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Volume 1

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

Volume 1: Sections 1–9

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NOTATION

The following is a list of the acronyms and abbreviations (including units of measure and elements and compounds) used in this document. Some acronyms and abbreviations used only in tables are defined in those tables.

ACRONYMS AND ABBREVIATIONS

AEC	Atomic Energy Commission
AED	aerodynamic equivalent diameter
ALOHA™	Areal Locations of Hazardous Atmospheres
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
APLL	large aircraft crash
APLS	small aircraft crash
aq	aqueous
ARF	airborne release fraction
ASB-II	Air Support Building II
BCL	Battelle Columbus Laboratories
BDBE	beyond design basis earthquake
BNL	Brookhaven National Laboratory
C&S	Certified and Segregated Facility
CBD	integrity of secondary containment
CFA	Central Facilities Area
CFR	Code of Federal Regulations
CH	contact-handled
CIF	Consolidated Incineration Facility
CPC	chemical process cell
CPP	Chemical Processing Plant
CSB	Canister Storage Building
CSF	Consolidated Storage Facility
CST	chemical source term
DAW	dry active waste
D&D	decontamination and decommissioning
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
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ER	environmental restoration
FEMP	Fernald Environmental Management Project
FY	fiscal year
GAC	granular activated carbon
GAO	U.S. General Accounting Office

GDC	general design criteria
GPC	general purpose concentrator
GTCC	Greater-than-Class-C waste
GWSB	Glass Waste Storage Building
Hanford	Hanford Site
HEPA	high-efficiency particulate air (filter)
HFEF	Hot Fuel Examination Facility
HLW	high-level waste
HLLW	high-level liquid waste
HW	hazardous waste
HWHF	High-Level Waste Handling Facility
HWSF	hazardous waste storage facility
HWVP	Hanford Waste Vitrification Plant
IFSF	Interim Fuel Storage Facility
ILW	intermediate-level waste
INEL	Idaho National Engineering Laboratory
IT	International Technology Corporation
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
Middlesex	Middlesex Sampling Plant
MWIR	Mixed Waste Inventory Report
MWTP	Mixed Waste Treatment Project
NEPA	National Environmental Policy Act
NPH	natural phenomena hazards
NPIAS	National Plan for Integrated Airport Systems
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PAEC	Potential Any Adverse Effect Concentration
PBB	integrity of primary containment
PC	performance category
PEIS	Programmatic Environmental Impact Statement
PGDP	Paducah Gaseous Diffusion Plant
PLC	Potentially Life-Threatening Concentration
PORTS	Portsmouth Gaseous Diffusion Plant
PPPL	Princeton Plasma Physics Laboratory
PREPP	Process Experimental Pilot Plant
PSAR	Preliminary Safety Analysis Report
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
SpG	specific gravity
SNF	spent nuclear fuel
SQUG	Seismic Qualification Users Group
SRS	Savannah River Site
SSC	system, structure, and component
SST	single-shell tank
STRF	source term release fraction
SWEPP	Solid Waste Experimental Pilot Plant
TC	treatability category
TRUPACT	Transuranic Package Transporter
TRUW	transuranic waste
TSA	Transuranic Storage Area
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
TSS	tension support structures
VOG	vessel off-gas
WAC	waste acceptance criteria
WCSF	Waste Canister Storage Facility
WERF	Waste Experimental Reduction Facility
WHC	Westinghouse Hanford Company
WIPP	Waste Isolation Pilot Plant
WM	waste management
WRAP	Waste Receiving and Processing Facility
WSRC	Westinghouse Savannah River Company
WVDP	West Valley Demonstration Project
WVNS	West Valley Nuclear Services Co., Inc.

ELEMENTS AND COMPOUNDS

Ag	silver
$AlCl_3$	aluminum
As	arsenic
Ba	barium
$BaCl_2$	barium chloride
BTX	benzene, toluene, and xylene
C-14	carbon-14
$C_2H_4O_2$	acetic acid (glacial methyl formate)
$C_2H_5\text{-}O\text{-}C_2H_5$	diethyl ether
C_3H_6O	acetone
C_6H_6	benzene
$C_6H_{10}O_5$	cellulose monomer unit
C_8H_{18}	octane
$C_{20}H_{12}$	benzo[a]pyrene
$Ca(ClO)_2$	calcium hypochlorite
$CaCl_2O_2$	calcium hypochloride

CaO	calcium oxide
CaO	quicklime
$Ca(OH)_2$	calcium hydroxide
Cd	cadmium
$CdCl_2$	cadmium chloride
$Cd(NO_3)$	cadmium nitrate
CdO	cadmium oxide
CH_3COCl	acetyl chloride
CH_3COOH	glacial acetic acid
CH_3I	methyl iodide
$Cl_2C\text{-}CH_2$	isomeric dichlorethylene
$Cl_2HC\text{-}CH_2Cl$	1,1,2-trichloroethame
$Cl_3C\text{-}CH_3$	1,1,1-trichloroethane
CO	carbon monoxide
CO_2	carbon dioxide
CO_x	carbon oxides
Cr	chromium
$CrCl_3$	chromium chloride
CrO_3	chromium oxide
Cs	cesium
CsI	cesium oxide
CS_2	carbon disulfide
Freon	dichlorodifluoromethane
H_2	hydrogen
H-3	tritium
HBr	hydrobromic acid
H-CC-Cl	chloroacetylene
HCl	hydrogen chloride
HCl(*aq*)	hydrochloric acid
HCN	hydrogen cyanide
HF	hydrogen fluoride
Hg	mercury
HI	hydroiodic acid
H_2O	water
$H\text{-}3_2O$	tritiated water
H_2SO_4	sulfuric acid
HNO_3	nitric acid
I_2	elemental iodine
KCN	potassium cyanide
$K_2Cr_2O_7$	potassium dichromate
$KMnO_4$	potassium permanganate
K_2O	potassium oxide
KOH	potassium hydroxide
Kr	krypton
Li	lithium
MEK	methyl ethyl ketone
MH	metal hydride
$MOnO_2$	manganese (IV) oxide
N_2O	nitrous oxide
Na	sodium

NaCN	sodium cyanide
$Na_2Cr_2O_7$	sodium dichromate
Na_2SO_4	sodium sulfate
$Na_2S_2O_8$	sodium persulfate (sodium peroxydisulfate)
NH_3	ammonia
NH_4NO_3	ammonium nitrate
NH_4OH	ammonium hydroxide
NO_x	nitrogen oxides
NO_2	nitrogen dioxide
O_2	oxygen
PAH	polycyclic aromatic hydrocarbon
Pb	lead
$PbCl_2$	lead chloride
Pu	plutonium
PuF_4	plutonium fluoride
Rb	rubidium
Ru	ruthenium
RuO_4	ruthenium tetroxide
S-35	sulfur-35
Se	selenium
SO_2	sulfur dioxide
Te	tellurium
TiO_2	titanium dioxide
TNT	trinitrotoluene
U	uranium
UO_2	uranium dioxide

UNITS OF MEASURE

atm	atmosphere(s)
°C	degree(s) Celsius
Ci	curie(s)
cm	centimeter(s)
cm^2	square centimeter(s)
cm^3	cubic centimeter(s)
cp	centipoise(s)
d	day(s)
dp	differential pressure
°F	degree(s) Fahrenheit
ft	foot (feet)
ft^2	square foot (feet)
ft^3	cubic foot (feet)
g	gram(s)
g	gravity (acceleration due to)
gal	gallon(s)
h	hour(s)
in.	inch(es)
J	joule(s)
kg	kilogram(s)

kJ	kilojoule(s)
km	kilometer(s)
kPa	kilopascal(s)
L	liter(s)
lb	pound(s)
lb_m	pound(s) mass
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mg	milligram(s)
min	minute(s)
mm	millimeter(s)
mol	mole(s)
MPa	megapascal(s)
MPa_g	megapascal(s), gauge
mph	mile(s) per hour
ms	millisecond(s)
oz	ounce(s)
µm	micrometer(s)
nCi	nanocurie(s)
P	poise(s)
PE-Ci	Pu-239 equivalent curies
ppm	part(s) per million
psi	pound(s) per square inch
ρgh	density, acceleration, height of fall
psig	pound(s) per square inch gauge
rem	roentgen equivalent man
s	second(s)
s^2	second(s) squared
t	metric ton(s)
ton	short ton(s)
W	watt(s)
yd^3	cubic yard(s)
yr	year(s)

ANALYSIS OF ACCIDENT SEQUENCES AND SOURCE TERMS AT TREATMENT AND STORAGE FACILITIES FOR WASTE GENERATED BY DOE WASTE MANAGEMENT OPERATIONS

by

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ABSTRACT

This report documents the methodology, computational framework, and results of facility accident analyses performed for the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS). The accident sequences potentially important to human health risk are specified, their frequencies are assessed, and the resultant radiological and chemical source terms are evaluated. A personal-computer-based computational framework and database have been developed that provide these results as input to the WM PEIS for calculation of human health risk impacts.

The methodology is in compliance with the most recent guidance from DOE. 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. Although it allows reasonable estimates of the risk impacts associated with each alternative, the main goal of the accident analysis methodology is to allow reliable estimates of the relative risks among the alternatives. Rather than developing all accident sequences in detail the accident models are 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. This allows many of the uncertainties in the data that are reflected in estimates of absolute risk to be canceled in estimates of relative risk providing a sufficient and scrutable basis for discriminating among alternatives.

The WM PEIS addresses management of five waste streams in the DOE complex: low-level waste (LLW), hazardous waste (HW), high-level waste (HLW), low-level mixed waste (LLMW), and transuranic waste (TRUW). Currently projected waste generation rates, storage inventories, and treatment process throughputs have been calculated for each of the waste streams. This report summarizes the accident analyses and aggregates the key results for each of the waste streams. Source terms are

estimated and results are presented for each of the major DOE sites and facilities by WM PEIS alternative for each waste stream. Key assumptions in the development of the source terms are identified. The appendices identify the potential atmospheric release of each toxic chemical or radionuclide for each accident scenario studied. They also provide discussion of specific accident analysis data and guidance used or consulted in this report.

1 INTRODUCTION AND OVERVIEW

1.1 SUMMARY

This report documents the methodology, computational framework, and results of facility accident analysis performed for the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS) (DOE 1995a). The objective of the WM PEIS is to examine the potential impacts, including human health and environmental consequences, of an integrated program for managing wastes under the aegis of the Office of the Assistant Secretary for Environmental Management. Facility accident analysis specifically addresses potential radiological and hazardous releases to the environment during plausible facility accidents.

The output of the facility accident analyses is a specification for each waste type of the accident sequences potentially important to human health risk, 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 (Ci) of each radionuclide released during an accident, where release is conservatively assumed to be instantaneous. A chemical source term is defined by specifying the release rate and duration 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 calculation of the human health and risk impacts of the identified waste management alternatives.

The accident sequences analyzed were selected for their potential importance to human health. In light of the lack of specific process and facility design information (including intrasite locations and associated characteristics of these locations), the analyses focused on accidents with potential 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.

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 accident initiators affected by site characteristics such as seismic or tornadic vulnerability or proximity to airports. However, 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 EISs or safety documents where specific facilities are assessed.

1.2 SCOPE AND OBJECTIVES

The requirements on the scope of the accident analysis are driven by the scope of the WM PEIS and by DOE guidance discussed subsequently. The WM PEIS addresses strategic alternatives for management of five different types of waste in the DOE complex: low-level waste (LLW), hazardous waste (HW), high-level waste (HLW), low-level mixed waste (LLMW), and transuranic waste (TRUW). For each waste type, four categorical strategies have been devised for the consolidation of wastes 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 DOE sites throughout the country. Moreover, a number of technologies for waste treatment and options for storage are to be 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 encompassed by the actions evaluated in the WM PEIS. This guidance also calls for a graded approach emphasizing the risk-dominant scenarios. 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 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 strategy that would enable focus on the risk-dominant sites and facilities for the storage and treatment operations and on the alternatives for waste consolidation under consideration in the WM PEIS for each waste type.

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 methodology 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. The WM PEIS includes options for consolidating waste from both new and existing sites and facilities. 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 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 and evaluate the relative risk of the many combinations of process technology, facility selection, and site consolidation strategies in the WM PEIS alternatives for each waste type. The purpose is not only to provide baseline accident frequency and source term estimates, as required for the WM PEIS, 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. To allow accident risk to be characterized as a function of the throughput of a given waste type at each facility, thereby facilitating comparative evaluations, the requirements included integrating the computational packages of the accident analysis with the databases storing the data on the waste inventory and interfacing with the computer codes for health effects.

1.3 ANALYTIC APPROACH

To meet these objectives, an integrated approach was developed that includes the following interrelated elements:

- Selection of operations and related facility configurations across the DOE complex that have large and potentially hazardous inventories of radioactive or chemically toxic wastes vis-à-vis the attendant vulnerabilities and demographics of the facilities,

- Development and probabilistic evaluation of a uniform set of the risk-dominant sequences of accidents,

- Determination of the evolution and final compositions of radiologically or chemically hazardous material source terms predicted to be released from these sequences.

A personal-computer-based computational framework and database have been developed to automate these elements and provide source term input for the health effects analyses. This report discusses the aspects of accident analysis through source term generation.

The source terms were subsequently used for assessment of the radiological or toxicological health effects and risks of accidents to the general public and to the workforces. This assessment is discussed elsewhere in the WM PEIS. In addition to source term development, the main elements in assessing risk include (1) development or integration of existing site-specific demographics and meteorological data and calculation of attendant unit-risk factors and (2) assessment of the radiological or toxicological consequences of accident releases to the general public and to the workforces by combining the source term and unit-risk information.

Figure 1.1 illustrates the integration of these elements into a systematic approach for performing risk impact analysis for the WM PEIS. The waste management alternatives discussed in the WM PEIS include siting options for storing and treating each waste type prior to disposal. Storage inventories and treatment throughput for each site affected by a given alternative are then defined by the current inventories, existing and projected waste generation rates, and the disposition of the waste. The volume and radionuclide composition of each waste are tracked in a relational database as the waste is processed to final disposal. Details of the methodology and computational framework developed to implement or link these elements for the accident analysis are described in Section 2. The source terms for all accidents analyzed are provided in the appendices.

Implementation of the phased approach is being accomplished through the collaborative efforts of interdisciplinary teams from Argonne National Laboratory-East (ANL-E) and Oak Ridge National Laboratory (ORNL). Risk-dominant accident sequences and associated source term information were selected and developed by ANL-E as the first part of the analysis. The unit-risk factors outlined above were developed by ORNL as the second part of the analysis and transmitted to ANL-E for use in the screening phases to establish the reference accident sequences. The potential source terms for the dominant risk accident sequences were then calculated by ANL-E and transmitted to ORNL for the health effects calculations.

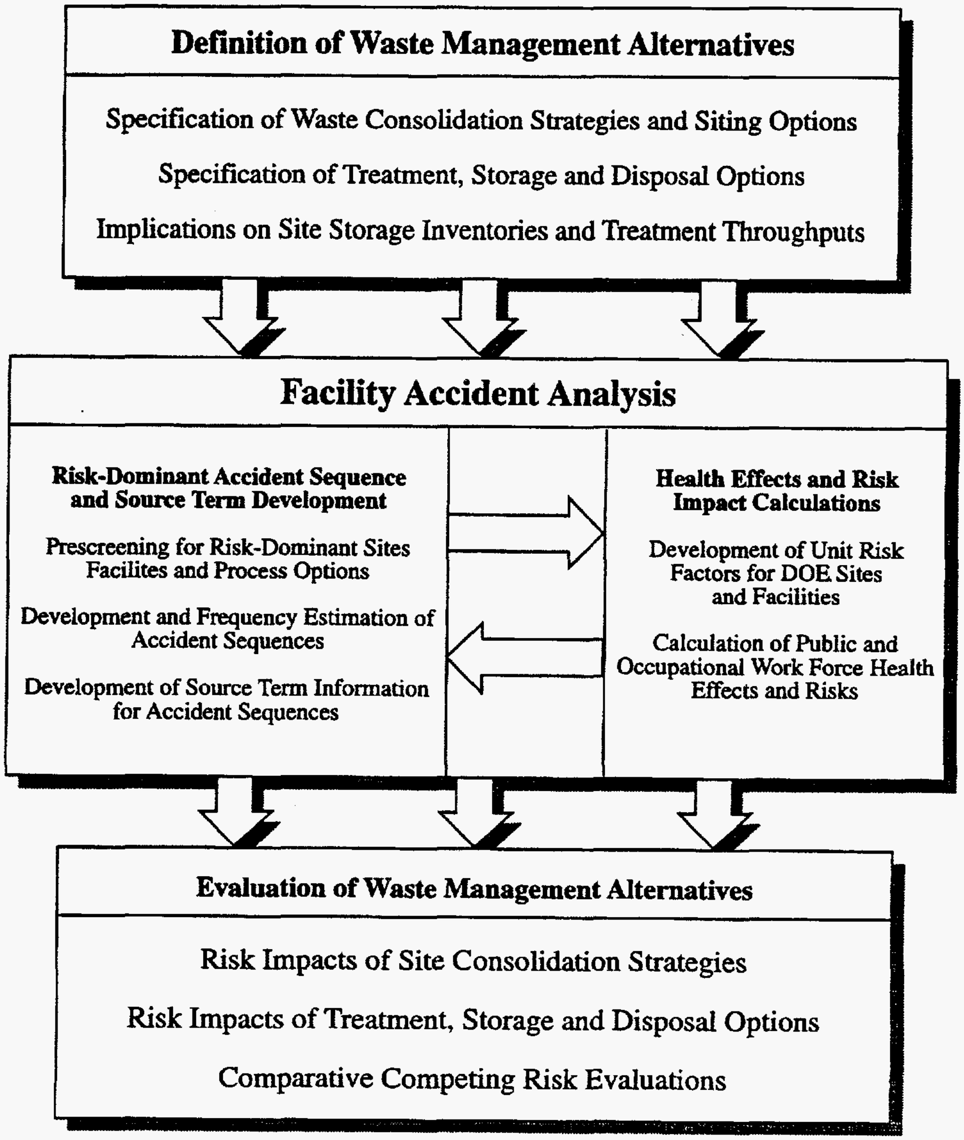

FIGURE 1.1 Overview of Facility Accident Analysis Interactions for the WM PEIS

1.4 ORGANIZATION OF REPORT

Section 2 describes the overall methodology for the accident analysis and the integration of the computational components into a complete analytical framework. It also describes the use and integration of generic and site-specific accident analysis data, with waste stream inventory data, storage and treatment process characterizations, and site and facility demographics information developed in the WM PEIS to provide a complete accident analysis data package.

Currently projected waste generation rates, storage inventories, and treatment process throughputs have been calculated. Specific results are presented in this report for each of the waste streams in the WM PEIS. Sections 3 through 8 summarize the accident analyses and aggregate the key results for each of the waste streams. Source terms are estimated and results are presented for each of the major DOE sites and facilities by consolidation alternative for each waste stream. Key assumptions in the development of the source terms are identified. Appendices A and B (Volume 2) are compilations of the chemical and radiological source terms that identify the potential atmospheric release of each toxic chemical or radionuclide for each accident sequences studied.

Section 9 lists the reference materials used for this report. They include DOE orders and standards, U.S. Nuclear Regulatory Commission (NRC) regulations, NEPA documentation, technical reports developed in support of this regulatory guidance, and site-specific safety analysis and environmental impact documentation and related supporting technical reports that were used in support of the WM PEIS accident analysis.

Appendices C through H (Volume 3) provide discussion of specific accident analysis data and guidance used or consulted in this report.

2 METHODOLOGY AND COMPUTATIONAL FRAMEWORK FOR ACCIDENT ANALYSIS

2.1 OVERVIEW

This section describes the methodology and computational framework for the facility accident analysis for the WM PEIS. Figure 2.1 illustrates the major components, related input and output of data from the facility accident analysis, and an overview of the interactions of the analysis with other elements of the WM PEIS project. Implementation of this analysis included selection and development of the accident sequences and associated output for the 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 a consequence associated with a unit release of a radionuclide to the environment from a facility or a given site for a given receptor.

This chapter is organized to reflect the phased approach depicted in Figure 2.1. Sections 2.2 through 2.4 explain how the illustrated program 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 2.5 and 2.6 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.

2.2 SELECTION OF RISK-DOMINANT OPERATIONS, FACILITIES, AND RELATED TYPES OF ACCIDENTS

A review of the alternatives for WM was performed to focus the analysis of the large number of processes and facility configurations possible within the WM alternatives to address only those configurations with accidental radiological or chemical releases potentially important to overall risk and that may allow reasonable discrimination among alternatives. This section first describes the process of categorization and then describes the three classes of accidents selected: (1) general handling accidents, (2) accidents at storage facilities, and (3) accidents involving treatment processes and facilities.

2.2.1 Categorization and Screening

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

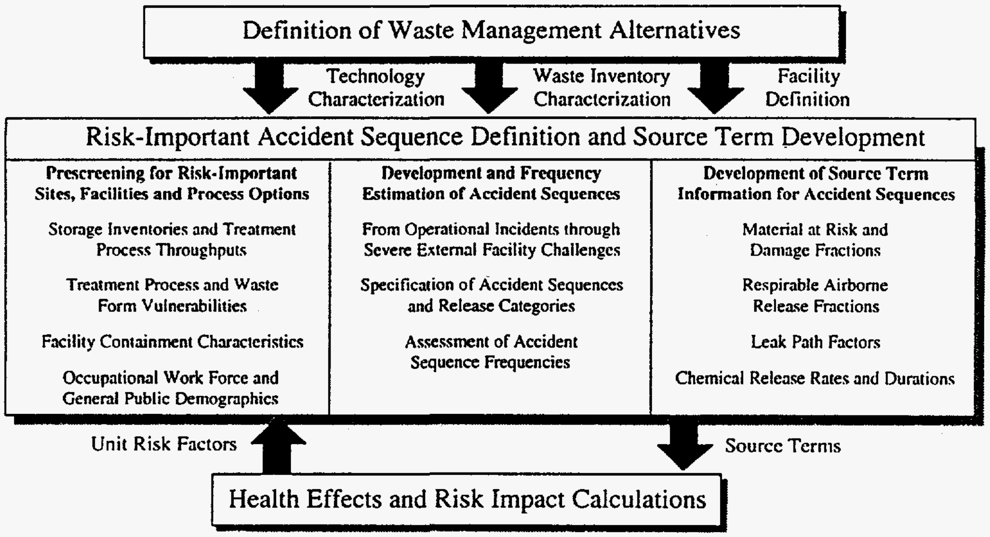

FIGURE 2.1 Major Components and Related Input and Output of Data for Facility Accident Analysis

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.

Facilities considered in the WM PEIS also include operating and preoperational facilities and conceptual designs for facilities. 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 operation, facility, site, and general population.

Only airborne releases were considered, on the basis of evidence in existing DOE safety analyses that airborne pathways dominate the accident consequences and drive the facility risks. Releases via surface runoff or to the ground cause longer term effects that are not a strong indicator of risk and would not be a strong discriminator for WM PEIS alternatives. The only reasonable threats that could cause immediate and appreciable effects via nonairborne pathways are large, stored volumes of HLW (tank farms). However, DOE has removed storage of HLW from consideration in the analysis, and releases via nonairborne pathways are not considered.

Amount and Composition of MAR. Each alternative for waste consolidation discussed in the WM PEIS implicitly defines unique pretreatment and post-treatment 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 (Kotek et al. 1995). Accordingly, for each alternative for each waste type, the DOE sites were ranked by the curie and radiation hazard content of treatability categories for that waste type to determine those sites with the largest curie inventories of potentially risk-dominant waste. A similar review of ranking was done to determine sites with the greatest chemical inventories within the waste type (process chemical accidents that could not be strongly correlated with waste inventories or throughputs were not analyzed). These rankings led to the restriction of analyses for any given waste type to those sites with sufficient inventories to justify development of distinct source terms.

Vulnerability of MAR. A major 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. As a result, only selected WM operations and treatment technologies were analyzed for source term development.

Characteristics of Facility Containment. Facilities considered in the WM PEIS range from outdoor storage pads with no capability for containment to facilities that have the structural capability to withstand the forces from significant natural phenomena. The containment characteristics of the existing or proposed storage or treatment facilities were judged by their hazard category or natural phenomena hazards (NPH) performance category (PC) and by implied attendant operational and emergency procedures and structural capabilities. This process led to the restriction of analyses herein to generic facilities with characteristics defined by their DOE Hazard Category. (Hazard category and NPH PC are discussed and defined in Section 2.5.1).

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. Estimates of the population of workers for each treatment technology and facility were developed in the WM PEIS as a function of the throughput of the waste inventory to be processed. Consideration of these populations and their proximity to the point of release vis-à-vis the appropriate radiological or hazardous material inventories of the MAR provided an initial identification of those processes and facilities potentially dominating 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.

Review of the operations and facilities against these criteria led to the establishment of three broad classes of accidents as determined by their release characteristics and the facilities and populations affected. These classes include (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.

2.2.2 General Handling Accidents

General handling accidents were defined as a distinct class, because hands-on operational accidents are expected to dominate the radiological and chemical risk to workers (because of 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; however, airborne releases resulting from breaches in a container are relatively insignificant compared with releases involving fires or explosions. As a result, these handling accidents usually constitute little hazard to the general public.

2.2.3 Storage Facility Accidents

Accidents at storage facilities were singled out as a separate class because they potentially involve large quantities of MAR. Moreover, because 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 dominate the risk of releases to on-site personnel and the general population for many DOE sites.

Besides potential importance to risk, two other criteria were used to determine which storage facilities and related accidents should be analyzed or reviewed: (1) potential for discrimination among PEIS alternatives and (2) quantity and quality of information available for guidance or input to analysis. As a result, current storage (i.e., storage prior to treatment) of LLMW, LLW, and TRUW was not analyzed because the results will not help to discriminate among alternatives. This results from the underlying assumption used in the PEIS analyses that all sites will accumulate or at least not reduce these waste inventories for roughly 10 years, at which time complex-wide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases), independent of alternative. 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, this information will be discussed in the sections for these waste streams.

Calculation of the cost and risk impacts of current storage of HLW is 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, and, accordingly, HW storage accidents have been analyzed and will be discussed.

2.2.4 Accidents Involving Treatment Processes and Facilities

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 process temperatures and pressures, combustible materials, and feed lines of natural gas or fuel. Moreover, the MAR may not only involve substantial inventories but may also have physical or chemical or highly concentrated toxicological or radiological characteristics that pose a threat to both the immediate workforce of the facility and the populations surrounding the facility. As a result, 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 a sufficient radiological and hazardous concentration or mechanistic stresses and energies capable of creating an airborne release likely to dominate risk to either the work force or the public. 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 consideration as large-scale accidents. 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 subsequently.

Ion Exchange. Ion exchange is a standard technology for removing dissolved ionic solids, radionuclides, and toxic pollutants. 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 solutions of sulfuric acid or sodium hydroxide. 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. Abnormal 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, presence of dry resin in the column, and high column temperatures (leading to ignition) (Ayer et al. 1988). This accident was predicted to 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, and ferrous and nonferrous bulk metals. The incoming metal is shredded and then transported to a furnace where it is melted and cast into ingots. Any combustible material in the incoming feed is thermally destroyed in a secondary combustion chamber (SCC). Highly radioactive materials tend to collect in the slag, which is skimmed from the top of the melt and poured 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 liquid 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 heavy-metal 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, the ash residue, or the residues in the filtration system. Feedstock fires may pose a toxicological risk for mixed wastes because of the relatively high concentrations of organics.

Wet-Air Oxidation. Wet-air oxidation is the aqueous-phase oxidation of suspended organic substances by using elevated temperatures and pressures. Water (H_2O) catalyzes oxidation so that reactions proceed at much lower temperatures (175–340°C [347–644°F]) than are required for oxidation in open-flame combustion such as incineration. Although the pressures (2–20 MPa [20–200 atm]) are higher than those in other thermal treatment processes, the MAR is more dilute and is in an aqueous noncombustible liquid form. As a result, 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 and to be generally enveloped by incineration, a competing technology.

Vitrification. In vitrification, prepared wastes are mixed with glass-forming materials and transferred to the melter that converts the concentrated frit-slurry feed into a molten liquid at a nominal temperature of 1,150 °C (2,102 °F). The final product of vitrification is a molten borosilicate glass. The key accident in vitrification 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 melter is located (e.g., shrapnel formation from the vessel rupture), and damage to the off-gas filtration units and adjacent areas of the facility.

A comparative review of the characteristics of the identified treatment processes led to the selection of incineration as the technology most likely to dominate risk to the staff of the facility and the site, as well as 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 as appropriate for tank ruptures with pressurized releases.

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, sludges and resins, or wastes resulting from HLW partitioning is a process comparable to incineration in terms of the temperature, potential for pressurization, and the combustible-material hazards. However, dispersibility of the feedstock would be equivalent to 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 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 restricted to incineration accidents, with a limited set of analyses performed for wet-air oxidation. Accidents associated with other types of treatment were generally not considered because of the arguments presented previously and because the throughputs for other treatment processes are generally low compared with incineration.

2.3 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 DOE, the NRC, and the U.S. Environmental Protection Agency (EPA 1993), 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* (DOE 1993f) and the Idaho National Engineering Laboratory (INEL) and spent nuclear fuel (SNF) EIS (EG&G 1994a) were also reviewed to provide guidance for the selection and evaluation of accident sequences. Finally, recent safety analysis reports (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 2.3.1). 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 2.3.2). Nuclear criticality events were considered independently (see Section 2.3.3).

2.3.1 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 on-site population, and the general population surrounding the site. In general, operational safeguards and equipment are in place to ensure that the impacts of all events on the public health 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 on-site or at adjacent facilities, and (2) potentially catastrophic natural phenomena (e.g., 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 2.2. The screening process used to intercompare the process and facility characteristics with generic accident consideration is illustrated in Figure 2.2. Table 2.1 shows the matrix of accident categories analyzed.

Finally, the accident sequences emerging from the initiators were categorized by the frequency classes traditionally considered in safety documentation (Table 2.2). Risk-dominant accident sequences from each of the frequency ranges shown were assessed in a manner consistent with recent NEPA guidance (DOE 1993a), in light of their potential for affecting different populations; however, accident initiators leading to sequences with nominal frequencies less than 1.0E–06/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 the true frequency was greater than 1.0E–06/yr.

Qualitative descriptions of the types of events composing the accident initiator categories are found in Table 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 for each site (see Appendix F of this document) from either site-specific documentation or generic guidance, depending on the proximity to airports and the exposure to flight patterns. Frequencies for fires and explosions were generally derived from generic data. Appendix C of this document summarizes fire and explosion information used for guidance.

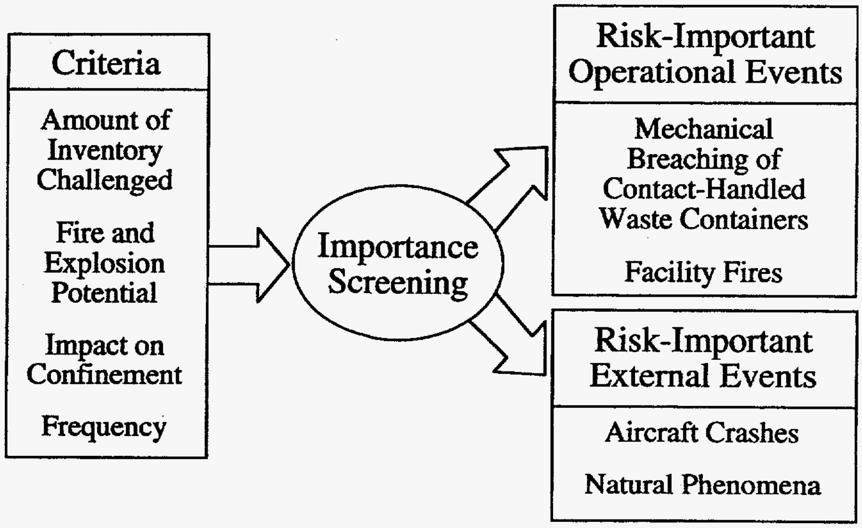

FIGURE 2.2 Screening of Risk-Dominant Accident Sequences

Natural phenomena considered as external accident initiators included earthquakes, floods, extreme winds or tornadoes, and volcanic activity; 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 waste management facilities at only three major sites, Hanford, Los Alamos National Laboratory (LANL), and INEL. Eruption of the active volcanoes near the Hanford site 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 (EG&G 1994a). 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 the 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 DOE SARs and in the DOE *Defense Programs Safety Survey* (DOE 1993f) suggest 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) show 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

TABLE 2.1 Risk-Dominant Accident-Initiator Categories for Waste Management Operations and Facilities[a]

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

[a] Risk-dominant accident initiator.

[b] NA = not applicable.

TABLE 2.2 Frequency Classes Traditionally Considered in Safety Documentation

Frequency Class	Frequency(/yr)	Definition
Likely	>1.0E−02	May be expected to occur once or more during the lifetime of the facility
Unlikely	1.0E−04 to 1.0E−02	Not expected but may occur during the lifetime of the facility
Extremely unlikely	1.0E−06 to 1.0E−04	Will probably not occur during the lifetime of the facility
Not credible	<1.0E−06	Has extremely low probability of occurring

to unprotected outdoor storage areas, the damage assumed for seismic events in the WM PEIS 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 this document); 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 2.5.1.

2.3.2 Specification and Evaluation of Accident Sequences

For the internal accident initiators defined in Table 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 waste management activities constitute a significant resource of information on accident assessment, and many of the analyses have been reviewed by peers and approved by DOE. These analyses included scenarios that are very similar to those needed for the WM PEIS and that could be used to estimate 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 analyses for accidents with accident phenomenologies, facility types, hazardous material types, and circumstances similar to accidents considered in the WM PEIS evaluation. The frequency selected for the

TABLE 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 eventuating 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 safety analysis reports (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 impacts will have different frequencies and consequences and are considered independently.

Catastrophic Challenges to the Site and Facility from Natural Phenomena

Earthquake

An earthquake near or 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 near or 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 truce since liquid HLW storage is not considered in the analysis.

Extreme Winds or Tornado

Extreme winds or tornadoes near or 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 either enveloped 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.

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 toward the high end of the frequencies reported in existing analyses, as discussed in Section 2.6.

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 Users Group (SQUG), and 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 categorical classes of facilities to (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 2.5.1) 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 amount of each radionuclide or toxic chemical in the original inventory available for release (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 1993f) to accident progression analysis (see Section 2.4). The approach also allows the evaluation of contributions from both the accident initiation and the subsequent accident sequence to the damage and ARFs.

The final step in evaluation involved the integration of the radionuclide or chemical compositions of the waste process inventories of MAR 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 of health effects and risk.

2.3.3 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 SRS (DuPont 1987) considered nuclear criticality as implausible on the basis of the 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 a 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 unwarranted.

A nuclear criticality in a TRUW solid-waste storage-and-handling facility (e.g., Waste Receiving and Processing Facility [WRAP] Module 2 [DOE 1991c] 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); 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. Accidents of nuclear criticality are not discussed further in this report.

2.4 DEVELOPMENT OF SOURCE TERMS FOR ACCIDENT SEQUENCES

2.4.1 Radiological Source Terms

The method used to estimate radiological source terms is similar to that used in the DOE *Defense Programs Safety Survey Report* (DOE 1993f). 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:

$$\text{Source term} = MAR \times DF \times RARF \times LPF, \qquad (2.1)$$

where *MAR* is the material at risk, *DF* is the damage fraction, *RARF* is the respirable airborne release fraction, and *LPF* is the leak path factor.

Figure 2.3 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* (DOE 1993f), the treatment of the components has been extended as discussed in Section 2.3.2 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 release fraction (STRF) is defined as follows:

$$STRF = DF \times RARF \times LPF, \qquad (2.2)$$

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 2.2).

2.4.1.1 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.

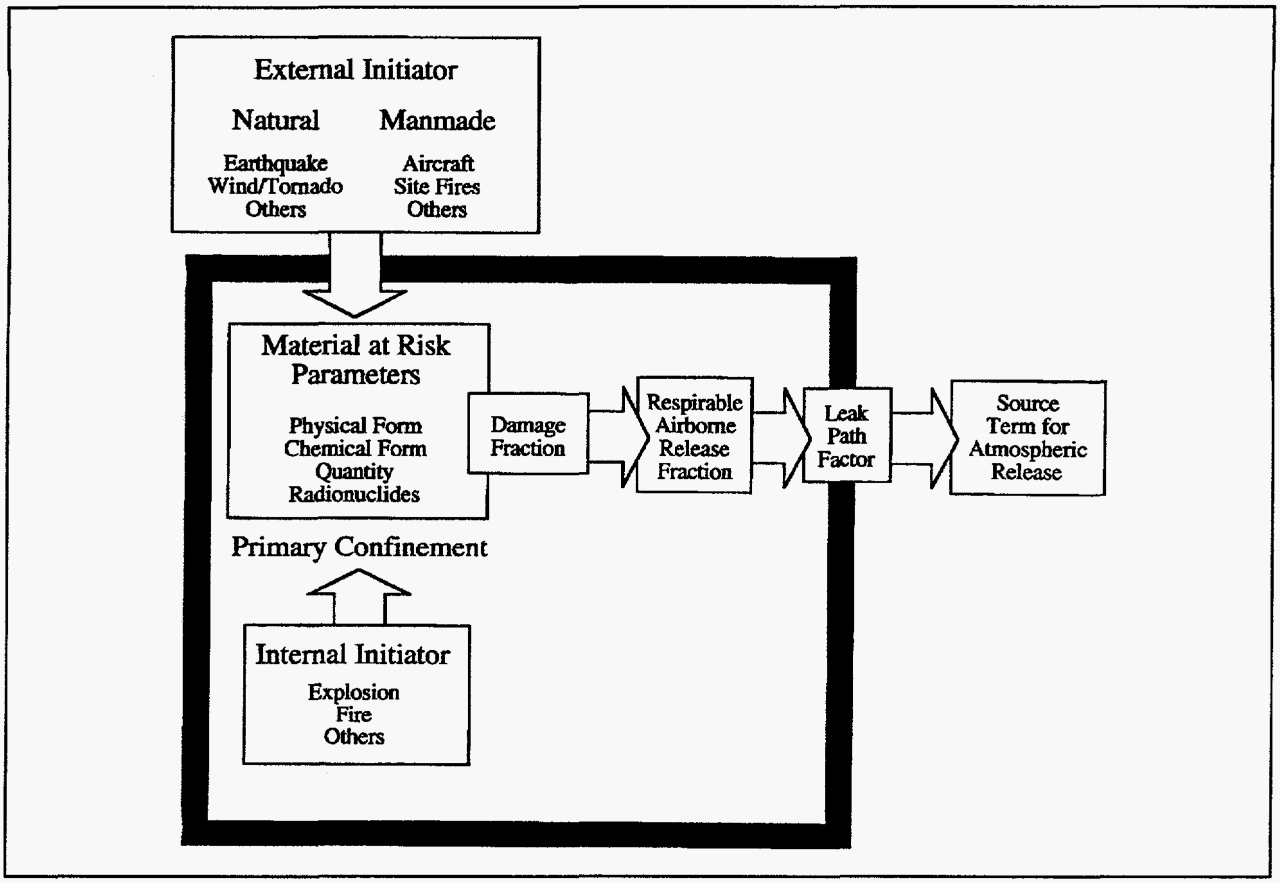

FIGURE 2.3 Conceptual Flow Diagram for Source Term Development

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 if the MAR is large 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.

2.4.1.2 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 airborne release fraction (RARF) is the product of the ARF and the respirable fraction (RF). The RF for particulates is conservatively defined as the fraction of particulates with aerodynamic equivalent diameters below 10 µm. The aerodynamic equivalent diameter is the sphere of material with a density of 1 g/cm^3 that has 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 (1994), 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 (e.g., 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 Appendix D and the results sections. 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 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.

2.4.1.3 Leak Path Factor

The leak path factor (LPF) is the fraction of the airborne inventory that passes through the containment barriers and filters to escape 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 provides LPFs as a function of the effectiveness of the filters used in DOE facilities and the intracontainment transport properties of gases and particulates; it also summarizes the values used herein.

2.4.2 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 endpoints:

1. Spills resulting in partial vaporization of the waste ("spill only"),

2. Spills followed by ignition of the waste ("spill plus fire"), and

3. "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"), or

   - 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/concentration of reactive materials (often unknown), and the proximity and nature of nearby reactive materials (including packaging, shelving, and flooring). Details on the selection of the accident scenarios, the chemistry involved in their progress, and the estimation of the release rates of the toxic gases are provided in Sections 6 and 8 for LLMW and HW.

2.5 GENERAL FACILITY MODELING AND INVENTORY ASSUMPTIONS

As discussed in Section 2.2.1, 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.

2.5.1 DOE Design and Performance Criteria

To understand how the facilities for TSD operations are affected by the various accident initiators discussed in Section 2.3.1, an understanding of how DOE facilities are designed and evaluated is necessary. The DOE has established general design criteria (GDC) for all types of facilities (DOE 1989). The GDC in DOE Order 6430.1A provide the minimum requirements for the design, construction, and maintenance of facilities; these GDC must be followed for all new construction, including modifications of facilities. For facilities constructed before 1989, similar predecessor GDC 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 DOE Order 6430.1A, including the requirements for a higher design pedigree (such as control system redundancy or natural phenomena resistant design) for systems, structures, and components (SSCs) that perform a safety function.

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 SSCs should be commensurate with the importance that the SSCs have with respect to the protection of the on-site 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 off-site effects. Category 3 facilities are the least hazardous and do not have the potential to cause off-site effects or more than minor on-site 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 WM 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 WM 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 SSCs are designed to prevent accidents or to mitigate the consequences 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 and Short 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; 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 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 2.4, 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 Categories 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 1993e), 5481.1B (DOE 1987a), 6430.1A (DOE 1989), and 5480.28 (DOE 1993c, formerly

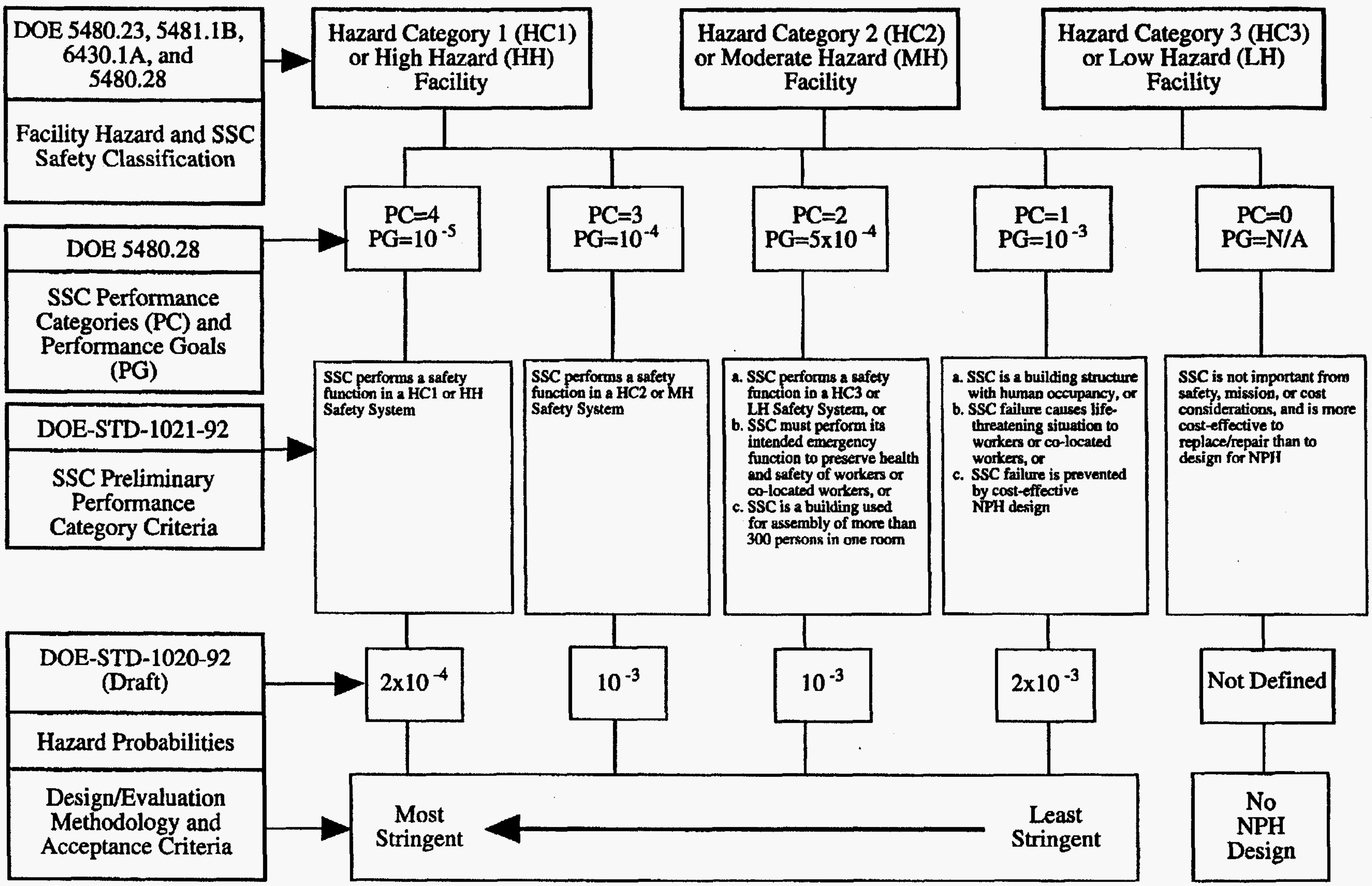

FIGURE 2.4 DOE Performance Goals for Hazard Category 1, 2, and 3 Facilities (DOE 1993b)

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-1020-92 (DOE 1993d), formerly UCRL-15910 (Kennedy and Short 1990). Although some of the concepts in these standards are still in draft form and have not been approved for use by the DOE, the approval process is well along; no changes large enough to affect the results of the WM PEIS accident analysis are anticipated.

In general, the facility categories referenced in the WM PEIS 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.

2.5.2 Storage Facility Accidents

2.5.2.1 Low-Level Waste, Low-Level Mixed Waste, and Transuranic Waste

The underlying assumption used in the PEIS is that all sites will accumulate or at least not reduce these waste inventories for roughly 10 years, at which time complex-wide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases) independent of alternative. As a result, accidents for 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 protection sheds prior to shallow land disposal or treatment. LLMW is generally packaged in drums or containers and stored in Resource Conservation and Recovery Act (RCRA)-compliant weather protection sheds pending treatment. TRUW is generally packaged in drums or containers and stored in concrete structures, in weather protection sheds, in earthen berms, or, in the case of remote-handled (RH)-TRUW, in below-grade caissons. Most contact-handled (CH)-TRUW, which dominates the total TRUW inventories, is stored in facilities with minimal containment, although DOE sites are increasingly moving toward qualified TRUW storage.

2.5.2.2 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 analyzes are described in the section on HLW.

2.5.2.3 Hazardous Waste

Hazardous waste is generally packaged in 208-L (55-gal) drums and stored in RCRA-compliant staging areas or weather protection sheds before off-site shipment for commercial treatment and disposal. An HW storage facility (HWSF) typically has over 100 different chemicals that 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 2.5) was assumed in the analyses. No credit was taken for containment or filtration.

2.5.3 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 to the process modules consist of (1) front-end support, providing waste receipt and lag storage; (2) treatment receiving and inspection; (3) container open, dump, and sort; (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 (e.g., before incineration); (2) removal or destruction of aqueous organics before evaporation; (3) metal removal; (4) metal recovery; (5) mercury removal and recovery; and (6) stabilization of various waste constituents by immobilization, conversion to stable forms, or removal.

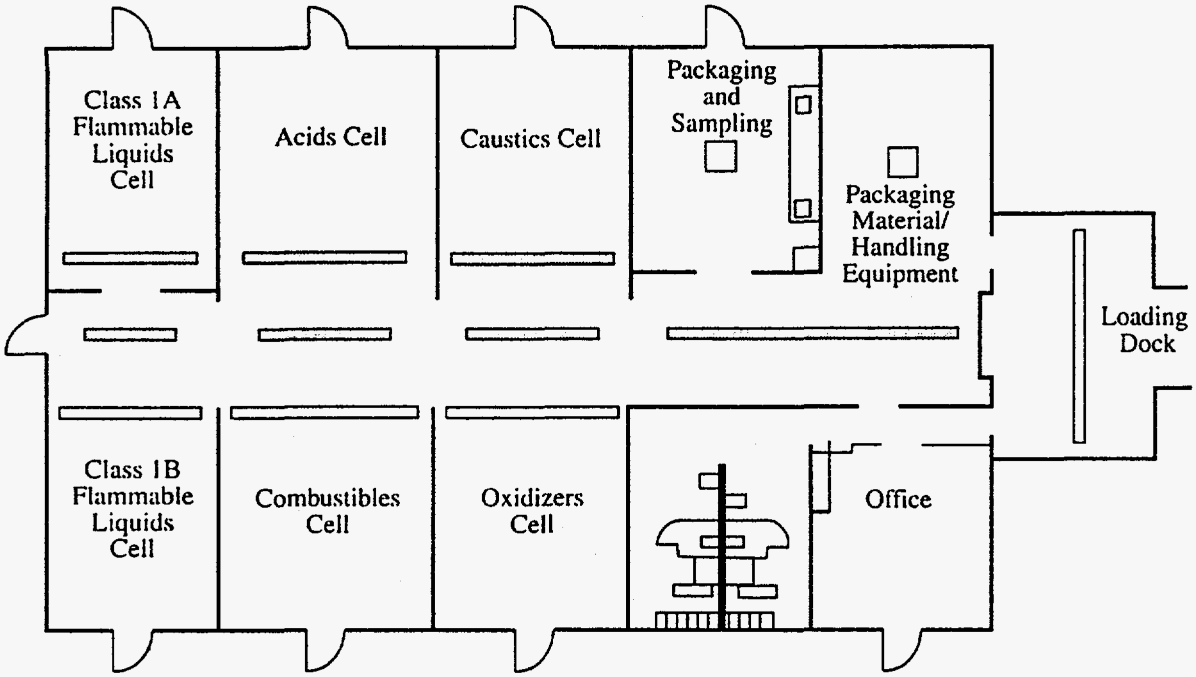

FIGURE 2.5 Typical Design for Hazardous Waste Storage Facility

As discussed in Section 2.2.4, 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 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 SCC; 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. 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 SRS, wet ash is found in all ash areas except the two combustion chambers (DuPont 1987). Dry ash is generated in other DOE incinerators and, because of its greater dispersibility, is assumed here for source term development.

The 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). The off-gas from incineration contains carbon monoxide (CO), SO_2, and NO_x. Acid gases are typically removed by scrubbing. Radioactivity and some

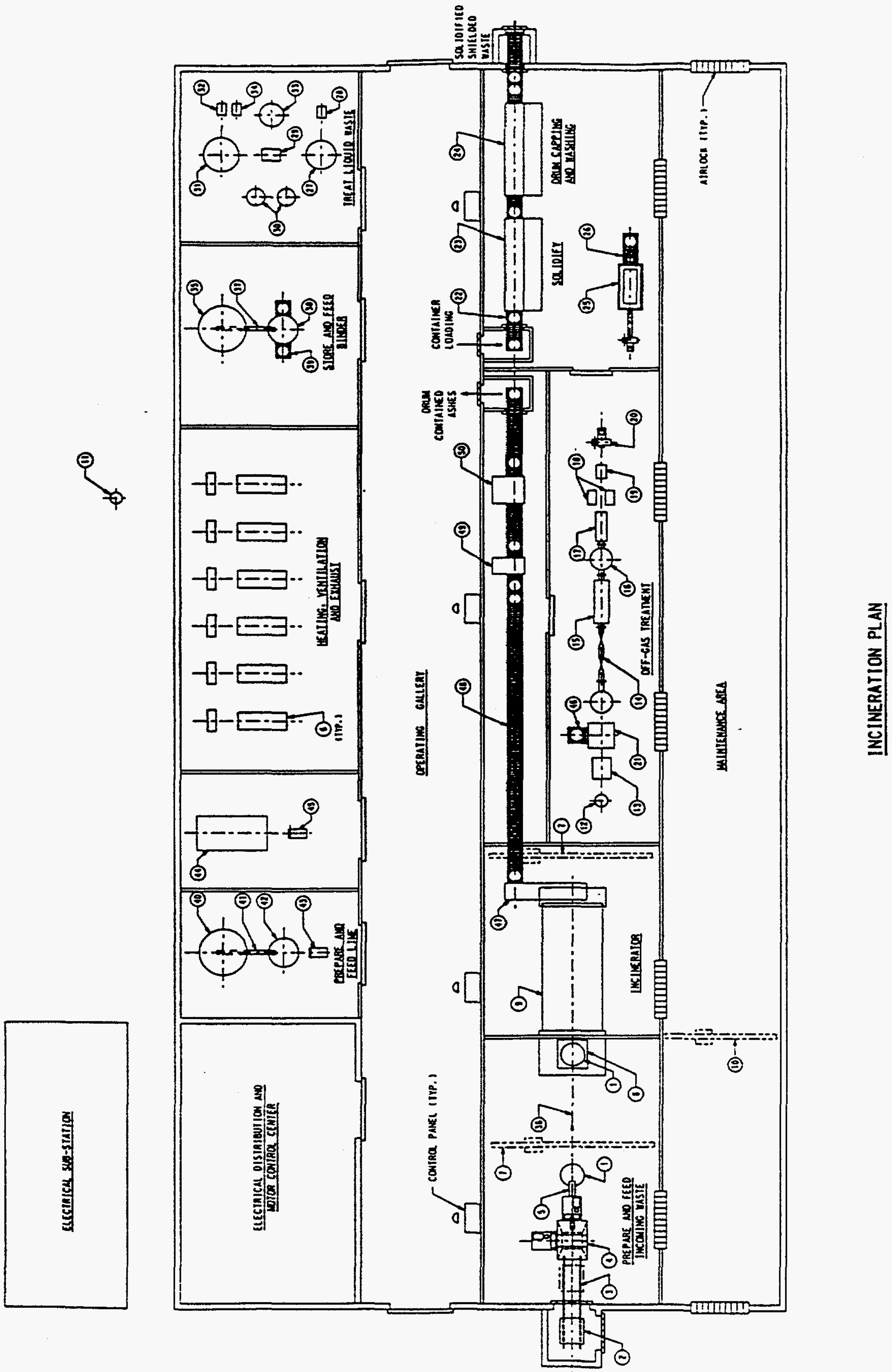

FIGURE 2.6 Plan of Generic Incineration Facility Assumed for Accident Analysis

Figure 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 = I.D. 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

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 [C-14], tritium [H-3], and sulfur 35 [S-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 for its systems were assumed. Double-HEPA-filtration SSCs 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.

2.6 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 sections describing the analyses for that waste type.

Following the generation of these data, a number of new or previously unavailable accident analyses addressing facility accidents have been obtained that were performed in support of recently published DOE Safety Analysis Reports (SARs) and EISs. Another new document of particular relevance that has just been published is the new DOE Standard (DOE 1994) on RARFs, which provides the latest RARF values published by DOE for use in accident analysis. Some of these latest values supercede some of the RARF values used herein. At the time of this writing, these reports were being reviewed to determine whether they would significantly affect the source term calculations or frequency assignments developed herein. Review to date suggests that the assumptions used for the PEIS accident calculations tend to lead to somewhat more conservative releases than would be calculated using the most recent DOE guidance.

2.6.1 General Handling Accidents

The dominant contributor to worker risk from radiological or chemically hazardous releases is expected to result from mechanical breaches of waste containers in handling accidents. 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,c) at the Hanford site 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 (4-ft) height design specification for drum drop (Type A package; *Code of Federal Regulations*, Title 49 [49 CFR Part 173]) integrity. 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.

Treatment processes entail minor hazards to the operating staff, including puncture wounds during waste sorting, minor contamination from glove failures, and minor spread of contamination from treatment equipment pressurization and off-gas treatment confinement failures (e.g., corrosion, gasket failures). The risk from exposure to radiation from these operational incidents is judged to be enveloped by the analysis for general handling accidents herein.

The frequencies for chemical spills involving HW or LLMW were derived using site-specific inventories of individual representative chemicals, along with the assumptions identified previously 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.

2.6.1.1 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) plastic-lined, carbon steel, 208-L (55-gal) drums; (2) plastic-lined wooden boxes (120×120×210 cm [4×4×7 ft] or 60×120×210 cm [2×4×7 ft]); (3) TRUPACT-II standard waste boxes (metal boxes measuring 120×120×210 cm [4×4×7 ft]); or (4) ST-5 metal boxes (120×120×120 cm [4×4×6 ft]). The Waste Isolation Pilot Plant (WIPP) final SAR (DOE 1990b) assumes that 25% of the package contents are spilled (i.e., a damage fraction of 2.5E−01) for events dislodging the drum lid and that 10% of the waste package(s) are inadvertently punctured with 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 for the representative handling accidents analyzed herein.

The physical and chemical composition of the MAR in storage was defined by weighting the relative treatability category inventories at each site.

2.6.1.2 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 of external drum breach of 1.4E+00/yr per facility. The EIS for new production reactor capacity (DOE 1991d) 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 railcar loading, (1.1E−01/yr). 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 (e.g., 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 1 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 (DOE 1991a) 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 4.0E−05 was used in a probabilistic safety analysis of a LANL facility (Sasser 1992). The mixed low-level waste 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 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 1994b).

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 exist, 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

$$f_{mb} = 0.0002 \times n_x , \tag{2.3}$$

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

$$f_{mb} = 0.0002 \times N , \tag{2.4}$$

where N is the capacity of the facility in number of drums.

The previous frequency estimate should envelop frequencies of 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 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 1991b). 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 (e.g., 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 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, (e.g., the HLW canisters are designed to be dropped from a height of 9 m [30 ft] without loss of integrity). Beyond 9 m (30 ft), the integrity of the canisters is uncertain (e.g., the maximum height that a Hanford canister can drop in a storage facility is 13 m [42 ft]). Canisters are probably most vulnerable to damage during transfer from the on-site 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 [30 ft]) would not result in a breach, canister rupture would require the drop of a heavy structure (e.g., 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, frequency for an HLW breach is

$$f_{HLW} = 0.004/370 = 0.00001/Canister. \tag{2.5}$$

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 1E-03/yr. The preliminary design at Hanford assumes a production rate of 890 canisters per year, leading to a frequency of 9E-03/yr.

The frequencies for chemical spills involving HW or LLMW are derived using site-specific inventories of individual representative chemicals, along with the assumptions identified above 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.

2.6.2 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 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.

2.6.2.1 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 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 on-site 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 was assumed to have a MAR equivalent to the contents of a single 208-L (55-gal) drum and to have a DF of 1. 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).

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 1982b). This value is consistent with existing documentation and is judged to be reasonable in light of the existing preventive and mitigative safeguards discussed previously.

2.6.2.2 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 (e.g., benzene at the SRS [WSRC 1994a]), 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 (e.g., 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 (e.g., 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 (i.e., 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 the Hanford site (WHC 1991a) 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 water 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 sections on treatment facility accidents.

2.6.2.3 External Event Accident Sequences

External event challenges are important to the human health risk from radiological releases insofar as they have the potential to create fires or explosions that can disperse and render airborne radioactive waste materials. As discussed in Section 2.3.1, 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 on-site fire brigades unlikely.

Event trees described in Appendix G 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, and the DOE. Accident sequences are developed for aircraft impacts (small and large aircraft are considered separately) and seismic events. As discussed in Section 2.3.1, 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 2.5. The results are covered in the chapters on specific waste types.

2.6.3 Treatment Facility Accidents

The major concern with treatment facilities is 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 Appendix G to structure and facilitate the evaluation. Results for both internal and external events are shown in the individual sections for each waste type.

2.6.3.1 Treatment Process Incidents

In general, the processes of the generic treatment facility described in Section 2.5 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 of treatment equipment pressurization, from spills and from off-gas treatment confinement failures (corrosion, gasket failures, etc.). Such minor operational incidents in treatment have been folded into general handling accidents and, as a result, are not discussed further.

2.6.3.2 Off-Gas System Failures

Potential on-site and off-site 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 (e.g., noble gases, volatile radionuclides such as H-3, or high-temperature conversion of dichlorodifluoromethane [Freon] to phosgene); but off-gas events tend to be minor because of the high gas sweep-rate and the inertness of the off-gas constituents relative to the chemically reactive radionuclides and hazardous materials given off during facility fires or explosions. The on- and off-site risks from such accidents are enveloped by potential facility fires or explosions that involve chemically reactive releases of nuclides and chemicals that have extended residence times in the body. Thus, abnormal operation of the off gas systems are not considered further.

2.6.3.3 Treatment Process Vessel Accidents

Aqueous processes to remove RCRA contaminants entail short-term storage in tanks, transfer pumps, vessels and pipe lines, 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 (e.g., 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 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 below). 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), 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 waste management database (Kotek et al. 1995). 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.

2.6.3.4 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 on-site 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 (DuPont 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 below.

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 characteristics 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 discussed below. 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. Engineering judgment, which is based, in part, on the information developed herein and largely presented in Appendix C, 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 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 Experiment Pilot Plant (PREPP) actually present in the baghouse and HEPA filters, a value of roughly 3.0E–02 (DuPont 1989). All of the baghouse and HEPA filter ash was assumed to be affected by the fire, resulting in a DF of 1. 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 Appendix G.

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 in Section 8.

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 (DuPont 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 with the F and H Canyons of the SRS (WSRC 1994a).

Analysis of actual event data at the SRS indicates a failure probability for manual fire suppression of 1.0E–01 to 5.0E–01 per demand, assuming the fire is detected (WSRC 1994b). Most SARs use a reasonably conservative value of 1.0E–02 per demand for failure of automatic fire suppression systems on the basis of the DOE study (DOE 1982b). 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 1.0E–03/yr for a fully developed fire in an operating area, as derived from RWMC documentation. The previously cited Electric Power Research Institute study (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 RFETS range from 5.0E–02/yr to 5.0E–01/yr on the basis of facility-specific experience (e.g., 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 WIPP estimates. This includes a generic fire frequency of 1.0E–01 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 in Section 8.

2.6.3.5 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 dryers were discounted in the SARs for RFETS Buildings 910 and 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.

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 the SCC, respectively. 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 (15-psig) 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 Power Plant (SWEPP) with TRUW solid feedstock (EG&G 1993b).

The post-treatment 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.

2.6.4 Summary of Data Used

A summary of the key generic source term and frequency parameters discussed in the preceding sections is presented in Table 2.4. Although the values actually applied for the accidents for individual waste types are summarized in Sections 3-8, these values are largely based on this table. The MAR units of volume were converted to Ci for each waste type and DOE site with the information provided in the WM PEIS waste characterization database. Although the total Ci value is given in Table 2.4, the activity was distributed into the corresponding radionuclides in the source term files used for consequence calculations.

TABLE 2.4 Frequency and Source Term Parameters for General Handling and Internal Facility Accidents

Event	Reported Frequencies(/yr) Low	Reported Frequencies(/yr) High	WM PEIS Frequency Estimate (/yr)	Reported or Representative Source Term Parameters: MAR Units	No. of Units	DF
General Handling Accidents						
Packaged Wastes						
Crane drop with impact and breach	8.0E–02	1.2E–01	–	Package[b]	1	2.5E–01 or 1.0E+00[c]
Forklift puncture with impact, breach, and spill	–[a]	7.5E–02	–	Package	2	1.0E–01 or 1.0E+00[c]
Internal overpressurization and breach	–	2.1E–02	–	Package	1	–
Toppled stacked array	–	7.5E–02	–	Drum	4	2.5E–01 or 1.0E+00[c]
Representative breach and rupture	–	–	2.0E–00[d]	Drum	1	2.5E–01 or 1.0E+00[c]
Fires in Storage or Staging Areas						
Spontaneous combustion fire	2.6E–02	5.0E–01	f	Drum	1	1.0E+00
Small fuel or chemical fire	8.3E–04	3.3E–03	f	Drum	2	1.0E+00
Facility fire	2.0E–04	1.0E–03	f	Drum	g	1.0E+00
Local manual-suppression failure	1.0E–01/d[h]	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–04	Drum	g	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	–	Drum	1	1.0E+00
Representative explosion	–	–	f	–	–	–
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	Baghouse and HEPA ash inventory	1	1.0E+00
Explosions in Treatment Facilities						
Spontaneous combustion or explosion	1.0E–04	1.5E–02		Incinerator kiln ash inventory	1	1.0E+00
Representative explosion	–	–	1.5E–02	Incinerator kiln ash inventory	1	1.0E+00

[a] A hyphen indicates data not available.

[b] A type A (49 CFR) 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.

[c] Waste packages containing liquids were assigned a DF of 1.0E+00.

[d] Per operation.

[e] Because of the focus of the WM PEIS alternatives and the low overall risk relative to drum or canister storage accidents in the WM PEIS program, source term analyses were not performed for tank storage.

[f] 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.

[g] Total number of waste drums in facility.

[h] d = per demand.

2.7 SELECTION AND CALCULATION OF FINAL SOURCE TERMS

The source term information discussed previously was combined with selected unit-risk factors to develop preliminary screening estimates of the impacts of the accident sequences in order 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 risk-dominant to public risk were then developed based on importance to risk to the maximally exposed individual (MEI) at the site boundary.

The calculation of the source terms 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 is illustrated in Figure 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 alternatives for waste management. Ranking of the accident sequences for risk dominance at each site was performed 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: >1.0E-02, between 1.0E-02 and 1.0E-04, between 1.0E-04 and >1.0E–06, and <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

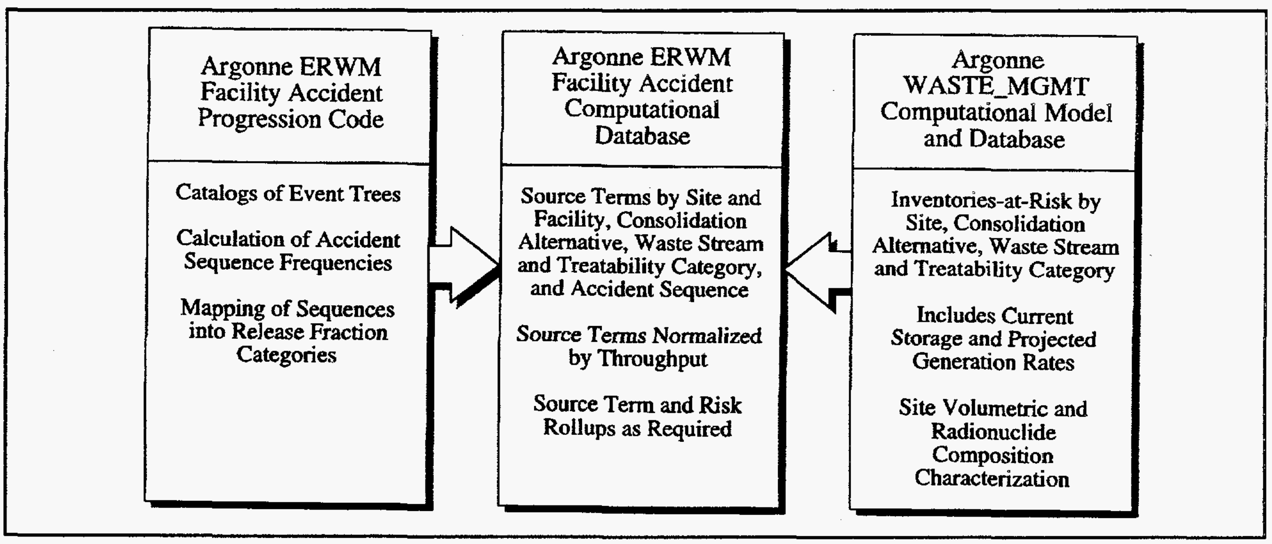

FIGURE 2.7 Computational Framework for Facility Accident Analysis Source Terms (ERWM = environmental restoration and waste management)

complete set of sequences, with classification of their frequency categories, is shown in Sections 3-8. A representative list of sequences is presented in Table 2.5. The final calculation of the health effects for both general and workforce populations by using the source terms described herein is reported in WM PEIS Appendix D.

2.8 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 Source terms were also selected from risk-dominant sequences in the following annual frequency categories: >1.0E–02, between 1.0E–02 and 1.0E–04, between 1.0E–04 and arise in the inherent limitations of the accident sequence modeling and the incomplete knowledge of the facilities and operations 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. Uncertainties exist 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 by 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 end of spectrum accident sequences with frequencies near or less than 1.0E-05, such as those initiated by beyond design basis earthquakes (BDBEs).

The uncertainties in the source term calculations affect 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 are affected by uncertainties. Uncertainties in the MAR and DF arise from lack of precise knowledge of the 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. No conservatisms were assumed in developing the MAR. Damage fractions were

TABLE 2.5 Representative Accidents Analyzed for Source Term Development

Type of Facility/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[c] or tornado	Site-[d] and accident-sequence-specific	Accident-sequence-specific	Event tree sequences screened on risk to identify single sequence
Treatment Facility[b]			
Operational Events			
Facility fire	1.0E–03/yr	Ash in baghouse and HEPA filters (3% of facility waste inventory or 0.03% of "incinerable" throughput)	Not for HW stream
Facility explosion	1.5E–02/yr	Ash in kiln (12% of facility waste inventory or 0.12% of "incinerable" 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[c] or tornado	Accident-sequence-specific	Accident-sequence-specific	Event tree sequences screened on risk to identify single sequence

[a] Used for screening only.

[b] Applied only to incinerators at each DOE site. Vitrification accidents were screened for LLW and wet-air oxidation accidents were screened for LLMW.

[c] Earthquake used to upper bound consequences of tornado.

[d] Frequency was assigned as the larger of those for a 0.15-g earthquake or a 113-km/h (70-mph) wind. (g = acceleration due to gravity.)

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 from 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 (1994). 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 (say greater than 1.0E-02) to orders of magnitude of RARF values of less than 1.0E-04. Uncertainties in the physical compositions and containment configurations of the MAR suggest and additional order of magnitude in the RARF uncertainty.

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 basis as it was for HW, suggesting an order of magnitude uncertainty. Also, only a small number of accident release types were identified because of the generic nature of the chemical profile available for those mixed waste types. The uncertainty there 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 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 that are ultimately derived from and calculated for different facility accident sequences are judged to provide useful information in discriminating among strategic alternatives.

3 ACCIDENT ANALYSIS FOR HIGH-LEVEL WASTE

3.1 OVERVIEW OF HIGH-LEVEL WASTE MANAGEMENT

As defined by the Nuclear Waste Policy Act, HLW is:

> (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including the liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations and (2) other highly radioactive material that the Nuclear Regulatory Commission (NRC), consistent with existing law, determines by rule to require permanent isolation. (U.S. Congress 1983)

These wastes contain transuranic elements and fission products that are highly radioactive, heat-generating, and long-lived.

The two primary sources of HLW in the United States are (1) defense wastes generated from the reprocessing of SNF and weapons production targets and (2) commercial wastes generated from the power reactor fuel cycle. Spent nuclear fuel was reprocessed for defense purposes at three sites: SRS, INEL, and Hanford. SNF was commercially reprocessed at WVDP.

DOE Order 5820.2A (DOE 1988), "Radioactive Waste Management," requires proper handling and storage of HLW. It also requires each generator of HLW to develop a technology for permanent disposal of HLW in a geologic repository, when one becomes available. High-level waste is currently stored in underground tanks. An evaluation of various HLW treatment technologies resulted in the selection of vitrification as the technology best suited for treating the majority of DOE HLW. The DOE approach to ending the current storage of HLW is to immobilize that part of the waste that is highly radioactive in a more stable glass form by using high-temperature vitrification to produce glass logs that are sealed in canisters. A glass made of boron and silicon (i.e., borosilicate glass) was chosen as the protective material for HLW immobilization because of (1) its long-term stability, (2) its resistance to the stresses of disposal in a repository, (3) its capability to withstand leaching under conditions that could potentially exist in a repository, and (4) its suitability for large-scale, remote operations with highly radioactive waste.

High-level waste management follows six implementation phases: current storage, retrieval, pretreatment, treatment, interim canister storage, and geologic repository disposal. Current storage, retrieval, pretreatment, treatment, and geologic repository disposal are outside the scope of the WM PEIS; therefore, accidents during these implementation phases are not considered. The required waste management facilities include expanded interim storage facilities under the various alternatives at Hanford, SRS, and WVDP.

Three of the HLW sites (WVDP, SRS, and Hanford) plan to use cylindrical stainless steel canisters, 61 cm (24 in.) in diameter and 300 cm (118 in.) long, filled with borosilicate glass to about 85% of the canister volume. The canister designs for Hanford and SRS are identical; the WVDP design has a smaller wall thickness and a wider fill neck. Based on the current design, the canisters will be fabricated from 304L stainless steel.

Canisters of vitrified HLW from Hanford, SRS, and WVDP will be placed in an interim on-site storage facility awaiting transport to a geologic repository. Comparison of the interim storage facilities at the three sites is given in Table 3.1. Canisters produced at WVDP will be placed in storage racks that hold four canisters each, then transported in these racks to the on-site 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 will be modified for HLW interim storage. The racks will be stored on two levels to provide a storage area for failed equipment. The storage area has 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 (i.e., 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. There is no stacking of canisters 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 5 yr of vitrification operations at the Defense Waste Processing Facility (DWPF). The storage capacity of the existing facility was predicated upon the assumption that a geologic repository would be available when 1992 fresh waste would be processed. Additional storage capacity for 2,286 HLW canisters will be required to assure interim storage of all SRS HLW canisters.

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 (SST) wastes depends upon the pretreatment process to be selected, with a maximum of 60,000 canisters having been projected for minimal pretreatment (GAO 1993). This analysis assumes that a

TABLE 3.1 Interim Storage Facilities for HLW Canisters

Variable	WVDP	SRS	Hanford
Facility name	WCSF	GWSB	TBD[a]
Storage capacity (HLW canisters)	344	2,268[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] TBD = to be determined.

[b] Additional storage capacity of 2,268 canisters will be required.

total estimated 15,000 HLW canisters will be produced from all the HLW at Hanford. The vitrified HLW waste canisters are to be placed in interim storage on-site. This is similar to storage at SRS, except that three canisters are stacked per storage tube and a thermosyphon ventilation system would be used to remove decay heat in the Hanford design. As currently designed, the conceptual facility will be able to store 15,000 canisters containing vitrified HLW. Detailed descriptions of HLW treatment processes and facilities be found in the report by Folga et al. (1995).

Table 3.2 shows the HLW alternatives considered in the WM PEIS.

The decentralized alternative would provide on-site interim storage for all treated HLW awaiting shipment to a geologic repository for permanent disposal. The regional consolidation alternatives call for the vitrified-HLW canisters produced at one or more sites

TABLE 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; and
- 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; and
- 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.

to be transported for interim storage at another site. Centralization at one site (Hanford) is also considered.

3.2 RISK-DOMINANT ACCIDENTS AND MODELING ASSUMPTIONS

3.2.1 Selection of Accidents

Accidents with the potential to produce significant off-site 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, which is the only waste management phase of relevance to the WM PEIS.

Nuclear criticality was discounted due to the low concentration of fissionable material in the canister and to the absence of a mechanism of accumulating a critical mass. This was supported by safety documentation. The effective multiplication factor for criticality in an interim storage facility is required by 10 CFR 60.131(b)(7) (NRC 1994) to 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 1987b) 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 safety analysis reports for the various HLW interim storage facilities (Herborn and Smith 1990; WSRC 1990; WVNS 1994) do not consider the risk of fire within an interim storage facility, generally because there is no significant accumulation of combustibles in the vicinity to support significant fire propagation. Thus, a major destructive fire was judged to be unimportant to risk. Similarly, since a large source of combustible material would not be available for ignition and/or chemical reaction, 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 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, 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 1982a,b; 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 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. (Since a cell cover weighs approximately 30 tons, 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. It is not expected that the energetics of the accident would 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/yr, 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:

$$\textit{Frequency}\ (\mathrm{yr}^{-1}) = (4 \times 10^{-3}/\mathrm{yr}) \times \textit{Canister Production Rate} \,/\, 370. \quad (3.1)$$

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 above, the initiating frequency for a canister drop accident at SRS is estimated to be 4.0E-03/yr, based on an annual production rate of 410 canisters per year. (The frequency of a canister rupture at SRS is estimated in WSRC [1990] to be 2.0E-03/yr; the value used in this analysis can therefore be considered to be conservative.) WVDP will handle only approximately 100 canisters/yr, and the annual frequency is therefore reduced to 1.0E-03.

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 in general contains between 1,650 to 1,900 kg of glass (see Table 3.3). It is also assumed in this analysis 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 (damage fraction of unity) and dispersed into the vault. The majority of the glass fragments are too heavy to remain airborne, with a fraction (1.5E-04) of the glass lying within the respirable range (<10 μm). The RARF for glass that has been subjected to a crush/impact accident stress as a function of filtration is shown in Table 3.4. The RARF is in general a function of the physical characteristics of the waste and the accident stress to which it is subjected. The mapping of the HLW treatability categories (which are based on the physical characteristics of the waste form) with the accident analysis physical forms is shown in Table 3.5.

TABLE 3.3 Dimensions, Weights, and Radioactivities of HLW Canisters

Variable	WVDP	SRS	Hanford
Outer diameter (cm)	61	61	61
Overall height (cm)	300	300	300
Material of construction	SS[a] 304L	SS 304L	SS 304L
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) (January 1990)	104,300	234,400	137,000
Decay heat per canister (W)[b] (January 1990)	311	709	389

[a] SS = stainless steel.

[b] W = watt.

TABLE 3.4 Respirable Airborne Release Fraction as a Function of Filtration for WM HLW Storage Facility Accidents[a]

Loss of Filtration	Partial Filtration	Full Filtration
1.5E-04	1.5E-07	3.0E-10

[a] Double banks of HEPA filtration assumed; efficiency of first bank is 99.9%, efficiency of second bank is 99.8%.

The analysis of emissions from the Interim Fuel Storage Facility (IFSF) at INEL assumes that all emissions are ground releases because the release point is not greater than 2.5 times the associated building height (DOE 1993g). Because stack locations and heights cannot be defined until a conceptual design has been completed, ground releases were assumed here with both full filtration and loss of filtration. While these two sequences are to be applied for public risk estimation, worker risk is based on unfiltered releases.

3.3 RESULTS

Preliminary results of the accident sequences described above were reviewed for risk dominance using the frequency-weighted dose to the MEI and then grouped into four annual frequencies: anticipated (>1.0E-02), unlikely (between 1.0E-04 and 1.0E-02), very unlikely (between 1.0E-06 and 1.0E-04), and extremely unlikely (<1.0E-06) as a function of site. Representative source terms for the important sequences were then selected as the bases for human health effects calculations. The source term parameters and frequency groups for HLW accidents for all WM PEIS alternatives are shown in Table 3.6. Detailed radionuclide releases are provided in Appendix B.

TABLE 3.5 Mapping of HLW Treatability Categories with Accident Analysis Physical Forms[a]

Site[b]	TSD Function	MAR Based on Contents of:[b]	Accident Physical Form	Comments/Assumptions
Hanford	Current tank storage	One DST	Aqueous slurry	DST waste consists of mixtures of HLW, TRUW, and LLW existing as crystallized salts or oxides, and is considered to be aqueous slurry (ORNL 1992).
Hanford	Retrieval	Retrieval line	Aqueous solution	Hydraulic retrieval assumed, which involves addition of water to mobilize waste prior to transport.
Hanford	Pretreatment	CPF	Aqueous solution	Review of conceptual Hanford pretreatment facility design (Boomer 1992) indicated that the majority of the HLW within the facility is an aqueous solution.
Hanford	Pretreatment	Fully loaded cesium ion-exchange column	Combustible solids - polyethylene	Radioactive cesium (Cs) assumed to be removed by a Duolite-like ion-exchange resin made of polyethylene.
Hanford	Pretreatment	3.8-m^3 DCRT	aqueous slurry	Slurry is formed from retrieved waste due to recirculation (concentration factor of approximately 3×).
Hanford	Treatment	Vitrification melter	Viscous (molten) liquid	Molten glass spill due to failure of melter drain system; MAR consists of borosilicate glass similar in behavior to molten lava.
Hanford	Treatment	Vitrification melter	Viscous (molten) liquid	Steam-glass explosion due to failure of cooling system; MAR consists of borosilicate glass similar in behavior to molten lava.
Hanford	Treatment	HWVP	Aqueous slurry	External event assumed to result in rupture of all waste holding tanks and spillage of molten glass; molten glass spill neglected on the basis of Herborn and Smith (1990), due to low inventory in comparison with entire facility and low release fraction.
Hanford	Glass canister storage	One HLW glass canister	Brittle solids (glass)	Brittle (glass) solids surrogate for borosilicate-type glass produced during vitrification.

TABLE 3.5 (Cont.)

Site[b]	TSD Function	MAR Based on Contents of:[b]	Accident Physical Form	Comments/Assumptions
SRS	Current tank storage	One Type-III tank	Aqueous solution	Majority of the SRS HLW inventory (≈45%) associated with an alkaline liquid with a high-salt solution and many crystallized salt solids.
SRS	Retrieval	Retrieval line	Aqueous solution	Hydraulic retrieval assumed, which involves addition of water to mobilize waste prior to transport.
SRS	Pretreatment	One Type-III tank	Aqueous solution	Based on material characteristics for in-tank precipitation process given in Choi and Fowler (1990).
SRS	Pretreatment	Salt cake tank	Aqueous slurry	Salt cake tank contains washed sludge waste assumed to be equivalent in physical form to an aqueous slurry.
SRS	Treatment	SRE	Superheated aqueous solution	Dominant accident scenario in literature involves release of evaporator contents at high pressure and temperature (WSRC 1990).
SRS	Treatment	SRAT	Aqueous slurry	SRAT contains washed sludge, which is assumed to be equivalent in physical form to an aqueous slurry.
SRS	Treatment	Vitrification melter	Viscous (molten) liquid	Steam-glass explosion due to failure of cooling system; MAR consists of borosilicate glass similar in behavior to molten lava.
SRS	Treatment	DWPF	Aqueous slurry	External event assumed to result in rupture of all waste holding tanks and spillage of molten glass; molten glass spill neglected on the basis of WSRC (1994a) due to low inventory in comparison with entire facility and low release fraction.
SRS	Glass canister storage	One HLW glass canister	Brittle solids (glass)	Brittle (glass) solids surrogate for borosilicate-type glass produced during vitrification.
WVDP	Pretreatment	Tank 8D-2	Aqueous slurry	Tank 8D-2 contains washed sludge waste assumed to be equivalent in physical form to an aqueous slurry.

TABLE 3.5 (Cont.)

Site[b]	TSD Function	MAR Based on Contents of:[b]	Accident Physical Form	Comments/Assumptions
WVDP	Treatment	CFMUT	Aqueous slurry	Based on waste description given in Barnes et al. (1988).
WVDP	Treatment	Vitrification melter	Viscous (molten) liquid	Steam-glass explosion due to failure of cooling system; MAR consists of borosilicate glass similar in behavior to molten lava.
WVDP	Treatment	Vitrification facility	Aqueous slurry	External event assumed to result in rupture of all waste holding tanks and spillage of molten glass; molten glass spill neglected due to low inventory in comparison with entire facility and low release fraction.
WVDP	Glass canister storage	One HLW glass canister	Brittle solids (glass)	Brittle (glass) solids surrogate for borosilicate-type glass produced during vitrification.

[a] Abbreviations: CFMUT = Concentrated Feed Makeup Tank; CPF = Conceptual Pretreatment Facility; DST = Double-shell tank; DCRT = Double-Containment Receiver Tank; DWPF = Defense Waste Processing Facility; HWVP = Hanford Waste Vitrification Plant; MAR = material at risk; SRAT = Slurry Receipt and Adjustment Tank; SRE = Slurry Mix Evaporator.

[b] HLW accident analysis for INEL not included due to nonexistent safety documentation for the immobilization process and possible conflicts with the accident analysis for the INEL sitewide EIS.

TABLE 3.6 Frequencies and Source Term Parameters for WM HLW Accidents

WM PEIS Alternative	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 (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	Hanford	Glass canister crush, fully filtered release	NA[a]	×			6.2E−01	1.4E+05	1.0	4.1E−05
All	Hanford	Glass canister crush, unfiltered release	NA	NA	×	NA	6.2E−01	1.4E+05	1.0	2.1E+01
All	SRS	Glass canister crush, fully filtered release	NA	×	NA	NA	6.2E−01	2.3E+05	1.0	7.0E−05
All	SRS	Glass canister crush, unfiltered release	NA	NA	×	NA	6.2E−01	2.3E+05	1.0	3.5E+01
All	WVDP	Glass canister crush, fully filtered release	NA	×	NA	NA	6.2E−01	1.1E+05	1.0	3.3E−05
All	WVDP	Glass canister crush, unfiltered release	NA	NA	×	NA	6.2E−01	1.1E+05	1.0	1.7E+01

[a] NA = not applicable.

4 ACCIDENT ANALYSIS FOR TRANSURANIC WASTE

Potentially public-risk-dominant facility accidents identified for all waste management alternatives include: (1) facility fires initiated from internal causes, (2) an earthquake or tornado that causes damage and possible fires in the facility; and (3) the crash of a large or small aircraft into the facility resulting in fire and possible explosion. These accidents are of concern because they can involve large inventories of material at risk and phenomenological mechanisms (fire and blast effects) to render airborne some of this radioactive material. The risk dominant accidents for each site were screened using preliminary data for the generation of accident source terms to estimate the consequences and risks.

Following the generation of preliminary source terms, a number of new or previously unavailable accident analyses addressing storage facility accidents have been obtained that were performed in support of recently published DOE SARs and EISs. Another new document of particular relevance that has just been published is the new DOE Standard (DOE 1994) on RARFs, which provides the latest RARF values published by DOE for use in accident analysis. A RARF is defined as the fraction of material exposed to accident stresses that become airborne as a result of the accident. These latest values supersede the RARF values used in the screening studies cited above. At the time of this writing, these reports were being reviewed to provide additional insights into the development of the postulated WM PEIS facility accidents and the development of the final values of the associated source terms. The analyses for accidents that will be published in the final draft of the WM PEIS and this document will reflect the information in these reports and will follow the general methodology developed in Section 2.

Accidents for current storage were not analyzed because the results will not help to discriminate among alternatives. This results from the underlying assumption used in the PEIS analyses that all sites will accumulate or at least not reduce these waste inventories for roughly 10 years, at which time complex-wide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases) independent of alternative. However, because recent DOE saftey or NEPA information on storage facility accidents provides guidance on the potential risk impacts applicable to storage, this information is discussed herewith.

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 4.1 and discussed below.

Table 4.1 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

TABLE 4.1 Representative Accidents and Source Term Parameters from Recent DOE Safety Analysis Documents Relevant to TRUW Storage

Safety Document	Scenario	DF[a]	ARF or RARF[b]	Release	Consequence
LANL PSAR[c] 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[d]	1.7E-02 rem (MEI)[e]
	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 1995b)	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 1993)	1. Earthquake with spill of drums (67% of 1,200 drums breached)	25% (10% of inner packages, if doubly packaged)	8.8E-07 to 1.0 E-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 4.1 (Cont.)

Safety Document	Scenario	DF[a]	ARF or RARF[b]	Release	Consequence
Hazard Classification and Preliminary Safety Evaluation (PSE) for WRAP Module 2 (WHC 1991a)	1. 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[f] (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	9.4E-02 rem (MEI)
	2. Aircraft crash into HFEF[g] WIPP waste (46 drums)	5.0E-01	2.5E-04	1.4E-02Ci	6.0E-04 rem (MEI)
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[h] 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)

[a] DF = damage fraction.

[b] ARF = airborne release fraction; RARF = respirable airborne release fraction.

[c] PSAR = Preliminary Safety Analysis Report.

[d] PE-Ci = Pu-239-equivalent curies.

[e] Maximally exposed individual off site.

[f] TSA = TRUW Storage Area.

[g] HFEF = Hot Fuel Examination Facility at ANL-W.

[h] ASB II = Air Support Building II.

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 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 (EG&G 1994b) 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 concentration of the drum content was averaged to be 0.16 Ci/ft^3 for a total drum activity of 1.176 Ci. However, for the box spill accident, the content is taken to be 10 times higher in concentration. 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 Waste Management EIS (EG&G 1994a) involving TRUW are 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 4.1 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 Argonne National Laboratory-West (ANL-W). This accident is considered to be the bounding externally initiated event because it could cause a major breach of barriers, involve a large MAR, and have a high-energy stress of 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 4.1 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 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 unlikely 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, as originally configured, was designed to be constructed as a series of modules including units to process contact handled (Module 1) and remote handled (Module 2) TRUW. 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 (PSE) (WHC 1991a) identified and analyzed a set of accident scenarios to characterize the range of potential hazards attendant upon 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 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-4 is assumed for the fire affecting 30 drums in the lag storage area. A maximally exposed off-site individual is estimated to receive a dose of 0.3 rem with an accident frequency of 1.0E-03/yr. No credit is taken for HEPA filtration.

In a precursor report (WHC 1991b), the prototype concept of a WRAP facility was analyzed for the effects of a BDBE. 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.

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 6).

The final draft of the WM PEIS will use a systematic and internally consistent set of assumptions for analysis of accidents at all sites. However, the latest information from the aforementioned references will be used to guide the development of the accidents and the calculations of the appropriate source terms. The WM PEIS analyses for TRUW treatment facilities will be similar to those discussed in the chapters for LLW and LLMW accidents. Finally, the handling accidents affecting CH-TRUW will be analyzed in a manner similar to that for analyzing CH-LLW and CH-LLMW. Treatment facility and handling accidents will all be included in the final draft of the WM PEIS.

5 ACCIDENT ANALYSIS FOR LOW-LEVEL WASTE

5.1 OVERVIEW OF LOW-LEVEL WASTE MANAGEMENT

LLW includes all radioactive waste not classified as HLW, TRUW, SNF, or most of the by-product material defined in Section 11(e) 2 of the Atomic Energy Act of 1954. When chemically hazardous components regulated under RCRA are present, the waste is referred to as LLMW. A specific category of LLW considered separately for risk impact analysis is referred to as Greater-than-Class-C (GTCC). This category, which has concentrations of radionuclides exceeding thresholds specified in 10 CFR 61.55, is discussed in Section 7 of this report.

LLW results from a variety of DOE activities, including defense-related activities and the processing of special nuclear materials and energy research and development activities. It ranges from low-activity waste that can be disposed of without treatment by engineered, shallow land disposal techniques, to higher-activity waste requiring the use of treatment and disposal techniques that provide greater confinement. Operations waste includes contaminated equipment (components and maintenance waste), contaminated dry solids, and solidified sludges from processing (e.g., evaporator bottoms).

LLW is also generated during environmental restoration activities from the treatment of contaminated environmental media such as soil, groundwater, surface water, and underlying sediments. LLW generated during D&D of surplus facilities includes (1) neutron-activated wastes such as a nuclear reactor vessel and its internal components, (2) surface-contaminated wastes including radioactively contaminated concrete walls and process piping, and (3) miscellaneous wastes such as spent ion-exchange resins, cartridge filters, and discarded contaminated items such as tools and contaminated clothing.

LLW is generated at more than 30 sites. The major waste generators are SRS, ORR, LANL, Hanford, and Portsmouth Gaseous Diffusion Plant (PORTS) (by volume for 1991 generation data). Site-specific waste acceptance criteria (WAC) affect the type and quantity of disposed materials. All DOE sites must minimize the quantities of generated waste, with commercial and on-site volume reduction emphasized to minimize the use of disposal land areas. LLW from environmental restoration (ER) activities is generated during the cleanup of sites contaminated by radioactive waste and from contaminated facilities. Generally these ER sites and facilities were initially associated with the production of materials for national defense. LLW from previous ER activities has either been shipped to one of the six disposal sites or retained on-site under controls commensurate with a site-specific plan. As ER activities continue, the number of sites with ER-derived LLW will increase. However, ER LLW is excluded from consideration in the WM PEIS.

Table 5.1 summarizes the waste management alternatives and specific cases currently under evaluation in the WM PEIS. Each case results in distinct inventories for potential TSD at each DOE site. The table provides an abbreviated case description, and

TABLE 5.1 Programmatic Alternatives for LLW Management[a]

WM PEIS Alternative[b]	Action	Hanford	LLNL	NTS	INEL	RFETS	LANL	Pantex	PGDP	FEMP	PORTS	SRS	ORR	Other
No action: all sites treat using existing capabilities; disposal at 6 sites	Treat at all Dispose at 6	T[c] D[d]	T –[e]	T D	T D	T –	T D	T –	T –	T –	T –	T D	T D	T –
Decentralized treatment: stabilization at all sites	Treat at all	T	T	T	T	T	T	T	T	T	T	T	T	T
Decentralized	Dispose at 16	D	D	D	D	D	D	D	D	D	D	D	D	T
Regionalized 1	Dispose at 12	D	D	D	D	D	D	D	D	D	D	D	D	D
Regionalized 3	Dispose at 6	D	–	D	D	–	D	–	–	–	–	D	D	D
Regionalized 6	Dispose at 2	D	–	–	–	–	–	–	–	–	–	D	–	–
Regionalized 7	Dispose at 2	–	–	D	–	–	–	–	–	–	–	D	–	–
Centralized 1	Dispose at 1	D	–	–	–	–	–	–	–	–	–	–	–	–
Centralized 2	Dispose at 1	–	–	D	–	–	–	–	–	–	–	–	–	–
Decentralized treatment: stabilization at all sites														
Volume reduction at 11 sites	Treat at 11	T	T	–	T	T	T	T	T	T	T	T	T	–
Regionalized 2	Dispose at 12	D	D	D	D	D	D	D	D	D	D	D	D	–
Regionalized treatment: stabilization at all sites														
Volume reduction at 7 sites	Treat at 7	T	–	–	T	T	–	–	–	–	–	T	T	–
Regionalized 4	Dispose at 6	D	–	D	D	–	D	–	–	–	–	D	D	–
Centralized 3	Dispose at 1	D	–	–	–	–	–	–	–	–	–	–	–	–
Centralized 4	Dispose at 1	–	–	D	–	–	–	–	–	–	–	–	–	–
Volume reduction at 4 sites	Treat at 4	T	–		T	–		–	–	–	–	T	T	–
Regionalized 5	Dispose at 6	D	–	D	D	–	D	–	–	–	–	D	D	–
Centralized treatment and disposal: Centralized 5	Treat at 1 Dispose at 1	T D	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –	– –
Sensitivity analyses[f]	–	–	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 5.1 (Cont.)

[a] FEMP = Fernald Environmental Management Project, NTS = Nevada Test Site, ORR = Oak Ridge Reservation, Pantex = Pantex Plant, PGDP = Paducah Gaseous Diffusion Plant, PORTS = Portsmouth Gaseous Diffusion Plant, and RFETS = Rocky Flats Environmental Technology Center.

[b] The WM PEIS considers four alternatives: No Action, Decentralized, Regionalized, and Centralized. This table provides an abbreviated case description and treatment (T) and disposal (D) codes for each of the 12 highest volume sites. The No Action Alternative is based on all sites using existing and planned and approved treatment facilities and disposing at the 6 disposal sites in accordance with current arrangements. The remainder of the table illustrates the variations of the Decentralized, Regionalized, and Centralized alternatives for both treatment and disposal. Wastewater treatment and stabilization are assumed to take place at all sites. Volume reduction treatment techniques, such as incineration, compaction, and supercompaction, are coupled with stabilization for the Decentralized, Regionalized, and Centralized alternatives. Disposal is then considered at 1, 2, 6, 12, or 16 sites. Analysis of all of the alternative combinations of treatment and disposal provides the basis for the comparison of the WM PEIS alternatives.

[c] T = treatment.

[d] D = disposal.

[e] "--" = not applicable.

[f] Sensitivity analyses considered three treatment variations — including vitrification, simple compaction (versus supercompaction), and volume reduction without incineration — and varied engineered disposal options (near-surface burial versus aboveground vaults).

treatment (T) and disposal (D) codes for each of the 16 highest-volume sites. The no action alternative is based upon all sites using existing, and planned and approved treatment facilities and disposing at the six disposal sites in accordance with current arrangements. The remainder of the table illustrates the variations of the decentralized, regionalized, and centralized alternatives for both treatment and disposal. Wastewater treatment and stabilization is assumed to take place at all sites. Volume reduction treatment techniques such as incineration, compaction, and supercompaction are coupled with stabilization for decentralized, regionalized and centralized alternatives. Disposal is then considered at 1, 2, 6, 12, or 16 sites. Analysis of all the alternative combinations of treatment and disposal provides the basis for the comparison of the WM PEIS alternatives.

The treatment technologies employed are dependent on the physical characteristics of the waste and the final waste form as defined by the site-specific WAC. LLW is treated primarily for volume reduction or for rendering the waste more suitable for disposal. Ten representative treatment technologies with associated process options for the TSD of LLW are considered in the WM PEIS. Detailed descriptions of treatment processes can be found in Goyette (1995). Process options encompass (1) incineration, (2) solidification, (3) vitrification, (4) compaction and supercompaction, (5) size reduction (e.g., shredding, metal cutting, and shearing), (6) evaporation, (7) general aqueous treatment, and (8) various waste packaging alternatives. Disposal alternatives include shallow land burial, above-ground vault/tumulus, below-ground vault, or enhanced confinement structures. Figure 5.1 identifies the representative physical waste types or treatability categories, possible waste management technologies, and the potential flow paths of the waste during treatment.

5.2 RISK-DOMINANT ACCIDENTS AND MODELING ASSUMPTIONS

Accident selection has been based on potential risk dominance, with the general modeling assumptions and related source term parameters described in Section 2. The RARFs are a function of the physical form of the material rendered airborne, which varies by treatability category for each waste type. A matrix has been developed for each waste type to map the treatability categories into the physical forms for which airborne release data (Appendix D) were developed. The LLW mapping, shown in Table 5.2, is based on the WM PEIS waste and process descriptions (Feizollahi and Shropshire 1992; Goyette 1995).

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.

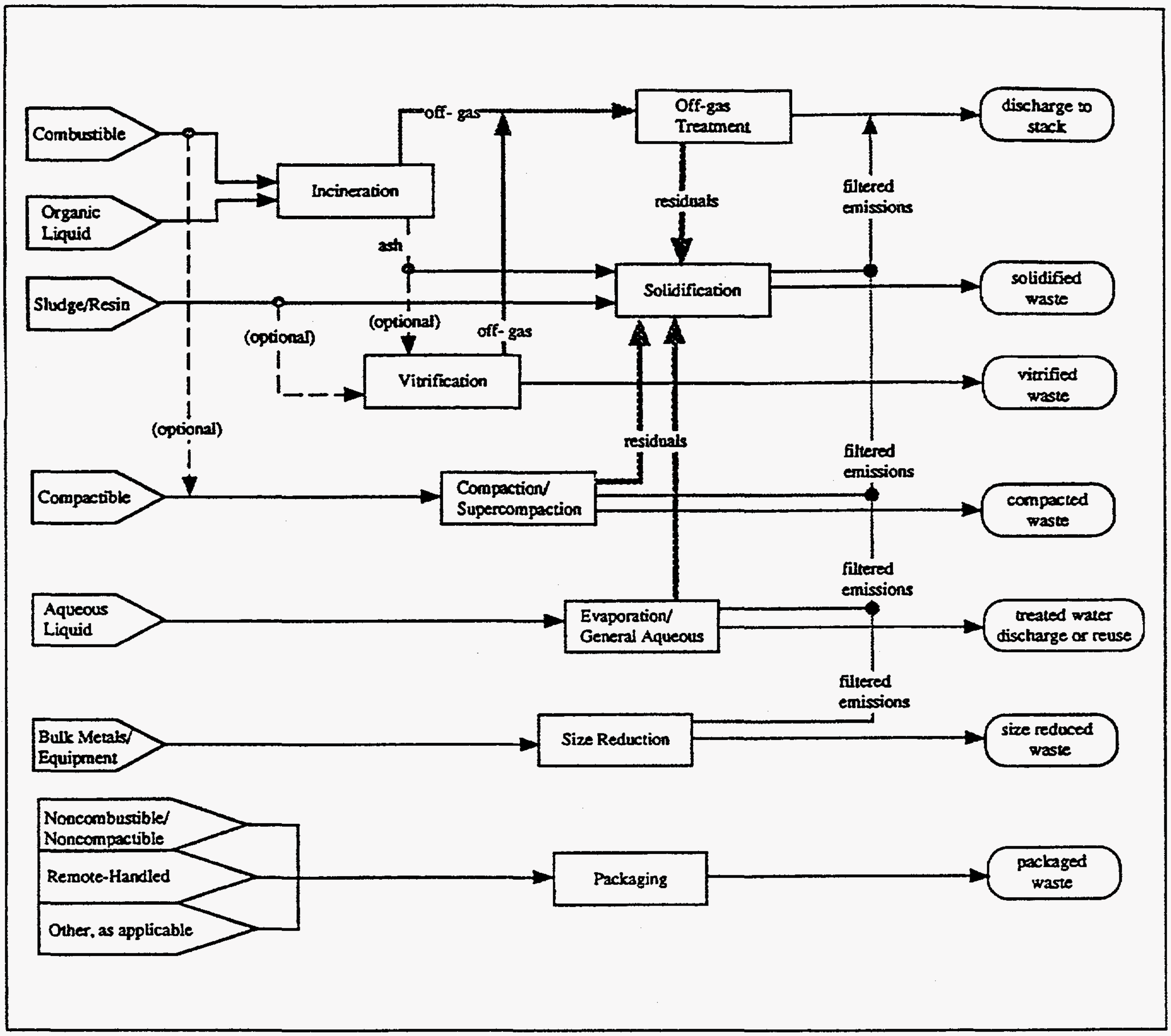

FIGURE 5.1 LLW Management Technologies and Flow Paths

Although the inventories, physical forms, and radiological compositions of waste stored at each site were characterized in the WM PEIS and stored in a database, 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, 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.

TABLE 5.2 Mapping of LLW Treatability Categories with Accident Analysis Physical Forms

LLW Treatability Category	Technology	Form[a]	Accident Physical Form	Comments/Assumptions
Aqueous liquids	General aqueous treatment[b]	Product	Aqueous solution	Output waste form is a dilute aqueous LLW solution.
		Solid residual	Aqueous slurry	Solid residual is an aqueous slurry to be sent for solidification.
Aqueous liquids	Current storage	Input	Aqueous solution	Input waste form is a dilute aqueous LLW solution.
Aqueous liquids	Evaporation	Product	Superheated aqueous solution	Assumes dominant accident sequences involve release of evaporator contents (at high temperature and pressure) and radionuclide composition of product stream similar to evaporator contents.
		Solid residual	Aqueous slurry	Evaporator bottoms are an aqueous slurry with a high solids concentration to be sent for solidification.
Aqueous liquids	Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Combustible solids	Current storage	Input	Dry active solid	Based on waste form description given in Goyette (1995).
Combustible solids	Incineration	Product	Noncombustible powder	
		Liquid residual	Aqueous solution	Slurry blowdown from off-gas treatment is an aqueous solution (Goyette 1995).
Combustible solids	Packaging	Product	Dry active solid	Assumes packaging does not affect physical form.
Combustible solids	Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Combustible solids	α-Incineration[c]	Product	Noncombustible powder	
		Liquid residual	Aqueous solution	
Combustible solids	α-Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Activated metals	Current storage	Input	Inert metal	Based on waste form description given in Goyette (1995).
Activated metals	Packaging	Product	Inert metal	Assumes packaging does not affect physical form.

TABLE 5.2 (Cont.)

LLW Treatability Category	Technology	Form[a]	Accident Physical Form	Comments/Assumptions
Activated metals	Size reduction	Product	Inert metal	Assumes production of noncombustible powder during size reduction is negligible, on the basis of release fraction information for normal operations (Goyette 1995).
Surface-contaminated metals	Current storage	Input	Noncombustible powder	Noncombustible powder assumed to contaminate outer surfaces of waste.
Surface-contaminated metals	Decontamination	Product	Inert metal	Assumes decontamination removes surface contamination resulting in a potentially activated metal.
		Liquid residual	Aqueous slurry	Based on waste form description given in Goyette (1995).
Surface-contaminated metals	Metal melting	Product	Viscous (molten) liquid	Assumes dominant accident sequence involves process upset during melting stage and radionuclide composition of product stream similar to molten material.
		Liquid residual	Aqueous slurry	Based on waste form description given in Goyette (1995).
Surface-contaminated metals	Packaging	Product	Inert metal	Assumes packaging does not affect physical form.
Surface-contaminated metals	Size reduction	Product	Inert metal	Based on waste form description given in Goyette (1995).
Surface-contaminated metals	α-Size reduction	Product	Inert metal	Based on waste form description given in Goyette (1995).
Noncombustible-noncompactible solids	Current storage	Input	Inert metal	Based on waste form description given in Goyette (1995).
Noncombustible-noncompactible solids	Packaging	Product	Inert metal	Assumes packaging does not affect physical form.
Noncombustible-noncompactible solids	Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Noncombustible-noncompactible solids	α-Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Noncombustible-noncompactible solids	Supercompaction	Product	Inert metal	Assumes supercompaction does not affect initial physical form.
		Liquid residual	Aqueous solution	Fugitive liquids from supercompaction stated to be an aqueous solution (Feizollahi and Shropshire 1992).

TABLE 5.2 (Cont.)

LLW Treatability Category	Technology	Form[a]	Accident Physical Form	Comments/Assumptions
Noncombustible-noncompactible solids	α-Supercompaction	Product	Inert metal	Assumes α-supercompaction does not affect initial physical form.
		Liquid residual	Aqueous solution	Fugitive liquids from α-supercompaction stated to be an aqueous solution (Feizollahi and Shropshire 1992).
Organic liquids	Current storage	Input	Organic combustible liquid	Based on waste form description given in Goyette (1995).
Organic liquids	Incineration	Product	Noncombustible powder	Assumes organic liquids contain both suspended and dissolved solids, so that incinerator ash is a noncombustible powder.
		Liquid residual	Aqueous solution	Assumes slurry blowdown from off-gas treatment is an aqueous solution.
Organic liquids	α-Incineration	Product	Noncombustible powder	Assumes organic liquids contain both suspended and dissolved solids, so that incinerator ash is a noncombustible powder.
		Liquid residual	Aqueous solution	Slurry blowdown from off-gas treatment is an aqueous solution (Goyette 1995).
Organic liquids	Solidification	Product	Noncombustible aggregated solid	Assumes product from solidification process is a nonflammable monolithic solid.
Organic liquids	α-Solidification	Product	Noncombustible aggregated solid	Assumes product from α-solidification process is a nonflammable monolithic solid.
Organic liquids	Packaging	Product	Organic combustible liquid	Assumes packaging does not affect physical form although packaging of liquid generally involves addition of absorbent to remove excess free liquids prior to shipment.
Other/special case	Current storage	Input	Inert metal	Accident analysis assumption due to lack of information about this waste form.
Other/special case	Packaging	Product	Inert metal	Assumes packaging does not affect physical form.
Remote-handled	Current storage	Input	Inert metal	Typically activated metal waste.
Remote-handled	Packaging	Product	Inert metal	Assumes packaging does not affect physical form.

TABLE 5.2 (Cont.)

LLW Treatability Category	Technology	Form[a]	Accident Physical Form	Comments/Assumptions
Sludge/resin	Current storage	Input	Aqueous slurry	Sludge/resin form stated to be wet solid (Goyette 1995).
Sludge/resin	Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Sludge/resin	α-Solidification	Product	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for grout monolithic product.
Sludge/resin	Vitrification	Product	Brittle solid (glass)	
		Liquid residual	Aqueous slurry	Slurry blowdown from off-gas treatment is an aqueous solution (Goyette 1995).
Sludge/resin	α-Vitrification	Product	Brittle solid (glass)	
		Liquid residual	Aqueous slurry	Slurry blowdown from off-gas treatment is an aqueous solution (Goyette 1995).

[a] Waste form divided into input, product, liquid residual, and solid residual waste forms.

[b] General aqueous treatment typically involves removal of suspended and dissolved solids.

[c] α refers to treatment of waste categorized as alpha-emitting.

5.2.2 Storage Facility Accidents

Accidents and source terms for current storage were not analyzed because the results will not help to discriminate among alternatives. This results from the underlying assumption used in the PEIS analyses that all sites will accumulate or at least not reduce these inventories for roughly ten years at which time complex-wide treatment will begin. Thus all sites will achieve their maximum inventories (leading to maximum poential releases during a storage facility accident), independent of alternative. However, recent DOE safety reports and NEPA information are cited in Section 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.

5.2.3 Treatment Facility and Inventory Modeling Assumptions

Incineration has been assessed as 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 here 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 accidents to envelop the releases from treatment process accidents (see Section 2). 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, chemical, 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 fraction of 3.0E–02 of the total amount of ash existing in the facility (DF = 3.0E–02);

- A rotary kiln explosion caused by combustible gas buildup that affects the ash existing in the rotary kiln (a fraction of 1.2E–01 of the total in the facility; DF = 1.2E–01) and partially degrades the filtration system of the facility (LPF = 1.0E–03); and

- External events leading to a fire. All 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 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); therefore, the intrafacility source term used to determine worker risk is 1,000 times the atmospheric source term.

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 treatment technologies, only source terms for incineration facility accidents are provided because they were found to bound other treatment accidents, including vitrification, which resulted in atmospheric releases much lower than analogous incineration accidents.

The WM LLW accidents analyzed here are listed in Table 5.3. Fourteen cases are considered for WM LLW alternatives, including Cases 1-9, 12, 14, 14a, 19, and 21. Only cases that included incineration for treatment were analyzed; therefore, no treatment process or facility was analyzed for Cases 2-8 in which all sites perform minimum treatment. 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.

- *Case 9 (Regionalized 2).* Eleven sites (Hanford, INEL, LANL, Oak Ridge Reservation [ORR], SRS, PORTS, Paducah Gaseous Diffusion Plant [PGDP], Fernald Environmental Management Project [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).

TABLE 5.3 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
General Handling[c]	All	Hanford	X	–[d]	–	–	–	–
	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[e]	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[e]	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[e]	19	INEL	–	X	X	X	X	–
Incineration	21	Hanford	–	X	X	X	X	–
α-Incineration[e]	21	Hanford	–	X	X	X	X	–

[a] Only one source term, generally corresponding to the risk-dominant sequence for each accident initiator, was considered.

[b] Fourteen cases are considered for WM LLW alternatives, including Cases 1-9, 12, 14, 14a, 19, and 21. Only cases that included incineration for treatment were analyzed; therefore, no treatment process or facility was analyzed for Cases 2-8 in which all sites perform minimum treatments. Cases 12 (Regionalized 5), 14 (Centralized 3), and 14a (Centralized 4) involve regionalized 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.
- *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] "–" = not applicable.

[e] α-Incineration refers to incineration of waste categorized as alpha-emitting.

- *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 5.4 and 5.5 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 are provided in Appendix B.

TABLE 5.4 Frequencies and Source Term Parameters for WM LLW Drum Handling Accidents

WM PEIS Alternative	Site	Accident	Frequency Bin (/yr) >1E-2	1E-4–1E-2	1E-6–1E-4	<1E-6	VMAR (m^3)	MAR (Ci)	DF	Total Release[a] (Ci)
All	Hanford	Drum handling breach	X	–[b]	–	–	2.0E-01	3.0E-01	0.25	4.3E-04
All	INEL	Drum handling breach	X	–	–	–	2.0E-01	2.1E-01	0.25	5.3E-05
All	LANL	Drum handling breach	X	–	–	–	2.0E-01	1.5E+01	0.25	2.1E+00*
All	LLNL	Drum handling breach	X	–	–	–	2.0E-01	2.1E+01	0.25	5.2E+00*
All	ORR	Drum handling breach	X	–	–	–	2.0E-01	1.4E-01	0.25	6.7E-05
All	PGDP	Drum handling breach	X	–	–	–	2.0E-01	6.0E-05	0.25	1.8E-08
All	Pantex	Drum handling breach	X	–	–	–	2.0E-01	1.2E-02	0.25	3.0E-03*
All	PORTS	Drum handling breach	X	–	–	–	2.0E-01	2.8E-06	0.25	6.4E-09
All	RFP	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	1.2E-06
All	SRS	Drum handling breach	X	–	–	–	2.0E-01	6.1E-01	0.25	4.8E-02*

[a] * = mainly H-3 released.

[b] "–" = not applicable

TABLE 5.5 Frequencies and Source Term Parameters for WM LLW Incineration Facility Accidents

WM PEIS Alternative[a]	Site	Accident Sequence	Frequency Bin (/yr) >1.0E–02	Frequency Bin (/yr) 1.0E–04 - 1.0E–02	Frequency Bin (/yr) 1.0E–06 - 1.0E–04	Frequency Bin (/yr) <1.0E–06	Waste Form of MAR	Source Term Parameters VMAR (m^3)	Source Term Parameters MAR (Ci)	Source Term Parameters DF	Source Term Parameters RARF[b]	Source Term Parameters LPF[b]	Total Release (Ci)
1	INEL	Explosion in the rotary kiln	X	–[c]	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	–	–	–	Combustible	6.1E–02	2.0E–02	1.2E–01	1.0E–01	1.0E–03	2.4E–07
9	ORR	Fire in the baghouse area	–	X	–	–	Combustible	6.1E–02	2.0E–02	3.0E–02	1.0E–02	1.0E–00	5.9E–06
9	ORR	Earthquake followed by fire and explosion	–	–	X	–	Combustible	6.1E–02	2.0E–02	2.0E–01	1.0E–01	1.0E–00	3.9E–04
9	PORTS	Explosion in the rotary kiln	X	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	–	–	–	Combustible	1.3E–01	1.5E–03	1.2E–01	1.0E–01	1.0E–03	1.8E–08

TABLE 5.5 (Cont.)

WM PEIS Alternative	Site	Accident Sequence	Frequency Bin (/yr)				Waste Form of MAR	Source Term Parameters					Total Release (Ci)
			>1.0E-02	1.0E-04 - 1.0E-02	1.0E-06 - 1.0E-04	<1.0E-06		VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	
9	PGDP	Fire in the baghouse area	–	X	–	–	Combustible	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	–	Combustible	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	Combustible	1.3E-01	1.5E-03	5.0E-02	1.0E-01	1.0E-00	7.6E-06
9	RFETS	Explosion in the rotary kiln	X	–	–	–	α–Combustible[d]	7.0E-01	1.5E-01	1.2E-01	1.0E-01	1.0E-03	1.8E-06
9	RFETS	Fire in the baghouse area	–	X	–	–	α–Combustible	7.0E-01	1.5E-01	3.0E-02	1.0E-02	1.0E-00	4.6E-05
9	RFETS	Earthquake followed by fire and explosion	–	–	X	–	α–Combustible	7.0E-01	1.5E-01	2.0E-01	1.0E-01	1.0E-00	3.1E-03
9	RFETS	Small aircraft impact with fire and explosion	–	–	–	X	α–Combustible	7.0E-01	1.5E-01	5.0E-02	1.0E-01	1.0E-00	7.7E-04
9	SRS	Explosion in the rotary kiln	X	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	–	–	–	Combustible	5.0E-01	2.1E-02	1.2E-01	1.0E-01	1.0E-03	2.6E-07
12	ORR	Fire in the baghouse area	–	X	–	–	Combustible	5.0E-01	2.1E-02	3.0E-02	1.0E-02	1.0E+00	6.4E-06
12	ORR	Earthquake followed by fire and explosion	–	–	X	–	Combustible	5.0E-01	2.1E-02	2.0E-01	1.0E-01	1.0E+00	4.3E-04
12	PORTS	Explosion in the rotary kiln	X	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	–	Organic	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	–	–	Organic	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	–	Organic	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	Organic	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	–	–	–	Combustible	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	–	–	Combustible	3.6E-01	1.1E+00	3.0E-02	1.0E-02	1.0E+00	3.3E-04

TABLE 5.5 (Cont.)

WM PEIS Alternative	Site	Accident Sequence	Frequency Bin (/yr) >1.0E-02	1.0E-04 - 1.0E-02	1.0E-06 - 1.0E-04	<1.0E-06	Waste Form of MAR	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
12	SRS	Earthquake followed by fire and explosion	–	–	X	–	Combustible	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	Combustible	3.6E–01	1.1E+00	3.0E–01	1.0E–01	1.0E+00	3.3E–02
12	RFETS	Explosion in the rotary kiln	X	–	–	–	α–Combustible	7.0E–01	1.5E–01	1.2E–01	1.0E–01	1.0E–03	1.8E–06
12	RFETS	Fire in the baghouse area	–	X	–	–	α–Combustible	7.0E–01	1.5E–01	3.0E–02	1.0E–02	1.0E–00	4.6E–05
12	RFETS	Earthquake followed by fire and explosion	–	–	X	–	α–Combustible	7.0E–01	1.5E–01	2.0E–01	1.0E–01	1.0E–00	3.1E–03
12	RFETS	Small aircraft impact with fire and explosion	–	–	–	X	α–Combustible	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	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	7.8E–03	1.0E+00	3.0E–01	1.0E–01	1.0E–00	3.1E–02
19	INEL	Explosion in the rotary kiln	X	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	1.8E+00	9.8E+00	3.0E–01	1.0E–01	1.0E–00	2.9E–01
19	INEL	Explosion in the rotary kiln	X	–	–	–	α–Combustible	7.0E–01	1.5E–01	1.2E–01	1.0E–01	1.0E–03	1.8E–06
19	INEL	Fire in the baghouse area	–	X	–	–	α–Combustible	7.0E–01	1.5E–01	3.0E–02	1.0E–02	1.0E–00	4.6E–05
19	INEL	Earthquake followed by fire and explosion	–	–	X	–	α–Combustible	7.0E–01	1.5E–01	2.0E–01	1.0E–01	1.0E–00	3.1E–03
19	INEL	Large aircraft impact with fire and explosion	–	–	–	X	α–Combustible	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	–	–	–	Combustible	7.3E–01	2.1E–02	1.2E–01	1.0E–01	1.0E–03	2.6E–07
19	ORR	Fire in the baghouse area	–	X	–	–	Combustible	7.3E–01	2.1E–02	3.0E–02	1.0E–02	1.0E–00	6.4E–06
19	ORR	Earthquake followed by fire and explosion	–	–	X	–	Combustible	7.3E–01	2.1E–02	2.0E–01	1.0E–01	1.0E–00	4.3E–04
19	SRS	Explosion in the rotary kiln	X	–	–	–	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	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	–	–	Combustible	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	–	Combustible	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	Combustible	2.9E+00	1.2E+01	3.0E–01	1.0E–01	1.0E–00	3.6E–01
21	Hanford	Explosion in the rotary kiln	X	–	–	–	α–Combustible	7.0E–01	1.5E–01	1.2E–01	1.0E–01	1.0E–03	1.8E–06
21	Hanford	Fire in the baghouse area	–	X	–	–	α–Combustible	7.0E–01	1.5E–01	3.0E–02	1.0E–02	1.0E–00	4.6E–05
21	Hanford	Earthquake followed by fire and explosion	–	–	X	–	α–Combustible	7.0E–01	1.5E–01	2.0E–01	1.0E–01	1.0E–00	3.1E–03
21	Hanford	Large aircraft impact with fire and explosion	–	–	–	X	α–Combustible	7.0E–01	1.5E–01	3.0E–01	1.0E–01	1.0E–00	4.6E–03

TABLE 5.5 (Cont.)

[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] – = not applicable.

[d] α refers to treatment of waste categorized as alpha-emitting.

6 ACCIDENT ANALYSIS FOR LOW-LEVEL MIXED WASTE

6.1 OVERVIEW OF LOW-LEVEL MIXED WASTE MANAGEMENT

LLMW contains both low-level radioactive and hazardous components and generally results from the same processes that generate LLW. The radioactive component, which can range from low to high activity, is regulated under the Atomic Energy Act as amended, while the hazardous component is regulated under RCRA. Some hazardous components are subject to land disposal restrictions (LDRs) under RCRA, which imposes treatment standards. Storage subject to LDRs is restricted by EPA regulations. All disposal of hazardous components must also be in compliance with RCRA standards. The current program, pursuant to the Federal Facility Compliance Act of 1992, will provide either DOE or commercial treatment capacity subject to LDRs for newly generated and stored LLMW. It will dispose of treated LLMW in DOE facilities permitted under RCRA. The DOE currently has neither RCRA-permitted disposal facilities nor adequate treatment capacity for restricted LLMW.

The inventory and future generation rate data used in the WM PEIS for LLMW were compiled by the Mixed Waste Treatment Project (MWTP) from data published in May 1994 as the *Mixed Waste Inventory Report* (MWIR; DOE 1994). This report lists about 415,000 m^3 (548,000 yd^3) of LLMW either currently stored or projected for generation over the next 20 years at 43 DOE sites. More than 99% of this waste has been or will be generated at 12 sites (Hanford, INEL, ORR, RFETS, SRS, LANL, FEMP, PORTS, PGDP, LLNL, ANL-E, and Middlesex Sampling Plant [Middlesex]). The largest generating sites are Hanford (148,000 m^3 [195,000 yd^3]), ORR (73,500 m^3 [97,000 yd^3]), RFETS (69,400 m^3 [91,600 yd^3]), and INEL (35,000 m^3 [46,200 yd^3]). Various waste streams are not considered in the LLMW analysis for the WM PEIS (see Wilkins et al. 1995 for the specific details on the exclusion of particular waste streams).

The WM PEIS alternatives being considered for TSD of LLMW are the following.

No Action (Existing and Approved)

- Continue to store untreated LLMW in existing and approved storage facilities at current generator/storage locations pending availability of treatment capacity.
- Utilize existing and approved DOE and commercial treatment facilities to meet RCRA LDRs.

Decentralization

- Establish treatment facilities (including the capacity for mobile treatment technologies), storage facilities, and possibly disposal facilities for treated LLMW at all sites where LLMW is to be generated or is currently stored.

- The WM PEIS will consider both (1) treatment to meet LDRs at all sites and (2) minimal treatment at all sites with treatment to meet LDRs at large sites (that is those with greater than 99% of the wastes).

Regionalization

- Same as decentralization, except consolidate some treatment capabilities at the 11 DOE sites with greater than 99% of wastes. All sites will treat their own aqueous wastes.

Centralization

- Same as regionalization, except further consolidate some treatment capabilities and possibly dispose at only one DOE site. All sites will treat their own aqueous wastes.

The decentralized alternative considers establishing treatment and storage facilities at all current storage or future generation sites with disposal at as many as 13 sites. Regionalization and centralization alternatives consider consolidation of selected treatment capabilities with some level of treatment at every site. LLMW alternatives are summarized in Table 6.1.

LLMW is classified as CH or RH and alpha- (having transuranic alpha-emitting radionuclides) or non-alpha contaminated. Each of these classifications (CH-alpha, CH-non-alpha, RH-alpha, and RH-non-alpha), is further subdivided into 32 waste types depending on the physical and chemical characteristics, which in turn dictate the possible treatment technologies used in the treatment of LLMW.

The WM PEIS treatment technologies were compressed into the nine generic treatment capabilities described in Table 6.2, combinations of which define the treatment train for each of the different waste streams. Figure 6.1 is a flow sheet of the entire LLMW treatment complex showing the LLMW streams taken from current storage to final form. Detailed description of treatment processes can be found in Wilkins et al. (1995).

The WM PEIS approximated site-dependent radiological profiles based on the radiological profile of LLW generated at a site, independent of the waste types, with the radionuclides allowed to decay over an average elapsed time according to the site's process history. The WM PEIS approximated waste-stream-dependent chemical profiles for each of the 32 different waste types, independent of the site of origin, by averaging over the concentrations of chemical contaminants in MWIR.

TABLE 6.1 Specification of LLMW Alternatives[a]

WM PEIS Alternative[b]	Action	Hanford	LLNL	ETEC	NTS	INEL	RFETS	LANL	Pantex	PGDP	FEMP	PORTS	ORR	Middlesex	SRS	Other
No action: LDR treatment at 3 sites. All sites store	Treat at all	-	-	-	-	T[c]	-	-	-	-	-	-	T	-	T	-
	Store at all	S[d]	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Decentralized: LDR treatment at 49 sites	Treat at all	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
Disposal at 16 sites	Dispose at 16	D[e]	D	-[f]	D	D	D	D	D	D	D	D	D	D	D	-
Regionalized 1: LDR treatment at 11 sites	Treat at 11 + 2	T	T	T*[g]	-	T	T	T	T	T	T	T	T	T*	T	-
Disposal at 12 sites	Dispose at 12	D	D	-	-	D	D	D	D	D	D	D	D	D	D	-
Regionalized 2: LDR treatment at 7 sites	Treat at 7	T	-	-	-	T	T	T	-	-	-	T	T	-	T	-
Disposal at 6 sites	Dispose at 6	D	D	-	D	D	-	-	-	-	-	-	D	-	D	-
Regionalized 3: LDR treatment at 7 sites	Treat at 7	T	-		-	T	T	T	-	-	-	T	T	-	T	-
Disposal at 1	Dispose at 1	-	-	-	D	-	-	-	-	-	-	-	-	-	-	-
Regionalized 4: LDR treatment at 4 sites	Treat at 4	T	-	-	-	T	-	-	-	-	-	-	T	-	T	-
Disposal at 6 sites	Dispose at 6	D	-	-	D	D	-	D	-	-	-	-	D	-	D	-
Centralized: LDR treatment at 1 site	Treat at 1	T	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Disposal at 1 site	Dispose at 1	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sensitivity analyses[h]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] ETEC = Energy Technology Engineering Center; Middlesex = Middlesex Sampling Plant.

[b] The WM PEIS considers four alternatives: No Action, Decentralized, Regionalized, and Centralized. This table provides an abbreviated case description and treatment (T) and disposal (D) codes for each of the 14 highest volume sites. The No Action Alternative is based on all sites using existing treatment facilities and placing the treated waste in monitored, aboveground storage facilities at all DOE sites. The Decentralized Treatment Alternative analyzes LDR treatment at 49 sites with disposal at 16 sites. Several regionalized treatment alternatives are considered, which include LDR treatment at 11, 7, or 4 sites, with disposal at either 12, 6, or 1 site(s). The Centralized Alternative analyzes treatment and disposal at only 1 site. The Remote-Handled Alternative involves treatment and disposal at 4 sites.

[c] T = treatment.

[d] S = storage.

[e] D = disposal.

[f] Not applicable.

[g] T* = specialized treatment.

[h] Sensitivity analyses include examination of vitrification and nonthermal treatment options, engineered disposal options, the use of alternative characterization methods, and the consolidation of special waste streams.

TABLE 6.2 Generic Treatment Categories and Descriptions

Treatment Capability	Abbreviation	Description
Organic destruction	ORDST	Destruction of organic liquids and solids using a broad spectrum of thermal and nonthermal organic destruction technologies. Examples include incineration; other thermal technologies such as vitrification, plasma hearth, and molten metal; and nonthermal technologies such as chemical oxidation, electron beam, and silent discharge plasma. Some of these technologies are also applicable for the STABL and METRC capabilities.
Aqueous liquids (wastewater treatment for organics)	WWTOR	Treatment technologies for oxidation of organics contained in a predominantly aqueous medium. Examples include wet oxidation, catalyzed wet oxidation, supercritical water oxidation, and related technology variations
Metal removal	METRM	Metal ion and particulate removal from liquids. Examples include settling, filtration, precipitation, ion exchange, and carbon adsorption.
Stabilization	STABL	All immobilization and microencapsulation technologies. Examples include cementation, vitrification, and polymer encapsulation.
Metal recovery	METRC	Methods for separation/collection of metals from waste streams for reuse or recycle. Examples include sorting, melting, and decontamination.
Mercury separation	HGSEP	All mercury separation, collection, and immobilization methods. Examples include gravitational, thermal, and chemical techniques to separate mercury for recycle or for immobilization by amalgamation.
Decontamination	DECON	Extractive, mechanical, hydraulic, thermal, and electrochemical techniques used to remove contamination from substrate materials.
Neutralization	NEUTR	Acid or base additions to neutralize waste streams.
Deactivation	DEACT	Appropriate technologies to deactivate reactives such as a sodium or uranium metal or cyanides prior to disposal.

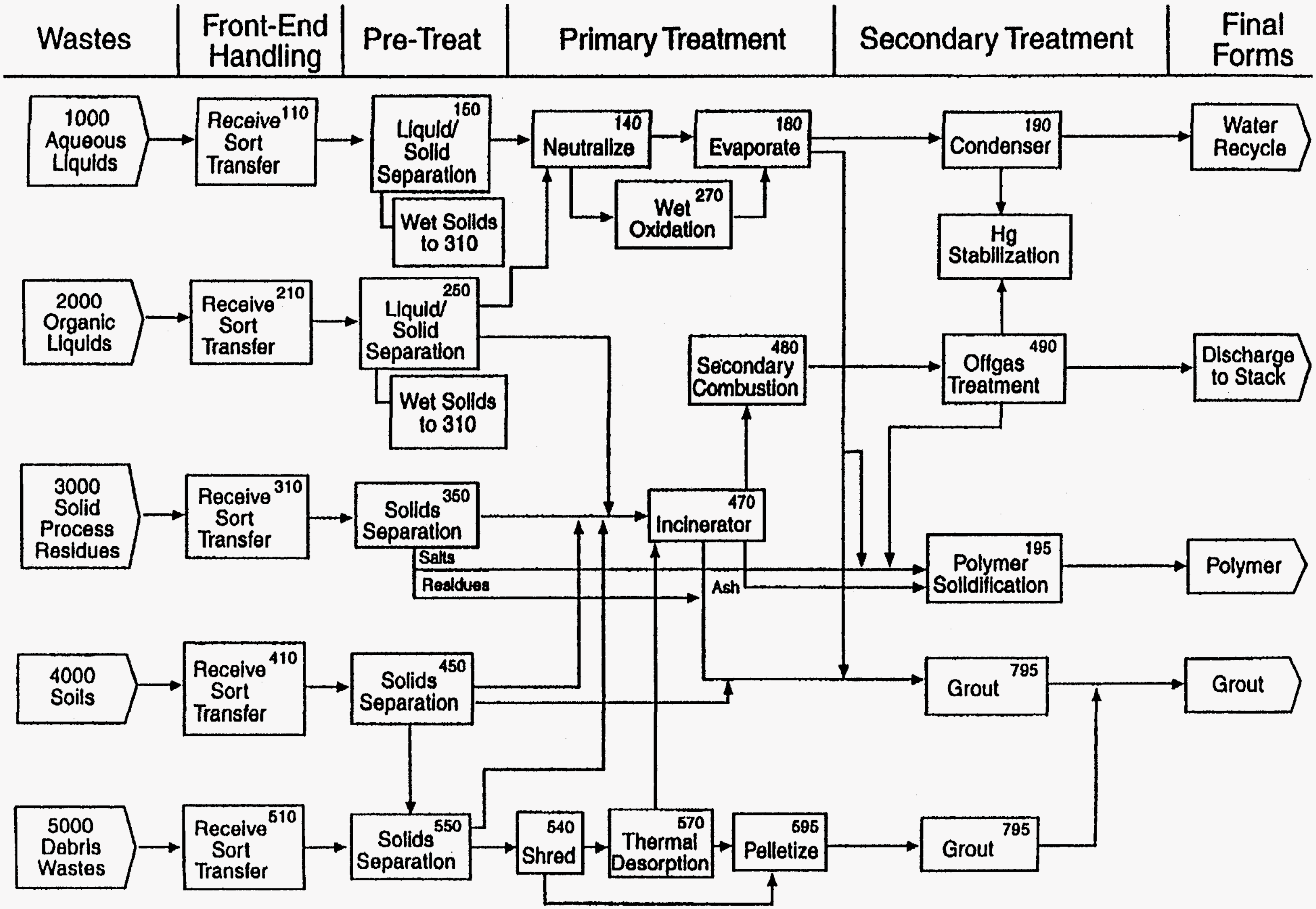

FIGURE 6.1 LLMW Baseline Treatment Flowsheet

6.2 RISK-DOMINANT ACCIDENTS AND MODELING ASSUMPTIONS

The selection of accidents considers importance to risk of both radiological and chemical hazards. The general modeling assumptions and related parameters for radiological MAR, DF, and LPF are detailed in Section 2. The RARFs are a function of the physical form of the material rendered airborne, which varies by treatability category for each waste type. A matrix has been developed for each waste type to map the treatability categories into the physical forms for which airborne release data (Appendix D) were developed. The LLMW mapping shown in Table 6.3 is based on the WM PEIS waste and process descriptions (Wilkins et al. 1995).

Review of the hazardous contents of the wastes and their concentrations suggests that spills of organic liquids (Treatability Categories [TCs] 3-6) followed by evaporation and/or combustion reactions are the events most likely to lead to the airborne release of chemically hazardous substances. The possibility of fires is strongest in the waste streams containing combustible organic substances in large proportions. These include TC 6 (58% organic solvents), TC 12 (organic particulates, oily sludges), TC 13-14 (solid organic materials), TC 19 (combustible debris), TC 20 (heterogeneous debris, including paper), TC 21 (organic lab packs), and TC 23 (solid lab packs). The inorganic contaminants are present in small concentrations and are unlikely to become involved, except in a catalytic role, in any chemistry leading to the release of toxic materials. It is assumed that the listed elements are present either in elemental form or in common oxidation states such as arsenic (As[III)], barium (Ba[II]), cadmium (Cd[II]), chromium (Cr[III] and Cr[VI]), lead (Pb[II]), selenium (Se[II] and Se[VI]), Hg(I) and Hg(II), and silver (Ag[I]). Table 6.4 summarizes the chemical release characteristics developed for the accidents.

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 their high frequency 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 throughput at that site. The assumption (taken independently for both chemical and radiological accidents) 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 >0.001/yr frequency category.

Representative radiological accident scenarios involve a single drum and assume that 25% of its inventory is subjected to stresses capable of rendering the contents 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.

TABLE 6.3 Mapping of LLMW Treatability Categories with Accident Analysis Physical Forms[a]

LLMW Treatability Category	Accident Physical Form	Comments/Assumptions
Aqueous liquid (TC 1-2)	Aqueous solution	Input waste form is a dilute aqueous LLMW solution.
Organic liquid (TC 3-6)	Organic combustible solution	Input waste form consists of flammable components (i.e, petroleum distillates, solvents) with low amounts of suspended solids.
Inorganic sludges/particulates (TC 7-8)	Aqueous slurry	Based on logic of previous treatability category. When the particulates are not in intimate contact with the solution so that they can be considered easily dispersible, then the accident category of "Noncombustible Powder" may be more appropriate. This waste stream does not include significant organics or halogenated compounds.
Salt waste (TC 9)	Noncombustible powder	
Cemented solids (TC 10)	Noncombustible aggregated solid	Noncombustible aggregated solids surrogate for cemented solids; would expect minimal risk from any potential current storage accidents, unless the cohesiveness of the cement has been degraded.
Organic sludges/particulates (TC 11-12)	Organic combustible slurry	Assumes a homogeneous mixture of solid particulates and an organic solution, with the particulate surfaces "wetted" by the solution. If, however, the particulates are not in intimate contact with the solution so that they can be considered easily dispersible, then the accident category of "Combustible Powder" may be more appropriate.
Solid organic materials (TC 13-14)	Combustible solid plastic	
Soils without debris (TC 15)	Noncombustible powder	Based on Mishima's original accident categories taken from the WRAP II safety documentation (WHC 1991b).
Soils with <50% debris (TC 16)	Noncombustible powder	As above.
Inorganic debris (TC 17-18)	Inert metal	Waste includes construction materials, equipment, and structures.

TABLE 6.3 (Cont.)

LLMW Treatability Category	Accident Physical Form	Comments/Assumptions
Organic debris (TC 19)	Dry active waste	Based on waste form description (ORNL 1994).
Heterogeneous debris (TC 20)	Inert metal	Logic used for "Inorganic Debris" also applied to this treatability category.
Lab packs with organic liquids (TC 21)	Organic combustible solution	RARFs for dry active waste were developed from available data for combustible trash and lab packs; assume that the presence of RCRA toxic metals will not significantly affect the release characteristics of this treatability category.
Lab packs without organic liquids (TC 22)	Aqueous solution	Assumes the aqueous liquids in the lab packs are not absorbed.
Solid lab packs (TC 23)	Dry active waste	
Reactive metals (TC 24)	Reactive metal	By definition.
Explosives (TC 25)	Not considered in accident analysis	When the accident physical forms were initially developed, the WM PEIS treatability categories for LLMW did not include this treatability category. Further information on the nature of contamination is required; it may, however, be expected that the explosive material has a fine layer of surface contamination. In this case, the "Combustible Powder" accident physical form may be applicable. For assessment of shock-induced explosions, the trinitrotoluene (TNT) equivalence of various explosives given in Table 3.4 of NUREG-1320 (Ayer et al. 1988) may be used. However, it should be noted that the release of energy may be great enough to cause failure of containment boundaries and lead to opening of alternative flow paths during an accident, affecting the LPF.
Compressed gases (TC 26)	Not considered in accident analysis	The release category is dependent on the compressed gas(es); if the gas is a noncondensible or a noble gas, then the "Noble Gas" category should be applied. A similar situation applies for halogens and condensible vapors.

TABLE 6.3 (Cont.)

LLWM Treatability Category	Accident Physical Form	Comments/Assumptions
Liquid Hg	Waste-form dependent	When the accident physical forms were initially developed, the WM PEIS treatability categories for LLMW did not include this treatability category. It is assumed that the solution and not the mercury itself is radioactively contaminated. One significant mercury-containing solution is the LLMW stream generated at Savannah River during reprocessing and other waste processing steps. The SRS stream is an organic liquid containing small amounts of mercury; in this case, the "Organic Combustible Solution" accident physical form may be applicable. Aqueous solutions containing mercury are also present; in this case, the appropriate accident physical form would be "Aqueous Liquids, Solutions."
Elemental Pb (TC 28)	Waste-form dependent	When the accident physical forms were initially developed, the WM PEIS treatability categories for LLMW did not include this treatability category. This treatability category may in general contain both surface contamination and induced activity in the lead. In the case of surface contamination (of radionuclides other than lead), then the "Noncombustible Powder" accident physical form may be applied. If, however, this stream contains significant amounts of induced activity, then the "Inert Metal" physical form may be more appropriate for accident stresses that do not involve high temperatures (e.g., mechanical releases).
Be dust (TC 29)	Waste-form dependent	See above.
Batteries, Pb-acid, Cd (TC 30)	Noncombustible powder	Assumes that neither the lead nor cadmium are radioactive, and that the majority of the radioactivity is associated with surface contamination.

[a] Be = beryllium, Cd = cadmium, Hg = mercury, and PB = lead.

TABLE 6.4 Chemical Releases Analyzed for LLMW[a]

Accident Sequence	Toxic Gases Released	Mass of Waste	Release Rate
Spill of aqueous non-halogenated organic liquids (TC 4)	Acetone, butanone, methanol	73 kg/drum	907-1,361 g/min[b]
Spill of aqueous halogenated organic liquids (TC 3)	Trichloroethanes, other chlorohydrocarbons	3 kg/drum	45 g/min
Spill of "pure" organic liquids halogenated by (TC 5)	Trichloroethanes tetrachloroethanes	23 kg/drum 5 kg/drum	227 g/min 45 g/min
Spill of "pure" nonhalogenated organic liquids (TC 6)	Acetone, butanone, methanol, BTX	27 kg/drum 91 kg/drum	454 g/min[a] 907 g/min[a]
Spill of "pure" nonhalogenated organic liquids (TC 6) followed by fire	BTX, CO, Cd fumes, Cr compounds, soot	5 kg/drum 91 kg/drum 0.2 kg/drum 0.2-.5 kg/drum 36 kg/drum	136 g/min 3,175 g/min 9 g/min 9 g/min 1,225 g/min.
Incinerator staging area fire; involvement of TC 12 (organic sludges), TC 19 (combustible debris), organic liquid intermediate, and organic particulates intermediate	CO	40-50% of mass of drum	3,175 g/min/drum
		60% of mass of	907 g/min/drum
	HCl	Cl-containing compounds in the stream	
		5% of mass of BTX present	136 g/min/drum
	BTX fumes		
		40% of mass of BTX plus 10% of total mass	136 g/min/drum
	Soot		
		100% of mass of Cd present	
			9 g/min/drum
	Cd fumes (condensing to very small particles)	250% of mass of Cr present	
	Cr compounds		9 g/min/drum

[a] BTX = benzene, toluene, and xylene; Cd = cadmium; CO = carbon monoxide; Cr = chromium; and HCL = hydrogen chloride.

[b] An approximation of 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 (g/min)
MW = molecular weight (g/mole)
A = surface area (m^2)
VP = effective vapor pressure (mm Hg)
R = 82.05 atm cm^3/mol K
t = temperature (°C)
μ = windspeed (m/s)

It is assumed that t = 30°C, A = 20 m^2, and windspeed = 2 m/s. For acetone in TC 4, MW = 58 and VP = 0.36 × 285 mm Hg. For acetone in TC 6, VP = 0.14 × 285 mm Hg. For benzene in TC 6, MW = 78 and VP = 0.44 × 120 mm Hg.

Representative chemical releases assume a single drum with 100% (DF = 1) of its contents spilled. The release characteristics for the spills are as follows.

Spill of TC 4 Waste. This aqueous nonhalogenated organic liquid waste is approximately 50% water, which makes a fire unlikely. A 208-L (55-gal) drum contains about 75 kg (160 lb) of acetone, butanone, and methanol. In a spill, the evaporation of moderately toxic acetone, butanone (or "MEK," methyl ethyl ketone), and methanol would take place at a rate of 907-1,361 g/min (2-3 lb/min) and last 60-90 min.

Spill of TC 3 Waste. This aqueous halogenated organic liquid waste contains approximately 50% water. A 208-L drum contains about 3 kg (6 lb) (about 1.5%) trichloroethanes and other chlorohydrocarbons. In a spill, the trichloroethanes would evaporate at a low rate (>45 g/min [0.1 lb/min]) and last at least 60 min. Some gaseous hydrogen chloride would also escape, but the amount would be negligible.

The organic compounds in TC 3 are known to decompose when exposed to moisture, light, air, heat, and metal surfaces. The decomposition routes are hydrolysis, oxidation, and dehydochlorination. All three routes give corrosive HCl as a product. An example is the hydrolysis of 1,1,1-trichloroethane:

$$H_2O + Cl_3C\text{-}CH_3 \text{ ---> } CH_3COCl \text{ (acetyl chloride)} + 2\ HCl,$$

or

$$2\ H_2O + Cl_3C\text{-}CH_3 \text{ ---> } CH_3COOH \text{ (acetic acid)} + 3\ HCl.$$

These reactions are normally slow, but are catalyzed by metal chlorides, including (but not limited to) barium chloride ($BaCl_2$), cadmium chloride ($CdCl_2$), chromium chloride ($CrCl_3$), and lead chloride ($PbCl_2$).

The dehydrochlorination of 1,1,2-trichloroethane ($Cl_2HC\text{-}CH_2Cl$) yields HCl plus the isomeric dichloroethylenes ($Cl_2C\text{-}CH_2$):

$$Cl_2HC\text{-}CH_2Cl \text{ ---> } Cl_2C\text{-}CH_2 + HCl.$$

1,1,1-Trichloroethane experiences a similar reaction. Under strongly basic conditions (and at higher temperature), the $Cl_2C\text{-}CH_2$ can lose another molecule of HCl to give the spontaneously flammable gas chloroacetylene:

$$H_2C\text{-}CCl_2 \text{ ---> } H\text{-}CC\text{-}Cl + HCl.$$

This last reaction is unlikely under the conditions of storage of the wastes: the system would be acidic from HCl produced previously.

Finally, the reaction of 1,1,1-trichloroethane with aluminum is vigorous at or near ordinary conditions:

$$2\ Al + 6\ Cl_3C\text{-}CH_3 \quad \text{--->} \quad 2\ AlCl_3 + 3\ H_3C\text{-}CCl_2\text{-}CCl_2\text{-}CH_3.$$

The analogous reaction with iron is much slower but, like the reaction with Al, is favored by acidic conditions. Such reactions precluded the use of these solvents in cleaning and degreasing operations (especially for aluminum) until stabilizers were discovered to prevent (vastly slow) them. Metal-cleaning and vapor-degreasing grades of 1,1,1-trichloroethane and 1,1,2-trichloroethane may contain up to 7% by mass of a wide variety of stabilizers.

In chlorohydrocarbon-containing wastes, storage might allow time for the slow decomposition of chlorohydrocarbons to generate enough HCl to corrode and breach the walls of the container. It is also possible that unanticipated reactions in the waste might destroy or sequester the stabilizer, allowing more rapid generation of HCl.

Spill of TC 5 Waste. This waste contains 5% water and "pure halogenated organic liquids," with a 208-L drum containing approximately 30 kg (60 lb) of chlorohydrocarbons. In a spill, unreacted trichloroethanes (12.1%) and tetrachloroethanes (2.7%) would evaporate at <0.2 kg/min (<0.5 lb/min) and last at least 2 h. The escape of gaseous hydrogen chloride would be slight.

Spill of TC 6 Waste. A 208-L drum of this "pure" nonhalogenated organic liquid waste contains about 30 kg of acetone, butanone, and methanol and about 90 kg (200 lb) of BTX (benzene, toluene, and xylene). Evaporation of moderately toxic acetone and butanone and methanol would take place at a rate of 0.5 kg/min (1 lb/min) and last 40 to 60 min. The evaporation of the less volatile but more prevalent BTX fraction would take place at a rate approximating 1 kg/min (2 lb/min) and last 90-100 min.

Spill of TC 6 Waste Followed by Fire. Waste stream TC 6 contains at least 58% flammable organic materials and <5% water, too low a proportion to prevent combustion of the organic substances in air. Even if the unspecified 27% of the waste stream is nonflammable, a fire is possible. Acetone ($C_3H_6O[l]$) and butanone ($C_4H_8O[l]$) are volatile and exceedingly flammable, giving mainly carbon dioxide and water in a fire:

$$C_3H_6O(l) + 4\ O_2(g) \quad \text{--->} \quad 3\ CO_2(g) + 3\ H_2O(g) \qquad \Delta H^o = -1{,}658\ kJ,$$

and

$$2\ C_4H_8O(l) + 11\ O_2(g)] \quad \text{--->} \quad 8\ CO_2(g) + 8\ H_2O(g) \qquad \Delta H^o = -4{,}844\ kJ,$$

where "s" is solid, "g" is gas, and "l" is liquid. The complete combustion of benzene (which, together with xylene and toluene constitutes 44% of TC 6) would generate similarly innocuous products. For example, the complete combustion of benzene (C_6H_6[l]) proceeds as follows:

$$2\ C_6H_6(l)\ +\ 15\ O_2(g)\ \text{--->}\ 12\ CO_2(g) + 6\ H_2O(g) \qquad \Delta H^o = -6{,}271\ kJ.$$

The combustion of BTX in a pool in the open air is, however, quite incomplete and yields CO and soot. Soot is a mixture of carbon and many compounds, including polycyclic aromatic hydrocarbons (PAHs) such as benzo[a]pyrene ($C_{20}H_{12}$). Thus, a range of oxidation reactions takes place:

$$10\ C_6H_6(l)\ +\ 6\ O_2(g)\ \text{--->}\ 3\ C_{20}H_{12}(s)\ +\ 12\ H_2O(g),$$

$$2\ C_6H_6(l)\ +\ 3\ O_2(g)\ \text{--->}\ 12\ C(s)\ +\ 6\ H_2O(g),$$

and

$$2\ C_6H_6(l)\ +\ 9\ O_2(g)\ \text{--->}\ 12\ CO(g)\ +\ 6\ H_2O(g).$$

The ratio of oxygen to benzene increases from 0.6 to 4.5 in this series.

The heat of combustion of the first portions of the hydrocarbons would evaporate other portions. A fire in 210 kg (460 lb) of waste (a single 208-L drum full of TC 6 waste having a density of 1 kg/L) would involve about 90 kg (200 lb) of BTX. It would evaporate perhaps 5 kg (10 lb) of unreacted BTX, an inhalation hazard, and generate on the order of 40 kg (80 lb) of soot and 90 kg of CO. The combustion of the acetone, butanone, and methanol, which contain oxygen in their molecules, would give mainly CO_2 (and water), although some CO would always form; substantial quantities of CO could form if the fire smoldered because of a lack of air. Such a fire would last perhaps 30 min (depending on the area of the spill). The proportions of the products would depend on the area of the spill as well as other circumstances of the fire.

TC 6 waste contains 1,100 mg/kg of Cd, for a total of about 225 g (0.5 lb) in a 208-L drum. Elemental Cd and its common compounds ($CdCl_2$, cadmium oxide [CdO], and cadmium nitrate [Cd $(NO_3)_2$]) emit toxic fumes of Cd(g) when strongly heated. These Cd fumes would present an inhalation hazard. TC 6 also contains 920 mg/kg of Cr. Therefore, about 230 g (0.5 lb) of Cr might also be released, probably in the form of a somewhat larger mass (about 450 g [1 lb]) of compounds of Cr such as $CrCl_3$ and chromium oxide [CrO_3]. This assumes the original presence of the Cr as $CrCl_3$ or CrO_3, or the conversion of other Cr-containing substances to these compounds in the fire.

6.2.2 Storage Facility Accidents

Accidents for current storage were not analyzed because the results will not help to discriminate among alternatives. This results from the underlying assumption used in the PEIS analyses that all sites will accumulate or at least not reduce these waste inventories for roughly 10 years, at which time complex-wide treatment will begin. Thus, all sites will achieve their maximum inventories (leading to maximum potential releases), independent of alternative. 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 6.5.

The INEL SAR for the Radioactive Waste Management Complex (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 and 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 resulting in an exposure of 2.0E-02 rem (MEI). A second accident was identified as 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 6.5 for this accident (i.e., 0.041 Ci and 0.75 rem) is 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 6.5 lists the parameters and results for the similar C&S bounding accident.

The RFETS SAR for the Central Waste Storage Facility (Building 906) identifies 3 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.6-5.

A PSE conducted for WRAP (Module 2) at Hanford identifies an accident scenario. An earthquake, including waste spills and fire, 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 6.5).

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 particulates in the waste 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

TABLE 6.5 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)[a]
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[b] 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	2.1E-06	2.0E-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-4 particulate 1.0E-5 metals 1.0 liquids	Varies with assumptions about fire	NA
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

[a] MEI = Maximally exposed individual off-site.

[b] C&S = Certified and Segregated Facility

[c] NA = not available.

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 very low frequency but with very high consequences.

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 storage facility accidents would be small.

6.2.3 Treatment Facility and Inventory Modeling Assumptions

Incineration was assessed as the treatment technology most likely to be important to risk to facility employees 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 2. 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 on-site 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 (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 (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.

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 intrafacility source term used to determine worker risk equaling 1,000 times the atmospheric source term for this accident.

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 operational fire was analyzed.

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 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 toxic chemical concentrations in the incinerator feedstock fire are much higher than 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 6.6. Eight cases are considered for the WM LLMW alternatives: Cases 1, 2, 4, 7, 10, 15, 17, and 26. Cases 7 (Regionalized 2: seven sites treat, six sites dispose) and 10 (Regionalized 3: seven sites treat, one site disposes) are equivalent with respect to the risk-dominant treatment technologies and the amount of waste throughput at each site; therefore, only Case 7 was analyzed. 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. 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.

Tables 6.7-6.9 summarize the radiological source term parameters and frequency groups for the accidents. Separate incineration facilities were assumed for treating alpha and non-alpha contaminated waste. Detailed radionuclide releases are provided in Appendix B. Chemical source terms for accidents are provided in Appendix A.

TABLE 6.6 Summary of WM LLMW Radiological Accidents Analyzed[a]

			Operational Events			External Events		
Function	WM PEIS Alternative[b]	Site[c]	Handling Breaches	Facility Fire	Facility Explosion	Seismic	Large Aircraft	Small Aircraft
Handling	All	Ames	×	–[d]	–	–	–	–
	All	ANL-E	×	–	–	–	–	–
	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 6.6 (Cont.)

			Operational Events			External Events		
Function	WM PEIS Alternative[b]	Site[c]	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	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[e]	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 6.6 (Cont.)

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[a] Only one source term, generally corresponding to the risk-dominant sequence for each accident initiator, was selected for transmittal to ORR.

[b] 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. All WM PEIS cases are defined in Chapter 2 of the WM PEIS. 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.

[c] Abbreviations: 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.

[d] – = not applicable.

[e] α-incineration refers to incineration of waste categorized as alpha-emitting.

TABLE 6.7 Frequencies and Radiological Source Term Parameters for WM LLMW Drum Handling Accidents

WM PEIS Alternative	Site	Accident	Frequency Bin (/yr) >1E-2	1E-4–1E-2	1E-6–1E-4	<1E-6	VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	Ames	Drum handling breach	X	–[a]	–	–	2.0E-01	1.1E-03	0.25	2.4E-07
All	ANL-E	Drum handling breach	X	–	–	–	2.0E-01	1.5E-01	0.25	3.5E-04
All	ANL-W	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	BAPL	Drum handling breach	X	–	–	–	2.0E-01	6.1E-01	0.25	3.5E-03
All	Battelle	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	5.4E-08
All	BNL	Drum handling breach	X	–	–	–	2.0E-01	1.5E-01	0.25	2.8E-04
All	CNS	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.5E-01
All	Colonie	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	5.0E-08
All	ETEC	Drum handling breach	X	–	–	–	2.0E-01	1.5E-01	0.25	3.7E-04
All	FMEP	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	4.5E-07
All	GATOMIC	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	2.6E-07
All	GJCT	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	1.8E-06
All	HANF	Drum handling breach	X	–	–	–	2.0E-01	6.1E-01	0.25	3.1E-03
All	INEL	Drum handling breach	X	–	–	–	2.0E-01	3.5E+00	0.25	2.9E-02
All	ITRI	Drum handling breach	X	–	–	–	2.0E-01	5.5E-01	0.25	1.3E-01
All	KAPL	Drum handling breach	X	–	–	–	2.0E-01	7.0E+00	0.25	8.2E-02
All	KCP	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	KKS	Drum handling breach	X	–	–	–	2.0E-01	7.0E+00	0.25	7.3E-02
All	KWS	Drum handling breach	X	–	–	–	2.0E-01	7.1E+00	0.25	1.1E-01
All	LANL	Drum handling breach	X	–	–	–	2.0E-01	5.4E-01	0.25	1.3E-01
All	LBL	Drum handling breach	X	–	–	–	2.0E-01	1.3E+01	0.25	3.1E+00
All	LERHR	Drum handling breach	X	–	–	–	2.0E-01	1.5E-01	0.25	3.2E-04
All	LLNL	Drum handling breach	X	–	–	–	2.0E-01	1.2E+01	0.25	3.1E+00
All	MINS	Drum handling breach	X	–	–	–	2.0E-01	7.1E+00	0.25	9.4E-02
All	Mound	Drum handling breach	X	–	–	–	2.0E-01	1.3E+01	0.25	3.1E+00
All	NNS	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	NTS	Drum handling breach	X	–	–	–	2.0E-01	1.3E+01	0.25	3.1E+00
All	ORNL	Drum handling breach	X	–	–	–	2.0E-01	1.5E-01	0.25	3.0E-04
All	Paducah	Drum handling breach	X	–	–	–	2.0E-01	3.8E-01	0.25	2.5E-05
All	PANT	Drum handling breach	X	–	–	–	2.0E-01	5.3E-01	0.25	1.3E-01
All	PHNS	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	PNS	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	PORTS	Drum handling breach	X	–	–	–	2.0E-01	2.8E-04	0.25	6.1E-08
All	PPPL	Drum handling breach	X	–	–	–	2.0E-01	1.3E+01	0.25	3.1E+00
All	PSNS	Drum handling breach	X	–	–	–	2.0E-01	7.3E+00	0.25	1.6E-01
All	RFP	Drum handling breach	X	–	–	–	2.0E-01	5.2E-03	0.25	1.8E-06
All	RMI	Drum handling breach	X	–	–	–	2.0E-01	1.1E-03	0.25	3.0E-07

TABLE 6.7 (Cont.)

WM PEIS Alternative	Site	Accident	Frequency Bin (/yr) >1E-2	1E-4–1E-2	1E-6–1E-4	<1E-6	VMAR (m^3)	MAR (Ci)	DF	Total Release (Ci)
All	SNLA	Drum handling breach	X	–	–	–	2.0E-01	9.6E-01	0.25	1.1E-01
All	SNLL	Drum handling breach	X	–	–	–	2.0E-01	1.3E+01	0.25	3.1E+00
All	SRS	Drum handling breach	X	–	–	–	2.0E-01	9.2E-01	0.25	1.0E-01
All	UMC	Drum handling breach	X	–	–	–	2.0E-01	5.2E-03	0.25	1.3E-06
All	WVDP	Drum handling breach	X	–	–	–	2.0E-01	6.1E-01	0.25	3.7E-03

[a] – = not applicable.

TABLE 6.8 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	Accident	>1.0E–02	1.0E–04 – 1.0E–02	1.0E–06 – 1.0E–04	<1.0E–06	Waste Form of MAR	VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
1	INEL	Explosion in the rotary kiln	X	–[c]	–	–	Inorganic particulates	1.2E–01	4.2E+00	1.2E–01	1.0E–01	1.0E–03	5.1E–05
1	INEL	Fire in the baghouse area	–	X	–	–	Inorganic particulates	1.2E–01	4.2E+00	3.0E–02	1.0E–02	1.0E+00	1.3E–03
1	INEL	Earthquake followed by fire and explosion	–	–	X	–	Inorganic particulates	1.2E–01	4.2E+00	2.0E–01	1.0E–01	1.0E+00	8.5E–02
1	ORR	Explosion in the rotary kiln	X	–	–	–	Inorganic sludge	2.2E+00	4.3E+00	1.2E–01	1.0E–01	1.0E–03	5.1E–05
1	ORR	Fire in the baghouse area	–	X	–	–	Inorganic sludge	2.2E+00	4.3E+00	3.0E–02	1.0E–02	1.0E+00	1.3E–03
1	ORR	Earthquake followed by fire and explosion	–	–	X	–	Inorganic sludge	2.2E–01	4.3E+00	2.0E–01	1.0E–01	1.0E+00	8.6E–02
1	SRS	Incineration ash explosion	X	–	–	–	Halogenated organic liquid	2.5E–01	5.9E+00	1.2E–01	1.0E–01	1.0E–03	7.1E–05
1	SRS	Fire in the baghouse area	–	X	–	–	Halogenated organic liquid	2.5E–01	5.9E+00	3.0E–02	1.0E–02	1.0E+00	1.8E–03
1	SRS	Earthquake followed by fire and explosion	–	–	–	–	Halogenated organic liquid	2.5E–01	5.9E+00	2.0E–01	1.0E–01	1.0E+00	1.2E–01
2	Ames	Explosion in the rotary kiln	X	–	–	–	Solid lab packs	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	–	–	Solid lab packs	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	–	Solid lab packs	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	–	–	–	Contaminated soil	8.1E–01	6.2E–01	1.2E–01	1.0E–01	1.0E–03	7.4E–06
2	ANL-E	Fire in the baghouse area	–	X	–	–	Contaminated soil	8.1E–01	6.2E–01	3.0E–02	1.0E–02	1.0E+00	1.9E–04
2	ANL-E	Earthquake followed by fire and explosion	–	–	X	–	Contaminated soil	8.1E–01	6.2E–01	2.0E–01	1.0E–01	1.0E+00	1.2E–02
2	Bettis	Explosion in the rotary kiln	X	–	–	–	Organic particulates	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	–	–	Organic particulates	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	–	Organic particulates	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	–	–	–	Organic lab packs	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	–	–	Organic lab packs	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	–	Organic lab packs	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	–	–	–	Inorganic sludge	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	–	–	Inorganic sludge	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	–	Inorganic sludge	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	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	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	–	–	–	Aqueous/nonhalogen organic liquid	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	–	–	Aqueous/nonhalogen organic liquid	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	–	Aqueous/nonhalogen organic liquid	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	–	–	–	Contaminated soil	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	–	–	Contaminated soil	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	–	Contaminated soil	1.6E–01	1.2E–01	2.0E–01	1.0E–01	1.0E+00	2.4E–03

TABLE 6.8 (Cont.)

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	Waste Form of MAR	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
2	FEMP	Explosion in the rotary kiln	X	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	1.0E-03	5.7E-06	2.0E-01	1.0E-01	1.0E+00	1.1E-07
2	GJPO	Explosion in the rotary kiln	X	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil <50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil <50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Aqueous/nonhalogen organic liquid	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	–	–	Aqueous/nonhalogen organic liquid	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	–	Aqueous/nonhalogen organic liquid	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil<50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	1.0E-03	1.3E-01	2.0E-01	1.0E-01	1.0E+00	2.7E-03

TABLE 6.8 (Cont.)

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	Waste Form of MAR	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
2	LANL	Explosion in the rotary kiln	X	–	–	–	Aqueous/nonhalogen organic liquid	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	–	–	Aqueous/nonhalogen organic liquid	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	–	Combustible debris	4.5E–03	4.6E–02	2.0E–01	1.0E–01	1.0E+00	9.1E–04
4	LLNL	Explosion in the rotary kiln	X	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Inorganic sludge	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	–	–	Inorganic sludge	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	–	Inorganic sludge	2.2E+00	4.3E+00	2.0E–01	1.0E–01	1.0E+00	8.6E–02
4	PGDP	Explosion in the rotary kiln	X	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil <50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	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	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil <50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	1.3E–01	4.3E+00	2.0E–01	1.0E–01	1.0E+00	8.6E–02

TABLE 6.8 (Cont.)

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	Waste Form of MAR	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
7	LANL	Explosion in the rotary kiln	X	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	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	–	–	–	Contaminated soil	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	–	–	Contaminated soil	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	–	Contaminated soil	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	2.5E–01	6.0E+00	2.0E–01	1.0E–01	1.0E+00	1.2E–01
15	Hanford	Explosion in the rotary kiln	X	–	–	–	Contaminated soil <50% debris	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	–	–	Contaminated soil <50% debris	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	–	Contaminated soil <50% debris	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Inorganic sludge	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	–	–	Inorganic sludge	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	–	Inorganic sludge	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	–	–	–	Halogenated organic liquid	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	–	–	Halogenated organic liquid	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	–	Halogenated organic liquid	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	–	–	–	Inorganic sludge	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	–	–	Inorganic sludge	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	–	Inorganic sludge	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	6.5E–05	9.9E–03	2.0E–01	1.0E–01	1.0E+00	2.0E–04

TABLE 6.8 (Cont.)

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	Waste Form of MAR	Source Term Parameters VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
26	INEL	Explosion in the rotary kiln	X	–	–	–	Heterogeneous debris	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	–	–	Heterogeneous debris	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	–	Heterogeneous debris	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	–	–	–	Aqueous liquid	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	–	–	Aqueous liquid	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	–	Aqueous liquid	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	7.8E–04	8.3E–02	2.0E–01	1.0E–01	1.0E+00	1.7E–03

[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.

[b] "–" = not applicable.

TABLE 6.9 Frequencies and Radiological Source Term Parameters for WM LLMW Alpha-Incineration Facility Accidents

			Frequency Bin (/yr)					Source Term Parameters					
WM PEIS Alternative[a]	Site	Accident Sequence	>1.0E-02	1.0E-04 – 1.0E-02	1.0E-06 – 1.0E-04	<1.0E-06	Waste Form of MAR	VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
2	INEL	Explosion in the rotary kiln	X	–[c]	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Aqueous/halogen organic liquid	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	–	–	Aqueous/halogen organic liquid	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	–	Aqueous/halogen organic liquid	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	–	–	–	Aqueous/nonhalogen organic liquid	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	–	–	Aqueous/nonhalogen organic liquid	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	–	Aqueous/nonhalogen organic liquid	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	–	–	–	Aqueous liquid	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	–	–	Aqueous liquid	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	–	Aqueous liquid	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Aqueous/halogen organic liquid	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	–	–	Aqueous/halogen organic liquid	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	–	Aqueous/halogen organic liquid	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	–	–	–	Aqueous/nonhalogen organic liquid	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	–	–	Aqueous/nonhalogen organic liquid	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	–	Aqueous/nonhalogen organic liquid	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	–	–	–	Aqueous liquid	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	–	–	Aqueous liquid	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	–	Aqueous liquid	1.6E-01	1.4E-02	2.0E-01	1.0E-01	1.0E+00	2.8E-04
4	SRS	Incineration ash explosion	X	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	2.1E-01	4.8E-01	2.0E-01	1.0E-01	1.0E+00	9.5E-03

TABLE 6.9 (Cont.)

			Frequency Bin (/yr)					Source Term Parameters					
WM PEIS Alternative[a]	Site	Accident Sequence	>1.0E–02	1.0E–04 – 1.0E–02	1.0E–06 – 1.0E–04	<1.0E–06	Waste Form of MAR	VMAR (m^3)	MAR (Ci)	DF	RARF[b]	LPF[b]	Total Release (Ci)
7	INEL	Explosion in the rotary kiln	X	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	1.5E–01	9.3E+00	2.0E–01	1.0E–01	1.0E+00	1.9E–01
7	LANL	Explosion in the rotary kiln	X	–	–	–	Aqueous/halogen organic liquid	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	–	–	Aqueous/halogen organic liquid	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	–	Aqueous/halogen organic liquid	2.9E–02	4.0E–02	2.0E–01	1.0E–01	1.0E+00	8.1E–04
7	RFETS	Explosion in the rotary kiln	X	–	–	–	Aqueous liquid	1.6E–01	1.4E–02	1.2E–01	1.0E–01	1.0E–03	1.7E–07
7	RFETS	Fire in the baghouse area	–	X	–	–	Aqueous liquid	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	–	Aqueous liquid	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Combustible debris	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	–	–	Combustible debris	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	–	Combustible debris	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	–	–	–	Inorganic particulates	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	–	–	Inorganic particulates	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	–	Inorganic particulates	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	–	–	–	Aqueous liquid	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	–	–	Aqueous liquid	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	–	Aqueous liquid	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	–	–	–	Heterogeneous debris	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	–	–	Heterogeneous debris	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	–	Heterogeneous debris	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] Values shown are for particulate (nonvolatile) solids such as U-235 or Pu-238; see Appendix D.

[c] "–" = not applicable.

7 ACCIDENT ANALYSIS FOR GREATER-THAN-CLASS-C LOW-LEVEL WASTE

7.1 OVERVIEW OF GREATER-THAN-CLASS-C LOW-LEVEL WASTE MANAGEMENT

GTCC is LLW generated by licensees of the NRC or Agreement States with concentrations of certain radionuclides exceeding thresholds as specified in 10 CFR 61.55. DOE has responsibility for the disposal of commercial GTCC under the Low-Level Radioactive Waste Policy Amendments Act of 1985. Disposal requires a NRC-licensed geologic repository or an NRC-approved alternative facility that provides isolation of the waste. At the request of NRC and the Agreement States, DOE currently provides interim storage for limited amounts of GTCC LLW, primarily small sealed radioactive sources (e.g., Cs and Sr for medical therapy research and Am for well logging). A much larger future potential source includes nuclear utility waste, mainly activated metals from SNF assemblies and reactor core components. Uncertainties include the effect of concentration averaging and a clear delineation between SNF and GTCC, the resolution of which could substantially alter projected volumes.

The DOE program consists of three phases: (1) continuation of limited interim storage of (primarily) sealed sources, (2) providing a centralized dedicated storage facility until an NRC-licensed facility is available, and (3) disposal in either an HLW repository or a separate NRC-licensed facility. Because the DOE has not yet initiated efforts on an NRC-licensed facility, the current program assumes disposal in the HLW repository. Nuclear utility volumes will be needed to define Phase 2 centralized storage requirements, potential packaging and treatment requirements, and fee specifications. The dedicated and interim storage phases could be merged depending on commercial reactor decommissioning decisions. The WM PEIS only considers alternatives for current interim storage of sealed sources. These alternatives are:

No Action (Existing and Approved)

- Continue to store limited quantities of commercial GTCC at Hanford, FEMP, INEL, LANL, ORR, and SRS in existing and approved storage facilities.

Decentralization

- Continue no action 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.

7.2 ACCIDENT CONSIDERATIONS AND CONCLUSIONS RELATING TO SOURCE TERMS

Current projected volumes of sealed sources (on the order of a few cubic meters) are uncertain with regard to the mix of compositions that will be received and are expected to be a minimal fraction of the total volume provided by utility waste. Independent of the mix of sealed sources received, the facility accident potential associated with these sources will be small for the following reasons:

- Most of these sources are doubly encapsulated in stainless steel,
- The source material form is physically and chemically stable,
- Quantities are relatively small, and
- The sources will probably be stored in their shipping packages. Since these packages will meet U.S. Department of Transportation and NRC requirements, they will already be designed to withstand transportation accidents that are likely to be more severe than those postulated for a storage facility.

Thus, the utility waste inventories will undoubtedly dictate future facility accident impacts. Moreover, given the overall programmatic uncertainties, the results of analyses of facility accidents for current DOE interim storage of sealed sources would have no bearing on the DOE guidelines. For these reasons no source terms have been developed.

8 ACCIDENT ANALYSIS FOR HAZARDOUS WASTE

8.1 OVERVIEW OF HAZARDOUS WASTE MANAGEMENT

Hazardous waste is waste regulated under RCRA, the Toxic Substances Control Act, or by the States. DOE sources of HW include defense, nuclear energy, and energy research programs. Examples of HW include laboratory solutions, acids, caustics, degreasing agents, and materials contaminated with hazardous cleaning compounds. Wastewater, which represents 97% of the DOE complex's total volume of HW, is generally treated on-site at the largest facilities. The WM PEIS alternatives do not address wastewater because on-site treatment remains part of each alternative. The DOE strategy is to first minimize the generation of hazardous waste. For the HW generated, the next step is to properly classify, treat, and dispose of that waste.

Between 1984 and 1991, DOE shipped 13 million kg/yr (14,330 tons/yr) of HW to off-site commercial waste management facilities. Each site implements its own waste management program, with the use of commercial facilities generally exceeding use of DOE facilities. A DOE moratorium now prohibits shipping certain wastes to commercial facilities unless the wastes can be proven to be solely in the hazardous classification (i.e., it has been demonstrated that there is "no added" radioactivity from DOE operations, and the surface radioactivity satisfies limits established in DOE orders).

The WM PEIS alternatives being considered for TSD of HW are the following.

No Action/Decentralization

- Minimize generation to the extent possible.
- Maintain and operate existing approved DOE storage facilities and limited treatment facilities at DOE sites in accordance with applicable permit requirements.
- Manifest, package, and ship HW to commercial permitted TSD facilities.

Regionalization

- Manage approximately 50% of the HW with DOE-owned and -operated facilities to be permitted under RCRA.

Centralization

- Manage all HW in a very limited number of either DOE-owned and -operated or commercial facilities. Approximately 90% of the waste in this alternative is to be treated at DOE-owned and -operated facilities.

The alternatives and specific cases considered in the WM PEIS are shown in Table 8.1. They address the extent and manner of continued reliance on commercial TSD facilities. A selected number of these commercial facilities were chosen to represent the spectrum of commercial facilities DOE has been using and that are available for DOE use. In addition, instead of considering all 35 or so DOE facilities, the focus has been on the 10 facilities that produce more than 90% of the hazardous waste. The alternatives cover the mix of treatment alternatives from minimal to considerable use of outside commercial facilities. The treatment technologies and the HW categories are summarized in Table 6.2. Detailed descriptions of HW treatment processes can be found in Lazaro et al. (1995).

The assessment here considers only the quantities of HW arising from ongoing DOE facility waste management activities (WM HW). Wastes generated by the environmental restoration program (ER HW wastes) were excluded from consideration in the WM PEIS.

Accidents involving the on-site treatment of WM waste were expected to lead to low consequences and risk (except possibly for incineration, because of the high dispersibility of the resulting ash and the potential for enhanced propagation due to the elevated temperature and pressure). For incineration, an accident involving a facility fire and explosion was postulated to occur.

8.2 RISK-DOMINANT ACCIDENTS AND FACILITY 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 representative of (1) potentially life-threatening health effects and (2) the potential for any adverse health effects were selected. Potential for any 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 determined. The HW constituents of concern were chosen from the U.S. Department of Transportation (DOT) list of poison inhalation hazards and from toxicological analyses (Hartmann et al. 1994). Eleven installations that accept more than 90% of the HW from the DOE complex were selected as representative of the DOE sites. Inventory data for the selected installations 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 of a release.

All accident sequences were divided into the following three general categories, each having subcategories and including potentially life-threatening and any adverse effects endpoints.

1. Spills resulting in partial vaporization of the waste ("spill only"),

TABLE 8.1 Specification of HW Alternatives[a]

WM PEIS Alternative[b]	Action	Hanford	INEL	LLNL	LANL	SNL-NM	Pantex	KCP	ANL-E	Fermi	ORR	SRS	Commercial TSDs
No Action/Decentralized:[c]	Treat at 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	T	T	T
	Dispose	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	D
Regionalized 1:													
50% treated/disposed on-site at 5 sites	Treat at 5	T	T	NA	T	NA	NA	NA	NA	NA	T	T	T
50% treated/disposed commercially	Dispose	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	D
Regionalized 2:													
90% treated/disposed on-site at 2 sites	Treat at 2	NA	T	NA	NA	NA	NA	NA	NA	NA	T	NA	T
10% treated/disposed commercially	Dispose	NA	D	NA	NA	NA	NA	NA	NA	NA	D	NA	D

[a] T = Treatment by on-site organic destruction; D = Disposal; NA = not applicable.

[b] The WM PEIS considers the potential consequences of increased use of on-site facilities for treatment and disposal versus reliance on commercial facilities. The existing program (No Action Alternative) relies heavily on commercial vendors for treatment and disposal of wastes with organic constituents. This table presents a breakdown of activities at 11 sites for these three alternatives. The WM PEIS focuses on waste with organics; the sites denoted by a single "T" in the table conduct organic destruction. It is assumed, however, that these sites also conduct any additional treatment necessary to meet LDRs. In addition, although organic destruction is assumed to be a part of the existing program at only three locations (LANL, ORR, SRS), most sites perform some very limited degree of treatment on-site using one or more of the following treatment technologies: fuel blending, fuel burning, solvent recycling, stabilization, deactivation, metal removal and recovery, mercury removal and recovery, aqueous treatment, and/or recycling.

[c] Most sites conduct on-site treatment and/or neutralization or deactivation of selected waste streams.

2. Spills followed by ignition of the waste ("spill plus fire"), and

3. "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"), and

   - Explosion from exposure of reactive material to air followed by fire ("fire and explosion").

Table 8.2 lists the representative accidents chosen to serve as surrogates for all risk-dominant sequences. Thirteen accidents involve the release of potentially life-threatening toxic gases. Five accidents (1e-g and 2e-f) involve the release of materials not considered potentially life-threatening but analyzed for any adverse effects. The development of these accidents took account of the following:

- The 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, and oxidizers; and

- The 90-day residence limit for RCRA HW in a storage facility.

The accident sequences include a range of high-probability, low-consequence accidents and high-consequence, low-probability accidents. In general, they involve a chemical or physical change in stored materials after an initial incident. Equations were written to represent the changes anticipated to occur during the accidents. Toxic gaseous products were identified and their masses estimated from the mass of the reactants and the stoichiometry of the reactions. Annual frequency of accidents includes both the spill frequency and, where appropriate, the probability that all the agents are present at the same time. Rates of releases were estimated based on engineering judgment and the recognition that such rates often 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/concentration of reactive materials (often unknown), and the proximity and nature of nearby reactive materials (including packaging, shelving, and flooring). Appendix H provides details of the selection of the accident sequences, the chemistry involved in their progress, and the estimation of toxic gas release rates.

TABLE 8.2 Airborne Release Assumptions for Representative HW Accidents[a]

	Scenario	Toxic Gas Released	Mass of Waste Spilled	Release Rate Functional Form		Annual Frequency (/container handling operation)[c]	Concentration Limit (ppm)[b]	
				min	lb/min		PAEC Value	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 10-150	3	2.0E−04	2.5E+01	5.6E+02
(1b)	Acid waste spill (i.e., HCl), releasing moderately toxic vapor	HCl	450 lb of 37% HCl (166 lb)	0-10 10-600	2	2.0E−04	8.0E−01	1.0E+02
(1c)	Acid waste spill (i.e., HF), releasing highly toxic vapor	HF	30 lb of 50% HF (15 lb)	0-10 10-600	2	2.0E−04	1.0E+00	2.4E+01
(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 10-100	1	2.0E−04	4.1E−01	3.5E+02
(1e)	Weak acid waste spill (i.e., $C_2H_4O_2$), releasing mildly toxic vapor	$C_2H_4O_2$	30 lb of 100% $C_2H_4O_2$	0-10 10-900	0.3	2.0E−04	1.5E+01	NA[d]
(1f)	Volatile liquid spill (i.e., CS_2), releasing toxic vapor	CS_2	18 lb of 100% CS_2	0-3 3-60	0.5	2.0E−04	5.5E−01	NA
(1g)	Liquid spill (i.e., $Cl_3C\text{-}CH_3$), releasing mildly toxic vapor	$Cl_3C\text{-}CH_3$	100 lb of 100% $Cl_3C\text{-}CH_3$	0-10	40	2.0E−04	3.1E+01	NA
Spill Plus Fire[e]								
(2a)	Spill of aromatic hydrocarbon (i.e., BTX) results in burning pool; polyaromatic soot and unburned hydrocarbons become airborne	PAH soot and unburned hydrocarbons	250 lb of benzene (12% raw, 40% soot, and 48% CO_x)	0-120	2.1	2.0E−05	1.8E+01	3.0E+03
(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	5	2.0E−05 (probability of HF present)	1.0E+00	2.4E+01
(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	40	2.0E−05 (probability of KCN present)	1.0E+00 (1 mg/m^3)	5.0E+00 (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	2.8	2.0E−05 (probability of Hg present)	1.0E−02 (mg/m^3)	1.0E−01 (mg/m^3)

TABLE 8.2 (Cont.)

Scenario		Toxic Gas Released	Mass of Waste Spilled	Release Rate Functional Form		Annual Frequency (/container handling operation)[c]	Concentration Limit (ppm)[b]	
				min	lb/min		PAEC Value	PLC Value
Spill Plus Fire (Cont.)								
(2e)	Spills and ignition of flammable liquid, breaching nearby containers with Cd-containing compounds (i.e., Cd salts or batteries)	Cd fumes	300 lb of CdO (17.5 lb of Cd fumes)	0-30 (for fires of 950°C)	10	2.0E−05 (probability of Cd present)	7.5E−02	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 burned and unburned dichromate salts	30 lb of dichromate dust	1-5	6	2.0E−05 × 1.2E−02 (probability of dichromate salt present)	1.0E−01 (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	12	2.0E−05 × 1.0E−02 (probability of NH_3 present)	2.5E+01	5.6E+02
(3b)	Accidental confinement of oxidizing and reducing agents; reaction generates heat igniting packaging, breaching nearby container	NH_3 or contents of any other nearby gas cylinder	NH_3 (60 lb)	0-5	12	3.0E−03 (probability of both agents present)	2.5E+01	5.6E+02
(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, breaching nearby containers	NH_3 or any other nearby gas cylinder	NH_3 (60 lb)	0-5	12	3.0E−03 (probability of both agents present)	2.5E+01	5.6E+02
(3d)	Accidental rupture of compressed gas cylinder (NO_x, flammable) due to valve failure, releasing toxic gas	NH_3	Compressed gas 100 lb/ container	0-5	100	2.0E−05[g]	2.5E+01	5.6E+02
(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	12	3.0E−03[h]	2.5E+01	5.6E+02

TABLE 8.2 (Cont.)

[a] See notation list for compounds referred to in this table.

[b] Limits apply for a 15-min exposure and are in parts per million (ppm) unless otherwise specified.

[c] Number of containers at each site.

[d] NA = not applicable.

[e] It is assumed that 1 in 10 spills will be ignited by a nearby spark (a conservative value) for an outdoor storage facility. When an accident sequence requires a number of initiating steps involving more than one type of waste, the probability that all of the necessary constituents 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 probability of compressed gas container breach is 1 per 10,000 handling operations; the value for breaching secondary containment is 1 in 10.

[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 probability of an accident depends on the throughput of the waste type(s) involved. The progression of some accident sequences requires certain additional waste types to be near the initiating container. For instance, accident subcategory 2d in Table 8.2 is dependent upon the probability that flammable liquids, accelerants, and Hg cells are being stored at the same time.

A release is defined as some form of airborne emission (e.g., vapor, gas, aerosol, or particulates) from the original chemical or a reaction product. Recall that all hazardous chemical releases were placed into one of 18 subcategories depending on (1) the category of accident (e.g., spill, spill plus fire), (2) the range of accidents within the category, and (3) the particular health end point. (Note also that many chemicals in the inventory of each site pose no risk if released and therefore do not need to be considered further.) The HW inventories for FY 1992 for 12 DOE sites (the 11 referred to earlier and NTS) were studied 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 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 using mass balance equations with consideration of vapor pressure and heat of vaporization at room temperature (see Appendix H).

8.2.1 Packaged Waste Storage and Handling Operations

Hazardous wastes are first accumulated in drums or lab packs at the source (laboratory or shop), then 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.

8.2.1.1 Material at Risk and Damage Fractions

Since storage packages are typically plastic-lined, carbon steel, 208-L (55-gal) drums, the MAR for handling accident scenarios is assumed to be one drum. Double containment is typical of packaged, chemically hazardous liquids with an intervening packing of absorbent material; however, consistent with previous analyses, the assumption is made that the liquid is completely spilled (i.e., DF = 1) upon breach of the waste package (Salazar and Lane 1992; ORR 1993).

8.2.1.2 Spill Scenario Frequencies

The frequency of container breaches is on the order of 1.0E−04 per handling operation (see Section 2). Because HW storage facilities are allowed to hold materials for a maximum of 90 days, it was assumed that all the containers that arrive at a facility are 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 2, the annual frequency for a spill from a container breach for chemical x due to a handling accident can then be given by

$$f_{sx} = 2 \times 10^{-4}\, n_x \, , \tag{8.1}$$

where n_x is the number of waste containers of chemical x received annually at the facility.

8.2.1.3 Spill Plus Fire Scenario Frequencies

The frequency of occurrence for subcategory 3a in Table 8.6 — the spill, ignition, and atmospheric release of chemical x — is given by

$$f_{sfx} = f_{sx}\, P_f \, , \tag{8.2}$$

where P_f is the conditional probability of ignition (1.0E−01 for outdoor storage pads and 2.0E−01 for enclosed facilities; see Section 2). The frequency of occurrence in accident subcategories 2b-f (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:

$$f_{sfy} = \left(2 \times 10^{-4}\, n_f\, P_f\, P_{fy}\right) + \left(2 \times 10^{-4}\, n_y\, P_f\right) , \tag{8.3}$$

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. P_{fy} is approximated by the ratio of the number of chemical y drums to the total number of containers. The second term in the expression is added only when chemical y is also flammable.

8.2.1.4 Frequencies of Other Event Combinations

Accident subcategory 3a involves a spill and subsequent fire, which then induces an explosion. 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

$$f_{sfey} = 2 \times 10^{-4}\, n_f\, P_f\, P_{fy}\, P_e \, , \tag{8.4}$$

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 P_e, the conditional probability that the engulfed gas canister will explode, conservatively assumed to be 1.

Fire-only scenarios (3b and c) 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

$$f_{frc} = 3 \times 10^{-3} \, n_{rc} \, , \tag{8.5}$$

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 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 is expected to be relatively small. The combustible material closest to the containers is usually a cardboard pallet, which requires temperatures higher than 232°C (450°F) 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 required for releases of other toxic gases, 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, providing double-walled storage of the compressed gas. The annual frequency of double-walled container breach per unit handling operation is estimated at 1.0E–05, implying an order of magnitude credit for the second containment. This estimate 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

$$f_{secg} = 2 \times 10^{-5} \, n_{cg} \, , \tag{8.6}$$

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

$$f_{ferx} = 3 \times 10^{-3}\, n_{rx} \,, \tag{8.7}$$

where n_{rx} is the number of containers containing potentially reactive chemical *rx* (or its equivalent) that are received annually at the facility. It should be noted that 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. Ether should never be stored for extended periods because of this potential accidence sequence.

8.2.2 Storage Facility Accidents

HW is generally packaged in 208-L (55-gal) drums and stored in RCRA-compliant staging areas or weather protection sheds prior to off-site shipment for commercial treatment and disposal. An HWSF typically houses more than 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 based on toxicity, corrosivity, reactivity, and ignitability. Most HWSFs have containment berm areas and individual storage cells that permit waste segregation per RCRA/EPA criteria, some 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 2.5) was assumed for the analyses.

A facilitywide fire has been chosen as the representative internal accident. This is the type of accident scenario considered as the maximum reasonably foreseeable accident in the INEL HWSF SAR (EG&G 1990). It would engulf a large fraction of the facility, would involve secondary explosions and fire propagation from one area to another, and would consume numerous chemicals that vent hazardous substances upon combustion or heating.

External 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 proportional to the average number of drums 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.

Evaluation of Source Term Parameters and Frequencies. The chemicals in the facility fire source term are those identified as particularly hazardous in spills with fire (Table 8.5). 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 that for the individual drum fires. The DF is assumed to be 1, because the accident scenario assumes no mitigation. In the representative seismic event, it is assumed 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 facilitywide fire plus the hazardous releases due to explosions caused by fires or impacts. The representative chemicals in these accidents are shown on Table 8.4. As in the case of facility fires, the DF for aircraft-induced accidents is taken as 1 due to the 90-day limit on storage of RCRA waste.

Conditional probabilities for ignition and fire attendant upon violent breach of flammable liquid packages are estimated to lie between 1.0E–01 and 1 (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 facilitywide fire frequency of 1.0E–04/yr.

The frequencies of the external initiators are site-dependent as discussed in Section 2. A conditional probability of container breach of 1 has been used for large airplane impacts and of 9.0E–01 for small airplane impacts, consistent with the LLW storage facility analysis (LLW and HW are both generally packaged in DOT 208-L drums). For earthquakes, the best estimate (Coats and Murray 1984) 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.

8.2.3 Treatment Facility Accidents

Incineration was selected as the most risk-dominant 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) igniting a feedstock fire are also analyzed. A generic treatment facility, consisting of a series of linked treatment process modules, was described in Section 2. A DOE Hazard Category of 2, concomitant performance of its systems, and double-HEPA filtration systems were assumed.

Evaluation of Source Term Parameters and Frequencies. 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 upon the magnitude of the initiator, and is assumed to be 1.0E–01 for an internal explosion, 2.0E–01 for seismic events and small plane crashes, and 3.0E–01 for large airplane impacts. This accounts for the scattered physical locations of the waste in the treatment facility and that only some of the chemicals in the feedstock area are identified as airborne release hazards in Table 8.2.

Estimates discussed in Section 2 of an annual frequency of 1.5E-02/yr for explosions in the rotary kiln assembly and the secondary combustion chamber, respectively, agree with the experience of commercial incineration operation, and provide the basis for the internal fire frequencies used herein. The frequencies of aircraft-initiated accidents are site dependent. They were obtained in the same manner as 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.

8.3 RESULTS

The airborne release parameters for all accident types were shown in Table 8.2. Table 8.3 summarizes the estimated frequencies for the different handling accidents in the decentralized, regionalized, and centralized alternatives for each DOE site based on the appropriate surrogate chemical inventories. Single drum inventories are assumed for the handling accidents.

Tables 8.4 and 8.5 summarize the results for the storage and treatment facility accidents by site and alternative. The column labeled "Total Number 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 8.3 Site-Dependent Annual Frequencies of Representative HW Handling Accidents

Site	Decentralized Alternative						
Spill[a]	(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	0.00E+00	0.00E+00	0.00E+00	8.00E–04	0.00E+00	0.00E+00	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	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E–03
Pantex	0.00E+00	2.20E–03	4.00E–04	1.22E–02	2.00E–04	0.00E+00	0.00E+00
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[a]	(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	0.00E+00	0.00E+00	
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	0.00E+00	7.24E–03	2.78E–05	2.31E–03	2.37E–03	0.00E+00	
Other[a]	(3a)	(3b)	(3c)	(3d)	(3e)		
ANL-E	1.39E–05	3.00E–03	9.30E–02	2.80E–04	1.20E–02		
Fermi	0.00E+00	0.00E+00	3.00E–03	1.40E–04	0.00E+00		
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	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Pantex	0.00E+00	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 8.3 (Cont.)

Site	Regionalized Alternative						
Spill[a]	(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[a]	(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[a]	(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	Centralized Alternative						
Spill[a]	(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[a]	(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							
	(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 8.2 for definitions of accidents and released chemicals.

TABLE 8.4 Frequencies and Source Term Parameters for WM HW Storage Facility Accidents

WM PEIS Alternative[a]	Site	Accident Frequency (/yr)	Total Number Containers	Damage Fraction	Number Containers Breached	Representative Subcategory Chemicals - 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
	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

TABLE 8.4 (Cont.)

WM PEIS Alternative[a]	Site	Accident Frequency (/yr)	Total Number Containers	Damage Fraction	Number Containers Breached	Representative Subcategory Chemicals - Containers Involved[b]							
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	NA[c]	29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LLNL	NA	207	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LANL	NA	80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ORR	NA	17	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	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	NA	33	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Fermi	NA	6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
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	NA	189	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ORR	NA	62	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	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	NA	192	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Small Aircraft Impacts													
1	INEL	NA	34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KCP	2.7E−07	29	1.0E+00	29	15	0	0	5	1	0	2	6
	LLNL	2.7E−07	207	1.0E+00	207	84	6	5	13	8	3	8	80
	LANL	2.7E−07	80	1.0E+00	80	35	5	4	0	7	5	5	19
	ORR	2.7E−07	17	1.0E+00	17	17	0	0	0	0	0	0	0
	Pantex	NA	33	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hanford	NA	19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 8.4 (Cont.)

WM PEIS Alternative[a]	Site	Accident Frequency (/yr)	Total Number Containers	Damage Fraction	Number Containers Breached	Representative Subcategory Chemicals - Containers Involved[b]							
	SNL-NM	NA	130	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	SRS	NA	107	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ANL-E	2.7E−07	33	1.0E+00	33	8	1	4	11	2	2	1	4
	Fermi	2.7E−07	6	1.0E+00	6	1	0	1	2	0	0	0	2
2	INEL	NA	34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hanford	NA	157	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LANL	2.7E−07	189	1.0E+00	189	71	12	7	27	26	8	8	30
	ORR	2.7E−07	62	1.0E+00	62	33	1	3	12	2	1	2	8
	SRS	NA	107	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	INEL	NA	503	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ORR	2.7E−07	192	1.0E+00	192	106	1	5	39	24	2	3	12

[a] Case 1 is the No Action/Decentralized Alternative with two treatment sites, Case 2 is the Regionalized 1 Alternative with five treatment sites, and Case 3 is the Regionalized 2 Alternative with two treatment sites.

[b] Refer to Table 8.2 for definitions of released chemicals.

[c] NA = not applicable.

TABLE 8.5 Frequencies and Source Term Parameters for WM HW Incineration Facility Accidents

WM PEIS Alternative[a]	Site	Accident Frequency (/yr)	Total Number Containers	Damage Fraction	Number Containers Breached	Representative Subcategory Chemicals – Containers Involved[b] (2a)	(2b)	(2c)	(2d)	(2e)	(2f)
Representative Fire											
2	INEL	1.5E–02	20	1.0E–01	2	1	0	0	0	1	0
	LANL	1.5E–02	50	1.0E–01	5	3	0	0	1	1	0
	ORR	1.5E–02	50	1.0E–01	5	2	1	0	1	1	0
	Hanford	1.5E–02	30	1.0E–01	3	2	0	0	1	0	0
	SRS	1.5E–02	20	1.0E–01	2	1	0	0	1	0	0
3	INEL	1.5E–02	80	1.0E–01	8	5	1	0	1	1	0
	ORR	1.5E–02	80	1.0E–01	8	5	0	0	2	1	0
Seismic Events											
2	INEL	5.0E–05	20	2.0E–01	4	2	0	0	0	1	1
	LANL	5.0E–05	50	2.0E–01	10	7	1	0	1	1	0
	ORR	5.0E–05	50	2.0E–01	10	5	1	0	2	2	0
	Hanford	5.0E–05	30	2.0E–01	6	4	0	1	1	0	0
	SRS	5.0E–05	20	2.0E–01	4	2	0	0	1	1	0
3	INEL	5.0E–05	80	2.0E–01	16	9	1	1	3	2	0
	ORR	5.0E–05	80	2.0E–01	16	10	0	1	3	2	0
Large Aircraft Impacts											
2	INEL	1.2E–09	20	3.0E–01	6	3	0	0	0	2	1
	LANL	NA[c]	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ORR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Hanford	5.4E–09	30	3.0E–01	9	6	0	1	2	0	0
	SRS	5.0E–09	20	3.0E–01	6	4	0	0	1	1	0
3	INEL	2.7E–09	80	3.0E–01	24	12	2	1	4	4	1
	ORR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Small Aircraft Impacts											
2	INEL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LANL	7.0E–09	50	2.0E–01	10	6	1	1	1	1	0
	ORR	7.0E–09	50	2.0E–01	10	5	1	0	2	2	0
	Hanford	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	SRS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	INEL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ORR	7.0E–09	80	2.0E–01	16	10	0	1	3	2	0

[a] Case 1 is the No Action/Decentralized Alternative with two treatment sites, Case 2 is the Regionalized 1 Alternative with five treatment sites, and Case 3 is the Regionalized 2 Alternative with two treatment sites.

[b] Refer to Table 8.2 for definitions of released chemicals.

[c] NA = not applicable.

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