 facilities indicate a greater reliability for wet pipe sprinkler systems. Typical site-specific values range from 5.0E-02 to 1.0E-03 per demand for a fire department to fail to respond. Also, the SRS data indicate a probability range of 3.0E-02 to 3.0E-01 for the fire department to successfully put out the fire. Because this analysis presumes either automatic or manual fire detection and notification, either or both are required for any credit to be taken.

The EIS for the WIPP (DOE, 1990a) applies a frequency of 1E-03/yr for a fully developed fire in an operating area, as derived from the RWMC documentation. The more recent WIPP SEIS-II (DOE, 1996) estimates an annual occurrence frequency of about 1.0E-04. A study by the Electric Power Research Institute (EPRI, 1979) estimates 1.0E-02/yr for a fully developed fire (on the basis of a generalized fire initiator of 1.0E-01/yr), and general estimates of fire initiator frequencies (for TRUW processing and handling activities) for the RFETS range from 5.0E-02/yr to 5.0E-01/yr on the basis of facility-specific experience (for example, Building 910 [EG&G, 1992a]). The RWMC analyses (EG&G, 1993b) are predominantly focused on fires initiated by helicopter crashes (in various locations), typically with a frequency of 1.2E-05/yr to 5.4E-05/yr. Other sites are more concerned with external challenges from aircraft crashes and earthquakes. Aircraft fuel, ruptures of natural gas pipelines, and spilled organic liquids in storage facilities constitute the combustible or ignitable source for these challenges.

The estimated frequency for a fully developed facility fire used herein is 1.0E-03, consistent with the earlier WIPP estimates. This estimate includes a generic fire frequency of 1.0E-01/yr and a fire suppression system failure probability of 1.0E-02. In light of safeguards associated with hazard category 2 facilities, this estimate is judged to be conservative. For the HW feedstock fire, refer to the HW analysis section.

F.2.7.3.5 *Treatment Facility Incinerator Explosions*

Except for incineration and wet-air oxidation (of mainly aqueous wastes, with less severe consequences), no significant explosion initiators were identified for processing. Failure of a wet-oxidation unit would result in a pressurized spray release. Nitrated organic reactions at high temperatures in evaporators and driers were discounted in the SARs for RFETS Building 910 and Building 374 (EG&G, 1992a,b) because (1) alkaline solutions do not react significantly, (2) heavy metals are absent, and (3) processes are at low pressure. In general, the accident literature for evaporation focuses primarily on accidents involving loss of filtration; however, unlike many processing activities, incineration has a potential for accumulations and leaks of combustible gas, with a possibility for explosions.

Evaluation of Source Term Parameters. The assumption is that the explosion (which could potentially occur because of the existence of fuel, oxygen, and high temperatures) takes place inside the rotary kiln incinerator. The MAR was derived by averaging the ash inventory at the CIF and PREPP in the kiln incinerator and was determined to be 12% of the total ash inventory existing in the facility. All of the waste present in the rotary kiln incinerator was conservatively assumed to be affected by the explosion, for a DF of 1.0E+00.

Evaluation of Frequencies. The safety analysis for the CIF, which is designed to accommodate LLW but includes various RCRA wastes as candidate feedstocks, estimates an annual frequency of 1.5E-02/yr for explosions in the rotary kiln assembly and in the secondary combustion chamber. Because it envelops the other estimates, the CIF estimated frequency of 1.5E-02/yr is used herein. A frequency of 2.9E-04/yr for an explosion during RWMC processing activities was estimated (no unit operation is specified), with a frequency for a facility room fuel-air explosion estimated at 2.0E-04/yr (previously reported values were as low as 5.0E-07/yr). A more refined and detailed analysis estimated that conditions conducive to an explosive event exceeding the 100-kPa capability of the vessels could occur at a frequency approaching 3.0E-02/yr. Such overpressures could potentially rupture the vessels and release the contents. Various INEL studies cite an explosion frequency of 1.0E-04/yr derived primarily from earlier analyses to support operations of the RWMC/Solid Waste Experimental Pilot Plant (SWEPP) with TRUW solid feedstock (EG&G, 1993b).

The posttreatment stored waste may be presumed to be more stable (depending on the method of immobilization) and more robustly packaged. The only qualitatively defined scenario entails a propane gas leak with ignition. The SAR for RFETS Building 910 assigned a conservative value of 4.4E-02/yr for a heating gas line rupture and ignition to impact postprocessing material stored in the processing facility. Because the source term for this accident is much smaller than that for the rotary kiln explosion, this sequence was not developed further.

F.2.7.4 Summary of Data Used

A summary of the key generic source term and frequency parameters discussed in the preceding sections is presented in Table F.2-4. Although the values actually applied for the accidents for the individual waste types are summarized in the chapters on specific-waste-type accident analysis, these values are largely based on this table. The MAR units of number of packages in the facility inventory were converted to curies for each waste type and DOE site, with the information provided in the PEIS waste characterization database. The activity was then distributed into the corresponding radionuclides in the source term files used for consequence calculations.

Table F.2-4. Frequency and Source Term Parameters for General Handling and Internal Facility Accidents

Event	Reported Annual Frequencies		WM PEIS Frequency Estimate per Year	Reported or Representative Source Term Parameters		
	Low	High		MAR	MAR Units	DF
General Handling Accidents						
Packaged Wastes						
Crane drop with impact and breach	8.0E-02	1.2E-01	--	1.0E+00	Package[a]	2.5E-01 or 1.0E+00[b]
Forklift puncture with impact, breach, and spill	--	7.5E-02	--	2.0E+00	Package	1.0E-01 or 1.0E+00[b]
Internal overpressurization and breach	--	2.1E-02	--	1.0E+00	Package	-
Toppled stacked array	--	7.5E-02	--	4.0E+00	Drum	2.5E-01 or 1.0E+00[b]
Representative breach and rupture	--	--	2.5E-04[c]	1.0E+00	Drum	2.5E-01 or 1.0E+00[b]
Fires in Storage or Staging Areas						
Spontaneous-combustion fire	2.6E-02	5.0E-01	--[d]	1.0E+00	Drum	1.0E+00
Small fuel or chemical fire	8.3E-04	3.3E-03	--[d]	2.0E+00	Drum	1.0E+00
Facility fire	2.0E-04	1.0E-03	--[d]	e	Drum	1.0E+00
Local manual-suppression failure	1.0E-01/d[f]	5.0E-01	--	--	--	--
Automatic-suppression failure	--	1.0E-02/d	--	--		--
Fire brigade response failure	3.0E-02/d	3.0E-01/d	--	--		--
Representative facility fire without mitigation	--	--	1.0E-04	e	Drum	1.0E-01
Explosions in Storage or Staging Areas						
Packaged Waste (LLMW and TRUW Only)						
Spontaneous combustion or explosion	1.0E-06	1.0E-04	--	1.0E+00	Drum	1.0E+00
Representative explosion	--	--	--[d]	--	--	--
Fires in Treatment Facilities						
Facility fire						
Local manual-suppression failure	1.0E-01/d	5.0E-01/d	--	--	--	--
Automatic-suppression failure	--	1.0E-02/d	--	--	--	--
Fire brigade response failure	3.0E-02/d	3.0E-01/d	--	--	--	--
Representative facility fire without mitigation	--	--	1.0E-03	1.0E+00	Baghouse and HEPA ash inventory	1.0E+00

Table F.2-4. Frequency and Source Term Parameters for General Handling and Internal Facility Accidents—Continued

Event	Reported Annual Frequencies		WM PEIS Frequency Estimate per Year	Reported or Representative Source Term Parameters		
	Low	High		MAR	MAR Units	DF
Explosions in Treatment Facilities						
Spontaneous combustion or explosion	1.0E-04	1.5E-02	-	1.0E+00	Incinerator kiln ash inventory	1.0E+00
Representative explosion	--	--	1.5E-02	1.0E+00	Incinerator kiln ash inventory	1.0E+00

Note: -- = covered by representative breach or rupture.
[a] A Type A 208-L (55-gal) plastic-lined carbon-steel drum was chosen as the representative waste package for MAR calculations in determining source terms for all packaged waste breach or rupture events.
[b] Waste packages containing liquids were assigned a DF of 1.0E+00.
[c] Per operation.
[d] Because of the combined relative infrequency and low health impact of individual container fires and explosions, only facility fires were analyzed in the WM PEIS.
[e] Total number of waste drums in facility.
[f] Per demand.

F.2.8 SELECTION AND CALCULATION OF FINAL SOURCE TERMS

Preliminary combination of the source term information discussed previously with selected so called unit risk factors (actually unit dose conversion factor) was performed to develop preliminary screening estimates of the impacts of the accident sequences to determine the risk-dominant scenarios. Unit risk factors were developed to estimate the health effects on the exposed populations from releases of unit amounts of radionuclides or hazardous chemicals (see WM PEIS Appendix D). This involved (1) the development of or integration of existing information on the site-, facility-, and treatment-specific demographics to characterize the workforce and general population potentially exposed to hazardous material and (2) the development of the meteorologic and release dynamics and characterization data necessary for calculating the transport of radioactive or toxicological plumes to the exposed population. Final source terms for the scenarios most important to public risk were then developed on the basis of the importance to risk to the maximally exposed individual (MEI) at the site boundary. The final risk-dominant scenarios selected were at or near the maximum reasonably foreseeable accidents.

The calculation of risk merged the frequencies and source term parameters for the accident sequences with the inventory characterization for the MAR. The computational framework and interaction of the code packages are illustrated in Figure F.2–7. Preliminary results of the operational and external event accident sequences described previously were screened for each waste type for the sites defined in the various

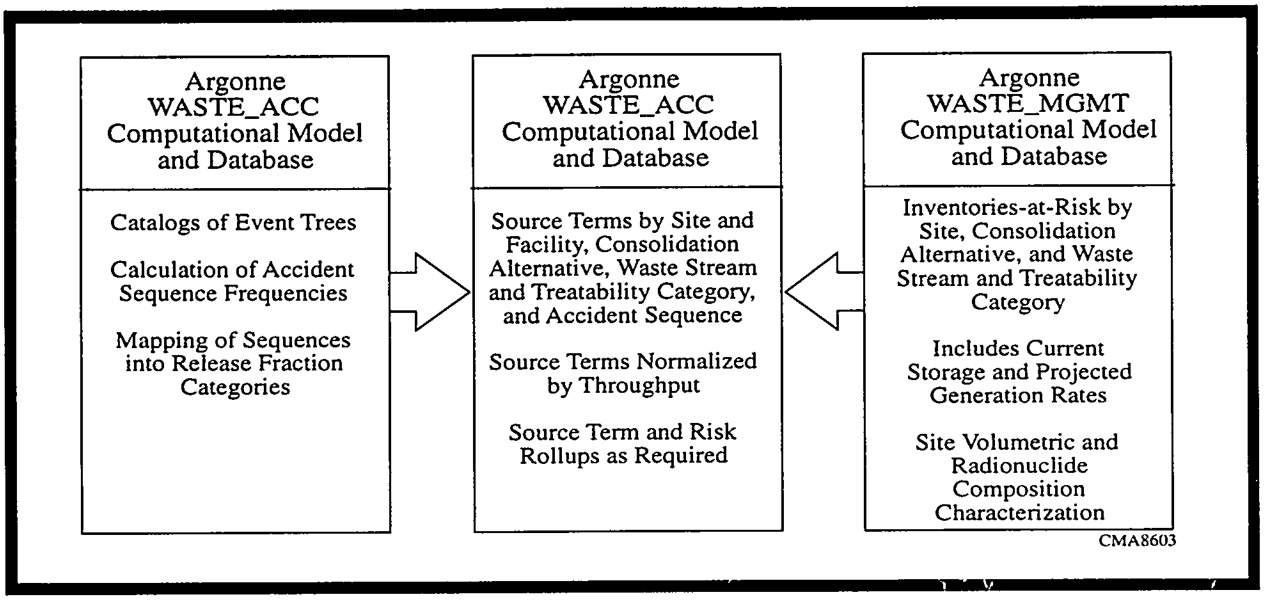

Figure F.2-7. Computational Framework for Facility Accident Analysis Source Terms.

alternatives for WM. Ranking of the accident sequences for risk dominance at each site was performed by using the frequency-weighted dose to the MEI as the screening criterion. Source terms were also selected from risk-dominant sequences in the following annual frequency categories: greater than 1.0E-02, between 1.0E-02 and 1.0E-04, between 1.0E-04 and 1.0E-06, and less than 1.0E-06. The selected source terms were then used to perform the health effects calculations for radiological and chemical releases from facility accidents.

The complete set of sequences, with classification of their frequency categories, is shown in the chapters describing the results for each waste type. A representative list of sequences is presented in Table F.2-5. The final calculation of the health effects for both general and occupational workforce populations by using the source terms described herein is reported in WM PEIS Appendix D.

F.2.9 Uncertainty in Facility Accident Analysis

Considerable uncertainties exist in various aspects of the facility accident analysis. The uncertainties range from issues pertaining to completeness of the analysis to numerical uncertainties in the parameters used in estimating the accident sequence frequency and the airborne release source terms.

Uncertainties in the representativeness and completeness of the accident analysis arise from inherent limitations of the accident sequence modeling and the incomplete knowledge of the facilities and operations

Table F.2–5. Representative Accidents Analyzed for Source Term Development

Type of Facility and Accident	Frequency	MAR × DF	Notes
Operational Handling			
Drum breach	2.0E–04/drum/yr	25% of drum (100% for liquid waste)	
Storage or Staging Area[a]			
Facility fire	1.0E–04/yr	10% of combustible drums in facility	Not applied to drums with vitrified, solidified, or otherwise highly stable waste or to noncombustible liquid waste
External Events			
Small- or large-aircraft impact	Site, aircraft, and accident sequence specific	Aircraft and accident sequence specific	Event tree sequences for both small and large aircraft screened on risk to identify single sequence
Earthquake[b] or tornado	Site[c] and accident sequence specific	Accident sequence specific	Event tree sequences screened on risk to identify single sequence
Treatment Facility[d]			
Operational Events			
Facility fire	1.0E–03/yr	Ash in baghouse and HEPA filters (3% of facility waste inventory or 0.03% of throughput)	Not for HW stream
Facility explosion	1.5E–02/yr	Ash in kiln (12% of facility waste inventory or 0.12% of throughput)	Not for HW stream
External Events			
Small- or large-aircraft impact	Site, aircraft, and accident sequence specific	Aircraft and accident sequence specific	Event tree sequences for both small and large aircraft screened on risk to identify single sequence
Earthquake	Accident sequence specific	Accident sequence specific	Event tree sequences screened on risk to identify single sequence

[a] Used for screening only.
[b] Earthquake used to upper-bound consequences of tornado.
[c] Frequency was assigned as the larger of those for a 0.15-g earthquake or a 113-kilometer per hour (km/h) (70-miles [mi]/h) wind.
[d] Applied only to incinerators at each DOE site. Vitrification accidents were screened out for LLW, and wet-air oxidation accidents were screened out for LLMW.

involved. Representativeness was addressed by reviewing existing safety analysis documentation and selecting accidents that were similar to or which bounded those found in the literature for the relevant operations, processes, and facilities. The issue of completeness was addressed by selecting surrogate accidents representative of classes of accidents and bounding the product of the frequency and the severity of the surrogates so that the risk from each class of accidents was enveloped.

The numerical estimates of the frequency of the different accident sequences analyzed are also uncertain. There exist uncertainties in both the frequency of the initiating events and in the conditional probabilities of the accident progression path. The numerical estimates were generally conservatively obtained using accepted DOE or NRC safety guidance or site-specific safety documentation. Event trees were used to help organize the information, structure the sequences, and automate the calculations. Uncertainties in the frequencies of the sequences are expected to range from factors of from 3 to 10 for anticipated accident sequences (i.e., those with annual frequencies greater than 1.0E-02 per year) to from 2 to 3 orders of magnitude for accident sequences with frequencies near or less than 1.0E-05 such as those initiated by beyond design basis earthquakes.

The uncertainties in the source term calculations apply for both the radiological and the chemical releases. The radiological source terms were calculated as the product of four contributing factors, namely MAR, DF, RARF, and LPF, all of which have uncertainties. Uncertainties in the MAR and DF arise from lack of precise knowledge of waste stream inventory amounts, physical characteristics, radiological profiles, and operational and containment configurations of the treatment and storage of waste streams under potential accident environments. Estimates of the current inventory radioactivity contents (i.e., reflecting both amount and composition) are probably uncertain by factors of from 2 to 100, depending on the type of waste, where it was generated, and its current disposition. Minimally conservative assumptions were used in developing the MAR. Damage fractions were chosen using generally conservative assumptions based on existing safety guidance and general knowledge of the physical characteristics of the MAR and the likely configurations and containment properties of the relevant storage and treatment facilities.

The RARF was conservatively adapted to the waste streams subjected to the dominant accident stresses encountered during the postulated sequences by assigning high or bounding values from the RARFs compiled in DOE-HDBK-3010-94 (DOE, 1994b). The uncertainties caused by imprecise knowledge of accident stresses and imprecise extrapolation of experimental values, which themselves are uncertain, suggest uncertainty ranges from factors of 3 to 10 for high RARF values, of greater than 1.0E-02, to orders of magnitude for RARF values of less than 1.0E-04. Uncertainties in the physical compositions and containment configurations of the MAR suggest an additional order of magnitude in the RARF uncertainty. Generally conservative RARF values were selected for analysis.

The LPF uncertainties for sequences with full or partial filtration exist due to incomplete knowledge of leak paths and filtration efficiency during accident conditions. For sequences in which the containment structure is damaged, a LPF of unity is conservatively assumed.

The chemical release source term uncertainties in the MAR and DF parallel those for the radiological release source terms. Uncertainties due to the completeness of the HW database, which was developed from actual shipping manifests, are expected to be small, roughly a factor of two. For the hazardous component of mixed waste the chemical breakdown was more generic and was not available on a drum by drum basis as it was for HW, suggesting an order of magnitude uncertainty. Also, only a small number of accident release types were identified due to the generic nature of the chemical profile available for those mixed waste types. This uncertainty is expected to add another order of magnitude. Uncertainties in the estimated chemical source terms are expected to have a variability of about one order of magnitude because chemical reactions can take place in different ways depending upon temperatures, the presence of catalysts, and the precise chemical concentrations of constituents, parameters for which there is very limited information only.

Recognizing that the uncertainties in the various source term factors are often interdependent, the uncertainty in source term estimates covers several orders of magnitude. Reasonable predictions of the distribution of source terms cannot be quantitatively established without a much greater level of knowledge of the waste stream inventories, the future generation of wastes within each category, and the actual characterization of the operations, processes, facility configurations, operating and safety procedures invoked. Developing this level of knowledge is beyond the scope of the WM PEIS.

Although the absolute values of the source term estimates range in uncertainty to several orders of magnitude, the comparisons among the source terms are much less uncertain. Considerable effort was expended to assure that the accident analysis approach and underlying assumptions were consistently applied for all waste streams, types of accidents considered, and operations, processes and facilities evaluated. Thus the relative health and risk impacts, to the extent that they depend on source terms that are ultimately derived from and calculated for different facility accident sequences, are judged to provide useful, comparative information for discriminating among strategic alternatives.

F.3 High-Level Waste

F.3.1 Alternatives and Sites Analyzed

Management of HLW can involve up to six phases: current storage, retrieval, pretreatment, treatment, interim storage, and geologic repository disposal. Current storage, retrieval, pretreatment, treatment, and geologic repository disposal are outside the scope of the WM PEIS so that accidents during these phases are not considered. Thus only accidents which occur during interim storage are considered in the EIS for various alternatives at Hanford, SRS, and WVDP.

Canisters of vitrified HLW from Hanford, SRS, and WVDP are to be placed in an interim storage facility awaiting transport to a geologic repository. Table F.3-1 is a comparison of the interim storage facilities at the three sites. Canisters produced at WVDP will be placed in storage racks that hold four canisters each and then will be transported in these racks to the onsite Waste Canister Storage Facility (WCSF). The immobilized HLW will be temporarily stored in a previously decontaminated and refurnished process cell known as the Chemical Process Cell (CPC), which has been modified for HLW interim storage. The storage area has a capacity for 344 canisters and will be equipped with two coolers to remove the decay heat.

The interim canister storage facility at SRS is designed to hold canisters in vertically sealed cavities within a concrete structure forming the storage vault (that is, a concrete modular vault). The Glass Waste Storage Building (GWSB) at SRS will be an air-cooled dry storage vault. It consists of rows of tubes or vaults placed below grade into which the canisters are lowered. No stacking of canisters occurs within the storage tubes. Concrete plugs provide a cover for the tubes. Storage capacity is currently provided for 2,286 canisters, the output from approximately five years of vitrification operations at the Defense Waste

Table F.3-1. Interim Storage Facilities for HLW Canisters

Variable	WVDP	SRS	Hanford
Facility name	WCSF	GWSB	TBD[a]
Storage capacity (HLW canisters)	344	2,565[b]	15,000
Storage method	Process cell	Modular concrete vault	Modular concrete vault
Footprint (m^2)	190	4,343	12,200
Vault volume (m^3)	2,490	63,404	141,000
Cooling method	Air cooler	Exhaust fans	Natural convection

[a] Conceptual facility under design.

[b] Storage capacity for an additional 2,286 canisters will also be required.

Processing Facility (DWPF). The storage capacity of the existing facility was predicated on the assumption that a geologic repository would be available by the time 1992 fresh waste would be processed. Additional storage capacity for 2,286 HLW canisters is required to handle interim storage of the fresh waste for a total required capacity of 4,572 canisters at SRS.

The previous design for the Hanford Waste Vitrification Plant (HWVP), was estimated to produce about 2,000 canisters of glass from high-activity waste from the Hanford double-shell tanks (DSTs). The number of glass canisters from single-shell tank wastes depends on the pretreatment process to be selected, with a maximum of 60,000 canisters having been projected for minimal pretreatment (U.S. General Accounting Office, 1993). This analysis assumes that a total estimated 15,000 canisters will be produced from all the HLW at Hanford. The vitrified waste canisters are to be placed in interim storage on site. This storage is similar to storage at SRS, except that three canisters are stacked per storage tube and a thermosiphon ventilation system would be used to remove decay heat in the Hanford design. As currently designed, the conceptual facility at Hanford would be able to store 15,000 canisters containing vitrified HLW. Detailed descriptions of HLW treatment processes and facilities can be found in the report by ANL (1996c).

The HLW alternatives in the WM PEIS are shown in Table F.3–2. The decentralized alternative would provide onsite interim storage for all treated, stabilized HLW awaiting shipment to a geologic repository for permanent disposal. The regional consolidation alternatives call for the vitrified-HLW canisters produced at one site (or sites) to be transported for interim storage at another site. Centralization at one site (Hanford) is also considered.

F.3.2 Risk-Dominant Accidents and Modeling Assumptions

F.3.2.1 Selection of Accidents

Accidents with the potential to produce significant offsite consequences were identified using available safety documentation. Although HLW contains various hazardous components, the primary risk is from radiological hazards. Because of the stable nature of vitrified waste, chemical releases do not occur in interim storage being considered in the WM PEIS.

Table F.3–2. Programmatic Alternatives for HLW

No Action Alternative

- Store HLW canisters at Hanford, SRS, INEL, and WVDP in existing and approved storage facilities
- Continue current treatment approaches at each site
- Continue interim storage of liquid and calcine HLW at INEL
- Continue activities necessary for ultimate disposal of HLW in a geologic repository

Decentralized Alternative

- Continue storage of HLW at Hanford, SRS, INEL, and WVDP
- Continue current treatment approaches at each site
- Continue interim storage of stabilized (vitrified or glass-ceramic) HLW at each site
- Continue activities necessary for ultimate disposal of HLW in a geologic repository

Regionalized 1 Alternative

- Same as Decentralized Alternative, except provide interim storage facilities at SRS for WVDP vitrified HLW canisters

Regionalized 2 Alternative

- Same as Decentralized Alternative, except provide interim storage facilities at Hanford for WVDP vitrified HLW canisters

Centralized Alternative

- Same as Regionalized 1, except provide interim storage facilities at Hanford for WVDP, INEL, and SRS HLW canisters

Nuclear criticality was discounted due to the low concentration of fissionable material in the canister and due to the absence of a mechanism of accumulating a critical mass. This assumption was supported by safety documentation. 10 CFR 60.131(b)(7) (1993) requires that the effective multiplication factor for criticality in an interim storage facility be at least 5% below unity. Reported values for SRS canisters show a large margin of subcriticality (McDonell and Jantzen, 1986). Because the inventories of fissionable radionuclides at Hanford and WVDP are lower than at SRS, an even greater margin would be expected.

Radiological releases from severe fires and explosions were considered first. DOE Order 5480.7A (DOE, 1993e) establishes requirements for an improved level of risk for fire protection for all facilities for which either loss of value or risk to health and safety would be of concern. The SARs for the various HLW interim storage facilities (Herborn and Smith, 1990; WSRC, 1990; West Valley Nuclear Services Co., Inc., 1994) do not consider the risk of fire within an interim storage facility, generally because no significant accumulation of combustibles occurs in the vicinity to support significant fire propagation. Thus, a major destructive fire was judged to be unimportant to risk. Similarly, because a large source of combustible material would not be available for ignition or chemical reaction (or both), the possibility of a catastrophic operational explosion was discounted. An aircraft crash with a resulting aviation fuel fire was also discounted because it would have a frequency of less than 1.0E-06/yr and limited radiological consequences, given the containment of the encapsulated radioactive materials (Mishima et al., 1986).

Natural phenomena were also considered, with the limiting accident being an earthquake. Braun et al. (1993) estimated an annual frequency of 3.37E-08/yr for an earthquake-induced canister drop with subsequent airborne release for interim storage at Hanford (this scenario assumed full filtration; loss of filtration would result in an even lower frequency estimate). In general, natural phenomena-induced events, such as tornadoes and earthquakes, were discounted as important contributors to the overall risk of HLW interim storage operations (Braun et al., 1993) due to the high integrity of the HLW canisters, as well as the low probability of occurrence.

Review of the available safety documentation (DOE, 1982; Idaho Operations Office, 1982; Machida et al., 1989; Mishima et al., 1986; WSRC, 1990) suggests that the risk-dominant accident during interim glass canister storage is the breaching of an immobilized canister during handling operations, including a canister drop from the shielded canister transporter (SCT) into the vault tube during transfer, and canister damage during transfer because of movement of the SCT cask relative to the vault tube opening (Braun et al., 1993). A rupture could also occur from a cell cover dropping on an encapsulated canister. (Because a cell cover weighs approximately 27,216 kg, canister rupture is expected following a direct hit.) The initiating event is attributable to operator error in handling or to handling equipment failure (NRC, 1988). Particulates would then be generated that are small enough to be suspended and hence could be exhausted to the atmosphere. The energetics of the accident would not be expected to severely degrade the facility filtration. At the time of rupture, each canister is assumed to be full.

The estimated frequency for a HLW canister drop with subsequent release at the Hanford glass storage facility, which would handle approximately 370 canisters per year, is 4.0E-03/yr (Braun et al., 1993). The frequency of a canister breach depends on the number of handling operations, which is taken to be equal to the annual canister production rate:

$$frequency\ (yr^{-1}) = (0.004/yr) \times canister\ production\ rate/370 \qquad (F.3\text{-}1)$$

This analysis assumes a canister loading rate of 790 canisters per year for Hanford; therefore, the initiating frequency for a canister drop at Hanford is estimated to be about 8.0E-03/yr. Given the previous information, the initiating frequency for a canister drop accident at SRS is estimated to be 4.0E-03/yr, on the basis of an annual production rate of 410 canisters per year. (The frequency of a canister rupture at SRS is estimated [WSRC, 1990] to be 2.0E-03/yr; the value used in this analysis can therefore be considered to be conservative.) The WVDP facility will only handle approximately 100 canisters per year, and the annual frequency is therefore reduced to 1.0E-03/yr.

F.3.2.2 Source Term Modeling Assumptions

Site-specific compositions were assumed for the MAR (taken to be the contents of one canister). A full canister of glass generally contains between 1,650 and 1,900 kg of glass (see Table F.3-3). This analysis

Table F.3-3. Dimensions, Weights, and Radioactivity of HLW Canisters

Variable	WVDP	SRS	Hanford
Outer diameter (cm)	61	61	61
Overall height (cm)	300	300	300
Material of construction	SS; 304 L[a]	SS; 304 L	SS; 304 L
Nominal wall thickness (cm)	0.34	0.95	0.95
Weight (kg)			
Canister	252	500	500
Glass or ceramic	1,900	1,682	1,650
Total	2,152	2,182	2,150
Radioactivity per canister (Ci)[b] (January 1990)	104,300	234,400	137,000
Decay heat per canister (W)[c] (January 1990)	311	709	389

Notes: SS = single shell; Ci = curie(s); W = watt(s).

also assumes that the mechanical impact from the canister drop accident results in fracturing the vitrified HLW and breaking the canister. The glass particles are released from the damaged canister (DF of unity) and are dispersed into the vault. The majority of the glass fragments are too heavy to remain airborne. 1.5E-04 is taken as the fraction of glass being within the respirable range ($<10\ \mu m$). The RARF for vitrified glass that has been subjected to a crush/impact accident stress is shown in Table F.3-4. Source term retention by filtration is also shown.

Because stack locations and heights cannot be defined until a conceptual design has been completed, ground-level releases were assumed with both full filtration and loss of filtration. Both of these conditions were used in estimating risk to the public. Worker risk was only calculated for unfiltered releases.

F.3.3 Results

Results for the accident sequences described above were categorized based on importance to risk to the public by using the frequency-weighted dose approach (to the MEI). They were grouped into the four annual frequency categories shown in Table F.2-2. The source term parameters and frequency groups for HLW accidents for all WM PEIS alternatives are shown in Table F.3-5. Detailed releases by radionuclide are provided in the report by ANL (1996a).

F.4 Transuranic Waste

F.4.1 Alternatives and Sites Analyzed

The TRUW WM alternatives in the WM PEIS are summarized in Table F.4-1. Calculated source terms results are discussed herein for the identified sites.

F.4.2 Risk-Dominant Accidents and Modeling Considerations

Selection of accidents for modeling has been based on importance to risk with the general modeling assumptions and related source term parameters described in ANL (1996a,d,e). A hazard unique to TRUW among the WM PEIS waste types is the potential for nuclear criticality due to separation and/or

Table F.3-4. RARF as a Function of Filtration for HLW Storage Facility Accidents[a]

Variable	Loss of Filtration	Partial Filtration	Full Filtration
RARF	1.5E-04	1.5E-07	3E-10

[a] Double banks of HEPA filtration are assumed; for full filtration, efficiency of first bank is 99.9%; efficiency of second bank is 99.8%.

Table F.3-5. Frequencies and Source Term Parameters for WM HLW Accidents Analyzed

WM PEIS Alternative	Site	Accident	Frequency Bin (per year) >1.0E-2	1.0E-4 to 1.0E-2	1.0E-6 to 1.0E-4	<1.0E-6	Source Term Parameters VMAR (m³)	MAR (Ci)	DF	Total Release (Ci)
All	Hanford	Glass canister crush, fully filtered release	--	X	--	--	6.2E-01	1.4E+05	1.0E+00	4.1E-05
All	Hanford	Glass canister crush, unfiltered release	--	--	--	X	6.2E-01	1.4E+05	1.0E+00	2.1E+01
All	SRS	Glass canister crush, fully filtered release	--	X	--	--	6.2E-01	2.3E+05	1.0E+00	7.0E-05
All	SRS	Glass canister crush, unfiltered release	--	--	--	X	6.2E-01	2.3E+05	1.0E+00	3.51E+01
All	WVDP	Glass canister crush, fully filtered release	--	X	--	--	6.2E-01	1.1E+05	1.0E+00	3.3E-05
All	WVDP	Glass canister crush, unfiltered release	--	--	--	X	6.2E-01	1.1E+05	1.0E+00	1.7E+01

Notes: VMAR = volume of MAR; -- = not applicable.

accumulation of fissile materials. However, as discussed in Section F.2.4.3, nuclear criticality is not an important contributor to risk and is not further analyzed.

F.4.2.1 Handling Accidents

Handling accidents during the staging and storage of CH waste are expected to dominate the risk of exposure for workers because of the high frequency of such accidents and the proximity of the workers

Table F.4–1. Transuranic Waste Alternatives

Alternative	Number of Sites		Treatment Standard	ANL-E	ETEC	Hanford	INEL	LANL	LBL	LLNL	Mound	NTS	ORR	PGDP	RFETS	SNL-NM	SRS	UofMO	WIPP	WVDP
	CH Treat	RH Treat																		
No Action	11	5	WIPP-WAC	TS	S	TS	TS	TS	TS	TS	TS	S	TS	S	TS	S	TS	TS		S
Decentralized	16	5	WIPP-WAC	TS	T	TS	TS	TS	T	TS	TS	TS	TS	T	TS	T	TS	T		T
Regionalized 1	5	2	Reduced Gas			T[a]	T	T					T[b]		T		T			
Regionalized 2	5	2	LDR			T[a]	T	T					T[b]		T		T			
Regionalized 3	3	2	LDR			T[a]	T						T[b]				T			
Centralized	WIPP	2	LDR			T[c]							T[b]						T	

Notes: T = treatment to one of three standards: process to current waste acceptance criteria at WIPP (WIPP-WAC); shred and grout to reduce potential for gas generation at the repository (Reduced Gas); and treat to meet land disposal restrictions using thermal organic destruction and complete treatment train; S = storage after treatment under No Action and Decentralized Alternatives or store current inventory under No Action Alternative. Blanks indicate that no storage or treatment of TRUW takes place at a site under the specified alternatives.

[a] The Hanford Site treats both contact-handled (CH) and remote-handled waste (RH).

[b] ORR treats RH waste only.

[c] The Hanford Site treats RH waste only.

during hands-on operations. The frequencies of accidents at a given site would be a strong function of waste throughput at that site. The assumption used (see Section F.2.7.1) is that two severe breaches of containment occur per year for each inventory of 10,000 drums handled. It is assumed for the results herein that handling breaches fall in the >0.01/yr frequency category.

Representative radiological accident scenarios assume that a single drum is affected, such that 25% of its contents are rendered airborne (DF = 2.5E-01). The composition of the representative drum is taken as a volume-weighted average of the treatability category compositions (excluding aqueous streams) at each site.

F.4.2.2 Storage Facility Accidents

Accidents and source terms for current storage were not analyzed explicitly. Unlike treatment, which will predominantly use new facilities that will have common characteristics, current (pretreatment) storage will use a variety of predominantly preexisting facilities that vary greatly in the amounts and types of waste inventories stored, the configurations in which they are stored, and the containment or confinement characteristics of the storage buildings or enclosures.

However, current SARs and DOE site EISs predict consequences for a range of selected waste storage accidents of varying frequency. A brief summary of some of these accidents, assumptions used by the sites in preparing the analyses, and release or health effects-related results are shown in Table F.4–2 and discussed below for information.

Table F.4–2 includes accident results from recent analyses such as the LANL *Preliminary Safety Analysis Report for the Retrieval of Transuranic Waste* (PSAR) (Benchmark, 1994) and the INEL SAR for the Waste Storage Facility (EG&G, 1994b). The LANL PSAR analyzed three credible accidents, including drum spill due to failure during handling, puncture of a crate by a forklift, and breaching of multiple drums in storage due to earthquake-caused toppling from storage arrays. In addition, LANL analyzed one beyond-design-basis accident defined as a single drum fire in the retrieval dome. LANL estimates that only about 0.4% of the drums contain a potential source of hydrogen that could lead to a fire or explosion. LANL neither analyzed a fire in the storage dome nor provided a rationale for not doing so. The source terms for accidents involving multiple containers are evaluated, assuming that the contents of the containers are distributed the same as those of the entire population of containers (average drums). The toppling accident due to an earthquake is assumed to only involve drums stacked on the third level. Furthermore, to

Table F.4-2. Representative Accidents and Source Term Parameters From Recent DOE Safety Analysis Documents Relevant to TRUW Storage

Safety Document	Scenario	DF	ARF or RARF	Release	Consequence
LANL PSAR for Retrieval of TRUW (Benchmark, 1994)	1. Drum spill at retrieval dome	5.0E-01	1.0E-03 to 5.0E-05	8.7E-04 PE-Ci	1.7E-02 rem (MEI)
	2. Forklift puncture of crate in storage dome (4 drums)	5.0E-02	1.0E-03 to 5.0E-05	2.9E-04 PE-Ci	6.8E-03 rem (MEI)
	3. Design-basis earthquake in the storage dome with multiple drum spill (3% of 16,655 drums in the facility spilled)	5.0E-01	1.0E-03 to 5.0E-05	1.2E-02 PE-Ci	2.9E-02 rem (MEI)
	4. Drum fire in the retrieval dome (beyond-design-basis accident)	1.0	5.0E-04	1.5E-01 PE-Ci	1.4 rem (MEI)
INEL SAR for Waste Storage Facility (EG&G, 1994b)	1. Drum fire/explosion (maximum credible design basis accident)	1.0	1.0E-03	1.2E-03 Ci	5.0E-02 rem (MEI)
	2. Box spill (1 box = 15 drums)	1.0E-01	1.0E-04	1.8E-03 Ci	4.2 rem (worker)
	3. Beyond design basis tornado with breach of 1,440 drums and 576 boxes	1.0E-01 (drums) 1.0 (boxes)	1.0E-04	1.2 Ci	9.7E-02 rem (MEI)
SRS Draft EIS (DOE, 1995)	1. Drum rupture and fire	Not available	Not available	Not available	7.2E-04 rem (MEI)
	2. Drum fire in culvert	Not available	Not available	Not available	2.4E-01 rem (MEI)
	3. Fire caused by vehicle crash (28 drums)	Not available	Not available	Not available	4.4E-02 rem (MEI)
	4. Drum deflagration in culvert during drum retrieval	Not available	Not available	Not available	5.7E-02 rem (MEI)
ORNL SAR for Waste Storage Facility, Bldg. 7574 (ORNL, 1994)	1. Earthquake with spill of drums (67% of 1,200 drums breached)	25% (10% of inner packages, if doubly packaged)	8.8E-07 to 1.0E-03	Not available	5.0E-01 rem (MEI)
	2. Fire (12 drums)	1.0 (liquid) 0.5 (solid)	1.1E-01 (liquid) to 5.3E-04 (solid)	Not available	1.0E-01 rem (MEI)

Table F.4-2. Representative Accidents and Source Term Parameters From Recent DOE Safety Analysis Documents Relevant to TRUW Storage-Continued

Safety Document	Scenario	DF[a]	ARF or RARF[b]	Release	Consequence
Hazard Classification and Preliminary Safety Evaluation (PSE) for WRAP Module 2 (WHC, 1991a)	Seismic impacts with fire in incoming storage area (size reduction)	1.0	5.3E-04	2.1E-01 PE-Ci	3.0E-01 rem (MEI)
WRAP PSE (WHC, 1991b)	1. Seismic impacts with fire in shipping and receiving area (19% of 100 drums and 4 boxes)	1.9E-01	5.3E-04	5.9E-01 PE-Ci	Not available
	2. Drum/package spill (2 drums)	0.5 (1st drum) 0.25 (2nd drum)	1.0E-04 (1.0E-07 if filtered)	3.7E-06 PE-Ci	6.0E-03 rem (MEI)
INEL EIS (EG&G, 1994a)	1. Lava flow in TSA (52,000 stored drums and 5.5E+04 m^3 soil covered)	0.25 to 0.75	1.0E-04 to 1.0E-07	2.7 Ci	Not available
	2. Aircraft crash into HFEF WIPP waste (46 drums)	5.0E-01	2.5E-04	1.4E-02Ci	Not available
RWMC SAR (EG&G, 1993b)	1. Earthquake-initiated breach at TSA (65,443 drums)	1.0E-02	1.0E-03	7.4E-01 Ci	1.8E+00 rem (MEI)
	2. Fuel air explosion and fire at TSA	2.01E-01 (explosion) 5.0E-02 (fire)	1.0E-03 (explosion) 5.0E-04 (combustibles) 1.0E-05 (noncombustibles)	1.3E+01 Ci	3.2E+01 rem (MEI)
	3. Medium fire at ASB II caused by propane pipe leak (9,455 drums)	1.0E-02	5.0E-04 (combustibles) 1.0E-05 (noncombustibles)	2.0E-02 Ci	4.8E-02 rem (MEI)
	4. Helicopter crash causing a large fire at ASB II (9,455 drums)	5.0E-02	5.0E-04 (combustibles) 1.0E-05 (noncombustibles)	9.7E-02 Ci	2.3E-01 rem (MEI)
WIPP SEIS-II (DOE, 1996)	1. Container puncture, drop, and lid failure 2. Single 55-gallon drum fire	0.1 (2 drums) 0.25 (3rd drum)	1.0E-07 (based on LPF of 1.0E-03)	3.6E-06 PE-Ci	From 4.0E-06 rem (MEI) at SRS to 5.1E-04 rem (MEI) at ORNL
	3. Beyond-design-basis earthquake with facility collapse	0.5	3.1E-07 (based on LPF of 1.0E-03)	1.2E-05 PE-Ci	From 1.5E-05 rem (MEI) at SRS to 2.3E-03 rem (MEI) at ORNL
		0.25 of total facility inventory	5.0E-05	Site-dependent	From 3.2 rem (MEI) at SRS to 150 rem (MEI) at RFETS

Notes: DF = damage fraction; ARF = airborne release fraction; RARF = respirable airborne release fraction; PE-Ci = Pu-239-equivalent curies; MEI = Maximally exposed individual off site; TSA = TRUW Storage Area; HFEF = Hot Fuel Examination Facility at ANL-W; ASB II = Air Support Building II; LPF = leak path factor. Please refer to Section 5.4.1 of Volume I for guidance in interpreting MEI risks.

determine the number of drums at risk, the number of containers stacked at the third level is reduced by almost 90% due to interferences in the storage dome. Throughout the PSAR, inventories are expressed in terms of Pu-239-equivalent curies (PE-Ci). Consequences to the MEI at the site boundary were as follows: 1.7E-02, 6.8E-03, 2.9E-02, and 1.4 rem for drum spill, forklift puncture in crate, multiple drum spill caused by earthquake, and drum fire, respectively. The drum spill and forklift puncture in the crate were considered to be anticipated accidents with frequencies greater than 1.0E-02/yr. The earthquake accident was considered to be unlikely, with a frequency range between 1.0E-02 and 1.0E-04/yr. The beyond-design-basis drum fire was not considered credible, with a frequency of less than 1..0E-06/yr.

The INEL SAR for the Waste Storage Facility identifies three bounding accidents, including a drum fire and explosion, a box spill, and a tornado causing the breach of a large number of waste containers. An earthquake accident is identified but judged to be bounded by the tornado accident. The average concentration of the drums was 0.16 Ci/ft^3 (total drum activity of 1.176 Ci). However, for the box spill accident, the content is taken to be 10 times higher. It is estimated that 99% of the boxes at INEL are below this value (a box is equivalent to 15 drums in volume). A box spill accident is estimated to have a frequency of 1.2E-01/yr. The drum fire and explosion accident is considered to be the maximum bounding accident within design basis and is estimated to have a frequency of 2.0E-06/yr. The tornado accident is considered to be a beyond-design-basis accident with a frequency of 1.0E-07/yr. The consequence to the MEI at the site boundary for a tornado accident is estimated to be 9.7E-02 rem.

The accidents considered in the DOE Programmatic Spent Nuclear Fuel and INEL Environmental Restoration and Waste Management EIS (EG&G 1994a) involving TRUW were a lava flow over the entire RWMC and an aircraft crash. The molten lava flow caused by a volcanic eruption was determined to be a reasonable foreseeable bounding accident with an estimated frequency of 2.0E-05/yr. Although the RWMC includes waste management operations involving LLMW, LLW, and TRUW, the results shown in Table F.4–2 are for CH-TRUW stored in the Transuranic Storage Area (TSA) inside the inflated Air Support Weather Shield buildings. TRUW at TSA consists of approximately 10,400 m^3 stored in drums (52,000 drums) and 55,000 m^3 of soil-covered waste. The waste is assumed to come into direct contact with the lava. A two-phased release is assumed to take place. In the first phase, the combustible fraction of the waste is assumed to burn with a release fraction similar to a sustained fire. In the second phase, the remaining waste (noncombustible) is assumed to be mixed with the molten lava resulting in a release similar to off-gassing from a vitrification process. The aircraft accident in the INEL EIS assumes that a large commercial jet crashes into the Hot Fuel Examination Facility (HFEF) at ANL-W. This accident is considered to be the bounding externally initiated event because it could cause a major breach of barriers, involve large MAR, and have a high-energy impact followed by fire. The frequency of this accident is estimated to be in the range of 1.0E-06 to 1.0E-08 per year. The waste present in the HFEF includes 20 fresh fuel assemblies, 50 stored subassemblies, and 46 drums of WIPP TRUW. However, the results presented in Table F.4–2 are pertinent to WIPP TRUW only. The number of drums affected by the crash is assumed to be 23 with an ARF of 5.0E-04 and RF of 5.0E-01.

The SRS EIS (DOE, 1995) identifies four representative bounding accidents associated with management of TRUW. These accidents include an internally induced drum rupture and fire, a drum fire in the culvert, a vehicle crash causing a drum fire, and a deflagration event in the culvert during TRUW retrieval activities involving a single drum. The SRS EIS reports consequence results for these accidents but does not include releases and source term parameters such as DFs, ARF, and RARF. All these accidents except the vehicle crash involve a single drum on the basis of the assumption that the other drums are sealed with a gasket and the lids are secured with metal ring clamps, and, therefore, the fire would not propagate to these drums. The internally induced drum rupture and fire is assumed to occur because of overpressurization due to gas buildup from radiolytic decomposition of cellulosic waste and the ignition of the generated hydrogen. The frequency of such an accident is estimated to be 2.1E-02/yr. The drum fire in the culvert is also assumed to be caused by hydrogen gas generated through radiolytic decomposition of organic waste and is estimated to have a frequency of 8.1E-04/yr. The vehicle crash with resulting fire at the TRUW storage pads is assumed to involve 28 drums with an estimated frequency of 6.5E-05/yr. The drum deflagration in the culvert is assumed to be caused by a flammable gas mixture of hydrogen and air that could exist inside a drum as the result of radiolysis of polyethylene wrappings. This accident is estimated to have a frequency of 1.0E-02/yr.

The ORNL SAR for the Waste Storage Facility, Building 7574 (ORNL, 1994) identifies two events as the worst-case bounding accidents: spill of drums caused by earthquake and fire inside the building affecting a stack of drums. Building 7574 at ORNL is used to store TRUW and solid LLW. The waste may contain liquids and powders. Some of the waste may be placed in plastic liners inside the drums. The maximum number of drums that can be stored in the building is 1,200. These drums are stored in an array of four drums per pallet and stacked three pallets high. In the earthquake accident, only 67% of the total number of drums is assumed to be breached (the second and third levels). Twenty-five percent of the drum content is assumed to be spilled. If the waste is placed in a plastic liner, then only 10% is assumed to be spilled. The frequency of an earthquake causing waste containers to fall is considered to be in the range of 1.0E-02 to 1.0E-04 per year. The consequence to an individual at the boundary of the site is estimated to be less than 0.5 rem for this accident. The fire accident inside the building is assumed to affect up to one stack of

12 drums. Liquid waste is considered to be flammable and to burn completely. The remainder of the waste is assumed to be 50% combustible. The frequency of a fire accident is considered to be in the range of 1.0E-02 to 1.0E-04/yr. The consequence from such an accident to the individual at the boundary of the site is estimated to be less than 0.1 rem. Release in terms of curies is not reported in this SAR.

The WRAP facilities, as originally configured, were designed to be constructed as a series of modules including units to process contact handled (Module 1) and remote handled (Module 2) TRUW waste. A subsequent project reconfiguration resulted in redefinition of the module missions such that module 2 would have been intended to handle and treat radioactive mixed waste (as discussed below). A Hazard Classification and Preliminary Safety Evaluation (WHC, 1991a) identified and analyzed a set of accident scenarios to characterize the range of potential hazards for WRAP Module 1 operation. Consistent with DOE guidance on hazard class determination, the range of accidents analyzed included worst case scenarios resulting in completely unmitigated releases. The accident scenarios addressed both waste treatment and packaged waste lag storage and included drum spill, metal box drop and breach, liquid spill from waste pump, drop of a failed HWVP melter, and the most applicable one to the WM PEIS, a design basis earthquake (DBE). The applicable portion of the WRAP 2 scenario is the earthquake-initiated fire in the size reduction area (the Incoming Storage area). A release fraction of 5.3E-04 is assumed for the fire affecting 30 drums in the lag storage area. A maximally exposed offsite individual is estimated to receive a dose of 0.3 rem with an accident frequency of 1.0E-03/yr. No credit is taken in for HEPA filtration.

In a precursor report (WHC, 1991b), the prototype concept of a WRAP facility was analyzed for the effects of a DBE. In the preconceptual design phase, the WRAP I module was scoped to handle and process contact-handled TRUW. The Shipping and Receiving area was scoped to provide lag storage for 100 drums and 4 boxes. The waste packages are damaged by falling girders and portions of the roof. Based on estimates of debris and geometry of the storage array, 19% of the waste packages are estimated to be breached. The resulting fire is assumed to result in a release fraction of 5.3E-04. Aggregate dose consequences were estimated for the total facility release, but no estimates were provided for the contribution from Lag Storage.

The WIPP SEIS-II (DOE, 1996) calculates accidents based on generic radiological airborne source terms that are a function of the accident type only. Site-specific meteorology and population data are applied for six TRUW sites (Hanford, INEL, LANL, RFETS, ORNL, and SRS). Three representative bounding accidents associated with storage of TRUW are identified. These accidents include a drum spill, internally induced drum rupture and fire, and a beyond-design-basis earthquake that results in collapse of the storage facility. The drum spill is assumed to occur due to operator error and would result in puncture of two drums and lid failure for a third drum, each containing 80 plutonium equivalent curies (PE-Ci). It is assumed that 10 percent of the TRUW spills out of the two punctured drums and 25 percent of the waste spills out of the third lidless container. An airborne release fraction of 1.0E–03 is applied in the analyses, with a respirable fraction of 0.1, and credit is taken for HEPA filtration (LPF of 1.0E–03). The frequency of this accident is stated to be 1.0E–02 per year, and negligible offsite impacts are estimated.

The internally induced drum rupture and fire event affects a single drum containing 80 PE-Ci, 50 percent of which is postulated to be consumed by the fire. It is assumed that 5E–04 of the radioactive materials are suspended as respirable particles, and that 60 percent are deposited within the facility prior to release through HEPA filtration (LPF of 1.0E–03). The frequency of this accident is stated to be 1.0E–04 per year, and negligible offsite impacts are estimated.

The earthquake scenario assumes a beyond-design-basis seismic event that results in collapse of the structure onto the waste containers, which breaches 25 percent of the drum inventory. An average of 25 percent of the drum contents are assumed to spill from the breached drums, with a respirable airborne release fraction of 1.0E–04 and 50 percent deposition within the facility prior to release. The amount of material that would be affected by this scenario is site dependent and not reported in this EIS. The estimated maximum annual frequency is stated to be 1.0E–07, with the consequence to the MEI at the site boundary ranging from 3.2 rem at SRS to 150 rem at RFETS. The number of latent cancer fatalities in the offsite population ranged from 6 at ORNL to 200 at Hanford and 300 at RFETS. The high number of fatalities predicted for this accident scenario at RFETS and Hanford may be attributable to very conservative underlying assumptions used in developing the source term.

In reviewing the cited analyses, it was observed that there is considerable variation in the assumptions used by the various DOE sites to develop accidents and associated source term parameters. However, it appears from the analyses that overall, the risks to the public health resulting from storage facility accidents would be small, although the predicted releases are greater than those from LLMW accidents (see Section F.6).

It should be noted that explicitly analyzing risks from storage would not help to discriminate among alternatives because of the assumption used in the WM PEIS for estimating the treatment throughputs that dictate the inventories to be stored before treatment. This assumption is that all sites will accumulate or at least not reduce these inventories for roughly 10 years, at which time complexwide treatment will begin.

Thus, all sites will achieve their maximum inventories (leading to maximum potential releases during a storage facility accident) independent of alternative.

F.4.2.3 Treatment Facility Accidents

Assessments have shown that incineration is the treatment technology most likely to dominate risk to facility and site staff, as well as to the surrounding general populations. Severe radiological accidents investigated herein focus on sequences involving fire and explosions capable of producing large airborne releases of the highly dispersible ash present in storage or in the filtration systems of incinerators.

A generic treatment facility, consisting of a series of linked process modules, each providing a specific treatment process, was defined to assess releases from treatment accidents (see Section F.2.6.3). A DOE Hazard Category of 2 and concomitant structural performance requirements on its systems were assumed. Double HEPA filtration systems were assumed to be in place (see Section F.2.6.3). The inventory was based on the facility throughput at each site. Volumetric inventories and physical and radiological compositions for each waste treatability category were considered at each site for each alternative.

Accidents investigated included operation-induced facility fires and external-event-induced fires and explosions. Treatment facility accident sequences analyzed include:

- A fire in the baghouse area of an incineration facility causing a complete failure of the filtration systems (LPF = 1) with a damage fraction of 3.0E–02 of the total amount of ash existing in the facility available for release (DF = 3.0E–02);
- A rotary kiln explosion caused by combustible gas buildup that affects the ash existing in the rotary kiln (a damage fraction of 1.2E–01 of the total in the facility available for release; DF = 1.2E–01) and partially degrades the filtration system of the facility (LPF = 1.0E–03); and
- External events leading to a fire. External-event source term parameters vary according to the particular sequence.

All accidents are assumed to be ground level releases without filtration with the exception of the rotary kiln explosion accident where a stack emission and partial HEPA filtration is assumed with a remaining efficiency of 99.9% (LPF = 1.0E–03).

F.4.3 RESULTS

Preliminary results for the accident sequences described above were reviewed to determine risk for risk-dominant sequences using the frequency-weighted dose to the MEI. The results were then grouped into four annual frequency categories: likely (>1.0E–02), unlikely (between 1.0E–02 and 1.0E–04), extremely unlikely (between 1.0E–04 and 1.0E–06), and not credible (<1.0E–06). Representative source terms for the important sequences were then selected as the bases for health effects calculations. Of the treatment technologies, only source terms for incineration facility accidents are provided because incineration facility accidents were found to bound other treatment accidents, including wet-air oxidation.

Table F.4–3 gives the WM TRUW facility accidents that were considered for analysis. The cases analyzed are described as follows:

- Case 6 (*Regionalized 2*). Five sites (Hanford, INEL, LANL, RFETS, and SRS) treat CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 8 (*Regionalized 3*). Three sites (Hanford, INEL, and SRS) treat CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 9 (*Centralized*). One site (WIPP) treats CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 15 (*Remote-handled*). Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.

Table F.4–4 summarizes the radiological source terms and frequencies for drum handling accidents at TRUW facilities. Table F.4–5 summarizes the radiological source terms and frequencies for incineration facility accidents. Detailed radionuclide releases are provided in ANL (1996c).

F.5 Low-Level Waste

F.5.1 ALTERNATIVES AND SITES ANALYZED

The LLW WM alternatives in the WM PEIS are summarized in Table F.5–1. Source term results for the alternatives are discussed in the following sections.

Table F.4-3. Summary of WM TRUW Accidents Analyzed[a]

Function	WM PEIS Alternative	Site	Operational Events: Handling Breaches	Operational Events: Facility Fire	Operational Events: Facility Explosion	External Events: Seismic	External Events: Large Aircraft	External Events: Small Aircraft
Drum handling	All	ANL-W	X	--	--	--	--	--
	All	Hanford	X	--	--	--	--	--
	All	INEL	X	--	--	--	--	--
	All	LANL	X	--	--	--	--	--
	All	LLNL	X	--	--	--	--	--
	All	Mound	X	--	--	--	--	--
	All	ORNL	X	--	--	--	--	--
	All	RFETS	X	--	--	--	--	--
	All	SRS	X	--	--	--	--	--
α-Incineration[b]	6	Hanford	--	X	X	X	--	--
	6	INEL	--	X	X	X	--	--
	6	LANL	--	X	X	X	--	--
	6	RFETS	--	X	X	X	--	--
	6	SRS	--	X	X	X	--	--
	8	Hanford	--	X	X	X	--	--
	8	INEL	--	X	X	X	--	--
	8	SRS	--	X	X	X	--	--
	9	WIPP	--	X	X	X	--	--
r-Incineration[c]	15	Hanford	--	X	X	X	--	--
	15	ORNL	--	X	X	X	--	--

Notes: -- = not applicable.

[a] Only one source term, generally corresponding to the risk-dominant sequence for each accident initiator, was considered.

- Case 6 (*Regionalized 2*). Five sites (Hanford, INEL, LANL, RFETS, and SRS) treat CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 8 (*Regionalized 3*). Three sites (Hanford, INEL, and SRS) treat CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 9 (*Centralized*). One site (WIPP) treats CH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.
- Case 15 (*Remote-handled*). Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. Disposal of treated TRUW is at WIPP.

[b] α-incineration refers to incineration of waste categorized as alpha-emitting.

[c] r-incineration refers to incineration of RH waste.

Greater than Class C (GTCC) wastes are a special case as discussed below in this section. The DOE program for GTCC LLW consists of three phases: (1) continuation of limited interim storage of (primarily) sealed sources, (2) provision of an interim centralized dedicated storage facility until an NRC-licensed facility is available, and (3) final disposal in either a HLW repository or a separate NRC-licensed facility. The dedicated and interim storage phases could be merged, depending on commercial reactor decommissioning decisions. Nuclear utility volumes of GTCC will be needed to define phase 2 centralized storage requirements, potential packaging and treatment requirements, and fee specifications. Because the DOE has not yet initiated efforts on an NRC-licensed interim facility, the current program assumes disposal in the HLW repository.

Table F.4-4. Frequencies and Source Term Parameters for WM TRUW Drum Handling Accidents

		Frequency Bin (/yr)				Source Term Parameters			
WM PEIS Alternative	Site	>1.0E-0.2	1.0E-0.4 to 1.0E-0.2	1.0E-0.6 to 1.0E-0.4	<1.0E-0.6	VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	ANL-W	X	--	--	--	2.0E-01	1.2E+00	0.25	2.0E-04
All	Hanford	X	--	--	--	2.0E-01	3.0E+00	0.25	4.2E-04
All	LANL	X	--	--	--	2.0E-01	3.6E+00	0.25	7.9E-04
All	LLNL	X	--	--	--	2.0E-01	4.0E+00	0.25	1.0E-03
All	RFETS	X	--	--	--	2.0E-01	6.1E+00	0.25	1.4E-03
All	SRS	X	--	--	--	2.0E-01	2.2E+01	0.25	2.7E-03

Notes: -- = not applicable

Table F.4-5. Frequencies and Source Term Parameters for WM TRUW Incineration Facility Accidents

Site	Accident	VMAR (m^3)	MAR (Ci)	TRF	Total Release (Ci)	Frequency (/yr)	Frequency Class
Case 6 (Regionalized 2)							
Hanford	Explosion in the rotary kiln	1.9E-01	7.4E+01	8.4E-06	6.2E-04	1.5E-02	I
Hanford	Fire in the baghouse area	1.9E-01	7.4E+01	1.8E-06	1.3E-04	1.0E-03	II
Hanford	Earthquake with fireball blasting HEPA filters	1.9E-01	7.4E+01	4.6E-04	3.4E-02	1.2E-05	III
INEL	Explosion in the rotary kiln	1.0E+00	2.1E+02	8.4E-06	1.8E-03	1.5E-02	I
INEL	Fire in the baghouse area	1.0E+00	2.1E+02	1.8E-06	3.8E-04	1.0E-03	II
INEL	Earthquake with fireball blasting HEPA filters	1.0E+00	2.1E+02	4.6E-04	9.7E-02	1.2E-05	III
LANL	Explosion in the rotary kiln	6.2E-01	2.1E+02	8.4E-06	1.7E-03	1.5E-02	I
LANL	Fire in the baghouse area	6.2E-01	2.1E+02	1.8E-06	3.7E-04	1.0E-03	II
LANL	Earthquake with fireball blasting HEPA filters	6.2E-01	2.1E+02	4.6E-04	9.5E-02	1.2E-05	III
RFETS	Explosion in the rotary kiln	8.8E-02	5.3+01	8.4E-06	4.4E-04	1.5E-02	I
RFETS	Fire in the baghouse area	8.8E-02	5.3+01	1.8E-06	9.5E-05	1.0E-03	II
RFETS	Earthquake with fireball blasting HEPA filters	8.8E-02	5.3+01	4.6E-04	2.4E-02	1.2E-05	III
SRS	Explosion in the rotary kiln	1.6E-02	1.1E+00	8.4E-06	9.2E-06	1.5E-02	I
SRS	Fire in the baghouse area	1.6E-02	1.1E+00	1.8E-06	2.0E-06	1.0E-03	II
SRS	Earthquake with fireball blasting HEPA filters	1.6E-02	1.1E+00	4.6E-04	5.0E-04	1.2E-05	III
Case 8 (Regionalized 3)							
Hanford	Explosion in the rotary kiln	1.9E-01	7.4E+01	8.4E-06	6.2E-04	1.5E-02	I
Hanford	Fire in the baghouse area	1.9E-01	7.4E+01	1.8E-06	1.3E-04	1.0E-03	III
Hanford	Earthquake with fireball blasting HEPA filters	1.9E-01	7.4E+01	4.6E-04	3.4E-02	1.2E-05	II
INEL	Explosion in the rotary kiln	1.7E+00	4.7E+02	8.4E-06	4.0E-03	1.5E-02	I
INEL	Fire in the baghouse area	1.7E+00	4.7E+02	1.8E-06	8.5E-04	1.0E-03	III
INEL	Earthquake with fireball blasting HEPA filters	1.7E+00	4.7E+02	4.6E-04	2.2E-01	1.2E-05	II
SRS	Explosion in the rotary kiln	1.6E-02	1.1E+00	8.4E-06	9.2E-06	1.5E-02	I
SRS	Fire in the baghouse area	1.6E-02	1.1E+00	1.8E-06	2.0E-06	1.0E-03	III
SRS	Earthquake with fireball blasting HEPA filters	1.6E-02	1.1E+00	4.6E-04	5.0E-04	1.2E-05	II
Case 9 (Centralized)							
WIPP	Explosion in the rotary kiln	1.9E+00	5.5E+02	8.4E-06	4.6E-03	1.5E-02	I
WIPP	Fire in the baghouse area	1.9E+00	5.5E+02	1.8E-06	9.9E-04	1.0E-03	II
WIPP	Earthquake with fireball blasting HEPA filters	1.9E+00	5.5E+02	4.6E-04	2.5E-01	1.2E-05	III
Case 15 (Remote-handled)							
Hanford	Explosion in the rotary kiln	4.6E-03	1.7E+00	8.4E-06	1.5E-05	1.5E-02	I
Hanford	Fire in the baghouse area	4.6E-03	1.7E+00	1.8E-06	3.1E-06	1.0E-03	II
Hanford	Earthquake with fireball blasting HEPA filters	4.6E-03	1.7E+00	4.6E-04	8.0E-04	1.2E-05	III
ORNL	Explosion in the rotary kiln	4.2E-02	3.4E+01	8.4E-06	2.8E-04	1.5E-02	I
ORNL	Fire in the baghouse area	4.2E-02	3.4E+01	1.8E-06	6.0E-05	1.0E-03	II
ORNL	Earthquake with fireball blasting HEPA filters	4.2E-02	3.4E+01	4.6E-04	1.5E-02	1.2E-05	III

[a] Frequency categories are defined in Table F.2-2. I = likely, II = unlikely, III = extremely unlikely, and IV = not credible.

Table F.5-1. Low-Level Waste Alternatives

Alternative	Number of Sites		ANL-E	BNL	FEMP	Hanford	INEL	LANL	LLNL	NTS	ORR	PGDP	Pantex	PORTS	RFETS	SNL-NM	SRS	WVDP
	Treat	Dispose																
No Action	10*	6				TD	TD	D	T	D	TD	T			T		TD	
Decentralized		16	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Regionalized 1		12			D	D	D	D	D	D	D	D	D	D	D		D	
Regionalized 2	11	12			TD	TD	TD	TD	TD	D	TD	TD	TD	TD	TD		TD	
Regionalized 3		6				D	D	D		D	D						D	
Regionalized 4	7	6				TD	TD	TD		D	TD			T	T		TD	
Regionalized 5	4	6				TD	TD	D		D	TD						TD	
Regionalized 6		2				D											D	
Regionalized 7		2								D							D	
Centralized 1		1				D												
Centralized 2		1								D								
Centralized 3	7	1				TD	T	T			T			T	T		T	
Centralized 4	7	1				T	T	T		D	T			T	T		T	
Centralized 5	1	1				TD												

Notes: T = treat. "Treat" in the context of LLW means volume reduction using thermal organic destruction, size reduction, and compaction followed by solidification.
All sites would do "minimum treatment," in all alternatives which consists of solidification of liquids and "fines" (powdered material), packaging, and shipment.
D = dispose. Each of the 6-site disposal alternatives uses the 6 same sites; each of the 12-site disposal alternatives uses the same 12 sites. Blanks indicate that a site does not treat or dispose LLW under the specified alternative.
[a] Ten sites use existing facilities for Volume Reduction. Three sites (LBL, RMI, and Mound) not listed as major sites above include volume reduction facilities.

The WM PEIS considers the following alternatives for continued interim storage of sealed sources:

- *No Action.* Continue to store limited quantities of commercial GTCC at Hanford, Fernald Environmental Management Project (FEMP), INEL, LANL, Oak Ridge Reservation (ORR), and SRS in existing and approved storage facilities.
- *Decentralization.* Continue the No Action alternative, and either expand existing or establish new interim storage facilities at DOE sites as may be required for additional limited commercial quantities (for example, in response to an emergency request by the NRC).
- *Regionalization.* Same as decentralization, except ship and store at a limited number of DOE sites (probably between two and five) until an appropriate disposal facility is available.
- *Centralization.* Same as decentralization, except ship and store at one DOE site until an appropriate disposal facility is available.

Current projected volumes of sealed sources are on the order of a few cubic meters and constitute a small fraction of the overall volume of low-level waste. The mix of source compositions that will be received from utilities is uncertain. Independent of the composition mix of sealed sources, the facility accident potential will be small because the source material form is physically and chemically stable, most sources are doubly encapsulated in stainless steel, quantities are relatively small, and the sources will probably be stored in their shipping packages. Because these packages will meet U.S. Department of Transportation (DOT) and NRC requirements, the packages will already be designed to withstand severe accidents.

Because of (1) the overall programmatic uncertainties, (2) the fact that utility waste inventories will undoubtedly dictate future facility accident impacts, and (3) the relatively small contribution of sealed source storage accidents to risk, accident source terms for the continued DOE interim storage of sealed sources were not developed.

F.5.2 Risk-Dominant Accidents and Modeling Considerations

Accident selection has been based on importance to risk, with the general modeling assumptions and related source term parameters described in Section F.2.2. LLW is generally rags, papers, filters, discharged protective clothing, and other materials contaminated with small amounts of radioactivity that are susceptible to fire-initiated events. The general modeling assumptions and related parameters for radiological source terms are detailed in Section F.2.5.1.

The results are based on the underlying assumption that all sites will accumulate, or at least not reduce, waste inventories for at least 10 years, at which time complexwide treatment will begin. Thus, all sites attain their maximum inventory of LLW in about 10 years.

F.5.2.1 Handling Accidents

Storage or staging operations and related handling accidents were investigated because they are expected to dominate the exposure risk to workers due to their frequency and to the proximity of the workers to waste in hands-on operations. Representative handling accidents involve a single drum and assume that 25% of the drum inventory is affected and subject to stresses capable of rendering the contents airborne.

The inventories, physical forms, and radiological compositions of waste stored at each site were characterized in the WM PEIS and stored in a database. However, compilation of detailed information for individual operations and facilities on each site was beyond the scope of the WM PEIS. Accordingly, handling accidents assume a single site-dependent radiological and physical composition derived by volume-weighting the inventories of the treatability categories within each waste type. The composition is based on waste generation and inventory data at each site. Since each site is assumed to store only its own waste, the source terms associated with these handling accidents will not change from one alternative to another.

F.5.2.2 Storage Facility Accidents

Accidents and source terms for current storage were not analyzed explicitly. Unlike treatment, which will predominantly use new facilities that will have common characteristics, current (pretreatment) storage will use a variety of predominantly preexisting facilities that vary greatly in the amounts and types of waste inventories stored, the configurations in which they are stored, and the containment or confinement characteristics of the storage buildings or enclosures. Recent DOE safety reports and NEPA information are cited in Section F.6 to provide guidance on the potential risk impacts applicable to LLMW storage facility accidents. This same information can be used to evaluate the anticipated risks of LLW storage facility accidents. Based on the available information, this risk for LLW storage accidents should be very low.

It should be noted that explicitly analyzing risks from storage would not help to discriminate among alternatives because of the assumption used in the WM PEIS for estimating the treatment throughputs that dictate the inventories to be stored before treatment. This assumption is that all sites will accumulate or at least not reduce these inventories for roughly 10 years, at which time complexwide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases during a storage facility accident) independent of alternative.

F.5.2.3 Treatment Facility Accidents

Evaluations have shown that incineration is the thermal treatment technology most likely to dominate risk to facility and site staff, as well as to the surrounding general populations. Radiological accidents investigated here in are focused on sequences involving fire and explosions capable of producing large airborne releases of the highly dispersible ash present in storage or in the filtration systems of incinerators.

A generic treatment facility, consisting of a series of linked process modules, each providing a specific treatment process, was defined to assess releases from treatment accidents (see Section F.2.6.3). A DOE Hazard Category of 2 and concomitant structural performance requirements on its systems were assumed. Double HEPA filtration systems were assumed to be in place. The inventory was based on the facility throughput at each site. Volumetric inventories and physical and radiological compositions for each waste treatability category were considered at each site for each alternative.

Accidents investigated included operation-induced facility fires and external-event-induced fires and explosions. Treatment facility accident sequences analyzed include:

- A fire in the baghouse area of the incineration facility causing a complete failure of the filtration systems (LPF = 1) with a damage fraction of 3.0E-02 of the total amount of ash existing in the facility at that time (DF = 3.0E-02)
- A rotary kiln explosion caused by combustible gas buildup that affects the ash existing in the rotary kiln (a damage fraction of 1.2E-01 of the total in the facility at the time; DF = 1.2E-01) and partially degrades the filtration system of the facility (LPF = 1.0E-03)
- External events leading to a fire. External-event source term parameters vary according to the sequence

All accidents are assumed to be ground releases without filtration with the exception of the rotary kiln explosion accident where a stack emission and partial HEPA filtration is assumed with a remaining efficiency of 99.9% (LPF = 1.0E-03). This sequence is used to estimate impacts for facility workers.

F.5.2.4 Disposal Facility Accidents

Disposal accidents were not evaluated because of the lack of details of ultimate disposal. However, except for dedicated centralized repositories such as Yucca Mountain or WIPP, disposal sites would generally lack a concentrated volume of material at risk being stored in a configuration susceptible to phenomena such as fires and explosions capable of causing significant releases. These repositories have accident analyses performed as part of their site-specific EISs. Although seismic events could breach in-ground containers, leading to airborne releases, such events would be bounded by accidents breaching the concentrated volumes of waste being held in a treatment or storage facility. The available safety literature does not indicate any credible accident sequence in which the risk from airborne releases in a low-level waste disposal facility would be sufficiently significant to rule out a site from consideration and thereby serve as a discriminator among disposal alternatives.

F.5.3 Results

Preliminary results of the accident sequences described above for various site consolidation cases within each WM PEIS alternative were reviewed for risk dominance using the frequency-weighted dose to the MEI. The results were then grouped into four annual frequency categories: likely (>1.0E-02), unlikely (between 1.0E-02 and 1.0E-04), extremely unlikely (between 1.0E-04 and 1.0E-06), and not credible (<1.0E-06). Representative source terms for the important sequences were then selected as the bases for health effects calculations. Of the thermal treatment technologies, only source terms for incineration facility accidents are provided because they were found to bound other treatment accidents, including potential vitrification facilities. Accident sequences for vitrification facilities result in atmospheric releases much lower than analogous incineration accidents in incineration facilities.

The WM LLW accidents analyzed here are listed in Table F.5-2. Fourteen cases are considered for analysis. Cases 12 (Regionalized 5), 14 (Centralized 3), and 14a (Centralized 4) involve treatment at seven sites with various disposal sites. These cases are equivalent with respect to the risk-dominant treatment technologies and amount of waste throughput at each site; therefore, only Case 12 was analyzed.

The WM PEIS cases analyzed are described as follows:

- *Case 1 (No Action).* All sites treat LLW by using existing, planned, and approved treatment facilities and dispose of LLW at the 6 current disposal sites in accordance with current arrangements. Two sites (INEL and SRS) incinerate.

Table F.5-2. Summary of WM LLW Accidents Analyzed[a]

Function	WM PEIS[b] Alternative Case	Site	Operational Events: Handling Breaches	Operational Events: Facility Fire	Operational Events: Facility Explosion	External Events: Seismic	External Events: Large Aircraft	External Events: Small Aircraft
Drum Handling[c]								
	All	Hanford	X	--	--	--	--	--
	All	INEL	X	--	--	--	--	--
	All	LANL	X	--	--	--	--	--
	All	LLNL	X	--	--	--	--	--
	All	ORR	X	--	--	--	--	--
	All	PGDP	X	--	--	--	--	--
	All	Pantex	X	--	--	--	--	--
	All	PORTS	X	--	--	--	--	--
	All	RFETS	X	--	--	--	--	--
	All	SRS	X	--	--	--	--	--
Incineration	1	INEL	--	X	X	X	X	--
	1	SRS	--	X	X	X	X	--
	9	FEMP	--	X	X	X	--	--
	9	Hanford	--	X	X	X	X	--
	9	INEL	--	X	X	X	X	--
	9	LANL	--	X	X	X	--	--
	9	LLNL	--	X	X	X	--	--
	9	ORR	--	X	X	X	--	--
	9	Pantex	--	--	--	--	--	--
	9	PORTS	--	X	X	X	--	--
	9	PGDP	--	X	X	X	--	X
	9	SRS	--	X	X	X	X	--
α-Incineration[d]	9	RFETS	--	X	X	X	--	X
Incineration	12	Hanford	--	X	X	X	X	--
	12	INEL	--	X	X	X	X	--
	12	LANL	--	X	X	X	--	--
	12	ORR	--	X	X	X	--	--
	12	PORTS	--	X	X	X	--	X
	12	RFETS	--	X	X	X	--	X
	12	SRS	--	X	X	X	X	--
α-Incineration[d]	12	RFETS	--	X	X	X	--	X
Incineration	19	Hanford	--	X	X	X	X	--
	19	INEL	--	X	X	X	X	--
	19	ORR	--	X	X	X	--	--
	19	SRS	--	X	X	X	X	--
α-Incineration[d]	19	INEL	--	X	X	X	X	--
Incineration	21	Hanford	--	X	X	X	X	--
α-Incineration[d]	21	Hanford	--	X	X	X	X	--

Notes: -- = not applicable.

[a] Only one source term, generally corresponding to the risk-dominant sequence for each accident initiator, was considered.

[b] The WM PEIS cases analyzed are described as follows:

- *Case 1 (No Action).* All sites treat LLW by using existing, planned, and approved treatment facilities and dispose of LLW at the 6 current disposal sites in accordance with current arrangements. Two sites (INEL and SRS) incinerate.
- *Case 9 (Regionalized 2).* Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).
- *Case 12 (Regionalized 4).* Seven sites (Hanford, INEL, LANL, ORR, PORTS, RFETS, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 19 (Regionalized 5).* Four sites (Hanford, INEL, ORR, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 21 (Centralized 5).* One site (Hanford) incinerates, supercompacts, reduces the size of, and grouts volume-reducible waste; all sites minimally treat other waste; disposal is at 1 site (Hanford).

[c] The 10 major storage sites were selected for handling accidents; FEMP is not included here because it is an ER site.

[d] α-Incineration refers to incineration of waste categorized as alpha-emitting.

- *Case 9 (Regionalized 2).* Eleven sites (Hanford, INEL, LANL, Oak Ridge Reservation [ORR], SRS, Portsmouth Gaseous Diffusion Plant (PORTS), Paducah Gaseous Diffusion Plant [PGDP], FEMP, Lawrence Livermore National Laboratory [LLNL], Pantex Plant [Pantex], and RFETS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 12 sites (Hanford, INEL, Nevada Test Site [NTS], LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).

- *Case 12 (Regionalized 4).* Seven sites (Hanford, INEL, LANL, ORR, PORTS, RFETS, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 19 (Regionalized 5).* Four sites (Hanford, INEL, ORR, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 21 (Centralized 5).* One site (Hanford) incinerates, supercompacts, reduces the size of, and grouts volume-reducible waste; all sites minimally treat other waste; disposal is at 1 site (Hanford).

Tables F.5–3 and F.5–4 summarize the radiological source term parameters and frequency bins assigned for each of the accidents. Separate incineration facilities were assumed for treating alpha- and nonalpha-contaminated waste. Detailed radionuclide releases are provided in ANL (1996a).

F.6 Low-Level Mixed Waste

F.6.1 Alternatives and Sites Analyzed

The LLMW WM alternatives in the WM PEIS are summarized in Table F.6–1. Calculational source term results are discussed herein for the identified sites.

One of the assumptions underlying the analysis is that the site will continue to accumulate or at least not reduce inventories of LLMW for about 10 years, at which time complexwide treatment will begin. Thus, all sites will achieve their maximum inventory in about 10 years.

F.6.2 Risk-Dominant Accidents and Modeling Considerations

The selection of accidents considers the importance to risk of both radiological and chemical hazards. The general modeling assumptions and related parameters for radiological source terms are detailed in Section F.2.5.1. Review of the hazardous contents of the wastes and their concentrations suggests that spills of organic liquids (WM PEIS treatment codes [TCs] 3 through 6), followed by evaporation or combustion reactions (or both), are the events most likely to lead to the airborne release of chemically hazardous

Table F.5-3. Frequencies and Source Term Parameters for WM LLW Drum Handling Accidents

		Frequency Bin (/yr)				Source Term Parameters			
WM PEIS Alternative	Site	>1.0E-02	1.0E-04 to 1.0E-02	1.0E-06 to 1.0E-04	<1.0E-6	VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	Hanford	X	--	--	--	2.0E-01	3.0E-01	0.25	4.3E-04
All	INEL	X	--	--	--	2.0E-01	2.1E-01	0.25	5.3E-05
All	LANL	X	--	--	--	2.0E-01	1.5E+00	0.25	2.1E+00*
All	LLNL	X	--	--	--	2.0E-01	2.1E+00	0.25	5.2E+00*
All	ORR	X	--	--	--	2.0E-01	7.1E-01	0.25	1.9E-03*
All	PGDP	X	--	--	--	2.0E-01	6.0E-05	0.25	1.8E-08
All	Pantex	X	--	--	--	2.0E-01	7.1E-05	0.25	1.7E-05*
All	PORTS	X	--	--	--	2.0E-01	2.8E-06	0.25	6.4E-09
All	RFETS	X	--	--	--	2.0E-01	1.1E-03	0.25	1.2E-06
All	SRS	X	--	--	--	2.0E-01	6.1E-01	0.25	4.8E-02*

Notes: -- = not applicable; * = mainly H-3 released.

Table F.5–4. Frequencies and Source Term Parameters for WM LLW Incineration Facility Accidents

WM PEIS Alternative[a]	Site	Accident	Frequency Bin (/yr) > 1.0E-02	1.0E-04 - 1.0E-02	1.0E-06 - 1.0E-04	< 1.0E-06	Source Term Parameters VMAR (m³)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
1	INEL	Explosion in the rotary kiln	X	–	–	–	4.3E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
1	INEL	Fire in the baghouse area	–	X	–	–	4.3E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
1	INEL	Earthquake followed by fire and explosion	–	–	X	–	4.3E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
1	INEL	Large aircraft impact with fire and explosion	–	–	–	X	4.3E-01	1.5E-01	3.0E-01	1.0E-01	1.0E-00	4.6E-03
1	SRS	Explosion in the rotary kiln	X	–	–	–	3.6E-01	1.1E+00	1.2E-01	1.0E-01	1.0E-03	1.3E-05
1	SRS	Fire in the baghouse area	–	X	–	–	3.6E-01	1.1E+00	3.0E-02	1.0E-02	1.0E-00	3.3E-04
1	SRS	Earthquake followed by fire and explosion	–	–	X	–	3.6E-01	1.1E+00	2.0E-01	1.0E-01	1.0E-00	2.2E-02
1	SRS	Large aircraft impact with fire and explosion	–	–	–	X	3.6E-01	1.1E+00	3.0E-01	1.0E-01	1.0E-00	3.3E-02
9	FEMP	Explosion in the rotary kiln	X	–	–	–	1.9E-01	2.8E-05	1.2E-01	1.0E-01	1.0E-03	3.3E-10
9	FEMP	Fire in the baghouse area	–	X	–	–	1.9E-01	2.8E-05	3.0E-02	1.0E-02	1.0E-00	8.3E-09
9	FEMP	Earthquake followed by fire and explosion	–	–	X	–	1.9E-01	2.8E-05	2.0E-01	1.0E-01	1.0E-00	5.6E-07
9	Hanford	Explosion in the rotary kiln	X	–	–	–	9.7E-04	5.3E-02	1.2E-01	1.0E-01	1.0E-03	6.3E-07
9	Hanford	Fire in the baghouse area	–	X	–	–	9.7E-04	5.3E-02	3.0E-02	1.0E-02	1.0E-00	1.6E-05
9	Hanford	Earthquake followed by fire and explosion	–	–	X	–	9.7E-04	5.3E-02	2.0E-01	1.0E-01	1.0E-00	1.1E-03
9	Hanford	Large aircraft impact with fire and explosion	–	–	–	X	9.7E-04	5.3E-02	3.0E-01	1.0E-01	1.0E-00	1.6E-03
9	INEL	Explosion in the rotary kiln	X	–	–	–	4.3E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
9	INEL	Fire in the baghouse area	–	X	–	–	4.3E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
9	INEL	Earthquake followed by fire and explosion	–	–	X	–	4.3E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
9	INEL	Large aircraft impact with fire and explosion	–	–	–	X	4.3E-01	1.5E-01	3.0E-01	1.0E-01	1.0E-00	4.6E-05
9	LANL	Explosion in the rotary kiln	X	–	–	–	1.4E+00	9.6E+00	1.2E-01	1.0E-01	1.0E-03	1.2E-04
9	LANL	Fire in the baghouse area	–	X	–	–	1.4E+00	9.6E+00	3.0E-02	1.0E-02	1.0E-00	2.9E-03
9	LANL	Earthquake followed by fire and explosion	–	–	X	–	1.4E+00	9.6E+00	2.0E-01	1.0E-01	1.0E-00	1.9E-01
9	LLNL	Explosion in the rotary kiln	X	–	–	–	6.9E-03	9.8E-01	1.2E-01	1.0E-01	1.0E-03	1.2E-05
9	LLNL	Fire in the baghouse area	–	X	–	–	6.9E-03	9.8E-01	3.0E-02	1.0E-02	1.0E-00	2.9E-04
9	LLNL	Earthquake followed by fire and explosion	–	–	X	–	6.9E-03	9.8E-01	2.0E-01	1.0E-01	1.0E-00	2.0E-02
9	ORR	Explosion in the rotary kiln	X	–	–	–	1.5E+00	1.1E-01	1.2E-01	7.0E-02	1.0E-03	9.4E-07
9	ORR	Fire in the baghouse area	–	X	–	–	1.5E+00	1.1E-01	3.0E-02	6.0E-05	1.0E-00	2.0E-07
9	ORR	Earthquake followed by fire and explosion	–	–	X	–	1.5E+00	1.1E-01	2.0E-01	7.0E-05	1.0E-00	1.6E-03
9	PORTS	Explosion in the rotary kiln	X	–	–	–	3.5E-01	1.8E-04	1.2E-01	1.0E-01	1.0E-03	2.1E-09
9	PORTS	Fire in the baghouse area	–	X	–	–	3.5E-01	1.8E-04	3.0E-02	1.0E-02	1.0E-00	5.3E-08
9	PORTS	Earthquake followed by fire and explosion	–	–	X	–	3.5E-01	1.8E-04	2.0E-01	1.0E-01	1.0E-00	3.5E-06
9	PGDP	Explosion in the rotary kiln	X	–	–	–	1.3E-01	1.5E-03	1.2E-01	1.0E-01	1.0E-03	1.8E-08
9	PGDP	Fire in the baghouse area	–	X	–	–	1.3E-01	1.5E-03	3.0E-02	1.0E-02	1.0E-00	4.6E-07
9	PGDP	Earthquake followed by fire and explosion	–	–	X	–	1.3E-01	1.5E-03	2.0E-01	1.0E-01	1.0E-00	3.0E-05
9	PGDP	Small aircraft impact with fire and explosion	–	–	–	X	1.3E-01	1.5E-03	5.0E-02	1.0E-01	1.0E-00	7.6E-06
9α[c]	RFETS	Explosion in the rotary kiln	X	–	–	–	7.0E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
9α	RFETS	Fire in the baghouse area	–	X	–	–	7.0E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
9α	RFETS	Earthquake followed by fire and explosion	–	–	X	–	7.0E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
9α	RFETS	Small aircraft impact with fire and explosion	–	–	–	X	7.0E-01	1.5E-01	5.0E-02	1.0E-01	1.0E-00	7.7E-04

Table F.5-4. Frequencies and Source Term Parameters for WM LLW Incineration Facility Accidents—Continued

WM PEIS Alternative[a]	Site	Accident	Frequency Bin (/yr) >1.0E-02	1.0E-04 - 1.0E-02	1.0E-06 - 1.0E-04	<1.0E-06	Source Term Parameters VMAR (m³)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
9	SRS	Explosion in the rotary kiln	X	--	--	--	3.6E-01	1.1E+00	1.2E-01	1.0E-01	1.0E-03	1.3E-05
9	SRS	Fire in the baghouse area	--	X	--	--	3.6E-01	1.1E+00	3.0E-02	1.0E-02	1.0E-00	3.3E-04
9	SRS	Earthquake followed by fire and explosion	--	--	X	--	3.6E-01	1.1E+00	2.0E-01	1.0E-01	1.0E-00	2.2E-02
9	SRS	Large aircraft impact with fire and explosion	--	--	--	X	3.6E-01	1.1E+00	3.0E-01	1.0E-01	1.0E-00	3.3E-02
12	Hanford	Explosion in the rotary kiln	X	--	--	--	7.8E-03	1.0E+00	1.2E-01	1.0E-01	1.0E-03	1.2E-05
12	Hanford	Fire in the baghouse area	--	X	--	--	7.8E-03	1.0E+00	3.0E-02	1.0E-02	1.0E+00	3.1E-04
12	Hanford	Earthquake followed by fire and explosion	--	--	X	--	7.8E-03	1.0E+00	2.0E-01	1.0E-01	1.0E+00	2.1E-02
12	Hanford	Large aircraft impact with fire and explosion	--	--	--	X	7.8E-03	1.0E+00	3.0E-01	1.0E-01	1.0E+00	3.1E-02
12	INEL	Explosion in the rotary kiln	X	--	--	--	4.3E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
12	INEL	Fire in the baghouse area	--	X	--	--	4.3E-01	1.5E-01	3.0E-02	1.0E-02	1.0E+00	4.6E-05
12	INEL	Earthquake followed by fire and explosion	--	--	X	--	4.3E-01	1.5E-01	2.0E-01	1.0E-01	1.0E+00	3.1E-03
12	INEL	Large aircraft impact with fire and explosion	--	--	--	X	4.3E-01	1.5E-01	3.0E-01	1.0E-01	1.0E+00	4.6E-03
12	LANL	Explosion in the rotary kiln	X	--	--	--	1.4E+00	9.6E+00	1.2E-01	1.0E-01	1.0E-03	1.2E-04
12	LANL	Fire in the baghouse area	--	X	--	--	1.4E+00	9.6E+00	3.0E-02	1.0E-02	1.0E+00	2.9E-03
12	LANL	Earthquake followed by fire and explosion	--	--	X	--	1.4E+00	9.6E+00	2.0E-01	1.0E-01	1.0E+00	1.9E-01
12	ORR	Explosion in the rotary kiln	X	--	--	--	1.5E+00	1.1E-01	1.2E-01	7.0E-02	1.0E-03	9.4E-07
12	ORR	Fire in the baghouse area	--	X	--	--	1.5E+00	1.1E-01	3.0E-02	6.0E-05	1.0E+00	2.0E-07
12	ORR	Earthquake followed by fire and explosion	--	--	X	--	1.5E+00	1.1E-01	2.0E-01	7.0E-02	1.0E+00	1.6E-03
12	PORTS	Explosion in the rotary kiln	X	--	--	--	2.3E-01	3.2E-05	1.2E-01	1.0E-01	1.0E-03	3.9E-10
12	PORTS	Fire in the baghouse area	--	X	--	--	2.3E-01	3.2E-05	3.0E-02	1.0E-02	1.0E+00	9.6E-09
12	PORTS	Earthquake followed by fire and explosion	--	--	X	--	2.3E-01	3.2E-05	2.0E-01	1.0E-01	1.0E+00	6.4E-07
12	PORTS	Small aircraft impact with fire and explosion	--	--	--	X	2.3E-01	3.2E-05	5.0E-02	1.0E-01	1.0E+00	1.6E-07
12	RFETS	Explosion in the rotary kiln	X	--	--	--	1.0E-03	2.2E-04	1.2E-01	1.0E-01	1.0E-03	2.6E-09
12	RFETS	Fire in the baghouse area	--	X	--	--	1.0E-03	2.2E-04	3.0E-02	1.0E-02	1.0E+00	6.6E-08
12	RFETS	Earthquake followed by fire and explosion	--	--	X	--	1.0E-03	2.2E-04	2.0E-01	1.0E-01	1.0E+00	4.4E-06
12	RFETS	Small aircraft impact with fire and explosion	--	--	--	X	1.0E-03	2.2E-04	5.0E-02	1.0E-01	1.0E+00	1.1E-06
12	SRS	Explosion in the rotary kiln	X	--	--	--	3.6E-01	1.1E+00	1.2E-01	1.0E-01	1.0E-03	1.3E-05
12	SRS	Fire in the baghouse area	--	X	--	--	3.6E-01	1.1E+00	3.0E-02	1.0E-02	1.0E+00	3.3E-04
12	SRS	Earthquake followed by fire and explosion	--	--	X	--	3.6E-01	1.1E+00	2.0E-01	1.0E-01	1.0E+00	2.2E-02
12	SRS	Large aircraft impact with fire and explosion	--	--	--	X	3.6E-01	1.1E+00	3.0E-01	1.0E-01	1.0E+00	3.3E-02
12α	RFETS	Explosion in the rotary kiln	X	--	--	--	7.0E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
12α	RFETS	Fire in the baghouse area	--	X	--	--	7.0E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
12α	RFETS	Earthquake followed by fire and explosion	--	--	X	--	7.0E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
12α	RFETS	Small aircraft impact with fire and explosion	--	--	--	X	7.0E-01	1.5E-01	5.0E-02	1.0E-01	1.0E+00	7.7E-04
19	Hanford	Explosion in the rotary kiln	X	--	--	--	7.8E-03	1.0E+00	1.2E-01	1.0E-01	1.0E-03	1.2E-05
19	Hanford	Fire in the baghouse area	--	X	--	--	7.8E-03	1.0E+00	3.0E-02	1.0E-02	1.0E-00	3.1E-04
19	Hanford	Earthquake followed by fire and explosion	--	--	X	--	7.8E-03	1.0E+00	2.0E-01	1.0E-01	1.0E-00	2.1E-02
19	Hanford	Large aircraft impact with fire and explosion	--	--	--	X	7.8E-03	1.0E+00	3.0E-01	1.0E-01	1.0E-00	3.1E-02

Table F.5–4. Frequencies and Source Term Parameters for WM LLW Incineration Facility Accidents—Continued

WM PEIS Alternative[a]	Site	Accident	Frequency Bin (/yr) >1.0E-02	1.0E-04 - 1.0E-02	1.0E-06 - 1.0E-04	<1.0E-06	Source Term Parameters VMAR (m³)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
19	INEL	Explosion in the rotary kiln	X	–	–	–	1.8E+00	9.8E+00	1.2E-01	1.0E-01	1.0E-03	1.2E-04
19	INEL	Fire in the baghouse area	–	X	–	–	1.8E+00	9.8E+00	3.0E-02	1.0E-02	1.0E-00	2.9E-01
19	INEL	Earthquake followed by fire and explosion	–	–	X	–	1.8E+00	9.8E+00	2.0E-01	1.0E-01	1.0E-00	2.0E-01
19	INEL	Large aircraft impact with fire and explosion	–	–	–	X	1.8E+00	9.8E+00	3.0E-01	1.0E-01	1.0E-00	2.9E-01
19α	INEL	Explosion in the rotary kiln	X	–	–	–	7.0E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
19α	INEL	Fire in the baghouse area	–	X	–	–	7.0E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
19α	INEL	Earthquake followed by fire and explosion	–	–	X	–	7.0E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
19α	INEL	Large aircraft impact with fire and explosion	–	–	–	X	7.0E-01	1.5E-01	3.0E-01	1.0E-01	1.0E-00	4.6E-05
19	ORR	Explosion in the rotary kiln	X	–	–	–	1.7E+00	4.9E-01	1.2E-01	7.0E-02	1.0E-03	4.1E-06
19	ORR	Fire in the baghouse area	–	X	–	–	1.7E+00	4.9E-01	3.0E-02	6.0E-05	1.0E-00	8.8E-07
19	ORR	Earthquake followed by fire and explosion	–	–	X	–	1.7E+00	4.9E-01	2.0E-01	7.0E-02	1.0E-00	6.9E-03
19	SRS	Explosion in the rotary kiln	X	–	–	–	3.6E-01	1.1E+00	1.2E-01	1.0E-01	1.0E-03	1.3E-05
19	SRS	Fire in the baghouse area	–	X	–	–	3.6E-01	1.1E+00	3.0E-02	1.0E-02	1.0E-00	3.3E-04
19	SRS	Earthquake followed by fire and explosion	–	–	X	–	3.6E-01	1.1E+00	2.0E-01	1.0E-01	1.0E-00	2.2E-02
19	SRS	Large aircraft impact with fire and explosion	–	–	–	X	3.6E-01	1.1E+00	3.0E-01	1.0E-01	1.0E-00	3.3E-02
21	Hanford	Fire in the baghouse area	–	X	–	–	2.9E+00	1.2E+01	3.0E-02	1.0E-02	1.0E-00	3.6E-03
21	Hanford	Earthquake followed by fire and explosion	–	–	X	–	2.9E+00	1.2E+01	2.0E-01	1.0E-01	1.0E-00	2.4E-01
21	Hanford	Large aircraft impact with fire and explosion	–	–	–	X	2.9E+00	1.2E+01	3.0E-01	1.0E-01	1.0E-00	3.6E-01
21α	Hanford	Explosion in the rotary kiln	X	–	–	–	7.0E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
21α	Hanford	Fire in the baghouse area	–	X	–	–	7.0E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
21α	Hanford	Earthquake followed by fire and explosion	–	–	X	–	7.0E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
21α	Hanford	Large aircraft impact with fire and explosion	–	–	–	X	7.0E-01	1.5E-01	3.0E-01	1.0E-01	1.0E-00	4.6E-03

Notes: – = not applicable.

[a] The WM PEIS cases analyzed are described as follows:

- *Case 1 (No Action).* All sites treat LLW by using existing, planned, and approved treatment facilities and dispose of LLW at the 6 current disposal sites in accordance with current arrangements. Two sites (INEL and SRS) incinerate.
- *Case 9 (Regionalized 2).* Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).
- *Case 12 (Regionalized 4).* Seven sites (Hanford, INEL, LANL, ORR, PORTS, RFETS, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 19 (Regionalized 5).* Four sites (Hanford, INEL, ORR, and SRS) incinerate, supercompact, reduce the size of, and grout volume-reducible waste; all sites minimally treat other waste; disposal is at 6 sites (Hanford, INEL, NTS, LANL, ORR, and SRS).
- *Case 21 (Centralized 5).* One site (Hanford) incinerates, supercompacts, reduces the size of, and grouts volume-reducible waste; all sites minimally treat other waste; disposal is at 1 site (Hanford).

[b] Values shown are for particulate (nonvolatile) solids such as U-235 or Pu-238; see Appendix D.

[c] α refers to treatment of waste categorized as alpha-emitting.

Table F.6–1. Low-Level Mixed Waste Alternatives

Alternative	Number of Sites		ANL-E	BNL	FEMP	Hanford	INEL	LANL	LLNL	NTS	ORR	PGDP	Pantex	PORTS	RFETS	SNL-NM	SRS	WVDP
	CH Non-Alpha Treat	Dispose																
No Action	3	0	S	S	S	S	TS	S	S	S	TS	S	S	S	S	S	TS	S
Decentralized	37	16	TD	TD	TD	TD	TD∝	TD∝	TD∝	D∝	TD	TD	TD	TD	TD∝	TD	TD∝	TD
Regionalized 1	11	12			TD	TD	TD∝	TD∝	TD∝	D∝	TD	TD	TD	TD	TD∝		TD∝	
Regionalized 2	7	6				TD	TD∝	TD∝		D∝	TD			T	T∝		TD∝	
Regionalized 3	7	1				T	T∝			D∝	T			T	T∝		T∝	
Regionalized 4	4	6				TD	TD∝	D∝		D∝	TD						TD∝	
Centralized	1	1				TD∝												

Notes: T = treatment to meet land disposal restrictions; D = disposal; S = indefinite storage. Blanks indicate that no treatment, storage, or disposal takes place at a site under the specified alternative. All sites have wastewater treatment capability as needed. Blanks indicate that a site does not treat, store, or dispose of LLMW under the specified alternative.

[a] The actions shown are for contact-handled wastes. Remote-handled (RH) wastes would be treated and disposed onsite at the Hanford Site, INEL, ORR, and SRS in all alternatives except No Action. RH waste would be stored under No Action.

[b] Facilities with the ∝ symbol treat or dispose of both contact-handled alpha and non-alpha waste.

substances. The possibility of fires is strongest in the waste streams containing a large fraction of combustible organic substances. Table F.6–2 summarizes the chemical release characteristics developed for the accidents (ANL, 1996a).

F.6.2.1 Handling Accidents

Handling accidents during the staging and storage of CH waste are expected to dominate the risk of exposure for workers because of the high frequency of such accidents and the proximity of the workers during hands-on operations. The frequencies of accidents at a given site would be a strong function of waste

Table F.6–2. Chemical Releases Analyzed for LLMW

Scenario	Toxic Gases Released	Mass of Waste	Release Rate
Spill of aqueous nonhalogenated organic liquids (TC 4)	Acetone; butanone; methanol	160 lb/drum	2-3 lb/min[a]
Spill of aqueous halogenated organic liquid (TC 3)	Trichloroethanes; other chlorohydrocarbons	6 lb/drum	0.1 lb/min
Spill of "pure" halogenated organic liquids (TC 5)	Trichloroethanes Tetrachloroethanes	50 lb/drum 10 lb/drum	0.5 lb/min 0.1 lb/min
Spill of "pure" nonhalogenated organic liquids (TC 6)	Acetone; butanone; methanol BTX	60 lb/drum 200 lb/drum	1 lb/min[a] 2 lb/min[a]
Spill of "pure" nonhalogenated organic liquids (TC 6) followed by fire	BTX CO Cd fumes Cr compounds Soot	10 lb/drum 200 lb/drum 0.5 lb/drum 0.5-1.0 lb/drum 80 lb/drum	0.3 lb/min 7 lb/min 0.02 lb/min 0.02 lb/min 2.7 lb/min
Incinerator staging area fire involvement of TC 12 (organic sludges), 19 (combustible debris), organic liquid (intermediate), and organic particulates (intermediate)	CO HCl	40–50% of mass of drum 60% of mass of Cl-containing compounds in the stream	7 lb/min/drum 2 lb/min/drum
	BTX fumes Soot Cd fumes (condensing to very small particles) Cr compounds	5% of mass of BTX present 40% of mass of BTX plus 10% of total mass 100% of mass of Cd present 250% of mass of Cr present	0.3 lb/min/drum 3 lb/min/drum 0.02 lb/min/drum 0.02 lb/min/drum

Notes: BTX = benzene, toluene, and xylene; Cd = cadmium; Cr = chromium.
[a] An approximation to this release rate can be estimated from Salazar and Lane (1992):

$$QR = \frac{0.106\,\mu^{0.78}\,(MW)^{0.667}\,(A)\,VP}{R\,(t + 273)},$$

where

QR = release rate lb/min,
MW = molecular weight (g/mol),
A = surface area (ft^2),
VP = effective vapor pressure (mm Hg),
R = 82.05 atm cm^3/mol K,
t = temperature (°C), and
μ = wind speed (m/s).

The assumed options are that t = 30 °C, A = 220 ft^2, and wind speed = 2 m/s. For acetone TC 4, MW = 58 g/mol, and $VP = 0.36 \times 285$ mm Hg. For acetone in TC 6, $VP = 0.14 \times 285$ mm Hg. For benzene in TC 6, MW = 78 g/mol, and $VP = 0.44 \times 120$ mm Hg.

throughput at that site. The assumption used (see Section F.2.7.1) is that two severe breaches of containment occur per year for each 10,000 drums handled. It is assumed for the results herein that handling breaches fall in the >0.01/yr frequency category.

In determining radiological source terms for representative radiological accident scenarios, it is assumed that a single drum is affected, such that 25% of its contents are released (DF = 2.5E-01). The composition of the representative drum is taken as a volume-weighted average of the treatability category compositions (excluding aqueous streams) at each site.

Representative chemical releases assume a single drum with 100% (DF = 1.0E+00) of its contents spilled. The release characteristics for spills are described in the report by ANL (1996a).

F.6.2.2 Storage Facility Accidents

Accidents and source terms for current storage were not analyzed explicitly. Unlike treatment, which will predominantly use new facilities that will have common characteristics, current (pretreatment) storage will use a variety of predominantly preexisting facilities that vary greatly in the amounts and types of waste inventories stored, the configurations in which they are stored, and the containment or confinement characteristics of the storage buildings or enclosures. However, because recent DOE safety or NEPA information on storage facility accidents provides guidance on the potential risk impacts applicable to storage, this information is discussed herewith.

Current SARs predict consequences for a range of selected waste storage accidents of varying frequency. Sometimes these accidents involve facilities which store primarily LLMW. A brief summary of some of these accidents involving LLMW, assumptions used by the sites in preparing the analyses, and release or health effect results are shown in Table F.6-3.

The INEL SAR for the RWMC identifies three bounding accidents involving LLMW. All of these accidents occur at or involve in some manner the Air Support Building II (ASB-II), the facility which stores most of the LLMW at INEL. An accident with fire was identified as occurring at ASB-II. It is caused by a propane leak in the fuel line supplying the heat and inflation unit within the facility. This accident would involve only the waste stored at ASB-II and results in an exposure of 2.0E-02 rem (MEI). A second accident analyzed was initiated by an earthquake, sufficiently severe to damage all of the buildings (ASB-II included) at the RWMC. The radiological release and consequences listed in Table F.6–3 for this accident (i.e., 0.041 Ci and 0.75 rem) are due primarily to wastes stored in buildings other than ASB-II. The third accident, a fuel-air explosion originating in ASB-II, has the potential to release hazardous materials due primarily to the explosion and subsequent fire. However, a similar fuel-air explosion originating in the Certified and Segregated (C&S) Facility with the subsequent fire impacting all TSA facilities at the RWMC will bound the consequences of the fuel-air explosion originating at ASB-II. Because of this bounding condition the consequence analysis for the ASB-II accident was not performed. Table F.6–3 lists the parameters and results for the similar C&S bounding accident.

The RFETS SAR for the Central Waste Storage Facility (Building 906) identifies three accidents associated with LLMW. Each of these accidents assumes 8,300 drums of waste as the material at risk with each drum filled with waste to 50% of total volume. The void space is assumed to contain dust (at 100 mg/m^3) which is vented to the air upon breaching of the drum. Other variables of each accident type are given in Table F.6–3.

The PSE conducted for WRAP (Module 2) at Hanford identifies a bounding accident scenario which is an earthquake, including waste spills and fire. This event leads to a release of 0.041 Ci with a consequence of 3.9E-05 rem (MEI) with an accident frequency of 1.0E-03/yr (see Table F.6–3).

The International Technology Corporation (IT) has calculated the risks associated with the treatment, storage, and disposal of many types of LLMW. They have looked at many kinds of accidents related to the treatment, storage, and handling of these wastes. An example of a storage accident scenario is a fire within a container in the storage facility that might cause waste particulates to resuspend and be inhaled by workers. Members of the public might also be exposed to airborne effluents if building ventilation fails. IT Corporation has used a system analysis methodology to accumulate risk across different management options rather than breaking out the consequences and contaminant releases associated with a particular accident as the SARs usually do. This different approach to the problem has made comparison difficult with the more conventional approach of calculating the consequences of each separate accident. In general, IT has tended to look at sets of accidents of relatively high frequency with low consequences rather than the more standard approach of surveying accidents of lower frequency but with higher consequences (EG&G, 1993a).

Table F.6-3. Representative Accidents and Source Term Parameters From Recent DOE Safety Analysis Documents Relevant to LLMW

Safety Document	Scenario	DF	ARF or RARF	Release (Ci)	Consequence (MEI-rem)
RWMC SAR (EG&G, 1993b)	1. Propane line leak at ASB II Medium fire	1.0E-02	5.0E-04 (combustible) 1.0E-02 (noncombustible)	2.0E-02	2.0E-02
	2. Earthquake initiating breach in CH LLW pit and involving ASB II	1.0E-03	1.0E-03	4.1E-02	7.5E-01
	3. Fuel air explosion in ASB II, bounded by same type event in C&S Facility	2.0E-01	1.0E-03 (numbers for a C&S event)	1.3E+01	3.2
Building 906 SAR Central Waste Storage Facility					
(RFETS, 1994)	1. Earthquake and spill (collapsed building) Void space volume of 8,300 drums (MAR) (assume drum ½ full)	1.0	1.0	3.37E-05 g Pu-239	2E-06
	2. Spill from impacts 100% void space vented (8,300 drums)	1.0	1.0	100 mg/m^3 particulate loading in void space	NA[c]
	3. Fire ruptures all exposed containers	100% burn of combustibles 18% ablation of noncombustibles	5.0E-04 particulate 1.0E-05 metals 1.0 liquids	Varies with assumptions about fire	NA[c]
Hazard Classification and Preliminary Safety Evaluation (PSE) for WRAP Module 2 (WHC, 1991a)	1. Earthquake and spill of dry waste and fire	1.0	5.3E-04	4.1E-02	3.9E-05

Notes: DF = damage fraction; ARF = airborne release fraction; RARF = respirable airborne release fraction; MEI = maximally exposed individual offsite; C&S = Certified and Segregated Facility; NA = not available. Please refer to Section 5.4.1 of Volume I for guidance in interpreting MEI risks.

In reviewing the cited analyses, it was observed that there is considerable variation in the assumptions used by the various DOE sites to develop accidents and estimate associated source term parameters. However, it appears from the analyses that overall, the risks to the public health resulting from LLMW storage facility accidents would be small.

It should be noted that explicitly analyzing risks from storage would not help to discriminate among alternatives because of the assumption used in the WM PEIS for estimating the treatment throughputs that dictate the inventories to be stored before treatment. This assumption is that all sites will accumulate or at least not reduce these inventories for roughly 10 years, at which time complexwide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases during a storage facility accident) independent of alternative.

F.6.2.3 Treatment Facility Accidents

Evaluations have shown that incineration is the thermal treatment technology most likely to be important to risk for facility workers and the public. Radiological accident sequences involve severe fires and explosions that produce large airborne releases of the ash present in the incinerator area or in the filtration systems. A generic treatment facility, consisting of a series of linked treatment process modules, is described in Section F.2.6.3. A DOE Hazard Category of 2, concomitant system performance requirements, and double HEPA filtration systems were assumed. For each alternative, each waste treatability category at each site has a unique volumetric inventory and physical, chemical and radiological composition. Each incineration facility was assumed to have 1% of its annual incinerable LLMW throughput at the time of the accident.

Accidents investigated included operation-induced facility fires and explosions, and external-event-induced fires and explosions. Treatment facility accident sequences analyzed include:

- A fire in the baghouse area of the incineration facility dispersing the dry ash in the filters with a damage of 3% of the facility inventory (DF = 3.0E-02) and failing the filtration systems completely (LPF = 1),
- An incinerator explosion resulting from combustible gas buildup that disperses the ash in the rotary kiln with a damage of 12% of facility inventory (DF = 1.2E-01) and partially degrades the filtration system (LPF = 1.0E-03), and
- External events leading to a fire. External-event source term parameters vary according to the particular sequence.

All accidents are assumed to be ground releases without filtration, with the exception of the incinerator explosion where partial HEPA filtration and a stack emission are assumed. The LPF of 1.0E-03 results in the source term that produces the greater worker risk.

Wet-air oxidation was also analyzed because of the high treatment volumes at some of the sites. A rupture with a subsequent violent pressurized and unfiltered release to the atmosphere of the entire vessel contents was postulated as the only plausible sequence capable of producing any measurable consequences to site staff or the public. An earthquake that simultaneously breached the containment building was defined as the most likely initiator. Calculations were specifically performed for a limited set of alternatives and the resulting risk was found to be significantly lower than that for the incineration accidents. As a result, source terms for wet-air oxidation accidents were not used for health effects calculations.

Frequencies of accidents are consistent with those for the LLW analysis. The frequency of 1.5E-02/yr for explosions in the rotary kiln assembly and the secondary combustion chamber, respectively, provide the basis for the internal fire frequencies. The frequencies of aircraft-initiated accidents depend on the site. The annual frequency of a seismic event exceeding the design basis for a Hazard Category 2 facility is 1.0E-03/yr with the conditional probability of rupturing containment and initiating a fire estimated to equal 5.0E-02. Screening calculations of airplane accidents for the LLMW treatment facilities were performed and the risks were found to be much lower than the risk of an earthquake, or negligible. As a result, source terms for airplane accidents were not provided for health effects calculations.

The limiting chemical accident is assumed to be an operational fire in the feedstock staging area, which includes waste in processing and lag storage. The MAR was assumed to be 1% of annual throughput of the incineration facility as established by the WM PEIS alternative. A DF of 1.0E-01 was assumed to account for the presence of noncombustible material and the distribution of the combustible materials in areas other than the feedstock area. Because of the high frequency of internal fires compared with those caused by external events, only the internal, operational fire was analyzed.

F.6.2.4 Disposal Facility Accidents

Disposal accidents were not evaluated because of the lack of details of ultimate disposal. However, except for dedicated centralized repositories such as Yucca Mountain or WIPP, disposal sites would generally lack a concentrated volume of material at risk being stored in a configuration susceptible to phenomena such as fires and explosions capable of causing significant releases. These repositories have accident analyses performed as part of their site-specific EISs. Although seismic events could breach in-ground containers, leading to airborne releases, such events would be bounded by accidents breaching the concentrated volumes of waste being held in a treatment or storage facility. The available safety literature does not indicate any credible accident sequence in which the risk from airborne releases in a low-level mixed waste disposal facility would be sufficiently significant to rule out a site from consideration and thereby serve as a discriminator among disposal alternatives.

F.6.3 RESULTS

Preliminary results of the radiological accident sequences described above for various site consolidation cases within each WM PEIS alternative were reviewed for risk dominance using the frequency-weighted dose to the MEI, and then grouped into four annual frequency categories: likely (>1.0E-02), unlikely (between 1.0E-02 and 1.0E-04), extremely unlikely (between 1.0E-04 and 1.0E-06), and not credible (<1.0E-06). Representative source terms for the risk-dominant sequences were then selected as the bases for health effects calculations. Of the treatment technologies, only source terms for incineration facility accidents are provided because they were found to bound other treatment accidents, including wet-air oxidation, which resulted in atmospheric releases much lower than analogous incineration accidents. Chemical accident releases were also calculated.

No radiological source terms were estimated for the representative treatment facility chemical accident because they were determined to be unimportant to overall risk compared with radiological source terms for the reference radiological accident. Specifically, the radionuclide concentrations and dispersibility of the ash in the filter fire are much greater than for the feedstock fire and precludes the need for radiological source term calculations for the latter.

Similarly, no chemical source terms have been produced for the reference radiological accident because of their insignificance compared with the reference chemical accidents. Specifically, the concentrations of toxic chemical released in the incinerator feedstock fire are much higher than they are in the ash dispersed in the reference radiological accidents, precluding the need to calculate chemical source terms for the latter accident.

The waste management LLMW facility accidents analyzed here are summarized in Table F.6–4. Eight cases are considered for WM LLMW alternatives, including Cases 1, 2, 4, 7, 10, 15, 17 and 26. Case 7 (Regionalized 2: 7 sites treat, 6 sites dispose) and 10 (Regionalized 3: 7 sites treat, 1 site disposes) are equivalent with respect to the risk-dominant treatment technologies and the amount of waste at each site; therefore, only Case 7 was analyzed.

Table F.6-4. Summary of WM LLMW Radiological Accidents Analyzed[a]

			Operational Events			External Events		
Function	WM PEIS Alternative[b]	Site	Handling Breaches	Facility Fire	Facility Explosion	Seismic	Large Aircraft	Small Aircraft
Drum Handling	All	Ames	×	--	--	--	--	--
	All	ANL-W	×	--	--	--	--	--
	All	Bettis	×	--	--	--	--	--
	All	BCL	×	--	--	--	--	--
	All	BNL	×	--	--	--	--	--
	All	Charleston	×	--	--	--	--	--
	All	Colonie	×	--	--	--	--	--
	All	ETEC	×	--	--	--	--	--
	All	FEMP	×	--	--	--	--	--
	All	GA	×	--	--	--	--	--
	All	GJPO	×	--	--	--	--	--
	All	Hanford	×	--	--	--	--	--
	All	INEL	×	--	--	--	--	--
	All	ITRI	×	--	--	--	--	--
	All	KAPL-S	×	--	--	--	--	--
	All	KCP	×	--	--	--	--	--
	All	KAPL-K	×	--	--	--	--	--
	All	KAPL-W	×	--	--	--	--	--
	All	LANL	×	--	--	--	--	--
	All	LBL	×	--	--	--	--	--
	All	LEHR	×	--	--	--	--	--
	All	LLNL	×	--	--	--	--	--
	All	Mare Is	×	--	--	--	--	--
	All	Mound	×	--	--	--	--	--
	All	Norfolk	×	--	--	--	--	--
	All	NTS	×	--	--	--	--	--
	All	ORR	×	--	--	--	--	--
	All	PGDP	×	--	--	--	--	--
	All	Pantex	×	--	--	--	--	--
	All	Pearl H	×	--	--	--	--	--
	All	Ports Nav	×	--	--	--	--	--
	All	PORTS	×	--	--	--	--	--
	All	PPPL	×	--	--	--	--	--
	All	Puget So	×	--	--	--	--	--
	All	RFETS	×	--	--	--	--	--
	All	RMI	×	--	--	--	--	--
	All	SNL-NM	×	--	--	--	--	--
	All	SNL-CA	×	--	--	--	--	--
	All	SRS	×	--	--	--	--	--
	All	UofMO	×	--	--	--	--	--
	All	WVDP	×	--	--	--	--	--
Incineration	1	INEL	--	×	×	×	--	--
	1	ORR	--	×	×	×	--	--
	1	SRS	--	×	×	×	--	--
	2	Ames	--	×	×	×	--	--
	2	ANL-E	--	×	×	×	--	--
	2	Bettis	--	×	×	×	--	--
	2	BCL	--	×	×	×	--	--
	2	BNL	--	×	×	×	--	--
	2	Charleston	--	×	×	×	--	--
	2	Colonie	--	×	×	×	--	--
	2	ETEC	--	×	×	×	--	--
	2	FEMP	--	×	×	×	--	--
	2	GA	--	×	×	×	--	--
	2	GJPO	--	×	×	×	--	--
	2	Hanford	--	×	×	×	--	--
	2	INEL	--	×	×	×	--	--
	2	ITRI	--	×	×	×	--	--
	2	KAPL-S	--	×	×	×	--	--
	2	KCP	--	×	×	×	--	--
	2	KAPL-K	--	×	×	×	--	--

Table F.6-4. Summary of WM LLMW Radiological Accidents Analyzed[a]—Continued

			Operational Events			External Events		
Function	WM PEIS Alternative[b]	Site	Handling Breaches	Facility Fire	Facility Explosion	Seismic	Large Aircraft	Small Aircraft
	2	KAPL-W	—	×	×	×	—	—
	2	LANL	—	×	×	×	—	—
	2	LBL	—	×	×	×	—	—
	2	LEHR	—	×	×	×	—	—
	2	LLNL	—	×	×	×	—	—
	2	Mare Is	—	×	×	×	—	—
	2	Norfolk	—	×	×	×	—	—
	2	NTS	—	×	×	×	—	—
	2	ORR	—	×	×	×	—	—
	2	PGDP	—	×	×	×	—	—
	2	Pantex	—	×	×	×	—	—
	2	Pearl H	—	×	×	×	—	—
	2	Ports Nav	—	×	×	×	—	—
	2	PORTS	—	×	×	×	—	—
	2	PPPL	—	×	×	×	—	—
	2	Puget So	—	×	×	×	—	—
	2	RMI	—	×	×	×	—	—
	2	SNL-NM	—	×	×	×	—	—
	2	SRS	—	×	×	×	—	—
	4	ETEC	—	×	×	×	—	—
	4	FEMP	—	×	×	×	—	—
	4	Hanford	—	×	×	×	—	—
	4	INEL	—	×	×	×	—	—
	4	LANL	—	×	×	×	—	—
	4	LLNL	—	×	×	×	—	—
	4	ORNL	—	×	×	×	—	—
	4	PGDP	—	×	×	×	—	—
	4	Pantex	—	×	×	×	—	—
	4	PORTS	—	×	×	×	—	—
	4	RFETS	—	×	×	×	—	—
	4	SRS	—	×	×	×	—	—
	7	Hanford	—	×	×	×	—	—
	7	INEL	—	×	×	×	—	—
	7	LANL	—	×	×	×	—	—
	7	ORNL	—	×	×	×	—	—
	7	PORTS	—	×	×	×	—	—
	7	RFETS	—	×	×	×	—	—
	7	SRS	—	×	×	×	—	—
	15	Hanford	—	×	×	×	—	—
	15	INEL	—	×	×	×	—	—
	15	ORR	—	×	×	×	—	—
	15	SRS	—	×	×	×	—	—
	17	Hanford	—	×	×	×	—	—
	26	Hanford	—	×	×	×	—	—
	26	INEL	—	×	×	×	—	—
	26	ORR	—	×	×	×	—	—
	26	SRS	—	×	×	×	—	—
α-Incineration[c]	2	INEL	—	×	×	×	—	—
	2	LANL	—	×	×	×	—	—
	2	LLNL	—	×	×	×	—	—
	2	RFETS	—	×	×	×	—	—
	2	SRS	—	×	×	×	—	—
	4	INEL	—	×	×	×	—	—
	4	LANL	—	×	×	×	—	—
	4	LLNL	—	×	×	×	—	—
	4	RFETS	—	×	×	×	—	—
	4	SRS	—	×	×	×	—	—
	7	INEL	—	×	×	×	—	—
	7	LANL	—	×	×	×	—	—
	7	RFETS	—	×	×	×	—	—
	7	SRS	—	×	×	×	—	—
	15	INEL	—	×	×	×	—	—
	15	SRS	—	×	×	×	—	—
	17	Hanford	—	×	×	×	—	—
	26	INEL	—	×	×	×	—	—

Footnotes on next page

Table F.6-4. Summary of WM LLMW Radiological Accidents Analyzed[a]—Continued

Notes: -- = not applicable; Ames = Ames Laboratory; Bettis = Bettis Atomic Power Plant; BCL = Battelle Columbus Laboratories; BNL = Brookhaven National Laboratory; Charleston = Charleston Naval Shipyard; GA = General Atomics; GJPO = Grand Junctions Project Office; ITRI = Inhalations Toxicology Research Institute; KAPL-K = Knolls Atomic Power Laboratory (Kesselring); KAPL-S = Knolls Atomic Power Laboratory (Schenectady); KAPL-W = Knolls Atomic Power Laboratory (Windsor); KCP = Kansas City Plant; LBL = Lawrence Berkeley National Laboratory; LEHR = Laboratory for Energy-Related Health Research; Mare Is = Mare Island Naval Shipyard; Mound = Mound Plant; Norfolk = Norfolk Naval Shipyard; Pearl H = Pearl Harbor Naval Shipyard; Ports Nav = Portsmouth Naval Shipyard; PPPL = Princeton Plasma Physics Laboratory; Puget So = Puget Sound Naval Shipyard; RMI = Reactive Metals, Inc.; SNL-NM = Sandia National Laboratories (New Mexico); SNL-CA = Sandia National Laboratories (California); and UofMO = University of Missouri.

[a] Only one source term, generally corresponding to the risk-dominant sequence for each accident initiator, was selected for transmittal to ORR.

[b] The WM PEIS cases analyzed are described as follows:

- *Case 1 (No Action).* Three sites (INEL, ORR, and SRS) treat and store, all remaining sites store.
  Case 2 (Decentralized). Forty-nine sites treat, and 16 sites dispose.
- *Case 4 (Regionalized 1).* Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) treat, and 12 sites dispose.
- *Case 7 (Regionalized 2).* Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) treat, and 6 sites dispose.
- *Case 15 (Regionalized 4).* Four sites (Hanford, INEL, ORR, and SRS) treat, and 6 sites dispose.
- *Case 17 (Centralized).* One site treats (Hanford), and 1 site disposes.
- *Case 26 (Remote-handled).* Four sites (Hanford, INEL, ORR, and SRS) treat and dispose (RH).

[c] α-incineration refers to incineration of waste categorized as alpha-emitting.

The WM PEIS cases analyzed are described as follows:

- Case 1 (No Action). Three sites (INEL, ORR, and SRS) treat and store, all remaining sites store.
- Case 2 (Decentralized). Forty-nine sites treat, and 16 sites dispose.
- Case 4 (Regionalized 1). Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) treat, and 12 sites dispose.
- Case 7 (Regionalized 2). Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) treat, and 6 sites dispose.
- Case 15 (Regionalized 4). Four sites (Hanford, INEL, ORR, and SRS) treat, and 6 sites dispose.
- Case 17 (Centralized). One site treats (Hanford), and 1 site disposes.
- Case 26 (Remote-handled). Four sites (Hanford, INEL, ORR, and SRS) treat and dispose (RH).

Tables F.6–5 through F.6–7 summarize the radiological source term parameters and frequency groups for the accidents. Separate incineration facilities were assumed for treating alpha and nonalpha contaminated waste. Detailed radionuclide releases and chemical source terms for accidents are provided in ANL (1996a).

Table F.6–5. Frequencies and Radiological Source Term Parameters for WM LLMW Drum Handling Accidents

WM PEIS Alternative	Site[a]	Frequency Bin (/yr) >1.0E–02	1.0E–04 to 1.0E–02	1.0E–06 to 1.0E–04	<1.0E–06	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	Ames	X	—	—	—	2.0E–01	1.1E–03	0.25	2.4E–07
All	ANL-W	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	Bettis	X	—	—	—	2.0E–01	6.1E–01	0.25	3.5E–03
All	BCL	X	—	—	—	2.0E–01	1.1E–03	0.25	5.4E–08
All	BNL	X	—	—	—	2.0E–01	1.5E–01	0.25	2.8E–04
All	Charleston	X	—	—	—	2.0E–01	7.3E+00	0.25	1.5E–01
All	Colonie	X	—	—	—	2.0E–01	1.1E–03	0.25	5.0E–08
All	ETEC	X	—	—	—	2.0E–01	1.5E–01	0.25	3.7E–04
All	FEMP	X	—	—	—	2.0E–01	1.1E–03	0.25	4.5E–07
All	GA	X	—	—	—	2.0E–01	1.1E–03	0.25	2.6E–07
All	GJPO	X	—	—	—	2.0E–01	1.1E–03	0.25	1.8E–06
All	Hanford	X	—	—	—	2.0E–01	6.1E–01	0.25	3.1E–03
All	INEL	X	—	—	—	2.0E–01	3.5E+00	0.25	2.9E–02
All	ITRI	X	—	—	—	2.0E–01	5.5E–01	0.25	1.3E–01
All	KAPL-S	X	—	—	—	2.0E–01	7.0E+00	0.25	8.2E–02
All	KCP	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	KAPL-K	X	—	—	—	2.0E–01	7.0E+00	0.25	7.3E–02
All	KAPL-W	X	—	—	—	2.0E–01	7.1E+00	0.25	1.1E–01
All	LANL	X	—	—	—	2.0E–01	5.4E–01	0.25	1.3E–01
All	LBL	X	—	—	—	2.0E–01	1.3E+01	0.25	3.1E+00
All	LEHR	X	—	—	—	2.0E–01	1.5E–01	0.25	3.2E–04
All	LLNL	X	—	—	—	2.0E–01	1.2E+01	0.25	3.1E+00
All	Mare Is.	X	—	—	—	2.0E–01	7.1E+00	0.25	9.4E–02
All	Mound	X	—	—	—	2.0E–01	1.3E+01	0.25	3.1E+00
All	Norfolk	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	NTS	X	—	—	—	2.0E–01	1.5E–01	0.25	3.0E–04
All	ORR	X	—	—	—	2.0E–01	1.5E–01	0.25	3.0E–04
All	PGDP	X	—	—	—	2.0E–01	3.8E–01	0.25	2.5E–05
All	Pantex	X	—	—	—	2.0E–01	5.3E–01	0.25	1.3E–01
All	Pearl H	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	Ports Nev	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	PORTS	X	—	—	—	2.0E–01	2.8E–04	0.25	6.1E–08
All	PPPL	X	—	—	—	2.0E–01	1.3E+01	0.25	3.1E+00
All	Puget So	X	—	—	—	2.0E–01	7.3E+00	0.25	1.6E–01
All	RFETS	X	—	—	—	2.0E–01	5.2E–03	0.25	1.8E–06
All	RMI	X	—	—	—	2.0E–01	1.1E–03	0.25	3.0E–07

Table F.6-5. Frequencies and Radiological Source Term Parameters for WM LLMW Drum Handling Accidents—Continued

		Frequency Bin (/yr)				Source Term Parameters			
WM PEIS Alternative	Site[a]	>1.0E-02	1.0E-04 to 1.0E-02	1.0E-06 to 1.0E-04	<1.0E-06	VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	SNL-NM	X	--	--	--	2.0E-01	9.6E-01	0.25	1.1E-01
All	SNL-CA	X	--	--	--	2.0E-01	1.3E+01	0.25	3.1E+00
All	SRS	X	--	--	--	2.0E-01	9.2E-01	0.25	1.0E-01
All	UofMO	X	--	--	--	2.0E-01	5.2E-03	0.25	1.3E-06
All	WVDP	X	--	--	--	2.0E-01	6.1E-01	0.25	3.7E-03

Note: -- = not applicable.
[a] See Table F.6-4 footnote for spelled out versions of acronyms.

Table F.6–6. Frequencies and Radiological Source Term Parameters for WM LLMW Non-Alpha Incineration Facility Accidents

			Frequency Bin (/yr)				Source Term Parameters					
WM PEIS Alternative[a]	Site[b]	Accident	>1.0E–02	1.0E–04 to 1.0E–02	1.0E–06 to 1.0E–04	<1.0E–06	VMAR (m^3)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
1	INEL	Explosion in the rotary kiln	X	--	--	--	6.0E–02	2.1E+00	1.2E–01	1.0E–01	1.0E–03	2.6E–05
1	INEL	Fire in the baghouse area	--	X	--	--	6.0E–02	2.1E+00	3.0E–02	1.0E–02	1.0E+00	6.5E–04
1	INEL	Earthquake followed by fire and explosion	--	--	X	--	6.0E–02	2.1E+00	2.0E–01	1.0E–01	1.0E+00	4.3E–02
1	ORR	Explosion in the rotary kiln	X	--	--	--	1.1E+00	2.2E+00	1.2E–01	1.0E–01	1.0E–03	2.6E–05
1	ORR	Fire in the baghouse area	--	X	--	--	1.1E+00	2.2E+00	3.0E–02	1.0E–02	1.0E+00	6.5E–04
1	ORR	Earthquake followed by fire and explosion	--	--	X	--	1.1E+00	2.2E+00	2.0E–01	1.0E–01	1.0E+00	4.3E–02
1	SRS	Explosion in the rotary kiln	X	--	--	--	1.3E–01	3.0E+00	1.2E–01	1.0E–01	1.0E–03	3.6E–05
1	SRS	Fire in the baghouse area	--	X	--	--	1.3E–01	3.0E+00	3.0E–02	1.0E–02	1.0E+00	9.0E–04
1	SRS	Earthquake followed by fire and explosion	--	--	X	--	1.3E–01	3.0E+00	2.0E–01	1.0E–01	1.0E+00	6.0E–02
2	Ames	Explosion in the rotary kiln	X	--	--	--	3.3E–05	3.5E–07	1.2E–01	1.0E–01	1.0E–03	4.2E–12
2	Ames	Fire in the baghouse area	--	X	--	--	3.3E–05	3.5E–07	3.0E–02	1.0E–02	1.0E+00	1.0E–10
2	Ames	Earthquake followed by fire and explosion	--	--	X	--	3.3E–05	3.5E–07	2.0E–01	1.0E–01	1.0E+00	7.0E–09
2	ANL-E	Explosion in the rotary kiln	X	--	--	--	1.1E–02	1.4E–02	1.2E–01	7.0E–02	1.0E–03	1.1E–07
2	ANL-E	Fire in the baghouse area	--	X	--	--	1.1E–02	1.4E–02	3.0E–02	6.0E–05	1.0E+00	2.4E–08
2	ANL-E	Earthquake followed by fire and explosion	--	--	X	--	1.1E–02	1.4E–02	2.0E–01	7.0E–02	1.0E+00	1.9E–04
2	Bettis	Explosion in the rotary kiln	X	--	--	--	2.5E–04	7.5E–03	1.2E–01	1.0E–01	1.0E–03	8.9E–08
2	Bettis	Fire in the baghouse area	--	X	--	--	2.5E–04	7.5E–03	3.0E–02	1.0E–02	1.0E+00	2.2E–06
2	Bettis	Earthquake followed by fire and explosion	--	--	X	--	2.5E–04	7.5E–03	2.0E–01	1.0E–01	1.0E+00	1.5E–04
2	BCL	Explosion in the rotary kiln	X	--	--	--	6.3E–06	6.4E–08	1.2E–01	1.0E–01	1.0E–03	7.7E–13
2	BCL	Fire in the baghouse area	--	X	--	--	6.3E–06	6.4E–08	3.0E–02	1.0E–02	1.0E+00	1.9E–11
2	BCL	Earthquake followed by fire and explosion	--	--	X	--	6.3E–06	6.4E–08	2.0E–01	1.0E–01	1.0E+00	1.3E–09
2	BNL	Explosion in the rotary kiln	X	--	--	--	1.7E–02	3.3E–02	1.2E–01	1.0E–01	1.0E–03	3.9E–07
2	BNL	Fire in the baghouse area	--	X	--	--	1.7E–02	3.3E–02	3.0E–02	1.0E–02	1.0E+00	9.7E–06
2	BNL	Earthquake followed by fire and explosion	--	--	X	--	1.7E–02	3.3E–02	2.0E–01	1.0E–01	1.0E+00	6.5E–04
2	Charleston	Explosion in the rotary kiln	X	--	--	--	2.1E–04	6.8E–02	1.2E–01	1.0E–01	1.0E–03	8.2E–07
2	Charleston	Fire in the baghouse area	--	X	--	--	2.1E–04	6.8E–02	3.0E–02	1.0E–02	1.0E+00	2.0E–05
2	Charleston	Earthquake followed by fire and explosion	--	--	X	--	2.1E–04	6.8E–02	2.0E–01	1.0E–01	1.0E+00	1.4E–03
2	Colonie	Explosion in the rotary kiln	X	--	--	--	2.4E–04	1.5E–05	1.2E–01	1.0E–01	1.0E–03	1.7E–10
2	Colonie	Fire in the baghouse area	--	X	--	--	2.4E–04	1.5E–05	3.0E–02	1.0E–02	1.0E+00	4.4E–09
2	Colonie	Earthquake followed by fire and explosion	--	--	X	--	2.4E–04	1.5E–05	2.0E–01	1.0E–01	1.0E+00	2.9E–07
2	ETEC	Explosion in the rotary kiln	X	--	--	--	1.6E–01	1.2E–01	1.2E–01	1.0E–01	1.0E–03	1.5E–06
2	ETEC	Fire in the baghouse area	--	X	--	--	1.6E–01	1.2E–01	3.0E–02	1.0E–02	1.0E+00	3.6E–05
2	ETEC	Earthquake followed by fire and explosion	--	--	X	--	1.6E–01	1.2E–01	2.0E–01	1.0E–01	1.0E+00	2.4E–03
2	FEMP	Explosion in the rotary kiln	X	--	--	--	1.6E–01	8.5E–04	1.2E–01	1.0E–01	1.0E–03	1.0E–08
2	FEMP	Fire in the baghouse area	--	X	--	--	1.6E–01	8.5E–04	3.0E–02	1.0E–02	1.0E+00	2.6E–07
2	FEMP	Earthquake followed by fire and explosion	--	--	X	--	1.6E–01	8.5E–04	2.0E–01	1.0E–01	1.0E+00	1.7E–05
2	GA	Explosion in the rotary kiln	X	--	--	--	1.0E–03	5.7E–06	1.2E–01	1.0E–01	1.0E–03	6.8E–11
2	GA	Fire in the baghouse area	--	X	--	--	1.0E–03	5.7E–06	3.0E–02	1.0E–02	1.0E+00	1.7E–09
2	GA	Earthquake followed by fire and explosion	--	--	X	--	1.0E–03	5.7E–06	2.0E–01	1.0E–01	1.0E+00	1.1E–07

Table F.6-6. Frequencies and Radiological Source Term Parameters for WM LLMW Non-Alpha Incineration Facility Accidents—Continued

WM PEIS Altern-ative[a]	Site[b]	Accident	Frequency Bin (/yr) > 1.0E-02	1.0E-04 to 1.0E-02	1.0E-06 to 1.0E-04	< 1.0E-06	Source Term Parameters VMAR (m³)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
2	GJPO	Explosion in the rotary kiln	X	—	—	—	6.8E-05	3.3E-07	1.2E-01	1.0E-01	1.0E-03	4.0E-12
2	GJPO	Fire in the baghouse area	—	X	—	—	6.8E-05	3.3E-07	3.0E-02	1.0E-02	1.0E+00	1.0E-10
2	GJPO	Earthquake followed by fire and explosion	—	—	X	—	6.8E-05	3.3E-07	2.0E-01	1.0E-01	1.0E+00	6.7E-09
2	Hanford	Explosion in the rotary kiln	X	—	—	—	1.6E+00	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.2E-05
2	Hanford	Fire in the baghouse area	—	X	—	—	1.6E+00	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
2	Hanford	Earthquake followed by fire and explosion	—	—	X	—	1.6E+00	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
2	INEL	Explosion in the rotary kiln	X	—	—	—	1.3E-01	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.1E-05
2	INEL	Fire in the baghouse area	—	X	—	—	1.3E-01	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
2	INEL	Earthquake followed by fire and explosion	—	—	X	—	1.3E-01	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
2	ITRI	Explosion in the rotary kiln	X	—	—	—	8.5E-05	6.5E-05	1.2E-01	1.0E-01	1.0E-03	7.9E-10
2	ITRI	Fire in the baghouse area	—	X	—	—	8.5E-05	6.5E-05	3.0E-02	1.0E-02	1.0E+00	2.0E-08
2	ITRI	Earthquake followed by fire and explosion	—	—	X	—	8.5E-05	6.5E-05	2.0E-01	1.0E-01	1.0E+00	1.3E-06
2	KAPL-S	Explosion in the rotary kiln	X	—	—	—	2.3E-03	3.1E-01	1.2E-01	1.0E-01	1.0E-03	3.7E-06
2	KAPL-S	Fire in the baghouse area	—	X	—	—	2.3E-03	3.1E-01	3.0E-02	1.0E-02	1.0E+00	9.2E-05
2	KAPL-S	Earthquake followed by fire and explosion	—	—	X	—	2.3E-03	3.1E-01	2.0E-01	1.0E-01	1.0E+00	6.1E-03
2	KCP	Explosion in the rotary kiln	X	—	—	—	9.0E-05	1.2E-02	1.2E-01	1.0E-01	1.0E-03	1.4E-07
2	KCP	Fire in the baghouse area	—	X	—	—	9.0E-05	1.2E-02	3.0E-02	1.0E-02	1.0E+00	3.6E-06
2	KCP	Earthquake followed by fire and explosion	—	—	X	—	9.0E-05	1.2E-02	2.0E-01	1.0E-01	1.0E+00	2.4E-04
2	KAPL-K	Explosion in the rotary kiln	X	—	—	—	6.6E-03	2.0E-01	1.2E-01	1.0E-01	1.0E-03	2.4E-06
2	KAPL-K	Fire in the baghouse area	—	X	—	—	6.6E-03	2.0E-01	3.0E-02	1.0E-02	1.0E+00	6.0E-05
2	KAPL-K	Earthquake followed by fire and explosion	—	—	X	—	6.6E-03	2.0E-01	2.0E-01	1.0E-01	1.0E+00	4.0E-03
2	KAPL-W	Explosion in the rotary kiln	X	—	—	—	1.0E-03	1.3E-01	1.2E-01	1.0E-01	1.0E-03	1.6E-06
2	KAPL-W	Fire in the baghouse area	—	X	—	—	1.0E-03	1.3E-01	3.0E-02	1.0E-02	1.0E+00	4.0E-05
2	KAPL-W	Earthquake followed by fire and explosion	—	—	X	—	1.0E-03	1.3E-01	2.0E-01	1.0E-01	1.0E+00	2.7E-03
2	LANL	Explosion in the rotary kiln	X	—	—	—	5.9E-03	4.5E-03	1.2E-01	1.0E-01	1.0E-03	5.4E-08
2	LANL	Fire in the baghouse area	—	X	—	—	5.9E-03	4.5E-03	3.0E-02	1.0E-02	1.0E+00	1.4E-06
2	LANL	Earthquake followed by fire and explosion	—	—	X	—	4.5E-03	4.6E-02	2.0E-01	1.0E-01	1.0E+00	9.1E-04
2	NTS	Explosion in the rotary kiln	X	—	—	—	1.4E+00	1.1E+00	1.2E-01	7.0E-02	1.0E-03	9.1E-06
2	NTS	Fire in the baghouse area	—	X	—	—	1.4E+00	1.1E+00	3.0E-02	6.0E-05	1.0E+00	1.9E-06
2	NTS	Earthquake followed by fire and explosion	—	—	X	—	1.4E+00	1.1E+00	2.0E-01	7.0E-02	1.0E+00	1.5E-02
4	LLNL	Explosion in the rotary kiln	X	—	—	—	4.1E-03	4.7E-01	1.2E-01	1.0E-01	1.0E-03	5.7E-06
4	LLNL	Fire in the baghouse area	—	X	—	—	4.1E-03	4.7E-01	3.0E-02	1.0E-02	1.0E+00	1.4E-04
4	LLNL	Earthquake followed by fire and explosion	—	—	X	—	4.1E-03	4.7E-01	2.0E-01	1.0E-01	1.0E+00	9.5E-03
4	ORR	Explosion in the rotary kiln	X	—	—	—	2.2E+00	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.1E-05
4	ORR	Fire in the baghouse area	—	X	—	—	2.2E+00	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
4	ORR	Earthquake followed by fire and explosion	—	—	X	—	2.2E+00	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02

Table F.6-6. Frequencies and Radiological Source Term Parameters for WM LLMW Non-Alpha Incineration Facility Accidents—Continued

			Frequency Bin (/yr)				Source Term Parameters					
WM PEIS Alternative[a]	Site[b]	Accident	>1.0E-02	1.0E-04 to 1.0E-02	1.0E-06 to 1.0E-04	<1.0E-06	VMAR (m^3)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
4	PGDP	Explosion in the rotary kiln	X	--	--	--	1.3E-02	2.3E-01	1.2E-01	1.0E-01	1.0E-03	2.7E-06
4	PGDP	Fire in the baghouse area	--	X	--	--	1.3E-02	2.3E-01	3.0E-02	1.0E-02	1.0E+00	6.9E-05
4	PGDP	Earthquake followed by fire and explosion	--	--	X	--	1.3E-02	2.3E-01	2.0E-01	1.0E-01	1.0E+00	4.6E-03
4	Pantex	Explosion in the rotary kiln	X	--	--	--	8.3E-02	3.4E-02	1.2E-01	1.0E-01	1.0E-03	4.1E-07
4	Pantex	Fire in the baghouse area	--	X	--	--	8.3E-02	3.4E-02	3.0E-02	1.0E-02	1.0E+00	1.0E-05
4	Pantex	Earthquake followed by fire and explosion	--	--	X	--	8.3E-02	3.4E-02	2.0E-01	1.0E-01	1.0E+00	6.9E-04
4	PORTS	Explosion in the rotary kiln	X	--	--	--	7.3E-02	4.9E-01	1.2E-01	1.0E-01	1.0E-03	5.8E-06
4	PORTS	Fire in the baghouse area	--	X	--	--	7.3E-02	4.9E-01	3.0E-02	1.0E-02	1.0E+00	1.5E-04
4	PORTS	Earthquake followed by fire and explosion	--	--	X	--	7.3E-02	4.9E-01	2.0E-01	1.0E-01	1.0E+00	9.7E-03
4	RFETS	Explosion in the rotary kiln	X	--	--	--	6.8E-05	3.3E-07	1.2E-01	1.0E-01	1.0E-03	4.0E-12
4	RFETS	Fire in the baghouse area	--	X	--	--	6.8E-05	3.3E-07	3.0E-02	1.0E-02	1.0E+00	1.0E-10
4	RFETS	Earthquake followed by fire and explosion	--	--	X	--	6.8E-05	3.3E-07	2.0E-01	1.0E-01	1.0E+00	6.7E-09
4	SRS	Explosion in the rotary kiln	X	--	--	--	2.5E-01	6.0E+00	1.2E-01	1.0E-01	1.0E-03	7.2E-05
4	SRS	Fire in the baghouse area	--	X	--	--	2.5E-01	6.0E+00	3.0E-02	1.0E-02	1.0E+00	1.8E-03
4	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.5E-01	6.0E+00	2.0E-01	1.0E-01	1.0E+00	1.2E-01
7	Hanford	Explosion in the rotary kiln	X	--	--	--	1.6E+00	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.2E-05
7	Hanford	Fire in the baghouse area	--	X	--	--	1.6E+00	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
7	Hanford	Earthquake followed by fire and explosion	--	--	X	--	1.6E+00	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
7	INEL	Explosion in the rotary kiln	X	--	--	--	1.3E-01	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.1E-05
7	INEL	Fire in the baghouse area	--	X	--	--	1.3E-01	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
7	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.3E-01	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
7	LANL	Explosion in the rotary kiln	X	--	--	--	8.7E-02	8.0E-02	1.2E-01	1.0E-01	1.0E-03	9.6E-07
7	LANL	Fire in the baghouse area	--	X	--	--	8.7E-02	8.0E-02	3.0E-02	1.0E-02	1.0E+00	2.4E-05
7	LANL	Earthquake followed by fire and explosion	--	--	X	--	8.7E-02	8.0E-02	2.0E-01	1.0E-01	1.0E+00	1.6E-03
7	ORR	Explosion in the rotary kiln	X	--	--	--	3.4E-01	2.5E+00	1.2E-01	1.0E-01	1.0E-03	3.0E-05
7	ORR	Fire in the baghouse area	--	X	--	--	3.4E-01	2.5E+00	3.0E-02	1.0E-02	1.0E+00	7.4E-04
7	ORR	Earthquake followed by fire and explosion	--	--	X	--	3.4E-01	2.5E+00	2.0E-01	1.0E-01	1.0E+00	4.9E-02
7	PORTS	Explosion in the rotary kiln	X	--	--	--	8.2E-01	8.6E-01	1.2E-01	1.0E-01	1.0E-03	1.0E-05
7	PORTS	Fire in the baghouse area	--	X	--	--	8.2E-01	8.6E-01	3.0E-02	1.0E-02	1.0E+00	2.6E-04
7	PORTS	Earthquake followed by fire and explosion	--	--	X	--	8.2E-01	8.6E-01	2.0E-01	1.0E-01	1.0E+00	1.7E-02
7	RFETS	Explosion in the rotary kiln	X	--	--	--	9.0E-05	1.2E-02	1.2E-01	1.0E-01	1.0E-03	1.4E-07
7	RFETS	Fire in the baghouse area	--	X	--	--	9.0E-05	1.2E-02	3.0E-02	1.0E-02	1.0E+00	3.6E-06
7	RFETS	Earthquake followed by fire and explosion	--	--	X	--	9.0E-05	1.2E-02	2.0E-01	1.0E-01	1.0E+00	2.4E-04
7	SRS	Explosion in the rotary kiln	X	--	--	--	2.5E-01	6.0E+00	1.2E-01	1.0E-01	1.0E-03	7.2E-05
7	SRS	Fire in the baghouse area	--	X	--	--	2.5E-01	6.0E+00	3.0E-02	1.0E-02	1.0E+00	1.8E-03
7	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.5E-01	6.0E+00	2.0E-01	1.0E-01	1.0E+00	1.2E-01

Table F.6–6. Frequencies and Radiological Source Term Parameters for WM LLMW Non-Alpha Incineration Facility Accidents—Continued

WM PEIS Altern-ative[a]	Site[b]	Accident	Frequency Bin (/yr) > 1.0E–02	1.0E–04 to 1.0E–02	1.0E–06 to 1.0E–04	< 1.0E–06	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
15	Hanford	Explosion in the rotary kiln	X	--	--	--	1.6E+00	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.2E-05
15	Hanford	Fire in the baghouse area	--	X	--	--	1.6E+00	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.3E-03
15	Hanford	Earthquake followed by fire and explosion	--	--	X	--	1.6E+00	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
15	INEL	Explosion in the rotary kiln	X	--	--	--	1.4E-01	4.3E+00	1.2E-01	1.0E-01	1.0E-03	5.1E-05
15	INEL	Fire in the baghouse area	--	X	--	--	1.4E-01	4.3E+00	3.0E-02	1.0E-02	1.0E+00	1.2E-03
15	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.4E-01	4.3E+00	2.0E-01	1.0E-01	1.0E+00	8.6E-02
15	ORR	Explosion in the rotary kiln	X	--	--	--	2.7E+00	4.7E+00	1.2E-01	1.0E-01	1.0E-03	5.7E-05
15	ORR	Fire in the baghouse area	--	X	--	--	2.7E+00	4.7E+00	3.0E-02	1.0E-02	1.0E+00	1.4E-03
15	ORR	Earthquake followed by fire and explosion	--	--	X	--	2.7E+00	4.7E+00	2.0E-01	1.0E-01	1.0E+00	9.5E-02
15	SRS	Explosion in the rotary kiln	X	--	--	--	2.5E-01	6.0E+00	1.2E-01	1.0E-01	1.0E-03	7.2E-05
15	SRS	Fire in the baghouse area	--	X	--	--	2.5E-01	6.0E+00	3.0E-02	1.0E-02	1.0E+00	1.8E-03
15	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.5E-01	6.0E+00	2.0E-01	1.0E-01	1.0E+00	1.2E-01
17	Hanford	Explosion in the rotary kiln	X	--	--	--	3.5E+00	1.0E+01	1.2E-01	1.0E-01	1.0E-03	1.2E-04
17	Hanford	Fire in the baghouse area	--	X	--	--	3.5E+00	1.0E+01	3.0E-02	1.0E-02	1.0E+00	3.1E-03
17	Hanford	Earthquake followed by fire and explosion	--	--	X	--	3.5E+00	1.0E+01	2.0E-01	1.0E-01	1.0E+00	2.1E-01
26	Hanford	Explosion in the rotary kiln	X	--	--	--	6.5E-05	9.9E-03	1.2E-01	1.0E-01	1.0E-03	1.2E-07
26	Hanford	Fire in the baghouse area	--	X	--	--	6.5E-05	9.9E-03	3.0E-02	1.0E-02	1.0E+00	3.0E-06
26	Hanford	Earthquake followed by fire and explosion	--	--	X	--	6.5E-05	9.9E-03	2.0E-01	1.0E-01	1.0E+00	2.0E-04
26	INEL	Explosion in the rotary kiln	X	--	--	--	1.9E-01	1.8E+01	1.2E-01	1.0E-01	1.0E-03	2.2E-04
26	INEL	Fire in the baghouse area	--	X	--	--	1.9E-01	1.8E+01	3.0E-02	1.0E-02	1.0E+00	5.5E-03
26	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.9E-01	1.8E+01	2.0E-01	1.0E-01	1.0E+00	3.7E-01
26	ORR	Explosion in the rotary kiln	X	--	--	--	1.1E-02	3.0E+00	1.2E-01	1.0E-01	1.0E-03	3.6E-05
26	ORR	Fire in the baghouse area	--	X	--	--	1.1E-02	3.0E+00	3.0E-02	1.0E-02	1.0E+00	9.1E-04
26	ORR	Earthquake followed by fire and explosion	--	--	X	--	1.1E-02	3.0E+00	2.0E-01	1.0E-01	1.0E+00	6.1E-02
26	SRS	Explosion in the rotary kiln	X	--	--	--	7.8E-04	8.3E-02	1.2E-01	1.0E-01	3.0E-03	1.0E-06
26	SRS	Fire in the baghouse area	--	X	--	--	7.8E-04	8.3E-02	3.0E-02	1.0E-02	1.0E+00	2.5E-05
26	SRS	Earthquake followed by fire and explosion	--	--	X	--	7.8E-04	8.3E-02	2.0E-01	1.0E-01	1.0E+00	1.7E-03

Note: -- = not applicable.

a The WM PEIS cases analyzed are described as follows:

- *Case 1 (No Action)*. Three sites (INEL, ORR, and SRS) treat and store, all remaining sites store.
- *Case 2 (Decentralized)*. Forty-nine sites treat, and 16 sites dispose.
- *Case 4 (Regionalized 1)*. Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) treat, and 12 sites dispose.
- *Case 7 (Regionalized 2)*. Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) treat, and 6 sites dispose.
- *Case 15 (Regionalized 4)*. Four sites (Hanford, INEL, ORR, and SRS) treat, and 6 sites dispose.
- *Case 17 (Centralized)*. One site treats (Hanford), and 1 site disposes.
- *Case 26 (Remote-handled)*. Four sites (Hanford, INEL, ORR, and SRS) treat and dispose (RH) and dispose.

b Values shown are for (nonvolatile) solids such as U-235 or Pu-238; see Appendix D.

c See Table F.6–4 for facility acronyms.

Table F.6-7. Frequencies and Radiological Source Term Parameters for WM LLMW Alpha Incineration Facility Accidents

WM PEIS Alternative[a]	Site[b]	Accident	Frequency Bin (/yr)				Source Term Parameters					
			> 1.0E-02	1.0E-04 to 1.0E-02	1.0E-06 to 1.0E-04	< 1.0E-06	VMAR (m^3)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
2	INEL	Explosion in the rotary kiln	X	--	--	--	1.5E-01	9.3E+00	1.2E-01	1.0E-01	1.0E-03	1.1E-04
2	INEL	Fire in the baghouse area	--	X	--	--	1.5E-01	9.3E+00	3.0E-02	1.0E-02	1.0E+00	2.8E-03
2	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.5E-01	9.3E+00	2.0E-01	1.0E-01	1.0E+00	1.9E-01
2	LANL	Explosion in the rotary kiln	X	--	--	--	2.9E-02	4.0E-02	1.2E-01	1.0E-01	1.0E-03	4.8E-07
2	LANL	Fire in the baghouse area	--	X	--	--	2.9E-02	4.0E-02	3.0E-02	1.0E-02	1.0E+00	1.2E-05
2	LANL	Earthquake followed by fire and explosion	--	--	X	--	2.9E-02	4.0E-02	2.0E-01	1.0E-01	1.0E+00	8.1E-04
2	LLNL	Explosion in the rotary kiln	X	--	--	--	2.0E-02	1.7E-02	1.2E-01	1.0E-01	1.0E-03	2.0E-07
2	LLNL	Fire in the baghouse area	--	X	--	--	2.0E-02	1.7E-02	3.0E-02	1.0E-02	1.0E+00	5.0E-06
2	LLNL	Earthquake followed by fire and explosion	--	--	X	--	2.0E-02	1.7E-02	2.0E-01	1.0E-01	1.0E+00	3.4E-04
2	RFETS	Explosion in the rotary kiln	X	--	--	--	1.6E-01	1.4E-02	1.2E-01	1.0E-01	1.0E-03	1.7E-07
2	RFETS	Fire in the baghouse area	--	X	--	--	1.6E-01	1.4E-02	3.0E-02	1.0E-02	1.0E+00	4.2E-06
2	RFETS	Earthquake followed by fire and explosion	--	--	X	--	1.6E-01	1.4E-02	2.0E-01	1.0E-01	1.0E+00	2.8E-04
2	SRS	Explosion in the rotary kiln	X	--	--	--	2.1E-01	4.8E-01	1.2E-01	1.0E-01	1.0E-03	5.7E-06
2	SRS	Fire in the baghouse area	--	X	--	--	2.1E-01	4.8E-01	3.0E-02	1.0E-02	1.0E+00	1.4E-04
2	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.1E-01	4.8E-01	2.0E-01	1.0E-01	1.0E+00	9.5E-03
4	INEL	Explosion in the rotary kiln	X	--	--	--	1.5E-01	9.3E+00	1.2E-01	1.0E-01	1.0E-03	1.1E-04
4	INEL	Fire in the baghouse area	--	X	--	--	1.5E-01	9.3E+00	3.0E-02	1.0E-02	1.0E+00	2.8E-03
4	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.5E-01	9.3E+00	2.0E-01	1.0E-01	1.0E+00	1.9E-01
4	LANL	Explosion in the rotary kiln	X	--	--	--	2.9E-02	4.0E-02	1.2E-01	1.0E-01	1.0E-03	4.8E-07
4	LANL	Fire in the baghouse area	--	X	--	--	2.9E-02	4.0E-02	3.0E-02	1.0E-02	1.0E+00	1.2E-05
4	LANL	Earthquake followed by fire and explosion	--	--	X	--	2.9E-02	4.0E-02	2.0E-01	1.0E-01	1.0E+00	8.1E-04
4	LLNL	Explosion in the rotary kiln	X	--	--	--	2.0E-02	1.7E-02	1.2E-01	1.0E-01	1.0E-03	2.0E-07
4	LLNL	Fire in the baghouse area	--	X	--	--	2.0E-02	1.7E-02	3.0E-02	1.0E-02	1.0E+00	5.0E-06
4	LLNL	Earthquake followed by fire and explosion	--	--	X	--	2.0E-02	1.7E-02	2.0E-01	1.0E-01	1.0E+00	3.4E-04
4	RFETS	Explosion in the rotary kiln	X	--	--	--	1.6E-01	1.4E-02	1.2E-01	1.0E-01	1.0E-03	1.7E-07
4	RFETS	Fire in the baghouse area	--	X	--	--	1.6E-01	1.4E-02	3.0E-02	1.0E-02	1.0E+00	4.2E-06
4	RFETS	Earthquake followed by fire and explosion	--	--	X	--	1.6E-01	1.4E-02	2.0E-01	1.0E-01	1.0E+00	2.8E-04
4	SRS	Incineration ash explosion	X	--	--	--	2.1E-01	4.8E-01	1.2E-01	1.0E-01	1.0E-03	5.7E-06
4	SRS	Fire in the baghouse area	--	X	--	--	2.1E-01	4.8E-01	3.0E-02	1.0E-02	1.0E+00	1.4E-04
4	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.1E-01	4.8E-01	2.0E-01	1.0E-01	1.0E+00	9.5E-03
7	INEL	Explosion in the rotary kiln	X	--	--	--	1.5E-01	9.3E+00	1.2E-01	1.0E-01	1.0E-03	1.1E-04
7	INEL	Fire in the baghouse area	--	X	--	--	1.5E-01	9.3E+00	3.0E-02	1.0E-02	1.0E+00	2.8E-03
7	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.5E-01	9.3E+00	2.0E-01	1.0E-01	1.0E+00	1.9E-01

Table F.6–7. Frequencies and Radiological Source Term Parameters for WM LLMW Alpha Incineration Facility Accidents—Continued

			Frequency Bin (/yr)				Source Term Parameters					
WM PEIS Alternative[a]	Site[b]	Accident	>1.0E–02	1.0E–04 to 1.0E–02	1.0E–06 to 1.0E–04	<1.0E–06	VMAR (m^3)	MAR (Ci)	DF	RARF[c]	LPF[c]	Total Release (Ci)
7	LANL	Explosion in the rotary kiln	X	--	--	--	2.9E–02	4.0E–02	1.2E–01	1.0E–01	1.0E–03	4.8E–07
7	LANL	Fire in the baghouse area	--	X	--	--	2.9E–02	4.0E–02	3.0E–02	1.0E–02	1.0E+00	1.2E–05
7	LANL	Earthquake followed by fire and explosion	--	--	X	--	2.9E–02	4.0E–02	2.0E–01	1.0E–01	1.0E+00	8.1E–04
7	RFETS	Fire in the baghouse area	--	X	--	--	1.6E–01	1.4E–02	3.0E–02	1.0E–02	1.0E+00	4.2E–06
7	RFETS	Earthquake followed by fire and explosion	--	--	X	--	1.6E–01	1.4E–02	2.0E–01	1.0E–01	1.0E+00	2.8E–04
7	SRS	Explosion in the rotary kiln	X	--	--	--	2.1E–01	4.8E–01	1.2E–01	1.0E–01	1.0E–03	5.7E–06
7	SRS	Fire in the baghouse area	--	X	--	--	2.1E–01	4.8E–01	3.0E–02	1.0E–02	1.0E+00	1.4E–04
7	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.1E–01	4.8E–01	2.0E–01	1.0E–01	1.0E+00	9.5E–03
15	INEL	Explosion in the rotary kiln	X	--	--	--	1.5E–01	9.3E+00	1.2E–01	1.0E–01	1.0E–03	1.1E–04
15	INEL	Fire in the baghouse area	--	X	--	--	1.5E–01	9.3E+00	3.0E–02	1.0E–02	1.0E+00	2.8E–03
15	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.5E–01	9.3E+00	2.0E–01	1.0E–01	1.0E+00	1.9E–01
15	SRS	Explosion in the rotary kiln	X	--	--	--	2.1E–01	4.8E–01	1.2E–01	1.0E–01	1.0E–03	5.7E–06
15	SRS	Fire in the baghouse area	--	X	--	--	2.1E–01	4.8E–01	3.0E–02	1.0E–02	1.0E+00	1.4E–04
15	SRS	Earthquake followed by fire and explosion	--	--	X	--	2.1E–01	4.8E–01	2.0E–01	1.0E–01	1.0E+00	9.5E–03
17	Hanford	Explosion in the rotary kiln	X	--	--	--	1.6E–01	1.4E–02	1.2E–01	1.0E–01	1.0E–03	1.7E–07
17	Hanford	Fire in the baghouse area	--	X	--	--	1.6E–01	1.4E–02	3.0E–02	1.0E–02	1.0E+00	4.3E–06
17	Hanford	Earthquake followed by fire and explosion	--	--	X	--	1.6E–01	1.4E–02	2.0E–01	1.0E–01	1.0E+00	2.8E–04
26	INEL	Explosion in the rotary kiln	X	--	--	--	1.4E–04	1.5E–02	1.2E–01	1.0E–01	1.0E–03	1.8E–07
26	INEL	Fire in the baghouse area	--	X	--	--	1.4E–04	1.5E–02	3.0E–02	1.0E–02	1.0E+00	4.4E–06
26	INEL	Earthquake followed by fire and explosion	--	--	X	--	1.4E–04	1.5E–02	2.0E–01	1.0E–01	1.0E+00	2.9E–04

[a] The WM PEIS cases analyzed are described as follows:
- *Case 1 (No Action)*. Three sites (INEL, ORR, and SRS) treat and store, all remaining sites store.
- *Case 2 (Decentralized)*. Forty-nine sites treat, and 16 sites dispose.
- *Case 4 (Regionalized 1)*. Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) treat, and 12 sites dispose.
- *Case 7 (Regionalized 2)*. Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) treat, and 6 sites dispose.
- *Case 15 (Regionalized 4)*. Four sites (Hanford, INEL, ORR, and SRS) treat, and 6 sites dispose.
- *Case 17 (Centralized)*. One site treats (Hanford), and 1 site disposes.
- *Case 26 (Remote-handled)*. Four sites (Hanford, INEL, ORR, and SRS) treat and dispose (RH) and dispose

[b] See Table F.6–4 for determination of facility acronyms.

[c] Values shown are for particulate (nonvolatile) solids such as U-235 or Pu-238; see Appendix D.

F.7 Hazardous Waste

F.7.1 Alternatives and Sites Analyzed

The WM alternatives considered in the WM PEIS are summarized in Table F.7–1. The associated waste treatment categories are described in Table F.7–2. Calculational source term results for these alternatives are discussed herein.

A single site centralized alternative for the management of HW was not evaluated in the WM PEIS because the associated cost and risk, regulatory constraints, and practical considerations of attempting to manage all the diverse DOE waste classified as hazardous.

F.7.2 Risk-Dominant Accidents and Modeling Assumptions

The analysis herein develops distinct risk-dominant accident sequences and associated source terms for handling accidents, storage facility accidents, and treatment facility accidents. Accident scenarios involving chemical wastes that can (a) produce potentially life-threatening health effects and (b) have the potential for adverse health effects, were selected. Potential for adverse effects excluded carcinogenesis. Developing a category for carcinogenic effects alone would lead to accidents of negligible consequences, considering the specific chemicals present in the storage facilities. Consequently, only two categories of accidents were analyzed. The HW constituents of concern were chosen from the DOT list of poison inhalation hazards (PIHs) and from toxicological analyses for the determination of chemical wastes representative of potentially life-threatening health effects (Hartmann et al., 1994). Eleven sites that accept over 90% of the HW from the DOE complex were selected as representative of the DOE sites. Inventory data for the selected sites were taken from 1992 DOE HW shipment records. Because information on chemical concentrations is usually not given in HW inventory data, concentrations in industrial-grade products were assumed when modeling the source term from a release.

Table F.7–1. Hazardous Waste Alternatives

Alternative	Treat	ANL-E	FERMI	Hanford	INEL	KCP	LANL	LLNL	ORR	Pantex	SNL-NM	SRS
No Action	2				T				T			
Decentralized	3						T		T			T
Regionalized 1	5			T	T		T		T			T
Regionalized 2	2				T				T			

Note: T=Treatment. Blanks indicate that a site does not treat HW under the specified alternative.

Accidents were divided into three general categories, each having subcategories and including potentially life-threatening and any-adverse-effects end points:

- Spills resulting in partial vaporization of the waste ("pill only")
- Spills followed by ignition of the waste ("spill plus fire")
- "Other event combinations," which include
  - Spills followed by ignition of the waste and an induced explosion in a waste container ("spill plus fire plus explosion")
  - Facility fires resulting in a waste container breach ("fire only")
  - Mechanical failure of a compressed gas container resulting in an explosion ("spill and explosion")
  - Explosion from exposure of reactive material to air followed by fire ("fire and explosion")

Table F.7–3 lists the representative accidents chosen to serve as surrogates for all risk-dominant sequences and also lists associated mass of spill, release rate to the atmosphere, and annual frequency. Thirteen accidents involve the release of potentially life-threatening toxic gases. Five accidents (1e through 1g and 2e through 2f) involve the release of materials not considered potentially life-threatening but are analyzed for possible adverse effects. The development of the analysis is for these accidents took into account the following:

- The location proximity of classes of chemicals to each other in the storage facilities
- The typical designs of the storage facilities and the required separation of such groups of chemicals as flammable liquids, acids, caustics, combustibles, oxidizers, etc.
- The 90-day residence limit for RCRA HW in a storage facility, as it affects the MAR

Table F.7-2. Generic HW Treatment Categories and Descriptions

Treatment Capability	Abbreviation	Description
Organic destruction	ORDST	Destruction of organic liquids and solids by a broad spectrum of thermal and nonthermal technologies. Examples include incineration, vitrification, plasma hearth, molten metal, chemical oxidation, electron beam, and silent discharge plasma. Some of these technologies also apply to the STABL and METRC categories.
Aqueous liquids (wastewater treatment for organics)	WWTOR	Treatment technologies for oxidation of organics contained in predominantly aqueous media. Examples include wet oxidation, catalyzed wet oxidation, and supercritical water oxidation.
Metal removal	METRM	Metal ion and particulate removal from liquids by settling, filtration, precipitation, ion exchange, carbon adsorption, etc.
Stabilization	STABL	All immobilization and microencapsulation technologies (for example, cementation, vitrification, polymer encapsulation).
Metal recovery	METRC	Methods for separation and collection of metals from waste streams for reuse. Examples include sorting, melting, and decontamination.
Mercury separation	HGSEP	All Hg separation, collection, and immobilization methods. Examples include gravitational, thermal, and chemical techniques to separate Hg for recycling or for immobilization by amalgamation.
Decontamination	DECON	Extractive, mechanical, hydraulic, thermal, and electrochemical techniques used to remove contaminants from substrate materials.
Neutralization	NEUTR	Acid or base additions to neutralize waste streams.
Deactivation	DEACT	Appropriate technologies to deactivate reactive materials (such as sodium or uranium metal) or cyanides before disposal.

Table F.7-3. Airborne Release Assumptions for Representative HW Accidents

Scenario	Toxic Gas Released	Mass of Waste Spilled (lb)	Release Rate Functional Form (lb/min)	Annual Frequency (per Container-Handling[a] Operation)	Concentration Limit[b] PAEC Value	Concentration Limit[b] PLC Value
Spill						
(1a) Alkaline waste spill (i.e., NH_4OH) releasing moderately toxic by-products	NH_3	210 lb of 28% NH_4OH (59 lb)	0-10 min: 3 lb/min; 10-150 min: $3e^{-k_1(t-10)}$, c	2.0E-04	24.5	560
(1b) Acid waste spill (i.e., HCl) releasing moderately toxic vapor	HCl	450 lb of 37% HCl (166 lb)	0-10 min: 2 lb/min; 10-600 min: $2e^{-k_2(t-10)}$	2.0E-04	0.8	100
(1c) Acid waste spill (i.e., HF) releasing highly toxic vapor	HF	30 lb of 50% HF (15 lb)	0-10 min: 2 lb/min; 10-600 min: $2e^{-k_3(t-10)}$	2.0E-04	1	24
(1d) Fuming acid waste spill (i.e., HNO_3) releasing moderately toxic by-products	NO_x	30 lb of 70% HNO_3 (21 lb)	0-10 min: 1 lb/min; 10-100 min: $1e^{-k_4(t-10)}$	2.0E-04	0.41	350
(1e) Acid waste spill (i.e., $C_2H_4O_2$) releasing mildly toxic vapor	$C_2H_4O_2$	30 lb of 100% C_2H_4O2	0-10 min: 0.3 lb/min; 10-900 min: $0.3e^{-k_6(t-10)}$	2.0E-04	15	NA[d]
(1f) Volatile liquid spill (i.e., CS_2) releasing toxic vapor	CS_2	18 lb of 100% CS_2	0-3 min: 0.5 lb/min; 3-60 min: $0.5e^{-k_7(t-10)}$	2.0E-04	0.55	NA
(1g) Liquid spill (i.e., 1,1,1-trichloroethane) releasing mildly toxic vapor	1,1,1-trichloroethane	100 lb of 100% 1,1,1-trichloroethane	0-10 min: 40 lb/min	2.0E-04	31.2	NA
Spill Plus Fire[c]						
(2a) Spill of aromatic hydrocarbon (i.e., BTX) results in burning pool; polyaromatic hydrocarbon (PAH) soot and unburnt hydrocarbon (HC) become airborne	PAH soot and unburnt HC	250 lb of benzene (12% raw, 40% soot, and 48% Co_x)	0-120 min: 2.1 lb/min	2.0E-05	18.0	3,000
(2b) Spill of flammable liquid (e.g., toluene/acetone), which ignites (with help of $CaCl_2O_2$), and fire spreads to HF container	HF	10 lb of 50% HF (5 lb)	0-1 min: 5 lb/min (puff)	2.0E-05 probability of HF present	1	24
(2c) Spills and ignition of flammable liquid, engulfing nearby H_2SO_4, KCN, and NaCN containers, releasing only toxic HCN fumes	HCN	40 lb of organic solvents; 20 lb of H_2SO_4; 40 lb of KCN and NaCN	0-1 min: 40 lb/min (puff)	2.0E-05 probability of KCN present	1 mg/m^3	5 mg/m^3
(2d) Spills and ignition of flammable liquid, accelerated by $Na_2S_2O_8$ and NH_4NO_3, releasing Hg vapor from discarded Hg cells	Hg vapor	2,000 lb of naphtha; 630 lb of oxidizing agent; 50 lb of Hg cells	0-180 min: 2.8 lb/min	2.0E-05 probability of Hg present	0.01 mg/m^3	0.1 mg/m^3

Table F.7-3. *Airborne Release Assumptions for Representative HW Accidents—Continued*

Scenario	Toxic Gas Released	Mass of Waste Spilled (lb)	Release Rate Functional Form (lb/min)	Annual Frequency (per Container-Handling[a] Operation)	Concentration Limit[b] PAEC Value	Concentration Limit[b] PLC Value
(2e) Spills and ignition of flammable liquid, breaching nearby containers with Cd-containing compounds (i.e., Cd salts or Ni:Cd batteries)	Cd fumes	300 lb of CdO (17.5 lb of Cd fumes)	0-30 min: 10 lb/min (for fires of 950 °C)	2.0E-05 probability of Cd present	0.075 ppm	NA
(2f) Spills and ignition of flammable liquid, breaching nearby containers with dichromate salts (i.e., $Na_2Cr_2O_7$ or $K_2Cr_2O_7$)	Dust from burnt and unburnt dichromate salts	30 lb of dichromate dust	1-5 min: 6 lb/min	2.0E-05 × 1.2E-01 probability of dichromate salt present	0.1 mg/m^3	NA
Other						
(3a) Spills and ignition of flammable liquids; heat from fire causes explosion in compressed gas cylinder, venting NH_3	NH_3	Flammable liquid, 30.5 lb; compressed NH_3	0-5 min: 12 lb/min (puff)	2.0E-05 × 1.0E-02 probability of NH_3 present	24.5	560
(3b) Accidental confinement of oxidizing and reducing agents; reaction generates heat, igniting packaging and breaching nearby container	NH_3 or contents of any other nearby gas cylinder	NH_3 (60 lb)	0-5 min: 12 lb/min	3.0E-03 × probability of both agents present[f]	24.5	560
(3c) Accidental confinement of water with alkali-metal bases or alkali-earth oxides (i.e., Na_2O, K_2O, CaO); reaction generates heat, igniting packaging and breaching nearby containers	NH_3 or any other nearby gas cylinder	NH_3 (60 lb)	0-5 min: 12 lb/min	3.0E-03 × probability of both agents present[f]	24.5	560
(3d) Accidental rupture of compressed gas (NO_x; flammable) cylinder due to valve failure, releasing toxic gas	NH_3	Compressed gas (100 lb/container)	0-5 min: 100 lb/min	2.0E-05[g]	24.5	560
(3e) Accidental explosion (without previous spill) of diethyl ether peroxides formed by exposure to air; remaining diethyl ether ignites, spreading to nearby container	NH_3 or contents of any other nearby gas cylinder	Diethyl ether, 2 lb; 210 lb of NH_4OH (60 lb)	0-5 min: 12 lb/min	3.0E-03[h]	24.5	560

Notes: $CaCl_2$ = calcium hypochlorite; CaO = calcium oxide; CdO = cadmium oxide; $C_2H_4O_2$ = acetic acid; CS_2 = carbon disulfide; HCN = hydrogen cyanide; HF = hydrogen fluoride; HNO_3 = nitric acid; H_2SO_4 = sulfuric acid; KCN = potassium cyanide; $Na_2Cr_2O_7$ = sodium dichromate; Na_2O = sodium oxide; $Na_2S_2O_8$ = sodium persulfate; NH_3 = ammonia; NH_4NO_3 = ammonium nitrate; NH_4OH = ammonium hydroxide; and Ni = nickel.

a Number of containers at each site varies.

b Limits apply for a 15-minute exposure and are in parts per million (ppm) unless otherwise specified. PAEC = potential adverse effect concentration; and PLC = potential life-threatening concentration.

c Read as 3 × exp [-k (t-10)]; k_1 = 0.0145, k_2 = 0.0043, k_3 = 0.20, k_4 = 0.0494, k_6 = 0.0111, and k_7 = 0.2131; t = time (min).

d NA = not available.

e The assumption is that 1 in 10 spills will be ignited by a nearby spark (a conservative value) for an outdoor storage facility. When an accident scenario requires a number of initiating steps, involving more than one type of waste, the probability that all of the necessary constituents would be present at the same time must be included.

f The frequency of improper mixing of stored HW containers is approximately 3.0E-03 (according to Sasser [1992]).

g The value for the probability of compressed gas container breach is 1.0E-04 per container-handling operation; the value for breaching secondary containment is 1.0E-01.

h The frequency of improperly loading a container containing diethyl ether (allowing air to enter the container) is 3.0E-03 (according to Sasser [1992]).

The accident scenarios include a range from high-probability low-consequence accidents to high-consequence low-probability accidents. In general, the scenarios involve chemical or physical change in stored materials subsequent to an initial incident. Equations were written to represent the changes anticipated to occur during the accidents. Toxic gaseous products were identified, and the masses generated during an event were estimated from the mass of the reactants and the stoichiometry of the reactions. The annual frequency of accidents includes both the spill frequency and, where appropriate, the probability that all of the agents are present at the same time. Rates of releases were estimated based on the engineering judgement and the recognition that such rates usually decay exponentially with time. Obviously, the exact course of an accident is shaped by a multitude of factors, including (but not limited to) temperature, humidity, pooling versus spreading of spills, the exact composition and concentration of reactive materials (often unknown), and the proximity and nature of nearby reactive materials (including packaging, shelving, and flooring). Appendix H in ANL (1996a) provides details on the selection of the accident scenarios, on the chemistry involved in their progress, and on the estimation of the rates of release of the toxic gases.

The probability of an accident depends on the throughput of the waste type or types involved. The subsequent progression of some accident scenarios requires specific additional waste types to be in proximity to the initiating container; for instance, accident subcategory 2d is dependent on the probability that flammable liquids, accelerants, and Hg cells are being stored near one another.

A release is defined as some form of airborne release in terms of vapor, gas, aerosol, or particulates from the original chemical or the reaction product. Recall that all hazardous chemical releases were placed into one of 18 subcategories, depending on the category of accident (for example, spill or spill plus fire), the range of accidents within the category, and the particular health end point. Many chemicals in the inventory of each site pose no risk from release and therefore did not need to be considered further. The HW inventories for FY 1992 for 12 DOE sites (the 11 referred to earlier and NTS) were analyzed to determine the most representative set. Detailed chemical knowledge and engineering judgment were used to assign chemicals to categories. Accident risk during storage is dependent on the number of drums and the average masses of the chemicals placed in each category. Once each accident category was defined, the mass of a released chemical, the elapsed time for release, and the release rates were determined by the use of mass balance equations and consideration of vapor pressure and heat of vaporization at room temperature (ANL, 1996a).

F.7.2.1 Packaged Waste Storage and Handling Operations

Hazardous wastes are first accumulated in drums or laboratory packs at the source (laboratory or shop) and then are shipped to a centralized storage facility. Handling accidents during storage or staging operations are expected to dominate the risk of chemical releases to workers because of the frequency of handling and the proximity of the workers. Ignition or explosion of containers due to chemical reactions originating from container-loading errors have also been considered in handling accidents for HW.

F.7.2.1.1 *Material at Risk and Damage Fraction*

Because storage packages are typically plastic-lined, carbon steel 55-gal drums, the MAR for handling-accident scenarios is assumed to be one drum. Double containment with an intervening packing of absorbent material is typical of packaged chemically hazardous liquids; however, consistent with previous analyses, the assumption is made that the liquid is completely spilled (that is, DF = 1.0E+00) upon breach of the waste package (Salazar and Lane, 1992; ORNL, 1993).

F.7.2.1.2 *Spill Scenario Frequencies*

The frequency of container breaches is on the order of 1.0E–04 per handling operation (see Section F.2.7.1). Because HW storage facilities are allowed to hold materials for 90 days as a maximum, all of the containers that arrive at a facility are assumed to be shipped out within 90 days. Two handling operations per container of waste stored at the facility (one loading and one unloading) were assumed. Consistent with the discussion in Section F.2.7.1, the annual frequency for a spill from a container breach for chemical x due to a handling accident can then be given by

$$f_{sx} = 0.0002\, n_x \ , \qquad \text{(F.7–1)}$$

where n_x is the number of waste containers of chemical x received annually at the facility.

F.7.2.1.3 *Spill Plus Fire Scenario Frequencies*

The frequency of occurrence for subcategory 3a (the spill, ignition, and atmospheric release of chemical x) is given by

$$f_{sfx} = f_{sx} P_f \ , \qquad \text{(F.7-2)}$$

where P_f is the conditional probability of ignition (1E–01 for outdoor storage pads and 2E–01 for enclosed facilities) (Section F.2). The frequency of occurrence in accident subcategories 2b through 2f (the spill and ignition of a flammable chemical, followed by fire propagation and release of chemical y) depends on the concurrent presence of the flammable initiator and the container with the toxic chemical contents:

$$f_{sty} = 0.0002 \, n_f P_f P_{fy} + 0.0002 \, n_y P_f \ , \qquad \text{(F.7-3)}$$

where n_f is the number of flammable chemical containers, and P_{fy} is the conditional probability that fires involving the flammable chemicals propagate to and ignite the contents of drums containing chemical y. The expression P_{fy} is approximated by the ratio of the number of drums of chemical y to the total number of containers. The second term in the expression is added only if chemical y is also flammable.

F.7.2.1.4 *Frequencies of Other Event Combinations*

Accident subcategory 3a involves a spill and subsequent fire, which then induces an explosion. One SAR (EG&G, 1990) lists a value of 2.0E–02 for the annual probability of a fire-induced explosion sufficient to rupture the end walls of a facility. The reference scenario herein assumes the explosion of a compressed gas cylinder engulfed in fire. The frequency is given by

$$f_{sfey} = 0.0002 \, n_f P_f P_{fy} P_e \ , \qquad \text{(F.7-4)}$$

where the probability P_{fy} of a drum or cylinders being engulfed is estimated as the approximate fraction of drums containing compressed gas cylinders and where P_e, the conditional probability that the engulfed gas canister will explode, is assumed conservatively to be 1.0E+00.

Fire-only scenarios 3b and 3c involve the inadvertent mixing of incompatible wastes. Human error probabilities between 1.0E–03 and 3.0E–03 are reported (Trusty et al., 1989; Sasser, 1992) for loading or sorting a chemical in the wrong place. Subsequent chemical reactions then generate enough heat to ignite the packaging material with a frequency estimated by

$$f_{frc} = 0.003\, n_{rc} \ , \qquad \text{(F.7–5)}$$

where n_{rc} is the number of containers containing potentially reactive chemical *rc* (or its equivalent) that are received annually at the facility. The surrogate toxic gas assumed to be released during the accident is ammonia (NH_3).

The fire may then spread to other containers and result in a release of toxic chemicals; however, the probability that a reaction among incompatible wastes will generate enough heat to ignite nearby combustible material (that is, paper or cardboard) is expected to be relatively small. The combustible material closest to the containers is usually a cardboard pallet, which requires temperatures of over 232 °C to ignite. Furthermore, the frequency with which containers of toxic waste are stored in proximity to the potential fire needs to be considered. Given the combination of events needed to result in other toxic gas releases, only the NH_3 release is treated herein.

Accident subcategory 3d involves a mechanical breach and subsequent explosion of cylinders of compressed gases. Such cylinders are expected to be stored inside drums, thus providing double-walled storage of the compressed gas. The annual frequency of double-walled container breach per unit handling operation is estimated as 1.0E–05, implying an order of magnitude credit for the second containment, which is probably conservative, given that conditional breach probabilities after a drop are estimated at 1.0E–02. Thus, the frequency of a handling accident resulting in an explosion of compressed gas cylinder *x* is conservatively estimated as

$$f_{secg} = 0.00002\, n_{cg} \ , \qquad \text{(F.7–6)}$$

where n_{cg} is the number of drums with compressed gas containers received annually at the facility.

The spontaneous fire and explosion scenario 3e corresponds to a waste fire and explosion induced by an error in the loading of the waste containers. Some chemicals react violently on contact and must be segregated. The gases produced by such reactions may produce enough pressure inside containers to cause explosions, with resulting container failure. The frequency of this scenario is

$$f_{ferx} = 0.003\, n_{rx} \ , \qquad \text{(F.7–7)}$$

where n_{rx} is the number of containers containing potentially reactive chemical *rx* (or its equivalent) that are received annually at the facility. The spontaneous formation of peroxides upon exposure of ether to air (and the later ignition of those peroxides) is considered here to be an error in loading. In reality, ether should never be stored for extended periods because of this very problem.

F.7.2.2 Storage Facility Accidents

Hazardous wastes are generally packaged in 55-gal drums and stored in RCRA-compliant staging areas or weather protection sheds before offsite shipment for commercial treatment and disposal. A HWSF typically houses over 100 different chemicals, which may include chlorinated solvents, acids, bases, photographic chemicals, ignitable solids and liquids, compressed gases, metal salts, polychlorinated biphenyls, asbestos, and other regulated wastes. Because explosives are generally prohibited, the important hazard characteristics include volatility, flammability, dispersibility, and toxicity. The HW is characterized and segregated on the basis of toxicity, corrosivity, reactivity, and ignitability. Most HWSFs have containment berm areas and individual storage cells that permit waste segregation per RCRA and EPA criteria; some HWSFs have fire detection and suppression capability, and some have forced ventilation. Because of the great diversity of storage facility designs among the DOE sites, a generic facility with segregated storage (Figure F.2–5) was assumed in the analyses.

A facility-wide fire has been chosen as the representative internal accident. This fire is the type of accident scenario considered as the maximum reasonably foreseeable accident in the INEL HWSF SAR (EG&G, 1990). The fire would engulf a large fraction of the facility, could include secondary explosions and fire propagation from one area to another, and would consume numerous chemicals that vent hazardous substances on combustion or heating.

Externally initiated events have also been evaluated. The relevant chemicals identified in the operational accidents are assumed to be involved in the facility accident, with the amount of each chemical in facility sequences assumed to be proportional to the numbers of drums that, on average, are present at the facility.

A facility fire is the dominant sequence for aircraft impacts; a large spill resulting from numerous breached containers is the dominant sequence for earthquakes.

The chemicals in the facility fire source term are those identified as particularly hazardous in spills with fire (Table F.7–3). The sum of the amounts of these particularly hazardous chemicals defines the MAR, with the release rate and duration for each chemical the same as those for the individual drum fires. The DF is assumed to be 1.0E+00 because the accident scenario assumes no mitigation. In the representative seismic event, the assumption is that 1% of the containers fall and break (DF of 1.0E–02), leading to a large spill of varied chemicals. The externally induced fires (large- and small-aircraft impacts) result in a combined MAR that includes the hazardous releases in a facility-wide fire plus the hazardous releases due to explosions caused by fires or impacts. The representative chemicals in these accidents are shown in Table F.7–3. As in the case of facility fires, the DF for aircraft-induced accidents is taken as 1.0E+00.

Conditional probabilities for ignition and fire attendant upon violent breach of packages of flammable liquid are estimated to lie between 1.0E–01 and 1.0E+00 (ORNL, 1993). An initiating event frequency of 1.0E–02/yr for a fire involving local propagation is assumed here. A frequency of 1.0E–02 for failure of the segregation design, the fire suppression systems, or manual procedures is assumed, yielding a resulting facility-wide fire frequency of 1.0E–04/yr.

The frequencies of the external initiators are dependent on the site, as discussed in Section F.2.6. A conditional probability of container breach of 1.0E+00 has been used for large-airplane impacts and 9.0E–01 for small-airplane impacts, consistent with the LLW storage facility analysis (LLW and HW are both generally packaged in DOT 55-gal drums). For earthquakes, the best estimate (Kennedy et al., 1990) of the annual frequency of events with a peak ground acceleration exceeding 0.15 g at the different sites is taken as the frequency of seismic initiation. A ground acceleration of 0.15 g is assumed to be the minimum acceleration required to topple drums in the upper rows of a storage array. A conditional probability of 2.0E–01 for subsequent drum breach and spill, consistent with the LLW event tree analysis, has been used.

F.7.2.3 Treatment Facility Accidents

Evaluations show that incineration is also the risk-dominant thermal treatment technology for HW. Because SARs for both radioactive waste incinerators and commercial HW incinerators assign a high frequency to kiln explosions, the representative accident is taken to be an explosion that initiates a fire in the waste in the feedstock area. Three externally initiated events (large- and small-aircraft impacts and seismic events) that ignite a feedstock fire are also analyzed. A generic treatment facility, consisting of a series of linked treatment process modules, was described in Section F.2.6.3. A DOE Hazard Category of 2, concomitant performance of its systems, and double HEPA filtration systems were assumed.

The representative source term chemicals are those that were identified as particularly hazardous in case of a fire. The MAR is a fraction of the annual throughput of the incineration facility as established by the WM PEIS alternative. Information from commercial facilities indicates that only a few containers (a few hours' worth of throughput) are kept in the feedstock area. Therefore, 1% of the annual throughput was assumed to be in the staging area. This fraction represents the amount of waste in processing and lag storage. The DF depends on the magnitude of the initiator and is assumed to be 1.0E–01 for internal explosions, 2.0E–01 for seismic events and small-airplane crashes, and 3.0E–01 for large-airplane impacts. These values were assumed because of the scattered physical locations of the waste in the treatment facility and the fact that only some of the chemicals in the feedstock area were identified as airborne release hazards in Table F.7–3.

Estimates (discussed in Section F.2.7.3.5) of an annual frequency of 1.5E–02/yr for explosions in the rotary kiln assembly and in the SCC agree with the experience of commercial incineration operators and provide the basis for the internal fire frequencies used herein. The frequencies of aircraft-initiated accidents are dependent on the site. The frequencies were obtained in the same manner as those for the storage facilities. The conditional probabilities of containment and confinement rupture and fire initiation are consistent with those in the LLW accident analysis: 4.5E–01 and 1.0E–02 for large- and small-airplane crashes, respectively. The annual frequency of a seismic event exceeding the design basis for a Category 2 facility is 1.0E–03/yr. As in the LLW facility accident analysis, the conditional probability of rupturing containment and initiating a fire is estimated at 5.0E–02.

F.7.3 Results

The airborne release parameters for all accident types were shown in Table F.7–3. Table F.7–4 summarizes the estimated frequencies for the different handling accidents in the no-action decentralized, regionalized alternatives for each DOE site on the basis of the appropriate surrogate chemical inventories. Single-drum inventories are assumed for the handling accidents.

Table F.7–4. Site-Dependent Annual Frequencies of Representative HW Handling Accidents

Site/Event[a]	Decentralized Alternative						
Spill	(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)
ANL-E	1.00E-03	3.00E-03	8.00E-04	6.80E-03	4.00E-04	2.00E-04	1.20E-03
Fermi	0	0	0	8.00E-04	0	0	2.00E-04
Hanford	1.80E-03	1.00E-03	4.00E-04	7.20E-03	4.00E-04	0.00E+00	3.20E-03
INEL	2.60E-03	5.40E-03	6.00E-04	6.00E-03	0.00E+00	0.00E+00	3.60E-03
KCP	1.60E-03	0.00E+00	0.00E+00	2.00E-04	0.00E+00	0.00E+00	0.00E+00
LLNL	6.40E-03	3.08E-02	4.40E-03	5.84E-02	7.60E-03	4.00E-04	2.26E-02
LANL	3.60E-03	6.20E-03	3.60E-03	4.22E-02	3.60E-03	0.00E+00	7.60E-03
ORR	0	0	0	0	0	0	1.00E-03
Pantex	0	2.20E-03	4.00E-04	1.22E-02	2.00E-04	0	0
SNL-NM	4.20E-03	0.00E+00	8.20E-03	2.96E-02	8.00E-04	0.00E+00	6.40E-03
SRS	2.00E-04	0.00E+00	0.00E+00	1.50E-02	1.56E-02	0.00E+00	4.00E-04
Spill Plus Fire	(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	
ANL-E	8.00E-05	7.29E-04	3.19E-04	1.00E-03	1.82E-04	1.37E-04	
Fermi	0.00E+00	6.67E-05	6.67E-05	1.78E-04	0	0	
Hanford	4.00E-05	7.58E-04	9.48E-05	2.13E-04	1.90E-04	7.11E-05	
INEL	6.00E-05	1.34E-03	7.17E-05	2.15E-04	7.89E-04	2.63E-04	
KCP	0.00E+00	1.80E-03	2.95E-05	5.60E-04	1.18E-04	0.00E+00	
LLNL	4.40E-04	8.09E-03	5.04E-04	1.20E-03	8.16E-04	3.12E-04	
LANL	3.60E-04	3.20E-03	3.45E-04	0.00E+00	5.98E-04	4.37E-04	
ORR	0.00E+00	2.51E-03	0.00E+00	3.81E-05	3.81E-05	0.00E+00	
Pantex	4.00E-05	2.48E-03	5.52E-05	5.52E-04	3.31E-04	0.00E+00	
SNL-NM	8.20E-04	2.74E-03	3.62E-04	3.28E-03	2.31E-03	3.85E-04	
SRS	0	7.24E-03	2.78E-05	2.31E-03	2.37E-03	0	
Other Event	(3a)	(3b)	(3c)	(3d)	(3e)		
ANL-E	1.39E-05	3.00E-03	9.30E-02	2.80E-04	1.20E-02		
Fermi	0	0	3.00E-03	1.40E-04	0		
Hanford	3.33E-05	3.00E-03	6.60E-02	1.40E-04	1.20E-02		
INEL	5.09E-05	3.00E-03	1.47E-01	1.60E-04	2.70E-02		
KCP	7.57E-05	3.00E-03	9.00E-03	4.40E-04	3.00E-03		
LLNL	1.28E-04	1.20E-02	5.04E-01	6.40E-03	1.02E-01		
LANL	5.39E-05	1.80E-02	8.16E-01	1.48E-03	2.40E-02		
ORR	0	0	0	0	0		
Pantex	0	3.00E-03	1.02E-01	0.00E+00	3.00E-03		
SNL-NM	5.57E-05	8.40E-02	2.67E-01	1.26E-03	6.90E-02		
SRS	7.84E-06	0.00E+00	2.10E-01	0.00E+00	2.10E-02		

Table F.7-4. Site-Dependent Annual Frequencies of Representative HW Handling Accidents—Continued

Site/Event[a]	Regionalized Alternative						
Spill	(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)
Hanford	8.20E-03	3.22E-02	4.80E-03	6.56E-02	8.00E-03	4.00E-04	2.58E-02
INEL	2.60E-03	5.40E-03	6.00E-04	6.00E-03	0.00E+00	0.00E+00	3.60E-03
LANL	7.80E-03	8.40E-03	1.22E-02	8.40E-02	4.60E-03	0.00E+00	1.40E-02
ORR	2.60E-03	3.00E-03	8.00E-04	7.80E-03	4.00E-04	2.00E-04	2.40E-03
SRS	2.00E-04	0.00E+00	0.00E+00	1.50E-02	1.56E-02	0.00E+00	4.00E-04
Spill Plus Fire	(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	
Hanford	4.80E-04	7.38E-03	5.00E-04	1.18E-03	8.40E-04	3.20E-04	
INEL	6.00E-05	1.12E-03	6.00E-05	1.80E-04	6.60E-04	2.20E-04	
LANL	1.22E-03	7.00E-03	6.60E-04	3.30E-03	2.80E-03	7.20E-04	
ORR	8.00E-05	3.24E-03	3.60E-04	1.44E-03	2.60E-04	1.20E-04	
SRS	0.00E+00	5.20E-03	2.00E-05	1.66E-03	1.70E-03	0.00E+00	
Other Event	(3a)	(3b)	(3c)	(3d)	(3e)		
Hanford	7.85E-09	1.50E-02	5.70E-01	6.54E-03	1.14E-01		
INEL	0.00E+00	3.00E-03	1.47E-01	1.60E-04	2.70E-02		
LANL	0.00E+00	1.05E-01	1.19E+00	2.74E-03	9.60E-02		
ORR	7.28E-09	6.00E-03	1.05E-01	8.60E-04	1.50E-02		
SRS	0.00E+00	0.00E+00	2.10E-01	0.00E+00	2.10E-02		

Site/Event[a]	Centralized Alternative						
Spill	(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)
East	2.80E-03	3.00E-03	8.00E-04	2.28E-02	1.60E-02	2.00E-04	2.80E-03
West	1.86E-02	4.60E-02	1.76E-02	1.56E-01	1.26E-02	4.00E-04	4.34E-02
Spill Plus Fire	(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	
East	8.00E-05	8.44E-03	3.80E-04	3.10E-03	1.96E-03	1.20E-04	
West	1.76E-03	1.55E-02	1.22E-03	4.66E-03	4.31E-03	1.26E-03	
Other Event	(3a)	(3b)	(3c)	(3d)	(3e)		
East	7.41E-09	6.00E-03	3.15E-01	8.60E-04	3.60E-02		
West	3.76E-09	1.23E-01	1.90E+00	9.44E-03	2.37E-01		

[a] Refer to Table F.7-3 for definitions of accidents and released chemicals.

Tables F.7–5 and F.7–6 summarize the results for the storage and treatment facility accidents by site and alternative. The column labeled "Total Number of Containers" represents the MAR (that is, the total number of containers with the relevant chemicals for each accident that are estimated to be involved in accidents at the facility). The "Number of Containers Breached" is the product of the containers at risk and the DF. The remaining columns in the tables provide the breakdown of the total number of containers involved in the accident for each of the various relevant surrogate chemicals.

Table F.7–5. Frequencies and Source Term Parameters for WM HW Storage Facility Accidents

WM PEIS Alternative[a]	Site	Accident Frequency (per year)	Total Number of Containers	DF	Total Number of Containers Breached	Representative Subcategory Chemical Containers Involved[b]						
Representative Fire						(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	
1	INEL	1.0E-04	29	1.0E+00	29	14	1	1	2	8	3	
	KCP	1.0E-04	21	1.0E+00	21	15	0	0	5	1	0	
	LLNL	1.0E-04	119	1.0E+00	119	84	6	5	13	8	3	
	LANL	1.0E-04	56	1.0E+00	56	35	5	4	0	7	5	
	ORR	1.0E-04	17	1.0E+00	17	17	0	0	0	0	0	
	Pantex	1.0E-04	33	1.0E+00	33	23	1	1	5	3	0	
	Hanford	1.0E-04	15	1.0E+00	15	8	1	1	2	2	1	
	SNL-NM	1.0E-04	109	1.0E+00	109	30	10	4	36	25	4	
	SRS	1.0E-04	107	1.0E+00	107	65	0	0	21	21	0	
	ANL-E	1.0E-04	28	1.0E+00	28	8	1	4	11	2	2	
	Fermi	1.0E-04	4	1.0E+00	4	1	0	1	2	0	0	
2	INEL	1.0E-04	29	1.0E+00	29	14	1	1	2	8	3	
	Hanford	1.0E-04	94	1.0E+00	94	64	5	4	11	7	3	
	LANL	1.0E-04	151	1.0E+00	151	69	12	7	27	26	8	
	ORR	1.0E-04	52	1.0E+00	52	33	1	3	12	2	1	
	SRS	1.0E-04	107	1.0E+00	107	65	0	0	21	21	0	
3	INEL	1.0E-04	361	1.0E+00	361	194	24	16	58	53	16	
	ORR	1.0E-04	177	1.0E+00	177	106	1	5	39	24	2	
Seismic Events						(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)
1	INEL	1.8E-04	24	1.0E-02	0	0	0	0	0	0	0	0
	KCP	6.0E-05	2	1.0E-02	0	0	0	0	0	0	0	0
	LLNL	1.0E-03	165	1.0E-02	2	0	1	0	1	0	0	0
	LANL	6.0E-04	86	1.0E-02	1	0	0	0	1	0	0	0
	ORR	4.0E-04	1	1.0E-02	0	0	0	0	0	0	0	0
	Pantex	6.0E-05	19	1.0E-02	0	0	0	0	0	0	0	0
	Hanford	6.0E-05	19	1.0E-02	0	0	0	0	0	0	0	0
	SNL-NM	6.0E-04	61	1.0E-02	1	0	0	0	1	0	0	0

Table F.7–5. Frequencies and Source Term Parameters for WM HW Storage Facility Accidents—Continued

WM PEIS Alternative[a]	Site	Accident Frequency (per year)	Total Number of Containers	DF	Total Number of Containers Breached	Representative Subcategory Chemical Containers Involved[b]							
Seismic Events (Cont.)						(1a)	(1b)	(1c)	(1d)	(1e)	(1f)	(1g)	
	SRS	8.0E–05	40	1.0E–02	0	0	0	0	0	0	0	0	
	ANL-E	1.0E–04	17	1.0E–02	0	0	0	0	0	0	0	0	
	Fermi	1.0E–04	1	1.0E–02	0	0	0	0	0	0	0	0	
2	INEL	1.8E–04	24	1.0E–02	0	0	0	0	0	0	0	0	
	Hanford	6.0E–05	129	1.0E–02	1	0	0	0	1	0	0	0	
	LANL	6.0E–04	139	1.0E–02	1	0	0	0	1	0	0	0	
	ORR	4.0E–04	14	1.0E–02	0	0	0	0	0	0	0	0	
	SRS	8.0E–05	40	1.0E–02	0	0	0	0	0	0	0	0	
3	INEL	1.8E–04	374	1.0E–02	4	0	1	0	2	0	0	1	
	ORR	4.0E–04	61	1.0E–02	1	0	0	0	1	0	0	0	
Large-Aircraft Impacts						(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	(3a)	(3d)
1	INEL	2.0E–09	34	1.0E+00	34	14	1	1	2	8	3	3	2
	KCP	--	29	--	--	--	--	--	--	--	--	-	-
	LLNL	--	207	--	--	--	--	--	--	--	--	-	-
	LANL	--	80	--	--	--	--	--	--	--	--	-	-
	ORR	--	17	--	--	--	--	--	--	--	--	-	-
	Pantex	2.3E–07	33	1.0E+00	33	23	1	1	5	3	0	0	0
	Hanford	8.5E–09	19	1.0E+00	19	8	1	1	2	2	1	2	2
	SNL-NM	2.1E–05	130	1.0E+00	130	30	10	4	36	25	4	5	16
	SRS	8.2E–09	107	1.0E+00	107	65	0	0	21	21	0	0	0
	ANL-E	--	33	--	--	--	--	--	--	--	--	-	-
	Fermi	--	6	--	--	--	--	--	--	--	--	-	-
2	INEL	2.0E–09	34	1.0E+00	34	14	1	1	2	8	3	3	2
	Hanford	8.5E–09	157	1.0E+00	157	64	5	4	11	7	3	7	3
	LANL	--	189	--	--	--	--	--	--	--	--	-	-
	ORR	--	62	--	--	--	--	--	--	--	--	-	-

Table F.7-5. Frequencies and Source Term Parameters for WM HW Storage Facility Accidents—Continued

WM PEIS Alternative[a]	Site	Accident Frequency (per year)	Total Number of Containers	DF	Total Number of Containers Breached	Representative Subcategory Chemical Containers Involved[b]							
						(2a)	(2b)	(2c)	(2d)	(2e)	(2f)	(3a)	(3d)
Large-Aircraft Impacts (Cont.)													
	SRS	8.2E-09	107	1.0E+00	107	65	0	0	21	21	0	0	0
3	INEL	2.0E-09	503	1.0E+00	503	194	24	16	58	53	16	23	119
	ORR	--	192	--	--	--	--	--	--	--	--	--	--
Small-Aircraft Impacts													
1	INEL	--	34	--	--	--	--	--	--	--	--	--	--
	KCP	2.70E-07	29	1.0E+00	29	15	0	0	5	1	0	2	6
	LLNL	2.70E-07	207	1.0E+00	207	84	6	5	13	8	3	8	80
	LANL	2.70E-07	80	1.0E+00	80	35	5	4	0	7	5	5	19
	ORR	2.70E-07	17	1.0E+00	17	17	0	0	0	0	0	0	0
	Pantex	--	33	--	--	--	--	--	--	--	--	--	--
	Hanford	--	19	--	--	--	--	--	--	--	--	--	--
	SNL-NM	--	130	--	--	--	--	--	--	--	--	--	--
	SRS	--	107	--	--	--	--	--	--	--	--	--	--
	ANL-E	2.70E-07	33	1.0E+00	33	8	1	4	11	2	2	1	4
	Fermi	2.70E-07	6	1.0E+00	6	1	0	1	2	0	0	0	2
2	INEL	--	34	--	--	--	--	--	--	--	--	--	--
	Hanford	--	157	--	--	--	--	--	--	--	--	--	--
	LANL	2.70E-07	189	1.0E+00	189	71	12	7	27	26	8	8	30
	ORR	2.70E-07	62	1.0E+00	62	33	1	3	12	2	1	2	8
	SRS	--	107	--	--	--	--	--	--	--	--	--	--
3	INEL	--	503	--	--	--	--	--	--	--	--	-	--
	ORR	2.70E-07	192	1.0E+00	192	106	1	5	39	24	2	3	12

Note: -- = not applicable.

[a] Case 1 is the No Action/Decentralized alternative with two treatment sites. Case 2 is the Regionalized 1 alternative with five treatment sites. Case 3 is the Regionalized 2 alternative with two treatment sites.

[b] Refer to Table F.7-3 for definitions of released chemicals.

Table F.7-6. Frequencies and Source Term Parameters for WM HW Incineration Facility Accidents

WM PEIS Alternative[a]	Site	Accident Frequency (per year)	Total Number of Containers	DF	Number of Containers Breached	Representative Subcategory Chemical Containers Involved[b]					
						2a	2b	2c	2d	2e	2f
Representative Fire											
2	INEL	1.5E-02	20	1E-01	2	1	0	0	0	1	0
	LANL	1.5E-02	50	1E-01	5	3	0	0	1	1	0
	ORR	1.5E-02	50	1E-01	5	2	1	0	1	1	0
	Hanford	1.5E-02	30	1E-01	3	2	0	0	1	0	0
	SRS	1.5E-02	20	1E-01	2	1	0	0	1	0	0
3	INEL	1.5E-02	80	1E-01	8	5	1	0	1	1	0
	ORR	1.5E-02	80	1E-01	8	5	0	0	2	1	0
Seismic Events											
2	INEL	5.0E-05	20	2E-01	4	2	0	0	0	1	1
	LANL	5.0E-05	50	2E-01	10	7	1	0	1	1	0
	ORR	5.0E-05	50	2E-01	10	5	1	0	2	2	0
	Hanford	5.0E-05	30	2E-01	6	4	0	1	1	0	0
	SRS	5.0E-05	20	2E-01	4	2	0	0	1	1	0
3	INEL	5.0E-05	80	2E-01	16	9	1	1	3	2	0
	ORR	5.0E-05	80	2E-01	16	10	0	1	3	2	0
Large-Aircraft Impacts											
2	INEL	1.2E-09	20	3E-01	6	3	0	0	0	2	1
	LANL	--	--	--	--	--	--	--	--	--	--
	ORR	--	--	--	--	--	--	--	--	--	--
	Hanford	5.4E-09	30	3E-01	9	6	0	1	2	0	0
	SRS	5.0E-09	20	3E-01	6	4	0	0	1	1	0
3	INEL	2.7E-09	80	3E-01	24	12	2	1	4	4	1
	ORR	--	--	--	--	--	--	--	--	--	--
Small-Aircraft Impacts											
2	INEL	--	--	--	--	--	--	--	--	--	--
	LANL	7.0E-09	50	2E-01	10	6	1	1	1	1	0
	ORR	7.0E-09	50	2E-01	10	5	1	0	2	2	0
	Hanford	--	--	--	--	--	--	--	--	--	--
	SRS	--	--	--	--	--	--	--	--	--	--
3	INEL	--	--	--	--	--	--	--	--	--	--
	ORR	7.0E-09	80	2E-01	16	10	0	1	3	2	0

Note: -- = not applicable.
[a] Case 1 is the No Action/Decentralized Alternative with two treatment sites. Case 2 is the Regionalized 1 Alternative with five treatment sites. Case 3 is the Regionalized 2 Alternative with two treatment sites.
[b] Refer to Table F.7-3 for definitions of released chemicals.

F.7.4 REFERENCES

ANL. *See* Argonne National Laboratory.

American Institute of Chemical Engineers. 1989. *Guidelines for Process Equipment Reliability Data With Data Tables*. New York: Center for Chemical Process Safety.

Argonne National Laboratory. 1996a. *Analysis of Accident Sequences and Source Terms at Waste Treatment and Storage Facilities for Waste Generated by U.S. Department of Energy Waste Management Operations* by C. Mueller, B. Nabelssi, J. Roglans-Ribas, S.M. Folga, A. Policastro, W. Freeman, R. Jackson, S. Turner, and J. Mishima. ANL/EAD/TM-29. Argonne, IL.

Argonne National Laboratory. 1996b. *WASTE_MGMT: A Computer Model for Calculation of Waste Loads, Profiles, and Emissions* by T.J. Kotek, H.I. Avci, and B.L. Koebnick. ANL/EAD/TM-30. Argonne, IL.

Argonne National Laboratory. 1996c. *High-Level Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by S.M. Folga, G. Conzelmann, J.L. Gillette, P.H. Kier, and L.A. Poch. ANL/EAD/TM-17. Argonne, IL.

Argonne National Laboratory. 1996d. *WASTE_ACC: A Computer Model for Analysis of Waste Management Accidents* by B.K. Nabelssi, S.M. Folga, E.J. Kohout, C.J. Mueller, and J. Roglans-Ribas. ANL/EAD/TM-52. Argonne, IL.

Argonne National Laboratory. 1996e. *Supplemental Analysis Sequences and Source Terms for Waste Treatment and Storage Operations and Related Facilities for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by S.M. Folga, C.J. Mueller, B.K. Nabelssi, E.J. Kohout, and J. Mishima. ANL/EAD/TM-53. Argonne, IL.

Avci, H., L. Habegger, and T. Kotek. 1994. "Methodology for Integrated Evaluation of Alternative Siting and Treatment, Storage, and Disposal Strategies for U.S. Department of Energy Waste Management," in vol. 2, *WM '94: Working Towards a Cleaner Environment: Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education: Technology and Programs for*

Radioactive Waste Management and Environmental Restoration, ed. R.G. Post. 975-980. Tucson, AZ: Laser Options, Inc.

Ayer, J.E., et. al. 1988. *Nuclear Fuel Cycle Facility Accident Analysis Handbook.* NUREG-1320. Washington, DC: U.S. Nuclear Regulatory Commission. May.

Benchmark. *See* Benchmark Environmental Corporation.

Benchmark Environmental Corporation. 1994. *Preliminary Safety Analysis Report for the Retrieval of Transuranic Waste from Pads 1, 2, and 4 at TA-54, Area 6.* CST7G-REPORT-001, R.O. Prepared for Los Alamos National Laboratory.

Benhardt, H.C., and J.E. Held. 1994. *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities.* WSRC-TR-93-581. Feb. Aiken, SC: Westinghouse Savannah River Co.

Braun, D.J., S.E. Lindberg, M.F. Reardon, and G.P. Wilson. 1993. *Hanford Waste Vitrification Project Building Limited Scope Assessment.* WHC-SA-1544. Richland, WA: Westinghouse Hanford Co.

Coats, D.W., and R.C. Murray, 1984. *Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites.* UCRL-5382. Nov. Livermore, CA: Lawrence Livermore Laboratory.

Davis, M.L., and D.G. Satterwhite. 1989. *Fire Hazards Analysis of the Radioactive Waste Management Complex Air Support Buildings.* EGG-WM-8703. Sept. Idaho Falls, ID: EG&G Idaho, Inc.

DOE. *See* U.S. Department of Energy.

DOT. *See* U.S. Department of Transportation.

Du Pont. *See* E.I. Du Pont de Nemours and Co.

EG&G. 1990. *Safety Analysis Report for the Hazardous Waste Storage Facility.* EG&G-WM-PD-88-014-Rev. 1. Nov. Idaho Falls, ID: EG&G Idaho, Inc.

EG&G. 1992a. *Final Safety Analysis Report and Technical Safety Requirements for Building 910*. March. Golden, CO: EG&G Rocky Flats, Inc.

EG&G. 1992b. *Preliminary Safety Analysis Report for Building 374: Addendum*. Dec. Golden, CO: EG&G Rocky Flats, Inc.

EG&G. 1992c. *Draft Environmental Assessment: Idaho National Laboratory Low-Level and Mixed Waste Processing*. Dec. Draft. Idaho Falls, ID: EG&G Idaho, Inc.

EG&G. 1993a. *Mixed Low-Level Waste Systems Analysis Methodology and Applications Report*. Sept. Draft. Idaho Falls, ID: EG&G Idaho, Inc.

EG&G. 1993b. *Radioactive Waste Management Complex Safety Analysis Report*. EGG-WM-10881. Sept. Draft. Idaho Falls, ID: EG&G Idaho, Inc.

EG&G. 1994a. *DOE Programmatic Spent Nuclear Fuel and Waste Management Environmental Impact Statement*. Appendix J — Accident Analysis. June. Idaho Falls, ID: EG&G Idaho, Inc.

EG&G. 1994b. *Safety Analysis Report for the Waste Storage Facility*. EGG-WM-10774, Rev. 2. May. Idaho Falls, ID: EG&G Idaho, Inc.,

E.I. Du Pont de Nemours and Co. (Du Pont). 1987. *Safety Assessment Document: Consolidated Incineration Facility*. DPSTAD-200-6. Oct. Approved Draft. Aiken, SC: Savannah River Laboratory.

E.I. Du Pont de Nemours and Co. 1989. *CIF Fire Analysis*, Aiken, SC.

Electric Power Research Institute (EPRI). 1979. *Status Report on the EPRI Fuel Cycle Accident Risk Assessment*. EPRI-NP-1128. July. Research project 767-1. Palo Alto, CA.

EPRI. *See* Electric Power Research Institute.

Hartmann, H.M., A.J. Policastro, and M.A. Lazaro. 1994. "Hazardous Waste Transportation Risk Assessment for the U.S. Department of Energy Environmental Restoration and Waste Management Programmatic Environmental Impact Statement: Human Health Endpoints," in vol. 2, *WM '94: Working Towards a Cleaner Environment: Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education: Technology and Programs for Radioactive Waste Management and Environmental Restoration,* ed. R.G. Post. 1107–1114. Tucson, AZ: Laser Options, Inc.

Herborn, D.I., and D.A. Smith. 1990. *Hanford Waste Vitrification Plant Preliminary Safety Analysis Report*. WHC-EP-0250. July Draft. Rev. B. Richland, WA: Westinghouse Hanford Co.

Idaho Operations Office. 1982. *Environmental Evaluation of Alternatives for Long-Term Management of Defense High-Level Radioactive Wastes at the Idaho Chemical Processing Plant*. IDO-10105. Sept. Idaho Falls, ID.

Kennedy, R.P., et al. 1990. *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards.* UCRL-15910. June. Livermore, CA: Lawrence Livermore National Laboratory.

Machida, N., Y. Katano, Y. Kamiya, L.J. Jardine, and J. Hoekwater. 1989. "Conceptual Design of a High-Level Vitrified Waste Storage Facility," in *Proceedings of the 1989 Joint International Waste Management Conference Presented at Kyoto, Japan, October 22-28, 1989: High Level Radioactive Waste and Spent Fuel Management*, ed. F. Feizollahi. 291-296. New York: American Society of Mechanical Engineers.

McDonell, W.R., and C.M. Jantzen. 1986. "Effects of Waste Content of Glass Waste Forms on Savannah River High-Level Waste Disposal Costs," in *High-Level Nuclear Waste Disposal: Proceedings From the American Nuclear Society International Topical Meeting of High-Level Nuclear Waste Disposal: Technology and Engineering*. Sept. Columbus, OH.

Mishima, J., et al. 1986. *Potential Radiological Impacts of Upper-Bound Operational Accidents During Proposed Disposal Alternatives for Hanford Defense Waste*. PNL-5356. Richland, WA: Pacific Northwest Laboratory.

NRC. *See* U.S. Nuclear Regulatory Commission.

Oak Ridge National Laboratory. 1993. *ORRSF Preliminary Safety Analysis Report.* Y/ENG/PSAR-73. July Draft. Oak Ridge, TN: Martin Marrietta Energy Systems, Inc.

Oak Ridge National Laboratory. 1994. *Safety Analysis Report for the Waste Storage Facility, Building 7574.* ORNL/WM-SWO/7574/SAR/RO. Dec. Oak Ridge, TN.

ORNL. *See* Oak Ridge National Laboratory.

Pinkston, D. 1993. *U.S. Department of Energy Defense Programs Safety Survey Report.* DOE/DP/70056-H1. Nov. Washington, DC: U.S. Department of Energy.

RFETS. *See* Rocky Flats Environmental Technology Site.

Rocky Flats Environmental Technology Site, 1994, *Final Safety Analysis Report: Building 306, Centralized Waste Storage Facility.* Rev. 0. Aug. Golden, CO.

Salazar, R.J., and S. Lane. 1992. *Final Safety Analysis Document for Building 693 Chemical Waste Storage Building at Lawrence Livermore National Laboratory.* UCRL-ID-109144. Livermore, CA: Feb. Lawrence Livermore National Laboratory.

Sasser, M.K. 1992. "Probabilistic Safety Analysis for TA-63, Hazardous Waste Treatment Facility." Memorandum from M.K. Sasser (Los Alamos National Laboratory, Los Alamos, NM) to G. Lussiez. Sept.

Trusty, A.D., L.N. Haney, and D.G. Satterwhite. 1989. *Hazards Assessment of the Hazardous Waste Storage Facility*. EGG-PRA-4032. March. Idaho Falls, ID: Idaho National Engineering Laboratory.

U.S. Department of Energy. 1982. *Automatic Sprinkler System Performance and Reliability in United States Department of Energy Facilities, 1952-1980.* DOE/EP-0052. June. Washington, DC.

U.S. Department of Energy. 1987. *Safety Analysis and Review System.* DOE Order 5481.1B. May. Washington, DC.

U.S. Department of Energy. 1989. *General Design Criteria*. DOE Order 6430.1A. May. Washington, DC: Office of Project and Facilities Management.

U.S. Department of Energy. 1990a. *Final Supplement Environmental Impact Statement: Waste Isolation Pilot Plant*. DOE/EIS-0026-FS. Jan. Washington, DC.

U.S. Department of Energy. 1990b. *Waste Isolation Pilot Plant Final Safety Analysis Report*. WP-02-9-Rev. 0. May. Washington, DC.

U.S. Department of Energy. 1991a. *Draft Environmental Impact Statement for the Siting, Construction, and Operation of New Production Reactor Capacity*. DOE/EIS-0144D. April. Washington, DC: Office of New Production Reactors.

U.S. Department of Energy. 1991b. *Draft Analysis of the Environmental Effects of the Waste Receiving and Processing Facility Module*. Predecisional information. March. Washington, DC.

U.S. Department of Energy. 1991c. *Analysis of the Environmental Effects of the Waste Receiving and Processing Facility Module 2, Hanford Site, Richland, Washington*. WRAP-2. Predecisional Draft. Sept. Washington, DC.

U.S. Department of Energy. 1992a. *Retrieval and Re-Storage of Transuranic Storage Area Waste at the Idaho National Engineering Laboratory: Environmental Assessment*. DOE/EA-0499. Feb. Washington, DC: Office of Environmental Restoration and Waste Management.

U.S. Department of Energy. 1992b. *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*. DOE-STD-1027-92. Dec. Washington, DC.

U.S. Department of Energy. 1993a. *Recommendations for the Preparation of Environmental Assessments and Impacts Statements*. May. Washington, DC: Office of National Environmental Policy Act Oversight.

U.S. Department of Energy. 1993b. *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*. DOE-STD-1021-93. July. Washington, DC.

U.S. Department of Energy. 1993c. *Natural Phenomena Hazards Mitigation*. DOE Order 5480.28. Jan. Washington, DC: Office of Nuclear Energy.

U.S. Department of Energy. 1993d. *Nuclear Safety Analysis Reports*. DOE Order 5480.23. April. Washington, DC: Assistant Secretary of Nuclear Energy.

U.S. Department of Energy. 1993e. *Fire Protection*. DOE Order 5480.7A. Feb. Washington, DC: Assistant Secretary for Environment, Safety and Health.

U.S. Department of Energy. 1994a. *Natural Phenomena Hazards Design and Evaluation Criteria*. DOE-STD-1020-94. Feb. Draft. Washington, DC.

U.S. Department of Energy. 1994b. *Airborne Release Fractions/Rates and Respirable Fractions at DOE Nonreactor Facilities*. DOE-HDBK-3010-94. Nov. Washington, DC.

U.S. Department of Energy. 1995. *Savannah River Site Waste Management Draft Environmental Impact Statement Volume II*. DOE/EIS-0217D. Jan. Washington, DC.

U.S. Department of Energy. 1996. *Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement*. DOE/EIS-0026-S-2. Nov. Washington, DC.: Office of Environmental Management.

U.S. General Accounting Office. 1993. *Hanford Tank Waste Program Needs: Cost, Schedule, and Management Changes*. GAO/RCED-93-99. March. Washington, DC.

U.S. Nuclear Regulatory Commission (NRC). 1988. *Nuclear Fuel Cycle Facility Accident Analysis Handbook*. NUREG-1320. May.

West Valley Nuclear Services Co., Inc. 1994. *Safety Analysis Report for Vitrification System Operations and High-Level Waste Interim Storage*. WVNS-SAR-003. Rev.2. Draft C. March 28. West Valley, NY: West Valley Nuclear Services Co., Inc.

Westinghouse Electric Corp. 1991. *Waste Isolation Pilot Plant Fire Hazards and Risk Analysis*. DOE/WIPP-91-031. Pittsburgh, PA: Nuclear and Advanced Technology Division.

Westinghouse Hanford Co. 1991a. *Hazard Classification and Preliminary Safety Evaluation for Waste Receiving and Processing Facility (WRAP): Module 2: Project W100*. June Draft. Richland, WA.

Westinghouse Hanford Co. 1991b. *Hazard Classification and Preliminary Safety Evaluation for Waste Receiving and Processing Facility: Module 1: Project W026*. WHD-SD-W026-PSE-001-Rev. 0. Richland, WA.

Westinghouse Savannah River Co. (WSRC). 1990. *Safety Analysis: 200-S Area Savannah River Site Defense Waste Processing Facility Operations (U)*. DPSTSA-200-10-Rev. 1 SUP-20. Feb. Aiken, SC: Westinghouse Savannah River Co.

Westinghouse Savannah River Co. 1994. "Analysis of Operations." Chapter 9 in *Defense Waste Processing Facility Safety Analysis Report*. DPSTSA-200-10, supplement 20, Rev. 9. Jan. Aiken, SC.

WHC. *See* Westinghouse Hanford Co.

WSRC. *See* Westinghouse Savannah River Co.

Appendix G

Pollution Prevention

U.S. Department of Energy
Waste Management Programmatic Environmental Impact Statement

Contents

Tables

Acronyms and Abbreviations

The following is a list of acronyms and abbreviations (including units of measure) used in this appendix.

Ames	Ames Laboratory
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
BCL	Batelle Columbus Laboratories
Bettis	Bettis Atomic Power Laboratory
BNL	Brookhaven National Laboratory
CISS	Colonie Interim Storage Site
CH	contact-handled
Charleston	Charleston Naval Shipyard
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EO	Executive Order
EPCRA	Emergency Planning and Community Right-to-Know Act
ER	environmental restoration
ETEC	Energy Technology Engineering Center
FEMP	Fernald Environmental Management Project
Fermi	Fermi National Accelerator Laboratory
g	gram(s)
GA	General Atomics
GJPO	General Junction Projects Office
h	hour(s)
Hanford	Hanford Site
HLW	high-level waste
HW	hazardous waste
INEL	Idaho National Engineering Laboratory
ITRI	Inhalation Toxicology Research Institute
KAPL-K	Knolls Atomic Power Laboratory (Kesselring)
KAPL-S	Knolls Atomic Power Laboratory (Schenectady)
KAPL-W	Knolls Atomic Power Laboratory (Windsor)
KCP	Kansas City Plant
kg	kilogram(s)
km^2	square kilometer(s)
K-25	Oak Ridge K-25 Site

LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LDR	land disposal restrictions
LEHR	Laboratory for Energy-Related Health Research
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level radioactive waste
m^3	cubic meter(s)
Mare Is	Mare Island Naval Shipyard
MAWS	Minimum Additive Waste Stabilization
mi^2	square mile(s)
Mound	Mound Plant
mrem	millirem(s)
nCi	nanocurie(s)
Norfolk	Norfolk Naval Shipyard
NTS	Nevada Test Site
ORR	Oak Ridge Reservation
Pantex	Pantex Plant
Pearl H	Pearl Harbor Naval Shipyard
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Naval Shipyard
PP	pollution prevention
PPOA	pollution prevention opportunity assessment
PPPL	Princeton Plasma Physics Laboratory
Puget So	Puget Sound Naval Shipyard
PWA	process waste assessment
RCRA	Resource Conservation and Recovery Act
RDDT&E	Research, Development, Demonstration, Testing, and Evaluation
R&D	research and development
RFETS	Rocky Flats Environmental Technology Site
RH	remote-handled
RMI	Reactive Metals, Inc.
SNL-CA	Sandia National Laboratories (California)
SNL-NM	Sandia National Laboratories (New Mexico)
SRS	Savannah River Site
TRUW	transuranic waste
TSD	treatment, storage, and disposal
UofMO	University of Missouri (Columbia)
VOCs	volatile organic compounds

WAC	waste acceptance criteria
WIPP	Waste Isolation Plant Project
WM	waste management
WMin/PP	waste minimization and pollution prevention
WM PEIS	Waste Management Programmatic Environmental Impact Statement
WVDP	West Valley Demonstration Project
Y-12	Oak Ridge Y-12 Plant
yr	year(s)

APPENDIX G
Pollution Prevention

G.1 DOE's Pollution Prevention Program

A quantitative evaluation of the potential effect of pollution prevention is included in the WM PEIS in response to public comments during the scoping process (DOE, 1994a). Within the U.S. Department of Energy (DOE), pollution prevention encompasses those activities that involve source reduction and recycling of all waste and pollutants and includes those practices that reduce or eliminate pollutants through increased efficiency in the use of raw materials, energy, water, or other resources, or the protection of natural resources by conservation. The term "source reduction" can be applied to any practice that reduces the amount of any hazardous substance, pollutant, or contaminant that enters any waste stream or that otherwise is released into the environment prior to recycling, treatment, or disposal. Source reduction also describes any practice that reduces the hazards to public health and the environment associated with the release of any such substances, pollutants, or contaminants (DOE, 1994b).

Waste Minimization/Pollution Prevention (WMin/PP) programs derive from the Pollution Prevention Act of 1990 (Public Law 101-508, November 5, 1990), which established a national strategy for waste management and pollution control. This strategy places primary reliance on source reduction, followed by environmentally safe recycling, treatment, and disposal. DOE Order 5400.1, "General Environmental Protection Program" (DOE, 1988), requires that DOE facilities develop a WMin/PP plan as part of an environmental protection plan. The purpose of this appendix is to discuss how DOE's pollution prevention programs and practices may affect the waste loads that waste management (WM) facilities receive, and, consequently, the need for such facilities. This appendix contains estimates of reductions in waste loads, estimated risks associated with WM activities, and estimated WM costs resulting from pollution prevention practices.

On August 3, 1993, President Clinton issued Executive Order (EO) 12856, "Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements" (EO, 1993). To help ensure that Federal agencies manage their facilities so that the objectives of the Pollution Prevention Act are met to the maximum extent practicable, EO 12856 requires agencies to develop voluntary goals to reduce their total releases of toxic chemicals or toxic pollutants to the environment and offsite transfers of such toxic chemicals or toxic pollutants by 50% by December 31, 1999.

Subsequent to the issuance of EO 12856, the Secretary of Energy on December 28, 1993, directed that DOE's policy shall be to embrace pollution prevention as the DOE's strategy to reduce the generation of all waste streams and thus minimize the impact of DOE operations on the environment, as well as improving the safety of operations and energy efficiencies. The Secretary further directed cognizant Secretarial Offices in DOE to identify, plan, and allocate funds for field implementation of WMin/PP activities during the Departmental budget and review process so that there is an identified budget dedicated to pollution prevention activities each year.

On December 27, 1994, the Secretary of Energy approved a Departmental pollution prevention strategy for compliance with EO 12856. DOE has a pollution prevention strategy that requires DOE sites to engage in pollution prevention and to have an established program for implementing this policy. In approving the Departmental strategy, the Secretary directed that information on progress made toward meeting the milestones and achieving the goals set forth in the strategy are to be included in site pollution prevention awareness plans and in Annual Reports to the Secretary on Waste Generation and Waste Minimization Progress. Specific milestones and goals contained in the approved strategy include the following:

- Achieve a Departmentwide 50% reduction of total releases of toxic chemicals to the environment and offsite transfers of such toxic chemicals from the baseline year by December 31, 1999.
- Establish a Departmentwide plan, with goals, to eliminate or reduce unnecessary acquisitions of hazardous substances or toxic chemicals.
- Establish a Departmentwide plan, with goals, to reduce DOE manufacture, process, and use of extremely hazardous substances and toxic chemicals.
- Review DOE standards and specifications to identify opportunities to eliminate or reduce unnecessary acquisitions of hazardous or toxic substances by August 31, 1995, and complete all necessary revisions by December 31, 1998.

In accordance with DOE's policy on pollution prevention, DOE issued the 1994 Waste Minimization/ Pollution Prevention Crosscut Plan (DOE 1994b), which established Departmentwide goals to meet the targets of EO 12856. The 1994 crosscut plan, as well as the approved DOE strategy for compliance with EO 12856, calls for each DOE site to establish site-specific goals to reduce the generation and use of radioactive materials and other hazardous materials to the extent practicable. The 1994 crosscut plan focuses on wastes and pollutants generated within DOE and includes an activity plan. The outline of the activity plan, as presented in Table G-1, attempts to fully integrate WMin/PP practices into DOE operations.

Table G-1. Outline of the WMin/PP Activity Plan

1. WMin/PP Policy Direction Activities	
1.1 Establish goals to minimize waste generation	Each DOE site will set quantitative WMin/PP goals and implement plans for achieving these goals.
1.2 Establish senior management commitment and follow-through for DOE WMin/PP activities	All DOE and contractor organizations will translate the Secretarial WMin/PP policy into policies specific to their sites or programs and be accountable for incorporating WMin/PP into routine operations.
1.3 Distinguish WMin/PP budget allocations through activity data sheets	Specific WMin/PP budgets will be established through preparation of separate Activity Data Sheets.
1.4 Promote regulatory review and reform	The Department will work with regulators and stakeholders to ensure that the best waste management practices are evaluated and incorporated into Federal and State regulations and laws.
1.5 Update DOE policies, orders, and procedures to integrate WMin/PP	DOE policies, orders, and procedures will be updated to reflect the Department's focus on integrating WMin/PP objectives into all activities.
2. WMin/PP Infrastructure Development	
2.1 Standardize material and tracking systems	The Department will develop standards and criteria to measure materials and wastes and provide performance requirements for materials and waste tracking systems.
2.2 Estimate waste management costs for use in decision making	The Department will develop standards for estimating the costs and benefits of introducing WMin/PP changes into its operations.
2.3 Facilitate WMin/PP technology transfer and information exchange	The Department will enhance existing systems to optimize WMin/PP technology transfer and information exchange within the DOE complex.
2.4 Develop a DOE WMin/PP incentives program	The Department will acknowledge and reward reductions in waste generation and environmental releases.
2.5 Develop and conduct WMin/PP employee training and awareness programs	The Department will operate a comprehensive WMin/PP training program that considers all applicable job-specific situations.
2.6 Develop and implement a WMin/PP outreach and public relations program	The Department will inform government agencies and local communities of WMin/PP accomplishments and invite them to participate in environmental activities and initiatives.
3.1 Develop and maintain consistent sitewide WMin/PP programs at all sites	The Department will provide core sitewide WMin/PP activities and services at every site. It will clarify its organizational roles and responsibilities to ensure stable funding and consistent management of its sitewide WMin/PP programs.

Table G-1. Outline of the WMin/PP Activity Plan—Continued

3. WMin/PP Program Implementation	
3.2 Develop and maintain consistent generator-specific programs	The Department will require that waste-generating organizations include appropriate WMin/PP concepts and techniques into their program operations and other activities such as weapons disassembly, decontamination and decommissioning, and environmental restoration.
3.3 Perform opportunity assessments and identify WMin/PP projects	The Department, acting to minimize total costs, will perform opportunity assessments and identify and implement WMin/PP projects that show a rapid (within 36 months) return on investment.
3.4 Design WMin/PP into new products, processes, and facilities	The Department will integrate WMin/PP into all new design criteria.
3.5 Integrate WMin/PP into research, development, and demonstration programs	The Department will couple waste generation and R&D communities to ensure that WMin/PP R&D projects offering the greatest technical benefit are available to generator organizations.
3.6 Modify procurement practices to promote WMin/PP	The Department will promote the purchase of less toxic, more durable, more energy-efficient materials.
3.7 Develop multimedia WMin/PP strategies	The Department will require that all operations develop and implement engineering design-based pollution and waste prevention strategies, process chemistry and technology strategies, operations-based WMin/PP strategies, and maintenance-based proactive strategies.

Source: Appendix C of DOE (1994b).

DOE's WMin/PP practices in 1991 and 1992 are described in the WMin/PP annual report (DOE, 1993b). The following are some examples of WMin/PP practices:

- Substitution of nonhazardous (or less hazardous) for more hazardous solvents. For example, substitution reduced the use of naphtha-based solvents by 90% at the Pantex Plant. Several sites substituted a less harmful material for 1,1,1-trichloroethane.
- Resale to outside manufacturers of virgin chemicals that have exceeded the stringent shelf life requirements of the weapons programs.
- Offsite reclamation of lead batteries (lead acid, gel-cells, and nickel-cadmium), waste oil, and photo fixer for silver reclamation.
- Onsite reclamation and recycling of antifreeze, Freon, and waste oil.
- Implementation of a chemical exchange program whereby chemicals no longer needed were made available for use by other scientists who would otherwise buy additional chemicals.

- Offsite recycle of Freon and methylene chloride resulting in recovery for reuse of approximately 80% of the solvent.
- Replacement of flammable scintillation cocktails with a nonhazardous, biodegradable material that eliminated a mixed waste stream at Brookhaven National Laboratory.

A procedure that may identify opportunities and be a component of a facility's pollution prevention program is the process waste assessment (PWA), also known as a pollution prevention opportunity assessment (PPOA). A PPOA is an analysis of a process or activity to identify opportunities to eliminate or reduce the generation of waste or the consumption of raw materials, water, or energy. Once identified, opportunities are evaluated and compared to determine the most efficient and cost-effective option.

The approach used reflects one method of estimating waste minimization impacts in the absence of installation-specific goals for the reduction of wastes and pollution. A 50% reduction in the future generation of waste to be handled in WM treatment, storage, and disposal (TSD) facilities has been assumed. Cost and risk reductions for the operation of waste management TSD facilities have been calculated based on this assumption. The other factor in cost calculations not yet available is the probable cost of achieving this 50% level of waste generation in the operating facilities that generate the waste. In some instances, such as capital equipment investments to meet the goal, the cost could be substantial and the net dollar gain through pollution prevention would be lower than projected. Since these latter costs cannot yet be calculated, they are considered beyond the scope of this Waste Management Programmatic Environmental Impact Statement (WM PEIS).

G.2 Effect of Pollution Prevention on Waste Management Activities

Executive Order 12856 requires the Secretary of Energy and the heads of other Federal agencies to ensure that the agency develop voluntary goals to either reduce the agency's total release of toxic chemicals to the environment and offsite transfers of such toxic chemicals for treatment and disposal by 50%, or to plan for a 50% reduction in the release or offsite transfer of toxic pollutants. The Executive Order defines toxic chemicals to be those chemicals for which toxic chemical release forms shall be completed pursuant to section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA). Toxic pollutants include toxic chemicals. Federal agencies may choose to include other substances such as extremely hazardous chemicals as defined by EPCRA or hazardous wastes as defined under the Resource Conservation and Recovery Act as toxic pollutants.

The 1994 WMin/PP crosscut plan states that site-specific goals for reduction of wastes and pollution will be set. The Executive Order does not expressly refer to the various waste types; rather, it refers to and defines toxic chemicals and toxic pollutants. The DOE's interpretation of the Executive Order, whether ultimately strict or broad, will influence site-specific goals. It can be expected that these goals will call for source reductions of at least 50% in the aggregate. Source reduction and recycling would be greater than 50% for some waste streams and less than 50% for other waste streams. However, as site-specific pollution prevention plans may not be waste-stream-specific, a simple assumption is made that source reduction and recycling will result in a 50% reduction in the annual transfer to WM of each waste stream for each year of the time spans considered in the WM PEIS. This assumption does not represent the flexibility allowed by DOE policy; more precise estimates require the definition of site-specific goals. However, recent DOE experience indicates that more than a 50% source reduction is achievable for some waste streams.

G.2.1 Waste Types Addressed

DOE's pollution prevention program applies to all DOE activities and all types of waste that these activities generate. This appendix emphasizes pollution prevention as it relates to four waste types: (1) low-level radioactive waste (LLW), (2) low-level mixed waste (LLMW), (3) hazardous waste (HW), and (4) transuranic waste (TRUW). Because high-level waste (HLW) is no longer being generated, pollution prevention activities cannot be applied to HLW.

Much of DOE's pollution prevention policy is directed toward source reduction, which affects WM by reducing the quantity of waste that is transferred to its facilities. Source reduction by generators in Defense Programs, Energy Research, and other DOE offices will affect WM operations significantly by reducing the amount and radioactivity level of waste that WM handles. Source reduction could result in fewer shipments of waste and in either TSD facilities with smaller capacities or fewer TSD facilities.

The following sections contain estimates of reductions in the waste loads to TSD facilities, the cost of constructing and operating these facilities, and the human health risks to the public and workers from a 50% reduction in the annual generation of the four waste types described in WM PEIS Chapters 6–10. The impact of a given percentage reduction in general depends on the existing inventory of waste. If the inventory is large compared with annual generation, then a reduction in annual generation will have little effect because most of the waste processed will be from the inventory. On the other hand, if the inventory is small compared with annual generation, a reduction in annual generation will have a greater effect. For the four waste types considered, existing inventories are most significant for TRUW and least significant for HW.

G.2.2 Low-Level Waste

Estimates of the effect of source reduction on LLW facilities are based on information in the LLW technical report (ANL, 1996a), the WM facility human health risk appendix (Appendix D), and the waste management costs technical report (INEL, 1995a). LLW is divided into 10 waste categories (for example, combustible, surface-contaminated bulk metals and equipment) that define how the waste is treated. Two alternatives with volume reduction treatment (incineration, supercompaction, size reduction, and grout stabilization) are considered here. Regionalized Alternative 2 has volume reduction treatment at 11 sites and disposal at 12 sites; Regionalized Alternative 5 has such treatment at 4 sites and disposal at 6 sites. The waste inventory and annual generation information does not include waste transferred to waste management from environmental restoration (ER) operations. Some of these categories of waste are amenable to recycling. For example, surface-contaminated metals and equipment could be decontaminated and recycled.

G.2.2.1 Waste Load Reductions

Estimates of the effect of pollution prevention are given in Table G-2 for treatment waste loads and in Table G-3 for disposal waste loads. These tables contain waste loads based on current annual generation and waste loads when a 50% decrease in annual generation is assumed. The waste loads are based on the waste inventory and 20 years of annual generation being treated and disposed of in 10 years. It is assumed, in effect, that the inventory and waste generated for 10 years are stored until the treatment facilities become available during a second 10-year period. This assumption does not apply to aqueous waste and saltstone waste at SRS, which will be treated and disposed of over 20 years. Thus, the treatment and disposal waste loads in Tables G-2 and G-3 are for the second 10-year period. The effect of the first 10 years of operation (for aqueous waste and saltstone at SRS) is mainly on the need for disposal capacity. Existing capacity by technology is also given in these tables so that the effect of pollution prevention practices on the need for new capacity can be assessed.

Table G–2. Effect of Pollution Prevention on Waste Management LLW Treatment Waste Loads (Second 10 Years of Treatment)

Treatment Site	Treatment Technology	Existing Capacity (m^3/yr)	Regionalized 2 (m^3/yr)		Regionalized 5 (m^3/yr)	
			Current	WMin/PP[a]	Current	WMin/PP[a]
FEMP	Thermally treat	--	7.7E+02	4.4E+02	*	*
	Solidify	--	3.5E+01	2.0E+01	*	*
	Supercompact	--	NA	NA	*	*
	Size reduce	--	1.0E+02	6.4E+01	*	*
Hanford	Thermally treat	--	5.3	3.0	3.5E+01	2.0E+01
	Solidify	--	5.3E+01	3.0E+01	5.5E+01	3.1E+01
	Supercompact	4.0E+03	4.8E+03	2.4E+03	5.0E+03	2.5E+03
	Size reduce	--	3.1E+03	2.0E+03	3.2E+03	2.0E+03
INEL	Thermally treat[b]	2.3E+03	1.7E+03	1.0E+02	1.0E+04	5.8E+03
	Solidify	2.8E+04	1.0E+03	5.8E+02	1.3E+03	7.4E+02
	Supercompact	5.7E+03	6.8E+02	3.3E+02	5.7E+03	2.9E+03
	Size reduce	5.0E+03	2.1E+03	1.3E+03	7.1E+03	4.5E+03
LANL	Thermally treat	--	5.6E+03	3.2E+03	*	*
	Solidify	--	2.6E+02	1.3E+02	*	*
	Supercompact	--	4.8E+03	2.7E+03	*	*
	Size reduce	--	1.1E+03	6.9E+02	*	*
LLNL	Thermally treat	--	2.9E+01	1.7E+01	*	*
	Solidify	--	2.1E+02	1.2E+02	*	*
	Supercompact	1.5E+03	1.2E+02	5.9E+01	*	*
	Size reduce	1.2E+02	7.5E+01	4.8E+01	*	*
ORR	Thermally treat[b]	--	2.4E+02	1.4E+02	3.1E+03	1.8E+03
	Solidify[c]	--	7.9E+02	4.4E+02	9.3E+02	5.3E+02
	Supercompact	1.4E+03	4.4E+03	2.2E+02	5.0E+03	2.5E+03
	Size reduce	--	1.6E+04	1.0E+04	2.7E+04	1.7E+04
Pantex	Thermally treat	-	NA	NA	*	*
	Solidify	--	6.6E-02	3.8E-02	*	*
	Supercompact	1.1E+03	1.8E+01	1.0E+01	*	*
	Size reduce	--	2.4E+02	1.5E+02	*	*
PGDP	Thermally treat	--	5.4E+02	3.1E+02	*	*
	Solidify[c]	--	5.4E+01	3.1E+01	*	*
	Supercompact	--	5.8E+02	2.9E+02	*	*
	Size reduce	--	9.4E+01	5.9E+01	*	*
PORTS	Thermally treat	--	1.5E+03	8.8E+02	*	*
	Solidify	--	1.3E+02	7.2E+01	*	*
	Supercompact	--	6.9E+01	3.5E+01	*	*
	Size reduce	--	1.1E+04	6.9E+03	*	*

Table G-2. Effect of Pollution Prevention on Waste Management LLW Treatment Waste Loads (Second 10 Years of Treatment)—Continued

Treatment Site	Treatment Technology	Existing Capacity (m^3/yr)	Regionalized 2 (m^3/yr)		Regionalized 5 (m^3/yr)	
			Current	WMin/PP[a]	Current	WMin/PP[a]
RFETS	Thermally treat	--	2.8E+03	1.6E+03	*	*
	Solidify	--	2.6E+02	1.5E+02	*	*
	Supercompact	5.6E+03	5.9	3.0	*	*
	Size reduce	--	4.2E+02	2.7E+02	*	*
SRS	Thermally treat[b]	8.2E+03	1.5E+03	8.3E+02	1.5E+03	8.3E+02
	Solidify	2.1E+02	2.0E+03	1.1E+03	2.0E+03	1.1E+03
	Supercompact	4.0E+03	9.4E+03	4.7E+03	9.4E+03	4.7E+03
	Size reduce	--	9.2E+02	5.8E+02	9.2E+02	5.8E+02

Notes: -- = no existing capacity; * = not a treatment site for this alternative.
[a] The pollution prevention case assumes a 50% reduction in annual generation. When the waste inventory to be worked off over 10 years is taken into account, the waste loads are 57.5%, 56.6%, 50.4%, and 62.5% of the no reduction waste loads for thermal treatment, solidification, supercompaction, and size reduction, respectively.
[b] There are thermal treatment facilities at INEL, ORR, and SRS; these are assumed to be dedicated to treating LLMW and unavailable for LLW.
[c] For ORR and PGDP, the existing solidification capacities are assumed to be adequate to meet the no action waste loads.

Table G-3. Effect of Source Reductions on Waste Management LLW Disposal Waste Loads (Second 10 Years of Disposal)

Disposal Site	Existing Disposal Capacity (m^3/yr)	Regionalized 2 (m^3/yr)		Regionalized 5 (m^3/yr)	
		Current	WMin/PP[a]	Current	WMin/PP
Hanford	8.5E+03	2.1E+03	1.1E+03	2.1E+03	1.1E+03
INEL	3.9E+03	3.9E+03	2.0E+03	4.7E+03	2.6E+03
NTS	4.5E+04	1.8E+02	9.1E+01	2.7E+02	1.4E+02
LANL	1.3E+03	5.1E+03	2.7E+03	6.4E+03	3.5E+03
ORR	6.0E+02	1.3E+04	8.2E+03	4.1E+04	2.3E+04
SRS	5.4E+03	4.5E+04	2.3E+04	4.6E+04	2.3E+04
PORTS	+	1.2E+04	6.3E+03	*	*
PGDP	+	4.2E+03	2.1E+03	*	*
LLNL	+	6.2E+02	3.1E+02	*	*
Pantex	+	2.9E+02	1.8E+02	*	*
RFETS	+	1.0E+03	6.3E+02	*	*

Notes: + = no existing capacity; * = not a disposal site for this case.
[a] The pollution prevention results are based on a 50% reduction in annual generation. However, the volumes disposed of decrease by less than 50% because the category-dependent inventory is also being disposed of.

The waste loads for the pollution prevention cases with a 50% reduction in annual generation are more than 50% of the base cases, that is, a 50% reduction in annual generation rate results in less than a 50% reduction in waste load. This is because the waste loads include existing inventories of waste that are treated along with the new waste. The ratio of inventory to annual generation is dependent on waste category and site. For simplicity, complex-averaged ratios are used for each waste category. These complexwide waste load reductions are 42.5% for thermal treatment, 43.4% for solidification, 49.6% for supercompaction, and 37.5% for size reduction. For the four technologies considered, source reduction is estimated to be most effective in reducing waste loads for supercompaction and least effective in reducing waste loads for size reduction. Overall, the total waste load reduction for the four volume reduction technologies is estimated to be approximately 43%. The waste categories contributing to each volume reduction treatment are taken from ANL (1996a).

As Table G-2 shows, a majority of the 11 sites have no existing capacity for most volume reduction treatments listed in the table. Except for the Idaho National Engineering Laboratory (INEL), the other DOE sites do not have existing capacities for the complete set of the volume reduction technologies considered. Source reduction would reduce the capacities required of new facilities. For the alternatives considered, an annual generation reduction of 50% is estimated to eliminate the need for additional supercompaction capacity at the Hanford Site; for the cases with four regional treatment centers, this annual generation reduction also would eliminate the need for new supercompaction and size reduction capacity at the INEL.

As indicated in Table G-3, the assumed annual waste generation reduction from pollution prevention practices affects the adequacy of the existing disposal capacity at INEL. Without the reduction in annual generation, the capacity is inadequate; with an assumed 50% reduction in annual generation, it is adequate. For new disposal sites and some existing disposal sites (LANL, ORR, and SRS), generation reduction would reduce the amount of new capacity needed. For Hanford and the Nevada Test Site (NTS), the existing disposal capacities are adequate regardless of generation reduction. Overall, a 50% generation reduction is estimated to result in approximately a 48% reduction in disposal waste loads.

G.2.2.2 Cost Savings

Cost savings from pollution prevention reductions are estimated for treatment, disposal, and transportation. Because installation-specific goals are as yet unavailable, it is assumed that pollution prevention practices reduce new source generation by the same percentage (50%) throughout the DOE complex. There may be additional costs to waste generators to effect such waste generation reductions; however, the costs of making reductions are beyond the scope of this WM PEIS. The savings from waste generation reduction considered here are the waste management cost savings, which may be higher than the net savings.

Waste management cost savings associated with treatment, disposal, and transportation are considered. These are based on planning-level life-cycle costs for 10 years of operations (see INEL, 1995a) and the Site Data Tables in Volume II. Facility costs for treatment and disposal can be considered to consist of costs related to operations and costs related to construction. Operations costs are assumed to be proportional to throughput (waste load). Cost savings for construction depends on whether there are existing facilities for the type of treatment at a site. If there are no existing facilities, then costs for construction are assumed to be proportional to waste load. If there are existing facilities, then costs for construction are assumed to be proportional to the difference between the existing capacity and the capacity needed to process (or dispose of) the waste load. A given percentage reduction in waste load results in a greater percentage decrease in capacity needed when there is existing capacity. For example, if existing capacity is half the capacity needed to treat a given waste load, a reduction of 40% in waste load will result in an 80% reduction in the new capacity needed. In general, if the existing waste load is equivalent to E; the fractional decrease in waste loads with pollution prevention is equivalent to F; the additional capacity needed without pollution prevention is equivalent to Δ; and Δ_{WMin} is the additional capacity needed with pollution prevention, then the fractional new capacity needed is:

$$\Delta_{WMin}/\Delta = (1 - F) - F \times E/\Delta \qquad (G.1)$$

Cost savings have been estimated for the two volume reduction cases considered above. Estimates of cost savings for treatment at the sites with volume reduction facilities are presented in Table G–4. The treatment costs considered are for thermal treatment, grout stabilization, supercompaction, size reduction (i.e., shredding and compacting), packaging, and certification and shipping. The same percentage decreases in costs (F) for thermal treatment, grout stabilization, size reduction, and supercompaction are used as percentage decreases in waste load (see Table G–2). The percentage decreases in costs for packaging and certification and shipping are taken to be the cost-weighted average for thermal treatment, grout stabilization, supercompaction, and size reduction. When there is an existing facility, the complement of Δ_{WMin}/Δ from equation (G.1) is used for the fractional decrease in construction costs. If equation (G.1) is negative, then the existing capacity is adequate for the assumed decrease in annual generation rate.

For three situations, the existing capacity is estimated to become inadequate for reductions in annual generation of between 0 and 50%. For a generation reduction of less than 26%, existing supercompaction capacity at the Hanford Site becomes inadequate; for a generation reduction of less than 10%, the existing supercompaction capacity at INEL becomes inadequate; and for a generation reduction of less than 37%, the existing size reduction capacity at INEL becomes inadequate. From Table G-4, overall, a 50% generation reduction is estimated to result in approximately a 40% reduction in costs for treatment.

Estimates of cost savings for disposal for an assumed 50% reduction in annual generation of LLW are given in Table G-5 for the alternatives being considered. Percentage cost reductions for disposal are assumed to be equal to percentage waste load reductions for disposal for operations and for construction when there is no existing disposal facility. When there is an existing facility, then the complement of equation (G.1) is used. Overall, a 50% reduction in annual generation is estimated to result in approximately a 48% reduction in disposal costs.

The waste management costs technical report (INEL, 1995a) also contains estimates of transportation costs of LLW for the two volume reduction cases being considered. From the volume information in (ANL, 1996a), percentage waste load reductions by generating site for a 50% reduction in annual LLW generation were calculated by volume-averaging over waste categories. These generating-site percentage load reductions were multiplied by the transportation costs from each site to yield an estimate of the reduction in transportation costs from a 50% reduction in annual generation. Thus, this estimate is based on the assumption that the cost of transporting waste is proportional to the volume of waste moved and that all transport is from the generation site. Table G-6 contains the estimate of the total savings in transportation and the total savings for treatment and disposal from the information in Tables G-4 and G-5, respectively. Overall cost reductions for treatment, disposal, and transportation are estimated to be approximately 45% for a 50% reduction in annual generation.

The total savings are in the range of $8 to $9 billion for 10 years of operations. These values are for a 20-year interval (inventory and 20 years of waste generation are treated and disposed of in 10 years) and are approximately $400 million per year. This estimate of savings is consistent with a recent estimate of avoidable DOE waste management costs (Teclaw et al., 1993), which estimated avoidable annual costs for LLW of between $10 million and $10 billion.

Table G-4. Effect of Pollution Prevention on Costs of Waste Management LLW Treatment[a] for Two Volume Reduction Alternatives (in dollars)

Installation	Regionalized 2		Regionalized 5	
	Current	WMin/PP[b]	Current	WMin/PP
FEMP	3.12E+08	1.83E+08	--	--
Hanford	9.62E+08	5.88E+08	1.00E+09	6.12E+08
INEL	1.11E+09	6.34E+08	2.86E+09	1.63E+09
LANL	8.12E+08	4.81E+08	--	--
LLNL	2.82E+08	1.60E+08	--	--
ORR	3.77E+09	2.38E+09	4.52E+09	2.82E+09
Pantex	1.42E+08	8.92E+07	--	--
PGDP	4.85E+08	2.88E+08	--	--
PORTS	9.14E+08	5.70E+08	--	--
RFETS	6.90E+08	4.08E+08	--	--
SRS	1.27E+09	7.17E+08	1.27E+09	7.48E+08
Total	1.07E+10	6.57E+09	9.65E+09	5.81E+09

Note: -- = not a regional treatment site for this alternative.
[a] Treatments considered are thermal treatment, grout stabilization, supercompaction, size reduction (i.e., shredding and compaction), packaging, and certification and shipment. The cost of other treatment steps is not considered for LLW in this Appendix.
[b] A 50% reduction annual generation rate is assumed. Costs for operations are assumed to be proportional to throughput. Cost reductions for construction depends on whether there are existing facilities or not. If there are no existing facilities, costs for construction are assumed to be proportional to throughput. If there are existing facilities, cost for construction are proportional to the capacity of new construction needed.

G.2.2.3 Human Health Risk Reduction

For the volume reduction cases considered above, reductions in human health risk from reduction in annual generation are estimated for routine operations at the volume-reduction treatment centers and disposal sites. Incidence of cancer is taken as the measure of human risk because it applies to the four waste types considered in this appendix (person-rem would apply to LLW, LLMW, and TRUW, but not to HW). Cancer incidence based on the risk from the second 10 years of treatment and storage, not risks per year of operations, were obtained from tables in the human health risk appendix (Appendix D).

Table G-5. Effect of Pollution Prevention 50% Reduction in Annual Generation on Costs for Waste Management LLW Disposal in Two Volume Reduction Alternatives (in dollars)

Installation	Regionalized 2		Regionalized 5	
	Current	WMin/PP	Current	WMin/PP
Hanford	3.8E+08	2.0E+08	3.8E+08	2.1E+08
INEL	4.2E+08	2.2E+08	6.2E+08	3.1E+08
LANL	6.0E+08	3.1E+08	1.8E+09	9.8E+08
LLNL	3.1E+08	1.6E+08	NA	NA
NTS	2.0E+07	1.1E+07	5.9E+07	3.1E+07
ORR	3.7E+08	2.1E+08	8.0E+08	4.3E+08
Pantex	8.0E+07	5.1E+07	NA	NA
PGDP	3.1E+08	1.6E+08	NA	NA
PORTS	5.2E+08	2.7E+08	NA	NA
RFETS	3.5E+08	1.8E+08	NA	NA
SRS	3.4E+09	1.7E+09	3.4E+09	1.7E+09
Total	6.8E+09	3.4E+09	6.6E+09	3.7E+09

Note: NA = not applicable; not a disposal site for this alternative.

Table G-6. Summary of Effect of Pollution Prevention 50% Reduction in Annual Generation on Costs[a] for Waste Management LLW in Two Volume Reduction Alternatives (in dollars)

Activity	Regionalized 2		Regionalized 5	
	Current	WMin/PP	Current	WMin/PP
Treatment[b]	1.0E+10	6.6E+09	9.6E+09	5.8E+09
Disposal	6.8E+10	3.4E+09	6.6E+09	3.7E+09
Transportation[c]	6.4E+07	3.3E+07	3.3E+08	2.1E+08

[a] Costs are life-cycle costs for treatment at regional treatment facilities, disposal, and all transportation.
[b] Treatments considered are thermal treatment, supercompaction, size reduction, packaging, and certification and shipment.
[c] Based on transport by truck.

Table G–7 contains estimates of the effect of a 50% across-the-board reduction in annual generation on cancer incidence among the offsite population and WM workers at sites with volume-reduction facilities. The alternatives considered have either 11 or 4 sites with volume reduction facilities. The radiological risk to the offsite population at the sites with volume reduction facilities arises mainly from releases from thermal treatment facilities. Thus, the effect of generation reduction is estimated on the basis of inventory and annual generation (with and without reduction) of waste in the two LLW categories (combustible, compactible solids; organic liquids) that feed a specific thermal treatment facility. There is an exception for the Pantex Plant volume reduction center, which does not treat the waste categories undergoing thermal treatment. At the Pantex Plant, the health risk to the offsite population is assumed to arise from size-reduction treatment. The human health risk to workers is more evenly distributed among treatment facilities, with the risk being greatest at handling facilities where all waste categories are handled. Therefore, the effect of source reduction is estimated on the basis of the ratio of inventory to annual generation for all waste categories for the LLW treated at a volume-reduction site. From Table G–7, a 50% source reduction is estimated to result in approximately a 46% reduction in cancer incidence to both the general public and workers at treatment facilities.

Table G–8 contains estimates of the effects of a 50% across-the-board reduction in annual generation on human health risk at disposal facilities. Here, the assumed population consists of farm families that are at risk through the groundwater pathway. The percentage reduction in risk at a site from source reduction to these farm families is taken to be the same as the reduction in disposal waste load in Table G–3. Overall, a 50% source reduction is estimated to result in a 49% human health risk reduction to farm families.

G.2.3 LOW-LEVEL MIXED WASTE

LLMW is waste that contains both radioactive material and hazardous material. Thus LLMW should be processed so that the hazardous constituents can be treated in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) and the radioactive components are treated for safe disposal. LLMW may be classified as either contact-handled (CH: dose at waste surface <200 mrem/h) or remote-handled (RH: dose at waste surface >200 mrem/h); and also as either alpha LLMW (combined activity of transuranic radionuclides between 10 and 100 nCi/g), or non-alpha LLMW (combined activity of transuranic radionuclides <10 nCi/g). The technologies appropriate for treatment of LLW depend on

Table G-7. Effect of Pollution Prevention 50% Reduction in Annual Generation on Health Risks from Waste Management LLW Treatment (Cancer Incidence Among the Offsite Population and WM Workers for Second 10 Years of Treatment)

Site	Receptor	Regionalized 2		Regionalized 5	
		Current	WMin/PP	Current	WMin/PP
FEMP	Population[a]	7.9E-01	4.3E-01	--	--
	Worker[b]	2.3E-02	1.2E-02		
Hanford	Population	1.2E-05	6.0E-06	1.6E-01	8.6E-02
	Worker	6.9E-01	3.5E-01	7.2E-01	3.6E-01
INEL	Population	4.6E-06	2.5E-06	1.4E-03	7.6E-04
	Worker	5.8E-01	3.0E-01	1.9	1.2
LANL	Population	2.7E-02	1.4E-02	--	--
	Worker	6.5E-01	3.4E-01		
LLNL	Population	1.3	7.0E-01	--	--
	Worker	1.7E-01	1.2E-01		
ORR	Population	2.8E-04	2.5E-04	1.0	5.0E-01
	Worker	1.1	6.7E-01	1.5	9.1E-01
Pantex	Population	1.5E-06	1.3E-06	--	--
	Worker	2.7E-03	2.5E-03		
PGDP	Population	6.4E-06	4.2E-06	--	--
	Worker	5.8E-03	3.2E-03		
PORTS	Population	1.8E-04	9.8E-05	--	--
	Worker	9.6E-02	4.9E-02		
RFETS	Population	6.3E-04	3.3E-04	--	--
	Worker	4.0E-03	2.1E-03		
SRS	Population	2.1E-03	1.8E-03	2.1E-03	1.8E-03
	Worker	9.6E-01	4.8E-01	9.6E-01	4.8E-01

Note: -- = not a volume-reduction treatment center for this case.
[a] Risk to the offsite population is assumed to arise predominantly from releases from thermal treatment. The reduction in risk from a 50% source reduction is estimated on the basis of site-specific inventories and annual generation rates for the waste categories that are thermally treated (Categories 1 and 9). At the Pantex Plant, which does not have thermal treatment, reduction in risk is based on size reduction treatment of waste categories 3 and 4.
[b] Risk to workers is relatively evenly distributed among treatments; site-specific inventories and annual generation averaged over all waste categories for the sites of origin are used to estimate the reduction in risk to workers from a 50% source reduction.

Table G–8. Effect of Pollution Prevention Reduction on Health Risk From Waste Management LLW Disposal (Cancer Incidence Among All Farm Family Lifetimes for Second 10 Years of Disposal)

Disposal Site	Regionalized 2		Regionalized 5	
	Current	**WMin/PP**[a]	**Current**	**WMin/PP**
Hanford	2.1E-01	1.2E-01	6.1E-01	3.4E-01
INEL	0	0	0	0
NTS	0	0	0	0
LANL	0	0	0	0
ORR	7.7E-05	4.8E-05	3.6E-05	2.2E-05
SRS	7.2E-03	3.6E-03	7.2E-03	3.6E-03
PORTS	4.5E-04	3.8E-04	*	*
PGDP	2.8E-02	1.4E-02	*	*
LLNL	2.3E-04	1.2E-04	*	*
Pantex	0	0	*	*
RFETS	2.1E-05	1.1E-05	*	*

Note: * = not a disposal site.
[a] The WMin/PP results are based on a 50% reduction in annual generation. However, the volumes disposed of decrease by less than 50% because the category-dependent inventory is also being disposed of.

the physical and chemical properties of the waste. In contrast, technologies appropriate for treatment of LLMW depend on both the physical and chemical properties of the waste, and on the RCRA contaminant category of the hazardous constituents. Only general categories of RCRA contaminants frequent in DOE waste have been considered. These are toxic organics, toxic metals, mercury, ignitables, corrosives, reactives, and combinations thereof. LLMW may require treatment by several technologies in series.

Estimates of the effect of a 50% reduction in annual generation have been made for three diverse alternatives for LLMW generated from waste management operations (WM LLMW). These are the Decentralized Alternative with disposal of CH LLMW at 16 sites, Regionalized Alternative 2 with treatment of CH non-alpha LLMW at 7 sites and disposal at 6 sites, and the Centralized Alternative with all CH treatment and disposal at one site, the Hanford Site. Estimates of the effect of this source reduction are based on information in the LLMW technical report (ANL, 1996b); Appendix D, "Waste Management Facility Human Health Risk Estimates;" and the waste management costs technical report (INEL, 1995b).

G.2.3.1 Waste Load Reductions

Estimates on annual treatment waste load of the effect of a 50% step decrease in generation of WM LLMW are given in Tables G-9 and G-10 for CH non-alpha LLMW and CH alpha LLMW, respectively. The waste loads without the WMin/PP source reduction (the columns labeled "Current") are from ANL (1996b). The effect of pollution prevention was obtained from the site-totaled inventories and annual generation rates and the assumption that inventory and 20 years of generation will be treated and disposed of in a 10-year period. With the assumed 50% reduction in annual generation, in effect, 20 years of generation is reduced to 10 years of generation. The ratio of inventory plus 10 years of generation to inventory plus 20 years of generation gives the impact of pollution prevention. This ratio is applied to the contribution to the waste load at a treatment site from a generation site. From these tables, it is seen that waste minimization is more effective in reducing the CH non-alpha waste load than the CH alpha waste loads. For CH non-alpha LLMW, the assumed 50% reduction is estimated to reduce the overall waste load by approximately 36%, while the same percentage decrease in annual generation of CH alpha LLMW is estimated to decrease CH alpha waste load by only approximately 9%. Table G-11 gives the estimated percentage decreases from a 50% source reduction for RH non-alpha LLMW.

The percentage reductions in the waste loads from a 50% source reduction for disposal of waste management CH non-alpha LLMW and waste management CH alpha LLMW are given in Tables G-12 and G-13, respectively. As can be shown from these tables, the impact of the assumed decrease in annual generation disposal waste loads is similar to the impact on treatment waste loads, namely, approximately a 35% reduction for non-alpha waste and a 9% reduction for alpha waste.

Some existing facilities in the DOE complex were assumed to be used for treatment of LLMW. Conversely, because disposal facilities for LLMW would have to be permitted pursuant to RCRA and existing DOE disposal facilities do not have such permits, it was assumed that there are no existing disposal facilities for LLMW. Table G-14 gives the capacities of existing treatment facilities (ANL, 1996b), except for aqueous treatment, the capacities required without source reduction, and the capacities required with the assumed source reduction. From the table it is seen that the existing capacities are adequate for those sites and technologies.

Table G-9. Percentage Reduction in Annual Treatment Throughput of Waste Management CH Non-Alpha LLMW

Site	Decentralized		Regionalized 2		Centralized	
	Current[a]	% Reduct[b]	Current	% Reduct	Current	% Reduct
Ames	4.0E-02	12	--	--	--	--
ANL-E	1.6E+01	40	--	--	--	--
ANL-W	2.0	21	--	--	--	--
BCL	1.0E-02	50	--	--	--	--
BNL	1.9E+01	28	--	--	--	--
Bettis	4.8	23	--	--	--	--
Charleston	3.0E-01	46	--	--	--	--
CISS	1.1	0	--	--	--	--
ETEC	1.7	24	--	--	--	--
FEMP	2.6E+02	1	--	--	--	--
GA	4.3	1	--	--	--	--
GJPO	1.5E-01	29	--	--	--	--
Hanford	3.6E+03	45	3.7E+03	46	1.4E+04	36
INEL	1.8E+02	30	6.1E+02	36	--	--
ITRI	3.5	46	--	--	--	--
K-25	2.7E+03	30	--	--	--	--
KAPL-S	8.3	49	--	--	--	--
KAPL-K	1.0E+01	49	--	--	--	--
KAPL-W	4.0	50	--	--	--	--
KCP	8.0E-02	0	--	--	--	--
LANL	3.8E+01	25	1.2E+02	32	--	--
LBL	2.8E+01	46	--	--	--	--
LEHR	7.0E-01	17	--	--	--	--
LLNL	2.2E+02	47	--	--	--	--
Mound	2.2E-03	25	--	--	--	--
Mare Is	5.2	41	--	--	--	--
Norfolk	6.0E-01	50	--	--	--	--
NTS	3.0E+02	45	--	--	--	--
ORR[d]	5.9E+03	36	6.3E+03	25	--	--

Table G–9. Percentage Reduction in Annual Treatment Throughput of Waste Management CH Non-Alpha LLMW—Continued

Site	Decentralized		Regionalized 2		Centralized	
	Current[a]	% Reduct[b]	Current	% Reduct	Current	% Reduct
Pantex	6.9E+01	40	--	--	--	--
PGDP	6.0E+01	0	--	--	--	--
Pearl H	6.0E-01	32	--	--	--	--
Ports Nav	1.0E-01	33	--	--	--	--
PORTS	3.3E+03	42	3.5E+03	38	--	--
PPPL	2.0E-03	25	--	--	--	--
Puget So	2.3E+01	33	--	--	--	--
RFETS	0	NA[c]	1.9E-01	20	--	--
RMI	2.9	12	--	--	--	--
SNL-CA	1.1E+01	45	--	--	--	--
SNL-NM	1.0E+01	0	--	--	--	--
SRS	9.4E+02	38	9.4E+02	38	--	--
Y-12	1.8E+03	19	--	--	--	--

Note: -- = not a treatment site under the Regionalized or Centralized Alternatives.
[a] Annual throughput in m^3.
[b] Percentage reduction annual throughout from a 50% reduction in annual generation.
[c] NA = not applicable because no CH non-alpha LLMW is generated at RFETS.
[d] ORR includes K-25, Y-12, and ORNL.

Table G–10. Reduction in Annual Treatment Throughput of Waste Management CH Alpha LLMW From a 50% Decrease in Annual Generation

Site	Decentralized		Regionalized 2		Centralized	
	Current	% Reduct	Current	% Reduct	Current	% Reduct
Hanford	--	--	--	--	1.0E+00	9
INEL	2.5E+03	0	2.5E+03	4	--	--
LANL	2.1E+02	42	2.1E+02	42	--	--
LLNL	2.0E+02	48	--	--	--	--
Mound	8.0	4	--	--	--	--
RFETS	2.1E+03	10	6.9E+03	10	--	--
SRS	4.1E+02	14	4.2E+02	14	--	--
WVDP	5.5	29	--	--	--	--

Note: -- = not a regional treatment site.

Table G-11. Percentage Reduction in Annual Treatment and Disposal Throughput of Waste Management RH Non-Alpha LLMW From a 50% Decrease in Annual Generation

Site	Treatment (m^3/yr)	Disposal (m^3/yr)	Reduction (%)
Hanford	7.4E-02	1.2E-02	0
INEL	8.6E+02	1.5E+02	49
ORR	3.5E+02	7.0E+02	17
SRS	2.8	8.8E-01	47

Table G-12. Percentage Reduction in Annual Disposal Throughput (m^3/yr) for Waste Management CH Non-Alpha LLMW

	Decentralized		Regionalized 2		Centralized	
Disposal Site	Current	% Reduct[a]	Current	% Reduct	Current	% Reduct
ANL-E	1.4E+02	40	--	--	--	--
BNL	8.4E+01	28	--	--	--	--
FEMP	1.1E+02	1	--	--	--	--
Hanford	1.3E+03	46	1.3E+03	46	5.3E+03	35
INEL	4.3E+01	30	1.4E+02	26	--	--
LANL	1.1E+01	25	3.3E+02	33	--	--
LLNL	1.9E+02	34	--	--	--	--
NTS	1.0E+01	50	--	--	--	--
ORR	1.5E+03	25	1.1E+04	32	--	--
Pantex	2.0E+01	40	--	--	--	--
PGDP	2.2E+01	0	--	--	--	--
PORTS	5.8E+02	42	--	--	--	--
RFETS	5.7E-01	29	--	--	--	--
SNL-NM	1.4	1	--	--	--	--
SRS	4.4E+02	38	4.5E+02	38	--	--

Note: -- = not a disposal site for this alternative.
[a] Percentage reduction annual throughput from a 50% reduction in annual generation.

Table G-13. Percentage Reduction in Annual Disposal Throughput for Waste Management CH Alpha LLMW

Disposal Site	Decentralized		Regionalized 2		Centralized	
	Current[a]	% Reduct[b]	Current	% Reduct	Current	% Reduct
Hanford	--	--	--	--	3.2E+03	9
INEL	6.1E+02	0	7.0E+02	6	--	--
LANL	5.6E+01	21	2.4E+03	10	--	--
LLNL	8.1E+01	48	--	--	--	--
RFETS	2.3E+03	10	--	--	--	--
SRS	1.1E+02	14	1.1E+02	14	--	--
WVDP	1.1	29	--	--	--	--

Note: -- = not a disposal site for this alternative.
[a] Annual throughput in m^3.
[b] Percentage reduction annual throughout from a 50% reduction in annual generation.

G.2.3.2 Cost Savings

Cost savings associated with the treatment, disposal, and transportation of CH waste management LLMW are considered. These are based on planning-level life-cycle costs for 10 years of operations (see INEL, 1995b). As with LLW, treatment and disposal costs are divided into operations costs and construction (or capital) costs. Operations costs are assumed to be proportional to throughput and (waste load). Capital costs are assumed to be proportional to throughput also, except when there is existing capacity for a specific treatment step that is inadequate for the waste load. However, as shown in Table G-14, the existing capacity is adequate for the waste load. Therefore, capital costs are also assumed to be proportional to waste load, because no new capacity is needed when there is existing capacity.

Estimates of the impact of a 50% reduction in annual generation for the three alternatives being considered are given in Table G-15 for CH waste management LLMW, both non-alpha and alpha. The transportation, operations, and capital costs without pollution prevention reductions are from INEL (1995b). The table indicates that for the assumed source reduction and linearity between waste load and cost, substantial savings may result from pollution prevention reductions. These savings range from over $3 billion for the Decentralized Alternative to nearly $2 billion for the Centralized Alternative.

Table G–14. Effect of Pollution Prevention 50% Reduction in Annual Generation on the Need for New Facilities to Meet Waste Management CH Non-Alpha LLMW Treatment Needs

Site/Facility	Existing Capacity (kg/h)[a]	Current WMin/PP	Capacity Required (kg/h)		
			Decentralized	Regionalized 2	Centralized
Hanford					
GROUT	2.1E+03	Current	3.1E+02	3.3E+02	1.1E+03
		WMin/PP	1.6E+02	1.8E+02	6.8E+02
INEL					
INCIN	3.2E+02	Current	7.3	1.5E+01	--
		WMin/PP	5.0	1.1E+01	--
GROUT	3.8E+02	Current	8.6	4.1E+01	1.0E-02
		WMin/PP	5.9	3.0E+01	7.E-03
ORR					
INCIN	1.9E+03	Current	5.9E+02	6.4E+02	--
		WMin/PP	3.8E+02	5.0E+02	--
Pantex					
GROUT	1.0E+01	Current	3.8	7.3E-02	7.3E-02
		WMin/PP	2.3	4.4E-02	4.4E-02
RFETS					
GROUT	3.8E+03	Current	--	1.5E-02	--
		WMin/PP	--	1.2E-02	--
SRS					
INCIN	1.1E+03	Current	1.7E+02	1.7E+02	--
		WMin/PP	1.0E+02	1.1E+02	--
GROUT	5.9E+03	Current	5.0E+1	5.0E+01	1.0E-02
		WMin/PP	3.1E+01	3.1E+01	6.8E-03

Notes: -- = no throughput for this process for this alternative; INCIN = thermal treatment; GROUT = grout stabilization.
[a] 1 kg/h=7.1 m^3/yr.

G.2.3.3 Human Health Risk Reduction

Reductions in human health risk for a 50% reduction in annual generation are estimated for routine operations of treatment facilities and from long-term releases from disposal facilities. As before, cancer incidence is taken as the measure of human health risk. For treatment facilities, cancer incidence among two populations are considered, the offsite population and WM workers. For disposal facilities, the risk to all nearby farm family generations is considered. For LLMW, cancer incidence arises from exposure to chemical carcinogens as well as from radiological doses. The estimated reductions in cancer incidence among the offsite population near treatment site, among WM workers at treatment sites, and among farm family generations near disposal sites are given in Tables G–16 through G–18, respectively. As before, it is assumed that health risk decreases linearly with waste load.

Table G-15. Effect of Pollution Prevention on Cost of Treatment, Disposal, and Transportation of CH Waste Management LLMW (in dollars)

Case/Operation	Non-Alpha		Alpha[a]	
	Current	WMin/PP	Current	WMin/PP
Decentralized				
Treatment				
Operations & maintenance	4.0E+09	2.6E+09	2.2E+09	1.8E+09
Capital	2.0E+09	1.4E+09	1.5E+09	1.3E+09
Disposal				
Operations & maintenance	1.1E+09	6.6E+08	7.6E+08	7.0E+08
Capital	2.7E+08	1.7E+08	3.0E+08	3.0E+08
Transportation	4.8E+05	3.5E+05	1.7E+05	1.4E+05
Total	7.4E+09	4.8E+09	4.8E+09	4.1E+09
Regionalized 2				
Treatment				
Operations & maintenance	2.7E+09	1.8E+09	2.5E+09	2.2E+09
Capital	9.1E+08	6.0E+08	1.6E+09	1.4E+09
Disposal				
Operations & maintenance	8.2E+08	5.0E+08	6.5E+08	5.8E+08
Capital	1.8E+08	1.0E+08	9.1E+07	8.2E+07
Transportation	1.5E+07	9.5E+06	8.4E+06	7.4E+06
Total	4.3E+09	2.8E+09	4.5E+09	4.0E+09
Centralized				
Treatment				
Operations & maintenance	2.8E+09	1.9E+09	2.0E+09	1.9E+09
Capital	7.6E+08	5.2E+08	1.2E+09	1.0E+09
Disposal				
Operations & maintenance	5.3E+08	2.9E+08	3.1E+08	2.9E+08
Capital	5.4E+07	2.9E+07	4.3E+07	3.9E+07
Transportation	1.9E+07	1.3E+07	7.8E+06	6.8E+06
Total	3.8E+09	2.5E+09	3.3E+09	2.9E+09

[a] CH non-alpha waste generated at INEL and LANL are treated at INEL and LANL CH alpha facilities.

Table G–16. Percentage Reduction in Risk to the Offsite Population[a] for Treatment of Waste Management LLMW

Site	Decentralized		Regionalized 2		Centralized	
	Current	% Reduct[b]	Current	% Reduct	Current	% Reduct
ANL-E	5.6E–05	40	2.0E–06	40	2.0E–06	40
BNL	4.1E–05	28	1.9E–07	28	1.9E–07	28
FEMP	9.1E–05	1	5.8E–07	1	5.8E–07	1
Hanford	5.0E–03	45	4.5E–02	45	8.5E–02	36
INEL	1.8E–04	30	2.1E–03	36	1.7E–05	36
KAPL-K	1.0E–03	49	8.9E–07	49	8.9E–07	49
KCP	1.3E–05	0	8.4E–09	0	8.4E–09	0
LANL	2.0E–03	25	2.9E–03	32	1.3E–04	25
LBL	3.5E–02	46	4.9E–08	46	4.9E–08	46
LLNL	5.2E–01	47	1.9E–06	47	1.9E–06	47
Mound	4.3E–04	25	7.3E–08	25	7.4E–08	25
NTS	2.7E–06	45	2.2E–08	45	2.2E–08	45
ORR	3.7E–03	25	4.1E–03	25	2.4E–05	25
Pantex	1.2E–04	40	8.0E–06	40	8.0E–06	40
PGDP	4.1E–04	0	2.8E–06	0	2.8E–06	0
PORTS	1.2E–05	42	3.6E–04	38	1.1E–07	38
RFETS	2.3E–04	20	2.4E–04	20	4.9E–06	20
SNL-NM	4.7E–04	0	6.1E–08	0	6.1E–08	0
SRS	5.9E–03	38	6.0E–03	38	4.6E–06	38
WVDP	8.6E–07	50	5.8E–07	50	5.9E–07	50
Total	5.8E–01	47	6.1E–02	42	8.6E–02	36

[a] Cancer incidence among the offsite population from radiation and chemical carcinogens.
[b] Percentage reduction in risk based on a 50% reduction in annual generation of LLMW.

Table G–17. Percentage Reduction in Risk to WM Workers[a] for Treatment of Waste Management LLMW

Site	Decentralized		Regionalized 2		Centralized	
	Current	% Reduct[b]	Current	% Reduct	Current	% Reduct
ANL-E	2.3E–04	40	1.1E–04	40	1.1E–04	40
BNL	4.3E–04	28	2.0E–04	28	2.0E–04	28
FEMP	1.1E–03	1	8.8E–04	1	8.8E–04	1
Hanford	3.6E–01	45	5.0E–01	45	1.8E+00	36
INEL	3.6E–01	30	3.9E–01	36	2.5E–01	36
KAPL-K	6.2E–03	49	2.2E–02	49	2.2E–03	49
KCP	1.2E–04	0	2.8E–06	0	2.8E–06	0
LANL	5.5E–03	25	8.2E–03	32	2.4E–03	25
LBL	1.3E–04	46	7.4E–05	46	7.4E–05	46
LLNL	2.8E–02	47	2.2E–03	47	2.2E–03	47
Mound	4.7E–05	25	4.3E–05	25	4.6E–05	25
NTS	4.8E–02	12	1.0E–02	12	1.0E–02	12
ORR	6.2E–01	25	4.2E–01	25	8.4E–02	25
Pantex	1.2E–03	40	5.8E–04	40	5.8E–04	40
PGDP	8.5E–04	0	5.2E–04	0	5.2E–04	0
PORTS	5.6E–03	42	2.7E–01	42	2.9E–03	42
RFETS	4.1E–03	20	4.6E–03	20	3.5E–03	20
SNL-NM	1.2E–03	0	6.1E–05	0	6.1E–05	0
SRS	3.7E–01	38	3.8E–01	38	1.1E–01	38
WVDP	8.6E–03	50	9.7E–05	50	1.0E–04	50
Total	1.8E+00	34	2.0E+00	36	2.3E+00	37

[a] Cancer incidence among the WM workers from radiation and chemical carcinogens.
[b] Percentage reduction in risk based on a 50% reduction in annual generation of LLMW.

Table G-18. Percentage Reduction in Risk[a] From Disposal of CH Waste Management LLMW

Disposal Site	Decentralized		Regionalized 2		Centralized	
	Current	% Reduct[b]	Current	% Reduct	Current	% Reduct
ANL-E	6.4E-04	40	--	--	--	--
BNL	9.0E-03	28	--	--	--	--
FEMP	2.6E-04	1	--	--	--	--
Hanford	6.5E-02	46	8.0E-02	46	8.7E-01	35
INEL	4.1E-05	30	4.2E-05	26	--	
LANL	5.5E-03	25	3.2E-03	33	--	--
LLNL	2.6E-04	34	--	--	--	--
NTS	4.3E-04	46	--	--	--	--
ORR	4.5E-01	25	8.1E-01	32	--	--
Pantex	3.6E-04	40	--	--	--	--
PGDP	2.4E-04	0	--	--	--	--
PORTS	8.8E-03	42	--	--	--	--
RFETS	2.5E-02	29	--	--	--	--
SNL-NM	3.2E-02	1	--	--	--	--
SRS	7.2E-03	38	7.2E-03	38	--	--
Total	6.1E-01	29	9.1E-01	33	8.7E-01	35

Note: -- = not a disposal site for this alternative.
[a] Cancer incidence among all farm family lifetimes from radiation and chemical carcinogens.
[b] Percentage reduction in risk based on a 50% reduction in annual generation of CH non-alpha LLMW.

From Table G-16, it is seen that the effectiveness of pollution prevention in reducing health risk to the offsite population near treatment sites varies significantly with alternative. For the Decentralized Alternative, this risk is dominated by the risk at LLNL and the health risk reduction is 47%. In contrast, the health risk for treatment at Hanford dominates the Centralized Alternative 17 and is reduced by only 36%. From Table G-17, the aggregate reduction in WM worker health risk at treatment sites is not as strongly dependent on alternative and is approximately 35% for all three alternatives. From Table G-18, the aggregate reduction in health risk from the assumed source reduction from pollution prevention varies from 29% for the Decentralized Alternative to 35% for the Centralized Alternative.

G.2.4 HAZARDOUS WASTE

Hazardous waste contains materials that are hazardous under RCRA and other Federal environmental statutes (such as the Toxic Substances Control Act) but does not contain radioactive materials. As with LLMW, HW is treated primarily to meet statutory requirements. Estimates of the effect of reduction in annual generation on HW facilities are based on information in the hazardous waste technical report (ANL, 1996c); Appendix D, "Waste Management Facility Human Health Risk Estimates;" and the waste management costs technical report (INEL, 1995c).

The vast majority of HW is contaminated wastewater and is always treated onsite in wastewater treatment facilities. This appendix addresses HW other than contaminated wastewater, that is, HW that is transferred for treatment at specialized facilities, either onsite or offsite. Most, approximately three-quarters, of the HW generated in the DOE complex is generated at 11 sites. This appendix considers only HW generated at these 11 sites.

G.2.4.1 Waste Load Reductions

Table G-19 contains quantities of HW transferred for treatment by type of treatment for 1992 for the 11 top HW-generating sites. Storage of HW is limited by RCRA to 90 days at unpermitted facilities. Therefore, unlike the other waste types, there is no year-to-year storage of HW and no inventories to be worked off with the HW generated annually. Also, because there is no long-term storage, waste loads for HW generated by waste management operations are based on 20 years of generation being treated and disposed of in 20 years. Thus, a given percentage reduction in annual production is estimated to result in the same percentage reduction in treatment waste loads. For a 50% across-the board reduction in annual generation, the values in Table G-19 would be cut in half.

G.2.4.2 Cost Savings

Two of the alternatives considered in the WM PEIS are elaborated here. The first is Regionalized Alternative 2 in which there are two DOE treatment hubs: one in the east at ORR and the second in the west at INEL. In this alternative, all HW is shipped to the DOE hubs where approximately 90% of treatment is performed. Three treatments (stabilization, battery recycling, and mercury removal) take place at

Table G-19. Technologies Used to Treat Hazardous Waste Transfers (1992)

Treatment Technology	Quantity[a] (kg)	Comments
Incineration	1.6E+06	This is the principal form of treatment for a wide range of organic wastes.
Organic removal/recovery	9.8E+05	This treatment technology is primarily fuel burning or blending, and solvent recycling or distillation.
Stabilization	2.6E+05	This treatment technology is most commonly used for inorganic waste. The waste is mixed with solidification agents, such as Portland cement, to meet disposal facility waste acceptance criteria.
Deactivation	2.7E+05	Treatment technologies that are so classified include neutralization of corrosive waste, and controlled detonation, reaction, or deactivation of explosives.
Metal removal/recovery	9.4E+04	This technology involves precipitation of heavy metals from aqueous solutions. The resulting precipitate may be further treated to recover metals or be stabilized prior to land disposal.
Mercury recovery/treatment	1.1E+05	This is a specialized treatment (e.g., mercury roasting or retorting, amalgamation, or incineration of organic wastes containing mercury) that is offered only by a few commercial facilities in the country.
Aqueous treatment	6.3E+04	This type of treatment includes a range of technologies, including biological treatment, wet air oxidation, and chemical oxidation/reduction.
Recycling	6.8E+03	Most DOE "recycled" wastes are lead acid storage batteries and scrap metals.

[a] Quantities are based on offsite transfers from the eleven top HW generators.

commercial facilities after shipment from DOE hubs. The second case is Regional Alternative 1 in which HW is shipped to five DOE hubs. The DOE hubs perform roughly half of the organic removal and recovery treatment and ship treated HW to commercial facilities for other treatment.

Table G-20 shows the cost savings for a 50% across-the-board reduction in annual generation based on cost information in the waste management costs technical report (INEL, 1995c). The table breaks out costs for treatment and disposal at DOE and commercial facilities, and for transportation. In ANL (1996c), existing facilities for treatment of HW are identified. However, the cost estimates in INEL (1995c) are based on the assumption that these existing facilities are dedicated to treatment of LLMW and that all HW

Table G–20. Cost Savings at HW Treatment Hubs and From Pollution Prevention 50% Reduction in Annual Generation ($1,000)

Site	Regionalized 2[a]	Regionalized 1[b]
ANL-E		
Transportation	1.5E+03	3.3E+03
Commercial Treatment and Disposal	NA[c]	NA
Fermi		
Transportation	5.8E+02	1.5E+04
Commercial Treatment and Disposal	NA	NA
Hanford		
Government Treatment and Disposal	NA	3.0E+04
Transportation	6.8E+01	2.4E+03
Commercial Treatment and Disposal	NA	4.2E+03
INEL		
Government Treatment and Disposal	6.6E+04	1.1E+04
Transportation	1.8E+03	6.8E+02
Commercial Treatment and Disposal	2.7E+03	1.0E+03
KCP		
Transportation	3.9E+03	8.0E+03
Commercial Treatment and Disposal	NA	NA
LANL		
Government Treatment and Disposal	NA	2.8E+04
Transportation	1.3E+01	1.2E+03
Commercial Treatment and Disposal	NA	4.0+03
LLNL		
Transportation	7.1E+03	5.2E+03
Commercial Treatment and Disposal	NA	NA
ORR		
Government Treatment and Disposal	5.6E+04	3.3E+04
Transportation	6.8E+01	1.4E+03
Commercial Treatment and Disposal	1.1E+04	1.5E+04
Pantex		
Transportation	1.9E+03	1.9E+03
Commercial Treatment and Disposal	NA	NA
SNL-NM		
Transportation	4.4E+03	5.0E+03
Commercial Treatment and Disposal	NA	NA

Table G-20. Cost Savings at HW Treatment Hubs and From Pollution Prevention 50% Reduction in Annual Generation ($1,000)—Continued

Site	Regionalized 2[a]	Regionalized 1[b]
SRS		
Government Treatment and Disposal	NA	1.4E+04
Transportation	1.3E+03	2.2E+03
Commercial Treatment and Disposal	NA	1.5E+03
Total		
Government Treatment and Disposal	1.2E+05	1.2E+05
Transportation	2.4E+04	4.4E+04
Commercial Treatment and Disposal	1.4E+04	2.5E+04
Total	1.6E+05	1.9E+05

[a] This case has two DOE treatment hubs, one in the east and one in the west; only hubs ship to commercial facilities.
[b] This case has five DOE treatment hubs; only hubs ship to commercial facilities.
[c] NA = not available.

treatment facilities at DOE sites are new facilities. Therefore, the values in Table G-20 are based on the assumption that both operations and construction cost savings are proportional to source reduction.

G.2.4.3 Human Health Risk Reductions

Reduction in human health risk for a 50% across-the-board reduction in annual generation of HW from routine operations of hazardous waste facilities were estimated for the same two alternatives (Regionalized 2 and Regionalized 1) considered above. The human health risk considered cancer incidence for three types of receptors: the onsite population of noninvolved workers, the offsite population, and workers at WM facilities. Risks to the onsite and offsite population are proportional to throughput. Aggregate risks to WM workers are proportional to the number of such workers, which will be assumed to be proportional to throughput. The estimated reduction for 20 years of operations is tabulated by DOE site and case in Table G-21. With these assumptions, the reductions in human health risks are 50% of the human health risks given in Appendix D.

Table G-21. Reduction in Cancer Incidence[a] at DOE HW Treatment Hubs From Pollution Prevention 50% Reduction in Annual Generation

Hub/Receptor	Regionalized 2	Regionalized 1
Hanford		
Noninvolved worker population	--	1.3E-03
Offsite population	--	2.1E-03
WM workers	--	1.4E-01
INEL		
Noninvolved worker population	6.5E-04	7.0E-05
Offsite population	4.8E-04	5.0E-05
WM workers	3.7E-01	3.8E-02
LANL		
Noninvolved worker population	--	4.7E-03
Offsite population	--	1.0E-02
WM workers	--	1.5E-01
ORR		
Noninvolved worker population	1.6E-02	5.5E-03
Offsite population	4.7E-02	1.8E-02
WM workers	5.5E-01	2.1E-01
SRS		
Noninvolved worker population	--	3.0E-04
Offsite population	--	6.0E-04
WM workers	--	4.6E-02
Total		
Noninvolved worker population	1.7E-02	1.2E-02
Offsite population	4.8E-02	3.0E-02
WM workers	9.2E-01	5.8E-01

Note: -- = not a treatment hub for this alternative.
[a] Cancer incidence arising from 20 years of treatment.

G.2.5 Transuranic Waste

TRUW is defined as radioactive waste contaminated with alpha-particle-emitting transuranic radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g at the time of assay. The DOE distinguishes between CH TRUW (packaged waste with an external surface dose rate not exceeding 200 mrem/h) and RH TRUW (packaged waste with an external surface dose rate exceeding 200 mrem/h). TRUW generated prior to 1970 is buried in shallow landfill-type disposal grounds and is considered as an ER waste. TRUW waste generated since 1970 is considered a waste management waste. Some TRUW wastes are contaminated with hazardous materials. Such material can be treated using the same processes as for LLMW, with additional precautions appropriate for the radioactive component being TRUW rather than LLW.

Estimates of the effect of source reduction on TRUW facilities are based on information in the transuranic waste technical report (ANL, 1996d); Appendix D, "Waste Management Facility Human Health Risk Estimates;" and the waste management costs technical report (INEL, 1995d).

G.2.5.1 Waste Load Reduction

Tables G–22 and G–23 contain estimates of the effect on generating site waste loads of an across-the-board 50% source reduction of CH TRUW and RH TRUW, respectfully. Inventory and generation rates for a site are obtained from volume-weighted averages over treatment classes. The waste loads are based on inventory and 20 years of generation being treated in 10 years. The inventories and waste loads include the following waste stream categories from the DOE (1994e) *Mixed Waste Inventory Report*: 1000 (aqueous liquids); 2000 (organic liquids); 3000 (solid process wastes); 4000 (soils); and 5000 (debris). Waste categories 6000 (special: lab packs with and without reactive metals) and 7000 (inherently hazardous; for example, reactive metals, mercury, and cadmium batteries) are not included because impacts of their treatment, storage, and transportation were not considered elsewhere in the WM PEIS. The percentage differences in waste load attributed to source reduction are smaller than for the other waste types considered because the inventories are larger relative to annual generation. Thus, changes in annual generation rates have relatively smaller effects on waste loads. Averaged over the DOE complex, a 50% reduction in annual generation of CH TRUW is estimated to reduce CH TRUW waste loads by 19%, and a 50% reduction in annual generation of RH TRUW is estimated to reduce RH TRUW waste loads by 48%.

The effect of a 50% across-the-board reduction in annual generation is considered for four representative CH TRUW alternatives and one RH TRUW alternative. The four CH TRUW alternatives are: Regionalized Alternative 3, 3 regional sites with treatment to RCRA compliance; Regionalized Alternative 2, 5 regional sites with treatment to RCRA compliance; Regionalized Alternative 1, 5 regional sites with stabilization treatment; and the Decentralized Alternative, 16 sites treating to the Waste Isolation Plant Project (WIPP) waste acceptance criteria (WAC). These four alternatives provide diversity in the number of treatment sites and the level of treatment. The RH alternative has two sites with RCRA treatment. The effect of this source reduction on the waste loads at the regional treatment facilities for the three regional site and five regional

Table G-22. Effect of Pollution Prevention 50% Reduction in Annual Generation on CH-TRUW Generating Site Waste Loads

TRUW Site	Inventory (m^3)	Generation Rate (m^3/yr)	Waste Loads[a] (m^3/yr)		Percentage Difference
			Current	WMin/PP	
ANL-E	1.5E+01	4.7E+01	9.6E+01	4.9E+01	49%
Hanford	1.2E+04	1.2E+03	3.6E+03	2.3E+03	35%
INEL	3.8E+04	1.4E+01	3.8E+03	3.8E+03	1%
LANL	8.2E+03	1.3E+02	1.1E+03	9.3E+02	12%
LBL	8.0E-01	1.0E-02	1.0E-01	9.0E-03	10%
LLNL	2.0E+02	7.4E+01	1.7E+02	1.1E+02	33%
Mound	2.7E+02	1.2E+03	1.5E+02	9.0E+01	40%
NTS	6.1E+02	0	6.1E+01	6.1E+01	0%
PGDP	1.4E+01	0	1.4	1.4	0%
RFETS	1.5E+03	2.4E+02	6.2E+02	3.7E+02	38%
SNL-NM	1.0	0	1.0E-01	1.0E-01	0%
SRS	5.1E+03	5.8E+02	1.7E+03	1.1E+03	35%
UofMO	0	1.0E-01	2.0E-01	1.0E-01	50%
Total	6.7E+04	2.4E+03	1.1E+04	8.8E+03	19%

[a] Assumes inventory and 20 years of generation are treated in 10 years; for the WMin/PP case, the annual generation rate is half the current generation rate. Includes waste stream categories: aqueous liquids (1000); organic liquids (2000); solid process residues (3000); soils (4000); and debris (5000).

site CH TRUW cases and for the two regional site RH TRUW cases is given in Table G-24. For the Decentralized Alternative, with 16 sites treating to the WIPP WAC, the treatment takes place where the waste originates so that the percentage waste load reductions in Table G-22 apply.

G.2.5.2 Cost Savings

Cost savings from WMin/PP are considered for the four CH TRUW alternatives and for one RH TRUW alternative. Since disposal at WIPP is common to all alternatives, costs of disposal are considered to be beyond the scope of this appendix. The estimates of the effects of a 50% reduction in annual generation on costs used the effects of that reduction on waste loads in Tables G-22 through G-24. Table G-24 was used for the effects on treatment at and transportation from regional treatment facilities. Tables G-22 (for CH

Table G-23. Effect of Pollution Prevention 50% Reduction in Annual Generation on RH TRUW Generating Site Waste Loads

TRUW Site	Inventory (m^3)	Generation Rate (m^3/yr)	Waste Loads[a] (m^3/yr)		Percentage Differences
			Current	WMin/PP	
ANL-E	0.00	1.7E+01	3.4E+01	1.7E+01	50%
Hanford	2.0E+02	7.7E+02	1.6E+03	7.9E+02	49%
INEL	1.1E+02	2.5E+01	6.1E+01	3.6E+01	41%
LANL	7.9E+01	5.0E-01	8.9	8.4	6%
ORR	1.3E+03	1.8E+01	1.7E+02	1.5E+02	12%
SRS	1.0	1.0	2.1	1.1	48%
Total	1.7E+03	8.5E+02	1.8E+03	9.4E+02	48%

[a] Assumes inventory and 20 years of generation are treated in 10 years; for the WMin/PP case, the annual generation rate is half the current generation rate. Includes waste stream categories: aqueous liquids (1000); organic liquids (2000); solid process residues (3000); soils (4000); and debris (5000).

Table G-24. Effect of Pollution Prevention 50% Reduction in Annual Generation on Regional Treatment Site TRUW Waste Loads

Regional Treatment Site	Percentage Decrease in Waste Load[a]		
	CH 3 Regional Sites	CH 5 Regional Sites	RH 2 Regional Sites
Hanford	41	41	49
INEL	7	1	--
LANL	NA	35	--
ORR	NA	NA	19
RFETS	NA	39	--
SRS	35	12	--

Notes: -- = not a regional treatment site under the specified alternative; NA = not applicable.
[a] Assumes inventory and 20 years of generation are treated in 10 years; for the WMin/PP case, the annual generation rate is half the current generation rate.

waste) and Table G-23 (for RH waste) were used for the effects on treatment at and transportation from other sites.

Reductions in costs of treatment storage, and transportation were assumed to be proportional to reduction in waste load. In estimating the effect of reduction in annual generation on the facilities cost, the same distinction was made between situations where there are existing facilities and when there are no existing facilities, as in Section G.2.2.2. Using information on existing facilities from INEL (1995d), Table G-25 summarizes the effect of a 50% reduction in annual generation on the need for new capacity. For the cases considered, the existing facilities at the Rocky Flats Environmental Technology Site (RFETS) and the aqueous treatment facility at LANL are estimated to have adequate capacity regardless of source reduction in annual generation. On the other hand, the grout stabilization facility would not have sufficient capacity even with a 50% reduction.

The effects of the assumed source reduction on the planning level life-cycle costs of operations and maintenance, construction, and transportation are given in Tables G-26 and G-27 for the TRUW alternatives and an RH TRUW alternative, respectively. For the TRUW alternatives, the assumed reduction in annual generation is estimated to result in a 22% reduction in costs, while the cost reduction for RH TRUW is estimated to be 26%. In Table G-26, the costs are for both CH and RH TRUW.

G.2.5.3 Human Health Risk Reduction

Reductions in human health risk from a 50% across-the-board reduction in the annual generation of TRUW were estimated for the same four CH TRUW alternatives and RH TRUW alternative considered above. The human health risk considered was cancer incidence among the offsite population and among workers at WM facilities. Risk reduction is assumed to be proportional to throughput reduction. With this assumption, the estimated reductions in risk for 10 years of operation of treatment facilities are given in Table G-28. The table shows that reduction in annual generation of CH TRUW is estimated to have a larger impact on human health risk to the public (approximately 30% reduction) than to WM workers (approximately 18% reduction). This is because human health risks are estimated to be greater at SRS than at other sites. Because SRS has a relatively small ratio of inventory to annual generation, reductions in annual generation are relatively effective in reducing human health risk.

Table G-25. Effect of Pollution Prevention Reduction[a] on the Need for New CH TRUW Facilities

Site/Facility	Existing Capacity (m^3/yr)	Current/ WMin/PP	Total Capacity Required by Case (m^3/yr)			
			Decentralized	Regionalized 1	Regionalized 2	Regionalized 3
LANL						
AQWTR	2.0E+02	Current	NA	NA	6.7E+01[c]	NA
		WMin/PP	NA	NA	6.0E+01[c]	NA
INCIN[b]	6.8E+02	Current	NA	NA	3.9E+02[c]	NA
		WMin/PP	NA	NA	3.4E+02[c]	NA
GROUT	7.7	Current	1.6E+02	1.4E+02	1.5E+02	NA
		WMin/PP	1.4E+02	1.2E+02	1.3E+02	NA
RFETS						
AQWTR	1.5E+05	Current	NA	NA	4.3E+01[c]	6.1[c]
		WMin/PP	NA	NA	2.6E+01[c]	3.8[c]
CMPCT	3.6E+03	Current	NA	3.7E+02[c]	3.9E+02[c]	NA
		WMin/PP	NA	2.3E+02[c]	2.4E+02[c]	NA
GROUT	5.0E+02	Current	1.1E+02[c]	7.2E+01[c]	8.5E+01[c]	6.1E-01[c]
		WMin/PP	6.4E+01[c]	5.4E+01[c]	5.0E+01[c]	6.1E-01[c]

Notes: NA = not applicable; AQWTR = aqueous water treatment; INCIN = thermal treatment; CMPCT = shredding and compaction; and GROUT = grout stabilization.
[a] The required capacities for pollution prevention are based on an assumed 50% across-the-board reduction in annual generation.
[b] Thermal treatment unit at LANL is currently unfunded and in shutdown mode.
[c] The existing capacity is sufficient regardless of reduction in annual generation.

Table G-26. Effect of Pollution Prevention on Costs for Four TRUW Alternatives[a] (in dollars)

Alternative	O&M[b]		Construction[c]		Transportation	
	Current	WMin/PP	Current	WMin/PP	Current	WMin/PP
Decentralized	4.7E+09	3.6E+09	2.1E+09	1.6E+09	5.6E+08	4.8E+08
Regionalized 1	4.9E+09	3.7E+09	2.3E+09	1.8E+09	5.1E+08	4.4E+08
Regionalized 2	5.5E+09	4.2E+09	3.0E+09	2.2E+09	4.5E+08	4.1E+08
Regionalized 3	5.1E+09	3.9E+09	2.9E+09	2.1E+09	4.9E+08	4.0E+08

[a] Based on a 50% across-the-board reduction in annual generation.
[b] Includes decontamination and decommissioning costs for both CH and RH TRUW.
[c] Includes preoperations costs for both CH and RH TRUW.

Table G-27. Effect of Pollution Prevention on Costs for an RH TRUW Alternative[a]

Site	O&M[b]		Construction[c]		Transportation	
	Current	WMin/PP	Current	WMin/PP	Current	WMin/PP
ANL-E	3.4E+06	1.7E+06	NA[d]	NA	2.1E+05	1.0E+05
Hanford	7.7E+08	5.6E+08	4.2E+08	3.0E+08	1.3E+07	9.4E+06
INEL	3.9E+07	2.3E+07	1.0E+07	6.0E+06	3.5E+05	2.1E+05
LANL	1.2E+07	1.1E+07	3.3E+06	3.1E+06	1.0E+05	9.5E+04
ORR	3.6E+08	3.0E+08	2.6E+08	2.1E+08	5.5E+05	4.5E+05
Total	1.2E+09	9.0E+08	6.9E+08	5.2E+08	1.4E+07	1.0E+07

[a] This is for treatment to RCRA standards at two installations (Hanford and Oak Ridge); ANL-E ships to ORR; INEL and LANL ship to Hanford. It is assumed that there is a 50% across-the-board reduction in annual generation.
[b] Includes preoperations costs.
[c] Includes decontamination and decommissioning costs.
[d] NA = not applicable.

Table G-28. Effect of Pollution Prevention Source Reduction on Cancer Incidence for TRUW Alternatives

Alternative	Offsite Population		WM Workers	
	Current	WMin/PP[a]	Current	WMin/PP
CH Decentralized	5.5E-04	4.0E-04	2.1	1.8
CH Regionalized 1	8.6E-04	6.3E-03	2.2	1.8
CH Regionalized 2	2.8	2.0	2.0	1.7
CH Regionalized 3	6.5E-01	4.3E-01	2.2	1.8
RH[b]	1.6E-01	1.3E-01	3.4E-01	2.8E-01

[a] 50% across-the-board reduction in annual generation.
[b] Treat RH TRUW at 2 sites to RCRA LDR.

In contrast, health risks to WM workers are more evenly spread among sites, with WM workers at INEL having the greatest cancer incidence. At INEL, the inventory of CH TRUW far exceeds annual generation. Thus, pollution prevention has a smaller impact on estimated cancer incidence among WM workers.

G.3 Pollution Prevention Applied to Environmental Restoration and Decontamination and Decommissioning Activities

Environmental restoration activities are directed toward removal and treatment of contaminated media and facilities. Waste and pollution may be generated during restoration activities just as they may be generated by decontamination and decommissioning (D&D) of plants and equipment and by dismantlement of weapons systems. Appendix B of the 1994 crosscut plan (DOE, 1994b) states that pollution prevention is applicable to the processes and techniques used to perform ER and D&D activities. In this section, application of pollution prevention practices to ER and D&D activities is discussed in view of the Office of Science and Technology's research, development, demonstration, testing, and evaluation program.

G.3.1 Groundwater and Soils Cleanup

Some of DOE's most pressing ER needs are for cleanup or containment of radioactive and hazardous contaminants in soils and groundwater. DOE is responsible for waste management and cleanup of more than 100 contaminated installations (containing approximately 3,700 contaminated sites) in 36 states (DOE, 1993b). These sites have over 26,000 acres with hazardous and radiologically contaminated surface water, groundwater, and soil that are in need of some measure of remediation. The following are a few examples of the extent of the contamination. At SRS and the Hanford Site, for example, soils and groundwater are contaminated with volatile organic compounds (VOCs). At the Nevada Test Site, more than 13 km^2 of soil are contaminated with plutonium, and a large quantity of soil is contaminated with uranium at the Fernald Environmental Management Project (FEMP) Site.

The DOE Office of Science and Technology Research, Development, Demonstration, Testing and Evaluation (RDDT&E) efforts include several programs directed for groundwater and soils cleanup. One concept being explored that is in conformity with pollution prevention principles is the Minimum Additive Waste Stabilization (MAWS) concept for stabilization of LLW and LLMW (DOE, 1994c). This new approach to vitrification uses multiple waste streams as substitutes for additives otherwise needed to be purchased. The MAWS concept integrates vitrification with other treatment technologies as appropriate, increasing waste loadings and reducing costs. The minimum additive waste stabilization technology is being demonstrated at FEMP. Applicable waste streams appear to be soils, sludges, groundwater, and ash and debris from burn pits.

Most of the RDDT&E programs in the ER area are integrated programs or demonstrations. In an integrated program, multiple technologies are assembled and evaluated as a cradle-to-grave solution to a representative generic environmental problem (DOE, 1993a). Some current RDDT&E integrated demonstrations are for VOCs in non-arid soils, VOCs in arid soils, cleanup of mixed waste landfills, uranium in soils, and in-situ remediation. Some of the technologies in the integrated demonstrations can be considered source reduction technologies. One such technology is methane-enhanced bioremediation, in which methane is injected via horizontal wells to become a food source for indigenous microorganisms known to be capable of degrading trichloroethylene (DOE, 1994d). By destroying contamination rather than transferring it from one medium to another, methane-enhanced bioremediation can be considered a pollution prevention technique (DOE, 1994d).

G.3.2 Decontamination, Decommissioning, and Recycle

Because many facilities in the DOE complex are aging or changing their missions, there is a need to deactivate and decommission a large number of surplus buildings that currently contain radiological, hazardous, mixed, and special (such as asbestos) contaminants. Facilities in the DOE complex are assumed to contain substantial quantities of scrap steel, nickel, aluminum, and copper, which if decontaminated could be recycled and reused. The Office of Science and Technology's RDDT&E program has a component concerned with reuse and recycle of both metal and concrete from decommissioned facilities (DOE, 1993a). Technologies being considered for the removal of both surface and volume contamination because they appear to have no technological barriers, worker safety problem, or public health limitations are:

- Surface decontamination of concrete using a microwave process
- Surface decontamination of metals using a laser process
- Volumetric decontamination of concrete using an electrostatic process
- Volumetric decontamination of stainless steel and of mild steel using a refining process
- Surface decontamination (internal) of equipment using a gas-phase process
- Volumetric decontamination of transite/asbestos using a melting process

This component includes developing industrial capacity to reuse and recycle the contaminated material.

G.4 References

ANL. *See* Argonne National Laboratory.

Argonne National Laboratory. 1996a. *Low-Level Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.L. Goyette and D.A. Dolak. ANL/EAD/TM-20. Argonne, IL.

Argonne National Laboratory. 1996b. *Information Related to Low-Level Mixed Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by B.D. Wilkins, D.A. Dolak, Y.Y. Wang, and N.K. Meshkov. ANL/EAD/TM-32. Argonne, IL.

Argonne National Laboratory. 1996c. *Hazardous Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by M.A. Lazaro, A.A. Antonopoulos, M.P. Esposito, and A.J. Policastro. ANL/EAD/TM-25. Argonne, IL.

Argonne National Laboratory. 1996d. *Transuranic Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by K.J. Hong, T.J. Kotek, S.M. Folga, B.L. Koebnick, Y.Y. Wang, and C.M. Kaicher. ANL/EAD/TM-22. Argonne, IL.

DOE. *See* U.S. Department of Energy.

Executive Order (EO). 1993. "Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements." Executive Order 12856 of August 3, 1993; 58 FR 41981, August 6.

Idaho National Engineering Laboratory. 1995a. *Waste Management Facilities Cost Information for Low-Level Waste* by D.E. Shropshire, M.J. Sherick, and C. Biagi. INEL-95/0013. June. Idaho Falls, ID.

Idaho National Engineering Laboratory. 1995b. *Waste Management Facilities Cost Information for Mixed Low-Level Waste* by D.E. Shropshire, M. Sherick, and C. Biagi. INEL-95/0014, Rev. 1. June. Idaho Falls, ID.

Idaho National Engineering Laboratory. 1995c. *Waste Management Facilities Cost Information for Hazardous Waste* by D.E. Shropshire, M. Sherick, and C. Biagi. INEL-95/0016, Rev. 1. June. Idaho Falls, ID.

Idaho National Engineering Laboratory. 1995d. *Waste Management Facilities Cost Information for Transuranic Waste* by D.E. Shropshire, M. Sherick, and C. Biagi. INEL-95/0015, Rev. 1. June. Idaho Falls, ID.

INEL. *See* Idaho National Engineering Laboratory.

Teclaw, C.E., A. Youngblood, R. Kidman, and J. Betschart. 1993. *Avoidable Waste Management Costs at DOE Facilities*. LA-UR-93-1154. March. Los Alamos, NM: Los Alamos National Laboratory.

U.S. Department of Energy. 1988. "General Environmental Protection Program." DOE Order 5400.1, Nov. 9. Washington, DC: Office of Environment, Safety and Health.

U.S. Department of Energy. 1993a. *Office of Technology Development Program for Research, Development, Demonstration, Testing, and Evaluation (FY 1993 Program Summary)*. DOE/EM-0109P. Oct. Washington, DC: Office of Waste Management, Office of Technology Development.

U.S. Department of Energy. 1993b. *Annual Report on Waste Generation and Waste Minimization Progress 1991-1992*. Dec. Washington, DC: Office of the Secretary.

U.S. Department of Energy. 1994a. *Implementation Plan, Waste Management Programmatic Environmental Impact Statement*. Jan. Washington, DC: Office of Waste Management.

U.S. Department of Energy. 1994b. *1994 Waste Minimization/Pollution Prevention Crosscut Plan*. Jan. Washington, DC: Office of the Secretary.

U.S. Department of Energy. 1994c. *Minimum Additive Waste Stabilization (MAWS) Technology Summary*. DOE/EM-0124P. Feb. Washington, DC: Office of Waste Management, Office of Technology Development.

U.S. Department of Energy. 1994d. *Mixed Waste Integrated Program (MWIP) Technology Summary*. DOE/EM-0125P. Feb. Washington, DC: Office of Waste Management, Office of Technology Development.

U.S. Department of Energy. 1994e. *Mixed Waste Inventory Report: Final Phase II Mixed Waste Inventory Report Data*. EM-352. May. Washington, D.C.

Appendix H

Technology Development

U.S. Department of Energy
Waste Management Programmatic Environmental Impact Statement

Contents

Table

Acronyms and Abbreviations

The following is a list of acronyms and abbreviations (including units of measure) used in this appendix.

Acronyms

ARARs	Applicable or Relevant and Appropriate Requirements
BDAT	best demonstrated available technology
BUSS	Beneficial Uses Shipping System
CAA	Clean Air Act
CEM	continuous emission monitoring
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CH	contact-handled
CWCO	catalytic wet chemical oxidation
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DNAPL	dense nonaqueous phase liquid
EM	Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ESC	expedited site characterization
FTIR	Fourier transform infrared
FY	fiscal year
INEL	Idaho National Engineering Laboratory
ISV	in-situ vitrification
LDR	land disposal restriction
LIBS	laser-induced breakdown spectroscopy
LLMW	low-level mixed waste
LNAPL	light nonaqueous phase liquid
MAWS	minimum additive waste stabilization
NEPA	National Environmental Policy Act
NO_x	nitrogen oxides
PCB	polychlorinated biphenyl
PHP	plasma hearth process
PNA	polynuclear aromatic
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
SCDE	supercritical carbon dioxide extraction

SCWO	supercritical water oxidation
TCLP	toxicity characteristics leach procedure
TD	Technology Development
TSCA	Toxic Substances Control Act
VOC	volatile organic compound
WM PEIS	Waste Management Programmatic Environmental Impact Statement

Abbreviations

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
psi	pounds per square inch

APPENDIX H
Technology Development

H.1 Introduction

This appendix addresses the potential impact of technology development on the Waste Management Alternatives described in Chapter 3 of the Waste Management Programmatic Environmental Impact Statement (WM PEIS). This discussion outlines the approach taken by the U.S. Department of Energy's (DOE's) Office of Environmental Management (EM) through its Office of Technology Development and discusses selected examples of emerging technologies that may influence the WM PEIS Alternatives or mitigate the impact of EM activities.

The Office of Technology Development is responsible for managing an aggressive national program of applied research, development, demonstration, testing, and evaluation for environmental cleanup, waste management, and related technologies. This Technology Development (TD) Program undertakes a focused problem-oriented approach to have technologies available for use to support the DOE's environmental management needs in a manner that also supports the DOE's industrial competitiveness goals. The TD Program is designed to resolve major technical issues, to rapidly advance beyond current technologies for waste management operations, and to expedite compliance with applicable environmental laws and regulations. The underlying strategy is to identify and develop high-payoff waste management technologies that can: (1) cleanup the inventory of DOE nuclear component manufacturing sites and (2) better manage DOE-generated waste than is possible with existing environmental cleanup technologies. In many cases, the development of new technologies presents the best hope for ensuring a substantial reduction in risk to the environment and improved safety for workers and the public within realistic financial constraints.

The availability, and the projected availability, of appropriate technologies govern what can be cleaned up, how, and how soon. DOE's objective is to manage its waste with the greatest effectiveness, efficiency, and lowest tolerable risks to people (health, safety, jobs) and the environment. Although emerging technologies are discussed in the context of the WM PEIS, they will likely play their most prominent role in the National Environmental Policy Act (NEPA) process during remediation at individual sites or during the decision-making process of facility design and selection. This is the point at which candidate technologies would receive specific consideration. To date, thirty-nine technologies developed and demonstrated by the Office of Technology Development have been either implemented or selected for implementation by DOE sites. Many of these technologies have been transferred to industry and are commercially available. Many more are in various stages of demonstration needed to become viable candidates for implementation. Past accomplishments in technology development are detailed in a series of Annual Reports to Congress required under Public Law 101-189.

The technologies postulated by DOE for use in waste management applications for the purpose of estimating attributes associated with the various WM PEIS Alternatives are ones which have already been widely approved by regulators. On the other hand, the technologies discussed in this Appendix, while believed to be sound in theory, require significant development before they would be considered proven, demonstrated, and generally acceptable to regulators. Emerging technologies must meet at least one, and preferably all, criteria for being "better, faster, safer, cheaper" than the current baseline technologies that they may supplant. Representative emerging technologies, if available for wide application, are considered in this appendix to help determine whether they might alter the selection of WM PEIS Alternatives. Consideration is also given to the potential ability of technology development to mitigate the environmental and economic costs of the EM program.

H.2 Focus Areas and Crosscutting Programs

The EM Office of Technology Development is organized on the basis of focus areas and cross-cutting programs. Five major remediation and waste management focus areas identified and targeted for action on the basis of risk, prevalence, or need for technology development to meet environmental requirements and regulations include: contaminant plume containment and remediation; mixed waste characterization, treatment, and disposal; high-level waste tank remediation; landfill stabilization; and facility transitioning, decommissioning, and final disposition.

Subsurface Contaminants. This focus area deals with uncontained hazardous and radioactive contaminants in soil and groundwater. At most sites, information about contaminant distribution and concentration is insufficient. Moreover, many containment and treatment technologies are ineffective or too costly to use. Improvements are being sought in containment systems and systems to remediate contaminated soils and groundwater.

Mixed Waste Characterization, Treatment, and Disposal. This focus area addresses major technical challenges to managing low-level mixed waste. Disposal capacity for mixed waste is expensive and severely limited; DOE now spends millions of dollars each year to store mixed waste because of the unavailability of accepted treatment technology and disposal capacity. Currently available waste management practices require extensive, and therefore expensive, waste characterization before disposal. Improvements are being sought in thermal and nonthermal treatments emissions, nonintrusive drum characterization, material handling, and final waste forms.

High-Level Waste Tank Remediation. This focus area is primarily concerned with deteriorating tank structures and consequent leakage of their contents. Research and technology development activities must concentrate on safe, reliable, cost-effective methods for characterization, retrieval, treatment, and final disposal of high-level tank wastes. Special emphasis is placed on in-situ or remotely handled processes and waste volume minimization.

Landfill Stabilization. This focus area addresses the significant remediation challenges posed by numerous DOE landfills. Some existing landfills have contaminants that are migrating, thus requiring interim containment before final remediation. Materials buried in "retrievable" storage pose another problem—retrieval systems that reduce worker exposure and reduce the quantity of secondary waste must be developed. Development of in-situ methods for containment and treatment is also a high-priority need.

Facility Transitioning, Decommissioning, and Final Disposition. This focus area addresses the technological problems associated with the numerous weapons complex facilities no longer needed because of age or changing national security requirements. While the building and scrap materials at the facilities are a potential resource with significant economic value, current regulations lack clear release standards. The recovery, recycling, or reuse of these resources can be encouraged by enhanced technological developments for their decontamination. In addition, material removal, handling, and processing technologies must be improved to enhance worker safety and to reduce cost.

In addition to these focus areas, the Office of Technology Development manages three cross-cutting programs: *characterization*, *efficient separations*, and *robotics*. The objective of these cross-cutting programs is to provide needed research or technologies, in a timely, cost-effective manner, to support waste management, environmental restoration, and facility transition and management missions.

The remainder of this appendix contains a discussion of several emerging technologies. Section H.3 discusses emerging treatment and airborne monitoring technologies for waste management, with example technologies for managing low-level mixed waste, particularly the organic components of such waste. Section H.4 is an analogous discussion of emerging technologies particularly relevant to characterization and environmental remediation issues, with emphasis on their impacts on groundwater and soil contamination. The technology discussed in Section H.4 is relevant to this PEIS to the extent to which it increases (that is, by making remediation technically and economically feasible at additional DOE sites) or decreases (that is, by enabling in-situ cleanup of soil and groundwater sites) the volume of waste to be transferred to the EM Office of Waste Management for treatment and disposal. Section H.5 discusses technologies that relate to transportation risks associated with most WM PEIS Alternatives. While technologies are discussed under particular categories for convenience, the reader should note that many technologies overlap both site remediation and waste management categories.

H.3 Waste Management Technologies in Development

DOE has identified nearly 2,000 different stored mixed, high-level, transuranic, or low-level waste streams at more than 50 of its sites. The Office of Technology Development has undertaken a systematic approach to solving key problems in waste management (and environmental restoration) by conducting technology development in the categories of characterization and monitoring, retrieval, treatment, and stabilization in a form suitable for final disposal. During fiscal year (FY) 1996, the Office supported the work packages shown in the Attachment to this appendix. Waste management (as opposed to environmental restoration) efforts are being conducted most extensively in the Mixed Waste Characterization, Treatment, and Disposal Focus Area and in the crosscutting areas of characterization, robotics, and efficient separations; some other efforts (for example, pollution prevention) are also being conducted.

In this section, the technical capabilities and limitations of emerging technologies are compared with the baseline technology (usually incineration) for organic destruction in low-level mixed waste. This discussion will concentrate on the treatment of low-level mixed waste (LLMW) for several reasons: this type of waste is most broadly distributed throughout the DOE complex, at large and small sites; past practices for the storage and treatment of these wastes have led to public concerns about possible safety and health impacts; few treatment technologies have been proven for LLMW; and these are not acceptable for most of the LLMW streams. Thus, new technological advances for mixed waste treatment are widely sought.

The organic destruction step is particularly suited for illustration because it clearly offers the potential for advances in an overall system integrating treatment, monitoring, and improved final waste forms. Technology for each of these areas is included in this discussion. The choice of organic destruction technology is also important within the framework of the WM PEIS because of the potential impacts at sites of all sizes within the DOE complex. Thus, this issue relates directly to the degree of centralization and the choice among the Alternatives analyzed in this PEIS.

H.3.1 Definition of the Issue

Most of the approximately 50 DOE sites where LLMW now exists, has existed, or is expected to exist, generate and store small volumes of LLMW. More than 99% of DOE LLMW exists at just 13 of them. Of the 50 sites, about half would require treatment of 10 cubic meters or less of LLMW per year, and several would require treatment of less than 1 cubic meter. Although much LLMW would not be suitable for incineration (for example, bulk wastes contaminated with heavy metals) the baseline technology for dealing with the organic components of these wastes is assumed for discussion purposes to be treatment using a thermal technology, such as incineration. Specific treatment categories and volumes for DOE sites are provided elsewhere in the WM PEIS.

Land disposal restrictions specifically prohibit the disposal of a wide range of waste categories into the earth (40 CFR Part 268). Prominent on the list of prohibited waste categories are organic compounds regulated under the Resource Conservation and Recovery Act (RCRA). The inventory of DOE-generated LLMW contains the regulated organics as well as substances, such as inorganics, metals, and low-level radioactive constituents.

Use of emerging technologies in treating organic mixed wastes could change the number of treatment facilities, as well as respond to concerns about the social equity of treating waste at one site shipped from elsewhere—particularly from other States or regions. Alternate thermal or nonthermal approaches to organic destruction that would make onsite treatment of small volumes more feasible could minimize these concerns and reduce the importance of organic LLMW components in decisions between centralized and decentralized treatment configurations. The degree of centralization may also be affected if similar emerging technologies, applicable at larger scales, alter the balance of costs, risks, or public acceptance of currently available technologies for treating wastes at the larger volume sites.

H.3.2 Baseline Technology

According to 40 CFR 268.42, the U.S. Environmental Protection Agency (EPA)-approved technology-based standard treatment for organic destruction is incineration; a technology that has attained this status is commonly referred to as best demonstrated available technology, or BDAT.

The schedule for availability for incineration is not a problem; the technology has been applied to the treatment of both hazardous and mixed waste. Although improvements in technique are still being made, no further development is required for using the technology at conventional fixed facilities.

The cost of incinerators is a concern. Incinerators have a relatively high initial capital cost, especially when used to treat small volumes of mixed waste. An incinerator must be designed and sized to maintain a sufficient residence time at an elevated temperature to ensure the high level of destruction necessary to meet regulatory requirements. In addition, current units are larger than the size required to treat the low volumes of waste at smaller sites. The size of the treatment unit cannot simply be reduced proportionally for smaller waste volumes; therefore, the cost per unit volume would increase as less material is treated. Because of the high capital costs for constructing fixed facilities, industry has developed mobile incinerators for hazardous waste treatment. However, no mobile systems are yet commercially available to treat DOE's mixed wastes.

Technical limitations are also a concern when applied to the DOE complex. Treatment units must be designed to accommodate a wide range of wastes with different compositions and physical characteristics. Some degree of overdesign will be necessary, resulting in a larger, more costly, and more complex system. Difficulties with segregating secondary wastes (for example, ash) may also require additional treatment and incur additional costs. Incinerators require a complex off-gas treatment system to ensure that the release of hazardous compounds will be below specified or permitted levels. This problem is compounded for many DOE wastes by the presence of radionuclides. These may contaminate the off-gas stream as entrained particulates, or through volatilization resulting from the elevated temperatures required for complete combustion. The off-gas treatment system needs redundancy in design to insure appropriate levels of safety under all conditions.

Public acceptability issues are complicated by the interplay between onsite treatment and transportation. (Public acceptance is explicitly or implicitly considered by regulators under RCRA and the Comprehensive

Environmental Response, Compensation, and Liability Act (CERCLA); therefore, public acceptance strongly affects the timing for new technologies to become widely accepted and the willingness of the private sector to invest in these technologies. Consequently, judgments about acceptability are necessarily a part of an emerging technologies evaluation.) Public and stakeholder concerns about the potential for release of hazardous materials during treatment have affected the application of incineration at existing public sites and may similarly affect DOE sites. On the other hand, construction of treatment units at a site would eliminate the costs and risks associated with transportation of the wastes to other locations for treatment. These decentralized, onsite options should be favored by those stakeholders along the transportation routes, and those near the sites that would otherwise have been receivers of shipped wastes.

H.3.3 EMERGING TREATMENT TECHNOLOGIES (MIXED WASTE CHARACTERIZATION, TREATMENT, AND DISPOSAL FOCUS AREA)

H.3.3.1 Introduction

This section contains a general discussion of some alternative technologies and addresses several in greater detail. Many alternative treatment technologies are being developed or demonstrated within DOE or the private sector. These include thermal treatments that destroy organic components at high temperatures and nonthermal treatments that destroy organic components at lower temperatures. Table H–1 lists specific technologies applicable to the destruction of small volumes of LLMW that were examined during preparation of this document. The list of technologies applicable to larger sites would be similar.

H.3.3.2 General

The potential advantages of the emerging technologies are compared to the baseline (incineration) using similar criteria.

The schedule for availability for these emerging technologies *is* an issue. The alternative technologies are not developed to the point where application is guaranteed, especially within the time frame important to

Table H-1. Emerging Technologies Evaluated for Organic Destruction of LLMW at Small-Volume Sites[a]

Thermal Treatments
Plasma hearth (fixed hearth and centrifugal hearth units are commercially available)
Steam reforming
Mobile incinerators
Molten salt oxidation (MSO)
Catalytic extraction (e.g., molten metal technologies)
Reverse burn gasification (e.g., ChemChar)
Thermal reductive (e.g., ECO-Logic)
Pyrolysis
Vitrification
Nonthermal Treatments
Chemical oxidation Acid digestion Wet oxidation Wet air oxidation Wet chemical oxidation Supercritical water oxidation Catalyzed wet chemical oxidation Catalyzed acid oxidation Chemical and biological treatment
Biological treatment (both oxidative and anaerobic)
Photolytic oxidation Ultraviolet (UV) oxidation, including UV-hydrogen peroxide and UV-ozone Catalyzed UV oxidation Laser-induced oxidation Photothermal detoxification unit
Electrochemical oxidation Direct (electron beam) Indirect (catalyzed electrochemical oxidation [CEO], mediated electrochemical oxidation [MEO])
Dehalogenation (e.g., potassium ethylene glycolate KPEG process)

[a] Technologies tabulated are being evaluated by either private industry or the Federal Government.

selecting a programmatic Alternative. Thus, the capability of a new technology, or combination of technologies, to treat all incinerable wastes is not certain.

While some pilot-scale testing has been completed for many emerging technologies, some technologies are still being evaluated at the bench scale. Because of the limited amount of data available from the testing that has been completed, considerable technical testing is necessary before full-scale demonstrations are justified. For example, because of the difficulties and costs of handling radioactive materials, only a few tests have been carried out so far with actual mixed wastes. Most developmental efforts have used surrogates (nonradioactive materials with similar chemical or physical properties to the radioactive contaminants).

The capital cost of many of these technologies, both thermal and nonthermal, may be lower than an incinerator with similar capacity. However, because of the early stage of development, only rough cost estimates have been completed for most emerging technologies. Emerging technologies may also offer advantages in simplicity and may be more readily transported from site to site. A portable system would reduce the capital costs by avoiding the construction of multiple facilities. Another potential cost saving occurs with the reduction in characterization required for those technologies that are more "robust" than incinerators. For these cases, a wide variety of wastes can be processed without the need for extensive characterization before treatment. This would also reduce the cost for constructing complex characterization facilities at the small-volume sites and thus cut total system costs.

Technical limitations may be fewer than for incineration in the case of some of these emerging technologies; however, others may have additional limitations. Nonthermal technologies do not involve high temperature, reducing the potential for volatilization of metals and radionuclides. In addition, many of these approaches generate much lower volumes of off-gas compared to incineration. Similarly, some thermal treatment technologies under development would generate lower volumes of off-gas. Thus, a less complex off-gas treatment system may be possible. However, for some nonthermal systems, other components (such as nitrogen oxides [NO_x]) and secondary waste streams (such as spent reaction solutions) may also require treatment. The complexity of the total system, including secondary treatment, must be considered when comparing to the baseline. As with the baseline treatment, many emerging technologies may be designed for application in mobile units.

Public acceptability may be higher for nonthermal treatment technologies than for incineration, inasmuch as they do not bear the incineration label and may be viewed as alternatives.

The situation is further complicated by private sector market considerations. Because incineration is controversial, but is nonetheless BDAT for organic destruction of hazardous wastes, private industry is developing many alternatives to incineration to capture non-Federal markets. Much of the technology development effort has been directed toward specific waste streams found in large volume within the private sector. Only a limited amount of testing has been done to learn the range of waste types that can be treated efficiently with any particular technology. A significant amount of additional work will have to be done to show applicability, and to find acceptable processing conditions for a broader variety of waste streams, before wide market acceptance of an emerging technology is likely. Further, the emergence of a technology capable of capturing a significant share of the private sector market could lead to a sharp decline in the willingness of industry to act in partnership with DOE to continue to address DOE waste streams for which the new technology is not applicable—with adverse implications for the development of technology useful to DOE.

H.3.3.3 Specific Example: Plasma Hearth Process

The plasma hearth process (PHP) is a robust process that can treat a wide variety of wastes through exposure to plasma at temperatures greater than 3,000°C. The fixed-hearth plasma process has the potential to treat nearly all mixed waste streams present in the DOE complex, including solid combustibles, heterogeneous debris, and chemical containers. The process burns off organic components of the waste stream. The inorganic components are melted to form a glassy slag and a metal phase that can be separated and potentially recycled. Radionuclides and heavy metal contaminants are bound in the slag, which has been shown to have sufficiently low leachability to pass the EPA toxicity characteristics leach procedure (TCLP). The process includes a secondary destruction unit to ensure high organic destruction efficiency regardless of the properties of the incoming waste. Additional treatment of this secondary waste may be necessary to render the final form compliant with land disposal restriction (LDR) regulations.

The PHP can treat multiple mixed waste types contained in drums without opening them. This would greatly reduce the need for characterization of the waste before treatment and may result in a large saving in the total system cost compared with that for a less robust technology.

Schedule for availability. The plasma hearth process may be usable at one or more small-volume sites within a few years. Scale-up to larger volume applications would follow. Development of the plasma hearth process is still at the pilot scale. Tests have been carried out with several surrogate low-level mixed and transuranic waste streams. An integrated nonradioactive pilot-scale demonstration system was constructed at Retech, Inc. (California) in FY 1995, with bench-scale radioactive testing scheduled for FY 1997. Argonne National Laboratory–West conducted an integrated bench-scale radioactive demonstration in FY 1995. The results of the demonstration on actual mixed wastes allowed a more reliable estimate of the availability of the PHP for treatment of LLMW. An integrated pilot-scale plasma hearth test system will be ready for operation in FY 1997 at Retech, Inc. This system is expected to be similar in capacity to that required to provide treatment at the smaller DOE sites. Thus, a significant amount of information on the capabilities and any limitations of this technology will be available at the time NEPA and other regulatory decisions are made about application of technologies for treating DOE's wastes at specific sites.

Cost. Savings could occur with use of the plasma hearth process. (Estimated cost savings will be a product of the Office of Technology Development Cost/Benefit Project, an ongoing activity to establish economic parameters for technologies as a guide to setting priorities in the program and a support for technology transfer.) Baseline incineration and cementation technology requires detailed characterization and segregation of containerized heterogeneous mixed waste, followed by high-temperature incineration and cementation of the ash byproduct. PHP technology has an economic advantage over the baseline technology, with the major differences being driven by the costs of process equipment and operation, annual maintenance, and disposal. The reduced cost of process equipment is the principal factor accounting for a large cost difference over the 20-year life cycle. In PHP, pretreatment characterization requirements are reduced and the final waste form usually passes leachability requirements for final disposal.

Technical limitations. Two problem areas exist for the plasma hearth process: off-gas and materials (drum) handling. Only 1% of the air for fossil fuel burners is required for operation of the plasma torch; therefore, the volume of off-gas is much lower. The lower volume of gas is easier to monitor and control, and increases the potential for operation with a closed off-gas system, in which the release of contaminants to the atmosphere is eliminated by recycle of the off-gas. However, test results to date have shown the possibility of high levels of NO_x formation.

The plasma hearth process can be designed with a primary destruction chamber that is relatively small (e.g., contains a single 55-gallon drum of waste at a time) or scalable to accommodate multiple drums. Thus, it is applicable to small-volume DOE sites, either as fixed or mobile units. However, design issues do arise in handling drums of waste with the plasma torch before and after treatment. For example, the inorganic slag produced will initially be at a high temperature. The temperature complicates the process of moving the slag into waste drums for disposal without compromising the integrity of the drums.

Public acceptability. The public acceptability of this process is unknown. Although the PHP involves high temperatures, the low volume of off-gas may minimize fears about the release of hazardous substances. In addition, the low thermal mass of the system would allow rapid shutdown in case of a process upset. This attribute should also be viewed favorably.

H.3.3.4 Specific Example: Catalytic Wet Chemical Oxidation

Wet chemical oxidation systems use the reaction of oxygen, or an alternative oxidizing agent, to destroy the organic constituents of a waste in an aqueous solution. In catalytic wet chemical oxidation, one or more chemical species are added to increase the rate at which the oxidation reactions progress. The example catalytic wet chemical oxidation system being developed by Delphi Research, Inc. (DETOX), uses an iron catalyst and a co-catalyst to degrade the organic contaminants in a strong acid solution. The system operates at temperatures much below those used in incineration and at moderate pressures. The expected operating conditions are approximately 150°F and 70 psi.

Schedule for availability. The DETOX system will undergo a pilot-scale cold test at the Savannah River Technology Center in FY 1997. Because design of a portable system is under way, application to wastes at small sites may be possible within 3 to 5 years. However, because of the early stage of development, a high degree of uncertainty remains about issues associated with the technology.

Cost. Catalytic wet chemical oxidation uses equipment typical of that used in chemical processing operations. A system could be constructed at a scale appropriate for treatment of the wastes at the small-volume sites or scaled up. Because the equipment is readily available, development costs should not be an impediment to commercialization. However, because development is still in the early stages, equipment and treatment costs have not yet been determined. The processing required for spent reaction acid solutions and for stabilization and disposal would add to the cost.

Technical limitations. The DETOX technology has been demonstrated at bench scale, with destruction efficiencies of 99.9999% achieved for liquid hydrocarbons, including some chlorinated organics. Successful treatment has also been demonstrated for solid combustibles and for contaminated soils. However, only a limited amount of data is available. Treatment of materials that volatilize from the reactor will require further study even though off-gas volume will be small. Because of the strongly acidic nature of the reaction mixture, engineering development is focused on construction materials, along with scale-up problems. Other technical problems include treatment of the spent reaction solutions and system integration.

Public acceptability. As stated above, catalytic wet chemical oxidation is a nonthermal technology that operates at moderate temperature and slightly elevated pressure. Although the technology should not suffer from the incineration stigma, achieving public acceptability will likely require educating the public.

H.3.3.5 Specific Example: Vitrification

Vitrification of wastes into glass is an alternative to incineration, as well as a stabilization technology for incinerator secondary waste. Wastes and glass additives are combined and melted in a refractory furnace at approximately 1,100°C. Organic components and liquids are destroyed while radionuclides and metals are entrapped in a glass final waste form.

A broad range of waste, such as organic liquids, wet solids, dry solids, and heterogeneous solids, can be processed in a glass melter. Contaminants are chemically bound into the glass rather than simply encapsulated in the material. This will lead to improved leachability resistance over grout. Long-term stability is being evaluated as part of the technology development efforts. The stability of glass waste forms is higher than that for cement-based waste forms. Initial studies show the leachability results of low-level waste vitrification to be comparable to high-level waste glass standards. The glass reduces waste volume by at least 30% and meets land disposal restrictions. Minimal volatilization of most metals occurs because of the oxidizing atmosphere that allows wastes to form oxides and stay in the glass phase. Employing appropriate melter technology, such as a cold top unit, will minimize volatilization of other metals, such as mercury, by causing condensation on the cap.

Schedule for availability. Waste vitrification is the selected waste form process for high-level waste at DOE's Savannah River Site near Aiken, South Carolina. The Defense Waste Processing Facility (DWFP) became operational on March 12, 1996. Vitrification of mixed waste inorganic sludge has been demonstrated at the bench scale at the Rocky Flats Environmental Technology Site (RFETS) using microwave energy. Further technology development of low-level waste vitrification for higher waste loading and for organic destruction will incorporate experience gained from high-level waste solidification.

Cost. Oxide raw materials for glass are inexpensive. However, melting equipment, energy required for melting, and off-gas requirements may be more expensive than incineration. The volume reduction of at least 30% for waste vitrification translates into a large cost savings in disposal. The Minimum Additive Waste Stabilization (MAWS) concept of combining waste streams and using waste materials as the glass additive is also being developed by DOE. This would decrease costs in two ways—by further reducing volume and by decreasing the cost of additives.

Technical limitations. One important concern remaining to be addressed for organic destruction application is a potential problem with glass integrity because of concentration sensitivity for carbon, some radionuclides (e.g., uranium), and some hazardous metals. This integrity concern may prove to be a stumbling block for this application. Vitrification is expected to have other important applications in DOE remediation and waste management where these materials are not present in the streams. Applications may include environmental restoration wastes, decontamination and decommissioning wastes, and incinerator ash.

Public acceptability. Public confidence should be high considering that high-level waste vitrification began at the DWPF and also at the West Valley Demonstration Project (WVDP) in 1996.

H.3.4 EMERGING AIR MONITORING TECHNOLOGIES

Progressive monitoring technologies are not treatment technologies like those listed in Table H-1, but may be a key factor in enhancing public acceptance of currently available and advanced waste treatment and organic destruction technologies. The baseline monitoring methodology involves periodic sample collection of process emissions, transferring samples to a laboratory instrument, and analysis. Advanced air monitoring technologies would allow improved and real-time evaluation of the effectiveness of toxic compound destruction during treatment of mixed waste, thereby contributing to the safety and acceptability of current and advanced treatment technologies.

The primary technical limitation of current methods is the inability to conduct real-time monitoring of certain species. Online analysis of the incinerator effluent would satisfy the requirements of the Clean Air Act (CAA) while simultaneously addressing public concern over waste incineration. Public acceptance of any waste treatment depends heavily on the ability of sensors to monitor the effectiveness of the treatment and to demonstrate that effluent streams do not contribute to worker and public risk exposure. The sensors need to be integrated with control systems and safety procedures to ensure that, if effluent levels exceed their limits, contaminants are controlled in a manner that prevents their entry into the environment.

Several technologies are emerging with the potential to effectively monitor important waste treatment parameters, such as those that measure incinerator performance. These new, real-time, continuous emission monitoring (CEM) technologies would be significantly cheaper than currently required monitoring techniques. Real-time monitoring makes it possible to perform diagnostic control of feed materials to help maintain necessary incinerator operating parameters and to allow process control of gaseous effluents containing unacceptably high levels of contaminants before release. Continuous monitoring will directly address issues of environmental safety, and the technology can be used to identify and quantify organic chemicals in the air. Thus, a continuous monitor directly addresses some public concerns about thermal treatment systems.

Typical examples of these new technologies should be available for demonstration in 1 to 5 years. The schedule is controlled by technical and regulatory acceptance concerns that can only be satisfied by testing.

Fourier transform infrared (FTIR) monitoring is one emerging technology that has already undergone testing on the Toxic Substances Control Act (TSCA) incinerator at Oak Ridge. FTIR is a mathematical method that allows for spectroscopic signal averaging to significantly improve signal-to-noise ratios and improve levels of detection of organic and selected inorganic molecular stack emissions. FTIR is not a new technique, but advances in instrument design allow its use in association with in-situ devices. FTIR is thus beneficial for generating rapid results while dramatically reducing the problem of spectral interference, or failure to differentiate between different chemical species.

In an indication of potential regulatory acceptance, EPA has facilitated these tests by issuing a protocol for an FTIR continuous emission monitor to ensure that the data that the technology can obtain will be compliant. The method can readily be extended to cover thermal treatment, stack, and ambient air monitoring.

Techniques for continuous emission monitoring of elements (for example, heavy metals and radionuclides) has not yet gone through a similar protocol/data verification process. Laser-induced breakdown spectroscopy (LIBS) is one such technology. In LIBS, laser light is focused on a specific region to vaporize a small amount of material. The vaporized material forms a short-lived plasma, which emits light that is collected, dispersed, and analyzed. Elements targeted specifically are among those of primary concern at many DOE and industrial waste sites—chromium, lead, arsenic, selenium, antimony, cadmium, zirconium, uranium, beryllium, and thorium. Technical issues that must still be addressed include: (1) determining possible spectral interferences; and (2) understanding detection limits, sensitivities, and precisions of the best spectral line or lines to be analyzed. Both issues must be resolved before LIBS can achieve regulatory acceptance.

FTIR development was completed in FY 1995 and the technology will be demonstrated in FY 1997 as part of the Plasma Hearth Process project. The LIBS system has been demonstrated in FY 1995 and FY 1996. Other important CEM technology demonstrations include the real-time airborne alpha emissions monitor (will be demonstrated in FY 1997), and the total, elemental and speciated mercury monitor (successfully demonstrated in FY 1996).

These monitoring technology advances are not expected, by themselves, to alter the ranking of the WM PEIS waste management configuration Alternatives, but they may mitigate public concerns about air quality for whichever configuration is adopted.

H.3.5 Conclusions About Emerging Technologies for Waste Management

Emerging technologies exist that should enhance waste treatment at many small sites. Some of these emerging technologies offer the potential to be:

- Less costly than those using fixed incineration
- Technically suited for the treatment of small volumes of waste
- Transportable, if permitting and decontamination requirements are resolved
- Ready for application in a time frame compatible with the requirements for key policy decisions at individual sites
- More readily acceptable to the public and other stakeholders

The plasma hearth process, catalytic chemical oxidation, and vitrification appear to have the potential to treat mixed waste streams at many of the smaller sites; however, neither the successful development of the necessary technologies nor their application to all waste streams at DOE's smaller sites are certain within the time-frame for formulating policy decisions. The difficulty of organic destruction argues against treatment of all DOE mixed wastes at all small-volume sites.

The emerging technologies discussed in this section may also be suitable for large-scale applications and may affect decisions on the overall waste treatment configuration. Private sector development directed toward larger scale organic destruction applications is also active because of non-DOE markets. Although not directed toward small DOE sites, the pilot-scale versions of private sector technologies might be adaptable at such sites on a case-by-case basis, if the developers see such adaptation as closely tied to eventual commercialization at larger scales.

Emerging air monitoring technologies will also enhance the acceptance of current and advanced treatment technologies; this may have the greatest impact at large-volume treatment sites, but should be viewed primarily as a mitigation measure rather than one that affects configuration selection.

H.4 Restoration Technologies in Development

The environmental restoration of DOE sites and facilities will likely affect groundwater and soil. The restoration waste loads identified as part of the sensitivity analysis in this PEIS assume reliance on land use restrictions rather than remediation to handle certain exposure pathways. A rationale for such restrictions is that applying currently available (baseline) technology to the treatment of large volumes of soil or groundwater imposes excessive time, cost, and risk (to workers and transportation) penalties. This section describes several emerging characterization and treatment technologies, and addresses their potential impacts. Their potential to mitigate the cost of implementing baseline Environmental Restoration Program technologies is also discussed. Emerging technologies could also have a significant impact on other restoration problems not specifically addressed here.

Groundwater remediation is particularly important because due to relative volumes involved, it is more costly than soil remediation and would allow greater potential for cost savings from the application of new and emerging technology. However, as discussed below, new approaches to groundwater remediation increasingly recognize that the behavior of the solid matrix above and surrounding the groundwater is critical to a technology's success or failure.

The Office of Technology Development's efforts affecting soil and groundwater are conducted principally in two focus areas (Landfill Stabilization Focus Area and Contaminant Plume Containment and Remediation Focus Area), as well as in two cross cutting areas—characterization and robotics.

H.4.1 DEFINITION OF KEY ANALYSIS ISSUES

H.4.1.1 Contaminated Groundwater

Conventional technology cannot successfully treat the groundwater contamination occurring at some DOE sites to levels that would allow unrestricted access after remediation—particularly where the contaminant plume is large. Any emerging technology that radically increases the feasibility of treating groundwater to acceptable levels would lessen the need to restrict land use. Furthermore, even if cleanup levels consistent with such restrictions were adopted, but not envisioned as necessarily permanent (in effect, adopting a policy of taking interim actions and delaying cleanup while awaiting a new technology), the timing of technology emergence would determine when the restrictions would ultimately be lifted.

Groundwater contaminant plumes at DOE sites include volatile organic compounds (VOCs), such as carbon tetrachloride, trichloroethylene, and tetrachloroethylene; semivolatile organics, such as petroleum oil and polynuclear aromatics (PNAs), pesticides, and polychlorinated biphenyls (PCBs); heavy metals, such as chromium, lead, and mercury; toxic inorganic salts, such as nitrates; and radionuclides, such as uranium, transuranics, and tritium. Although most radioactive substances are inorganics and often can be treated similarly to other heavy metal extraction processes (with regard for the special problems of radioactivity), unique treatments are sometimes required for the lower-molecular-weight species of cesium, strontium, and tritium.

Tritium isolation, containment, and/or removal poses unique problems for waste management. Tritium, as an isotope of hydrogen, is primarily contained in waste bound in water molecules; thus, tritium is released to the environment as water vapor is released. Standard production-scale chemical separation methods are ineffectual in removing tritium from the water molecule. The only method that can segregate tritium-containing water molecules from normal water uses extremely expensive isotopic separation techniques, and at present, these are not developed to process bulk quantities of water. The only possible method to lower the release of tritium in water vapor would be to condense all water vapor released during the incineration process and collect the liquid water for disposal. This method would not be practical for two reasons. First, containment and storage of large quantities of liquid water are simply not cost effective and may be prohibited by current land-ban disposal restrictions. Second, since the tritium is effectively one with the water molecule, any alternative treatment of the contained water that would result in water evaporation and/or surface/groundwater discharge would introduce tritium to the environment through other pathways. Tritium-containing wastes could be segregated and stored until the tritium decays to harmless levels. The waste could then be treated and disposed of. This last method is feasible, given the approximately 12-year half-life of tritium.

In addition to the contaminants in the plume, contaminants are adsorbed onto the aquifer matrix material and referred to as "secondary contamination." Low-water-solubility organics adsorb to natural organic matter in the aquifer matrix, and positively charged ions (cations) of inorganic contaminants (for example, heavy metal and radionuclide cations) adsorb by ion exchange to the surface of clays or natural organic matter. When the plume is remediated and replaced by clean groundwater, the secondary contamination recontaminates the plume; this source may continue to release contaminants long after the primary source and the original plume have been remediated, thereby extending the life of the contamination plume. A means is needed to destroy secondary contamination in place, or to accelerate the desorption/exchange of the contaminants back into the groundwater. Thus, full cleanup of contaminated groundwater requires removal of the primary source (if it has not been completely depleted in generating the plume), removal of the plume itself, and removal of the secondary contamination.

Dense nonaqueous phase liquids (DNAPLs) are contamination sources that are difficult to locate or remove. DNAPLs flow downward through the surface soil and vadose zone to the water table; because they are denser than water, they can continue to sink into the aquifer until they reach an impermeable zone. Many DOE groundwater contaminants are potential DNAPLs, including PCBs, mercury, trichloroethylene, and tetrachloroethylene.

Small volumes of DNAPLs can give rise to large groundwater plumes having concentrations far above acceptable health-based levels. DNAPL pools, which may be hidden in weathered bedrock layers or dead-end fractures in bedrock, can continue to diffuse back into the aquifer gradually over prolonged periods. They may take 50 to 100 years or more to disappear through natural dissolution in groundwater. Because locating DNAPLs is so difficult, attempting to use conventional excavation methods for DNAPL removal may result in disturbance rather than recovery and can cause DNAPL migration to deeper positions in the subsurface.

Water-insoluble liquids that are less dense than water are called "light nonaqueous phase liquids" or LNAPLs. Refined petroleum fuels and oils can be LNAPLs, which are another source of contaminant plumes. LNAPLs tend to be more easily detected than DNAPLs and are thus more easily remediated. They tend to float on the water table and spread within the vadose zone. If present, LNAPLs tend to be readily collected with groundwater samples and during pumping of groundwater, and are seen as a separate phase floating on top of the water samples. Thus, LNAPLs are not nearly the special detection and removal problem that DNAPLs are, and will not be considered in detail in this discussion.

H.4.1.2 Contaminated Soils

A wide variety of soil types are present at DOE sites, including desert and humid climate soils, shallow and deep soils, permeable (sandy) and impermeable (clayey) soils, homogeneous and heterogeneous size mixes, and true soils and weathered bedrock (pre-soils). In general, common usage of the term "soil" (the correct geologic term is "overburden") includes all of the non-coherent subsurface matrix above the water table. The large volumes of soil requiring remediation at DOE sites imply that the risk to the public and to workers from handling so much soil, treating it, and transporting it to treatment facilities would be substantial. Emerging soil remediation technologies that would radically alter the need for handling and transport would also radically alter these estimated risks and capacity of required WM facilities.

The soil contaminants at DOE sites include the same VOCs, semivolatile organics, inorganics, and radionuclides found in groundwater (which is usually contaminated by soil-borne contamination). Because of the inherent affinity of many inorganic contaminants to adsorb on soil and subsurface minerals, and the low solubility and resultant accumulation of organics in the subsurface (which is enhanced immensely if the soil contains any natural organic matter), the solid matrix of the saturated and unsaturated zones can contain far more contamination than the water. Remediation attempts that approach the water alone are either destined for failure or extremely long-term programs.

The type of soil remediation technology that can greatly reduce the risks of excavation and treatment on the surface (or disposal in an engineered and approved facility) is remediation in the actual zone of contamination, that is, in-situ remediation. In-situ biological treatment is an available technology in need of significant refinement. In-situ chemical, thermal, and electrokinetic treatment technologies are being developed. Depending on the extent to which these technologies can be developed and implemented, future soil remediation should become considerably safer and more effective than existing approaches.

H.4.1.3 The Role of Characterization

The ability to remediate all DOE facilities to current Applicable or Relevant and Appropriate Requirements (ARARs), and to remediate many contamination sites to ARARs in a timely and cost-effective manner, is partly limited by the inability to characterize wastes effectively; that is, to identify locations and boundaries of the contaminated region and to identify the level and kind of contaminants present at the start and the conclusion of cleanup.

Inefficient characterization also increases worker risk, because of exposures during the characterization process and during actual remediation. Within the Office of Technology Development, characterization programs are given specialized, cross-cutting, technology development emphasis. Consideration involves not only environmental restoration needs, but also those associated with waste management and facility transition; the former will be emphasized in this section. Analogous "monitoring" technologies directly relevant to waste management are discussed in Section H.3.4 of this appendix.

The scope of characterization, monitoring, and sensor technology consideration includes:

- Initial location and characterization of wastes and waste environments (for example, transport and fate) before treatment
- Monitoring of waste retrieval, remediation, and treatment processes
- Characterization of the composition of final waste treatment forms to evaluate the performance of waste treatment processes
- Site closure and compliance monitoring

H.4.2 BASELINE REMEDIATION TECHNOLOGIES

H.4.2.1 Baseline Groundwater Remediation

The most commonly used baseline technology for plume remediation is pumping the groundwater to the surface through an extraction well, followed by treatment above ground. For organics, treatment might involve air stripping, biological treatment, or oxidation; for inorganics, treatments might involve ion exchange, oxidation, or precipitation. If the groundwater were accompanied by a LNAPL phase, an oil/water separation would be performed before further conventional treatment.

In general, ex-situ groundwater treatment technologies exist for almost any conceivable situation. Remediating contaminated groundwater with these technologies, however, often provides inadequate removal of secondary adsorbed organic or inorganic contaminants (both hazardous and radioactive) from the aquifer matrix during extraction pumping. Furthermore, if the source was a DNAPL, then remediation of groundwater by conventional pump-and-treat methods is usually effective only for remediating the existing plume, not for removing the contamination source or the secondary contamination.

The common technology now used to remove secondary heavy metals or inorganic radionuclides contamination is pumping and treating. The rate of desorption of secondary metal contaminants depends on the aquifer matrix material's ion exchange capacity (which depends on organic matter and mineral—especially clay—content), the pH and redox potential of the groundwater, and the specific metal species. Desorption may be extremely slow if conditions are not optimal, but no technology to create optimal conditions for metal desorption is now widely accepted by regulators as effective.

Although pumping and treating groundwater is often proposed for cleaning up plumes, in relatively few cases can this be expected to achieve acceptable levels of cleanup in a reasonable period (for example, 5 to 10 years) because of inadequate solubilization of secondary contamination. Pumping and treating for 50 to 100 years may often be required to desorb secondary contaminants adequately. In-situ bioremediation of organics and certain inorganics in groundwater is another currently available technology and, under appropriate conditions, it has the advantage of simultaneously treating the secondary adsorbed contamination in the aquifer. It can be effective for volatile, semivolatile, and relatively nonvolatile organic compounds. It is not considered effective for DNAPLs still in "pool" form. Also, inadequate in-situ treatment of secondary contaminants is likely to occur if:

- The organic material is only slightly water soluble (groundwater concentration would be too low to support biological activity); this tends to include many DNAPLs and most high molecular weight organics.
- The hydraulic conductivity of the aquifer is too low; in this case, the flow rate of nutrients or gases would be too low to support increased biological activity.
- The aquifer temperature is too low; here biological activity would be too weak to accomplish cleanup with microbes.
- The total amount of dissolved organics or toxic metals in the groundwater is high enough to poison the microbes.
- The destruction efficiency of the microbes for the contaminants is too low (refractory chemicals); then the contamination would remain untreated.

When in-situ bioremediation is adequate for cleaning up a plume and any secondary contamination of the aquifer, it should be possible to complete the cleanup in 1 to 5 years.

A currently available groundwater remediation technology for VOCs is in-situ air sparging, which will strip VOCs from the groundwater and will accelerate the removal of VOCs from the aquifer matrix as well. In-situ air sparging will also strip volatile LNAPLs and DNAPLs from the subsurface. This technique is discussed further in the following section because it also applies to soils.

H.4.2.2 Baseline Soil Remediation

The most commonly used baseline technology for soil remediation is excavation followed by transport to an acceptable disposal facility. Other available technologies involve excavation and surface processing. Ex-situ soil treatment methods (specifically, waste volume reduction methods) such as separation of the contaminated soil fraction and soil washing are being used more often to reduce the volume of waste requiring land disposal. A primary baseline technology for contaminant removal applicable to oxidizable substances is incineration. Other thermal processes induce volatilization and then capture the contaminants for further treatment or disposal.

In-situ treatment technologies are focusing on either immobilizing the contamination in an artificially generated rock matrix, or extracting the contamination by soil-washing. The primary immobilization technology involves solidification by chemical cementation. Depths are limited by the availability of the deep-soil mixing equipment needed. Soil washing is applicable to greater depths, but does require that the contaminant be readily mobilized by the wash fluid. Injection of solubilizing agents such as oxidants, reductants, acids, bases, or complexing substances is still an emerging technology.

In-situ bioremediation can be effective for many organic compounds. However, inadequate in-situ treatment of soil contaminants will occur under the same conditions described above for groundwater (insoluble contaminants, low temperatures, excessively high levels of contaminants, low hydraulic conductivity, inadequate destruction efficiency of the microbes). When in-situ bioremediation is appropriate for a site, it is possible to complete the remediation in 1 to 5 years.

In-situ air sparging is another currently available soil remediation technology, applicable to VOCs. This technique involves pumping air into the subsurface and sweeping out the more volatile substances. To some extent, this flushing can also enhance the volatilization of these compounds from an underlying aquifer matrix. In-situ air sparging will strip volatile separated phases—LNAPLs and DNAPLs—from the subsurface. Air sparging is inefficient for semivolatile organics such as most pesticides, PCBs, and PNAs.

H.4.2.3 Baseline Site Characterization

Today, the general method for characterizing a site entails drilling wells or clusters of wells, based on a grid outline of the site. Samples are taken from these wells to determine the geology, hydrology, and aquifer contaminant levels. When drilling a well, a split spoon auger may be used to sequentially collect soil samples until the aquifer is reached. Then, the well is cased and a section (approximately 10 feet) is screened to monitor the aquifer over a period of time. This procedure, when done for a specific grid pattern across the site, provides a horizontal mapping of aquifer contaminants. If a vertical profile is desired, a cluster of wells is installed at a specified point to monitor discreet levels of contaminants in the aquifer. For example, if the depth of an aquifer at a certain grid point is 50 feet, and 10-foot screens are called for by the regulators for well monitoring, then five wells must be drilled to analytically profile the aquifer at one grid point. Certain volatile contaminants and radioactive particles, such as gamma rays, are detectable at the surface, and certain information about the nature of the subsurface contaminants and potential exposures may be inferred. However, it is not generally possible to use that information to provide much more than guidance in planning the more detailed subsurface sampling.

The primary objective of site characterization is to map the contours of a contaminated area or contaminant plume; this mapping may be difficult if grid sample points are not well positioned along the plume contours, or if many data points indicate nondetectable contaminant levels. Further, the geological, hydrological, and chemical data are generally analyzed separately, not integrated. Thus, migration pathways and contaminant plume contours may not easily be determined.

Regulators establish protocols for the characterization program at each site, based upon data quality requirements, pre-existing knowledge of the site contaminants, hazards of known contaminants, and the particular statutes and regulations applicable to the program (for example, sites regulated under CERCLA and under RCRA within the same State may be responding to different regulators). Thus, instrumentation to be used, sampling frequency, and sample handling will not necessarily be identical across the entire DOE complex.

Samples are normally sent to an analytical laboratory where standard chemical and radiological instrumentation is used to measure contaminant identities and levels. Except under special circumstances, these laboratories typically are not on the site itself. The laboratories may be government operated, depending on the source site of the sample and suspected contaminants, but are often commercial enterprises, approved by the EPA through the Certified Laboratory Program.

Current characterization methods are expensive, time-consuming, intrusive, may give rise to new contaminant migration pathways, and can produce large quantities of secondary wastes. People collecting samples and those performing the analysis often do not communicate directly. Therefore, not all aspects of the data may be fully understood during analysis. Furthermore, appropriate modifications in the protocol based on past analyses may be slow to reach the field.

H.4.3 Emerging Remediation Technologies (Subsurface Contaminants Focus Area)

A number of strategies and technologies for contaminated groundwater and soil characterization and remediation are emerging. These technologies promise improvements in the scope of applicability, cost effectiveness, and completion times for future cleanups that would significantly reduce environmental hazards and risk. They include technologies for better field detection and pinpointing of groundwater and soil contamination, as well as chemical and thermal technologies for improved mobilization of contaminants for extraction and treating.

H.4.3.1 Improved Techniques to Detect, Remove, and Contain Primary Groundwater Contamination Sources

The detection of concentrated primary sources of contamination, especially DNAPLs, is difficult with conventional technologies. The existence and location of DNAPLs at DOE sites may often be undetermined. The cone penetrometer, a vehicle-mounted punch-like device used for many years to characterize the engineering properties of the shallow subsurface, has recently been adapted for sensing subsurface contamination using optic fiber sensors, and for continuous sampling of liquids or vapors without requiring removal of the penetrometer. Many punches of a cone penetrometer can be accomplished in the time and for the cost of installing a single groundwater monitoring well. The penetrometer should eventually permit detection of small pockets (0.5 cubic meters or less) of DNAPLs in-situations where installing a well would likely disturb, or spread them, but not accurately determine their location.

Recent improvements in the design and use of the cone penetrometer include the ability to penetrate rocky soils—through the use of higher drive weights and stronger, larger diameter penetrometer rods—and the ability to emplace well points and tubing, which can be used for soil gas measurements. The emplacement of well points may ultimately be modified to allow vapor or groundwater recovery without the necessity of installing a well.

Improved nonintrusive detection methods are being developed that may be expected to detect shallow pockets of DNAPLs. These detection technologies include seismic, passive and active magnetic, ground-penetrating radar, and induced resistivity/polarization methods. Current development is focused on improving their sensitivities at greater depths. Ground-penetrating radar shows the most promise. At present, none of these technologies is sensitive enough to be used alone or on all sites for DNAPL characterization, but when used in combination with other techniques such as the cone penetrometer, they can result in excellent delineation of DNAPLs.

Methods for adsorbing or siphoning pockets of DNAPLs are also needed to exploit these detection advances. A continuous sampling cone penetrometer may be adapted to pump DNAPLs to the surface, but such development has not yet begun. Conventional excavation methods may be adaptable for DNAPL removal without causing deeper migration, if conducted in conjunction with precise locating of DNAPLs with a cone penetrometer or other sensing device.

Emplacing conventional slurry walls or sheet piling, or hydraulic control using down-gradient extraction wells, are methods for containing a DNAPL source that can be used once DNAPL detection technologies emerge. These temporary containment technologies would allow time for source study while DNAPL removal methods are being considered or tested, without delaying initiation of other plume remediation activities.

Development of equipment capable of locating DNAPLs accurately enough for containment will likely occur in the next 3 to 5 years, but pinpointing individual DNAPL pools precisely enough for removal may be 5 to 10 years in the future. Because DNAPLs are one of the most common sources of groundwater contamination, these advances can be expected to save decades in remediation times, and hundreds of millions of dollars as compared with the alternative of simply attempting to pump and treat as long as necessary to exhaust the DNAPL source.

H.4.3.2 Improved Techniques to Detect Soil Contaminants

Detection and characterization of contamination using conventional technology involves the use of either fixed monitoring wells or shallow soil-gas surveys. Although improvements have occurred in location, sampling, and analysis speed, significant limitations of these methods make them expensive and somewhat unreliable. Improved techniques are under development to reduce cost and improve accuracy. These include the SEAMIST™ system and the previously discussed cone penetrometer. SEAMIST™ is an add-on to well technology that improves measurements of soil or water-borne contamination in both vertical and horizontal boreholes. The system facilitates chemical characterization and is a platform for geophysical sensors and video devices. Installation can be either temporary or permanent.

The technology uses an airtight membrane to line a conventional well or borehole. The membrane is forced into a drilled or punched well pneumatically. After emplacement, the entire hole wall is sealed, preventing ventilation of the pore space or circulation of pore water in the well. Once monitoring instruments are placed on the outer surface of the membrane, in contact with the hole wall, the membrane isolates each measurement location. High spatial resolution of the contaminant distribution is thereby possible.

Nonintrusive detection methods for contamination in groundwater are also applicable to characterization of soils. A suite of improved techniques for locating soil contamination probably will be in place in the next 3 to 5 years.

The same set of containment technologies already described for groundwater can usually be applied to soils once contaminants have been accurately located.

H.4.3.3 Improved General Site Characterization

In addition to purely "hardware" solutions, innovations that involve methodology may also be a key to characterization advances. The expedited site characterization (ESC) is one method for rapid, less expensive, and technically superior characterization of a site's groundwater and soil. ESC, as initially conceived, deploys a highly technical, multidisciplinary team to the field. The team collects data daily, discusses and integrates the results, and then formulates a strategy for sampling and analysis for the following day's activities. While field chemical instrumentation analysis costs vary, they are generally more than five times lower than offsite laboratory costs. For example, costs associated with sample transportation are eliminated. One typically exploits this cost savings potential, and the associated time savings from field analysis, to take more field samples. In addition, field testing is facilitated by being able to relocate sampling locations rapidly, if analytical results suggest that this is desirable. The resulting improvement in resolution of the plume allows for sampling many fewer monitoring wells and more than compensates for any differences in the quality of analyses that might occur between field and centralized laboratory settings. This dynamic approach to characterization saves time by reducing data integration and analysis turnaround times and saves money by minimizing well drilling and laboratory sample analyses. The net result is a faster and cheaper process that is arguably more accurate than conventional site characterization techniques.

The ESC has been successfully demonstrated at several U.S. Department of Agriculture sites in Nebraska and Kansas and at Bureau of Land Management landfill sites in New Mexico. Near-term tests will demonstrate the functionality and benefits of the process compared to conventional characterization methodologies and will characterize smaller sites focusing on organics, heavy metals, and radiological contaminants.

H.4.3.4 Improved Techniques to Mobilize and Remove Secondary Sources From Groundwater

In-situ air sparging can remediate a plume and its secondary contamination simultaneously if the contaminants are water insoluble VOCs, such as trichloroethylene and carbon tetrachloride. If semivolatile or nonvolatile organics are present that are also water insoluble, heat can be added to enhance volatility or water solubility. The aquifer matrix can be heated with steam, as has been shown in the Office of Technology Development's Dynamic Underground Stripping Project. There, steam was used to remove spilled gasoline by a combination of heating and gas stripping in the vadose zone and in the aquifer itself. If this technique were applied to nonvolatile, slightly soluble, secondary contamination, including inorganics or organics, solubilization in the groundwater could be enhanced.

Methods for heating the vadose zone also are being tested, including radio frequency or microwave heating and multiphase joule (conductive) heating of the subsurface. The solubility of contaminants in water, and the volatility of organics, can be enhanced by such heating. These techniques may also be applicable to aquifer matrices that have been pumped down temporarily.

Solubility enhancement for secondary contaminants is more developed than heating techniques. Organic secondary contaminants may be solubilized by flushing with appropriate ionic or nonionic surfactants or with enzymes. Aqueous surfactant solutions have been effective in removing water insoluble organics from soils, and would be expected to be as effective with aquifer matrices. Various surfactants are already approved for use on cropland as soil penetrants; inasmuch as they are also biodegradable, their use in aquifers should be considered acceptable by regulators. Enzymes are used in a variety of domestic cleaning and clothes washing materials because of their ability to degrade large organic molecules.

A wide variety of organic chelating agents (organic compounds that form soluble complexes with metal cations) can be used to solubilize heavy metals. These agents include ethylenediamine tetraacetic acid and citric acid. Some inorganics can be solubilized by acidic or basic buffers, or with oxidizing or reducing agents, allowing extraction. Electrokinetic techniques are being developed that would be applicable to shallow aquifers for mobilization of ionic contaminants. They would not require injection of reactive substances to promote mobility, but would use electrical fields to induce movement toward an extraction point.

The laboratory development of in-situ solubilization methods, including chelation, oxidation, and reduction, is in progress. Successful application in the field will depend on general improvements that must include treatment-chemical introduction and monitoring techniques, control and mass balance of contaminants and treatment reagents in the subsurface, and obtaining and maintaining sufficient permeability of the treatment zones. These developments can probably be expected in the next 3 to 10 years and will be widely applicable for groundwater remediation. The eventual savings in remediation times and costs will likely be a full order of magnitude.

H.4.3.5 Improved Techniques to Mobilize and Remove Soil Contamination

Many of the same technologies discussed above in connection with mobilization of contamination in groundwater are also applicable to soil remediation, particularly for soils where the groundwater table extends upward to shallow depths. Successful application of these technologies will require major improvements in general subsurface operations methods, including:

- Techniques for the injection of treatment solutions
- Techniques for monitoring reactions and movement
- Techniques for subsurface hydraulic control
- Techniques to enhance and maintain adequate subsurface permeability

As in the case with groundwater, these developments can probably be expected in the next 3 to 10 years and will be widely applicable for subsurface remediation. The eventual savings in remediation times and costs will probably be a full order of magnitude.

H.4.3.6 Improved In-Situ Treatment Technologies for Plumes and Secondary Sources in Groundwater

In-situ treatment of a groundwater plume tends to be cheaper than pumping and treating because less groundwater must be pumped, secondary sources can be treated simultaneously, and secondary waste streams are minimized. Both in-situ chemical and in-situ biological remediation technologies are under development.

In-situ chemical oxidation can destroy toxic organics or oxidize secondary organic contamination to the point that solubility increases and the oxidized products desorb and can be pumped to the surface for more complete ex-situ treatment. The candidate oxidants are those that degrade spontaneously to nontoxic products in the environment, such as ozone and hydrogen peroxide.

In-situ biodegradation recently became an available technology. Even so, technology development continues to address the significant limitations previously mentioned. Some examples are:

- For organics that are too water insoluble to desorb significantly, solubilization can be increased with surfactants or enzymes that do not harm the microbes. The desorbed contaminants can then be biodegraded in-situ.
- In areas where low aquifer temperature makes the rate of biodegradation very slow, in-situ heating will accelerate these rates so that bioremediation becomes practical.
- At sites where high levels of dissolved organics or toxic metals are present in the groundwater, or where the contaminants to be treated are refractory to biodegradation, microbes that can tolerate these conditions need to be developed and introduced into the subsurface. These goals are quite difficult, especially spreading microbes through the subsurface (which essentially behaves like a filter).
- In-situ biodegradation may be expected to tie up nonbiodegradable contaminants only temporarily, such as heavy metals and nonmetal radionuclides. Biomass decay may also produce byproducts capable of chelating and mobilizing toxic heavy metals. Methods must be developed for assessing this problem beforehand and for controlling it.

H.4.3.7 Improved In-Situ Treatment Technologies and Stabilization Technologies for Soil

In-situ treatment of soil contamination, by reducing the generation of secondary waste streams, tends to be cheaper than excavation and treating. In addition to in-situ immobilization technology, chemical and biological remediation technologies are under development. Many of the emerging technologies described above for groundwater and aquifer remediation may be applicable to soil and the vadose zone as well.

In-situ vitrification (ISV) is one emerging treatment technology for soils. Melting of the soil minerals and subsequent cooling to an impermeable glass-like mass will immobilize many soil contaminants. During the heating process some organics will volatilize; others will degrade. Any that escape the glass must be captured for treatment. The technology shows great promise for immobilization of radionuclides and for treatment of mixed wastes.

MAWS is a related process in which several waste streams with complementary characteristics are combined in order to take advantage of their separate characteristics. Doing so minimizes the need to add uncontaminated materials. In some cases, two merged streams can be vitrified when it would be impractical to vitrify one of the two alone. The benefit of this approach is that the final waste volume (for example, the wash residues from soil washing) is minimized because few or no additives are used and vitrification itself results in volume reduction.

In-situ biodegradation technology has advanced rapidly. Development continues to address the significant limitations previously mentioned in connection with groundwater. In addition, accessibility of microbes and nutrients to the contaminants sorbed in the soil interstices needs to be improved. General techniques such as soil-fracturing may be inadequate to improve the rate of degradation through access to the soil micro-structure.

H.4.4 Conclusions About Emerging Environmental Restoration Technologies

The conventional approach to groundwater contaminant extraction (pump and treat) is suitable for only a few sites and contaminants. The regions associated with many contaminated DOE sites:

- Are in the vadose zone without water
- Have such low permeabilities that pumping cannot extract the contaminated water
- Have contaminants with low solubilities or volatility and high soil affinities and are difficult to mobilize

The ability to locate primary sources of contaminants effectively, especially before they move into groundwater, and to contain them at those locations is a significant part of any strategy to avoid increasing costs and risks in the future. Emerging characterization technologies can reduce the cost, time, and worker risk associated with restoring sites by minimizing sampling and well costs, by reducing the number of trips and time in the field to collect potentially unnecessary samples, and by precisely locating contaminated region boundaries to minimize the handling of uncontaminated soil or groundwater.

The potential for significant cost reductions because of the availability of these or other advanced technologies could result in regulatory decisions to undertake more extensive remediation at particular DOE sites than would otherwise be the case. These decisions could result in increasing the waste loads being delivered from environmental restoration activities to waste management. However, this waste load effect is unlikely to be important at a programmatic level for at least two decades because in-situ technologies (which reduce waste loads) have greater potential for emergence and impact between now and that time. For unremediated sites, advanced characterization technologies can make it possible to monitor contaminant transport and provide confidence of the immobility of many contaminants and, therefore, minimal risk to public health.

Development of characterization and in-situ treatment technologies—reducing the need to excavate material for processing onsite or for transport elsewhere for disposal—will achieve the greatest improvement in safe, cost-effective soil remediation and minimization of waste management loading. Exposure risk, remediation cost, and danger to the population, from both contaminant contact and transport hazards, are substantially reduced through applying in-situ technologies. In-situ technologies are being developed and demonstrated for applications in the next 5 to 10 years. Some sites will still be recalcitrant, including those:

- With such poor hydraulic conductivity that most remediation methods would have difficult access
- Where the mix of contaminant chemistry (and subsurface interferences) limits the technology
- For which the extent of contamination, even with the best of innovative technology, would overwhelm financial resources

Although extremely difficult to remediate, situations of the first type (or others where the soil affinity makes the contaminant immobile) may pose less immediate risk. In other words, the same factors that inhibit remediant access may inhibit movement by the contaminants themselves. However, such inhibition is not reliable because of differing physical and chemical characteristics among the contaminants and remediants. Further, almost all sites will have soils that vary significantly in quality and characteristics. Accessibility to remediation injection or extraction will be patchy, and thus long-term "bleeding" of contaminants from isolated pockets of contamination will be a common problem.

These factors stress the importance of continuing research that enhances formation accessibility. This includes work to increase formation hydraulic conductivity and the ability to target, or pinpoint, the insertion of reagents and extraction of fluids. At present, the ability to manipulate groundwater flow is rudimentary. Plans for the application of any in-situ technologies will hinge on significant improvements in subsurface control. Because many technologies will involve powerful reagents and microbes and their nutrients, regulatory approval will depend on presentation of proof that the remediation can be controlled and will not worsen the environmental hazard by replacing one contaminant with another.

With regard to schedule, technologies adequate for soil remediation are expected to be successfully developed during the next 5 to 10 years. Their implementation should be widespread in another 5 to 10 years as they become generally accepted by remediation managers, regulators, and other stakeholders. The large number of possible approaches provides a basis for confidence that one or more approaches will prove successful despite uncertainties that may exist about any particular approach. The extent of soil contamination problems at DOE sites and non-DOE sites also provides confidence of continued private sector interest in commercialization.

On shorter time scales, there is little indication that all or most sites that cannot be remediated by available technologies could be remediated with emerging technologies. Formation accessibility is too difficult and hydraulic control in the subsurface is insufficient to ensure the success of in-situ methods. Short-term control until usable technologies are sufficiently mature, or long-term control and isolation, will be necessary to minimize risk where remediation is currently impossible.

Emerging technologies could mitigate the costs of remediation significantly. In the WM PEIS, DOE assumed a generic process that used new supplies of commercially available equipment and materials. Cost saving could result from the application of technologies discussed in this section. For example, the MAWS vitrification process could be less expensive than the generic vitrification process for certain applications, if on-site waste could be substituted for commercial oxide new material. Similarly, the use of the SEAMIST™ technology would provide better control of test wells, reducing the cost of characterization, and ultimately reducing the cost of pump and treat operations. These technologies are only a small fraction of the remediation technologies now under development within DOE, and many technologies should have numerous applications outside the DOE complex.

H.5 Transportation Technologies

Some of the waste management alternatives considered in the WM PEIS may require extensive transport of radioactive or hazardous materials on or between DOE sites. DOE's Transportation Management Division, with the EM Office of Compliance and Program Coordination, is sponsoring packaging research and development, packaging engineering and analysis, and packaging operations studies to produce a new generation of hazardous materials packaging.

H.5.1 Packaging Research and Development

Packaging research and development includes several related areas of development: development of analytical design codes, evaluation of packaging components, materials characterization, and packaging concepts.

Development of analytical methodologies design codes is the first such area. Structural analysis techniques are developed to predict packaging response accurately. Activities in this area emphasize establishing nonlinear dynamic analysis as an alternative for use in package certification. Specific activities will include investigation of acceptance criteria for inelastic analysis and benchmarking of these analysis codes. Thermal computational techniques are being improved. A better engineering description of hypothetical accident environments through use of new and existing analysis techniques and additional instrumentation is under development.

Development of analytical methodologies and design codes also includes activities to automate the analytical process. Transportation packagings are the final product of an iterative process of design, analysis, interpretation, modification, and redesign. This inherently inefficient design process can be vastly improved by automating evaluation of the structural, thermal, and shielding constraints to produce a more uniform factor of safety and thus more efficient design.

Evaluation of packaging components has already provided data on impact-limiting material and screening methods. A new constitutive plasticity model for wood stress through the crush range is being developed. Verification and refinement of a proposed crush failure theory for general triaxial stress states will be undertaken. A research and testing program for seal materials, begun in 1988, is characterizing the behavior of seal materials commonly used in radioactive material packages under normal and accident conditions, performance of the seals in nondeformed closures at both high and low temperatures, and response of seals to deformations in the closure region. A topic of particular interest to package designers is short-term closure movements that return to their initial configuration after a few milliseconds, resulting in the so-called "burp" release. Also of interest for many package types is the release of particulate materials instead of gaseous materials.

DOE currently is sponsoring work to establish the fracture mechanics methodology for ferritic materials, thereby extending the range of structural materials potentially usable for package construction.

One new concept is design of "Type B" transport packaging for plutonium and uranium that meets future regulatory requirements. The new package design uses nested cylindrical containment vessels with threaded closures and elastomeric seals and a composite material overpack of metallic wire mesh and ceramic or quartz cloth insulation material.

H.5.2 PACKAGING ENGINEERING AND ANALYSIS

The packaging engineering and analysis programs involve engineering, design, analysis, and testing for packaging development. New packaging concepts emerge to meet specific programmatic requirements. Innovative packaging designs for transporting high activity liquid waste and environmental samples that need cooling during transport are under development. The Beneficial Uses Shipping System (BUSS) cask has been developed for transporting special-form cesium chloride and strontium fluoride capsules and conceptual designs have been completed for packages for offsite shipment of Hanford tank waste liquid samples, Hanford tank waste core samples, and onsite shipment of large volume wastes.

Attachment to Appendix H

Office of Technology Development
FY 1996 Budget Request Work Packages
for the Focus Areas and Crosscutting Programs (Excluding Program Support, Program Direction, and Technology Integration)

Information From the Back-Up to the Budget Submission to the Office of Management and Budget, 10-10-94

Mixed Waste Focus Area

Plasma

- Prepare and conduct pilot-scale demonstration of the plasma arc treatment process (including off-gas system) using nonradioactive surrogates. Determine partitioning of surrogate radionuclides.
- Complete bench-scale testing of the plasma arc treatment process with actual radioactive mixed waste. Develop and demonstrate waste materials handling capabilities, both on the front and back ends of the treatment processes, in preparation for the field demonstration of the plasma hearth process. Test a closed-loop off-gas system with appropriate process monitoring and control (continuous emission monitors and control loop electronics) hardware.
- Facilitate the early field implementation of the plasma hearth process.

Vitrification

- Complete compact vitrification system demonstration integrating melter, off-gas systems, etc. Evaluate and implement closed-loop off-gas systems with complete process monitoring and control systems on the compact vitrification units.
- Modify high-level waste vitrification technology for the treatment of low-level waste. Complete demonstration of polymer solidification for quality assurance and process control of final forms production. Perform field-scale demonstrations on LLMW employing low-temperature waste stabilization processes such as polymer encapsulation and phosphate-based ceramics.

Rocky Flats compliance

- Design a nonradioactive demonstration unit for catalytic wet chemical oxidation (CWCO) system. Begin fabrication of demonstration unit for CWCO process. Test new materials for reactor vessel of CWCO process. Test waste blending to improve process parameters.
- Test more complex waste forms with a supercritical carbon dioxide extraction (SCDE) system. Evaluate enhancements for the SCDE system. Conduct a cold demonstration of SCDE. Begin design of volatilization, low-temperature thermal desorption, full-scale system.
- Continue development of microwave system. Test pelletizing process and select a drying technology. Demonstrate off-gas treatment and monitoring system. Design, fabricate, and install an upgraded bagless posting system. Design, fabricate, and test components of a break-open system. Perform nonradioactive bench-scale tests on surrogates of additional wastes. Perform tests on currently generated by-pass sludge. Perform full-scale tests on spiked surrogate wastes.
- Begin demonstration of macroencapsulation of miscellaneous waste. Conduct a polymer microencapsulation demonstration on radioactive nitrate salt waste. Conduct lab-scale testing of a thermal treatment process for waste. Prepare for radioactive lab-scale tests on surrogate waste of backlog sludge microencapsulation. Conduct a nonradioactive demonstration on new sludges. Conduct nonradioactive bench-scale tests on nonthermal treatment of waste.

Supercritical water oxidation

- Complete nonradioactive testing and demonstration of the supercritical water oxidation (SCWO) pilot plant with DOE hazardous and surrogate mixed wastes.
- Prepare an Environmental Impact Statement and a Preliminary Safety Analysis Report for the radioactive demonstration of the SCWO pilot plant.
- Complete a conceptual design of the SCWO pilot plant for the radioactive demonstration.

Other

- Complete a radioactive demonstration of the Delphi DETOX process to catalytically oxidize the organic constituents of waste streams in a contained reactor.
- Develop advanced effluent control systems, continuous emission monitors, cleanable high-efficiency particulate air filters, and other off-gas treatment and monitoring systems.
- Develop alternative low-temperature treatment technologies for mixed waste, specifically for combustible contaminants.
- Develop intelligent remote sensing systems and survey robots for radioactive storage areas.

- Develop alternative low-temperature final forms for mixed waste.
- Develop processes to refine and/or enhance basic knowledge solutions for the removal of heavy metals and mixed hazardous wastes from soils; use metal oxide particles as reagents for destruction and immobilization of hazardous substances.

Radioactive Tank Waste Remediation Focus Area

- Demonstrate real-time tank integrity inspection and waste mapping technologies with the light-duty utility arm (LDUA):
  - Camera systems, laser range finder, structured light hardware
  - Tank riser interface and confinement system
  - LDUA decontamination system
  - Supervisory control and data acquisition system for LDUA
- Conduct integrated testing and development of waste dislodging and conveyance tools for retrieval of multiple waste types:
  - Waste dislodging and conveyance hydraulic test bed
  - High-pressure water jet scarifier
  - Medium-pressure water jet scarifier
  - Further waste dislodging and conveyance work to plan retrieval operations and meet 99% retrieval minimum from TPA (Hanford Tri-Party Agreement)
- Conduct a hot cell demonstration of characterization of waste, which includes the Raman spectroscopy system:
  - Raman spectroscopy system
  - Further development for a higher resolution scanning Raman spectroscopy system
  - In-situ characterization and on-line monitoring of waste and data analysis methods
- Perform radioactive testing of an out-of-tank mobile evaporator:
  - Fabrication and radioactive testing of evaporator/concentrator compact processing unit (CPU)
- Conduct a radioactive demonstration of a mobile, field maintainable CPU for cesium removal:
  - Complete resin and skid testing and CPU design
  - CPU test unit
  - Cesium extraction resin

- Demonstrate sample retrieval and on-line, in-situ waste analysis with the LDUA system in Idaho:
  - LDUA adaptation for Idaho tanks and sample retrieval
  - Waste dislodging and conveyance tools adaptation for LDUA and Idaho tanks
- Conduct a hot demonstration of solid/liquid separation by using a cross-flow filtration system.
- Demonstrate low-pressure water-jet tools for waste removal from tanks, leading to a radioactive retrieval demonstration at Oak Ridge/Idaho; adapt the waste dislodging and conveyance scarifiers for Oak Ridge gunnite tanks.
- Using actual waste from the Melton Valley Storage Tank Farm, demonstrate sludge and supernatant processing of this waste:
  - Demonstrate sludge dissolution and TRUEX solvent extraction for partitioning of transuranic waste (TRUW) components.
  - Demonstrate sorbent removal of cesium, strontium, and technetium from supernate.
  - Complete sorbent testing for removal of strontium and technetium.
  - Continue development of general site-specific waste processing flowsheets.
  - Adapt sludge/supernate processing system for demonstration on Hanford tank waste.
  - Continue development of waste processing flowsheets.
- Demonstrate in-tank equipment designed to remove scrapped hardware from waste tanks.
- Use analysis techniques and sensors to characterize and monitor chemical and physical conditions within tanks (work includes spectroscopic techniques and LDUA development).
- Develop end-effectors for waste dislodging and conveyance.
- Develop solutions for tank waste by using CPUs.
- Develop waste disposal technologies.
- Refine and enhance basic knowledge solutions in the development of in-situ measurement of fissile, moisture, thermal properties, fission products, and head space gases; identify wide dynamic range tank hot spot.

Subsurface Contaminants Focus Area

Containment

- Demonstrate physical barriers formed from viscous liquids (polybutene and colloidal silica) emplaced under controlled viscosity conditions.

- Evaluate two new flowable bentonite-mineral-water-inorganic grout techniques to reduce the cost of barrier emplacement.
- Demonstrate hydraulic and diffusion barriers in the vadose zone surrounding buried waste.
- Demonstrate surface-controlled emplacement horizontal planar barriers beneath waste sites by using tilt meters and models to predict effectiveness.
- Assess polymer cement, ion-exchange cement, cement glass, and latex cement grouts for vertical subsurface barrier long-term effectiveness.
- Demonstrate four innovative advanced landfill cover designs and compare them with existing U.S. Environmental Protection Agency designs.
- Demonstrate dry barriers by using active/passive ventilation of coarse barrier layer to remove water.
- Demonstrate migration barrier covers by using locally available soils/rocks and synthetic barriers.
- Demonstrate a prototype model for the selection of barrier cover systems by using a decision analysis tool that analyzes tradeoffs to compare the effectiveness, risk, and cost of landfill cover technologies.

Stabilization

- Perform field-scale testing of buried waste encapsulation techniques at arid site burial grounds by injecting naturally occurring cementing solutions to form soil/waste monoliths that immobilize contaminants and are impervious to water migration.
- Initiate in-situ treatment techniques for buried waste (through field testing at a full-scale cold test pit location) that establish a vitrified glass matrix while destroying volatile organics.
- Develop other stabilization technologies (in association with industrial programs).
- Demonstrate long-term monitoring techniques and in-situ monitoring to predict failures, and assess the effectiveness of the stabilization technology by using time domain reflectometry/in-situ moisture monitoring, leachate collection systems, directional well holes, plant and intruder analysis, and subsurface geophysical evaluations.

Containment and stabilization

- Demonstrate active/passive acoustic system for the placement and monitoring of barrier technologies.
- Demonstrate electromagnetic measurement techniques for the monitoring of containment and stabilization activities.
- Demonstrate specialized borehole-deployed geophysical instrumentation for the monitoring of containment and stabilization activities.

Treatment

- Conduct hot bench-scale thermal treatment tests by using a direct current Graphite plasma furnace that can operate in the submerged or transfer arc mode.
- Conduct a hot bench-scale thermal treatment test by using a millimeter wave radiometer to determine spatial resolution of the temperature measurements.
- Conduct hot bench-scale thermal treatment tests by using a microwave plasma analyzer in the off-gas flow from a high-temperature furnace that allows real-time assay of off-gases for metals and organics.
- Conduct hot bench-scale off-gas treatment tests by using nonthermal electrical discharge plasma for the destruction of hazardous chemicals.
- Demonstrate batch/continuous leach technology for uranium-containing soils at Fernald Environmental Management Project (FEMP).
- Demonstrate by laboratory simulation the performance and economics of uranium heap leaching for comparison with the batch-reactor method using transparent leaching columns.
- Demonstrate minimum additive waste stabilization at Pantex by further developing the concept of blending waste in an integrated system centered on vitrification, using the Duramelter, and also including soil washing.
- Demonstrate magnetic techniques on uranium-contaminated soils at FEMP.
- Demonstrate biphasic separation techniques on uranium-contaminated soils at FEMP.
- Demonstrate ex-situ treatment technologies for the removal of mercury from Oak Ridge Reservation.

Removal

- Initiate a hot demonstration for Idaho National Engineering Laboratory (INEL) TRUW waste pits by using a dual-arm cooperative retrieval system that delivers dual manipulator capability to the dig-face and deploys various retrieval support tools.
- Initiate a hot demonstration for INEL TRUW waste pits by using innovative end-effectors and a conveyance system that achieves dust-free dumping and uses a self-guided vehicle to convey retrieved waste to a treatment facility.
- Initiate a hot demonstration by using dig-face characterization that uses multiple sensor data integration and interpretation for real time characterization data in support of retrieval operations.
- Initiate a hot demonstration of TRUW dust monitoring by using laser optical scattering techniques for dust assessment and laser-induced breakdown spectroscopy for real-time composition determination.

- Initiate a hot demonstration of retrieval integration by using a "rad hardened," teleoperated, 60,000-pound class excavator with supervisory control for data transfer and collision avoidance for the integrated system.
- Demonstrate buried waste contamination control in a "hot" environment by using dust generation minimization hardware/procedures and implement dust/contamination control measures (misting, wetting agents, forms, vacuum).

Assessment

- Conduct hot demonstrations of a radiological hazardous materials measurement system that consists of multiple measurement cells and integrates individual measurements to improve quantitative assay capability.
- Demonstrate a combined thermal epithermal neutron system that uses thermal neutrons to interrogate for fissile isotopes in waste drums.
- Demonstrate active passive computed tomography, which uses a high-purity germanium detector for nondestructive assay of gamma-emitting nuclides in sludge, combustibles, and metal matrices with a 55-gallon drum.
- Demonstrate digital radiography by using a high-energy x-ray source installed in a commercial scanner to measure density and nondestructively view the contents of high-density drums.
- Conduct glass/ceramic performance assessment to provide the necessary database and the thermodynamic/kinetic modeling capabilities to make reasonable long-term predictions regarding the performance and durability of low-level waste (LLW)/LLMW vitreous waste forms under potential disposal site conditions.
- Conduct a glass/ceramic composition envelope study to provide a database of vitreous waste form compositions and properties plus an easy-to-use modeling tool by using actual wastes, where available from three DOE sites, or reasonable surrogates to develop vitreous waste forms that are then tested for processability as well as durability characteristics.
- Demonstrate technologies for waste assay during waste handling operations.

Other

- Conduct research on and design advanced monitoring technologies for remediated landfills.
- Refine and enhance basic knowledge solutions in the development of methods and processes for nonintrusive and intrusive site characterization and waste assay.

- Refine and enhance basic knowledge solutions in the development of verification technologies for the emplaced barrier continuity with reduced site disruption; hot spot and full-scale retrieval of untreated waste.
- Refine and enhance basic knowledge solutions in the development of pre-, primary, and secondary ex-situ treatment and recycling secondary waste streams; subsurface contaminant technologies.

Contaminant Plume Containment and Remediation Focus Area (Merged With the Landfill Stabilization Focus Area to Form the Subsurface Contaminants Focus Area)

- Develop, demonstrate, and test reactive barriers and deep subsurface barriers:
  - Demonstrate a reactive barrier for strontium-90 and cesium-137 at an arid site.
  - Demonstrate a reactive barrier for technetium-99 and trichloroethylene at a humid site.
  - Conduct field-scale testing of permeable barriers at a humid site.
  - Develop methods to emplace reactive barrier materials at depths up to 50 feet.
  - Develop methods to extract or rejuvenate reactive materials to prolong barrier life.
  - Develop performance monitoring techniques for reactive barriers and subsurface impermeable barriers.
  - Demonstrate barrier emplacement tools to create an integrated barrier/floor wall.
- Develop and field test technologies for detecting/immobilizing/removing metals and radionuclides in groundwater:
  - Develop in-situ redox manipulation for immobilization of uranium in groundwater at Hanford.
  - Field test the MAG*SEP process for removal of radionuclides from groundwater at Savannah River.
  - Demonstrate the ex-situ biosorption of the uranium process on Fernald groundwater.
  - Develop new methods for the removal of technetium-99 from groundwater.
  - Demonstrate electrokinetic removal of uranium from Oak Ridge groundwater at the pilot scale.
  - Demonstrate electrokinetic methods for migration and removal of heavy metals in groundwater.
  - Develop in-well removal methods (recirculating wells) for various metals.
  - Field test mobile lab-based characterization methods for metals in groundwater, such as laser-based spectroscopy methods.
  - Demonstrate electrokinetic methods for removal of chromium at Sandia.

- Develop and field test detection, extraction, and treatment systems for dense nonaqueous-phase liquids (DNAPLs) in groundwater:
  - Develop and field test advanced extraction systems for DNAPLs by using foam/surfactant mixtures at Paducah or Oak Ridge.
  - Further develop and field test extraction systems for DNAPLs by using heating methods (e.g., radio-frequency heating, steam injection, ohmic heating).
  - Develop and field test DNAPL degradation by using aerobic/anaerobic bioremediation at Hanford.
  - Develop and field test advanced DNAPL detection systems.
- Develop, demonstrate, and evaluate in-situ groundwater treatment technologies for heavy metals, radionuclides, and DNAPLs:
  - Develop contaminant-specific ionic complexant soil flushing solutions.
  - Demonstrate in-well removal methods (recirculating wells) for various metals at the Pinellas Plant.
  - Demonstrate mobile lab-based characterization methods for metals in groundwater, such as laser-based spectroscopy methods.
  - Evaluate and demonstrate biological systems that concentrate tritium from groundwater.
  - Demonstrate DNAPL degradation by using staged aerobic/anaerobic bioremediation at Hanford.
  - Develop methods to reduce chemical contaminants (e.g., uranium and chromium) to an insoluble form by using bioremediation or chemical addition to soil.
  - Develop molecular diffusion and diffusion-related chemical reactions to concentrate tritium from groundwater.
  - Demonstrate advanced extraction systems for DNAPLs by using foam/surfactant mixtures at Paducah or Oak Ridge.
- Develop and demonstrate advanced remediation systems at arid sites (including biologic and chemical treatment and characterization and sensor systems):
  - Conduct a complete demonstration of measurement-while-drilling technology at Savannah River restoration site.
- Develop and demonstrate technologies for heavy metals and radionuclides to minimize secondary waste treatment and reuse treatment fluids:
  - Develop chromatography columns to selectively adsorb contaminant species.
  - Demonstrate MAG*SEP technology on radionuclide- and heavy-metal-contaminated groundwater at the Savannah River Site.

- Demonstrate and test technologies to immobilize or remove heavy metals, radionuclides, and DNAPLs in soil:
  - Demonstrate chromium (VI) immobilization by using gas-phase reducing agents at Savannah River restoration site.
  - Perform pilot-scale test of DNAPL destruction by using in-situ chemical oxidation with peroxide or permanganate at Portsmouth.
  - Perform pilot-scale test of electrokinetic removal of radionuclides from arid soil.
  - Perform pilot-scale test of staged anaerobic/aerobic biodegradation of DNAPLs in soil.
  - Test an ex-situ process of plant uptake and concentration at the pilot scale for radionuclide removal from groundwater.
- Improved subsurface access technology for difficult soil conditions:
  - Enhance cone penetrometer technology as an assay tool for subsurface characterization.
  - Develop horizontal drilling methods that can utilize existing well holes as points of origin.
  - Adapt and demonstrate existing remote sensing techniques for the characterization of contaminant plumes.
- Demonstrate temporary barrier systems for use with in-situ treatment systems.
- Develop and demonstrate in-situ treatment technologies for nonvolatile organic compounds (polychlorinated biphenyls [PCBs], PAHs):
  - Develop and demonstrate bioremediation techniques for degrading polyaromatics.
  - Demonstrate methods to destroy PCBs by using chemical oxidation.
- Develop and demonstrate in-situ remediation (stabilization, biological treatment, electrokinetic treatment, surfactant flushing, etc.), containment technologies (diffusion barriers, reactive barriers, etc.), and barrier technologies for site remediation (contaminants of special interest are DNAPLs and chlorinated organics).
- Develop characterization instruments for pre-, post-, and on-line analysis to determine the type, concentration, and location of contaminants to assist site remediation activities:
  - Demonstrate mobile lab-based characterization methods for metals in groundwater, such as laser-based spectroscopy methods.
  - Demonstrate advanced extraction systems for DNAPLs by using foam/surfactant mixtures at Paducah or Oak Ridge.
  - Demonstrate MAG*SEP technology on radionuclide- and heavy-metal-contaminated groundwater at the Savannah River Site.

- Develop and demonstrate on-line process control for in-situ treatment and mobile labs or onsite testing, and secondary waste minimization and recycling:
  - Demonstrate mobile lab-based characterization methods for metals in groundwater, such as laser-based spectroscopy methods.
  - Conduct a complete demonstration of an advanced volatile organic compound (VOC) remediation system at Hanford, including in-situ air stripping, in-situ chemical oxidation, and/or staged aerobic/anaerobic destruction of VOCs.
- Treat tritium in groundwater and aqueous waste streams and process data for fate and transport modeling.
- Refine and enhance basic knowledge solutions in the development of characterization of subsurface contamination, modeling of contaminants under heterogenous conditions; identifying and quantifying residual DNAPLs contamination in the subsurface and heavy metals in groundwater; lab to field experimentation on micro bio-organisms to analyze survivability and longevity.
- Refine and enhance basic knowledge solutions for groundwater and soils remediation of halogenated hydrocarbons; monitoring technologies for post-closure of the vadose zone; bioremediation technologies of DNAPLs.
- Refine and enhance basic knowledge solutions in the development of the destruction and removal of VOCs by using naturally occurring phenomena; competitive and mass transfer effects on the sorption and desorption of contaminants in soils.
  - Perform pilot-scale test of staged anaerobic/aerobic biodegradation of DNAPLs in soil.
- Refine and enhance basic knowledge solutions in the development of pre-, primary, and secondary ex-situ treatment and recycling secondary waste streams; subsurface contaminant technologies.

Decontamination and Decommissioning Focus Area

- Concrete decontamination: Demonstrate improved processes for the decontamination of surface and volumetric contaminated concrete (field pilot-scale electrokinetic process, field pilot-scale wall process, field pilot-scale coating process).
- Metal decontamination: Demonstrate improved processes for the decontamination of surface and volumetric contaminated metal (field pilot-scale flushing process, field pilot-scale carbon dioxide process, field pilot-scale ultrasonic process, field pilot-scale mechanical process, field pilot-scale chemical process).

- Concrete and metal structure dismantlement: Demonstrate improved processes for size reduction, dismantlement and containment of concrete and metal structures (field pilot-scale telescopic boom process, field pilot-scale overhead platform delivery system, field pilot-scale mobile platform delivery system, field pilot-scale size reduction end effectors, field pilot-scale dismantlement end effectors).
- Metal recycling: Demonstrate improved processes for the conversion of metal with residual contamination into useful products (field pilot-scale stainless steel into waste drums and boxes, field pilot-scale slab casting process, field pilot-scale nickel into stainless steel, field pilot-scale plasma melting process).
- Material stabilization: Demonstrate improved process for the stabilization of asbestos in place.
- Facility stabilization: Demonstrate improved processes for the stabilization of facilities (field pilot-scale fuel pool treatment processes, field pilot-scale fuel pool characterization processes, field pilot-scale plutonium glove-box size reduction process, field pilot-scale glove-box disposition process, field pilot-scale plutonium residue handling process).
- Facility stabilization: Demonstrate improved processes for the stabilization of facilities (field pilot-scale equipment disposition process, field pilot-scale equipment size reduction process, field pilot-scale equipment decontamination process, field pilot-scale equipment in process monitoring process, field pilot-scale glove-box in process monitoring system).
- Material disposition: Demonstrate improved process for the disposition of depleted uranium (field pilot-scale nonmetallic applications, field pilot-scale shielding application).
- Develop advanced worker systems.
- Develop systems for the removal of contaminated paint and other contaminants, such as grease, oil, and PCBs, from concrete and metal surfaces.
- Develop mobile workstations for decontamination and decommissioning (D&D).
- Develop recycling of radioactive contaminated scrap metal.
- Develop decontamination and dismantling end effectors and plasma arcs.
- Develop sampling, imaging, and characterization systems for pre-, post-, and on-line analysis during D&D.
- Develop robotics for D&D.
- Refine and enhance basic knowledge solutions in the development of solvent and material substitution and cryogenic decontamination and cutting.

Crosscutting Programs—Characterization

- Develop process monitors and controls for three candidate mixed waste treatment systems.
- Develop continuous real-time air monitors.
- Develop nondestructive remote techniques to characterize unopened waste containers and final waste forms.
- Develop process monitors and controls for treatment techniques other than the three candidate mixed waste treatment systems (e.g., supercritical oxidation).
- Detect tank leaks, head space gases (volatile and poisonous), and water content of waste tank matrices (for safety and public health issues).
- Test tank imaging technology for retrieval operations in a radioactive environment.
- Develop methods for less expensive and faster hot cell analysis and in-situ tank waste analysis (chemical analysis).
- Conduct in-situ testing of physical properties of tank waste.
- Develop on-line process monitoring and control for tank waste retrieval, transfer, and treatment operations.
- Develop field-deployable, real-time chemical and geophysical sensors and in-situ surface-based deployment systems to identify subsurface contaminants (DNAPLs) in support of the expedited site characterization process:
  - Develop performance monitoring techniques for reactive barriers.
  - Field test mobile lab-based characterization methods for metals in groundwater, such as laser-based spectroscopy methods.
  - Develop and field test advanced DNAPL detection systems.
  - Modify and adapt high-resolution geophysical technologies to better identify contaminant plumes (e.g., DNAPLs).
  - Enhance decision support and data fusion of optimal sampling; develop additional capabilities to map subsurface contaminant plumes.
- Develop large-area scanning and mapping systems for detection of uranium and other contaminants on facility and land surfaces.
- Develop nondestructive assay techniques to assay contaminants in constrained areas such as inside pipes and equipment.
- Transfer airborne deployment sensors from the classified community and configure them for environmental applications.

- Develop real-time sensor systems for decontamination of concrete surfaces to identify PCBs, uranium, plutonium, tritium, fission products, and mercury in the near-surface layer of concrete.
- Develop real-time sensor systems to characterize metal scrap contaminated with technetium-99 and activation products such as cobalt-60.
- Develop continuous real-time monitors for radioactivity in liquid streams.

Crosscutting Programs—Efficient Separations

- Develop/adapt radionuclide separation technologies for application to liquid mixed wastes.
- Develop technologies to remove volatile species (e.g., mercury, chlorides, organics) and therefore simplify treatment of mixed wastes.
- Complete the development and demonstration of cesium/strontium removal technologies to meet milestones for LLW pretreatment facilities; evaluate and integrate separation pretreatment processing schemes to meet LLW glass performance specifications:
  - Develop a baseline sludge treatment to determine the feasibility of meeting milestones at Richland; develop alternative sludge pretreatment technologies to ensure the minimization of high-level waste volume.
  - Accelerate sludge treatment efforts to meet the fiscal year 1998 Tri Party Agreement milestone at Hanford; emphasize the hot testing of actual tank wastes to evaluate behavior and HLW volume reduction under both alkaline (baseline) and acid conditions.
  - Develop technologies to remove technetium and TRUW from tank waste to improve waste form performance and to meet requirements for vitrification.
- Develop and adapt separation agents for cleanup of soils containing contaminants other than plutonium and uranium (e.g., technetium, heavy metals).
- Provide sorbents for incorporation into reactive barriers used for plume mitigation.
- Evaluate feasibility/cost of tritium removal technology (D&D) for cleanup of groundwater:
  - Perform pilot-scale test of electrokinetic removal of radionuclides from arid soil.
- Demonstrate tritium removal technologies from waste storage basins.
- Demonstrate improved residue treatment technology to meet Rocky Flats schedule.
- Expand and adapt sludge leaching technologies to D&D of solids.
- Evaluate separation need for recycle of wash liquids (D&D, soil) and process chemicals.

Crosscutting Programs—Robotics

- Develop systems to automatically handle drums of mixed waste on the front end of the mixed waste treatment process.
- Develop robotic systems to automatically inspect stored drums of mixed waste.
- Develop and demonstrate a back-end materials handling system at a waste treatment facility.
- Develop automated analytical chemistry modules for radionuclides, metals, organics, and inorganics.
- Develop a cooperating manipulators (dual-arm) system for D&D and tank waste applications.
- Develop automated analytical chemistry modules for radionuclides, metals, organics, and inorganics.
- Develop a mobile system to automatically measure and record chemical and radiological contamination on internal surfaces (e.g., walls, hot cells) of buildings.

Appendix I

Update of Site-Specific Waste Volumes for LLMW, LLW, and TRUW

Appendix I in the Final WM PEIS is a completely new appendix written specifically for the Final; therefore, there are no marginal rules or shading to indicate changes. Appendix I from the Draft WM PEIS has been combined with Appendix C in the Final.

U.S. Department of Energy
Waste Management Programmatic Environmental Impact Statement

Contents

Tables

Acronyms, Abbreviations, and Elements

The following is a list of acronyms, abbreviations (including units of measure), and elements used in this document.

Acronyms

Ames	Ames Laboratory
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
BCL	Battelle Columbus Laboratory
Bettis	Bettis Atomic Power Laboratory
BNL	Brookhaven National Laboratory
Charleston	Charleston Naval Shipyard
DOE	U.S. Department of Energy
ER	Environmental Restoration
ETEC	Energy Technology Engineering Center
FEMP	Fernald Environmental Management Project
Fermi	Fermi National Accelerator Laboratory
GA	General Atomics
GJPO	Grand Junction Projects Office
Hanford	Hanford Site
HLW	high-level waste
IDB	Integrated Data Base
INEL	Idaho National Engineering Laboratory
ITRI	Inhalation Toxicology Research Institute
K-25	Oak Ridge K-25 Site
KAPL-K	Knolls Atomic Power Laboratory (Kesselring)
KAPL-N	Knolls Atomic Power Laboratory (Niskayuna)
KAPL-S	Knolls Atomic Power Laboratory (Schenectady)
KAPL-W	Knolls Atomic Power Laboratory (Windsor)
KCP	Kansas City Plant
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LDRs	land disposal restrictions
LEHR	Laboratory for Energy-Related Health Research
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste

Mare Is	Mare Island Naval Shipyard
Mound	Mound Plant
MWIR	Mixed Waste Inventory Report
NEPA	National Environmental Policy Act
Norfolk	Norfolk Naval Shipyard
NR	Naval Reactor
NRF	Naval Reactor Facility
NTS	Nevada Test Site
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
Pantex	Pantex Plant
Pearl H	Pearl Harbor Naval Shipyard
PGDP	Paducah Gaseous Diffusion Plant
Pinellas	Pinellas Plant
PORTS	Portsmouth Gaseous Diffusion Plant
Ports Nav	Portsmouth Naval Shipyard
PPPL	Princeton Plasma Physics Laboratory
Puget So	Puget Sound Naval Shipyard
RFETS	Rocky Flats Environmental Technology Site
RMI	RMI Titanium Company
SLAC	Stanford Linear Accelerator Center
SNL-CA	Sandia National Laboratories (California)
SNL-NM	Sandia National Laboratories (New Mexico)
SRS	Savannah River Site
TBE	Teledyne Brown Engineering
TRUW	transuranic waste
UofMO	University of Missouri
WAC	WIPP Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WM	Waste Management
WM PEIS	Waste Management Programmatic Environmental Impact Statement
WVDP	West Valley Demonstration Project
Y-12	Oak Ridge Y-12 Plant

Abbreviations

Ci	curie(s)
ft^3	cubic foot (feet)
kg	kilogram(s)
m^3	cubic meter(s)
yr	year(s)

Elements

Ac	actinium
Am	americium
Ba	barium
Bi	bismuth
C	carbon
Ce	cerium
Cm	curium
Co	cobalt
Cr	chromium
Cs	cesium
Eu	europium
Fe	iron
Mn	manganese
Ni	nickel
Np	neptunium
Pa	protactinium
Pb	lead
Pm	promethium
Po	polonium
Pr	praseodymium
Pu	plutonium
Ra	radium
Rh	rhodium
Ru	ruthenium
Sb	antimony
Sm	samarium
Sr	strontium
Tc	technetium
Te	tellurium
Th	thorium
Tl	thallium
U	uranium
Y	yttrium
Zr	zirconium

APPENDIX I
Update of Site-Specific Waste Volumes for LLMW, LLW, and TRUW

I.1 Introduction

The Draft WM PEIS used the best available data for waste inventory, projected waste generation, and waste classification for estimates of the waste loads at the DOE sites when the analyses were prepared. Since that time, the Department has continued to update these estimates as part of an ongoing effort to improve the quality of information available for decision making.

Accordingly, DOE reviewed more recent waste load data for low-level mixed waste (LLMW), low-level waste (LLW), and transuranic waste (TRUW) to determine whether it needed to revise the analyses for the Final WM PEIS. For high-level waste (HLW), DOE used updated data in the Final WM PEIS that are generally consistent with recent HLW program estimates. Hazardous waste (HW) data, however, were not revised because DOE determined that the HW data used for the analyses in the Draft WM PEIS are sufficient to determine whether DOE's decisions should continue to rely on commercial management of HW, unlike the management alternatives for other waste types.

Selected reanalyses were performed for LLMW, LLW, and TRUW where warranted, and the results of the reanalyses have been incorporated into the Final WM PEIS. This appendix identifies the criteria DOE used to decide to reanalyze using the more recent data, compares the waste load data used in the Draft WM PEIS with the more recent data, and describes DOE's conclusions about the need to use the more recent data for specified sites. This information is contained in sections I.2, I.3, and I.4 for LLMW, LLW, and TRUW, respectively.

All alternatives were reanalyzed consistently for the sites identified as requiring reanalysis as a result of DOE's review. Health risks were reanalyzed for all sites selected for reanalysis. Cost and other parameters were reanalyzed only where changes in impacts were considered to be potentially large based on changes in waste volume. The appropriate sections of Volumes I and II of the Final WM PEIS were revised to incorporate all results of the reanalyses.

I.1.1 Sources of Waste Load Estimates

Analyses presented in the Draft WM PEIS used existing inventory and projected waste generation data for each site from several sources that are specific to the waste types. The sources of the prior estimates were the:

- Mixed Waste Inventory Report (MWIR) for 1994 (DOE, 1994) and updates from some sites—used for LLMW
- Integrated Data Base (IDB) for 1992 (DOE, 1992), Waste Management Information System (ORNL 1992), and updates from some sites—used for LLW
- MWIR for 1993 (DOE, 1993) and IDB for 1992 (DOE, 1992)—used for TRUW

The more recent information appears in the sources listed below. This information was compared with estimates used in the Draft WM PEIS to determine where reanalysis was warranted and was used for all of the reanalyses presented in the Final WM PEIS.

- MWIR for 1995 (DOE, 1995a)—used for LLMW
- IDB Report–1994 (DOE, 1995b)—used for LLW
- MWIR for 1995 (DOE, 1995a) and Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (BIR-2) for 1995 (DOE, 1995c)—used for TRUW

The data for TRUW were taken from two sources, MWIR 1995 and BIR-2, with most of the new information being taken from MWIR 1995. MWIR 1995 contains information on waste as it currently exists, specifying treatability groups, and is therefore more relevant to the WM PEIS analyses for calculating impacts from consolidating or decentralizing treatment of TRUW throughout the DOE complex. The information on as-generated waste forms is readily available from MWIR 1995, but is not readily extracted from the BIR-2 data. Some of the BIR-2 waste loads reflect some level of treatment, since they are intended to represent the volume of wastes in the forms in which they might be disposed of at WIPP. The BIR-2 was used in developing the *Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement* (WIPP SEIS-II; DOE, 1996b). For impacts at potential treatment sites, the Draft WIPP SEIS-II scaled the analysis presented in the Draft WM PEIS to reflect BIR-2 and other more recent information, as explained in the Draft WIPP SEIS-II. Thus, information on as-generated waste forms was not required for the WIPP analysis. BIR-2 was used in the Final WM PEIS, however, for its radiological profiles and for more definitive waste volume estimates for the years that are not covered by MWIR.

A BIR-3 database was published in June 1996 (DOE, 1996a). BIR-3 waste volumes and hazardous constituent inventories are unchanged from BIR-2, although the radionuclide inventories at some sites are changed slightly. This database was not available at the time of this analysis; however, the differences between BIR-3 and BIR-2 are minor and therefore BIR-2 data were considered sufficient for purposes of reanalysis involving TRUW.

I.1.2 COMPLEXWIDE CHANGES

A comparison of the data used in the Draft WM PEIS and the more recent data shows that when waste volumes are summed across the complex, the total estimated volumes in the more recent data changed by -15%, -45%, and +27% for LLMW, LLW, and TRUW, respectively. These changes do not include any estimates for waste transferred from environmental restoration (ER) activities to WM treatment facilities. The comparison also revealed differences in waste volumes at individual sites, as well as changes in their waste treatment category and radiological profiles. Each site was reviewed with regard to whether new waste load information was likely either (1) to cause an appreciable change in site-specific impacts identified in the Draft WM PEIS, or (2) to result in a change that could significantly alter the comparison of the alternatives.

I.1.3 ALTERNATIVES CONSIDERED

In order to determine whether to update waste load information, alternatives were selected for each waste type that were determined to be most sensitive to changes in waste load data. The alternatives used for each waste type are as follows.

For LLMW, DOE's determination regarding the need for reanalysis is based on the potential impacts associated with the Decentralized Alternative, comparing the data used in the Draft WM PEIS with the more recent data reported for each site. For LLW, DOE used either the Decentralized Alternative or Regionalized Alternative 2 impact estimates, whichever were higher (i.e., more conservative), as the best indicator of the effect of the more recent data. The Decentralized Alternative analyzes the data as reported by each site, without the averaging produced by the consolidation of waste inherent in the Regionalized or Centralized Alternatives. However, for LLW, the Regionalized Alternative 2 analyzes treatment with volume reduction, which tends to generate higher risk estimates for treatment than the Decentralized Alternative, which assumes minimum treatment.

For TRUW, DOE's determination regarding the need for reanalysis is based on the potential impacts associated with Regionalized Alternative 2 for all sites except WIPP. Regionalized Alternative 2 assumes treatment to Land Disposal Restrictions, which generates higher potential risk estimates for the offsite public than the Decentralized Alternative (assumes treatment to WIPP Waste Acceptance Criteria) or the Regionalized 1 Alternative (includes less intensive treatment technologies than Regionalized Alternative 2). Treatment under the Centralized Alternative, which potentially generates the highest risk estimates at WIPP, was reviewed to determine the need to reanalyze impacts at WIPP.

I.1.4 Criteria for Reanalysis

Using the specified alternative for each waste type (e.g., Decentralized, Regionalized 2, or Centralized Alternatives), DOE examined the potential changes in impacts that could be associated with changes in waste volume and radioactivity between the Draft WM PEIS and more recent data on a site-by-site basis. For the sites not analyzed as major sites in the Draft WM PEIS, changes in waste loads did not warrant reclassifying these sites as major sites, and they were removed from further consideration for reanalysis.

For the 17 major sites, DOE used two criteria to identify the need for reanalysis: (1) waste volume was used as an indicator of change for those impacts that are likely to vary with the amount of waste to be managed (e.g., worker risks, air quality, infrastructure, and economic impact); and (2) total radioactivity or the activity of key radionuclides were used as indicators of the degree to which new estimates would affect measures of potential human health risk and water quality. Using these criteria, DOE determined that reanalysis was warranted where potential changes to impacts (for either the Decentralized, Regionalized 2, or Centralized Alternatives, depending on the waste type) were large enough to substantially affect the site-specific results presented in the Draft WM PEIS or where the changes would likely affect comparisons among the alternatives. In a few instances, an individual impact area for a given site was projected to change enough to warrant reanalysis of that particular impact area, although other impact areas were not sufficiently changed to warrant full reanalysis. In these instances, results from the Draft WM PEIS data were retained, and the estimates for the impact area from the more recent data were noted in the appropriate sections of Volume I of the Final WM PEIS.

At sites where DOE determined it should update waste loads, it was not necessary to use these new waste loads in all alternatives. Updated waste volumes were used only in alternatives where these sites treat their own wastes. In Regionalized and Centralized Alternatives where these sites ship their waste to other sites for management, increases and decreases in waste loads from all contributing sites tend to balance out. There was therefore no need to universally update waste loads at Regionalized or Centralized management sites. Tables 6.3–1 through 6.3–7, 7.3–1 through 7.3–14, and 8.3–1 through 8.3–6 define shipment configurations for LLMW, LLW, and TRUW, respectively. These tables document the percent of waste received from off site. Percentages reported in these tables reflect updated waste loads in all alternatives regardless of whether the actual impact analyses were updated.

Table I.1-1 Summary of Sites Identified for Reanalysis

Site	LLMW	LLW	TRUW
ANL-E	V_d		
BNL		NPD	
FEMP			
Hanford			R_i
INEL			
LANL			
LLNL			
NTS	NPD	NPD	
ORR		R_i	
Pantex		V_d	
PGDP			
PORTS			
RFETS			
SNL-NM			
SRS			R_d
WVDP		NPD	
WIPP			R_d

Key: NPD = no previous data; V_d = volume decrease; R_i = radioactivity increase; R_d = radioactivity decrease.

Potential chemical emissions from treatment and chemical concentrations in the groundwater from disposal were not used as criteria for reanalysis of sites. Generally, chemical-related impacts were not large in the Draft WM PEIS or would be addressed through technology adjustments.

Sections I.1.4.1 and I.1.4.2 describe how each criterion was applied. Table I.1–1 summarizes the sites and waste types identified for reanalysis as a result of the review. The table also identifies the primary basis for the decision to reanalyze, as will be explained in the following sections.

I.1.4.1 Changes in Waste Volume

Volume Decreases. More recent data reveal a decrease in volumes of some waste types at some sites, although such decreases are relatively small. Where a decrease in volume occurred at a site for any waste type, the Draft WM PEIS data were retained for those sites for purposes of analysis, since the higher volumes would tend to generate greater impacts. However, large decreases in waste volumes were reported for ANL-E and Pantex for LLMW and LLW, respectively, and these sites were thus identified for reanalysis.

No Previous Data. Sites previously reporting no or negligible volumes for any waste type in the Draft WM PEIS but reporting any increases in more recent data were identified for reanalysis due to the potential for error in the prior data. The sites identified for reanalysis on this basis were NTS (for LLMW) and BNL, NTS, and WVDP (for LLW).

Volume Increases. Sites previously reporting some waste volumes and reporting increases in those volumes were considered individually. Potential effects of the increased waste volumes were estimated for several parameters: (1) worker risk from radiological exposure or physical hazards, (2) criteria air pollutant emissions, (3) infrastructure effects, and (4) socioeconomic impact in the region of influence. These four impact areas are roughly proportional to the volume of waste being treated or disposed of (i.e., the impacts increase as the volume increases).

However, an economy of scale is generally expected as volumes increase; an increase of one unit of waste would require less than one unit of resource or personnel for treatment or disposal. As described in Appendix C, Section C.3.2.2.5, an economy-of-scale factor was used in the WM PEIS to extrapolate from capacity to cost or resource curves whenever waste estimates fell outside the limits of the curves. The basic formula used was:

$$\text{New Resources} = \text{Old Resources} \times (\text{New Volumes/Old Volumes})^{0.7}$$

This economy-of-scale adjustment was used to estimate the increases in impacts that might be expected from increases in waste volumes, except in the case of air quality. If criteria pollutants were released from construction equipment or commuters' vehicles, the adjustment was applied, since emissions were directly related to resources (workers), which follows the economy-of-scale relationship above. Emissions from a facility are directly proportional to volume, however, so an economy-of-scale adjustment was not made in projecting emissions from facilities.

A review of the sites that reported increases in waste volumes from the estimates used in the Draft WM PEIS resulted in no additional sites being identified for full reanalysis. However, a potential increase was projected for air emissions for treatment of LLW at ANL-E sufficient to warrant identification in the discussion of air quality in Chapter 7 (LLW) of Volume I.

I.1.4.2 Changes in Radioactivity

More recent information on radionuclide profiles for LLMW, LLW, and TRUW was reviewed for each site to identify the potential for any changes in the health risk impact analyses. Changes in radionuclide profiles were examined for their potential to affect both waste treatment and disposal results for LLMW and LLW. For TRUW, the review focused only on the treatment because disposal of TRUW is outside the scope of this PEIS. The methodology that was used in the Draft WM PEIS for determining the radionuclide content of the air emissions and of the wastes disposed was applied to the more recent data for consistency in the comparisons.

For waste treatment impacts, potential increases in the offsite maximally exposed individual (MEI) cancer fatality risk were considered to be representative of all risk endpoints. Radionuclides in air emissions contributing to the highest risks were evaluated. A threshold of one in one million (E–06) was selected as a conservative indicator of the need to reanalyze human health risk impacts. This threshold is consistent with guidelines established by the U.S. Environmental Protection Agency (EPA, 1991).

For waste disposal impacts, increases in long-lived radionuclides (half-life greater than 300 years) were reviewed. This approach recognizes that groundwater contamination by radionuclides in waste in disposal facilities requires longer time frames because movement of the contaminants into groundwater occurs over many lifetimes. Changes in these radionuclides in terms of their potential to cause exceedances in Drinking Water Standards, which are related to human health risk, were used as the indicator.

The following criteria and rules were established to identify sites at which reanalysis was necessary as a result of more recent information on radionuclide profiles.

- Where the more recent data for a particular site ***did not result in*** (1) an offsite MEI cancer fatality risk estimate above a probability of E–06 or (2) an exceedance of drinking water standards, one of two courses was followed:
  - If the Draft WM PEIS had predicted (1) an offsite MEI cancer fatality risk much less than E–06 or (2) no exceedance of drinking water standards, then the change was not considered significant, and no reanalysis was needed.

 - If the Draft WM PEIS had predicted (1) an offsite MEI cancer fatality risk only slightly less than or greater than E–06 or (2) an exceedance of drinking water standards, then the original analysis was retained to preserve the conservative nature of the WM PEIS. An exception was made in cases where the risk estimates decreased considerably when the more recent data were used.

- Where the more recent data for a particular site ***resulted in*** (1) an offsite MEI cancer fatality risk estimate above a probability of E–06 or (2) an exceedance of drinking water standards, one of two courses was followed:
  - If the Draft WM PEIS had predicted (1) an offsite MEI cancer fatality risk only slightly less than or greater than E–06 or (2) an exceedance of drinking water standards, then the change was not considered sufficient to warrant a full reevaluation; however, the appropriate sections of Volume I were revised to indicate that an analysis using the more recent data is likely to show an increase in human health risks and that the extent of mitigation measures to prevent exceedances is likely to be greater than indicated by the Draft WM PEIS analysis.
  - If the Draft WM PEIS analysis originally resulted in (1) an offsite MEI cancer fatality risk much lower than E–06 or (2) no exceedance of drinking water standards, this constituted a significant change, and a full risk reanalysis was performed.

As a result of this review, a full reanalysis was conducted for LLW at ORR, and for TRUW at Hanford, SRS, and WIPP. Revisions to the discussion of risk were made to Volume I for (1) LLNL for LLMW, (2) FEMP and LANL for LLW, and (3) INEL and RFETS for TRUW. Potential exceedances of drinking water standards were noted in Volume I for (1) LLMW at FEMP, Hanford, SNL-NM, and SRS and (2) LLW at Hanford and SRS.

I.1.5 UNCERTAINTIES

Periodic updates of data on waste loads at the sites will continue in the future. Circumstances that may alter waste volume or radioactivity level estimates include the following:

- Changes in DOE's site missions that are not reasonably foreseeable at this time may occur in the future.
- Changes in regulations and statutes concerning the definitions of waste types may occur. For instance, if a "below regulatory concern" level is established for radionuclides, significant volumes of waste currently managed as low-level radioactive waste could be disposed of in solid (nonhazardous and nonradioactive) waste landfills.
- The success of pollution prevention efforts could reduce rates of waste generation.

- Waste management activities that result in opening, sorting, and surveying the contents of containers currently reported to be at full capacity may reveal actual volumes of waste less than those of the containers. These activities will provide better information on the relationship between the mass of the waste and its volume.
- Waste characterization techniques may affect the waste type assigned to a given inventory. Some waste currently classified as TRUW, for instance, may not contain 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste and may require reclassification as LLMW or LLW. Conversely, some LLW could be reclassified as TRUW.
- Waste characterization could result in different assignments to treatability groups, which dictate the type of treatment necessary. Emissions and associated risks to workers and the public may vary significantly, depending on treatment technology.
- Volume reduction of LLMW and LLW during treatment may result in a residue with sufficient concentrations of transuranic elements to warrant reclassification of the residue as TRUW. Regardless of classification, DOE may choose to manage certain waste streams together, even though they are different waste types, because they have similar characteristics and pose similar risks, such as alpha LLW and TRUW.
- Ongoing characterization of the contaminated sites will result in better estimates of ER-transferred waste. Likewise, increased program maturity will lead to more consistent reporting.

Some wastes included in the estimates used for analysis in the WM PEIS may have already been treated or disposed of, because DOE's waste management activities are an ongoing effort. Although the information used for analysis at any point in time may be subject to updates in the future, waste management decisions must nevertheless be based on currently available information. DOE will consider new information as it becomes available and will determine the need for additional NEPA reviews as appropriate.

I.2 LLMW Inventory Update

This section addresses the changes in LLMW volume at each DOE site as reported in MWIR 95. The more recent data were used to reanalyze the projected source terms on waste feedstock inputs to some of the treatment facilities, facility air emissions, and disposal volumes for the LLMW Decentralized, Regionalized, and Centralized Alternatives. The results of the new analysis were then compared with the results in the Draft WM PEIS, which were derived using the MWIR 94 data, to determine the need for any complete reanalysis. Radiological profiles for LLMW at individual sites were unchanged in the more recent data. As a result, changes in the radiological content of site air emissions are generally proportional to the changes in site waste volumes reported in this section.

Table I.2–1 presents a site-by-site comparison of the current waste inventory volume plus the projected 20-year waste volume for each site as reported in MWIR 94 and MWIR 95. Overall, the 1995 data show an approximate 15% decrease in the total amount (from 226,000 to 193,000 m^3) of LLMW that will need treatment across the DOE complex. The lower total is due primarily to large reported waste reductions at ANL-E, Hanford, and PORTS. Of the 42 sites that have (or will generate) LLMW, 27 showed increases in the expected amount of LLMW as reported in the 1995 data.

I.2.1 Analysis of LLMW Alternatives

To assess how the more recent estimates of LLMW treatment volumes may affect the WM PEIS, the Decentralized Alternative was analyzed as the best indicator of potential effects of changes in volume because the data can be analyzed for each site without the consolidations inherent in the Regionalized and Centralized Alternatives. The updated estimates for LLMW for each site and each waste treatment category were entered into the same computational model (WASTE_MGMT) used to analyze LLMW data in the Draft WM PEIS. The model uses the annual projected volume of LLMW at each site (derived from the site's waste inventory and projected waste generation), the radiological and chemical contaminant profile of the waste, and specific operating parameters for treatment facilities to estimate feedstock volumes for individual treatment and disposal facilities and radionuclide and chemical air emissions. The model results derived using the MWIR 95 waste volume data were then compared with the results using estimates derived from the MWIR 94 data. The comparison assumed equivalent radionuclide and chemical profiles and the same treatment facility parameters for the MWIR 95 and the MWIR 94 estimates. In the Decentralized Alternative, in which every site treats its own waste, the changes in radionuclide and chemical contaminant levels correlated directly with the changes in the input treatment volume. However, this relationship does not apply to contaminant levels in site air emissions from treatment facilities or treatment and disposal shipping volumes when there are changes in treatment categories. This is because changes in treatment categories result in the use of different treatment technologies.

A comparison of the Draft WM PEIS (MWIR 94) and more recent (MWIR 95) treatment volumes expected at the various treatment sites for the LLMW Regionalized Alternatives is given in Table I.2–2. This table shows that, in general, the difference in waste volume between the Draft WM PEIS and more recent data decreases at Regionalized and Centralized sites, reflecting the complexwide decrease in LLMW reported in the more recent data. This table thus illustrates that the Decentralized Alternative is the most sensitive to potential changes in impacts related to changes in waste volume, because each site treats its own waste. Thus impacts estimated in the Draft WM PEIS are expected to bound those estimated from the more recent data. Costs and transportation impacts, which are tabulated at the national level in the WM PEIS for the purposes of comparison of alternatives, rather than at sites, would similarly not increase, since volumes overall do not increase.

Tables I.2–3 and I.2–4 compare, for the Decentralized and Centralized Alternatives respectively, the disposal volumes and radionuclide concentrations at various disposal sites derived from the 1994 and 1995 data. Across the complex, disposal volumes after treatment of LLMW are predicted to decrease by approximately 15% when 1995 data are used. However, there is a predicted 35% increase in the overall, complexwide disposal volume, due primarily to the 37,000 m^3 of final-form waste (waste that does not require additional treatment) from Puget Sound Naval Shipyard (Puget So) reported with Hanford's disposal inventory.

I.2.2 Radiological Profiles

Tables I.2–5 and I.2–6 compare the total annual radiological air emissions (Ci/yr) expected at each site under the Decentralized and Centralized Alternatives, respectively. These tables compare the air emissions predicted for each site using estimates of LLMW based on MWIR 94 and MWIR 95 data. Total complexwide radiological air emissions are predicted to increase about 15% on the basis of 1995 data for alpha-emitting radionuclides and nearly 300% for tritium emissions due primarily to increases at LLNL.

For consolidation of waste in the Regionalized and Centralized Alternatives, the tritium-bearing wastes at western sites pose the only potential major increase in risks to the MEI. The emissions of tritium increase by a factor of 3 to 4 at several sites, which could increase MEI risks by the same factor. Only one site other than LLNL, Hanford, has MEI risks that are within a factor of 3 to 4 of 1E–06. Since waste from LLNL is treated at Hanford in the Regionalized and Centralized Alternatives, the increased tritium could affect Hanford emissions in a similar manner as at LLNL. This is discussed further in Section I.2.3.

For disposal, only Hanford is sensitive to increases in long-lived radionuclides from additional wastes in the Regionalized and Centralized Alternatives (other Regionalized or Centralized disposal sites either

Table I.2–1. Comparison of Low-Level Mixed Waste Treatment Volumes

Site	Estimated Inventory + 20 Years Generation (m^3)			Site	Estimated Inventory + 20 Years Generation (m^3)		
	Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c]		Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c]
Ames	0.4	0.2	-2.0	Mare Is	52	84	+1.6
ANL-E[d]	8,400	159	-52.8	Mound	80	100	+1.3
BCL	0.1	12[e]	+120.0	NTS[d]	0.3	3,000[e]	7,500
Bettis	48	4,800	+100.0	Norfolk	6	300	+50.0
BNL	190	30	-6.3	ORR[f]	59,000	50,000	-1.2
Charleston	3	9	+3.0	PGDP	600	1,000[e]	+1.7
Colonie	11	15	+1.4	Pantex	690	2,200	+3.2
ETEC	3.7	17[e]	+4.6	Pearl H	6	130	+21.7
FEMP	2,600	2,700[e]	+1.0	Pinellas	0.02	NR	NA
GA	43	69[e]	+1.6	PORTS	33,000	15,500[e]	-2.1
GJPO	1.5	0.8[e]	-1.9	Ports Nav	1	11	+11.0
Hanford[g]	36,000	12,000	-3.0	PPPL	0.02	9.4	+94.0
INEL	35,000	28,000	-1.3	Puget So[h]	230	3,000	+13.0
KCP	0.8	0.2	-4.0	RMI	29	32[e]	+1.1
KAPL-K	80	76	-1.1	RFETS	21,000	22,900[e]	+1.1
KAPL-S	100	64	-1.6	SNL-NM	100	290	+2.9
KAPL-W	40	75	+1.9	SRS	20,000	37,000[e]	+1.9
LEHR	7	NR	NA	SLAC	NR	6	NA
LBL	280	34	-8.2	UofMO	2	5	+2.5
LLNL	4,300	7,500	+1.7	WVDP	55	220	+4.0
LANL	2,800	1,000	-2.8	Total Complex	226,000	193,000	-1.2

NR = no data reported; NA = not applicable; no data to compare.
Notes: Charleston = Charleston Naval Shipyard; ETEC = Energy Technology Engineering Center; FEMP = Fernald Environmental Management Project, GA = General Atomic; GJPO = Grand Junction Projects Office; KAPL-K = Knolls Atomic Power Laboratory-Kesselring; KAPL-S = Knolls Atomic Power Laboratory-Schenectady; KAPL-W = Knolls Atomic Power Laboratory-Windsor; LEHR = Laboratory for Energy-Related Health Research; Mare Is = Mare Island Naval Shipyard; Norfolk = Norfolk Naval Shipyard; Pearl H = Pearl Harbor Naval Shipyard; Ports Nav = Portsmouth Naval Shipyard; RFETS = Rocky Flats Environmental Technology Site; RMI = RMI Titanium Company; and UofMO = University of Missouri.
[a] For LLMW, data used in the Draft WM PEIS are from 1994 MWIR (DOE, 1994).
[b] For LLMW, more recent data are from 1995 MWIR (DOE, 1995b).
[c] Factor of change is the ratio of more recent data (1995 MWIR) to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.
[d] These sites are evaluated in the Final WM PEIS using data from the 1995 MWIR (DOE, 1995b).
[e] These site estimates include Environmental Restoration wastes. Such wastes may not be transferred to WM facilities.
[f] Volume excludes 15,400 m^3 of grouted pond sludge that is being shipped for commercial disposal.
[g] Volume excludes 114,600 m^3 of wastewater to be generated and managed under the HLW program.
[h] Volume excludes 37,000 m^3 of waste in final form assumed to be shipped directly for disposal at Hanford as generated (see Table I.2–3).

Sources: DOE (1994, 1995b).

Table I.2-2. Comparison of Total Volumes of LLMW Proposed to be Treated at Treatment Sites (m^3)

Site	Alternative									
	41 Treatment Sites (Decentralized)		11 Treatment Sites (Regionalized 1)		7 Treatment Sites (Regionalized 2 or 3)		4 Treatment Sites (Regionalized 4)		1 Treatment Site (Centralized)	
	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95
Ames	0.4	0.2								
ANL-E	8,400	159								
BCL	0.1	12								
Bettis	48	4,800								
BNL	190	30								
Charleston	3	9								
Colonie	11	15								
ETEC	3.7	17								
FEMP	2,600	2,700	11,100	2,900						
GA	43	69								
GJPO	1.5	0.8								
Hanford	36,000	12,000	36,200	15,100	40,800	22,700	40,800	22,700	225,000	191,500
INEL	35,000	28,000	35,000	31,000	35,000	31,100	59,600	56,600		
KCP	0.8	0.2								
KAPL-K	80	75								
KAPL-S	100	64								
KAPL-W	40	75								
LEHR	7	0.0								
LBL	280	34								

Table I.2-2. Comparison of Total Volumes of LLMW Proposed to Be Treated at Treatment Sites (m^3)—Continued

Site	Alternative									
	41 Treatment Sites (Decentralized)		11 Treatment Sites (Regionalized 1)		7 Treatment Sites (Regionalized 2 or 3)		4 Treatment Sites (Regionalized 4)		1 Treatment Site (Centralized)	
	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95
LLNL	4,300	7,500	4,680	7,700						
LANL	2,800	1,000	2,900	1,290	3,590	3,490				
Mare Is	52	84								
Mound	80	100								
NTS	0.4	3,000								
Norfolk	6	300								
ORR	59,000	50,000	59,000	50,000	59,600	51,000	104,000	75,200		
PGDP	600	1,000	600	1,000						
Pantex	690	2,200	690	2,200						
Pearl H	6	130								
Pinellas	0.02	0.0								
PORTS	33,000	15,500	33,600	21,300	44,700	24,200				
Ports Nav	1	11								
PPPL	0.1	9.4								
Puget So	230	3,000								
RMI	29	32								
RFETS	21,000	22,900	21,000	22,000	21,000	22,000				
SNL-NM	100	290								
SRS	20,000	37,000	20,000	37,300	20,000	37,300	20,000	37,300		

Table I.2-2. Comparison of Total Volumes of LLMW Proposed to Be Treated at Treatment Sites (m^3)—Continued

Site	Alternative									
	41 Treatment Sites (Decentralized)		11 Treatment Sites (Regionalized 1)		7 Treatment Sites (Regionalized 2 or 3)		4 Treatment Sites (Regionalized 4)		1 Treatment Site (Centralized)	
	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95	MWIR 94	MWIR 95
SLAC	0.0	6								
UofMO	2	5								
WVDP	55	220								

Notes: Blanks indicate that no treatment (other than aqueous treatment) occurs at a site. The total volumes under each alternative will vary due to rounding. These values are 226,000 m^3 using data from MWIR 94 and 193,000 m^3 using MWIR 95, as shown in Table I.2-1.

Table I.2-3. Comparison of Volumes and Radionuclide Concentrations in LLMW Disposed of Under the Decentralized Alternative

Site	Volume (m^3/yr)			Major Radionuclide[e]	Concentration (Ci/yr)		
	Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c,d]		Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c,d]
ANL-E	577	3.0	-190	U-238	4.8	0.05	
				Ni-59	2.1	0.022	
				Tc-99	0.4	0.0041	
				Total	7.3	0.076	-96
BNL	8.4	0.7	-12.0	U-238	0.1	0.019	
				Ni-59	0.046	0.0085	
				Tc-99	0.0086	0.0016	
				Total	0.155	0.029	-5.3
FEMP	108	96	-1.1	U-238	0.44	0.53	
				Tc-99	0.0067	0.0080	
				Th-232	0.0037	0.0043	
				Total	0.45	0.54	+1.2
Hanford[f]	1,250	4,290	3.4	Ni-59	4.4	40	
				U-238	0.87	7.6	
				Total	5.3	47.6	+9.0
INEL	655	1,000	1.5	Ni-59	100	160	
				U-238	18	29	
				Nb-94	5	7	
				Total	123	196	+1.6
LANL	67	29	-2.3	Pu-240	0.072	0.019	
				Ni-59	0.036	0.013	
				Total	0.11	0.032	-3.4
LLNL	187	175	-1.1	U-238	1.3	2	
				Ni-59	0.84	0.53	
				Total	2.1	2.5	+1.2
NTS	90	208	2.3	U-238	0.35	0.0024	
				Total	0.35	0.0024	-146
ORR	2,040	1,770	-1.2	U-238	29	63	
				Ni-59	13	8.9	
				Total	44	74	+1.7
PDGP	22	23	1.0	U-238	29	27	
				Tc-99	8.7	8.1	
				Th-232	0.24	0.22	
				Total	38	35	-1.1
Pantex	20	62	3.1	Ni-59	0.013	0.029	
				Total	0.013	0.029	+2.2

Table I.2-3. Comparison of Volumes and Radionuclide Concentrations in LLMW Disposed of Under the Decentralized Alternative—Continued

Site	Volume (m^3/yr)			Major Radionuclide[e]	Concentration (Ci/yr)		
	Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c,d]		Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c,d]
PORTS	590	336	-1.7	U-238	0.56	0.20	
				Tc-99	0.17	0.058	
				Th-232	0.0046	0.0016	
				Total	0.73	0.26	-2.8
RFETS	1,390	1,240	-1.1	Pu-240	4.6	0.68	
				Pu-239	1.3	0.19	
				U-238	0.12	0.018	
				Total	6.0	0.88	-6.8
SNL-NM	1.4	6.1	+3.3	Ni-59	0.047	0.12	
				Pu-240	0.0098	0.042	
				Total	0.057	0.16	+2.8
SRS	552	929	+1.7	Ni-59	13	45	
				U-238	0.43	1.8	
				Total	13	47	+3.6
WVDP	0.0	3.6	NA	Ni-59	0.0	0.07	
				U-238	0.0	0.016	
				Total	0.0	0.086	NA
Total	7,560	10,200	1.35	Total	240	404	+1.7

Note: NA = not applicable; no data to compare.

[a] For LLMW, data used in the Draft WM PEIS are from MWIR 94 (DOE, 1994). Includes volume from smaller sites.

[b] For LLMW, more recent data are from MWIR 95 (DOE, 1995b). Includes volume from smaller sites.

[c] Factor of change is the ratio of more recent data (1995 MWIR) to data used in the Draft WM PEIS. Positive values indicate the more recent data are greater than data used in the Draft WM PEIS; negative values indicate that the more recent data are less than data used in the Draft WM PEIS.

[d] Changes in radiological concentration may differ from changes in volume due to changes in treatment categorization.

[e] Major radionuclides include only isotopes with half-lives ($t_{½}$) > 300 years.

[f] Includes 3,700 m^3/yr of final-form waste from Puget Sound Naval Shipyard.

Table I.2-4. Comparison of Volumes and Radionuclide Concentrations in LLMW Disposed of Under the Centralized Alternative

Site	Volume (m^3/yr)			Major Radionuclide[d]	Concentration (Ci/yr)		
	Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c]		Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c]
Hanford[e]	7,590	10,100	1.3	Ni-59	140	260	
				U-238	86	130	
				Tc-99	12	11	
				Total	238	401	+1.7

[a] For LLMW, data used in the Draft WM PEIS are from MWIR 94 (DOE, 1994).
[b] For LLMW, more recent data are from MWIR 95 (DOE, 1995b).
[c] Factor of change is the ratio of more recent data (1995 MWIR) to data used in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data used in the Draft WM PEIS; negative values indicate that the more recent data are less than data used in the Draft WM PEIS.
[d] Major radionuclides include only isotopes with half-lives ($t_{1/2}$) > 300 years.
[e] Includes 3,700 m^3/yr of final-form waste from Puget Sound Naval Shipyard.

Table I.2-5. Comparison of Radiological Air Emissions for LLMW: Decentralized Alternative

Site	Radionuclide Contributing Greatest Risk / Total Alpha Radioactivity[a]	Draft WM PEIS Data[b] (Ci/yr)	More Recent Data[c] (Ci/yr)	Factor of Change[d]
ANL-E	U-238	4.7E-05	4.3E-05	-1.09
	Total alpha	1.7E-04	1.6E-04	-1.1
BNL	U-238	1.0E-06	1.3E-07	-7.7
	Total alpha	3.3E-06	4.5E-07	-7.3
FEMP	U-238	3.7E-06	3.4E-06	-1.09
	Total alpha	1.1E-05	1.0E-05	-1.1
Hanford	Pu-238	8.6E-04	5.0E-04	-1.7
	Total alpha	1.2E-03	6.4E-04	-1.9
INEL	Tritium	2.8E+02	1.1E+03	3.9
	Total alpha	6.4E-04	2.3E-03	3.6
LANL	Tritium	2.3E+02	1.2E+02	-1.9
	Total alpha	2.3E-05	1.8E-05	-1.3
LLNL	Tritium	1.1E+04	3.7E+04	3.4
	Total alpha	5.0E-05	5.3E-05	1.1
NTS	U-238	2.1E-07	1.0E-07	-2.1
	Total alpha	4.9E-06	3.9E-07	-13
ORR	U-238	3.1E-04	7.3E-05	-4.2
	Total alpha	1.1E-03	8.6E-04	-1.3
Pantex	Tritium	1.0E+02	2.5E+02	2.5
	Total alpha	3.7E-06	6.1E-06	1.6
PGDP	U-238	1.8E-04	2.0E-04	1.1
	Total alpha	6.1E-04	6.0E-06	-1.02
PORTS	U-238	3.2E-06	1.9E-06	-1.7
	Total alpha	9.5E-06	5.6E-06	-1.7
RFETS	Pu-238	1.5E-05	1.8E-05	1.2
	Total alpha	1.6E-04	2.0E-04	1.3
SNL-NM	Tritium	5.9E+00	2.6E+01	4.4
	Total alpha	8.4E-07	1.7E-06	2.0
SRS	Tritium	1.5E+03	5.9E+03	3.9
	Total alpha	1.1E-04	2.6E-04	2.4
WVDP	Pu-238	1.5E-07	2.0E-05	130
	Total alpha	7.4E-07	2.5E-05	34

Footnotes appear on next page.

Table I.2-5. Comparison of Radiological Air Emissions for LLMW: Decentralized Alternative—Continued

[a] Radioactivity is for alpha-emitting radionuclides only. Tritium and other non-alpha emitting radionuclides are not included in this sum because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the health risk.
[b] For LLMW, Draft WM PEIS values calculated on the basis of data from 1994 MWIR (DOE, 1994).
[c] For LLMW, more recent values calculated on the basis of data from 1995 MWIR (DOE, 1995b).
[d] Factor of change is the ratio of more recent data (1995 MWIR) to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.

Table I.2-6. Comparison of Radiological Air Emissions Under the Centralized Alternative (Ci/yr) (Alpha-Emitting Radionuclides Only)

Site	Draft WM PEIS Data[a]	More Recent Data[b]	Factor of Change[c]
Hanford	4.0E-03	4.5E-03	+1.13

[a] For LLMW, Draft WM PEIS values calculated on the basis of data from 1994 MWIR (DOE, 1994).
[b] For LLMW, more recent values calculated on the basis of data from 1995 MWIR (DOE, 1995b).
[c] Factor of change is the ratio of more recent data (1995 MWIR) to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than the Draft WM PEIS data; negative values indicate that the more recent data are less than data in the Draft WM PEIS.

receive very little additional waste for disposal or have very low predicted concentrations of radionuclides in the groundwater over the period of analysis). The effect of the radiological increases for disposal at Hanford is discussed in Section I.2.3.

I.2.3 Conclusions About LLMW Sites With Waste Load Increases

Two sites—ANL-E and NTS—required reevaluation based on volume or radionuclide changes. The reanalyses are discussed below.

Ten additional sites with volume or radiological increases were reviewed and did not require further reevaluation: FEMP, Hanford, INEL, LLNL, Pantex, PGDP, RFETS, SNL-NM, SRS, and WVDP. However, the pertinent LLMW risk and water quality sections of Chapter 6, Volume I, were revised to note continuing management requirements for the disposal of uranium at FEMP, Hanford, and SRS and for the disposal of plutonium at SNL-NM. The risk sections of Chapter 6 were also revised to note the continuing requirement to carefully manage treatment of tritium-bearing wastes at LLNL and Hanford.

The four other major LLMW sites did not experience volume increases that caused large risks of cancer fatalities to the offsite MEI (exceeding one in one million) or radiological changes that would cause exceedances of water quality standards.

As noted earlier, sites other than the 17 major sites were not considered for evaluation. However, the radionuclides at these sites were included in the radiological profiles assessed for decentralized disposal. Volume changes at these sites, as discussed, did not affect the Regionalized or Centralized Alternatives. Radiological effects in treatment were assumed to correlate with volume changes and similarly would not affect Regionalized or Centralized Alternatives for treatment.

The following discussion of the sites expands upon the data in Tables I.2–7, I.2–8, and I.2–9, which are found at the end of Section I.2.3.2. The tables provide site comparisons showing the change for key parameters between the waste load data used in the Draft WM PEIS and more recent waste load data, including:

1. Change in volumes (see Table I.2–7). This relies on the waste volume tables presented in this section.
2. Change in both the emission of the radionuclide that has the greatest contribution to risk and the total radioactivity emission to the air for alpha-emitting radionuclides (see Table I.2–8). Non-alpha-emitting

radionuclides, such as tritium, are not included in the total radioactivity because their dose conversion factors for inhalation are several orders of magnitude less than those of the typical alpha emitter, and thus the tritium contributes little risk in most cases. However, in those cases where tritium may pose a significant potential risk at a particular site, it is listed separately in the table. The table also shows a projected new offsite population MEI risk by multiplying the MEI risk from the Draft WM PEIS by the factor of change for both the radionuclide that has the greatest contribution to risk and the total overall alpha radioactivity.

3. Increases in those long-lived radionuclides proposed for disposal at a site (see Table I.2–9). The table also shows projected new concentrations in the groundwater for the long-lived radionuclides and discusses whether these concentrations are likely to exceed water quality guidelines. The projected new concentrations are derived by multiplying the change factor by the previous concentrations in the groundwater. Because the water guidelines are risk-based, values lower than the guidelines are assumed to be protective of human health.

I.2.3.1 Sites Requiring Reevaluation

ANL-E

Volumes: As shown in Table I.2–2, the predicted 20-year volume of LLMW decreased at ANL-E from 8,400 m^3 to 159 m^3—a factor of 52.8. This is a much greater decrease than for any other major site and could cause the presentation of very inaccurate impact information. Although impacts predicted using data in the Draft WM PEIS are conservative, they would overestimate impacts and justify a reevaluation.

Radionuclides: Although radionuclide concentrations are not predicted to increase, the substantial decrease in volumes requires that impacts be reevaluated for their effect on health risks to the offsite population.

Conclusions: Reevaluate all LLMW impacts at ANL-E.

NTS

Volumes: As shown in Table I.2–1, the predicted 20-year volume of LLMW increased at NTS from 0.4 to 3,000 m^3—a factor of 7,500. This very large increase justifies a reevaluation.

Radionuclides: Although radionuclide concentrations are not predicted to increase, the substantial increase in volumes requires that impacts be reevaluated for their effect on health risks to the offsite population.

Conclusions: Reevaluate all LLMW impacts at NTS.

I.2.3.2 Sites Not Requiring Reevaluation

FEMP

Volumes: LLMW increased by a factor of 1.04, which results in an increase in workers and resources of 1.03, considering economy of scale. The Decentralized Alternative was used to estimate effects from volume increases.

The estimate of worker risk at FEMP presented in the Draft WM PEIS is 0.17 worker fatalities from treatment and disposal physical hazards and 0.0006 worker fatalities from radiological exposure. The increases in fatalities would thus be 0.005 (physical hazards) and 0.00002 (radiological exposure). These increases are small.

The most limiting criteria air pollutant is NO_2 emitted during construction operations. The concentration is estimated to reach 22% of the standards, so NO_2 emissions would increase to approximately 23% of the standards, which is still well below the standards.

For infrastructure, required acreage would increase from 8.5 to 8.8 acres; water, wastewater, and power, which were estimated to be 6.5% or less of capacity, would increase to 6.7% or less; and job increases would be less than 0.05% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, the projected offsite MEI risk of cancer fatalities from air emissions is less than one in one million (< E–06). In the Draft WM PEIS, concentrations of U-238 in the groundwater exceeded standards assuming unconstrained disposal; increases in U-238 reported for more recent data could increase the exceedance of groundwater standards by a factor of 1.2 in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage U-238 in disposal has been noted in the risk and water quality sections of Chapter 6, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

HANFORD

Volumes: Overall volumes decreased at the Hanford Site. An increase in disposal volumes, noted in Table 1.2–3, is caused by disposal of macro-encapsulated lead components from naval vessels. Disposal of these components will not cause large resource-related impacts. Radionuclide-related impacts are discussed below.

Radionuclides: For more recent waste data, the projected offsite MEI risk from air emissions under the Decentralized Alternative is less than one in one million (< 1.0E–06). For air emissions under the Regionalized and Centralized Alternatives, the overall increase in tritium releases for the DOE complex could cause the MEI risk at Hanford to increase from current projections of 3E–07 to 5E–07, to 1E–06. This potential increase has been noted in Chapter 6. For disposal, concentrations of U-238 in the groundwater exceeded standards in the Draft WM PEIS, assuming unconstrained disposal; increases in U-238 reported for more recent data could increase the exceedance of groundwater standards by a factor of 9 for the Decentralized Alternative and 1.5 for the Centralized Alternative in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage U-238 in disposal has been noted in the risk and water quality sections of Chapter 6, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

INEL

Volumes: LLMW disposal volumes increased by a factor of 1.5, which results in an increase in workers and resources of 1.33, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases. Only disposal was considered.

The estimate of worker risk in the Draft WM PEIS from disposal at INEL is 0.05 worker fatalities from treatment and disposal physical hazards and 0.14 worker fatalities from radiological causes. The increases in fatalities would be 0.01 (physical hazards) and 0.05 (radiological exposures). These increases are small.

Disposal operations produce localized, fugitive emissions and were not a significant contributor to adverse air quality.

For infrastructure, approximately 25% of the resources are required for disposal, as shown by the cost tables in Volume II. Disposal volume increases would therefore have less effect than the 33% resource increase. Because existing requirements for acreage are 56 acres; water, wastewater, and power requirements are estimated to be less than 13% of capacity; and jobs generated by the entire LLMW activity are only 1.6% of jobs in the region—the additional requirements for increased disposal volumes are small.

Radionuclides: Radionuclide increases at INEL are not predicted to exceed water quality standards. Air emissions from disposal are not significant contributors to risk; projected offsite MEI risk from treatment air emissions using more recent waste data is less than one in one million.

Conclusions: No further evaluation is required for volume or radionuclide changes.

LLNL

Volumes: LLMW volume increased by a factor of 1.7, which results in an increase in workers and resources of 1.4, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at LLNL in the Draft WM PEIS is 0.29 worker fatalities from treatment and disposal physical hazards and 0.05 worker fatalities from radiological exposures. The increases in fatalities would be 0.12 (physical hazards) and 0.02 (radiological exposure). These increases are small.

The most limiting criteria air pollutant is CO emitted during construction. This is estimated to reach 39% of the standards, so CO emissions would increase to approximately 55%, which is well below the standards.

For infrastructure, required acreage would increase from 12.6 to 17.6 acres; water, wastewater, and power, which were estimated to be 1.2% or less of capacity, would increase to 1.7% or less; and job increases would be less than 0.01% of employment in the region. These increased requirements are all small.

Radionuclides: For disposal, radionuclides that increase at LLNL are not predicted to exceed water quality standards. Air emissions from treatment had predicted risks of cancer fatalities to the offsite MEI in excess of one in one million in the Draft WM PEIS (i.e., 3E–06); these risks could increase by a factor of 3.4 based upon increases in the radionuclide (tritium) that has the greatest contribution to risk. This has been noted in the risk sections of Chapter 6, Volume I. However, since the previous analysis also noted exceedances of one in one million for risk of fatality during treatment, requiring mitigation through management of tritium, no further quantitative reevaluation beyond disclosing this in the risk presentations was considered necessary.

Conclusions: No further evaluation is required for volume or radionuclide changes.

PANTEX

Volumes: LLMW volume increased by a factor of 3.2, which results in an increase in workers and resources of 2.3, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at Pantex in the Draft WM PEIS is 0.04 worker fatalities from treatment and disposal physical hazards and 0.0006 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.06 (physical hazards) and 0.0008 (radiological exposures). These increases are small.

The most limiting criteria air pollutants are NO_2 and particulates emitted during facility operations. These are estimated to reach 1% of the standards, so emissions would increase to approximately 3.2%, which is well below the standards.

For infrastructure, required acreage would increase from 3.6 to 8.3 acres; water, wastewater, and power, which were estimated to be 0.3% or less of capacity, would increase to 0.7% or less; and job increases would be less than 0.1% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). Radionuclides that increase at Pantex are not predicted to exceed water quality standards.

Conclusions: No further evaluation is required for volume or radionuclide changes.

PGDP

Volumes: LLMW volume increased by a factor of 1.67, which results in an increase in workers and resources of 1.43, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at PGDP in the Draft WM PEIS is 0.02 worker fatalities from treatment and disposal physical hazards and 0.0004 worker fatalities from radiological exposures. The increases in fatalities would be 0.02 (physical hazards) and 0.0002 (radiological exposure). These increases are small.

The most limiting criteria air pollutant is NO_2 emitted during construction operations. This is estimated to reach 7% of the standards, so NO_2 would increase emissions to approximately 10%, which is well below the standards.

For infrastructure, required acreage would increase from 2.3 to 3.3 acres; water, wastewater, and power, which were estimated to be 0.09% or less of capacity, would increase to 0.13% or less; and job increases would be less than 0.1% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). For disposal, there are no radionuclides that increase, so the more recent waste data are not predicted to cause an exceedance of water quality standards.

Conclusions: No further evaluation is required for volume or radionuclide changes.

RFETS

Volumes: LLMW volume increased by a factor of 1.09, which results in an increase in workers and resources of 1.06, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at RFETS in the Draft WM PEIS is 0.69 worker fatalities from treatment and disposal physical hazards and 0.003 worker fatalities from radiological exposures. The increases in risk of fatality fatalities would be 0.04 (physical hazards) and 0.0002 (radiological exposure). These increases are small.

The most limiting criteria air pollutant is CO emitted during construction operations. This is estimated to reach 169% of the standards, so CO would increase emissions to approximately 179% of standards. This increase is a small change to a value already well over standards.

For infrastructure, required acreage would increase from 32.9 to 34.9 acres; water, wastewater, and power, which were estimated to be 33.3% or less of capacity, would increase to 35.3% or less; and job increases would be less than 0.004% of employment in the region. These are all small changes.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). For disposal, there are no radionuclides that increase, so the more recent waste data are not predicted to cause an exceedance of water quality standards.

Conclusions: No further evaluation is required for volume or radionuclide changes.

SNL-NM

Volumes: LLMW volume increased by a factor of 1.8, which results in an increase in workers and resources of 1.51, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at SNL-NM in the Draft WM PEIS is 0.006 worker fatalities from treatment and disposal physical hazards and 0.0003 worker fatalities from radiological exposures. The increases in risk of fatality fatalities would be 0.003 (physical hazards) and 0.0002 (radiological exposure). These increases are small.

Criteria air pollutants are still 0% of the standards, so increases are negligible.

For infrastructure, required acreage would increase from 0.83 to 1.3 acres; water, wastewater, and power, which were estimated to be 0.3% or less of capacity, would increase to 0.45% or less; and job increases would be less than 0.1% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). In the Draft WM PEIS, concentrations of plutonium in the groundwater exceeded standards assuming unconstrained disposal; increases in plutonium reported for more recent data could increase the exceedance of groundwater standards by a factor of 2.0 in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage plutonium in disposal has been noted in the risk and water quality sections of Chapter 6, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

SRS

Volumes: LLMW volume increased by a factor of 1.85, which results in an increase in workers and resources of 1.54, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at SRS in the Draft WM PEIS is 0.43 worker fatalities from treatment and disposal physical hazards and 0.15 worker fatalities from radiological exposures. The increases in fatalities would be 0.23 (physical hazards) and 0.08 (radiological exposure). These increases are not considered so large as to require a reevaluation on the basis of volumes.

The most limiting criteria air pollutant is CO emitted during facility operations. This is estimated to reach 10% of the standards, so the CO would increase emissions to approximately 18%, which is well below the standards.

For infrastructure, required acreage would increase from 22.6 to 35 acres; water, wastewater, and power, which were estimated to be 1.5% or less of capacity, would increase to 2.3% or less; and job increases would be less than 0.16% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). In the Draft WM PEIS, concentrations of U-238 in the groundwater exceeded standards assuming unconstrained disposal; increases in U-238 reported for more recent data could increase the exceedance of groundwater standards by a factor of 4.2 in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage U-238 in disposal facilities has been noted in the risk and water quality sections of Chapter 6, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

WVDP

Volumes: LLMW volume increased by a factor of 4, which results in an increase in workers and resources of 2.6, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The estimate of worker risk at WVDP in the Draft WM PEIS is 0.005 worker fatalities from treatment and disposal physical hazards and 0.003 worker fatalities from radiological exposures (no LLMW was disposed of at WVDP). The increases in fatalities would be 0.008 (physical hazards) and 0.004 (radiological exposures). These increases are small.

Criteria air pollutants are still 0% of the standards, so increases are negligible.

For infrastructure, required acreage would increase from 1.5 to 3.9 acres; water, wastewater, and power, which were estimated to be 4% or less of capacity, would increase to 10% or less; and job increases would be less than 0.01% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of fatality from air emissions is less than one in one million (< 1.0E–06). Disposal was not evaluated for LLMW in the Draft WM PEIS because all LLMW at WVDP was categorized as alpha waste, which is transported to SRS for disposal in the Decentralized Alternative. In the more recent data, volumes of 3.6 cubic meters per year of nonalpha waste are listed for disposal. This quantity of LLMW was considered to be too small for analysis of a separate LLMW disposal facility; continued shipment to SRS with alpha LLMW was considered more reasonable.

Conclusions: No further evaluation is required for volume or radionuclide changes.

Table I.2-7. Sites Identified for Reanalysis Based on Changes in LLMW Volumes

Site	No Change	Decrease	Increase (Factor)	Reanalyze	Comment
ANL-E		●		●	**Very large decrease; impacts from Draft WM PEIS data are excessively large; reevaluate site.**
BNL		●			
FEMP			● (1)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
Hanford		●			
INEL			● (1.5)		Increases are for disposal volumes only.
LANL		●			
LLNL			● (1.7)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
NTS			● (7,500)	●	**Large increase—reevaluate site.**
ORR		●			
Pantex			● (3.2)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
PGDP			● (1.7)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
PORTS		●			
RFETS			● (1.1)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
SNL-NM			● (1.8)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
SRS			● (1.9)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
WVDP			● (4)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.

Table I.2-8. Sites Identified for Reanalysis Based on Changes in Radioactivity—Air Emissions as Indicators of Potential Changes in Health Risk

Site	Radioactivity Driver in Decentralized Alternative Total Alpha Radioactivity[a]	Change (Factor)	Prior MEI Risk	Projected New MEI Risk	Reanalyze	Comment
ANL-E	U-238 Total alpha	-1.09 -1.1	7.2E-09	< 7.2E-09 < 7.2E-09		Projected new risk is < 1.0E-06
BNL	U-238 Total alpha	-7.7 -7.3	1.6E-10	< 1.6E-10 < 1.6E-10		Projected new risk is < 1.0E-06
FEMP	U-238 Total alpha	-1.09 -1.1	4.9E-10	< 4.9E-10 < 4.9E-10		Projected new risk is < 1.0E-06
Hanford	Pu-238 Total alpha	-1.7 -1.9	3E-08	< 3E-08 < 3E-08		Projected new risk is < 1.0E-06
INEL	Tritium Total alpha	3.9 3.6	6.5E-09	2.7E-08 2.5E-08		Projected new risk is < 1.0E-06
LANL	Tritium Total alpha	-1.9 -1.3	6.2E-08	< 6.2E-08 < 6.2E-08		Projected new risk is < 1.0E-06
LLNL	Tritium Total alpha	3.4 1.1	2.5E-06	8.5E-06 2.7E-06		Draft WM PEIS and more recent projections exceed E-06 as noted in Chapter 6, Volume I.
NTS	U-238 Total alpha	-2.1 -13	0	0		Projected new risk is < 1.0E-06
ORR	U-238 Total alpha	-4.2 -1.3	3.3E-08	< 3.3E-08 < 3.3E-08		Projected new risk is < 1.0E-06
Pantex	Tritium Total alpha	2.5 1.6	2.9E-09	7.3E-08 4.6E-08		Projected new risk is < 1.0E-06
PGDP	U-238 Total alpha	1.1 -1.02	1.3E-08	1.4E-08 1.3E-08		Projected new risk is < 1.0E-06
PORTS	U-238 Total alpha	-1.7 -1.7	3.4E-10	< 3.4E-10 < 3.4E-10		Projected new risk is < 1.0E-06
RFETS	Pu-238 Total alpha	1.2 1.3	9.1E-10	1.1E-09 1.2E-09		Projected new risk is < 1.0E-06
SNL-NM	Tritium Total alpha	4.4 2.0	5.4E-09	2.4E-08 1.1E-08		Projected new risk is < 1.0E-06
SRS	Tritium Total alpha	3.9 2.4	1.7E-08	6.6E-08 4.1E-08		Projected new risk is < 1.0E-06
WVDP	Pu-238 Total alpha	130 34	3.8E-12	4.9E-10 1.3E-10		Projected new risk is < 1.0E-06

[a] Radioactivity is for alpha-emitting radionuclides only. Tritium and other non-alpha emitting radionuclides are not included in this sum because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the health risk.

Table I.2–9. Sites Identified for Reanalysis Based on Changes in Radioactivity—Exceedances of Drinking Water Standards as an Indicator of Changes in Groundwater Impacts From LLMW Disposal

Site	Long-lived Radionuclides Increasing	Factor of Change	Groundwater Concentration as % of Drinking Water Standard (%)		Comment
			Draft WM PEIS	Projected New	
ANL-E	None	NA	NA	NA	No increases.
BNL	None	NA	NA	NA	No increases.
FEMP	Tc-99 Th-232 U-238	1.2 1.2 1.2	0 0 400	0 0 480	Will not exceed standards. Will not exceed standards. Draft WM PEIS concentrations exceeded standards in disposal alternatives — new values increase exceedance, but do not change basic results: U-238 would be managed to meet standards. Reevaluation not required.
Hanford	Ni-59 Decentralized Ni-59 Centralized U-238 Decentralized U-238 Centralized	9 1.86 9 1.5	0 0 400 10,000	0 0 3,600 15,000	Will not exceed standards. Will not exceed standards. Draft WM PEIS concentrations exceeded standards in every alternative — new values increase exceedance but do not change basic results: DOE would need to manage U-238 to meet standards. Reevaluation not required.
INEL	Ni-59 U-238	1.6 1.6	0 0	0 0	Will not exceed standards.
LANL	None	NA	NA	NA	No increases.
LLNL	U-238	1.5	0	0	Will not exceed standards.
NTS	None	NA	0	0	No increases.
ORR	U-238	2.2	5–10	11–22	Will not exceed standards.
Pantex	Ni-59	2.2	0	0	Will not exceed standards.
PGDP	None	NA	NA	NA	No increases.
PORTS	None	NA	NA	NA	No increases.
RFETS	None	NA	NA	NA	No increases.
SNL-NM	Ni-59 Pu-240	2.5 2.0	0 900	0 1,800	Will not exceed standards. Draft WM PEIS concentrations exceeded standards in Decentralized Alternative — new value increases exceedance, but Pu-240 would be managed to meet standards. Reevaluation not required.
SRS	Ni-59 U-238	3.7 4.2	0 600	0 2,520	Will not exceed standards. Draft WM PEIS concentrations exceeded standards in every alternative — new values increase exceedance. DOE would need to manage U-238 to meet standards. Reevaluation not required.
WVDP	NA	NA	NA	NA	No disposal evaluated; waste is proposed for shipment to SRS for disposal.

I.3 LLW Inventory Update

The IDB for 1992 (DOE, 1992) and its supporting electronic database, the Waste Management Information System (ORNL, 1992), were used in preparing the LLW analysis in the Draft WM PEIS. These sources contained LLW data reported throughout the DOE complex for 1991. This section presents data published in the IDB Report–1994 (containing data reported for 1994 [DOE, 1995b]) and compares these data to the data used in the Draft WM PEIS.

In 1995, the IDB updated the site-specific LLW characterization data, including generation rates and existing inventory (DOE, 1995b). These data are compared with data in the Draft WM PEIS in Table I.3–1. A comparison of the data reported in these two sources, the IDB Report–1994 and the Draft WM PEIS, indicates that waste generation rates decreased at most sites. Major LLW generating sites in 1994 were Hanford, Idaho National Engineering Laboratory (INEL), the K-25 Site (K-25), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Savannah River Site (SRS), Y-12 Plant (Y-12), West Valley Demonstration Project (WVDP), and the Naval Reactor (NR) sites, which include Bettis Atomic Power Laboratory (Bettis), Knolls Atomic Power Laboratory (KAPL) (all facilities), and the Naval Reactor Facility (NRF). Combined waste generation rates at these sites were decreased by a total of 45%, compared with the earlier estimates in the Draft WM PEIS. No LLW generation rates or inventories were reported for PGDP and PORTS in the IDB Report–1994. The waste at these sites falls under the Environmental Restoration (ER) Program.

DOE facilities with small quantities of LLW generated in 1994 included Ames Laboratory (Ames), Argonne National Laboratory-East (ANL-E), Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (Fermi), Inhalation Toxicology Research Institute (ITRI), Kansas City Plant (KCP), Lawrence Berkeley Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL), Mound Plant (Mound), Nevada Test Site (NTS), Pantex Plant (Pantex), Pinellas Plant (Pinellas), Princeton Plasma Physics Laboratory (PPPL), Rocky Flats Environmental Technology Site (RFETS), Stanford Linear Accelerator Center (SLAC), and Sandia National Laboratories-California (SNL-CA).

The volumes of waste managed at different facilities under the various alternatives are represented by the "feedstock" volume. Feedstock volume is the amount entering the treatment or disposal system and is calculated in the WM PEIS as being equal to the waste inventory in storage at a given site plus the annual waste generation rate multiplied by 20 years of waste generation. Table I.3–2 presents total feedstock volumes in the Draft WM PEIS and those calculated from the IDB Report–1994.

Overall, the total reported feedstock volume of LLW decreased by 45%. Approximately one quarter of this decrease can be accounted for by the fact that both PORTS and PGDP did not report any LLW WM volumes in the IDB Report–1994, because wastes at PGDP and PORTS are ER wastes. Table I.3–2 also compares the total annual radionuclide activity of waste as reported in the Draft WM PEIS with that reported in the 1995 IDB. Here, reported complexwide treatment activities increased by about 80% overall.

I.3.1 Analysis of LLW Alternatives

For LLW, DOE used either the Decentralized Alternative or Regionalized Alternative 2 impact estimates as the best indicator of the effect of the more recent data on determining which sites should be reanalyzed (see Section I.1.3). However, five alternatives were used to compare estimates of disposal volumes using the more recent LLW data. LLW inventories, generation rates, and activities were entered into the WASTE_MGMT computational model (ANL, 1996a) to determine volumes and radionuclides disposed of under the Decentralized Alternative, three Regionalized Alternatives (Regionalized 2, 4, and 5), and Centralized Alternative 5. New waste treatability categories, volumes, and activities were developed from the IDB Report–1994. LLW radionuclide distributions were assumed to be similar to those used in the Draft WM PEIS; total activities were changed to reflect the updated information.

Updated disposal volumes at each site under the Decentralized Alternative are presented in Table I.3–3 and compared to those used in the Draft WM PEIS. The volumes represent disposal over the 10-year treatment and disposal time frame evaluated in the WM PEIS. No estimates of LLW for disposal at NTS, BNL, or WVDP were reported in the Draft WM PEIS analysis (this is reflected in the second column) because there was no waste on site and only onsite wastes were assumed to be disposed of at these sites under the Decentralized Alternative. Data for these sites were taken from the IDB Report–1994 for use in the Final WM PEIS analyses.

The complexwide decrease in disposal volumes of about 40%, using minimum treatment in the Decentralized Alternative, reflects the overall decrease in LLW generated and stored in the DOE complex as reported in the IDB Report–1994 and is comparable to the 45% decrease in treatment volumes. Disposal volumes under three Regionalized Alternatives (Regionalized 2, 4, and 5) and Centralized Alternative 5, calculated using the more recent data, are shown in Table I.3–4 and are compared with disposal volumes in the Draft WM PEIS. These particular alternatives represent maximum treatment of LLW using volume reduction technologies. The complexwide disposal volumes decrease by about 35% following volume reduction when the more recent data from the IDB Report–1994 are used, and this decrease is less than the 45% decrease in treatment volumes. The difference reflects not only changes in treatment volumes, but also changes in treatment categories, which can affect the amount of volume reduction occurring at a treatment site.

For LLW, conclusions about the need for reanalysis are based on either the Decentralized Alternative or Regionalized Alternative 2 impact estimates as the best indicator's of the effect of the more recent data. The Decentralized Alternative uses data reported by each site, without the averaging produced by consolidation of waste in the Regionalized or Centralized Alternatives. However, treatment with volume reduction, under Regionalized Alternative 2, would pose greater risks to the offsite population than the Decentralized Alternative, which utilizes minimum treatment. So Regionalized Alternative 2 is used to evaluate air emission impacts to the offsite population.

As noted in Table I.3–3, disposal volumes at sites under the Decentralized Alternative generally decrease. Accordingly, if these sites ship their waste to regionalized and centralized management sites, volumes would also generally decrease. Therefore, it is not anticipated that the more recent data would cause major new impacts or changes to the comparison of alternatives for the Regionalized or Centralized Alternatives. The exceptions are for volume reduction sites as shown in Table I.3–4. Using the more recent data, the percentage of waste suitable for volume reduction as compared with the percentage unsuitable for reduction has decreased at some sites, leading to larger disposal volumes—particularly at INEL and ORR, for some alternatives. Since the greater disposal volumes associated with the minimum treatment alternatives were evaluated at these same sites, impacts of the greater disposal volumes were analyzed in the Draft WM PEIS. Therefore there was no need to reevaluate Regionalized or Centralized Alternatives based upon larger disposal volumes. Costs and transportation impacts, which are calculated at the national level in the Draft WM PEIS for the purposes of comparison of alternatives, would similarly not increase, since volumes overall do not increase.

I.3.2 Radiological Profiles

Total activities of radionuclides disposed under the Decentralized Alternative, Regionalized Alternatives 2, 4, and 5, and Centralized Alternative 5 are shown in Tables I.3–5 and I.3–6. The total activity of radionuclides disposed of across the DOE complex increases by almost a factor of 2 when the more recent data are used.

The total activity (in curies) of long-half-life radionuclides (half-lives greater than 300 years) contained within disposed waste has the potential to cause future health risks after disposal. The activity of these radionuclides determines the potential risks to an individual or group of receptors using groundwater contaminated by disposal.

Activities for selected long-half-life radionuclides disposed under the Decentralized Alternative and Centralized Alternative 5, calculated by using the more recent data, are compared with the data used in the Draft WM PEIS in Tables I.3–7 and I.3–8. Centralized Alternative 5 assumes all wastes are treated and disposed of at Hanford; thus, disposal activities represent the aggregate total activity from disposal of all LLW. Changes at individual sites are evaluated in the Decentralized Alternative.

As shown by comparing values for the Decentralized Alternative in Tables I.3–5 and I.3–7 with values for Regionalized and Centralized disposal in Tables I.3–6 and I.3–8, analysis of sites using the Decentralized Alternative provides a representative estimate of potential impacts anticipated at most sites using more recent data. Exceptions are at ORR and Hanford, which have increased radioactivity in the Regionalized or Centralized Alternatives. As further discussed in Section I.3.3, ORR is reevaluated for this and other increases, while the increases causing exceedances at Hanford are discussed further in Chapter 7, Volume I.

Pantex has also been chosen for reevaluation of LLW impacts (see Section I.3.3). This selection was not predicated on changes in expected radionuclide concentrations but rather on substantial decreases in the expected volumes of waste needing treatment.

Table I.3–9 lists both the air emissions for the radionuclide that made the greatest contribution to risk in the Draft WM PEIS and the total emission to the air of alpha-emitting radionuclides for each site caused by treatment of LLW. This table compares the air emissions modeled by using the 1992 IDB and IDB Report–1994 data. Total complexwide radiological air emissions are predicted to increase by a factor of 1.7 when the more recent data are used. Analysis of air emissions in the Regionalized Alternative 2 provides estimates of impacts for more recent data at the sites that are most sensitive to air emissions, with the exception of sites affected by thermal treatment of tritium. For greater consolidation of waste in Regionalized and Centralized Alternatives, the increase in tritium-bearing waste, primarily at eastern sites, poses the only potential major increase in risks. This increase in tritium-bearing waste affects emissions at FEMP in Regionalized Alternative 2 and then transfers to PORTS in Regionalized Alternative 4 and Centralized Alternatives 3 and 4, to ORR in Regionalized Alternative 5, and to Hanford in Centralized Alternative 5. This is further discussed in Section I.3.3 and in the risk section of Chapter 7, Volume I.

Table I.3-1. Comparison of Site-Specific LLW Characterization Data

	Generation Rate (m^3/yr)		**Inventory (m^3)**	
Site	**Draft WM PEIS Data**[a]	**More Recent Data**[b]	**Draft WM PEIS Data**[a]	**More Recent Data**[b]
Ames	4	4.5	26	53.6
ANL-E	290	669	884	284
BNL[c]	--[d]	254	--	556
FEMP[e]	ER[f]	ER	ER	ER
Fermi	72	61.3	44.7	83.2
Hanford	4,450[g]	4,500	0	50.6
INEL[h]	5,091	3,200	3,520	14,100
KCP	1	18	4	116
LANL	7,480	1,900	0	0
LBL	62	14.6	53.1	19
LLNL	140	77	780	730
Mound	1,840	910	1,580	8,860
NR Sites[i]	1,516	1,050	0	0
NTS[c]	--	70.8	--	269
ORR[c]	10,200	12,600	48,000	19,000
PGDP	2,230	ER	5,270	ER
Pantex[c]	304	122	33,600	209
Pinellas	63	52.1	16	66
PORTS	4,790	ER	1,480	ER
PPPL	11	42.4	2.1	3
RFETS	1,930	503	2,350	5,320
RMI	2,410	--	2,540	--
SLAC	14	81.3	2,200	242
SNL-NM	92	31	680	51
SRS	25,200[j]	10,500	11,100	1,655
WVDP[c]	--	1,370	--	14,300
Total	68,100	38,000	114,000	65,000

Notes: Fermi = Fermi National Accelerator Laboratory; RMI = RMI Titanium Company; SNL-NM = Sandia National Laboratories-New Mexico.

[a] For LLW, Draft WM PEIS values calculated on the basis of data from 1992 IDB (DOE, 1992), WMIS (ORNL, 1992), and updates from some sites.

[b] For LLW, more recent values calculated on the basis of data from IDB Report-1994 (DOE, 1995b).

[c] These sites were evaluated in the Final WM PEIS using data from the IDB Report-1994.

[d] -- = no data reported.

[e] FEMP is an LLW treatment and shipping site. No WM LLW is currently reported there.

[f] ER = Environmental Restoration wastes not under Waste Management Program.

[g] Excludes Hanford grout waste stream.

[h] INEL data include ANL-W and NRF.

[i] NR sites are Bettis and KAPL (all facilities).

[j] Excludes SRS saltstone waste stream.

Sources: DOE (1992, 1995a); ORNL (1992).

Table I.3-2. Comparison of LLW Feedstock Volume and Annual Activity

Site	Inventory Plus 20-yr Generation (m^3)		Factor of Change[c]	Annual Activity (Ci/yr)		Factor of Change[c]
	Draft WM PEIS Data[a]	More Recent Data[b]		Draft WM PEIS Data[a]	More Recent Data[b]	
Ames	106	144	+1.4	0.02	0.0001	-20
ANL-E	6,680	13,700	+2.0	229	16	-14
BNL[d]	NR[e]	5,640	+[f]	NR	574	+
FEMP	ER[g]	ER	NA[h]	ER	ER	NA
Fermi	1,490	1,310	-1.1	1.11	6	+5.4
Hanford	89,000	90,000	+1.02	7,750	6,040	-1.3
INEL[i]	105,000	78,000	-1.3	138,000	270,000	+2.0
KCP	24	476	+19.8	0.11	0.23	+2.1
LANL	150,000	38,000	-3.9	385,000	9,690	-40
LBL	1,290	319	-4.1	1,600	120	-13
LLNL[j]	3,600	1,670	-1.9	24,500	3,650	-6.7
Mound	38,400	27,000	-1.4	6,060	1,400,000	+233
NR Sites[k]	30,300	21,000	-1.4	369,000	91,000	-4.1
NTS[d]	NR	1,690	+	NR	0.09	+
ORR[d,l]	252,000	271,000	+1.1	830	5,420	+6.5
PGDP	49,900	ER	NA	1.0	ER	NA
Pantex[d]	39,700	2,650	-15	19	NR	*[m]
Pinellas	1,280	1,110	-1.2	9,830	10,200	+1.04
PORTS	97,300	ER	NA	0.1	ER	*
PPPL	220	851	+3.8	0.119	9,560	+80,000
RFETS	41,000	15,400	-2.7	11	1.10	-10
RMI	50,700	NR	*	0.01	NR	*
SLAC	2,480	1,890	-1.3	0.01	0.1	0
SNL-NM[n]	2,520	670	-3.8	202	1.1	-180
SRS	515,000	211,000	-2.4	81,000	960	-82
WVDP[d]	NR	41,700	+	NR	NR	NA
Total	1,480,000	810,000	-1.8	1,023,000	1,804,000	+1.8

Footnotes appear on next page.

Table I.3-2. Comparison of LLW Feedstock Volume and Annual Activity —Continued

[a] For LLW, Draft WM PEIS values calculated on the basis of data from 1992 IDB (DOE, 1992), WMIS (ORNL, 1992), and updates from some sites.
[b] For LLW, more recent data are from IDB Report-1994 (DOE, 1995b).
[c] Factor of change is the ratio of more recent data (IDB Report-1994) to Draft WM PEIS data. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.
[d] These sites, NTS, BNL, WVDP, ORR, and Pantex, were analyzed in the Final WM PEIS by using the more recent data from the IDB Report-1994 (DOE, 1995b).
[e] NR = no data reported.
[f] + = the IDB Report-1994 reports a volume or activity, whereas no data were reported in the earlier data set used in the Draft WM PEIS.
[g] ER = Environmental Restoration wastes not under Waste Management Program.
[h] NA = not applicable; no data to compare.
[i] Includes ANL-W and NRF data.
[j] Includes SNL-CA data.
[k] NR sites include Bettis and KAPL.
[l] ORR = Oak Ridge Reservation and includes ORNL, K-25, Y-12, and ORISE.
[m] * = Draft WM PEIS data set reported a volume or activity where no data were reported in the IDB Report-1994 (DOE, 1995b).
[n] Includes ITRI.

Table I.3–3. Comparison of Disposal Volumes Under the Decentralized Alternative

Site	Disposal Volume (m^3)		Factor of Change[c]
	Draft WM PEIS Data[a]	More Recent Data[b]	
ANL-E	9,100	16,600	+1.8
BNL	NA[d]	5,760	+[e]
Hanford	94,400	96,800	+1.03
INEL	94,100	80,700	-1.2
LANL	163,000	51,600	-3.2
LLNL	8,320	4,850	-1.7
NTS	NA	1,830	+
ORR	243,000	294,000	+1.2
Pantex	40,000	2,910	-14
PGDP	53,800	528	-102
PORTS	231,000	80,000	-4.8
RFETS	45,000	16,900	-2.7
SNL-NM	2,750	733	-3.8
SRS	568,000	230,000	-2.6
WVDP	NA	49,500	+
Total	1,550,000	930,000	-1.7

[a] For LLW, Draft WM PEIS values calculated on the basis of data from 1992 IDB (DOE, 1992), WMIS (ORNL, 1992), and updates from some sites.
[b] For LLW, more recent data are from IDB Report–1994 (DOE, 1995b).
[c] Factor of change is the ratio of more recent data (IDB Report–1994) to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.
[d] NA = not applicable. No WM LLW was reported for these sites in the data set originally used. Data for these sites from the IDB Report–1994 were used in the Final WM PEIS analysis.
[e] + indicates that an LLW volume exists for this site in the IDB Report–1994 data set, whereas none was reported in the data set used in the Draft WM PEIS.

Table I.3-4. Comparison of Alternatives' Disposal Volumes

Site	Disposal Volume (m^3)														
	Decentralized			Regionalized 2			Regionalized 4			Regionalized 5			Centralized 5		
	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]
ANL-E	9,100	16,600	+1.8												
BNL	NA	5,760	+												
FEMP				0	0	No change									
Hanford	94,400	96,800	+1.03	20,700	24,000	+1.2	20,900	24,600	+1.2	20,900	24,600	+1.2	826,000	502,000	-1.6
INEL	94,100	80,700	-1.2	51,000	73,000	+1.4	51,000	73,000	+1.4	59,700	74,000	+1.3			
LANL	163,000	51,600	-3.2	50,900	32,300	-1.6	71,800	40,100	-1.8	63,700	38,900	-1.7			
LLNL	8,320	4,850	-1.7	6,200	2,090	-3.0									
NTS	NA	1,830	+	0	0	No change	6,180	1,970	-3.1	6,180	1,970	-3.1			
ORR	243,000	294,000	+1.2	49,100	133,000	+2.7	216,000	264,000	+1.2	214,000	264,000	+1.2			
Pantex	40,000	2,910	-14	7,890	2,910	-2.7									
PGDP	53,800	528	-102	41,500	525	-79									
PORTS	231,000	80,000	-2.9	123,000	130,000	+1.1									
RFETS	45,000	16,900	-2.7	12,000	4,590	-2.3									
SNL-NM	2,750	733	-3.8												
SRS	568,000	230,000	-2.5	455,000	100,000	-4.5	455,000	100,000	-4.5	455,000	100,000	-4.5			
WVDP	NA	49,500	+												
Total	1,550,000	930,000	-1.7	804,000	502,000	-1.6	809,000	502,000	-1.6	807,000	502,000	-1.6	812,000	502,000	-1.6

Note: Blanks indicate that site not used for disposal under this alternative.

[a] Factor of change is the ratio of more recent data (IDB Report-1994) to Draft WM PEIS data. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.

Table I.3-5. Comparison of Disposal Activities Under the Decentralized Alternative (Curies)

Site	Draft WM PEIS Data	More Recent Data	Factor of Change[a]
ANL-E	5.30E+03	4.60E+02	-12
BNL	NA[b]	1.21E+04	NA
Hanford[c]	1.55E+05	1.21E+05	-1.3
INEL	2.76E+06	7.60E+06	+2.8
LANL	7.72E+06	1.94E+05	-40
LLNL	6.37E+05	8.99E+04	-7.1
NTS	NA[b]	3.67	+
ORR	5.92E+04	1.27E+05	+2.2
PGDP	2.50E+01	5.97	-4.2
Pantex	2.47E+03	9.55E-01	-2,600
PORTS	7.51E+06	3.45E+07	+3.9
RFETS	2.33E+02	4.57E+01	-5.1
SNL-NM	5.12E+03	2.43E+01	-210
SRS[c]	1.79E+06	2.36E+05	-7.8
WVDP	NA[b]	1.44E+04	+
Total	2.06E+07	4.27E+07	+2.1

Note: NA = not applicable.
[a] Factor of change shows the factor of increase or decrease in disposal activity, comparing more recent data to data in the Draft WM PEIS. Positive values indicate that more recent data are greater than data in the Draft WM PEIS; negative values indicate that more recent data are less than data in the Draft WM PEIS.
[b] No WM LLW was reported for these sites in the data set originally used. Data for these sites and for ORR from the IDB Report-1994 were used in the Final WM PEIS analysis.
[c] Excludes Hanford grout waste and SRS saltstone waste streams.

Table I.3-6. Comparison of Disposal Activities Under the Regionalized and Centralized Alternatives

Site	Disposal Activity (Ci)											
	Regionalized 2			Regionalized 4			Regionalized 5			Centralized 5		
	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]	Draft WM PEIS Data	More Recent Data	Factor of Change[a]
ANL-E	--	--	--	--	--	--	--	--	--	--	--	--
BNL	--	--	--	--	--	--	--	--	--	--	--	--
Hanford[b]	1.55E+05	1.21E+05	-1.3	2.87E+05	2.11E+05	-1.4	2.87E+05	2.11E+05	-1.4	2.02E+07	4.21E+07	+2.1
INEL	2.76E+06	7.60E+06	+2.8	2.76E+06	7.60E+06	+2.8	2.76E+06	7.60E+06	+2.8	--	--	--
LANL	7.73E+06	1.94E+05	-40	7.73E+06	1.94E+05	-40	7.72E+06	1.94E+05	-40	--	--	--
LLNL	3.59E+05	8.99E+04	-4.0	--	--	--	--	--	--	--	--	--
NTS	0	0	None	2.27E+05	5.43E+01	-4,200	2.27E+05	5.43E+01	-4,200	--	--	--
ORR	5.92E+04	1.27E+05	+2.2	7.45E+06	3.45E+07	+4.6	7.45E+06	3.45E+07	+4.6	--	--	--
PGDP	2.50E+01	5.97	-4.2	--	--	--	--	--	--	--	--	--
Pantex	2.47E+03	9.55E+00	-2,600	--	--	--	--	--	--	--	--	--
PORTS	7.39E+06	3.45E+07	+4.7	--	--	--	--	--	--	--	--	--
RFETS	2.33E+02	4.57E+01	-5.1	--	--	--	--	--	--	--	--	--
SNL-NM	--	--	--	--	--	--	--	--	--	--	--	--
SRS[b]	1.79E+06	2.36E+05	-7.8	1.79E+06	2.29E+05	-7.8	1.79E+06	2.29E+05	-7.8	--	--	--
WVDP	--	--	--	--	--	--	--	--	--	--	--	--
Total	2.02E+07	4.21E+07	+2.1	2.02E+07	4.21E+07	+2.1	2.02E+07	4.21E+07	+2.1	2.02E+07	4.21E+07	+2.1

Note: NA = not applicable; -- = site not used for this alternative.

[a] Factor of change shows the factor of increase or decrease in disposal activity, comparing more recent data to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that more recent data are less than data in the Draft WM PEIS.
[b] Excludes Hanford grout waste and SRS saltstone waste streams.

Table I.3-7. Comparison of Disposal Activities—Selected Long-Half-Life Nuclides: Decentralized Alternative

Disposal Site/ Nuclide	Disposal Activity (Ci)		Factor of Change[a]
	Draft WM PEIS Data	More Recent Data	
ANL-E			
Ni-59	2.68	0.365	-7.3
Tc-99	1.62	0.103	-16
Th-232	0.00133	0.0105	+7.9
U-235	0.000125	0.000997	+8.0
U-238	9.79	1.87	-5.2
Pu-240	0.0282	0.00168	-18
Total	14.9	2.35	-6.2
BNL[b]			
Ni-59	ND[c]	6.06	d
Tc-99	ND	3.72	d
U-238	ND	22.1	d
Pu-240	ND	0.0605	d
Total	ND	33.8	d
Hanford			
Tc-99	3.44	2.94	-1.2
Th-232	0.434	1.65	+3.8
U-235	0.0410	0.156	+3.8
U-238	52.8	201	+3.8
Pu-240	2.29	1.96	-1.2
Total	59.0	208	+3.5
INEL			
Ni-59	5,500	14,300	+2.6
Tc-99	0.0896	13.1	+150
Pu-240	0.0597	8.75	+150
Total	5,500	14,300	+2.6
LANL			
Tc-99	115	3.02	-38
Th-232	26.8	56	+2.1
U-235	2.53	5.29	+2.1
U-238	3,260	6,830	+2.1
Pu-240	89.4	0.0474	-1,900
Total	12,300	6,900	-1.8
LLNL			
Tc-99	22.6	0.712	-31
U-235	0.00971	0	d
U-238	150	4.28	-35
Pu-240	0.181	2.07	+11
Total	184	7.41	-25

Table I.3-7. Comparison of Disposal Activities—Selected Long-Half-Life Nuclides: Decentralized Alternative—Continued

Disposal Site/ Nuclide	Disposal Activity (Ci)		Factor of Change[a]
	Draft WM PEIS Data	More Recent Data	
NTS[b]			
Tc-99	ND	0.00011	d
Pu-240	ND	0.0000734	d
Total	ND	0.000183	d
ORR[b]			
Tc-99	1.72	95.7	+56
Th-232	0.283	0.585	+2.1
U-235	0.0268	0.0553	+2.1
U-238	35	644	+18
Pu-240	1.09	1.05	None
Total	38.2	788	+21
PGDP			
Tc-99	0.0922	0.00652	-14
U-238	7.36	0.0396	-190
Np-237	0.0670	--[e]	d
Total	7.52	0.0494	-152
Pantex[b]			
Th-232	0.356	0.000130	-2,700
U-235	0.0336	0.0000123	-2,700
U-238	43.3	0.0159	-2,700
Total	43.7	0.0016	-2,700
Portsmouth			
Ni-59	14,700	1,410	-10
Tc-99	0.00481	0.00334	-1.4
Th-232	0.0122	0	d
U-235	0.00116	0	d
U-238	1.5	0	d
Pu-240	0.431	2.06	+4.8
Total	14,700	1,410	-10
RFETS			
Th-232	0.0579	0.00125	-46
U-235	0.00547	0.000118	-46
U-238	7.04	0.152	-46
Pu-240	1.48	0.317	-4.7
Total	8.58	0.470	-18

Table I.3-7. Comparison of Disposal Activities—Selected Long-Half-Life Nuclides: Decentralized Alternative—Continued

Disposal Site/ Nuclide	Disposal Activity (Ci)		Factor of Change[a]
	Draft WM PEIS Data	More Recent Data	
SNL-NM			
Tc-99	6.07	0.0291	-210
Th-232	0.00819	0	d
U-235	0.000774	0	d
U-238	37.9	0.177	-210
Pu-240	0.210	0	d
Total	47.2	0.221	-210
SRS			
Ni-59	1,790	12.8	-140
Tc-99	1,270[f]	0.192	-10,000
Th-232	1.37	5.11	+3.7
U-235	0.129	0.483	+3.7
U-238	299	622	+2.1
Pu-240	5.89	0.913	-6.8
Total	3,380	641	-5.3
WVDP[b]			
Tc-99	ND	0.423	d
Pu-240	ND	0.287	d
Total	ND	0.71	d

[a] Factor of change is the ratio of more recent data (IDB Report–1994) to Draft WM PEIS data. Positive values result when the more recent data are greater than the Draft WM PEIS data; negative values result when more recent data are less than the Draft WM PEIS data.
[b] More recent data were used for analysis of BNL, NTS, ORR, Pantex, and WVDP in the Final WM PEIS.
[c] ND = no data reported for this site.
[d] Either data set (IDB Report–1994 or Draft WM PEIS) showed zero for the indicated nuclide.
[e] Np-237 was not included in the radionuclide inventory for the more recent data comparison.
[f] SRS Tc-99 activities in the Draft WM PEIS Data column include activity in saltstone. Excluding this waste stream leaves 30 Ci of Tc-99 disposed at SRS. The change from Draft WM PEIS data to more recent is still greater than 1/100.

Table I.3-8. Comparison of Disposal Activities—Selected Long-Half-Life Nuclides: Centralized Alternative 5

Disposal Site/ Nuclide	Disposal Activity (Ci)		Factor of Change[a]
	Draft WM PEIS Data	More Recent Data	
Hanford			
Ni-59	22,100	16,100	-1.4
Ni-63	3,160,000	2,290,000	-1.4
Tc-99	179	120	-1.5
Sm-151	5,540	800	-7.0
Th-232	29.4	65.0	+2.2
U-235	2.78	6.15	+2.2
U-238	3,900	8,530	+2.1
Np-237	0.0670	0[b]	c
Pu-240	101	15.8	-6.4
Total	3,190,000	2,320,000	-1.4

[a] Factor of change is the ratio of more recent data (IDB Report-1994) to Draft WM PEIS data. Positive values result when the more recent data are greater than data in the Draft WM PEIS; negative values result when the more recent data are less than data in the Draft WM PEIS.
[b] Np-237 was not included in the radionuclide inventory for the more recent data comparison.
[c] Either data set (IDB Report-1994 or Draft WM PEIS) showed zero for the indicated nuclide.

Table I.3-9. Comparison of Radiological Air Emissions for LLW: Regionalized Alternative 2

Site	Radionuclide Contributing Greatest Risk / Total Alpha Radioactivity[a]	Draft WM PEIS Data[b] (Ci/yr)	More Recent Data[c] (Ci/yr)	Factor of Change[d]
ANL-E	U-238 Overall	4.1E-08 9.0E-08	2.2E-09 4.8E-09	-19 -19
BNL	U-238 Overall	NA	9.5E-08 2.0E-07	NA
FEMP	Tritium Total alpha	1.3E+04 9.4E-08	8.5E+04 1.3E-07	6.5 1.4
Hanford	Pu-238 Total alpha	3.0E-05 6.8E-05	3.3E-06 1.3E-05	-9.1 -5.2
INEL	Co-60 Total alpha	7.4E-02 1.9E-06	1.9E-02 2.2E-06	-3.9 1.2
LANL	U-238 Total alpha	9.4E-03 1.15E+02	1.9E-02 1.2E-01	2.0 -958
LLNL	Tritium Total alpha	2.8E+04 1.0E-04	1.4E+00 1.3E-06	-2.0E+04 -77
NTS	Pu-238 Total alpha	NA	6.5E-11 1.3E-10	NA
ORR	C-14 Total alpha	4.4E-03 3.8E-05	6.1E-03 1.3E-04	1.4 3.4
Pantex	Tritium Total alpha	2.5E-01 8.2E-06	1.3E+00 2.0E-10	5.2 -4.1E+04
PGDP	U-238 Total alpha	2.7E-06 8.1E-06	6.0E-18 1.8E-10	-4.5E+11 -4.5E+04
PORTS	Co-60 Total alpha	2.1E-01 6.0E-06	1.1E-03 1.2E-05	-190 2.0
RFETS	Pu-238 Total alpha	1.1E-05 4.2E-04	1.3E-06 4.7E-05	-8.5 -8.9
SNL-NM	U-238 Total alpha	4.3E-09 1.3E-07	NA	NA
SRS	Tritium Total alpha	3.8E+02 1.3E-03	3.6E-02 5.0E-03	-1.1E+04 3.8
WVDP	Pu-238 Total alpha	NA	1.4E-07 2.9E-07	NA

Footnotes appear on next page.

Table I.3-9. Comparison of Radiological Air Emissions for LLW: Regionalized Alternative 2—Continued

---

[a] The radioactivity is for alpha-emitting radionuclides only. Tritium and other non-alpha emitting radionuclides are not included because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the health risk.
[b] For LLW, Draft WM PEIS values calculated on the basis of data from the 1992 IDB (DOE, 1992).
[c] For LLW, more recent values calculated on basis of data from the IDB Report-1994 (DOE, 1995b).
[d] Factor of change is the ratio of more recent data (IDB Report-1994) to data in the Draft WM PEIS. Positive values indicate that the more recent data are greater than data in the Draft WM PEIS; negative values indicate that the more recent data are less than data in the Draft WM PEIS.

I.3.3 Conclusions About LLW Sites With Waste Load Increases

Five sites—BNL, NTS, WVDP, ORR, and Pantex—required reevaluation based on volume or radionuclide changes. These are discussed below.

Four additional sites with volume or radiological increases were reviewed and did not require further reevaluation—ANL-E, FEMP, Hanford, and SRS. However, the sections of Chapter 7, Volume I, that discuss risk were revised for FEMP, Hanford, and PORTS to note the requirement to mitigate potential air emission impacts if volume reduction using thermal treatment technologies is employed rather than other methods such as compaction. (Volume reduction is only employed at FEMP in Regionalized Alternative 2.) The health risk and water quality sections of Chapter 7, Volume I, were revised to note continuing management requirements for the disposal of uranium at the Hanford Site and SRS. The air quality section in Chapter 7 was revised for ANL-E to note that criteria air pollutants may approach air quality standards using the more recent data.

The more recent estimates of LLW volume at the other seven major LLW sites did not result in large impacts or risks or radiological changes that would cause exceedances of water quality standards or risks of cancer fatalities to the offsite MEI that exceeded one in one million.

Sites that are not major sites were not considered for evaluation. These sites are assumed to perform minimum levels of treatment and ship to other sites for more intensive treatment or disposal in every alternative. Therefore, impacts at these sites are not large. The radionuclides at these sites, however, were included in the radiological profiles of major sites that treat or dispose of their waste in the Decentralized and Regionalized Alternatives and were reviewed in evaluating these major sites.

The discussion of the sites which follows amplifies upon Tables I.3–10, I.3–11, and I.3–12, which are found at the end of Section I.3.3.2. The tables provide site comparisons showing the change for key parameters between the waste load data used for the Draft WM PEIS and newer waste load data, including:

1. Change in volumes (Table I.3–10). This discussion relies on the waste volume tables presented in this section.
2. Change in both the emission of the radionuclide that has the greatest contribution to risk in the Draft WM PEIS and the total radioactivity emission to the air for alpha-emitting radionuclides (Table I.3–11). As discussed in Section I.2, non-alpha-emitting radionuclides, such as tritium, are not included in the total radioactivity for the same reasons as for LLMW. If tritium or other non-alpha emitters pose a

significant potential risk at a particular site, they are listed separately in the table. The table also shows a projected new MEI risk by multiplying the MEI risk from the Draft WM PEIS by the factor of change for both the driving radionuclide and the total overall alpha radioactivity.

3. Increase in those long-lived radionuclides proposed for disposal at a site (Table I.3–12). The table also shows projected new concentrations in the groundwater for the long-lived radionuclides and discusses whether this concentration is likely to exceed water quality guidelines. The projected new concentrations are derived by multiplying the change factor by the previous concentrations in the groundwater. Since the water guidelines are risk-based, values lower than the guidelines are assumed to be protective of human health.

I.3.3.1 Sites Requiring Reevaluation

BNL, NTS, AND WVDP

Volumes: Previous data used in the Draft WM PEIS did not report LLW volume at BNL, NTS, or WVDP. More recent data for stored and projected generation of LLW at these sites are shown in Table I.3–1. This requires a new analysis to determine all LLW impacts at these sites.

Radionuclides: Radionuclide profiles are available for the more recent waste data, supporting an analysis for radiologically caused risks and impacts.

Conclusion: Reevaluate all LLW impacts at BNL, NTS, and WVDP, and revise the WM PEIS accordingly.

ORR

Volumes: LLW increased by a factor of 1.07, which results in an increase in workers and resources of 1.04, considering economy of scale. The Decentralized Alternative and Regionalized Alternative 2 were used to estimate effects from waste increases, depending on which caused greater impacts.

The existing estimate using Draft WM PEIS data of worker risk at ORR is 0.51 worker fatalities from physical hazards (Regionalized Alternative 2) and 0.52 worker fatalities from radiological exposures (Regionalized Alternative 2). The increases in fatalities based on the new data would thus be 0.02 fatalities for both physical hazards and radiological exposure. These increases are small.

The most limiting criteria air pollutant is NO_2 emitted during facility operations. This is estimated to reach 27% of the standards, so the increase would be approximately 2%, reaching 29% of standards.

For infrastructure, required acreage would increase from 81 to 84 acres; water, wastewater, and power, which were estimated to be 7% or less of capacity, would increase to 7.3% or less; and job increases would be less than 0.1% of employment in the region. These increases are all small.

Radionuclides: For more recent waste data, projected offsite MEI risk of cancer fatality from air emissions in Regionalized Alternative 2 is less than one in one million (< 1.0E–06). However, wastes causing increased tritium emissions noted at FEMP could pass to ORR in the Regionalized Alternative 5, potentially raising projected MEI risks at ORR. For disposal, most radionuclide increases reported for the more recent data are not predicted to cause exceedances of groundwater standards; however, concentrations of Tc-99, which increased by a factor of 56 in the more recent waste data, could cause groundwater standards to be exceeded. This constitutes a change in the impact situation at ORR and justifies reevaluation.

Conclusions: No further evaluation is required for impacts affected by volume changes. Impacts resulting from increased radionuclide concentrations were reevaluated. Volume data, which are also used for new risk calculations, were revised in Volume I to reflect more recent data for LLW at ORR.

PANTEX

Volumes: As shown in Table I.3–2, predicted 20-year volumes of LLW decreased at Pantex from 39,700 to 2,650 m^3—a factor of -15. This decrease is several-fold greater than for any other major site and had the potential for resulting in very inaccurate impact information. Although impacts predicted using the Draft WM PEIS data are conservative, the magnitude of the change justifies a reevaluation.

Radionuclides: Although radionuclide concentrations are not predicted to increase, the substantial decreases in volumes should also be reevaluated for their effect on risks.

Conclusions: Reevaluate all LLW impacts at Pantex, and revise WM PEIS accordingly.

I.3.3.2 Sites Not Requiring Reevaluation

ANL-E

Volumes: LLW volumes increased by a factor of 2.05, which adjusts to an increase in workers and resources of 1.65, considering economy of scale. The Decentralized Alternative was used to estimate effects from waste increases.

The existing estimate using Draft WM PEIS data of worker risk at ANL-E is 0.11 worker fatalities from physical hazards and 0.07 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.07 (physical hazards) and 0.05 (radiological exposures). These increases are small.

The most limiting criteria air pollutant is NO_2 emitted during construction of the new facilities. Nitrogen dioxide was previously estimated to reach 58% of the standards, so the waste increase could cause it to approach the standards at 96%. Since this increase is based on emissions from standard construction equipment and workers commuting to work on a typical construction project, it was not cause for a full reevaluation. A note was added to Chapter 7, Volume I, however, advising of the potential for equipment and vehicular emissions approaching guidelines at ANL-E.

Required acreage for infrastructure would increase from 4 to 6.8 acres; water, wastewater, and power, which were estimated to be 8% or less of capacity, would increase to 13% or less; and job increases would be less than 0.02% of employment in the region. These increases are all small.

Radionuclides: Since volume reduction treatment is not considered at ANL-E, air emissions are not a major source for risk using either previous or more recent waste data. For disposal, those radionuclides that increase at ANL-E using more recent data are not predicted to cause water quality standards to be exceeded in the groundwater.

Conclusions: No further evaluation is required for volume or radionuclide increases resulting from more recent waste data.

FEMP

Volumes: Volumes for waste generated at FEMP did not change using the more recent data; these volumes continue to be categorized as ER waste and are not evaluated in the WM PEIS. Volumes of waste shipped to FEMP for treatment decreased. Therefore, no reevaluation is required based upon volumes.

Radionuclides: There was no disposal of LLW evaluated at FEMP. Air emissions for volume reduction had predicted risks of cancer fatalities in excess of one in one million for the offsite MEI in the Draft WM PEIS (i.e., 4E–06); these risks could increase if volume reduction was pursued using thermal technologies and no mitigation, since both total radioactivity and the activity of the radionuclide with greatest contribution to risk increased in the more recent data by factors of 65 and 1.4, respectively. This potential increase in risk has been noted in the risk sections of Chapter 7, Volume I.

Conclusions: Because volume reduction of LLW is not a regulatory treatment requirement and because the previous data also noted exceedances of one in one million for risk of cancer fatality if volume reduction were employed, no further quantitative reevaluation beyond disclosing this in the risk presentations was considered necessary. No further evaluation is required for volume or radionuclide changes.

HANFORD

Volumes: LLW increased by a factor of 1.02, which adjusts to an increase in workers and resources of 1.014, considering economy of scale. The Decentralized Alternative and Regionalized Alternative 2 were used to estimate effects from waste increases, depending on which had caused greater impacts.

The existing estimate using Draft WM PEIS data of worker risk at Hanford is 0.44 worker fatalities from physical hazards (Regionalized Alternative 2) and 0.5 worker fatalities from radiological exposures (Regionalized Alternative 2). The increases in fatalities based on the new data would thus be 0.006 fatalities for physical hazards and 0.007 fatalities for radiological exposure. These increases are small.

The most limiting criteria air pollutants are NO_2 and particulates emitted during operation of the facilities. These were previously estimated to reach 1% of the guidelines, so the increase would not reach 2% of standards.

Required acreage for infrastructure would increase from 11.6 to 11.8 acres; water, wastewater, and power, which were estimated to be 5.5% or less of capacity, would increase to 5.6% or less; and job increases would be less than 0.01% of employment in the region. These increases are small.

Radionuclides: For more recent waste data, projected offsite MEI risk of cancer fatality from air emissions in the Regionalized Alternative 2 is less than one in one million (< 1.0E–06). However, overall increases in tritium emissions noted at FEMP could also increase tritium emissions at Hanford in the Centralized Alternative 5 when eastern waste is shipped to Hanford. When potential offsetting decreases from LLNL are considered, the current MEI risk of 2E–06 could increase to 4E–06. In the Draft WM PEIS, concentrations of U-238 in the groundwater exceeded standards assuming unconstrained disposal; increases in U-238 reported for more recent data could increase the exceedance of groundwater standards by a factor of 3.8 in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage tritium treatment and U-238 in disposal has been noted in the appropriate risk and water quality sections of Chapter 7, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

PORTS

Volumes: Volumes decreased; therefore no reevaluation is required.

Radionuclides: Radionuclide increases in the Decentralized Alternative and Regionalized Alternative 2 do not cause large increases in risk. However, the tritium emission increases at FEMP would pass to PORTS in the Regionalized Alternative 4 and Centralized Alternatives 3 and 4, potentially increasing the current MEI risk of 2E–06 to 2E–05.

Conclusions: The continuing requirement to carefully manage tritium emissions has been noted in the risk section of Chapter 7, Volume I.

SRS

Volumes: Volumes decreased at SRS; therefore no reevaluation is required.

Radionuclides: For more recent waste data, projected offsite MEI risk of cancer fatality from air emissions is less than one in one million (< 1.0E–06). In the Draft WM PEIS, concentrations of U-238 in the groundwater exceeded standards assuming unconstrained disposal; increases in U-238 reported for more recent data could increase the exceedance of groundwater standards by a factor of 2.1 in the absence of any mitigating measures.

Conclusions: The continuing requirement to carefully manage U-238 in disposal has been noted in the risk and water quality sections of Chapter 7, Volume I, of the Final WM PEIS. No further evaluation is required for volume or radionuclide changes.

Table I.3-10. Sites Identified for Reanalysis Based on Changes in LLW Volumes

Site	No Change	Decrease	Increase Factor	Reanalyze	Comment
ANL-E			● (2.05)		Increases in all worker fatalities <0.5. Priority air pollutants approach standards, noted in Chapter 7, Volume 1, on vehicular emissions; all infrastructure impact changes small. Reanalysis not warranted.
BNL			●	●	**Large increase - reevaluate site.**
FEMP	●				
Hanford			● (1.02)		Increases in all worker fatalities <0.5. Criteria pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
INEL		●			
LANL		●			
LLNL		●			
NTS			●	●	**Large increase - reevaluate site.**
ORR			● (1.07)		Increases in all worker fatalities <0.5. Criteria air pollutants remain well below standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
Pantex		●		●	**Large decrease - Reevaluate site.**
PGDP		●			
PORTS		●			
RFETS		●			
SNL-NM	●				
SRS		●			
WVDP			●	●	**Large increase - reevaluate site.**

Table I.3-11. Sites Identified for Reanalysis Based on Changes in Radioactivity—LLW Air Emissions as Indicators of Potential Changes in Health Risk

Site	Radioactivity Driver in Regionalized Alternative 2 — Total Alpha Radioactivity[a]	Change (Factor)	Old MEI Risk of Cancer Fatalities	Projected New MEI Risk of Cancer Fatalities	Reanalyze	Comment
ANL-E	U-238 Total alpha	-19 -19	1.4E-11	< 1.4E-11		Projected new risk is < E-06
BNL	NA	NA	NA	NA		NA
FEMP	Tritium Total alpha	6.5 1.4	4.4E-06	2.9E-05 6.2E-06		Draft WM PEIS and more recent projections exceed E-06 as annotated in Chapter 7, Volume I.
Hanford	Pu-238 Total alpha	-9.1 -5.2	7.3E-11	< 7.3E-11 < 7.3E-11		Projected new risk is < E-06
INEL	Co-60 Total alpha	-3.9 1.2	1.7E-10	< 1.7E-10 < 2.0E-10		Projected new risk is < E-06
LANL	U-238 Total alpha	2.0 -958	8.2E-07	1.7E-06 <8.2E-07		Draft WM PEIS and more recent projections exceed E-06 as annotated in Chapter 7, Volume I.
LLNL	Tritium Total alpha	-2E+04 -77	6.3E-06	< 6.3E-06 < 6.3E-06		Projected new risk is < E-06
NTS	NA	NA	NA	NA		NA
ORR	C-14 Total alpha	1.4 3.4	4.6E-10	6.4E-10 1.6E-09		Projected new risk is < E-06
Pantex	Tritium Total alpha	5.2 -4.1E+04	9.1E-12	4.7E-11 < 9.1E-12		Projected new risk is < E-06
PGDP	U-238 Total alpha	-4.5E+11 -4.5E+04	2.1E-10	< 2.1E-10 < 2.1E-10		Projected new risk is < E-06
PORTS	Co-60 Total alpha	-190 2.0	6.6E-09	< 6.6E-09 1.3E-08		Projected new risk is < E-06
RFETS	Pu-238 Total alpha	-8.5 -8.9	2.5E-09	< 2.5E-09 < 2.5E-09		Projected new risk is < E-06
SNL-NM	NA	NA	NA	NA		NA
SRS	Tritium Total alpha	-1.1E+04 3.8	5.7E-09	< 5.7E-09 < 2.2E-08		Projected new risk is < E-06
WVDP	NA	NA	NA	NA		NA

[a] Tritium and other non-alpha emitting radionuclides are not included in this overall sum because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the potential health risk.

Table I.3–12. Sites Identified for Reanalysis Based on Changes in Radioactivity—Exceedances of Drinking Water Standards as an Indicator of Changes in Groundwater Impacts From LLW Disposal

Site	Long-lived Radionuclides Increasing	Factor of Change	Groundwater Concentration as % of Drinking Water Standards (%)		Comment
			Draft WM PEIS	Projected New	
ANL-E	Th-232 U-235	7.9 8.0	0 0	0 0	Will not exceed standards.
BNL	NA	NA	NA	NA	**No previous data — reevaluate.**
FEMP	NA	NA	NA	NA	LLW disposal not evaluated.
Hanford	Th-232 Th-232 U-235 U-235 U-238 U-238	3.8 decentralized 2.2 centralized 3.8 decentralized 2.2 centralized 3.8 decentralized 2.1 centralized	0 0 1 7 600 9,000	0 0 3.8 15.4 2,280 18,900	Will not exceed standards for Th-232 or U-235. For U-238, Draft WM PEIS concentrations exceeded standards in every alternative; new values increase exceedance but do not change basic results: DOE would need to carefully manage U-238 to meet standards. Reevaluation not required.
INEL	Ni-59 Tc-99 Pu-240	2.6 150 150	0 0 0	0 0 0	Will not exceed standards.
LANL	Th-232 U-235 U-238	2.1 2.1 2.1	0 0 0	0 0 0	Will not exceed standards.
LLNL	Pu-240	11	0	0	Will not exceed standards.
NTS	None	NA	0	0	No increases.
ORR	Tc-99 Th-232 U-235 U-238	56 2.1 2.1 18	4 0 0 0	224 0 0 0	**Tc-99 increase causes standard exceedance — reevaluate site.**
Pantex	None	NA	NA	NA	No increases.
PGDP	None	NA	NA	NA	
PORTS	Pu-240	4.8	0	0	Will not exceed standards.
RFETS	None	NA	NA	NA	No increases.
SNL-NM	None	NA	NA	NA	No increases.
SRS	Th-232 U-235 U-238	3.7 3.7 2.1	0 0 700–900	0 0 1,470–1,890	Will not exceed standards. Will not exceed standards. Draft WM PEIS concentrations exceeded standards in every alternative; new values increase exceedance but do not change basic results: DOE would need to carefully manage U-238 to meet standards. Reevaluation not required.
WVDP	NA	NA	NA	NA	**No previous data — reevaluate site.**

I.4 TRUW Inventory Update

Potential health risks to workers and the general public from TRUW, as described in Chapter 8 of the Draft WM PEIS, were estimated on the basis of data on inventory and generation rates published during 1992 and 1993 (DOE, 1992, 1993). This section assesses the effect of using the more recent data (DOE, 1995b,c).

The more recent data were collected from each site that will store or generate TRUW. The data include estimates of the volumes of TRUW that DOE currently proposes to dispose of at WIPP and quantities of TRUW that DOE does not currently plan to dispose of at WIPP. TRUW not destined for WIPP under the proposed action in WIPP SEIS-II (DOE, 1996b) includes small quantities of nondefense TRUW from the ARCO Roy F. Weston Site, LBL, and WVDP, as well as TRUW contaminated with polychlorinated biphenyls and RH-TRUW (in excess of WIPP's disposal limits) at certain sites. Appendix B discusses the TRUW that would be generated from ER activities.

For updated wasteload information, DOE reviewed two databases that are now available containing information on TRUW: the MWIR 95 and the BIR-2. DOE also reviewed a third version of the *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report* [WIPP BIR-3] (DOE 1996a), which was published in June 1996, and the IBD Report–1994 (DOE, 1995b), published September 1995. Although the radionuclide inventories at some sites are changed slightly, the waste volumes and hazardous constituent inventories in WIPP BIR-3 are unchanged from WIPP BIR-2. The WIPP BIR-3 and the IDB Report–1994 databases were not available at the time of the WM PEIS analysis; however, the changes in WIPP BIR-3 and the IDB Report–1994 are minor, and, therefore, WIPP BIR-2 data were considered sufficient for analytical purposes. Most of the new information was taken from MWIR 1995. MWIR 1995 contains information on waste as it currently exists, specifying treatability groups, and is therefore more relevant to the WM PEIS analyses for calculating impacts from consolidating or decentralizing treatment of TRUW throughout the DOE complex. The information on as-generated waste forms is readily available from MWIR 1995 but is not readily extracted from the BIR-2 data. Some of the BIR-2 data reflect some level of treatment at some sites, since they are intended to represent the volume of the wastes in the forms they might be disposed of at WIPP.[1] BIR-2 was used in the Final WM PEIS, however, for its radiological profiles and for more definitive waste volume estimates for the years that are not covered by MWIR.

[1] For impacts at potential treatment sites, the Draft WIPP SEIS-II scaled the analysis presented in the Draft WM PEIS to reflect BIR-2 and other more recent information, as explained in the Draft WIPP SEIS-II.

A comparison of MWIR 95 with more recent site information at Hanford for RH-TRUW (22,000 m^3 in BIR-2 vs 160 m^3 in MWIR 95) showed that it was more appropriate to use BIR-2 data for that site. The largest waste streams at Hanford will not be generated until after the 5-year period covered by MWIR 95 and, thus, do not appear in MWIR 95. The projected TRUW volume for Hanford was taken from BIR-2 and appropriately modified for a 20-year time period to give a value of 51,500 m^3. For all other sites DOE used information from MWIR 95 and the 20-year projection methodology developed for LLMW in the Draft WM PEIS. The total sitewide radiological profile for inventory waste was taken from BIR-2 for all sites, and it was assumed that projected wastes at each site would have the same radiological content (Ci/kg) as the site's inventory wastes.

The wastes at each site are divided into different treatment categories. The wastes in each category at a site are assumed to have an identical radiological content per kilogram. Note that this assumption can produce quite a different result than an assumption based on radiological content per cubic meter due to the large differences in the apparent densities of wastes in each waste category. The MWIR 95 database has the appropriate mass information for each waste stream to determine average radioactivity values (Ci/kg) for each treatment category of waste. These apparent densities are assumed to be independent of the site.

Table I.4–1 presents the latest estimated volumes of TRUW from waste management activities at sites where TRUW is currently located and expected to be generated that DOE plans to dispose of at WIPP. The new Departmentwide TRUW volume (using BIR-2 data for Hanford and MWIR 95 data for all other sites) is approximately 135,000 m^3 (i.e., 116,000 + 19,000 ≈ 135,000 m^3) compared with the previously reported 110,000 m^3 (i.e., 97,000 + 9,100 ≈ 110,000 m^3). The increase in volume mainly resulted from an overall increase in volume estimates for Hanford, LANL, and ORR. Table I.4–2 provides total volumes of TRUW to be treated under various site configurations.

The more recent data in MWIR 95 also includes more detailed information regarding the characteristics of TRUW for each waste stream. With this information, waste streams were grouped into categories to facilitate efficient treatment of the TRUW streams considered in the study. The waste categories include aqueous liquids, organic liquids, solid process residues, soils, debris, special, inherently hazardous, and unknown. For each waste treatment level, TRUW in each waste category would be treated in a specific treatment train that includes a series of treatment technologies, including solidification, shredding, thermal treatment, and packaging (see Figures 8.2–1 through 8.2–3).

The quantities of waste (waste load) to be processed in TRUW management facilities were calculated on the basis of the updated TRUW inventory and generation data. The waste categories of special, inherently hazardous, and unknown streams are not included in waste load calculations. These wastes are assumed to be set aside to await special processing and characterization. Releases of radionuclides were then evaluated, and the volume of treated TRUW requiring storage was estimated. Methods of the calculations were described in a supporting document for this study (ANL, 1996b).

I.4.1 Analysis of TRUW Alternatives

To assess how the more recent TRUW waste load data may affect the WM PEIS, potential changes to impacts under Regionalized Alternative 2 were analyzed at all sites except WIPP. Under Regionalized Alternative 2, treatment to meet land disposal restrictions generates higher impacts than the Decentralized Alternative or Regionalized Alternative 1, which involve less intensive treatment. For WIPP, the Centralized Alternative involves the greatest impacts and was the basis for the review of WIPP.

Volumes change by similar or equal percentages for sites treating under Regionalized Alternative 3, as for Regionalized Alternative 2 (or the Centralized Alternative at WIPP), as noted in Table I.4–2. Therefore, the review of sites under Regionalized Alternative 2, and of WIPP under the Centralized Alternative, is more sensitive to potential changes to impacts that might result from the new waste load data.

Costs and transportation impacts, which are tabulated in the WM PEIS at the national level, rather than at sites, for the purposes of comparison of alternatives, would not experience major changes, since overall volumes only increase by 27%.

I.4.2 Radiological Profiles

The releases of radionuclides were estimated by using the more recent data. For purposes of illustration, Table I.4–3 compares estimated profiles, using more recent data and the data used in the Draft WM PEIS, for contaminants released from treatment facilities at sites considered in the representative Regionalized and Centralized Alternatives.

Table I.4-1. Comparison of TRUW Treatment Volumes (m^3)

Site	Contact-Handled TRUW				Remote-Handled TRUW			
	Draft WM PEIS Data[a]	BIR More Recent Data[b]	MWIR 95 More Recent Data	Factor of Change[c]	Draft WM PEIS Data[a]	BIR More Recent Data[b]	MWIR 95 More Recent Data	Factor of Change
Ames*	NR	0.3	0.01	NA	NR	NR	NR	NA
ANL-E	960	100	140	-6.9	340	NR	NR	NA
BCL*	NR	NR	NR	NA	NR	480	95	NA
Bettis*	NR	90	78	NA	NR	4.8	1.1	NA
ETEC	0.02	1.7	1.7	+85	NR	0.9	0.4	NA
Hanford	19,000	36,000	13,100	+1.9	6,300	15,500	280	+2.5
INEL[d]	38,000	29,300	40,000	+1.1	610	1,100	300	-2.0
KAPL*	NR	NR	NR	NA	NR	NR	1.2	NA
LANL	11,000	16,300	17,000	+1.5	89	160	190	+2.1
LBL	1	NR	1	1	NR	NR	NR	NA
LLNL	1,700	740	670	-2.5	NR	NR	NR	NA
Mound	1,500	270	270	-5.6	NR	NR	NR	NA
NTS	610	630	620	+1.0	NR	NR	NR	NA
ORR	1,000	1,500	1,600	+1.6	1,700	2,800	1,900	+1.1
PGDP	14	1.4	1.5	-9.3	NR	NR	NR	NA
Pantex*	NR	0.6	0.6	NA	NR	NR	NR	NA
RFETS	6,200	3,800	3,000	-2.1	NR	NR	NR	NA
SNL-NM	1	14	6.2	+6.2	NR	NR	2	NA
SRS	17,000	7,700	16,600	1	NR	NR	21	NA
TBE*	NR	0.2	NR	NA	NR	NR	NR	NA
USAMC*	NR	2.5	NR	NA	NR	NR	NR	NA
UofMO	2	1	0.9	-2.2	NR	NR	NR	NA
WVDP	0.5	160	36	+72.0	NR	350	480	NA
Total	97,000	96,300	94,000		9,100	20,300	3,300	

Notes: Volume data are rounded; NR indicates that the volume is either zero or unreported in the database indicated. * = new sites; NA = not applicable; TBE = Teledyne Brown Engineering; USAMC = U.S. Army Materiel Command.
[a] Inventory + 20 years generation (DOE, 1992; 1993).
[b] Inventory + 20 years generation (adjusted from BIR-2 [DOE, 1995c] by scaling the projected waste generation).
[c] Factor of change is the ratio of MWIR 95 data to Draft WM PEIS data. Positive values result when MWIR 95 data are greater than data in the Draft WM PEIS; negative values result when MWIR 95 data are less than data in the Draft WM PEIS. For Hanford, the factor of change is the ratio of BIR data to the Draft WM PEIS data.
[d] Includes TRUW from Argonne National Laboratory-West.

Table I.4-2. Comparison of Total Volumes of TRUW to Be Treated in Various Site Configurations (m^3)

Site	16 Treatment Sites[a] (Decentralized Alternative)			6 Treatment Sites (Regionalized Alternative 2)			4 Treatment Sites (Regionalized Alternative 3)			3 Treatment Sites[c] (Centralized Alternative)		
	Draft WM PEIS Data	More Recent Data	Factor of Change[b]	Draft WM PEIS Data	More Recent Data	Factor of Change[b]	Draft WM PEIS Data	More Recent Data	Factor of Change[b]	Draft WM PEIS Data	More Recent Data	Factor of Change[b]
ANL-E	1,300	140	-9.3									
ETEC	0.02	2.1	+105.0									
Hanford	25,000	51,000	+2.0	27,000	52,000	+1.9	27,000	52,000	+1.8	7,000	16,000	+2.3
INEL	39,000	40,000	+1.0	40,000	41,000	+1.0	57,000	61,000	+1.1			
LANL	11,000	17,000	+1.5	11,000	17,000	+1.5						
LBL[d]	1		NA									
LLNL	1,700	670	-2.5									
Mound	1,500	270	-5.6									
NTS	610	620	+1.0									
ORR	2,700	3,500	+1.3	2,000	1,900	-1.1	2,000	1,900	-1.1	2,000	1,900	-1.1
PGDP	14	1.5	-9.3									
RFETS	6,200	3,000	-2.1	6,200	3,000	-2.1						
SNL-NM	1	8.2	+8.2									
SRS	17,000	16,600	NA	20,000	19,000	-1.1	20,000	19,000	-1.1			
UofMO	2	0.9	-2.2									
WVDP[e]	0.5		NA									
WIPP			NA							97,000	116,000	+1.2

Note: Blanks indicate that no treatment (other than aqueous treatment) occurs at a site. NA = not applicable. Draft WM PEIS Total Volumes are 106,000 m^3 and total volumes for more recent data are 135,000 m^3, including WVDP, for every alternative. Site totals may not add to these values due to rounding.

[a] LBL and WVDP, which have nondefense and commercial TRUW, are not included in this table.

[b] Factor of change is the ratio of MWIR 95 data to Draft WM PEIS data. Positive values result when MWIR 95 data are greater than data in the Draft WM PEIS; negative values result when MWIR 95 data are less than data in the Draft WM PEIS.

[c] One treatment site for contact-handled TRUW and two treatment sites for remote-handled TRUW.

[d] LBL is a nondefense TRUW site; its TRUW was not included in the more recent data.

[e] WVDP is primarily a nondefense TRUW site; its TRUW was not included in this table.

Table I.4-3. Comparison of Radiological Air Emissions for TRUW: Regionalized Alternative 2

Site	Radionuclide Contributing Greatest Risk / Total Alpha Radioactivity[a]	Draft WM PEIS Data[b] (Ci/yr)	More Recent Data[c] (Ci/yr)	Factor of Change[d]
Hanford				
CH	Pu-238	1.24E-03	9.69E-02	78
	Pu-239	1.58E-03	3.32E-02	21
	Total alpha CH	1.4E-02	2.1E-01	15
RH	Pu-241	1.5E-01	9.2E-05	-1,630
	Total alpha RH	7.4E-01	4.8E-03	-154
INEL				
CH	Am-241	2.84E-02	1.55E-01	5.5
	Total alpha	1.6E-01	5.0E-01	3.1
LANL				
CH	Am-241	1.25E-01	3.31E-02	-3.8
	Total alpha	8.7E-01	5.7E-01	-1.5
ORR				
RH	Cm-244	7.2E-03	1.8E-03	-4
	Total alpha	1.2E-02	3.1E-03	-3.9
RFETS				
CH	Am-241	5.6E-03	2.1E-02	3.7
	Total alpha	4.5E-02	1.5E-01	3.3
SRS				
CH	Pu-238	2.4E+00	1.6E-03	-1,500
	Total alpha	2.8E+00	2.8E-02	-100
WIPP				
CH	Pu-238	2.5E+00	5.3E-01	-4.7
	Total alpha	4.1E+00	1.6E+00	-2.6

[a] Radioactivity is for alpha-emitting radionuclides only. Tritium and other non-alpha emitting radionuclides are not included in this sum because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the health risk.
[b] For TRUW, Draft WM PEIS values are calculated on the basis of data from 1992 IDB (DOE, 1992) and 1993 MWIR (DOE, 1993).
[c] For TRUW, more recent values are calculated on the basis of data from MWIR 95 (DOE, 1995b) except for Hanford, which uses data from the BIR-2.
[d] Factor of change is the ratio of more recent data (MWIR 95) to data in the Draft WM PEIS. Positive values result when the more recent data are greater than data in the Draft WM PEIS; negative values result when the more recent data are less than data in the Draft WM PEIS.

I.4.3 Conclusions About TRUW Sites With Waste Load Increases

Three sites—Hanford, SRS, and WIPP—required reevaluation based on volume or radionuclide changes. These are discussed below.

Six additional sites with volume or radiological increases were reviewed and did not require further reevaluation—INEL, LANL, ORR, RFETS, SNL-NM, and WVDP. However, the pertinent TRUW risk sections of Chapter 8, Volume I, were revised to note the continuing requirement to carefully manage TRUW at INEL and RFETS for air emissions if treatment to meet Land Disposal Restrictions is employed. The other major TRUW sites did not experience volume increases that caused significant new impacts or risks or radiological changes that would cause risks of cancer fatality to the offsite MEI to exceed one in one million.

Sites other than the major sites were not reviewed; however, the radionuclides at these sites were included in the radiological profiles at major sites reviewed in Regionalized Alternative 2, and at WIPP in the Centralized Alternative. Corrections to the total volume of TRUW ($\approx$110,000 m^3) analyzed in the Draft WM PEIS for the three sites undergoing reanalysis for TRUW yield a total volume of about 132,000 m^3, very near the new Departmentwide estimate for TRUW of 135,000 m^3.

The discussion of the sites which follows amplifies upon Tables I.4–4 and I.4–5, which are found at the end of Section I.4.3.2. The tables provide site comparisons showing the change for key parameters between the data used for the Draft WM PEIS and more recent data, including:

1. Change in volumes (Table I.4–4). These changes are based on the waste volume tables presented in this section.
2. Change in both the radionuclide in the air emissions which contributed the highest risk to the offsite MEI for the analyses in the Draft WM PEIS and for the total air emission radioactivity from alpha-emitting radionuclides (Table I.4–5). The table also shows a projected new offsite MEI risk by multiplying the offsite MEI risk from the Draft WM PEIS by the factor of change for both the radionuclide that has the greatest contribution to risk and the total overall alpha radioactivity.

I.4.3.1 Sites Requiring Reevaluation

Hanford

Volumes: Contact-handled and remote-handled TRUW at Hanford, both of which would be treated at Hanford in the Regionalized Alternatives, increased by a factor of 1.9 and 2.5, respectively, for an average increase of 2.04. This results in an increase in workers and resources of 1.65, considering economy of scale.

The existing estimate in the Draft WM PEIS data of worker risk for Hanford is 0.51 worker fatalities from physical hazards and 0.13 worker fatalities from radiological exposures. The increases in fatalities based on the new data would thus be 0.33 for physical hazards and 0.08 for radiological exposure. These increases are not considered so large as to require a reevaluation based upon volumes.

The most limiting criteria air pollutants are NO_2 and particulates emitted during operation of the facilities. These were previously estimated to reach 2% of the standards, so the increase would reach 4% of standards.

For infrastructure, required acreage would increase from approximately 25 to 41 acres; water, wastewater, and power, which were estimated to be 7.8% or less of capacity, would increase to as much as 13%; and job increases would be less than 0.25% of employment in the region. These increases are all small.

Radionuclides: The radionuclide that makes the greatest contribution to cancer risk to the offsite MEI from air emissions increased by a factor of 78, leading to a predicted increase in risk in excess of one in one million (i.e., 3E–06) from a previous risk considerably less than one in one million. Therefore the impacts related to the radiological content of the waste should be reevaluated.

Conclusion: Reevaluate risks based on large radionuclide increases. Volume data, which are also used for new risk calculations, were revised in Volume I to reflect more recent data for Hanford.

SRS

Volumes: There were no changes in predicted 20-year volumes; therefore, a reevaluation based upon volumes is not required.

Radionuclides: A very large decrease in the offsite radionuclide contributing the highest risk to the offsite MEI (factor of -1,500), at a site that had high risks to the offsite MEI and the offsite population, justifies a reevaluation.

Conclusion: Reevaluate risks based on large radionuclide decreases.

WIPP

Volumes: Contact-handled TRUW, which is treated at WIPP in the Centralized Alternative, increased by a factor of 1.20, which results in an increase in workers and resources of 1.14, considering economy of scale. The Centralized Alternative was used to estimate effects from waste increases.

The existing estimate in the Draft WM PEIS data of worker risk for WIPP is 0.44 worker fatalities from physical hazards and 0.16 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.09 (physical hazards) and 0.03 (radiological exposures). These increases are small.

The most limiting criteria air pollutant is particulates emitted during facility operations. This is estimated to reach 25% of the standard, so the more recent data would increase particulate emissions to just 30% of the standard.

For infrastructure, required acreage for treatment facilities would increase from approximately 8 to 10 acres; and infrastructure capacity for water, wastewater, and power, which were estimated to potentially require as much as 82% of current capacity (for wastewater treatment capacity), could increase to 98%. Job increases would be less than 0.06% of employment in the region. These changes for infrastructure are to be expected for a site that would require new facilities if a new mission such as TRUW treatment is implemented. However, the changes from volume increases in the more recent data are not large in comparison to those already disclosed in the WM PEIS. Consequently, they do not warrant a more detailed reevaluation in the programmatic document.

Radionuclides: A very large decrease in the radionuclide contributing the highest risk to the offsite MEI at SRS (factor of -1,500) carries over to WIPP as a factor of 4.7 decrease in the Centralized Alternative despite increases that occurred at Hanford. WIPP had high risks to the offsite MEI and to the offsite population using the Draft WM PEIS data; this change justifies a reevaluation.

Conclusion: Reevaluate risks based on large radionuclide decreases. The new volume data, which are used for risk calculations, were revised to reflect more recent data for WIPP.

I.4.3.2 Sites Not Requiring Reevaluation

INEL

Volumes: Contact-handled TRUW treated at INEL in the Regionalized Alternatives increased by a factor of 1.05, which results in an increase in workers and resources of 1.034, considering economy of scale. Regionalized Alternative 2 was used to estimate effects from waste increases.

The existing estimate in the Draft WM PEIS data of worker risk for INEL is 1.6 worker fatalities from physical hazards and 0.3 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.05 (physical hazards) and 0.01 (radiological exposures). These increases are small.

The most limiting criteria air pollutant is particulates emitted during facility operations. This is estimated to reach 10% of the standard, so the more recent data would increase particulate emissions to just 11% of the standard.

For infrastructure, required acreage would increase from 28 to 29 acres; water, wastewater, and power, which were estimated to be 6.6% or less of capacity, would increase to 6.8% or less; and job increases would be less than 0.03% of employment in the region. These increases are all small.

Radionuclides: The radionuclide contributing the greatest risk to the offsite MEI increased by a factor of 5.5, leading to predicted risk of cancer fatalities for the more recent data in excess of one in one million (5.0E–06). The previously predicted risk to the offsite MEI using data in the Draft WM PEIS was slightly below one in one million (9.1E–07). This increase was not sufficient to require a quantitative reevaluation, because the risks were already predicted to be essentially at one in one million; however, this increase has been noted in the pertinent sections in Chapter 8, Volume I, to highlight the need for management of air emissions if intensive treatment of TRUW is employed.

Conclusion: No further evaluation is required for volume or radionuclide changes.

LANL

Volumes: Contact-handled TRUW treated at LANL in the Regionalized Alternative 2 increased by a factor of 1.55, which results in an increase in workers and resources of 1.36, considering economy of scale. The Regionalized Alternative 2 was used to estimate effects from waste increases.

The existing estimate in the Draft WM PEIS data of worker risk for LANL is 0.84 worker fatalities from physical hazards and 0.14 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.30 (physical hazards) and 0.05 (radiological exposures). These increases are not considered so large as to require a reevaluation based upon volumes.

The most limiting criteria air pollutant is particulates emitted during facility operations. This is estimated to reach 5% of the standard, so the more recent data would increase particulate emissions to 7%, which is well below the standard. One additional air quality concern would be radionuclides, which were at 134% of the standard using the Draft WM PEIS data. Radionuclide concentrations would vary based upon radiological characteristics rather than volume, however. As noted in the table for TRUW air emissions, total curies for radionuclides in air emissions decreased; therefore air quality for radionuclides would improve. The conclusion is that a reevaluation based upon volumes as they affect air impacts is not required.

For infrastructure, required acreage would increase from 15 to 20 acres; water, wastewater, and power, which were estimated to be 1.2% or less of capacity, would increase to 1.6% or less; and job increases would be less than 0.18% of employment in the region. These increases are all small.

Radionuclides: Curies for radionuclides making the highest contribution to risk and air quality decreased; therefore a reevaluation based on radionuclides is not required.

Conclusion: No further evaluation is required for volume or radionuclide changes.

ORR

Volumes: Remote-handled TRUW treated at ORR in the Regionalized Alternatives increased by a factor of 1.12, which results in an increase in workers and resources of 1.08, considering economy of scale. The Regionalized Alternative 2 was used to estimate effects from remote-handled TRUW increases. Increases of contact-handled TRUW, which is shipped to other sites for treatment, would not cause large impacts at ORR and were not further evaluated.

The existing estimate in the Draft WM PEIS data of worker risk for ORR is 0.21 worker fatalities from physical hazards and 0.09 worker fatalities from radiological exposures. The increases in fatalities would thus be 0.02 (physical hazards) and 0.004 (radiological exposures). These increases are small.

The most limiting criteria air pollutant is NO_2 emitted during facility operations. This is estimated to reach 1% of the standard, so the more recent data would increase NO_2 emissions to just 1.1% of the standard.

For infrastructure, required acreage would increase from 6 to 7 acres; water, wastewater, and power, which were estimated to be 0.09% or less of capacity, would increase to 0.1% or less; and job increases would be less than 0.01% of employment in the region. These increases are small.

Radionuclides: For more recent waste data, projected offsite MEI risk from air emissions is less than one in one million (< 1.0E–06).

Conclusion: No further evaluation is required for volume or radionuclide changes.

RFETS

Volumes: Volumes decrease at RFETS; therefore no additional evaluation is required.

Radionuclides: The radionuclide contributing the greatest risk to the offsite MEI increased by a factor of 3.7, leading to predicted offsite risk using the more recent data in excess of one in one million (5.6E–06). The previously predicted risk to the offsite MEI using data in the Draft WM PEIS was already above one in one million (1.5E–06). This increase was not sufficient to require a quantitative reevaluation, since the risks were already predicted to be above one in one million; however, this has been noted in the pertinent sections in Chapter 8, Volume I, to highlight the need for management of air emissions if treatment to meet Land Disposal Restrictions of TRUW is employed.

Conclusion: No further evaluation is required for volume or radionuclide changes.

SNL-NM and WVDP

Volumes: Previously estimated small volumes of contact-handled TRUW (1 m^3 at SNL-NM and 0.5 m^3 at WVDP) are now estimated at 6.2 m^3 and 36 m^3, respectively. In addition, 480 m^3 of remote-handled TRUW are now reported at WVDP; none appeared in the Draft WM PEIS data. However, the West Valley Demonstration Project Act (42 U.S.C. 2021a) defines TRUW as "material contaminated with [transuranic] elements . . . in concentrations of 10 nanocuries per gram or in such other concentrations as the [Nuclear Regulatory] Commission may prescribe." One of the agreements in the Stipulation of Compromise Settlement between DOE and the Coalition on West Valley Nuclear Wastes and the Radioactive Waste Campaign (U.S. District Court, Western District of New York, May 27, 1987) is that DOE will seek a determination from the NRC as to whether WVDP waste containing material with an atomic number greater than 92 in concentrations greater than 10 nanocuries per gram is TRUW based on the definition in the WVDP Act. The West Valley Completion EIS (DOE, in preparation) indicates that, in the event that an alternative which includes on-premises disposal of this waste is ultimately selected, DOE will request a determination from NRC that a major portion of the material currently managed as TRUW can be classified as LLW. Since these sites are only considered for storage until another site is available, after which TRUW would be packaged and shipped, impacts are small for managing these new wastes and will not affect the comparison of alternatives. For example, the total worker risk at PGDP, which stores and packages for shipment volumes of contact-handled TRUW comparable to those now predicted at SNL-NM and WVDP, is 0.01 fatalities. Management of remote-handled TRUW at ANL-E, which involves volumes similar to those now predicted for WVDP, entails total worker risk estimates of 0.1 fatalities. DOE determined that these new waste estimates at SNL-NM and WVDP did not affect the programmatic comparison of alternatives and would not present major new impacts. Consequently, these sites were not selected for reevaluation.

Radionuclides: Radionuclides do not cause large risks at sites where only packaging and shipping are conducted.

Conclusion: No further evaluation is required for volume or radionuclide changes.

Table I.4-4. Sites Identified for Reanalysis Based on Changes in TRUW Volumes

Site	No Change	Decrease	Increase (Factor)	Reanalyze	Comment
ANL-E		●			
Hanford			● (CH 1.9; RH 2.5)		Increases in all worker fatalities < 0.5. Criteria air pollutants well within standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
INEL		● (RH)	● (CH1.05)		Increases in all worker fatalities < 0.5. Criteria air pollutants well within standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
LANL			● (CH 1.55; RH 2.1)		Increases in all worker fatalities < 0.5. Criteria air pollutants well within standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
LLNL		●			
NTS	●				
ORR			● (CH 1.6; RH 1.12)		ORR ships CH TRUW to other sites for treatment - change does not affect alternatives and has minor effect on impacts for RH TRUW. Increases in all worker fatalities < 0.5. Criteria air pollutants well within standards. Negligible increases in infrastructure impacts. Reanalysis not warranted.
PGDP		●			
RFETS		●			
SNL-NM			● (6.2)		TRUW is packaged and shipped in all alternatives; changes do not affect decisions.
SRS	●				
WVDP			● (CH 72; RH >480)		TRUW is packaged and shipped in all alternatives; changes do not affect decisions.
WIPP			● (1.13)		

Table I.4-5. Sites Identified for Reanalysis Based on Changes in Radioactivity—TRUW Air Emissions as Indicators of Potential Changes in Health Risk

Site	Radioactivity Driver in Regionalized Alternative 2 Total Alpha Radioactivity[a]	Change (Factor)	Prior MEI Risk	Projected New MEI Risk	Reanalyze	Comment
Hanford CH RH	Pu-238 Pu-239 Total alpha CH Pu-241 Total alpha RH	78 21 15 -1,630 154	9.4E-08 CH 1.3E-07 RH	7.0E-06 2.0E-06 1.4E-06 < 1.3E-07 < 1.3E-07	●	**Large change - reevaluate site**
INEL CH	Am-241 CH Total alpha	5.5 3.1	9.1E-07	5.0E-06 2.8E-06		Draft WM PEIS and new projections exceed E-06, as annotated in Chapter 8.
LANL CH	Am-241 Total alpha	-3.8 -1.5	6.7E-05	2.5E-06 1.0E-05		Risk is lower than in prior estimate; retain prior analysis
ORR RH	Cm-244 Total alpha	-4 -7	1.4E-06	5.6E-07 9.8E-07		Projected new risk is < 1.0E-06
RFETS CH	AM-241 Total alpha	3.7 3.3	1.5E-06	5.6E-06 5.0E-06		Draft WM PEIS and new projections exceed E-06, as annotated in Chapter 8.
SRS CH	Pu-238 Total alpha	-1,500 -100	2.4E-05	3.8E-08 2.4E-07	●	**Large decrease; site previously had largest risk - reevaluate risks**
WIPP CH	Pu-238 Total alpha	-4.7 -2.6	6.7E-05	3.2E-06 1.7E-05	●	**SRS decrease transfers to WIPP, which had elevated risk - reevaluate risks**

Notes: CH = contact-handled waste; RH = remote-handled waste.
[a] Radioactivity is for alpha-emitting radionuclides only. Tritium and other non-alpha emitting radionuclides are not included in this sum because of the small size of their dose conversion factor. Tritium and other nuclides are included separately in this table at sites where they contribute significantly to the potential health risk.

I.5 References

ANL. *See* Argonne National Laboratory.

Argonne National Laboratory. 1996a. *WASTE_MGMT: A Computer Model for Calculation of Waste Loads, Profiles, and Emissions* by T.J. Kotek, H.I. Avci, and B.L. Koenick. ANL/EAD/TM-30. Argonne, IL.

Argonne National Laboratory. 1996b. *Transuranic Waste Inventory, Characteristics, Generation, and Facility Assessment for Treatment, Storage, and Disposal Alternatives Considered in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement* by K. Hong, T.J. Kotek, S.M. Folga, B.L. Koebnick, Y.Y. Wang, and C.M. Kaicher. ANL/EAD/TM-22. Argonne, IL.

DOE. *See* U.S. Department of Energy.

EPA. *See* U.S. Environmental Protection Agency.

ORNL. *See* Oak Ridge National Laboratory.

Oak Ridge National Laboratory. 1992. *Waste Management Information System.* Computer database maintained by the Hazardous Waste Remedial Actions Program (HAZWRAP). Dec. Oak Ridge, TN: Martin Marietta Energy System.

U.S. Department of Energy. 1992. *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*. DOE/RW-006, Rev. 8. Prepared by Oak Ridge National Laboratory, Oak Ridge, TN.

U.S. Department of Energy. 1993. *Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities, and Technologies*. Vol. 1-6. DOE/NBM-1100. Washington, DC.

U.S. Department of Energy. 1994. *Mixed Waste Inventory Report: Final Phase II Mixed Waste Inventory Report Data*. EM-352. May. Washington, DC.

U.S. Department of Energy. 1995a. *Mixed Waste Inventory Summary Report*. DOE/M96-GT-029. Washington, DC.

U.S. Department of Energy. 1995b. *Integrated Data Base Report–1994: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*. DOE/RW-0006, Rev. 11. Sept. Prepared by Oak Ridge National Laboratory, Oak Ridge, TN.

U.S. Department of Energy. 1995c. *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*. CAO-94-1005, Rev. 2. Carlsbad, NM.

U.S. Department of Energy. 1996a. *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*. CAO-95-1121. Rev. 3. Carlsbad, NM.

U.S. Department of Energy. 1996b. *Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement*. DOE/EIS-0026-S-2. Carlsbad, NM.

U.S. Environmental Protection Agency. 1991. Office of Emergency and Remedial Response. *Risk Assessment Guidance for Superfund (Vol. 1), Human Health Evaluation Manual (Part B), Interim Final*. Publication 9285.7-01B.