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Risk Assessment for the On-Site Transportation of Radioactive Wastes for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement

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

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

ANL-E	Argonne National Laboratory-East
CFR	Code of Federal Regulations
CH-TRUW	contact-handled transuranic waste
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EM	Environmental Management
FEMP	Fernald Environmental Management Project
GTCC	greater-than-Class C waste
Hanford	Hanford Site
HCWC	Hanford Central Waste Complex
HLW	high-level waste
HWVP	High-Level Waste Vitrification Plant
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LDR	land disposal restriction
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
Mound	Mound Plant
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORR	Oak Ridge Reservation
PEIS	Programmatic Environmental Impact Statement
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
RFETS	Rocky Flats Environmental Technology Site
RH-TRUW	remote-handled transuranic waste
SFEIS	Supplemental Final Environmental Impact Statement
SMAC	Shipment Mobility/Accountability Collection
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SRS	Savannah River Site
TBD	to be determined
TRUSAF	Transuranic Storage and Assay Facility
TRUW	transuranic waste
TSD	treatment, storage, and disposal
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Project
WPPSS	Washington Public Power Supply Station
WVDP	West Valley Demonstration Project

UNITS OF MEASURE

Ci	curie(s)
gal	gallon(s)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
lb	pound(s)
m	meter(s)
m^3	cubic meter(s)
mi	mile(s)
mi^2	square mile(s)
mrem	millirem(s)
rem	roentgen-equivalent man
s	second(s)

RISK ASSESSMENT FOR THE ON-SITE TRANSPORTATION OF RADIOACTIVE WASTES FOR THE U.S. DEPARTMENT OF ENERGY WASTE MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

by

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ABSTRACT

This report documents the risk assessment performed for the on-site transportation of radioactive wastes in the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS). Risks for the routine shipment of wastes and the impacts from potential accidental releases are analyzed for operations at the Hanford Site (Hanford) near Richland, Washington. Like other large DOE sites, Hanford conducts waste management operations for all wastes types; consequently, the impacts calculated for Hanford are expected to be greater than those for smaller sites. The risk assessment conducted for on-site transportation is intended to provide an estimate of the magnitude of the potential risk for comparison with off-site transportation risks assessed for the WM PEIS.

1 INTRODUCTION

A comprehensive transportation risk analysis of radioactive waste shipments was undertaken as part of the production of the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS) (DOE 1996a). The WM PEIS was undertaken to assess the impacts of various treatment and disposal options for existing and future radioactive waste at DOE facilities. The implementation plan (DOE 1993) requires the assessment of thousands of radioactive waste shipments consisting of high-level waste (HLW), transuranic waste (TRUW), low-level waste (LLW), and low-level mixed waste (LLMW).

The WM PEIS transportation risk assessment includes both the on-site and off-site transportation of radioactive waste. On-site transportation is defined as transportation of waste between facilities within the boundaries of a given DOE site. Transfers of waste within a specific facility are not considered on-site shipments, but part of normal facility operations. The on-site transportation analysis considers local conditions and characteristics such as local weather, nonuniform population distributions, and agricultural data. Off-site transportation refers to transportation of waste between distinct sites, including portions of the routes that may be within the boundaries of the origin and destination sites. Off-site transportation involves a radioactive waste shipment moving over much greater distances, and simplifying assumptions and generalizations can be made. National average or typical values are chosen for such items as road and track dimensions, vehicle speed, traffic density, weather conditions, and stop times; population densities are modeled as being uniformly distributed in rural, suburban, and urban population zones. This report documents the on-site transportation risk assessment conducted for the WM PEIS. The off-site transportation risk assessment can be found in Monette et al. (1996a-d).

The impacts to human health during transportation of radioactive materials are caused by exposure to ionizing radiation. For each waste type, radiological risks (i.e., those risks that result from the radioactive nature of the waste) are assessed for both routine (i.e., normal) and accident transportation conditions. The radiological risk associated with routine transportation conditions results from the potential exposure of people to low levels of external radiation in the vicinity of a loaded shipment. The radiological risk from transportation accidents lies in the potential release and dispersal of radioactive material into the environment during an accident, and the subsequent exposure of people through multiple exposure pathways (e.g., exposure to contaminated ground or air, or ingestion of contaminated food).

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

At the levels expected during transportation operations, the primary adverse health effects from radiation exposure are the inductions of latent cancer cases (i.e., cancers that occur after a 5- to 30-year latency period from the time of exposure). The types of cancer cases induced by radiation are similar to naturally occurring cancers and are expressed at some point in the lifetimes of the exposed individuals. Under no reasonable circumstances — including accidents — are transportation operations expected to cause acute (short-term) radiation fatalities or produce immediate observable effects in exposed individuals. In this report, the radiological impacts are expressed as health risks in terms of the number of estimated cancer fatalities, cancer incidence, and genetic effects in exposed populations for each waste type. The health risk conversion factors (expected health effects per dose absorbed) were derived from ICRP Publication 60 (ICRP 1991).

The following section details the scope of the on-site transportation risk assessment. Section 3 covers the site-specific data used in the assessment, and Section 4 presents the waste type characterization and packaging information. The technical approach taken and the methodologies used are explained in Section 5. The routine impacts are presented in Section 6, and Section 7 presents potential accident consequences. The remaining sections address the uncertainties in the results and present a brief summary and comparison with the off-site transportation risk assessment.

2 SCOPE OF ASSESSMENT

The human health risks associated with the on-site transportation of radioactive wastes are generally much smaller than those from off-site transportation (DOE 1992a), largely because of the limited on-site shipment distances, population densities along the routes, and average travel speeds. The on-site transportation impacts are not likely to contribute significantly to differences among the WM PEIS alternatives being considered. Therefore, for the purposes of the WM PEIS, the on-site risk assessment has been limited to one representative site — the Hanford Site (Hanford). Hanford was selected primarily because it is a relatively large site that conducts waste management activities for all waste types. The impacts calculated for Hanford are believed to be typical of other large DOE sites and bound the impacts that would be expected for smaller sites. The risk assessment conducted for on-site transportation is intended to provide an estimate of the magnitude of the potential risk for comparison with off-site transportation risks.

The transportation risk assessment conducted for the WM PEIS estimates the human health risks associated with the transportation of radioactive wastes for a large number of alternatives. In general, the WM PEIS alternatives are considered independently for each waste type and reflect decentralized, regionalized, and centralized approaches. For each waste type, several options, referred to as cases, have been defined for each broad alternative. The individual cases differ in the number, location, and types of treatment, storage, and disposal facilities being considered. Detailed descriptions of the cases for each waste type can be found in DOE (1996a). For most cases at Hanford, the waste will be shipped to the Hanford Central Waste Complex (HCWC) in the 200 West Area (Duncan 1991, DOE 1991a), regardless of possible off-site shipment for treatment and disposal. Therefore, the on-site transportation risks presented here apply to all cases and cannot be used to discriminate among the alternatives.

It is important to note, however, that the methodologies and assumptions used in the transportation radiological risk assessment were selected in order to ensure meaningful comparisons among the off-site transportation risks for the programmatic alternatives. The overall transportation risk assessment uses a number of generic assumptions appropriate to the programmatic nature of the WM PEIS. For instance, because a detailed consideration of every possible waste shipment on-site and off-site is impractical, representative physical and radiological characteristics have been determined for each waste type (Folga et al. 1996; Goyette and Dolak 1996; Hong et al. 1996; Wilkins et al. 1996). This analysis does not include the updated LLW, LLMW, and TRUW volumes that are presented in Appendix I of the WM PEIS. These representative characteristics, including radionuclide inventories and package attributes, were used for the on-site analysis at Hanford for comparison with the off-site transportation results. They may not accurately reflect the actual past and present compositions of each waste shipment on-site at Hanford. Furthermore, the assessment considers waste currently stored or generated over the next 20 years, including estimates for future waste products that are highly uncertain (Duncan et al. 1992). Similarly, transportation routes on-site have been selected to be consistent with current practice, but may not be the actual routes that will be used in the future.

Transportation Modes. Although the transportation of radioactive waste can take place by a variety of modes, all shipments have been assumed to take place either by truck or rail. For each waste type, risks have been calculated separately for all truck or all rail transport, although the actual shipment campaigns for a selected waste type may involve a combination of the two modes. In reality, not all DOE sites have rail access or an on-site rail network as extensive as Hanford's, and shipment of waste by truck is a much more common practice. Shipments by barge, although possible, have not been explicitly considered because this transport mode has not been established as a major transport option for the WM PEIS assessment.

Receptors. Transportation-related risks, for routine transport and for an accident consequence, are calculated and presented separately for workers and members of the general public. For workers, risks from routine transport are assessed for truck and rail crews, workers in areas along the transport route, and a guard at an inspection point or facility gate. Risks to members of the general public are assessed collectively only for those sharing (driving on) the transport route with the waste shipment; no member of the general public lives along or works near the on-site transportation routes. For accidents, health risks are estimated for a maximally exposed individual (a worker or member of the general public), workers on-site, and the general public off-site.

3 SITE-SPECIFIC DATA

The Hanford Site is located in the southeastern section of the state of Washington. It covers a land area of approximately 1,450 km^2 (560 mi^2) (Cushing 1991). The DOE Richland Operations office manages the Hanford Site and employs a number of DOE contractors who operate in various facilities and work areas scattered across the site. Figure 3.1 is a map of the Hanford Site. A large number of contractor workers are located off-site at facilities in the city of Richland, which lies on the southeastern border of the Hanford Site. Only on-site workers were considered in this risk assessment.

The major radioactive waste treatment, storage, and disposal facilities at Hanford are part of the HCWC located in the 200 West Area. The HLW tank farms are located in the 200 East and West areas, with the High-Level Waste Vitrification Plant (HWVP) under construction in the 200 East Area for treatment of the tank waste (DOE 1987). The 200 East Area also disposes of its own LLW in shallow landfill burial grounds. All other on- and off-site-generated LLW is currently sent to the 200 West Area for burial (DOE 1989). Most of the contact-handled TRUW (CH-TRUW), defined as TRUW with less than a 200-mrem/h dose rate at the container surface, is currently sent for storage in 55-gal ($\approx$0.2-m^3) drums in the Transuranic Storage and Assay Facility (TRUSAF), part of the HCWC (Anderson et al. 1991). Remote-handled TRUW (RH-TRUW), defined as TRUW with a dose rate greater than 200 mrem/h at the container surface, is stored as CH-TRUW in shielded drums (Duncan 1991). A portion of the Waste Receiving and Packaging Module 1 currently under construction will eventually replace the TRUSAF and prepare the TRUW for off-site shipment for disposal in the Waste Isolation Pilot Project (WIPP) when WIPP becomes operational. The LLMW is currently being sent to storage pads within the HCWC until future treatment and disposal options are selected and approved.

In the past, more than 60% of the radioactive waste, depending on waste type, generated at Hanford, was created and stored or disposed of in the 200 areas (Brown et al. 1990). This portion of the waste requires no on-site transport. With a few exceptions, a large portion of the remaining waste is generated in the 300 Area or nearby in the 400 Area. Because a concise overview of past on-site shipments of all waste types is not readily available for Hanford, in addition to the uncertainties associated with future waste generation, the shipment route from the 300 Area to the 200 West Area was chosen as the representative on-site route to be used for this on-site transportation risk assessment. In addition to being a heavily used route (Daling et al. 1991), it is the longest on-site route typically used to transport waste to the 200 West Area, resulting in the maximum potential risks. On-site generation of radioactive waste at Hanford is discussed further by waste type in Section 4.

On-site shipment of radioactive waste by truck from outlying work areas to the 200 West Area can occur over public access roadways. A number of roads on the Hanford Site are accessible to the general public. State Route 240 is the major public highway

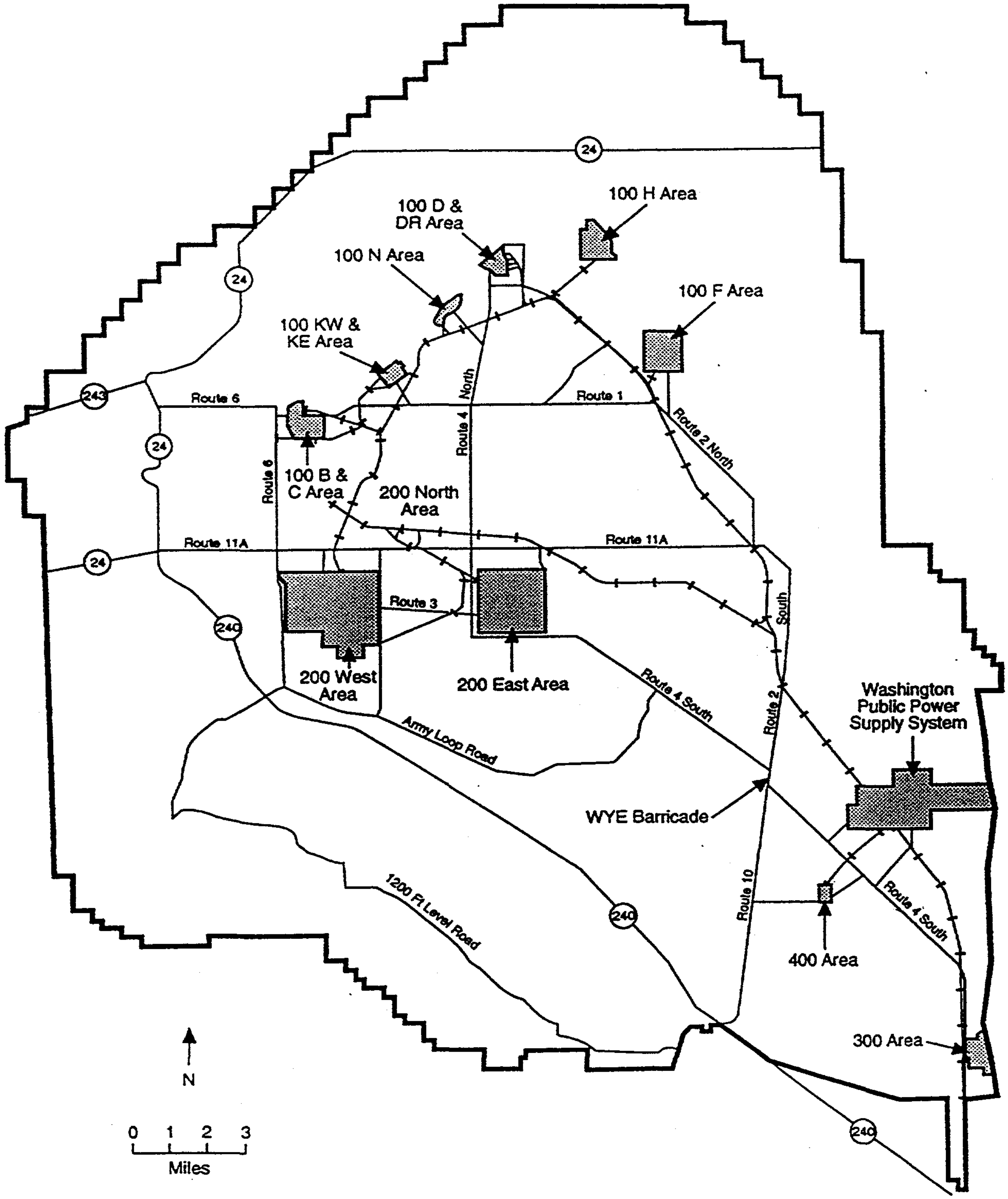

FIGURE 3.1 Hanford Site Map

traversing the site; state Routes 24 and 243 are also public highways crossing the site. Route 4 South is the most heavily traveled on-site route by employees, with controlled access north of the Wye Barricade. Shipments from the 300 and 400 areas to the 200 West Area traverse a portion of Route 4 South, south of the Wye Barricade, that is open to the public. A typical shipment of radioactive waste from the 300 Area would travel on Route 4 South alongside a portion of the 300 Area and past the 200 East Area to Route 3 westbound to the 200 West Area (DOE 1989).

The shipment route from the 300 Area to the 200 West Area maximizes the estimated routine risk to the transport crew members because their dose is directly proportional to the distance traveled. Maximum impacts to the public occur along the route because it is the only waste transportation route where a routine risk to the public could affect those individuals sharing the road with the shipment. No member of the public lives or works in areas along the on-site roadways. The route is also nearest the maximum population centers on-site (workers in the 300 Area) and off-site (public in the city of Richland) where a potential accident would have the greatest consequences.

Rail shipments would follow a similar route but would also pass through the Washington Public Power Supply Station (WPPSS) area before passing by the 200 East Area on the way to the 200 West Area. Table 3.1 lists the route specific parameters used in this risk assessment for each shipment. Table 3.2 gives additional information on the affected work areas.

For the accident consequences, the accident was assumed to occur on Route 4 South, or on the railroad tracks running parallel to Route 4 South, outside of the 300 Area. This on-site location provides the potential for maximum exposure to both on- and off-site populations. Table 3.3 lists the off-site population within an 80 km (50 mi) radius of the 300 Area. Table 3.4 lists the meteorological joint frequency data for the 300 Area that was used to evaluate wind dispersion of the radionuclides in the population consequence assessment.

TABLE 3.1 Route Parameters for On-Site Shipment of Radioactive Waste at Hanford

Mode	Origin	Destination	Distance (km)	Vehicle Speed (km/h)	One-Way Traffic Density (vehicles/h)	Number of Persons per Vehicle	Affected Work Areas	Distance from Route (m)	Distance along Route (km)
Truck	300 Area	200 West Area	37	56	640[a]	2	300	45	1.2
							200 East	45 m south 180 m west	2.0 1.0
							200 West	15 m assumed on each side	0.5
Rail	300 Area	200 West Area	45	24	NA[b]	NA[b]	300	60	1.2
							WPPSS	15 m assumed on each side	2.2
							200 West	15 m assumed on each side	0.5

[a] DOE (1989).

[b] NA = not applicable. The tracks at Hanford are exclusive use only.

TABLE 3.2 Worker Population Densities for Work Areas at Hanford

Work Area	Worker Population[a]	Land Area[b] (km^2)	Worker Density per km^2
100 B&C	4	1.7	3
100 D&DR	4	1.5	3
100 H	4	0.7	6
100 K	124	0.9	140
100 N	360	1.0	360
200 West	1,968	9.5	210
200 East	2,923	9.0	330
300	2,487	1.5	1,700
400	638	2.1	300
600[c]	514	1,450	0.35
WPPSS	1,125	4.4	260

[a] Source: Rhoads (1993).

[b] Estimated based on the following sources: Cushing (1991); DOE (1989); Westinghouse Hanford Company (WHC) (1986).

[c] The 600 Area encompasses those facilities on-site not included in the above areas.

TABLE 3.3 Off-Site Population Distribution within a 50-mi (80-km) Radius of the 300 Area at Hanford

Distance (mi)											
0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50	Sector Total	Direction
0	0	3	198	2,231	17,726	12,449	123	13,473	10,913	57,116	S
0	0	0	0	297	3,518	3,788	288	651	1,859	10,401	SSW
0	0	0	0	59	2,364	2,916	1,619	311	763	8,032	SW
0	0	0	0	0	967	3,238	5,812	13,516	713	24,246	WSW
0	0	0	0	0	0	730	1,669	16,968	12,843	32,210	W
0	0	0	0	0	0	0	417	1,703	2,120	4,240	WNW
0	0	0	0	0	0	0	181	1,279	1,428	2,888	NW
0	0	0	0	0	0	0	273	1,277	1,153	2,703	NNW
0	0	0	2	6	85	602	4,203	2,894	9,998	17,790	N
0	3	16	25	33	277	678	2,242	2,411	1,218	6,903	NNE
1	11	18	25	33	277	827	1,094	590	306	3,182	NE
2	11	18	25	33	277	754	741	480	535	2,876	ENE
3	11	18	25	33	276	170	255	761	1,001	2,553	E
2	11	18	25	33	264	117	454	878	10,548	12,350	ESE
2	11	18	25	33	277	15,318	3,337	1,322	3,257	23,600	SE
0	7	18	25	121	616	57,047	4,098	3,779	4,785	70,496	SSE
Population total											
10	65	127	375	2,912	26,924	98,634	26,806	62,293	63,440	281,586	

Source: Beck et al. (1991).

TABLE 3.4 Meteorological Joint Frequency Data for the 300 Area at Hanford[a]

Wind Speed (m/s)	Stability Category	Direction															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	A	0.10	0.05	0.07	0.09	0.14	0.08	0.08	0.11	0.09	0.05	0.04	0.04	0.03	0.03	0.05	0.07
	B	0.08	0.04	0.03	0.03	0.07	0.04	0.04	0.05	0.05	0.04	0.03	0.03	0.04	0.03	0.20	0.06
	C	0.07	0.03	0.03	0.05	0.08	0.06	0.06	0.06	0.07	0.03	0.02	0.03	0.04	0.03	0.04	0.05
	D	0.41	0.19	0.14	0.15	0.28	0.33	0.32	0.38	0.49	0.33	0.38	0.29	0.38	0.25	0.33	0.43
	E	0.36	0.13	0.11	0.11	0.24	0.32	0.40	0.47	0.65	0.40	0.42	0.37	0.52	0.40	0.43	0.42
	F	0.49	0.21	0.13	0.10	0.30	0.34	0.53	0.60	0.86	0.45	0.49	0.40	0.58	0.51	0.55	0.56
2.65	A	0.28	0.29	0.34	0.33	0.75	0.45	0.42	0.28	0.23	0.21	0.25	0.19	0.11	0.04	0.06	0.16
	B	0.16	0.13	0.11	0.11	0.18	0.15	0.19	0.12	0.11	0.09	0.07	0.06	0.04	0.03	0.03	0.08
	C	0.15	0.14	0.08	0.09	0.17	0.18	0.21	0.12	0.12	0.09	0.09	0.05	0.03	0.03	0.06	0.10
	D	1.26	0.49	0.32	0.32	0.85	1.04	1.23	0.76	0.89	0.65	0.52	0.38	0.34	0.26	0.50	0.98
	E	1.25	0.24	0.07	0.08	0.36	1.04	1.46	0.95	1.31	0.60	0.53	0.41	0.46	0.40	0.56	1.00
	F	1.18	0.17	0.03	0.01	0.21	1.24	2.20	1.26	1.17	0.51	0.29	0.15	0.24	0.25	0.49	0.97
4.70	A	0.33	0.46	0.28	0.09	0.15	0.18	0.23	0.13	0.27	0.46	0.54	0.33	0.13	0.06	0.08	0.10
	B	0.12	0.14	0.06	0.03	0.04	0.06	0.07	0.03	0.11	0.17	0.17	0.11	0.06	0.02	0.02	0.07
	C	0.17	0.12	0.07	0.02	0.03	0.06	0.07	0.04	0.10	0.12	0.16	0.10	0.04	0.00	0.05	0.08
	D	0.99	0.45	0.29	0.09	0.17	0.22	0.40	0.25	0.57	0.92	0.89	0.53	0.27	0.14	0.42	0.79
	E	1.23	0.24	0.06	0.04	0.08	0.28	0.29	0.19	0.61	0.78	0.81	0.58	0.30	0.16	0.39	0.63
	F	1.54	0.18	0.02	0.02	0.08	0.40	0.30	0.11	0.42	0.45	0.40	0.17	0.05	0.02	0.07	0.45
7.15	A	0.17	0.12	0.03	0.00	0.00	0.00	0.02	0.01	0.08	0.24	0.44	0.37	0.12	0.05	0.08	0.05
	B	0.04	0.04	0.01	0.00	0.00	0.00	0.01	0.00	0.04	0.09	0.11	0.11	0.05	0.01	0.03	0.03
	C	0.04	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.10	0.15	0.10	0.04	0.01	0.03	0.03
	D	0.24	0.13	0.03	0.02	0.01	0.02	0.04	0.02	0.21	0.55	0.72	0.45	0.20	0.06	0.34	0.34
	E	0.20	0.07	0.04	0.01	0.01	0.00	0.02	0.01	0.12	0.37	0.53	0.27	0.14	0.05	0.24	0.24
	F	0.10	0.05	0.01	0.02	0.00	0.00	0.00	0.00	0.05	0.11	0.18	0.07	0.01	0.00	0.01	0.06
9.800	A	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.09	0.14	0.11	0.08	0.01	0.03	0.02
	B	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.05	0.03	0.00	0.01	0.02
	C	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.05	0.01	0.00	0.01	0.00
	D	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.18	0.29	0.16	0.08	0.01	0.14	0.08
	E	0.04	0.08	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.11	0.26	0.05	0.03	0.00	0.08	0.06
	F	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.00	0.00	0.00

TABLE 3.4 (Cont.)

Wind Speed (m/s)	Stability Category	Direction															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
12.7	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.03	0.04	0.00	0.00	0.00
	B	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.00
	C	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00
	D	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.18	0.06	0.03	0.00	0.04	0.02
	E	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.14	0.01	0.01	0.00	0.01	0.00
	F	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
15.6	A	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
	B	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	C	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	D	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.01	0.01	0.00	0.00	0.00
	E	0.03	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.00
	F	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.0	A	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	D	0.05	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	E	0.12	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	F	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a] Values are the percentage of time the wind is blowing into a direction at a given wind speed in a given stability category.

Source: Shreckhise et al. (1993).

4 REPRESENTATIVE WASTE INVENTORIES, PACKAGING, AND SHIPMENT CONFIGURATIONS

4.1 DERIVATION OF WASTE TYPE INVENTORIES

The computational model WASTE_MGMT has been developed to support WM PEIS risk and cost analyses (Avci et al. 1994). Input to the model includes waste inventory and characterization data for each DOE site; operations data for the facilities used for treatment, storage, and disposal of the wastes; and the definitions of the various alternatives. The sources and development of the model input data are described in reports specific to each waste type (Folga et al. 1996; Goyette and Dolak 1996; Hong et al. 1996; Wilkins et al. 1996).

One output of the model consists of the quantity, physical form, and radiological characteristics of the waste shipped between sites for each case. This waste transportation data file includes, for each origin and destination pair, the total quantity of waste shipped on an annual basis (both volume and mass) as well as the total curie (Ci) activity of radionuclides in the waste being shipped. The effects of potential waste treatment, such as volume reduction or incineration, are considered in the model and reflected in changes in waste density and activity concentrations. The WASTE_MGMT output files are used directly as input to the transportation risk assessment and are provided in the supporting technical reports (Folga et al. 1996; Goyette and Dolak 1996; Hong et al. 1996; Wilkins et al. 1996). The annual shipment quantities for on-site shipments at Hanford are derived from these output files.

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

The dose (and corresponding risk) to populations and maximally exposed individuals during routine transportation conditions is directly proportional to the assumed shipment external dose rate. The federal regulations for maximum allowable external dose rates for exclusive-use shipments are presented in the next section. The actual shipment dose rate is a complex function of the composition and configuration of shielding and containment materials used in the waste packaging, the geometry of the loaded shipments, and characteristics of the waste material itself. The external dose rates assumed for each waste type are summarized in Table 4.1 and discussed in Sections 4.3 through 4.7.

TABLE 4.1 Shipment External Dose Rates for Each Waste Type

Waste Type	External Dose Rate (mrem/h at 1 m)
LLW[a]	1
LLMW[b]	1
TRUW[c]	CH = 5.7, 7.2 (truck, rail) RH = 7.1, 14.2 (truck, rail)

[a] Based on historical DOE LLW shipments as reported in the Shipment Mobility and Accountability Collection (Morris 1993).

[b] Based on comparison of LLMW and LLW radiological characteristics.

[c] Derived from DOE (1990b).

4.2 PACKAGING AND SHIPMENT CONFIGURATIONS

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

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

It is the policy at Hanford to use certified packaging for transportation of radioactive materials on-site whenever practicable (Mercado et al. 1992). Therefore, the packaging used for on-site transportation is assumed to be the same as that for off-site transportation. If an alternative means of packaging is necessary, a concept of equivalent safety is maintained while achieving the same shipping results. Packaging safety can be attained through such measures as limiting vehicle speeds, barricading roadways, increasing shielding and distance from the package for crew members, and/or reducing the number of miles driven. On-site shipments typically travel at lower speeds, about 56 km/h (35 mph) than off-site shipments, thereby reducing risks from accidents. In addition, the general public has access to a number of routes on the Hanford Site. Unless such a roadway is barricaded during radioactive waste transport, the shipment must meet all pertinent regulations. Stringent procedures are followed at Hanford to ensure the safety of the workers and the general public and provide the same level of safety for both on- and off-site shipments (WHC 1993a).

Although several federal and state organizations are involved in the regulation of radioactive waste transportation, primary regulatory responsibility resides with the U.S. Department of Transportation (DOT) and U.S. Nuclear Regulatory Commission (NRC). In addition, the DOE has formalized agreements with both the NRC and DOT to delineate their respective agency responsibilities. All transportation activities must take place in accordance with the applicable regulations of these agencies as specified in 49 CFR Part 173 and 10 CFR Part 71.

4.2.1 Package Types

Transportation packaging for radioactive materials must be designed, constructed, and maintained to ensure that it will contain and shield the material during normal transport conditions. For more highly radioactive material, the packaging must contain and shield the contents in severe accident conditions. The type of packaging used is determined by the total radioactive hazard presented by the material within the packaging. The basic types of packaging required by the applicable regulations are designated as Type A, Type B, or "strong and tight" (generally for low-specific-activity material). Only Type A and Type B packagings are of interest in this study.

Type A packaging must withstand the conditions of normal transportation without the loss or dispersal of the radioactive contents. Normal transportation refers to all conditions of transportation except those that result from accidents or sabotage. Approval of Type A packaging is achieved by demonstrating that the packaging can withstand specified test conditions that are intended to simulate normal transportation conditions. Type A packaging, typically a 55-gal ($\approx$0.2-m^3) drum or standard waste box, is commonly used to transport wastes having low activities of radioactive material. Type A packaging is routinely used in waste management operations for purposes of storage, transportation, and disposal. In general, the use of Type A packaging does not require special handling or packaging equipment.

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

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

- 10 mrem/h at any point 2 m from the vertical planes projected by the outer lateral surfaces of the car or vehicle, and

- 2 mrem/h in any position normally occupied in the car or vehicle.

Additional restrictions apply to package surface radiation levels; however, these restrictions do not affect the transportation radiological risk assessment.

For risk assessment purposes it is not necessary to specify the actual package that will be used, because all packagings of a given type are designed to meet the same performance criteria. For example, a 55-gal ($\approx$0.2-m^3) drum and a standard waste box, each designed to Type A packaging criteria, would be expected to behave similarly under routine and accident transportation conditions.

4.2.2 Shipment Configurations

To conduct the transportation risk assessment, assumptions must be made concerning the types of packaging, transport vehicles, and shipment capacities used for future waste shipments. Certain assumptions, such as vehicle types and legal weight restrictions, are common to all waste types. However, the radiological and physical characteristics of each waste type are such that separate packaging assumptions must be made for each. In all cases, it is assumed that waste would be characterized, treated, packaged, and labeled in accordance with applicable regulations prior to shipment.

For all waste types, it is assumed that certified packagings and exclusive-use vehicles would be used. Truck transportation is assumed to take place by legal weight heavy-haul combination (tractor-trailer) trucks. Typically, Type A packages are transported on common flatbed or covered trailers; Type B packages are generally shipped on trailers designed specially for the packaging being used. For truck transportation, the maximum payload weight has been taken to be 20,000 kg (44,000 lb), based on DOT highway weight limitations and an average tractor-trailer weight of 16,000 kg (36,000 lb).

For rail transportation, average payload weights for boxcars range from 45,000 to 68,000 kg (100,000 to 150,000 lb). A median payload weight of 54,000 kg (120,000 lb) has been assumed for assessment purposes.

As discussed above, the type of packaging is determined primarily by the radiological characteristics of the waste material. For risk assessment purposes, representative packagings have been determined for each radioactive waste type based on average waste characteristics; these packagings are consistent with currently accepted practice. In actuality, packagings are selected on a case-by-case basis and may differ from the representative types presented here. Packaging and shipment assumptions are discussed below and summarized in Table 4.2.

4.3 LOW-LEVEL WASTE

All LLW is assumed to be transported in Type A packaging, such as 55-gal (≈0.2-m^3) drums or standard waste boxes. Suitable Type A packagings are readily available from commercial sources and are used extensively at Hanford. The number of shipments on-site is calculated on the basis of projected site-specific waste inventory (weight) information and shipment capacity limitations for each transportation mode. The effects of potential waste treatment, such as volume reduction or incineration, are reflected in changes in waste density. The minimum number of shipments necessary to transport all of the waste is assumed. The amount of waste contained in each shipment is considered to be the average weight obtained by dividing the total amount by the number of shipments. Based on typical LLW densities, roughly a maximum of 80, 55-gal (≈0.2-m^3) drums would be shipped per truck and 300 per railcar.

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

Shipment information from SMAC was examined for fiscal years 1983 to the present (Morris 1993). Information was provided for three general radioactive material categories: irradiated fuel, other Highway Route Controlled Quantities, and low-level waste. (The material categories chosen were dictated by the format in which data are submitted and entered into SMAC and are not consistent with the waste type definitions used in the WM PEIS.) Of the 15,000 LLW shipments recorded in the SMAC database, approximately 2,500 reported external dose rates. The average dose rate reported was approximately 1 mrem/h measured at 1 m from the surface of a shipment. This value was used for future LLW shipments for the WM PEIS analysis for off-site shipments and on-site shipments at Hanford. In practice, external dose rates will vary not only from site to site and waste type to waste type, but also from shipment to shipment at a given site.

The majority of LLW at Hanford is treated and disposed of in the 200 East and 200 West areas. Historically, from 1986 to 1989, approximately 60% of this waste required no on-site transport because it was also generated in these areas (Brown et al. 1990). The

TABLE 4.2 Representative Packaging and Shipment Assumptions for Radioactive Waste Types

Waste Type	Packaging Type	Shipment Capacity[a]
LLW	Type A: ≈0.2-m^3 drums or standard waste boxes	Assumed to be limited by vehicle weight restrictions. Payload capacity: truck = 20,000 kg; rail = 54,000 kg.
LLMW	Type A: ≈0.2-m^3 drums or standard waste boxes	Assumed to be limited by vehicle weight restrictions. Payload capacity: truck = 20,000 kg; rail = 54,000 kg.
TRUW	Type B:	Assumed to be limited by package volume restrictions.
	CH = TRUPACT-II	3 TRUPACT-IIs per truck, 6 per railcar. Payload capacity: truck = 8.4 m^3; rail = 16.8 m^3.
	RH = RH-72B	1 RH-72B per truck, 2 per railcar. Payload capacity: truck = 0.89 m^3; rail = 1.8 m^3.

[a] Truck shipments are assumed to be legal weight. Truck payload capacities were calculated assuming a 36,000 kg gross vehicle weight limit and a tractor-trailer weight of 16,000 kg. The median railcar payload capacity was assumed to be 54,000 kg.

remaining LLW is generated primarily in the 100 and 300 areas. The LLW generated outside the 200 areas is disposed of in the 200 West Area. The 200 East Area disposes of its own LLW (DOE 1989).

The radionuclide inventories for Hanford LLW were separated into two categories, activated metals and heterogeneous solids, because of their physical differences and their release characteristics following a potential accident. Tables 4.3 and 4.4 give the inventories per shipment for truck and rail transport. These representative source terms are not expected to change on a case-by-case basis within WM PEIS alternatives because most of the present and future waste classification, treatment, packaging, and disposal facilities are located in the 200 areas. In most cases, the waste will be shipped to the 200 Area regardless of possible off-site shipment for treatment and disposal.

4.4 LOW-LEVEL MIXED WASTE

Low-level mixed waste is assumed to be shipped in a manner similar to LLW. Low-level mixed waste shipments would meet any additional characterization and labeling requirements associated with the hazardous waste component. In addition, shipments of liquid waste would meet regulatory requirements specified for liquids (i.e., packages would contain adequate absorbent to absorb twice the liquid volume, or a leak-tight overpack would be used [10 CFR Part 71]).

TABLE 4.3 Radionuclide Inventories per Shipment for Truck and Rail Transport of Heterogeneous LLW at Hanford

Radionuclide	Truck (Ci)	Rail (Ci)
H-3	1.56E−02	4.18E−02
Cr-51	3.98E−02	1.07E−01
Mn-54	7.53E−02	2.02E−01
Fe-55	2.83E−01	7.57E−01
Fe-59	2.55E−03	6.84E−03
Co-58	1.01E−01	2.71E−01
Co-60	8.02E−01	2.15
Ni-59	3.65E−03	9.77E−03
Ni-63	5.35E−01	1.43
Sr-90	1.36	3.63
Y-90	1.36	3.63
Zr-95	3.10E−03	8.31E−03
Tc-99	2.42E−04	6.48E−04
Ru-106	1.32E−01	3.54E−01
Rh-106	1.32E−01	3.54E−01
Sb-125	3.81E−02	1.02E−01
Te-125m	9.29E−03	2.49E−02
Cs-134	1.54E−01	4.12E−01
Cs-137	1.42	3.80
Ba-137m	1.34	3.60
Ce-144	4.44E−01	1.19
Pr-144	4.44E−01	1.19
Pr-144m	5.33E−03	1.43E−02
Pm-147	1.08	2.90
Sm-151	1.06E−02	2.82E−02
Eu-152	1.61E−04	4.31E−04
Eu-154	2.77E−02	7.42E−02
Eu-155	2.20E−02	5.88E−02
Th-208	1.90E−07	5.08E−07
Pb-212	5.04E−07	1.35E−06
Bi-212	5.04E−07	1.35E−06
Po-212	3.24E−07	8.68E−07
Po-216	5.04E−07	1.35E−06
Ra-224	5.04E−07	1.35E−06
Ra-228	3.01E−06	8.06E−06
Ac-228	3.01E−06	8.06E−06
Th-228	5.04E−07	1.35E−06
Th-231	2.90E−06	7.76E−06
Th-232	3.05E−05	8.17E−05
Th-234	3.72E−03	9.94E−03
Pa-234	3.81E−07	1.02E−06
Pa-234m	3.72E−03	9.94E−03
U-235	2.89E−06	7.72E−06
U-238	3.72E−03	9.94E−03
Pu-238	3.34E−02	8.93E−02
Pu-239	3.23E−04	8.64E−04
Pu-240	1.61E−04	4.31E−04
Pu-241	3.74E−02	1.00E−01
Am-241	4.85E−04	1.30E−03

Source: Derived from Goyette and Dolak (1996).

TABLE 4.4 Radionuclide Inventories per Shipment for Truck and Rail Transport of Activated-Metal LLW at Hanford

Radionuclide	Truck (Ci)	Rail (Ci)
Cr-51	9.06E−01	2.30
Mn-54	1.73	4.39
Fe-55	6.45	1.64E+01
Fe-59	5.82E−02	1.48E−01
Co-58	2.32	5.89
Co-60	1.82E+01	4.62E+01
Ni-59	8.33E−02	2.12E−01
Ni-63	1.18E+01	3.01E+01
Zr-95	7.06E−02	1.79E−01

Source: Derived from Goyette and Dolak (1996).

Approximately 20% of LLMW at Hanford is generated, treated, and disposed of in the 200 East and 200 West areas. The remaining LLMW is generated primarily in the 100 and 300 areas (Brown et al. 1990) and requires on-site shipment to the 200 West Area for treatment and/or storage. Representative truck and rail radionuclide inventories for Hanford LLMW are given in Table 4.5.

4.5 TRANSURANIC WASTE

The radiological characteristics of TRUW require the use of Type B packaging. The DOE has agreed to have the NRC certify the containers used for both CH- and RH-TRUW shipments as meeting Type B specifications (DOE 1990a). Shipments of TRUW will essentially consist of a number of Type A packages within reusable certified Type B packages. The Type B packages are assumed to be the TRUPACT-II for contact-handled waste and the RH-72B for remote-handled waste. A number of various Type B containers are maintained at Hanford for waste shipments (WHC 1993b).

The TRUPACT-II was certified as meeting NRC Type B packaging regulations in August, 1989. The container is a cylinder with a flat bottom and domed top and is transported in an upright position. Each TRUPACT-II is approximately 2.4 m (8 ft) in diameter and 3 m (10 ft) in height. The TRUPACT-II was designed to maximize payload capability in both volume and weight. The payload capacity of each TRUPACT-II is 3,300 kg (7,265 lb). Three TRUPACT-IIs are assumed to be transported per truck and six per railcar. The total waste shipment capacities are thus 9,900 kg (21,800 lb) for truck and 19,800 kg (43,600 lb) for rail.

TABLE 4.5 Radionuclide Inventories per Shipment for Truck and Rail Transport of LLMW at Hanford

Radionuclide	Truck (Ci)	Rail (Ci)
H-3	8.67E-01	2.26E+00
Co-60	1.46E-02	3.80E-02
Ni-59	2.23E-02	5.83E-02
Ni-63	2.29E+00	5.98E+00
Sr-90	1.03E+01	2.68E+01
Y-90	1.03E+01	2.68E+01
Nb-94	9.81E-04	2.56E-03
Tc-99	5.18E-03	1.35E-02
Cs-137	1.16E+01	3.02E+01
Ba-137m	1.08E+01	2.83E+01
Sm-151	1.66E-01	4.34E-01
Eu-154	1.74E-02	4.54E-02
Th-234	6.41E-03	1.67E-02
Pa-234m	6.41E-03	1.67E-02
U-238	6.41E-03	1.67E-02
Pu-238	5.18E-01	1.35E+00
Pu-239	7.02E-03	1.83E-02
Pu-240	4.00E-03	1.04E-02
Pu-241	1.15E-01	3.00E-01
Am-241	9.81E-03	2.56E-02

Source: Derived from Wilkins (1996).

The RH-72B shipping cask is assumed to be used for all RH-TRUW shipments (DOE 1996b). The RH-72B is being designed to meet Type B packaging specifications and is a scaled-down version of the certified NuPac-125B cask (DOE 1990a). (The NuPac-125B was used to transport core debris from the damaged Three Mile Island nuclear power station to the Idaho National Engineering Laboratory [INEL].) The RH-72B cask is approximately 3.6 m (12 ft) long and has a diameter of 1.1 m (3.5 ft). The payload capacity of each RH-72B is limited to 3,600 kg (8,000 pounds). One RH-72B is assumed to be transported per truck and two per railcar. Total shipment capacities are taken to be 3,600 kg (8,000 lb) for truck and 7,300 kg (16,000 lb) for rail.

For TRUW shipments, external package dose rates have been derived from information provided in the Supplemental Final Environmental Impact Statement (SFEIS) for WIPP (DOE 1990b). In the WIPP SFEIS, site-specific external package dose rates were presented for both CH- and RH-TRUW packages. For the assessment purposes of the

WM PEIS, the average external dose rates were calculated by using the SFEIS values. The average external package dose rates were calculated to be 3.1 mrem/h and 7.1 mrem/h at 1 m for CH- and RH-TRUW, respectively. The external dose rate at 1 m from a shipment for CH-TRUW was calculated to be 5.7 mrem/h for truck and 7.2 mrem/h for rail transport (three and six TRUPACT-II packages respectively) on the basis of the geometry of loaded shipments. Similarly, the external dose rate at 1 m from a shipment for RH-TRUW was calculated to be 7.1 mrem/h for truck and 14.2 mrem/h for rail transport (one and two RH-72B packages respectively). In practice, external dose rates will vary not only from site to site, but also from shipment to shipment at a given site.

The majority of TRUW at Hanford is treated and/or stored in the 200 West Area in the TRUSAF. On the basis of historical data from 1970 to 1988 (Anderson et al. 1991) and from 1986 to 1989 (Brown et al. 1990), approximately 80% of this waste requires no on-site transportation because it is also generated in this area. Approximately 1% of the remaining TRUW is generated in the 100 Area and the remainder in the 200 East and 300 areas.

Tables 4.6 and 4.7 give the radionuclide shipment inventories for CH-TRUW and RH-TRUW truck and rail transport. These representative source terms are not expected to change on an WM PEIS alternative case-by-case basis because most of the present and future TRUW waste classification, treatment, and packaging facilities are located in the 200 West Area. In most cases, the waste will be shipped to the 200 West Area regardless of possible off-site shipment for treatment and disposal.

4.6 HIGH-LEVEL WASTE

There are no on-site shipments at Hanford for the HLW types considered for inclusion in the WM PEIS. The HLW under consideration is confined to the tank farms and associated facilities in the 200 West and 200 East areas. All transfers of waste material are conducted through an extensive network of pipelines that connects the tank farms with present and future waste generators in addition to present and planned treatment facilities.

Likewise, there is no on-site transportation at the other sites identified in the WM PEIS involving HLW. All waste management operations concerning HLW at the INEL are centered at the Idaho Chemical Processing Plant facility. At the Savannah River Site (SRS), the HLW operations are confined to the Defense Waste Processing Facility and related tank farms. The West Valley Demonstration Project is such a small site, similar in size to facility areas at the other sites, that on-site shipments are not relevant.

TABLE 4.6 Radionuclide Inventories per Shipment for Truck and Rail Transport of CH-TRUW at Hanford

Radionuclide	Truck (Ci)	Rail (Ci)
Sr-90	5.58E+01	1.10E+02
Y-90	5.58E+01	1.10E+02
Ru-106	6.73E−01	1.33
Rh-106	6.73E−01	1.33
Cs-137	4.31E+01	8.53E+01
Ba-137m	3.78E+01	7.49E+01
Ce-144	6.73	1.33E+01
Pr-144	6.73	1.33E+01
Pm-147	5.05E+01	1.00E+02
Th-232	1.68E−05	3.32E−05
U-235	1.89E−04	3.74E−04
U-238	1.47E−03	2.91E−03
Pu-238	2.31E+01	4.57E+01
Pu-239	6.73	1.33E+01
Pu-240	1.68	3.32
Pu-241	4.63E+01	9.17E+01

Source: Derived from Hong et al. (1996).

TABLE 4.7 Radionuclide Inventories per Shipment for Truck and Rail Transport of RH-TRUW at Hanford

Radionuclide	Truck (Ci)	Rail (Ci)
Co-60	3.03E−01	6.05E−01
Ni-63	2.08E−03	4.16E−03
Sr-90	4.79E+01	9.57E+01
Y-90	4.79E+01	9.57E+01
Nb-95	2.69E−01	5.39E−01
Tc-99	3.77E−02	7.53E−02
Ru-106	1.28E+01	2.55E+01
Rh-106	1.28E+01	2.55E+01
Sb-125	2.22	4.44
Cs-134	1.48	2.96
Cs-137	5.86E+01	1.17E+02
Ba-137m	5.53E+01	1.11E+02
Ce-144	4.31E+01	8.63E+01
Pr-144	4.31E+01	8.63E+01
Pm-147	6.00E+01	1.20E+02
Eu-152	1.88E−03	3.76E−03
Eu-154	2.69E−01	5.39E−01
Eu-155	4.91E−01	9.83E−01
Th-232	3.29E−06	6.59E−06
U-235	3.50E−05	7.00E−05
U-236	3.50E−07	7.00E−07
U-238	2.82E−04	5.64E−04
Np-237	1.14E−04	2.27E−04
Pu-238	4.11	8.22
Pu-239	1.28	2.55
Pu-240	3.50E−01	7.00E−01
Pu-241	1.01E+01	2.02E+01
Pu-242	2.69E−07	5.39E−07
Am-241	1.55E−01	3.09E−01
Cm-244	3.64E−04	7.27E−04

Source: Derived from Hong et al. (1996).

5 TECHNICAL APPROACH

On-site assessment of transportation risk consists of site-specific information that cannot be described by generic, aggregated parameters like those used in the off-site, long-haul analysis. Such site-specific information includes the nonuniform worker population distribution (i.e., workers in various buildings or work areas), unique public population distribution adjacent to the site, and site-specific weather conditions. In order to make use of the site-specific information, the RISKIND computer code (Yuan et al. 1993) was used to perform the on-site assessment. This approach is consistent with the off-site analysis (Monette et al. 1996a-d). For the off-site analysis, RISKIND is used to complement the RADTRAN 4 assessment in which scenario-specific consequences are analyzed.

The RISKIND code was developed at Argonne National Laboratory for the DOE Office of Civilian Radioactive Waste Management for the specific purpose of analyzing radiological consequences and health risks to individuals from exposures associated with the transportation of SNF. The RISKIND code allows for extensive use of site-specific data. Site-wide characteristics such as weather data, nonuniform population densities, and surrounding agricultural production are all variable input parameters, as are receptor characteristics such as shielding, intake rates, and location relative to the shipment route. Minor modifications were made to the code for WM PEIS applications to accommodate shipments of all radioactive waste types.

The RADTRAN 4 computer code (Neuhauser and Kanipe 1992) was developed by Sandia National Laboratories to calculate population risks associated with the long-haul transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The code has been extensively reviewed, updated, and verified since it was issued in the late 1970s.

5.1 INCIDENT-FREE TRANSPORT

For incident-free conditions, RISKIND can calculate the dose and risk to specific individuals distinguished by their location relative to the cask when it is stationary or moving. The models incorporated into the code consider direct external exposure and exposure from radiation scattered from the ground and air. The dose rates calculated using RISKIND have been compared with outputs from existing shielding codes, and RISKIND has been found to produce realistic but conservative results. As a conservative assumption, potential shielding between the cask and the receptor is not considered.

The four different types of receptors likely to be exposed during on-site transit are:

- Truck/rail crew members (crew dose),
- On-site workers adjacent to the transport route (off-link worker population dose),

- On-site persons sharing the transport route (on-link dose), and
- A guard or inspector at the gate to a facility or at a checkpoint along the route.

The dose to the crew members can be calculated by multiplying the distance traveled by the shipment by the dose per kilometer calculated by RADTRAN 4 at the crew compartment. The dose rate at the crew compartment is limited to a maximum of 2 mrem/h by federal regulation. RADTRAN 4 was used for crew dose estimates to remain consistent with the off-site transportation risk assessment (Monette et al. 1996a-d).

On-site workers at Hanford are located within fairly well-defined facilities or work areas. Only those areas that receive any significant amount of radiation from a passing shipment were considered (Table 3.1). RISKIND was used to calculate the population dose to each affected area by specifying the minimum distance from the route, the maximum distance from the route, and the average population density of that specific work area. The dose for each area was calculated while the shipment was immediately adjacent to the area.

RISKIND calculated the dose to individuals sharing the truck transport route based on the average vehicle speed, average vehicle occupancy, road type, and one-way traffic densities (Table 3.1). This dose (on-link dose) was to people in vehicles traveling on the same road in the opposite direction of the shipment. This dose was to members of the general public as well as workers, because a section of the on-site route evaluated for this risk assessment is over public access roadways. No on-link dose for rail transport was calculated because the tracks at Hanford are exclusive use only, that is, there are no parallel sets of tracks over the route on which another train could be traveling.

For truck routes, the closest individual to the shipment, outside the loading facilities, would be the guard at the boundary of the shipping facility or at a checkpoint, such as the Wye Barricade, along a route. This dose was calculated directly by RISKIND. There is no analogous receptor for a rail shipment.

5.2 ACCIDENT CONDITIONS

For each waste type, on-site transport radiological accident consequences and the attendant health risks were calculated. On-site accident probabilities at Hanford (Wang et al. 1991) were used to determine the maximum credible radioactive release for each waste type.

Doses to a maximally exposed individual and on- and off-site populations have been calculated using RISKIND and parameters specific to Hanford. Doses include contributions from inhalation, cloudshine, and groundshine; no food ingestion pathway has been considered for maximally exposed individuals or on-site worker populations. The food ingestion pathway was only considered for rural population areas off-site.

6 ROUTINE INCIDENT-FREE RISKS

By definition, the consequences (dose) during routine transport on-site are expected to occur; therefore, the probability of routine consequences is taken to be unity. The radiological risk associated with routine transportation conditions results from the potential exposure of people to low-level external radiation in the vicinity of loaded shipments. The maximum allowable external dose rates for exclusive-use shipments and for the different waste types are discussed and presented in Section 4.

The health risk conversion factors used to estimate expected cancer fatalities, cancer incidence, and serious genetic effects from radiological exposures were derived from ICRP Publication 60 (ICRP 1991): 5.0×10^{-4} and 4.0×10^{-4} fatal cancer cases per person-rem for members of the public and workers, respectively; 1.7×10^{-3} and 1.4×10^{-3} induced cancer cases per person-rem for members of the public and workers, respectively; and 1.0×10^{-4} and 6.0×10^{-5} adverse genetic effects per person-rem for members of the public and workers, respectively. Cancer fatalities and incidence occur over the lifetimes of the exposed populations. Genetic effects occur in the descendants of the exposed population. The genetic health risk conversion factors used in this analysis include all generations.

The incident-free doses and risks on a per shipment basis have been presented separately in terms of total dose, expected cancer fatalities, expected number of cancer inductions, and expected genetic effects (Tables 6.1 to 6.4). The annual doses and risks, during the 20-year generation and transport period considered by the WM PEIS, are presented in Tables 6.5 to 6.7. All shipments are assumed to occur between the 300 Area and the 200 West Area for the entire 20-year generation and transport period considered by the WM PEIS.

The persons receiving the highest doses are members of the truck crews. If the same crew member were present for all shipments of TRUW for one year (206 shipments), he or she would receive a dose of 0.27 rem, almost 20 times less than the regulatory limit for workers of 5 rem/yr (DOE 1988), more than seven times less than the DOE administrative control limit of 2 rem/yr (DOE 1992b), and about three times more than the average annual background radiation of 0.080 rem/yr at the Hanford Site (Jaquish and Bryce 1990).

TABLE 6.1 Doses and Health Risks on a per Shipment Basis from Routine On-Site Transportation of LLW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	8.65E−04	1.92E−05	1.08E−06	2.15E−06
	Rail	3.13E−04	NA[f]	3.65E−06	NA
Fatalities	Truck	3.46E−07	9.58E−09	4.33E−10	8.60E−10
	Rail	1.25E−07	NA	1.46E−09	NA
Cancer incidence	Truck	1.21E−06	3.26E−08	1.52E−09	3.01E−09
	Rail	4.38E−07	NA	5.10E−09	NA
Genetic effects	Truck	5.19E−08	1.92E−09	6.50E−11	1.29E−10
	Rail	1.88E−08	NA	2.19E−10	NA

[a] A dose rate of 1 mrem/h at 1 m is assumed.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East, and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.2 Doses and Health Risks on a per Shipment Basis from Routine On-Site Transportation of LLMW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	8.65E–04	1.92E–05	1.08E–06	2.15E–06
	Rail	3.13E–04	NA[f]	3.65E–06	NA
Fatalities	Truck	3.46E–07	9.58E–09	4.33E–10	8.60E–10
	Rail	1.25E–07	NA	1.46E–09	NA
Cancer incidence	Truck	1.21E–06	3.26E–08	1.52E–09	3.01E–09
	Rail	4.38E–07	NA	5.10E–09	NA
Genetic effects	Truck	5.19E–08	1.92E–09	6.50E–11	1.29E–10
	Rail	1.88E–08	NA	2.19E–10	NA

[a] A dose rate of 1 mrem/h at 1 m is assumed.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East, and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.3 Doses and Health Risks on a per Shipment Basis from Routine On-Site Transportation of CH-TRUW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	2.64E−03	1.07E−04	5.47E−06	1.21E−05
	Rail	2.09E−03	NA[f]	2.44E−05	NA
Fatalities	Truck	1.06E−06	5.37E−08	2.19E−09	4.85E−09
	Rail	8.36E−07	NA	9.75E−09	NA
Cancer incidence	Truck	3.70E−06	1.82E−07	7.66E−09	1.70E−08
	Rail	2.92E−06	NA	3.41E−08	NA
Genetic effects	Truck	1.59E−07	1.07E−08	3.28E−10	7.28E−10
	Rail	1.25E−07	NA	1.46E−09	NA

[a] Dose rates of 5.7 (truck) and 7.2 (rail) mrem/h at 1 m are assumed.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.4 Doses and Health Risks on a per Shipment Basis from Routine On-Site Transportation of RH-TRUW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	2.64E−03	1.33E−04	6.11E−06	1.51E−05
	Rail	2.28E−03	NA[f]	4.69E−05	NA
Fatalities	Truck	1.06E−06	6.64E−08	2.44E−09	6.05E−09
	Rail	9.13E−07	NA	1.88E−08	NA
Cancer incidence	Truck	3.70E−06	2.26E−07	8.55E−09	2.12E−08
	Rail	3.20E−06	NA	6.56E−08	NA
Genetic effects	Truck	1.59E−07	1.33E−08	3.66E−10	9.07E−10
	Rail	1.37E−07	NA	2.81E−09	NA

[a] Dose rates of 7.1 (truck) and 14.2 (rail) mrem/h at 1 m are assumed.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.5 Annual Doses and Health Risks for the Routine On-Site Transportation of LLW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	5.04E−01	1.12E−02	6.30E−04	1.25E−03
	Rail	6.82E−02	NA[f]	7.95E−04	NA
Fatalities	Truck	2.01E−04	5.58E−06	2.52E−07	5.01 E−07
	Rail	2.73E−05	NA	3.18E−07	NA
Cancer incidence	Truck	7.05E−04	1.90E−05	8.82E−07	1.75E−06
	Rail	9.54E−05	NA	1.11E−06	NA
Genetic effects	Truck	3.02E−05	1.12E−06	3.78E−08	7.51E−08
	Rail	4.09E−06	NA	4.77E−08	NA

[a] Combined results for heterogeneous solids LLW and activated metals LLW: 582 shipments/year for 20 years if 100% truck, 218 shipments/year for 20 years if 100% rail.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East, and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.6 Annual Doses and Health Risks for the Routine On-Site Transportation of LLMW at Hanford[a]

		Receptor			
Dose/Risk	Mode	Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	7.44E−02	1.65E−03	9.31E−05	1.85E−04
	Rail	1.03E−02	NA[f]	1.20E−04	NA
Fatalities	Truck	2.98E−05	8.24E−07	3.72E−08	7.40E−08
	Rail	4.13E−06	NA	4.81E−08	NA
Cancer incidence	Truck	1.04E−04	2.80E−06	1.30E−07	2.59E−07
	Rail	1.44E−05	NA	1.68E−07	NA
Genetic effects	Truck	4.47E−06	1.65E−07	5.59E−09	1.11E−08
	Rail	6.19E−07	NA	7.22E−09	NA

[a] 86 shipments/year for 20 years if 100% truck, 33 shipments/year for 20 years if 100% rail.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East, and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

TABLE 6.7 Annual Doses and Health Risks for the Routine On-Site Transportation of TRUW at Hanford[a]

Dose/Risk	Mode	Receptor: Crew[b]	On-Link[c]	Off-Link[d]	Guard[e]
Dose (person-rem)	Truck	5.44E−01	2.69E−02	1.25E−03	3.06E−03
	Rail	2.35E−01	NA[f]	4.65E−03	NA
Fatalities	Truck	2.18E−04	1.34E−05	4.98E−07	1.22E−06
	Rail	9.42E−05	NA	1.86E−06	NA
Cancer incidence	Truck	7.62E−04	4.57E−05	1.74E−06	4.28E−06
	Rail	3.30E−04	NA	6.51E−06	NA
Genetic effects	Truck	3.27E−05	2.69E−06	7.48E−08	1.83E−07
	Rail	1.41E−05	NA	2.79E−07	NA

[a] Combined results for CH-TRUW and RH-TRUW. 19 (CH) + 187 (RH) shipments/year for 20 years if 100% truck, 10 (CH) + 94 (RH) shipments/year for 20 years if 100% rail.

[b] Two crew members at a distance of 3 m (truck). Five crew members at a distance of 152 m (rail).

[c] Workers and members of the public are both exposed.

[d] Affected worker populations are in the 300, 200 East, and 200 West areas. The WPPSS area is also affected for rail shipments.

[e] Maximally exposed individual. Exposed for one minute at 5 m for inspection of shipment manifest.

[f] NA = not applicable.

7 ACCIDENT CONSEQUENCE ASSESSMENT

7.1 ACCIDENT SEVERITY CATEGORIES

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

The NUREG-0170 accident classification scheme is shown in Figures 7.1 and 7.2 for truck and rail transportation, respectively. Severity is described as a function of the magnitudes of the mechanical forces (impact) and thermal forces (fire) to which a package may be subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range. The accident severity scheme is designed to take into account all credible transportation accidents, including accidents with low probability but high consequences and those with high probability but low consequences.

Each severity category represents a set of accident scenarios defined by a combination of mechanical and thermal forces. A conditional probability of occurrence — that is, the probability that if an accident occurs, it is of a particular severity — is assigned to each category. Table 7.1 shows the fractional occurrences for accidents by accident severity category and population density zone. Category I accidents are the least severe but most frequent, while Category VIII accidents are very severe but very infrequent. To determine the expected frequency of an accident of a given severity, the conditional probability in the category is multiplied by the baseline accident rate. Each population density zone has a distinct baseline accident rate and distribution of accident severities related to differences in average vehicle velocity, traffic density, and other factors, including location (i.e., rural, suburban, or urban).

For the accident consequence assessment, the doses were assessed for populations and individuals at Hanford assuming a severity Category VIII accident. This accident category represents the most severe accident scenarios that can be postulated. Accidents of this severity are extremely rare, occurring approximately once in every 100,000 truck or 10,000 rail accidents involving a radioactive waste shipment. On the basis of national accident statistics (Saricks and Kvitek 1994), for every one million shipment miles (loaded), the probability of an accident of this severity is 6×10^{-6} for shipment by truck and 1×10^{-6} for shipment by rail. At Hanford, the results of an accident sequence analysis (Wang et al. 1991) indicated that an accident with a fire release sequence (one that would fall in one of the highest accident severity categories) had an estimated frequency of 4.7×10^{-11}/km,

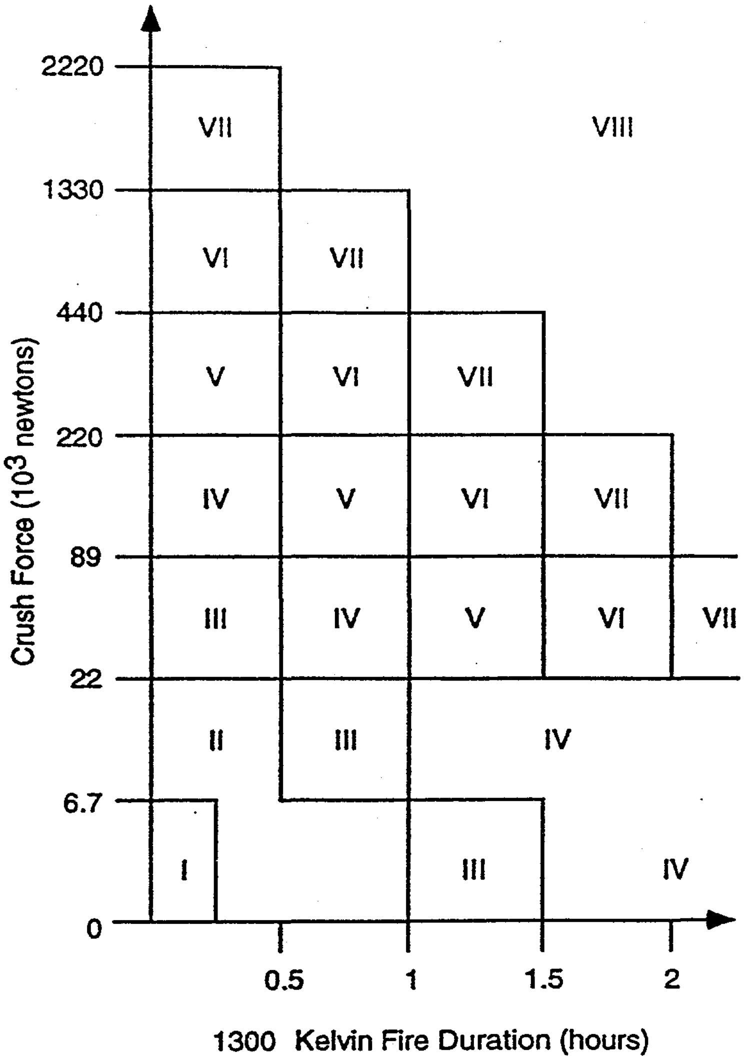

FIGURE 7.1 NUREG-0170 Accident Severity Category Classification Scheme for Truck Accidents (Source: NRC 1977)

1.7×10^{-9}/shipment from the 300 Area to the 200 West Area, well over one in a million for each waste type for the 20-year shipping period. However, it must be emphasized that no accidents resulting in fire have ever occurred at Hanford, and the lower speeds used during on-site transportation of radioactive material would result in less damage if an accident were to occur. Therefore, the potential impacts from the accident consequence assessment are considered to be highly conservative.

7.2 PACKAGE RELEASE FRACTIONS

Radiological consequences are calculated by assigning package release fractions to each accident severity category. The release fraction is defined as the fraction of the

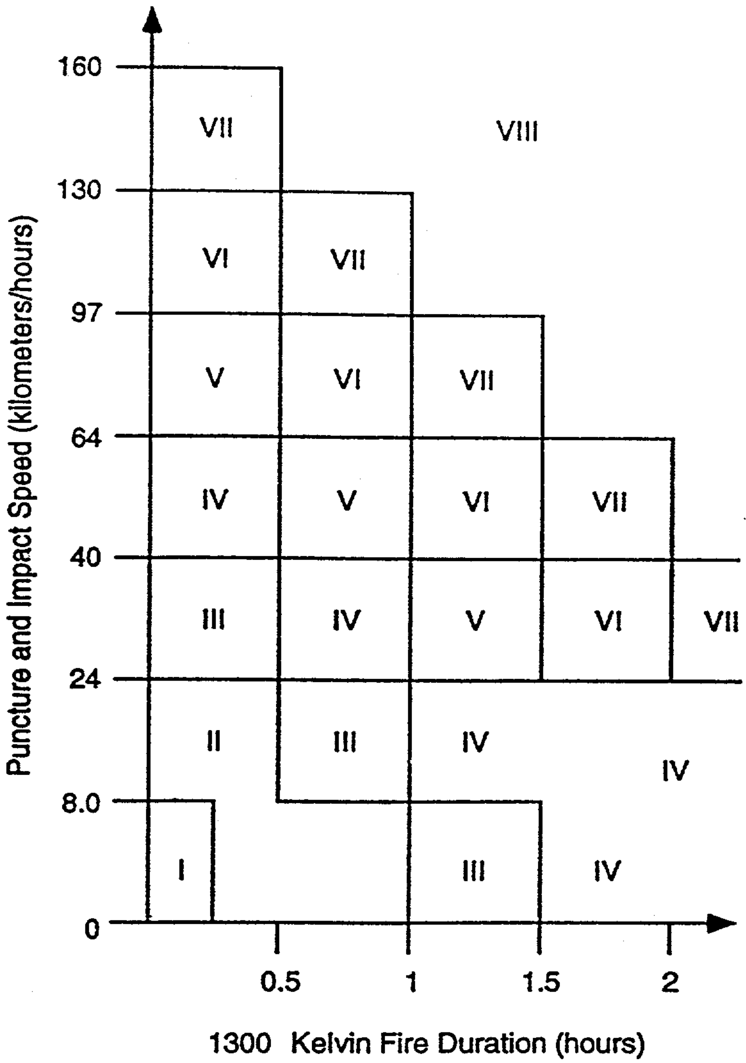

FIGURE 7.2 NUREG-0170 Accident Severity Category Classification Scheme for Rail Accidents (Source: NRC 1977)

radioactive material in a package that could be released from the package in a given severity of accident. Release fractions take into account all mechanisms necessary to create a release of radioactive material from a damaged package to the environment. Release fractions vary according to package type and the physical form of the waste. Type B packaging is designed to withstand the forces of severe accidents and therefore has smaller release fractions than Type A packaging. Most solid wastes are difficult to release in particulate form and are therefore relatively nondispersible. Conversely, liquid or gaseous materials are relatively easy to release if the container is compromised in an accident.

Package release fractions for accidents of each severity category are given in Table 7.2 for the package types considered in this assessment. The release fraction values were obtained from various sources, but all were derived based on the methods described in NUREG-0170 (NRC 1977).

TABLE 7.1 Fractional Occurrences for Accidents by Severity Category and Population Density Zones

Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zone: Rural	Suburban	Urban
Truck				
I	0.55	0.1	0.1	0.8
II	0.36	0.1	0.1	0.8
III	0.07	0.3	0.4	0.3
IV	0.016	0.3	0.4	0.3
V	0.0028	0.5	0.3	0.2
VI	0.0011	0.7	0.2	0.1
VII	8.5E−05	0.8	0.1	0.1
VIII	1.5E−05	0.9	0.05	0.05
Rail				
I	0.50	0.1	0.1	0.8
II	0.30	0.1	0.1	0.8
III	0.18	0.3	0.4	0.3
IV	0.018	0.3	0.4	0.3
V	0.0018	0.5	0.3	0.2
VI	1.3E−04	0.7	0.2	0.1
VII	6.0E−05	0.8	0.1	0.1
VIII	1.0E−05	0.9	005	0.05

Source: NRC (1977).

Also important for risk assessment purposes are the fraction of the released material that can be entrained in an aerosol (i.e., part of an airborne radioactive plume) and the fraction of the aerosolized material that is also respirable (i.e., of a size that can be inhaled into the lungs). These fractions depend on the physical form of the waste material. The aerosolized and respirable fractions of the amount released (Table 7.2) for various physical waste forms are given in Table 7.3. The release fractions for TRUW packages incorporate the aerosolized and respirable fractions based on characteristics of TRUW.

7.3 ATMOSPHERIC CONDITIONS

Radioactive material released to the atmosphere is transported by the wind. The amount of dispersion, or dilution, of the radioactive material concentrations in the air depends on the meteorological conditions at the time of the accident. Based on weather observations at Hanford (Stone et al. 1983), neutral conditions (Pasquill Classes C and D) occur about 32% of the time, while stable conditions (Pasquill Classes E and F) about 45%

TABLE 7.2 Estimated Release Fractions for Shipping Packagings under Various Accident Severity Categories

Severity Category	Type A[a]	Type B TRUPACT II[b]	Type B NuPac 72B[b]
Truck			
I	0	0	0
II	0.01	0	0
III	0.1	8.0E−09	6.0E−09
IV	1.0	2.0E−07	2.0E−07
V	1.0	8.0E−05	1.0E−04
VI	1.0	2.0E−04	1.0E−04
VII	1.0	2.0E−04	2.0E−04
VIII	1.0	2.0E−04	2.0E−04
Rail			
I	0	0	
II	0.01	0	0
III	0.1	2.0E−08	2.0E−08
IV	1.0	7.0E−07	7.0E−07
V	1.0	8.0E−05	1.0E−04
VI	1.0	2.0E−04	1.0E−04
VII	1.0	2.0E−04	2.0E−04
VIII	1.0	2.0E−04	2.0E−04

[a] Source: NRC (1977). Values are for total material release fraction.

[b] Source: DOE (1990a). Values are for the respirable release fraction.

of the time. Unstable conditions (Pasquill Class A and B) occur only about 22% of the time. Since both neutral and stable conditions are common and predominate at Hanford, doses were assessed under both neutral (Pasquill Stability Class D with a wind speed of 4 m/s) and stable (Pasquill Stability Class F with a wind speed of 1 m/s) atmospheric conditions. The results calculated for neutral conditions represent the most likely consequences and the results for stable conditions represent a "worst-case" weather situation.

7.4 ACCIDENT CONSEQUENCES AND HEALTH RISKS

Doses have been assessed for on-site worker and off-site general public populations and a maximally exposed individual assuming that an accident of the highest severity, as

TABLE 7.3 Aerosolized and Respirable Material Release Fractions for Various Physical Waste Forms

Physical Waste Form	Aerosol Fraction	Respirable Fraction
Vitrified waste[a]	1.0E−06	5.0E−02
Activated metals[a]	1.0E−06	5.0E−02
Heterogeneous solids[b]	1.0E−01	5.0E−02
Nonvolatile liquids	1.0E−01	5.0E−02
Volatile liquids	1.0	1.0

[a] Considered to behave as immobile material.
[b] Considered to behave as a loose powder.
Source: Neuhauser and Kanipe (1992).

defined in NUREG-0170 (NRC 1977), has occurred outside the 300 Area on or near Route 4 South under constant weather conditions. However, because of the low on-site vehicle speeds, the consequences presented are expected to be highly conservative.

For assessment of the impacts to the on-site worker population in the 300 Area, a constant wind blowing toward the east was assumed to maximize dose. An exposure time of two hours was assumed. A constant wind blowing toward the south-southeast was found to give the maximum off-site population dose. The assessment considers the off-site population within 50 mi (80 km) of the accident site and a one-year exposure period. The maximally exposed individual exposure period is assumed to be two hours.

The population doses include contributions from acute inhalation, acute cloudshine, groundshine, resuspended inhalation, and resuspended cloudshine. In addition, the ingestion pathway was included for off-site rural population density zones. The results presented are conservative in that shielding was not considered and no decontamination or mitigative actions were assumed to take place.

Accident consequences have been presented separately in terms of total dose (Table 7.4), expected cancer fatalities (Table 7.5), expected number of cancer inductions (Table 7.6), and expected genetic effects (Table 7.7).

Impacts from activated metal LLW are orders of magnitude smaller than the other waste considered because of its nondispersible nature. The accident with the worst impacts is a potential rail accident involving LLMW under stable weather conditions. This accident results in a collective off-site population dose of 180 person-rem, which is only twenty times larger than the 9 person-rem estimated from normal Hanford operations for the 80-km (50-mi) population surrounding the site for both 1985 and 1986, and 180 times the 80-km (50-mi) population dose for 1989 estimated to be 1 person-rem (Jaquish and Bryce 1990).

TABLE 7.4 Estimated Radiological Doses from a Postulated Severe Transportation Accident under Both Neutral (Pasquill Class D) and Stable (Pasquill Class F) Weather Conditions[a]

Source Term	On-Site Population (person-rem)[b,c]		Off-Site Population (person-rem)[c,d]		Maximally Exposed Individual (rem)[e,f]	
	Neutral	Stable	Neutral	Stable	Neutral	Stable
LLW (heterogeneous solids)						
Truck	7.6E–02	2.6E–01	9.0E–01	7.7	7.7E–03	2.6E–02
Rail	2.0E–01	6.9E–01	2.4	2.1E+01	2.1E–02	7.0E–02
LLW (activated metals)						
Truck	8.6E–08	2.9E–07	1.9E–05	1.6E–04	1.9E–08	6.5E–08
Rail	2.3E–07	7.8E–07	5.1E–05	4.3E–04	5.2E–08	1.7E–07
LLMW						
Truck	4.5	1.6E+01	8.1	6.9E+01	1.1E-01	3.6E-01
Rail	1.2E+01	4.0E+01	2.1E+01	1.8E+02	2.8E-01	9.3E-01
CH-TRUW						
Truck	1.0E+01	3.6E+01	6.0	5.2E+01	2.5E–01	8.4E–01
Rail	2.1E+01	7.0E+01	1.2E+01	1.0E+02	5.0E–01	1.7
RH-TRUW						
Truck	2.1	7.1	1.2	1.1E+01	5.0E–02	1.7E–01
Rail	4.1	1.4E+01	2.4	2.1E+01	1.0E–01	3.4E–01

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

[b] On-site population at the 300 Area assumed to have a uniform population density of 1,700 people/km^2 extending from 45 (truck) or 60 (rail) m for an accident.

[c] Population pathways: acute inhalation, acute cloudshine, groundshine, resuspended inhalation, resuspended cloudshine, ingestion of all foodstuffs including initially contaminated foodstuffs (off-site rural only). No decontamination or mitigative actions taken.

[d] Off-site population extends to a radius of 80 km from the accident site.

[e] The location of maximum exposure would be 160 and 400 m from the accident site under neutral and stable atmospheric conditions, respectively. The maximally exposed individual is assumed to be unshielded during the passage of a radioactive plume.

[f] Individual pathways: acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingestion dose is considered.

TABLE 7.5 Estimated Radiation-Induced Cancer Fatalities from a Postulated Severe Transportation Accident under Both Neutral (Pasquill Class D) and Stable (Pasquill Class F) Weather Conditions[a]

Source Term	On-Site Population (cancer fatalities)[b,c]		Off-Site Population (cancer fatalities)[c,d]		Risk to Maximally Exposed Individual (cancer fatalities)[e,f]	
	Neutral	Stable	Neutral	Stable	Neutral	Stable
LLW (heterogeneous solids)						
Truck	3.0E–05	1.0E–04	4.5E–04	3.8E–03	3.9E–06	1.3E–05
Rail	8.1E–05	2.8E–04	1.2E–03	1.0E–02	1.0E–05	3.5E–05
LLW (activated metals)						
Truck	3.4E–11	1.2E–10	9.5E–09	8.1E–08	9.7E–12	3.2E–11
Rail	9.2E–11	3.1E–10	2.5E–08	2.2E–07	2.6E–11	8.7E–11
LLMW						
Truck	1.8E-03	6.2E-03	4.0E-03	3.5E-02	5.3E-05	1.8E-04
Rail	4.7E-03	1.6E-02	1.1E-02	9.0E-02	1.4E-04	4.6E-04
CH-TRUW						
Truck	4.2E–03	1.4E–02	3.0E–03	2.6E–02	1.3E–04	4.2E–04
Rail	8.2E–03	2.8E–02	5.9E–03	5.2E–02	2.5E–04	8.3E–04
RH-TRUW						
Truck	8.2E–04	2.8E–03	6.0E–04	5.3E–03	2.5E–05	8.4E–05
Rail	1.6E–03	5.6E–03	1.2E–03	1.1E–02	5.0E–05	1.7E–04

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

[b] On-site population at the 300 Area assumed to have a uniform population density of 1,700 people/km^2 extending from 45 (truck) or 60 (rail) m for an accident.

[c] Population pathways: acute inhalation, acute cloudshine, groundshine, resuspended inhalation, resuspended cloudshine, ingestion of all foodstuffs including initially contaminated foodstuffs (off-site rural only). No decontamination or mitigative actions taken.

[d] Off-site population extends to a radius of 80 km from the accident site.

[e] The location of maximum exposure would be 160 and 400 m from the accident site under neutral and stable atmospheric conditions, respectively. The maximally exposed individual is assumed to be unshielded during the passage of a radioactive plume.

[f] Individual pathways: acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingestion dose is considered.

TABLE 7.6 Estimated Radiation-Induced Cancer Incidence from a Postulated Severe Transportation Accident under Both Neutral (Pasquill Class D) and Stable (Pasquill Class F) Weather Conditions[a]

Source Term	On-Site Population (cancer incidence)[b,c]		Off-Site Population (cancer incidence)[c,d]		Risk to Maximally Exposed Individual (cancer incidence)[e,f]	
	Neutral	Stable	Neutral	Stable	Neutral	Stable
LLW (heterogeneous solids)						
Truck	1.1E−04	3.6E−04	1.5E−03	1.3E−02	1.3E−05	4.4E−05
Rail	2.8E−04	9.7E−04	4.1E−03	3.5E−02	3.5E−05	1.2E−04
LLW (activated metals)						
Truck	1.2E−10	4.1E−10	3.2E−08	2.8E−07	3.3E−11	1.1E−10
Rail	3.2E−10	1.1E−09	8.6E−08	7.4E−07	8.8E−11	3.0E−10
LLMW						
Truck	6.3E-03	2.2E-02	1.4E-02	1.2E-01	1.8E-04	6.1E-04
Rail	1.7E-02	5.7E-02	3.6E-02	3.1E-01	4.7E-04	1.6E-03
CH-TRUW						
Truck	1.5E−02	5.0E−02	1.0E−02	8.9E−02	4.3E−04	1.4E−03
Rail	2.9E−02	9.9E−02	2.0E−02	1.8E−01	8.4E−04	2.8E−03
RH-TRUW						
Truck	2.9E−03	9.9E−03	2.0E−03	1.8E−02	8.5E−05	2.8E−04
Rail	5.8E−03	2.0E−02	4.1E−03	3.6E−02	1.7E−04	5.7E−04

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

[b] On-site population at the 300 Area assumed to have a uniform population density of 1,700 people/km^2 extending from 45 (truck) or 60 (rail) m for an accident.

[c] Population pathways: acute inhalation, acute cloudshine, groundshine, resuspended inhalation, resuspended cloudshine, ingestion of all foodstuffs including initially contaminated foodstuffs (off-site rural only). No decontamination or mitigative actions taken.

[d] Off-site population extends to a radius of 80 km from the accident site.

[e] The location of maximum exposure would be 160 and 400 m from the accident site under neutral and stable atmospheric conditions, respectively. The maximally exposed individual is assumed to be unshielded during the passage of a radioactive plume.

[f] Individual pathways: acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingestion dose is considered.

TABLE 7.7 Estimated Radiation-Induced Genetic Effects from a Postulated Severe Transportation Accident under Both Neutral (Pasquill Class D) and Stable (Pasquill Class F) Weather Conditions[a]

Source Term	On-Site Population (genetic effects)[b,c]		Off-Site Population (genetic effects)[c,d]		Risk to Maximally Exposed Individual (genetic effects)[e,f]	
	Neutral	Stable	Neutral	Stable	Neutral	Stable
LLW (heterogeneous solids)						
Truck	4.5E−06	1.5E−05	9.0E−05	7.7E−04	7.7E−07	2.6E−06
Rail	1.2E−05	4.1E−05	2.4E−04	2.1E−03	2.1E−06	7.0E−06
LLW (activated metals)						
Truck	5.1E−12	1.8E−11	1.9E−09	1.6E−08	1.9E−12	6.5E−12
Rail	1.4E−11	4.7E−11	5.1E−09	4.3E−08	5.2E−12	1.7E−11
LLMW						
Truck	2.7E-04	9.3E-04	8.1E-04	6.9E-03	1.1E-05	3.6E-05
Rail	7.1E-04	2.4E-03	2.1E-03	1.8E-02	2.8E-05	9.3E-05
CH-TRUW						
Truck	6.2E−04	2.1E−03	6.0E−04	5.2E−03	2.5E−05	8.4E−05
Rail	1.2E−03	4.2E−03	1.2E−03	1.0E−02	5.0E−05	1.7E−04
RH-TRUW						
Truck	1.2E−04	4.2E−04	1.2E−04	1.1E−03	5.0E−06	1.7E−05
Rail	2.5E−04	8.5E−04	2.4E−04	2.1E−03	1.0E−05	3.4E−05

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

[b] On-site population at the 300 Area assumed to have a uniform population density of 1,700 people/km^2 extending from 45 (truck) or 60 (rail) m for an accident.

[c] Population pathways: acute inhalation, acute cloudshine, groundshine, resuspended inhalation, resuspended cloudshine, ingestion of all foodstuffs including initially contaminated foodstuffs (off-site rural only). No decontamination or mitigative actions taken.

[d] Off-site population extends to a radius of 80 km from the accident site.

[e] The location of maximum exposure would be 160 and 400 m from the accident site under neutral and stable atmospheric conditions, respectively. The maximally exposed individual is assumed to be unshielded during the passage of a radioactive plume.

[f] Individual pathways: acute inhalation, acute cloudshine, and groundshine during passage of the plume. No ingestion dose is considered.

Because the estimates for a severe accident as presented here are highly conservative (on-site speeds are low and reduce the possibility of damage in an accident, and the release fractions are conservative), the consequences facing the public from an on-site accident at Hanford are only slightly more than normal operations at the site for one year.

The actual risk (probability times consequence) to the public from normal operations is the same as the accident consequence, because normal operations at Hanford occur (the probability is one). The actual risk to the public from the worst severe transportation accident postulated is more than one million times less than the consequences presented here. The probability of the accident is about 1 in a million, 1×10^{-6}, times the probability, 0.0056, associated with the wind blowing at 1 m/s towards the highest population centers under F stability category weather conditions at the time of the accident, the conditions used to estimate the consequences. The worst case on-site accident may have a consequence that is approximately 100 times larger than one year of operations at Hanford, but the actual risk is about 10,000,000 times less than one year of operations at Hanford.

8 UNCERTAINTY AND MITIGATIVE MEASURES

8.1 UNCERTAINTY AND CONSERVATISM

The sequence of analyses performed to generate the radiological risk estimates for the transportation of radioactive material include (1) estimation of source terms, (2) estimation of environmental transport and uptake of radionuclides, (3) calculation of radiation doses to exposed individuals, and (4) estimation of health effects. There are uncertainties associated with each of these steps. Uncertainties exist in the way the physical systems being analyzed are represented by the computational models, in the data required to exercise the models (from measurement errors, sampling errors, natural variability, or unknowns simply due to the future nature of the actions being analyzed), and in the calculations themselves (e.g., approximate algorithms used by the computers).

In principle, one can estimate the uncertainty associated with each input or computational source and predict the resultant uncertainty in each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final, or absolute, result. However, conducting such a full-scale quantitative uncertainty analysis is often impractical and sometimes impossible, especially for actions to be initiated at an unspecified time in the future.

In practice, the accuracy of the calculated results is closely related to the limitations of the computational models and to the uncertainties in each of the input parameters that the model requires. Uncertainties associated with the computational models are minimized by using state-of-the-art computer codes that have undergone extensive review. However, because there are numerous uncertainties that are recognized but difficult to quantify, assumptions are made at each step of the risk assessment process that are intended to produce conservative results (i.e., overestimate the calculated dose and radiological risk).

The scenarios, models, and input parameters used in the risk assessment calculations are routinely selected in such a way that most intermediate results and, consequently, the final estimates of impacts are greater than would be expected. As a result, even though the range of uncertainty in a quantity might be large, the value calculated for the quantity is close to one of the extremes in the range of possible values, so that the chance of the actual quantity being greater than the calculated value is low. Therefore, there exists an inherent bias in the risk assessment process that tends to produce conservative results.

Although it is not possible to accurately estimate the overall degree of conservatism, because of the combination of multiple unknowns used in this risk assessment, it is possible to identify assumptions that are known to produce conservative results. A number of these assumptions are discussed below.

External dose rates. Incident-free risks for populations and maximally exposed individuals are directly proportional to the assumed shipment external dose rates. Conservative assumptions have been applied. The actual exposure rates will be a function of the composition and configuration of shielding and containment materials used in the waste packaging, the geometry of the loaded shipments, and characteristics of the waste material itself. In practice, external exposure rates will vary not only from site to site and waste type to waste type, but also from shipment to shipment at Hanford, and they will range well below the levels assumed for this assessment.

Shielding of exposed populations during routine transport is not considered. For all incident-free exposure scenarios, no credit has been taken for shielding of exposed individuals. In reality, shielding will be afforded by trucks and cars sharing the transport routes, by natural topography, and by the offices and laboratories used by the workers on-site at Hanford. Incident-free exposures to external radiation may be reduced significantly depending on the type of shielding present. Shielding factors (i.e., the ratio of shielded to unshielded exposure rates) have been estimated to range from 0.02 to 0.7 for buildings similar to residential structures (NRC 1992). Similar levels of shielding may be provided to individuals exposed in vehicles.

Routine dose to the public. The only possible routine dose that members of the public could receive is from driving along Route 4 South, an on-link dose, while a radioactive shipment is present. In reality, all waste shipments will not be using this route. Shipments from the 100 areas and 200 East will be on routes denied access to the public. Also, most persons using Route 4 South are in fact workers at Hanford. The Wye Barricade makes Route 4 South impassable to the public after only a short distance. The routine dose attributed to the public is therefore a limit that is expected to be quite conservative.

Shielding and post-accident mitigative actions are not considered for dispersal accidents. For severe accidents involving the release and dispersal of radioactive materials in the environment, no post-accident mitigative actions, such as evacuation of the accident vicinity or interdiction of crops , have been considered in this risk assessment. In reality, mitigative actions would take place following an accident in accordance with U.S. Environmental Protection Agency (EPA) radiation protection guides for nuclear incidents (EPA 1990). Site-wide warning signals at Hanford would signal workers to take cover or evacuate immediately following any accidental release of radioactive material (WHC 1994). Site authorities would be in contact with off-site public officials to advise on the best course of action for the public should a hazard threaten to extend beyond the boundaries of the Hanford Site. The effects of mitigative actions on population accident doses are highly dependent upon the waste type involved and the severity, location, and timing of the accident. For this risk assessment, ingestion doses related to accidental release and dispersal are only calculated for rural areas (the calculated ingestion dose, however, assumes all food grown on contaminated ground is consumed, and is not limited to the rural population). Rural areas are taken to be those areas where the average population densities range from 0 to 54 persons/km^2 (0 to 139 persons/mi^2). Examination of the severe accident consequence assessment results has shown that ingestion of contaminated foodstuffs contributes on the order of 50% of the total population dose for rural accidents. Interdiction of foodstuffs would act to reduce, but not eliminate, this contribution.

8.2 MITIGATIVE MEASURES

The DOE and Hanford are committed to conducting all transportation activities in a manner protective of human health and safety. The hazards of transporting radioactive materials under both incident-free and accident conditions are minimized by existing regulations, as described. All activities related to the transportation of radioactive waste would be conducted in accordance with the applicable health and safety requirements of the federal government and the state of Washington, including requirements promulgated by the DOT in Title 49 of the CFR.

In addition to these policies, the DOE may impose administrative controls to control accumulated doses in specific circumstances. Examples of administrative controls would include requiring temporary lead shielding between loaded casks and service personnel and prohibiting transportation during inclement weather. These measures would act to ensure that all exposures are maintained below the regulatory dose limits specified in DOE Orders 5400.5 and 5480.11 (DOE 1990a, 1988) for members of the public and workers, respectively.

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

9 SUMMARY AND COMPARISON WITH OFF-SITE TRANSPORTATION

Consequences and risks from radiation exposure to workers and members of the general public were presented. Routine shipments of LLW, LLMW, and TRUW on-site at Hanford and postulated transportation accidents on-site were evaluated. It can be shown that annual doses to both workers and members of the public will be within the DOE regulatory limits of 5 rem/yr (DOE Order 5480.11 [DOE 1988]) and 100 mrem/yr (DOE Order 5400.5 [DOE 1988]) respectively.

For workers, truck crew members experience the highest exposure because they are the closest receptors to the waste package and also exposed for the longest period of time. Even if the same crew members were present for all waste shipments in one year, a highly improbable situation, they would still receive less than the 5 rem/yr limit. Members of the public can only receive an exposure while sharing the transport route with the waste shipment, an on-link dose. This collective dose for all waste types combined on an annual basis is well below the 100 mrem/yr limit set for a single individual.

Tables 9.1 to 9.6 summarize the radiological routine risks from on-site transportation at Hanford, compared with off-site transportation for all origin/destination pairs for each case considered by the WM PEIS for LLW, LLMW, and TRUW. (See the Appendix for summaries of the definitions of the cases considered in the WM PEIS for LLW, LLMW, and TRUW.) The impacts are generally two to three orders of magnitude less than those for off-site transportation. The collective on-site transportation risks from all DOE sites is not expected to be more than an order of magnitude larger than those for Hanford alone for several reasons. It must be emphasized that the radiological routine risks from transportation are directly related to the distance traveled. Only two other DOE sites, SRS and INEL, are comparable in size to Hanford. These three sites also account for the bulk of DOE radioactive waste. Thus, it might be expected that on-site risks could be at least three times higher than Hanford alone, but it is unreasonable to expect all on-site transportation to result in routine risk more than an order of magnitude larger than for Hanford alone. In addition, the longest on-site route was assumed for all waste shipments. The collective on-site transportation risks are therefore expected to be at least one to two orders of magnitude less than the off-site transportation, except in cases where all sites dispose of their own waste.

TABLE 9.1 Summary of LLW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of LLW Generation: Truck Mode

	Alternative[a]														
	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Regional-ized 5	Regional-ized 6	Regional-ized 7	Central-ized 1	Central-ized 2	Central-ized 3-	Central-ized 4	Central-ized 5	On-Site[b]
Shipment summary															
Shipments	87,360	24,420	25,800	25,880	84,200	87,390	92,200	174,390	188,930	242,730	257,270	250,020	264,060	241,540	11,640
Mileage (10^6 mi)	166	8.63	9.31	9.19	38.1	36.9	63.8	124	125	563	505	530	478	560	0.27
Population impacts															
Cargo-related[c]															
Dose risk (person-rem)															
Routine crew	4,690	319	343	338	1,210	1,190	1,900	3,870	3,890	15,800	14,500	14,900	13,700	15,700	10.1
Routine public	5,620	335	362	357	1,340	1,310	2,180	4,350	4,410	18,700	17,200	17,700	16,300	18,700	0.224
Latent cancer fatalities[d]															
Crew fatalities	1.9	0.13	0.1	0.1	0.5	0.48	0.8	1.5	1.6	6.3	5.8	6.0	5.5	6.3	0.004
Public fatalities	2.7	0.17	0.2	0.2	0.7	0.66	1.1	2.3	2.2	9.7	8.6	9.1	8.4	9.3	0.0001

Note: NA = not applicable.

a Alternative definitions are summarized in the Appendix.

b On-site impacts are calculated for the Hanford Site.

c Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.

d Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

Sources: Monette et al. (1996a-d).

TABLE 9.2 Summary of LLW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of LLW Generation: Rail Mode

	Alternative[a]														
	No Action	Decentralized	Regionalized 1	Regionalized 2	Regionalized 3	Regionalized 4	Regionalized 5	Regionalized 6	Regionalized 7	Centralized 1	Centralized 2	Centralized 3	Centralized 4	Centralized 5	On-Site[b]
Shipment summary															
Shipments	33,420	9,210	9,740	9,900	31,850	33,460	35,430	66,040	71,480	91,440	96,880	96,710	102,100	90,980	4,360
Mileage (10^6 mi)	69.9	3.50	3.74	3.78	17.2	16.6	25.3	51.4	54.4	224	219	218	212	223	0.122
Population impacts															
Cargo-related[c]															
Dose risk (person-rem)															
Routine crew	388	41.1	43.7	44.2	163	166	208	405	433	1,190	1,190	1,190	1,180	1,190	1.38
Routine public	849	128	135	136	408	368	470	820	845	2,340	2,340	2,310	2,310	2,330	0
Latent cancer fatalities[d]															
Crew fatalities	0.15	0.016	0.02	0.02	0.07	0.067	0.08	0.16	0.17	0.48	0.47	0.48	0.47	0.47	5.52×10^{-4}
Public fatalities	0.43	0.064	0.07	0.07	0.21	0.18	0.23	0.43	0.42	1.2	1.20	1.1	1.2	1.20	0

Note: NA = not applicable.

[a] Alternative definitions are summarized in the Appendix.

[b] On-site impacts are calculated for the Hanford Site.

[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

Sources: Monette et al. (1996a-d).

TABLE 9.3 Summary of LLMW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of LLMW Generation: Truck Mode

	Alternative[a]						
Impact	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Central-ized	On-Site[b]
Shipment summary							
Shipments	480	1,820	5,560	10,990	4,250	7,520	1,720
Mileage (10^6)	0.25	0.59	2.57	14.9	2.89	13.5	0.051
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	8.22	20.4	80.3	429	84.1	374	1.49
Routine public	9.72	23.1	92.6	513	98.6	447	0.033
Latent cancer fatalities[d]							
Crew fatalities	0.0033	0.0083	0.032	0.17	0.033	0.15	0.00060
Public fatalities	0.0055	0.013	0.053	0.27	0.048	0.29	1.72×10^{-5}

Note: NA = not applicable.

a Alternative definitions are summarized in the Appendix.

b On-site impacts are calculated for the Hanford Site.

c Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.

d Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

Sources: Monette et al. (1996a-d).

TABLE 9.4 Summary of LLMW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of LLMW Generation: Rail Mode

	Alternative[a]						
Impact	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Regional-ized 4	Central-ized	On-Site[b]
Shipment summary							
Shipments	350	1,030	2,490	4,540	2,050	3,340	660
Mileage (10^6)	0.23	0.48	1.37	6.76	1.57	6.46	0.026
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	1.97	4.98	12.9	41.3	12.5	36.6	0.206
Routine public	5.75	13.7	29.1	75.8	28.2	69.3	0.0024
Latent cancer fatalities[d]							
Crew fatalities	0.00081	0.0020	0.0052	0.017	0.0050	0.015	8.3×10^{-5}
Public fatalities	0.0031	0.0072	0.015	0.040	0.015	0.049	9.6×10^{-7}

Note: NA = not applicable.

[a] Alternative definitions are summarized in the Appendix.

[b] On-site impacts are calculated for the Hanford Site.

[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

Sources: Monette et al. (1996a-d).

TABLE 9.5 Summary of TRUW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of TRUW Generation: Truck Mode

	Alternative[a]						
Impact	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Central-ized	On-Site[b]
Shipment summary							
Shipments	0	23,900	21,680	18,640	20,600	21,640	206
Mileage (10^6)	-	42.4	38.3	34.0	37.2	38.7	0.0047
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	-	3,650	3,270	2,890	3,160	3,310	11
Routine public	-	3,870	3,360	2,940	3,310	3,490	0.56
Latent cancer fatalities[d]							
Crew fatalities	-	1.5	1.3	1.2	1.3	1.3	0.0044
Public fatalities	-	1.9	1.7	1.5	1.7	1.7	0.00028

Note: NA = not applicable.

[a] Alternative definitions are summarized in the Appendix.

[b] On-site impacts are calculated for the Hanford Site.

[c] Cargo-related impacts are impacts attributable to the radioactive nature of the waste material.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

TABLE 9.6 Summary of TRUW On-Site and Off-Site Transportation Impacts for Current Inventories Plus 20 Years of TRUW Generation: Rail Mode

	Alternative[a]						
Impact	No Action	Decentral-ized	Regional-ized 1	Regional-ized 2	Regional-ized 3	Central-ized	On-Site[b]
Shipment summary							
Shipments	0	12,010	10,890	9,360	10,340	10,870	104
Mileage (10^6)	-	20.3	18.2	15.8	17.4	18.4	0.0029
Population impacts							
Cargo-related[c]							
Dose risk (person-rem)							
Routine crew	-	836	756	656	718	759	4.8
Routine public	-	1,130	978	821	907	1,010	0
Latent cancer fatalities[d]							
Crew fatalities	-	0.33	0.30	0.26	0.28	0.30	0.0019
Public fatalities	-	0.57	0.49	0.41	0.46	0.51	0

Note: NA = not applicable.

[a] Alternative definitions are summarized in the Appendix.

[b] On-site impacts are calculated for the Hanford Site.

[c] Cargo-related impacts are impacts attributable to the radioactive nature of the wate material.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP publication 60 (ICRP 1991) health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public.

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APPENDIX:

WASTE MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT WASTE-TYPE-SPECIFIC CASE DEFINITIONS

The transportation risk assessment conducted for the U.S. Department of Energy (DOE) Waste Management Programmatic Environmental Impact Statement (WM PEIS) (DOE 1996) estimates the human health risks associated with the transportation of radioactive waste for a large number of alternatives. The WM PEIS alternatives for low-level waste (LLW), low-level mixed waste (LLMW), and transuranic waste (TRUW) are defined in this appendix to help the reader understand the comparison of off-site and on-site shipment risks presented in Section 9 of the main report.

In general, the WM PEIS alternatives are considered independently for each type of waste and reflect decentralized, regionalized, and centralized approaches. For each type of waste, several options, referred to as cases, have been defined for each broad alternative. The individual cases differ in the number, location, and types of treatment, storage, and disposal (TSD) facilities that are being considered. For each case, sites that do not have treatment or disposal capability ship waste to the nearest site that has the required capability. Summary descriptions of the cases are presented below for LLW, LLMW, and TRUW.

A.1 WM PEIS ALTERNATIVES FOR LLW

Transportation risks have been calculated for 14 LLW cases. The cases range from decentralized to centralized approaches to TSD. Case 1 represents the No Action Alternative. Treatment and disposal options vary from decentralized to centralized approaches. In general, sites without treatment or disposal capability would ship to the nearest site with such capability. The cases are summarized as follows:

- *No Action (Case 1).* All sites would treat LLW using existing, planned, and approved treatment facilities and dispose of LLW at the six current disposal sites in accordance with current arrangements.

- *Decentralized (Case 2).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at 16 sites (Argonne National Laboratory-East [ANL-E], Brookhaven National Laboratory [BNL], Fernald Environmental Management Project [FEMP], Hanford Site (Hanford), INEL, Lawrence Livermore National Laboratory [LLNL], Los Alamos National Laboratory [LANL], the Nevada Test Site [NTS], Oak Ridge Reservation [ORR], Paducah Gaseous Diffusion Plant [PGDP], Pantex Plant [Pantex], Portsmouth Gaseous Diffusion Plant [PORTS], Rocky Flats Environmental Technology Site [RFETS], Sandia National Laboratory-New Mexico [SNL-NM], Savannah River Site [SRS], and West Valley Demonstration Project (WVDP).

- *Regionalized 1 (Case 3).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).

- *Regionalized 2 (Case 9).* Eleven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at 12 sites (Hanford, INEL, NTS, LANL, ORR, SRS, PORTS, PGDP, FEMP, LLNL, Pantex, and RFETS).

- *Regionalized 3 (Case 4).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearest of six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).

- *Regionalized 4 (Case 12).* Seven sites (Hanford, INEL, LANL, ORR, Ports, RFETS, and SRS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).

- *Regionalized 5 (Case 19).* Four sites (Hanford, INEL, ORR, and SRS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at six sites (Hanford, INEL, NTS, LANL, ORR, and SRS).

- *Regionalized 6 (Case 5).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearer of two sites (Hanford and SRS).

- *Regionalized 7 (Case 6).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at the nearer of two sites (NTS and SRS).

- *Centralized 1 (Case 7).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at one site (Hanford).

- *Centralized 2 (Case 8).* All sites would minimally treat LLW, stabilizing fines and liquids, and dispose of LLW at one site (NTS).

- *Centralized 3 (Case 14).* Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (Hanford).

- *Centralized 4 (Case 14a).* Seven sites (Hanford, INEL, LANL, ORR, SRS, PORTS, and RFETS) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (NTS).

- *Centralized 5 (Case 21).* One site (Hanford) would thermally treat, supercompact, reduce the size of, and grout volume-reducible waste; all sites would minimally treat other waste; disposal would occur at one site (Hanford).

A.2 WM PEIS ALTERNATIVES FOR TRUW

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

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

- *Decentralized (CH-TRUW Case 4, RH-TRUW Case 11).* Ten sites (ANL-E, Hanford, INEL, LANL, LLNL, Mound, NTS, ORR, RFETS, and SRS) would treat CH-TRUW to meet the WIPP-WAC. Five sites (ANL-E, Hanford, INEL, LANL, and ORR) would treat RH-TRUW to WIPP-WAC. All treated TRUW would be disposed at WIPP.

- *Regionalized 1 (CH-TRUW Case 5, RH-TRUW Case 14).* Five sites (Hanford, INEL, LANL, RFETS, and SRS) would treat CH-TRUW to reduce gas generation. Two sites (Hanford and ORR) treat RH-TRUW to reduce gas generation. All treated TRUW would be disposed at WIPP.

- *Regionalized 2 (CH-TRUW Case 6, RH-TRUW Case 15).* Five sites (Hanford, INEL, LANL, RFETS, and SRS) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.

- *Regionalized 3 (CH-TRUW Case 8, RH-TRUW Case 15).* Three sites (Hanford, INEL, and SRS) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.

- *Centralized (CH-TRUW Case 9, RH-TRUW Case 15).* One site (WIPP) would treat CH-TRUW to LDR levels. Two sites (Hanford and ORR) treat RH-TRUW to LDR levels. All treated TRUW would be disposed at WIPP.

A.3 WM PEIS ALTERNATIVES FOR LLMW

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

- *No Action* (Case 1). Treatment and indefinite storage of LLMW generated in the future. No transportation occurs.

- *Decentralized (Case 2a).* Thirty-seven sites treat LLMW to LDR levels, and 16 sites dispose.

- *Regionalized 1 (Case 4).* Eleven sites treat LLMW, and 12 sites dispose.

- *Regionalized 2 (Case 7).* Seven sites treat LLMW, and six sites dispose.

- *Regionalized 3 (Case 10a).* Seven sites treat LLMW, and one site disposes (NTS).

- *Regionalized 4 (Case 15).* Four sites treat LLMW, and six sites dispose.

- *Centralized (Case 17).* One site treats LLMW (Hanford), and one site disposes (Hanford).

A.4 REFERENCE

U.S. Department of Energy, 1996, *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*, DOE/EIS-0200-F, Office of Environmental Management, Washington, D.C.