APPENDIX A

HAZARD AND ACCIDENT ANALYSIS
FOR
URANIUM MANAGEMENT PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

ARF	airborne release fraction
DOE	U.S. Department of Energy
DR	damage ratio
ERPG	Emergency Response Planning Guideline
HC-2	Hazard Category 2
IDLH	Immediately Dangerous to Life and Health
INEEL	Idaho National Engineering and Environmental Laboratory
LEU	low-enriched uranium
MAR	material-at-risk
mph	miles per hour
MTU	metric tons of uranium
N/A	not applicable
NU	normal uranium
PC-3	Performance Category 3
PEA	programmatic environmental assessment
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
RF	respirable fraction
SRS	Savannah River Site

APPENDIX A

HAZARD AND ACCIDENT ANALYSIS FOR URANIUM MANAGEMENT PROGAMMATIC ENVIRONMENTAL ASSESSMENT

A.1 INTRODUCTION

This appendix discusses the systematic identification and assessment of hazards associated with uranium management activities for the U.S. Department of Energy (DOE). This analysis includes a semiquantitative evaluation of the potential internal hazards, natural phenomena hazards, and other external events that could cause the identified hazards to develop into accidents. This appendix presents the potential consequences and risks to workers (immediate and co-located) and members of the public. Risks are evaluated for routine operations and nonroutine (accident) conditions.

Hazards and accidents are considered for a number of interim storage alternatives and disposition options, as described in Chap. 2 of the programmatic environmental assessment and summarized in Tables A.1 and A.2. Inventories for each interim storage alternative and disposition option are shown in Tables A.3 and A.4.

Table A.1. Uranium management interim storage alternatives

Alternative	Discussion
No Action	Continued storage at current sites. Total material included in the PEA is 14,200 MTU
Centralized storage at a single DOE site	All material transferred to a single, centralized DOE storage location
Centralized storage at a single commercial site	All material transferred to a single, centralized commercial storage location (east or west)
Partially consolidated storage at several DOE sites	Material is moved to the closest consolidated storage location
Partially consolidated storage at two DOE sites	Consolidate at one eastern DOE site (PORTS) and one western DOE site (INEEL)
Partially consolidated storage at two commercial sites	Consolidate at one eastern commercial site and one western commercial site
Partially consolidated storage based on physical form	Consolidate by physical form (i.e., the site with the largest quantity of a specific physical form is the preferred storage location for all materials of that form)

DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
MTU = metric tons of uranium.
PEA = programmatic environmental assessment.
PORTS = Portsmouth Gaseous Diffusion Plant.

Table A.2. Uranium management disposition options

Option	Discussion
Commercial processing/domestic sales	All material transferred from interim storage to a single commercial processing facility or single sales distribution point (east or west). Total material included is 14,200 MTU
Transfer to research facilities	Transfer ~50 MTU from interim storage to the furthest DOE or other research location
Transfer to other government agencies	Transfer ~2,500 MTU from interim storage to unspecified location (use furthest distance already evaluated)
Foreign sales	All LEU/NU (~4,050 MTU) transferred to eastern or western port for overseas shipment

DOE = U.S. Department of Energy.
LEU = low enriched uranium.
MTU = metric tons of uranium.
NU = normal uranium.
PEA = programmatic environmental assessment.

Table A.3. Uranium management interim storage inventories

		Current storage		Additional materials to be moved	
Alternative	Site/form	Amount, 10^3 MTU	Number of containers	Amount, 10^3 MTU	Number of containers
No Action	INEEL	1.5	639	N/A	N/A
	PGDP	<0.1	8		
	PORTS	4.4	24,765		
	SRS	3.0	2,867		
	Oak Ridge	1.4	6,431		
	All others	3.9	37,124		
Centralized storage at single DOE site	INEEL	1.5	639	12.7	71,195
	PGDP	<0.1	8	14.2	71,826
	PORTS	4.4	24,765	9.8	47,069
	SRS	3.0	2,867	11.2	68,967
	Oak Ridge	1.4	6,431	12.8	65,403
Centralized storage at single commercial site	East, West	N/A	N/A	14.2	71,834
Partially consolidated storage at several DOE sites	INEEL	1.5	639	1.7	21,391
	PGDP	<0.1	8	0.4	400
	PORTS	4.4	24,765	1.4	13,458
	SRS	3.0	2,867	<0.1	63
	Oak Ridge	1.4	6,431	0.4	1,812
Partially consolidated storage at two DOE sites	PORTS	4.4	24,765	6.6	49,705
	INEEL	1.5	639	1.7	22,129
Partially consolidated storage at two commercial sites	East	N/A	N/A	11.0	49,705
	West	N/A	N/A	3.2	22,129

Table A.3. Uranium management interim storage inventories (continued)

Alternative	Site/form	Current storage: Amount, 10^3 MTU	Current storage: Number of containers	Additional materials to be moved: Amount, 10^3 MTU	Additional materials to be moved: Number of containers
Partially consolidated storage based on physical form	Compound (PORTS)	1.7	7,221	<0.1	1,034
	Metal (SRS)	2.9	1,088	6.0	32,918
	Misc (PORTS)	0	0	1.2	4,998
	Oxide (PORTS)	0.9	15,333	0.5	7,807
	Reactfuel (INEEL)	0.5	184	0.4	827
	Residue (INEEL)	<0.1	55	<0.1	174
	Source (INEEL)	<0.1	8	<0.1	187

DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
MTU = metric tons of uranium.
N/A = not applicable.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table A.4. Uranium management disposition option inventories

Disposition option	Description	Material type(s)	Amount (10^3 MTU)	Number of containers
Commercial processing/domestic sales	All material transferred from interim storage to a single commercial processing facility or single sales distribution point (east or west)	All	14.2	71,834
Transfer to research facilities	Transfer ~50 MTU from interim storage to the furthest DOE or other research location	DU, NU LEU	0.05 0.05	204 844
Transfer to other government agencies	Transfer ~2,500 MTU from interim storage to unspecified location (use furthest distance already evaluated)	DU, NU LEU	2.5 2.5	10,186 42,188
Foreign sales	All LEU/NU (~4,050 MTU) transferred to eastern or western port for overseas shipment	LEU NU	3.3 0.7	56,408 1,432

DOE = U.S. Department of Energy.
DU = depleted uranium.
LEU = low-enriched uranium.
MTU = metric tons of uranium.
N/A = not applicable.
NU = normal uranium.

An additional activity to be evaluated for each alternative is the potential to ship small quantities [<0.01 metric tons of uranium (MTU)] from any storage location, either centralized or consolidated, to a second location such as a university or commercial facility.

A.2 ROUTINE OPERATIONS

During storage or disposition of uranium materials at any of the proposed sites, workers could be exposed to direct radiation from surface contamination on storage containers. However, all containers will have been checked, overpacked if necessary, and certified for transport before storage. Therefore, worker exposure due to routine operations associated with surveillance and maintenance of uranium materials is expected to be less than detectable levels.

In addition to surface contamination, radiation dose from the uranium materials can be expected. Dose rates from any single container are no more than 3 to 4 mrem/h. The dose rate at a distance of 0.3 m (1 ft) from a container is ~1 mrem/h, and the rate at a distance of 6 m (20 ft) is <0.05 mrem/h (approximately the same as normal background radiation doses). These dose rates are not affected by stacking the containers, because the containers and the materials themselves provide significant shielding. These dose rates are considered negligible to any receptor (e.g., facility worker, co-located worker, or public).

A.3 ACCIDENTS

Accidents that could occur under the proposed storage alternatives and disposition options are analyzed in this section. Potential accidents could be initiated during initial packaging, transportation of materials to one or more centralized or consolidated storage locations, storage, and transportation to one or more disposition options. Accidents can also be caused by natural phenomena (earthquake and wind). Reasonably foreseeable accidents have been screened, and the accidents with the greatest consequences to co-located workers and the public have been identified. These are the "bounding" accidents that provide an envelope for the consequences of other accidents with less impact.

Each consolidated or centralized storage location or disposition site is assumed to consist of one or more areas dedicated to the storage (either interim or until further processing or disposition occurs) of uranium materials. Fire-suppression systems may be available for storage or disposition in existing buildings. On-site fire department response, however, is assumed for all storage alternatives and disposition options.

A.3.1 Postulated Accident Scenarios

A hazard survey of the activities involved in packaging, transporting, and storing various forms and quantities of uranium was conducted for six potential storage locations and two generic commercial locations. The hazards identified for the storage alternatives are considered bounding for any accidents that might occur during the disposition options. The primary focus of the hazard survey was to identify those specific hazards that exist for each identified alternative and to evaluate the potential for that hazard to develop into an accident.

Accidents that could occur during implementation of the proposed action(s) can be grouped into two classes. As shown in Table A.5, these classes are fire and container breach. The accidents shown in Table A.5 are determined to be "credible," a term that is used in safety analysis to mean that the accident has an annual probability of 1E-6 or greater. Evaluation of accident frequency is largely qualitative and results in an estimate of the postulated accident scenarios' frequencies of occurrence. These are then assigned to high, moderate, low, or negligible categories of frequency, such as in the example shown in Table A.6. This table is adapted from CCPS (1992) and is similar to a table given in DOE (1994a).

The accidents shown in Table A.5 were selected to represent the range of postulated accidents that could occur under the proposed alternatives. Accidents are shown for general handling and storage operations and are applicable for all alternatives except as noted. Bounding accidents are selected for each major type of event in order to establish maximum consequences and risks for each alternative. These bounding accidents are discussed below.

Table A.5. Postulated accidents identified for uranium management activities

	Operational events		External events
Activity	Fire	Container breach	Natural phenomena

Table A.5. Postulated accidents identified for uranium management activities

	Operational events		External events
Activity	Fire	Container breach	Natural phenomena
Packaging, handling, loading, and unloading (not applicable for No Action alternative)	Forklift fire affecting small number of containers	Forklift impact with stored containers	Not applicable Containers handled for short period of time
		Container(s) dropped during handling	
Transportation (not applicable for No Action alternative)	Transport vehicle fire	Transport vehicle accident	Not applicable Containers handled for short period of time
General handling in storage or disposition facility	Forklift fire affecting small number of containers	Forklift impact with stored containers	Not applicable Containers handled for short period of time
		Container(s) dropped during handling	
Storage or processing (includes surveillance and maintenance)	Large fire affecting multiple containers in single area	Forklift impact with containers	Direct release, small fires in storage or processing area
	Small fire affecting limited number of containers	Corrosion, degradation of containers	

Table A.6. Frequency classes considered in accident analysis

Frequency category	Estimated annual frequency of occurrence	Description
Anticipated	f > 1E-2	Incidents that may occur several times during the lifetime of the facility (incidents that occur commonly).
Unlikely	1E-2 ≥ f > 1E-4	Accidents that are not anticipated to occur during the lifetime of the facility. Natural phenomena of this probability class include design basis earthquake, 100-year flood, maximum wind gust, etc.
Extremely unlikely	1E-4 ≥ f > 1E-6	Accidents that will probably not occur during the life cycle of the facility. This class includes most design basis accidents.
Beyond extremely unlikely	f < 1E-6	Accidents that are not credible.

A.3.1.1 Fires

Fires resulting in releases of uranium are postulated for handling, transportation, storage, and disposition operations. The types of fire include gasoline/diesel fuel fires caused by forklift accidents, transport vehicle fires, and building fires that spread to involve multiple containers. Due to activation of the fire-suppression system and/or fire department response, a building fire would be limited to a relatively small area. This is an extremely unlikely event due to minimal ignition sources and combustible loading. Forklift fires, involving limited numbers of containers, are more likely but result in substantially smaller releases to the atmosphere.

A.3.1.2 Container breach

Container breach includes events such as releases from leaking (primarily due to long-term corrosion); forklift puncture during movement of other containers; dropping during packaging, loading, placement into interim storage, or movement in a disposition facility; and damage as the result of a transport vehicle accident.

Single-container handling accidents are considered “bounding”; these events dominate the risk to workers because of their relatively high frequency and the proximity of the workers to any such release. Such events include overpacking containers prior to shipment, and moving containers to/from loading docks during shipment/receipt. These activities are prone to mechanical stresses in industrial accidents such as drops or punctures by a forklift; however, airborne releases resulting from breaches in a single container are relatively insignificant compared with releases involving fires. As a result, these events usually constitute little hazard to the general public.

A.3.1.3 Natural phenomena

Natural phenomena events, such as high wind and earthquake, have the potential to cause damage to buildings and structures leading to consequences that equal or exceed the consequences of operational events. With respect to natural phenomena, each potential storage or disposition location can be considered Performance Category 3 (PC-3) in accordance with DOE guidelines (DOE 1993). In accordance with DOE criteria (DOE 1994b), PC-2 facilities are required to withstand the earthquake, tornado, and high wind intensities shown in Table A.7. Although not explicitly determined, it is assumed that the uranium storage and disposition facilities are Hazard Category 2 (HC-2) facilities based on DOE criteria (DOE 1992). The frequencies shown in Table A.7 represent the frequencies of facility failure under challenge from natural phenomena.

Table A.7. Natural phenomena intensities

Event	Site	Intensity	Frequency/year
Earthquake	INEEL	0.17g	5E-4
	PGDP	0.35g	
	PORTS	0.19g	
	SRS	0.18g	
	Oak Ridge	0.19g	
	Generic eastern (assumed same as PORTS)	0.19g	
	Generic western (assumed same as INEEL)	0.17g	
Tornado	INEEL	N/A	2E-5
	PGDP	144 mph	
	PORTS	110 mph	
	SRS	137 mph	
	Oak Ridge	113 mph	
	Generic eastern	110 mph	
	Generic western	N/A	
Straight wind	All	70 mph	1E-3

INEEL = Idaho National Engineering and Environmental Laboratory.
mph = miles per hour.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

During the seismic event defined above, all facility structures are assumed to be destroyed, and nothing but rubble remains. All utilities, including fire suppression, are lost. All releases are at ground level. Hazardous materials that can be suspended in air in respirable form and be available for transport are considered to be released from direct seismic accelerations.

Following the direct seismic event, a number of small fires may occur due to electrical shorts or downed power lines. Any fires would be scattered throughout the rubble and would be exposed to the outside elements, since no building structure remains. The top layer of rubble would consist primarily of noncombustible materials such as reinforced concrete and structural steel from buildings, or structural supports from tension-support structures. The fire is assumed to be slow-burning amid rubble and fallen/breached containers. All fire mitigation facilities are assumed destroyed, and all roadways are blocked by debris. Therefore, there is no fire mitigation by either the on-site fire department or other outside agencies.

Seismic events are used as the surrogate initiator for straight winds or tornadoes, because standard atmospheric dispersion modeling predicts greater dispersion (and, therefore, greatly reduced airborne concentration) for high wind conditions than for the stable wind conditions assumed to be present during earthquakes (Hanna et al. 1982). Existing analyses in DOE safety analysis reports 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 waste drums stored on outdoor pads 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. The same phenomenon is assumed to apply to the containers proposed for uranium storage and disposition. To appropriately bound potential damage by projectiles to unprotected areas, the damage assumed for seismic events is conservatively defined to have higher damage ratios than those that might otherwise be used to bound the damage caused by high winds or wind-driven projectiles.

A.3.2 Development of Source Terms for Accident Sequences

The approach taken in this assessment is to convert material-at-risk (MAR) quantities to atmospheric source terms using conservative release factors (Hanna et al. 1982). These source term factors, based on DOE (1994c), take into account the physical mechanism through which material becomes airborne as well as the fraction of airborne materials in the respirable particle size range (<10 microns). The source term associated with each accident is the product of four factors that vary for type of materials affected by the accident:

$$\text{Source term} = \text{MAR} \times \text{DR} \times \text{ARF} \times \text{RF} \ ,$$

where

MAR = material at risk,
DR = damage ratio,
ARF = airborne release fraction,
RF = respirable fraction.

A.3.3 Evaluation of Source Term Parameters and Frequencies

This section describes the development of frequency and source term data for handling, transportation, storage, and disposition accidents.

A.3.3.1 Container breach accidents

The dominant contributor to worker risk from hazardous material releases is expected to result from mechanical breaches of containers during 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 events. Handling accidents include container breaches caused by drops or by impact from forklifts or other vehicles. Although one container would generally be breached in an accident, rupture of multiple containers could occur in instances when several containers are being handled at a time.

Source Term Parameters. The MAR for handling activities generally varies from one to four drums, depending on the method of stacking and the arrangement of the array. The maximum MAR for each physical form of material and container type is shown in Table A.8. The damage ratio (DR) for the MAR depends on several factors, including the physical form of the MAR and the severity of the accident stress. In general, breached containers with solid uranium forms (i.e., metal, reactfuel, source) are assumed to have DRs no greater than 0.10 (i.e., no more than 10% of the material is directly impacted or damaged by the event). For other containers with oxides or other unspecified forms, the single-container DR is assumed to be 0.25. The combined airborne release fraction (ARF) × respirable fraction (RF) for oxides and other forms subjected to free-fall spill and impaction stress is ~1E-5. The combined ARF × RF for solid materials is essentially negligible but is estimated to be 1E-6 as a conservative assumption.

Table A.8. Source term parameters for container breach accidents

Physical form	Type of container	DR	ARF × RF
Compound	Drum	0.25	1E-5
Metal	Metal box	0.10	1E-6
	Drum		
Miscellaneous	Drum	0.25	1E-5
Oxide	Metal box	0.25	1E-5
	Drum		
Reactfuel	Metal box	0.10	1E-6
	Drum		
Residue	Drum	0.25	1E-5
Source	Drum	0.25	1E-5

ARF = airborne release fraction.
DR = damage ratio.
RF = respirable fraction.

Frequency. On the basis of numerous studies evaluated for other environmental impact statements, a probability of one handling error per 10,000 containers handled is used in this analysis (WSRC 1994). It is assumed that two severe breaches of confinement occur for each inventory of 10,000 containers handled. All containers will be packaged, loaded for transport, and moved into an interim storage location within a relatively short period of time (assumed to be no more than 6 months). All containers will be handled again for transport to a disposition option. Based on the estimated total number of containers handled at any given location (see Tables A.3 and A.4), the frequency of container breach due to handling accidents is >1E-2/year (anticipated).

A.3.3.2 Facility fires

For the purposes of this assessment, fire in a storage or disposition facility is assumed to bound the risk to workers and the public from fires involving smaller numbers of containers due to forklift or other vehicle accidents. This event is a facility fire mitigated by the fire-suppression system and/or fire department response, and involves a limited area at a storage or disposition location.

Source Term Parameters. The MAR is assumed to be no more than 10% of the inventory at a storage or disposition location under any alternative (see Tables A.2 and A.3). The DR for materials in metal containers exposed to fires is 0.1. In addition, no more than 10% of the surface area of the solid forms (i.e., metal, reactfuel, and source) are exposed to the fire and subject to oxidation (overall DR of 0.01 for these materials). The ARF and RF for airborne release of particulates during relatively low-temperature (<900^{o}C) oxidation are 1E-4 and 1.0, respectively. For composite solids (all other physical forms), the ARF and RF are 6E-3 and 1E-2, respectively.

Frequency. Although fire data from DOE sites indicate that facility fires are credible, fires of this magnitude in storage or disposition facilities with low combustible loading and limited ignition sources are considered unlikely.

A.3.3.3 Seismic event

The dominant contributor to risk from uranium releases is expected to result from breaches of containers in an earthquake followed by a number of small fires. The event would impact all containers in a facility.

Source Term Parameters. The MAR is shown in Tables A.3 and A.4. The DR for the direct release is based on an evaluation of waste container storage in a DOE facility similar to those that might be used for storing these materials (Hand 1998). Overall DRs for stacked storage containers include the following:

- Five percent of the containers on the lowest level fall, as do 10% from the middle layer(s) and 15% from the top layer, for an overall fraction of 10% for containers falling from stacked storage arrays. This fraction applies to DU and NU materials that are stacked four high, and is conservative for LEU materials that are only stacked two high.
- Of the containers that fall, ~25% are breached.
- Of the containers that are breached, ~25% of the material is spilled outside the container for solid materials and 100% for composite materials.

Therefore, the DRs for materials initially released during a seismic event are:

- Solids: $DR = 0.10 \times 0.25 \times 0.25 = 0.00625$.
- Composites: $DR = 0.10 \times 0.25 \times 1.0 = 0.025$.

The combined ARF × RFs for solids and composite forms are the same as those for container handling events. Release factors for subsequent fires are the same as those described for facility fires; however, the MAR is 10% of the actual inventory because the fires are small, distributed throughout the facility, and impact only the outside layers of the rubble and fallen/breached containers.

Frequency. The annual frequencies of seismic events exceeding the design basis for HC-2 facilities were shown in Table A.7. Conditional probabilities are estimated to be 0.10 for inducing a number of unmitigated fires. The overall frequency for each site is, therefore, 5E-5/year (extremely unlikely).

A.3.4 Results

Radiological and toxicological source terms and consequences for the bounding accident scenarios are discussed in this section.

A.3.4.1 Source terms for bounding accident scenarios

Radiological airborne source terms are estimated based on MARs and release parameters identified in Sect. A.3.3 and are expressed in units of grams. The activity (Ci/g) for each type of material released is based on an assumed 20% ^{235}U for low-enriched uranium with a specific activity of 7.0E-7 Ci/g. This activity is considered bounding for all types of uranium considered in this evaluation because the actual distribution of material is ~71% depleted uranium, which has a specific activity of ~3.4E-7 Ci/g. The higher activity is used to estimate all radiological airborne source terms in units of curies. These source term estimates are shown in Table A.9 for the interim storage alternatives and disposition options. For the disposition options, it is assumed that the maximum amount for each option (shown in Table A.4) is moved to a single disposition location. The distribution of physical form of the materials included in the transfer to research facility and transfer to other government agency is assumed to be the same as the overall distribution of physical forms shown in Table A.1. The distribution of physical form for the foreign sales option is the same as that for the entire inventory of 4050 MTU of LEU/NU included in that option.

Toxicological airborne release rates are estimated based on an assumed release duration of 1 h for the total amount released and are expressed in units of mg/sec. These release rate estimates are also shown in Table A.9.

Table A.9. Source terms due to bounding accident scenarios

Alternative/ Option	Accident scenario	Site	Airborne source term, Ci	Airborne release rate, mg/sec
All	General container handling	All	1.71E-06	1.84E+00
No Action	Facility fire	INEEL	1.08E-04	4.28E+01
		PGDP	4.38E-07	1.74E-01
		PORTS	1.25E-03	4.94E+02
		SRS	2.46E-04	9.78E+01
		Oak Ridge	1.18E-04	4.69E+01
		Max other[a]	1.46E-04	5.79E+01
	Seismic (direct release)	INEEL	7.32E-06	2.90E+00
		PGDP	1.83E-07	7.25E-02
		PORTS	4.77E-04	1.89E+02
		SRS	3.11E-05	1.23E+01
		Oak Ridge	1.46E-05	5.80E+00
		Max other[a]	6.08E-05	2.41E+01
No Action (continued)	Seismic (fire)	INEEL	7.05E-06	2.80E+00
		PGDP	1.10E-07	4.35E-02
		PORTS	2.89E-04	1.15E+02
		SRS	2.37E-05	9.40E+00
		Oak Ridge	1.12E-05	4.45E+00
		Max other[a]	3.65E-05	1.45E+01

Table A.9. Source terms due to bounding accident scenarios (continued)

Alternative/ Option	Accident scenario	Site	Airborne source term, Ci	Airborne release rate, mg/sec
Centralized storage at a single site (includes commercial processing/domestic sales disposition option)	Facility fire	All	2.56E-03	1.01E+03
	Seismic (direct release)	All	8.24E-04	3.27E+02
	Seismic (fire)	All	5.11E-04	2.03E+02
Partially consolidated storage at several DOE sites	Facility fire	INEEL	2.49E-04	9.89E+01
		PGDP	3.73E-05	1.48E+01
		PORTS	1.73E-03	6.80E+02
		SRS	2.52E-04	1.00E+02
		Oak Ridge	3.04E-04	1.21E+02
	Seismic (direct release)	INEEL	2.67E-05	1.06E+01
		PGDP	7.50E-06	2.98E+00
		PORTS	6.64E-04	2.63E+02
		SRS	3.35E-05	1.33E+01
		Oak Ridge	9.21E-05	3.66E+01
	Seismic (fire)	INEEL	2.15E-05	8.52E+00
		PGDP	5.07E-06	2.01E+00
		PORTS	4.02E-04	1.59E+02
		SRS	2.51E-05	9.97E+00
		Oak Ridge	5.77E-05	2.29E+01
Partially consolidated storage at two sites	Facility fire	East	2.30E-03	9.13E+02
		West	2.57E-04	1.02E+02
	Seismic (direct release)	East	7.94E-04	3.15E+02
		West	2.99E-05	1.19E+01
	Seismic (fire)	East	4.88E-04	1.94E+02
		West	2.34E-05	9.29E+00
Partially consolidated storage based on physical form	Facility fire	PORTS	1.86E-03	4.38E+02
		SRS	6.22E-04	2.47E+02
		INEEL	7.60E-05	3.01E+01
	Seismic (direct release)	PORTS	7.75E-04	3.07E+02
		SRS	3.89E-05	1.54E+01
		INEEL	1.01E-05	4.01E+00
	Seismic (fire)	PORTS	4.65E-04	1.84E+02
		SRS	3.89E-05	1.54E+01
		INEEL	7.58E-06	3.01E+00
Transfer to research facility	Facility fire	Generic	8.98E-06	3.56E+00
	Seismic (direct release)	Generic	2.89E-06	1.15E+00
	Seismic (fire)	Generic	1.80E-06	7.13E-01
Transfer to other government agency	Facility fire	Generic	4.49E-04	1.78E+02
	Seismic (direct release)	Generic	1.45E-04	5.74E+01
	Seismic (fire)	Generic	8.98E-05	3.56E+01

Table A.9. Source terms due to bounding accident scenarios (continued)

Alternative/ Option	Accident scenario	Site	Airborne source term, Ci	Airborne release rate, mg/sec
Foreign sales	Facility fire	Generic	8.88E-04	3.52E+02
	Seismic (direct release)	Generic	3.12E-04	1.24E+02
	Seismic (fire)	Generic	1.91E-04	7.60E+01

[a]Max other represents the largest single amount at any site other than the DOE consolidated storage locations.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

A.3.4.2 Consequences for bounding accident scenarios

Consequences to facility workers, co-located workers (assumed to be 100 m from the release point), and the public are estimated for each bounding accident scenario for each storage or disposition location. For the facility worker and co-located worker, the consequences are the same regardless of site. For the public, consequences vary depending on distances to the site boundaries. Distances and associated dispersion parameters for each site are shown in Table A.10 for ground-level releases (container breach events and direct seismic event).

Table A.10. Distances and dispersion parameters for ground-level releases

Storage location	Distance to site boundary, m	Dispersion parameter χ/Q, sec/m^3
INEEL	526	1.56E-03
PGDP	511	1.56E-03
PORTS	715	8.47E-04
SRS	727	8.47E-04
Oak Ridge	537	1.56E-03
Generic eastern (assumed same as PORTS)	N/A	8.47E-04
Generic western (assumed same as INEEL)	N/A	1.56E-03
Max other; disposition options (worst-case)	N/A	1.56E-03

INEEL = Idaho National Engineering and Environmental Laboratory.
N/A = not applicable.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

For fires, the release point is elevated due to hot air buoyancy effects from fires. Although not specifically evaluated, the release height is estimated based on the model described in U.S. Army (1981). The maximum dispersion parameter occurs at a distance of 270 m from the release point for an elevated release. This value (3.51E-04 sec/m^3) is used for releases due to fires for all sites regardless of distance to the site boundary and is, therefore, conservative (i.e., dispersion parameters due to elevated releases for receptors located at other distances are lower).

Dispersion parameters are based on a point-source Gaussian dispersion model described by Hand et al. (1982) and are evaluated for F-Class wind stability with wind speed of 1.5 m/sec. All receptors are considered to be at ground level.

Consequences are shown in Tables A.11 and A.12 for all receptors. Other parameters used in estimating consequences include the following:

- Breathing rate of 3.3E-4 m^3/sec based on recommendations from the International Commission on Radiological Protection.

- Inhalation 50-year committed effective dose equivalent dose conversion factor for uranium of 1.2E+8 rem/Ci (DOE 1988).

- Consequences to facility workers based on instantaneous dispersion into a hemisphere 10 m in diameter. The worker walks through the hemisphere at a rate of 1 m/sec for a maximum exposure time of 10 sec. Consequences to facility workers during fires or natural phenomena events are considered to be negligible because these workers are assumed to evacuate the area before significant exposure can occur. This assumption is based on standard DOE site emergency response procedures that require facility worker evacuation in the event of accidents.

For fires, it is assumed that the co-located worker and the public are both exposed to the maximum downwind consequences. This is a conservative assumption because, in most cases, the location of maximum consequence occurs at a distance beyond the location of the co-located worker (i.e., 270 m vs. 100 m for the co-located worker). If actual dispersion parameters for elevated releases and receptors at 100 m were used, the estimated consequences would be significantly less.

Exposure duration is assumed to be the same as release duration for all events. This is a conservative assumption for fires, because downwind receptors are not likely to remain in a smoke plume once a fire is detected, and fire duration is several hours. For container handling events or direct release from a seismic event, it is also a conservative assumption because the material forms are such that no hazardous materials must become dislodged before they become airborne, and the overall release rate is slow relative to the rate of uptake by the receptor.

Table A.11. Radiological consequences due to bounding accident scenarios

Alternative/ Option	Accident scenario	Site	Radiological consequences, rem: Facility worker	Radiological consequences, rem: Co-located worker	Radiological consequences, rem: Public	Maximum consequence category
All	General container handling	INEEL, PGDP, Oak Ridge	7.08E-03	6.36E-03	2.89E-04	Negligible
		PORTS, SRS	7.08E-03	6.36E-03	1.57E-04	Negligible
No Action	Facility fire	INEEL	Negligible	1.51E-03	1.51E-03	Negligible
		PGDP	Negligible	6.15E-06	6.15E-06	Negligible
		PORTS	Negligible	1.75E-02	1.75E-02	Negligible
		SRS	Negligible	3.46E-03	3.46E-03	Negligible
		Oak Ridge	Negligible	1.66E-03	1.66E-03	Negligible
		Max other[a]	Negligible	2.05E-03	2.05E-03	Negligible
	Seismic	INEEL	Negligible	1.01E-02	5.55E-04	Negligible
		PGDP	Negligible	2.52E-04	1.29E-05	Negligible
		PORTS	Negligible	6.57E-01	2.02E-02	Negligible
		SRS	Negligible	4.29E-02	1.38E-03	Negligible
		Oak Ridge	Negligible	2.02E-02	1.07E-03	Negligible
		Max other[a]	Negligible	8.39E-02	4.30E-03	Negligible
Centralized storage at a single site (includes commercial processing/ domestic sales disposition option)	Facility fire	All	Negligible	3.59E-02	3.59E-02	Negligible
	Seismic	INEEL, PGDP, Oak Ridge	Negligible	1.14E+00	5.85E-02	Low
		PORTS, SRS	Negligible	1.14E+00	3.50E-02	Low
Partially consolidated storage at several DOE sites	Facility fire	INEEL	Negligible	3.50E-03	3.50E-03	Negligible
		PGDP	Negligible	5.23E-04	5.23E-04	Negligible
		PORTS	Negligible	2.40E-02	2.40E-02	Negligible
		SRS	Negligible	3.53E-03	3.53E-03	Negligible
		Oak Ridge	Negligible	4.27E-03	4.27E-03	Negligible
	Seismic	INEEL	Negligible	3.69E-02	1.97E-03	Negligible
		PGDP	Negligible	1.03E-02	5.39E-04	Negligible
		PORTS	Negligible	9.15E-01	2.81E-02	Negligible
		SRS	Negligible	4.67E-02	1.49E-03	Negligible
		Oak Ridge	Negligible	1.27E-01	6.55E-03	Negligible
Partially consolidated storage at two sites	Facility fire	East	Negligible	3.23E-02	3.23E-02	Negligible
		West	Negligible	3.61E-03	3.61E-03	Negligible

Table A.11. Radiological consequences due to bounding accident scenarios

Alternative/ Option	Accident scenario	Site	Radiological consequences, rem: Facility worker	Radiological consequences, rem: Co-located worker	Radiological consequences, rem: Public	Maximum consequence category
	Seismic	East	Negligible	1.09E+00	3.37E-02	Low
		West	Negligible	4.14E-02	2.19E-03	Negligible
Partially consolidated storage based on physical form	Facility fire	PORTS	Negligible	1.07E+00	3.27E-02	Low
		SRS	Negligible	5.38E-02	1.86E-03	Negligible
		INEEL	Negligible	1.40E-02	7.36E-04	Negligible
	Seismic	PORTS	Negligible	6.51E-01	2.00E-02	Negligible
		SRS	Negligible	4.96E+00	1.52E-01	Low
		INEEL	Negligible	5.43E-03	2.99E-04	Negligible
Transfer to research facility	Facility fire	Generic	Negligible	1.26E-04	1.26E-04	Negligible
	Seismic	Generic	Negligible	3.99E-03	2.06E-04	Negligible
Transfer to other government agency	Facility fire	Generic	Negligible	6.30E-03	6.30E-03	Negligible
	Seismic	Generic	Negligible	2.00E-01	1.03E-02	Negligible
Foreign sales	Facility fire	Generic	Negligible	1.25E-02	1.25E-02	Negligible
	Seismic	Generic	Negligible	4.31E-01	2.22E-02	Negligible

[a]Max other represents the largest single amount at any site other than the DOE consolidated storage locations.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Table A.12. Toxicological consequences due to bounding accident scenarios

Alternative/ Option	Accident scenario	Site	Toxicological consequences, mg/m^3			Maximum consequence category
			Facility worker	Co-located worker	Public	
All	General container handling	INEEL, PGDP, Oak Ridge	7.03E-02	6.32E-02	2.87E-03	Negligible
		PORTS, SRS	7.03E-02	6.32E-02	1.56E-03	Negligible
No Action	Facility fire	INEEL	Negligible	1.50E-02	1.50E-02	Negligible
		PGDP	Negligible	6.11E-05	6.11E-05	Negligible
		PORTS	Negligible	1.74E-01	1.74E-01	Low
		SRS	Negligible	3.43E-02	3.43E-02	Negligible
		Oak Ridge	Negligible	1.65E-02	1.65E-02	Negligible
		Max other[a]	Negligible	2.03E-02	2.03E-02	Negligible
	Seismic	INEEL	Negligible	1.01E-01	5.51E-03	Negligible
		PGDP	Negligible	2.50E-03	1.28E-04	Negligible
		PORTS	Negligible	6.53E+00	2.00E-01	Low
		SRS	Negligible	4.26E-01	1.37E-02	Negligible
		Oak Ridge	Negligible	2.00E-01	1.06E-02	Negligible
		Max other[a]	Negligible	8.33E-01	4.27E-02	Negligible
Centralized storage at a single site (includes commercial processing/domestic sales disposition option)	Facility fire	All	Negligible	3.56E-01	3.56E-01	Low
	Seismic	INEEL, PGDP, Oak Ridge	Negligible	1.13E+01	5.81E-01	High
		PORTS, SRS	Negligible	1.13E+01	3.48E-01	High
Partially consolidated storage at several DOE sites	Facility fire	INEEL	Negligible	3.47E-02	3.47E-02	Negligible
		PGDP	Negligible	5.19E-03	5.19E-03	Negligible
		PORTS	Negligible	2.39E-01	2.39E-01	Low
		SRS	Negligible	3.51E-02	3.51E-02	Negligible
		Oak Ridge	Negligible	4.24E-02	4.24E-02	Negligible
	Seismic	INEEL	Negligible	3.66E-01	1.95E-02	Negligible
		PGDP	Negligible	1.03E-01	5.35E-03	Negligible
		PORTS	Negligible	9.09E+00	2.79E-01	Low
		SRS	Negligible	4.59E-01	1.47E-02	Negligible
		Oak Ridge	Negligible	1.26E+00	6.51E-02	Low

01-217(doc)/093002

Table A.12. Toxicological consequences due to bounding accident scenarios

Alternative/ Option	Accident scenario	Site	Toxicological consequences, mg/m^3			Maximum consequence category
			Facility worker	Co-located worker	Public	
Partially consolidated storage at two sites	Facility fire	East	Negligible	1.09E+01	3.35E-01	High
		West	Negligible	4.11E-02	2.18E-02	Negligible
	Seismic	East	Negligible	5.53E+01	1.70E+00	High
		West	Negligible	4.31E-01	2.29E-02	Negligible
Partially consolidated storage based on physical form	Facility fire	PORTS	Negligible	2.59E-01	2.59E-01	Low
		SRS	Negligible	8.66E-02	8.66E-02	Negligible
		INEEL	Negligible	1.06E-02	1.06E-02	Negligible
	Seismic	PORTS	Negligible	1.06E+01	3.25E-01	High
		SRS	Negligible	5.34E-01	1.85E-02	Negligible
		INEEL	Negligible	1.39E-01	7.31E-03	Negligible
Transfer to research facility	Facility fire	Generic	Negligible	1.25E-03	1.25E-03	Negligible
	Seismic	Generic	Negligible	3.96E-02	2.04E-03	Negligible
Transfer to other government agency	Facility fire	Generic	Negligible	6.26E-02	6.26E-02	Negligible
	Seismic	Generic	Negligible	1.98E+00	1.02E-01	Negligible
Foreign sales	Facility fire	Generic	Negligible	1.24E-01	1.24E-01	Low
	Seismic	Generic	Negligible	4.28E+00	2.20E-01	Low

[a]Max other represents the largest single amount at any site other than the DOE consolidated storage locations.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Tables A.11 and A.12 also indicate the maximum consequence level for each scenario for each alternative. These levels are based on consequence categories shown in Tables A.13 and A.14. These are based on prevailing regulations, DOE Orders, and other DOE standards such as "DOE 1994d."

Table A.13. Consequence categories for public exposure

Consequence category	Description	Consequence level	
		Radiological	**Toxicological**
Negligible	Less than low off-site impact	≤0.1 rem	<0.1 × ERPG-2
Low	Negligible off-site impact	>0.1 to ≤5 rem	≤ERPG-2
Moderate	Minor off-site impact	>5 to ≤25 rem	Not defined (subjective)
High	Considerable off-site impact	>25 rem	>ERPG-2

ERPG = Emergency Response Planning Guideline.

Table A.14. Consequence categories for worker exposure

Consequence category	Description	Consequence level	
		Radiological	**Toxicological**
Negligible	Negligible on-site impact	≤1 rem	<0.1 x IDLH
Low	Minor on-site impact	>1 to ≤5 rem	≤IDLH
Moderate	Moderate on-site impact	>5 to ≤100 rem	Not defined (subjective)
High	Considerable on-site impact	>100 rem	>IDLH

IDLH = Immediately Dangerous to Life and Health.

The toxicological consequence levels are expressed in terms of Emergency Response Planning Guideline (ERPG) concentrations developed by the American Industrial Hygiene Association. ERPG-2 is defined as a threshold concentration that, for exposures of up to 1 h, will not produce irreversible health effects in the large majority of the general population. This value (1 mg/m^3 for uranium) is applied for public exposure. However, for workers, the Immediately Dangerous to Life and Health (IDLH) value is more appropriate. This value (10 mg/m^3 for uranium) is based on effects that might occur to unprotected workers as a consequence of a 30-min exposure. Therefore, IDLH values as defined by the National Institute for Occupational Safety and Health (NIOSH 1997) are used to define high consequences to facility and co-located workers.

A.4 PUBLIC AND WORKER RISK SUMMARY

Public and worker risks due to normal operations and accidents are shown in Table A.15. The risk categories are based on the accident frequency and maximum radiological or toxicological consequence level as shown in Fig. A.1. These accident scenarios that fall within Regions 7, 8, and 9 of the matrix are considered high risk, and those that fall within Regions 4, 5, and 6 are considered moderate risk. Those accident scenarios that fall within Regions 1 through 3 of the matrix are considered low risk and represent less than a marginal concern.

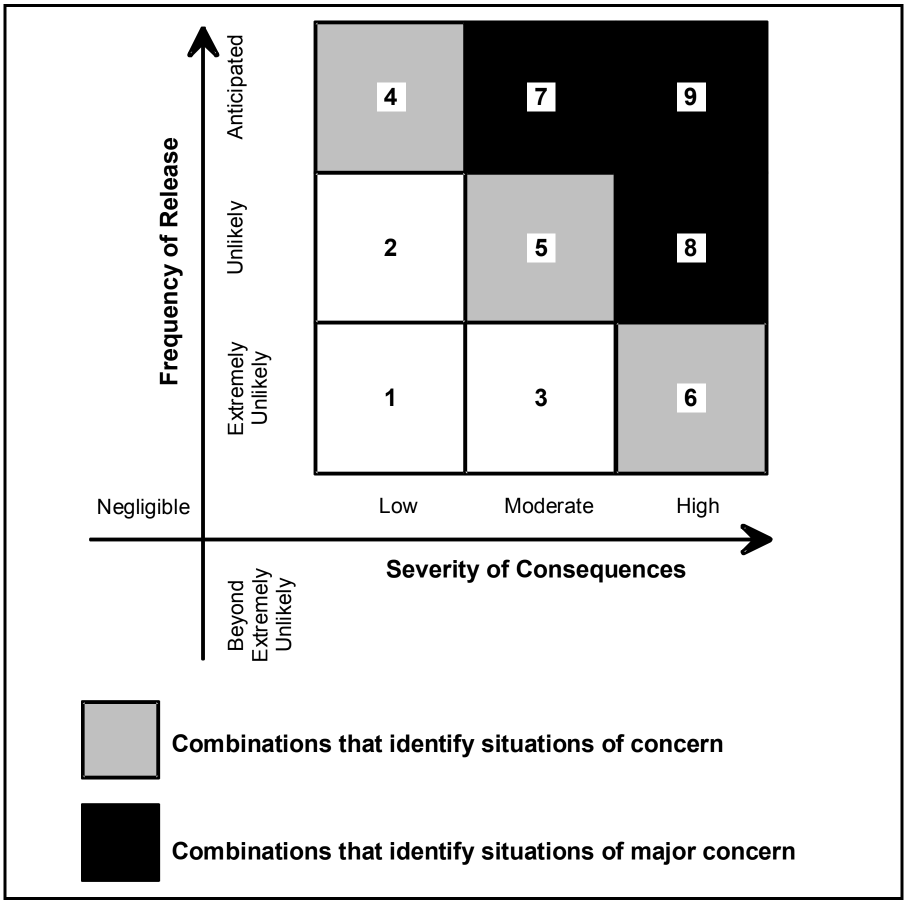

Fig. A.1. Frequency and consequence ranking matrix.

Table A.15. Risks due to normal operations and accidents

Alternative/Option	Accident scenario	Site	Frequency	Maximum radiological consequence	Maximum toxicological consequence	Risk
All	Normal operations	All	Anticipated	Negligible	Negligible	Negligible
All	General handling events	All	Anticipated	Negligible	Negligible	Negligible
No Action	Facility fire	INEEL, PGDP, SRS, Oak Ridge, Max other[a]	Unlikely	Negligible	Negligible	Negligible
		PORTS		Negligible	Low	Low
	Seismic	INEEL, PGDP, SRS, Oak Ridge, Max other[a]	Extremely unlikely	Negligible	Negligible	Negligible
		PORTS		Negligible	Low	Low
Centralized storage at a single site (includes commercial processing/domestic sales disposition option)	Facility fire	All	Unlikely	Negligible	Low	Low
	Seismic	All	Extremely unlikely	Low	High	Moderate
Partially consolidated storage at several DOE sites	Facility fire	INEEL, PGDP, SRS, Oak Ridge	Unlikely	Negligible	Negligible	Negligible
		PORTS		Negligible	Low	Low
	Seismic	INEEL, PGDP, SRS, Oak Ridge	Extremely unlikely	Negligible	Negligible	Negligible
		PORTS		Negligible	Low	Low
Partially consolidated storage at two sites	Facility fire	East	Unlikely	Negligible	Low	Low
		West		Negligible	Negligible	Negligible
	Seismic	East	Extremely unlikely	Low	High	Moderate
		West		Negligible	Negligible	Negligible
Partially consolidated storage based on physical form	Facility fire	PORTS	Unlikely	Negligible	Low	Low
		INEEL, SRS		Negligible	Negligible	Negligible
	Seismic	PORTS	Extremely unlikely	Low	High	Moderate
		SRS, INEEL		Negligible	Negligible	Negligible
Transfer to research facility	Facility fire	All	Unlikely	Negligible	Negligible	Negligible
	Seismic	All	Extremely unlikely	Negligible	Negligible	Negligible
Transfer to other government agency	Facility fire	All	Unlikely	Negligible	Negligible	Negligible
	Seismic	All	Extremely unlikely	Negligible	Low	Low

01-217(doc)/093002

Table A.15. Risks due to normal operations and accidents

Alternative/Option	Accident scenario	Site	Frequency	Maximum radiological consequence	Maximum toxicological consequence	Risk
Foreign sales	Facility fire	All	Unlikely	Negligible	Low	Low
	Seismic	All	Extremely unlikely	Negligible	Low	Low

[a]Max other represents the largest single amount at any site other than the DOE consolidated storage locations.
DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

A.5 REFERENCES

AIHA (American Industrial Hygiene Association). *Reference for ERPG-2*.

CCPS (Center for Chemical Process Safety). 1992. *Guidelines for Hazard Evaluation Procedures*, Second Edition with worked examples, American Institute of Chemical Engineers, New York, NY.

DOE (U.S. Department of Energy). 1988. *Internal Dose Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0071, Washington, D.C.

DOE (U.S. Department of Energy). 1992. *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*, DOE-STD-1027-92, Washington, D.C., Change Notice No. 1, 1997.

DOE (U.S. Department of Energy). 1993. *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*, DOE-STD-1021-93, Washington, D.C.

DOE (U.S. Department of Energy). 1994a. *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*, DOE-STD-3009-94, Washington, D.C.

DOE (U.S. Department of Energy). 1994b. *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, DOE-STD-1020-94, Washington, D.C.

DOE (U.S. Department of Energy). 1994c. *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Washington, D.C.

DOE (U.S. Department of Energy). 1994d. *Guidance for Preparation of DOE 5480.22 (TSR) and DOE 5480.23 (SAR) Implementation Plans*, DOE-STD-3011-94, Washington, D.C.

Hand, Frank. 1998. *Seismic Evaluation of T, SW/R, WD and HH Buildings and Buildings 22 and 23 at the DOE Mound Site*, Revision 2, Los Alamos Technical Associates, Inc., Albuquerque, NM.

Hanna, S.R., et al. 1982. *Handbook on Atmospheric Diffusion*, DOE/TIC-11223, Atmospheric Turbulence and Diffusion Laboratory, National Oceanic and Atmospheric Administration, U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.

NIOSH (National Institute for Occupational Safety and Health). 1997. *NIOSH Pocket Guide to Chemical Hazards*, Washington, D.C.

U.S. Army. 1981. *Handbook for Chemical Hazard Prediction*, DARCOM Handbook No. 385-2.1-80, U.S. Army Material Development and Readiness Command, National Technical Information Service, Springfield, VA.

WSRC (Westinghouse Savannah River Company). 1994. *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities*, WSRC-TR-93-581, Aiken, SC.