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Transportation Risk Assessment of Radioactive Wastes Generated by the N-Reactor Stabilization Program at the Hanford Site, Washington

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for the United States Department of Energy
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TRANSPORTATION RISK ASSESSMENT OF RADIOACTIVE WASTES GENERATED BY THE N-REACTOR STABILIZATION PROGRAM AT THE HANFORD SITE, WASHINGTON

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Abstract

The potential radiological and nonradiological risks associated with specific radioactive waste shipping campaigns at the Hanford Site are estimated. The shipping campaigns analyzed are associated with the transportation of wastes from the N-Reactor site at to the 200-W Area, both within the Hanford Reservation, for disposal. The analysis is based on waste that would be generated from the N-Reactor stabilization program.

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ACRONYMS

CEDE	committed effective dose equivalent
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
LCF	latent cancer fatalities
LLW	low-level waste
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
SNL	Sandia National Laboratories
TI	transportation index
TRU	transuranic

EXECUTIVE SUMMARY

This risk assessment calculates the potential radiological and nonradiological impacts to the public and workers from transportation of approximately 1981.6 m³ of assorted radioactive solid wastes from the N-Reactor site in the 100-N Area of the Hanford Reservation to the radioactive waste burial sites in the 200-W Area of the Hanford Reservation. The radioactive solid waste would be generated during the program to stabilize the N-Reactor facility. The study estimates the risks associated with the in-transit operations of the transportation campaign, which is expected to involve approximately 223 shipments by either truck or rail. The truck shipments would be along a 19-km route entirely within the boundaries of the Reservation; rail shipments would be along a 12-km government rail line on the Reservation.

Risks associated with the shipments are estimated for two shipping campaigns: a six-year campaign and a four-year campaign. Risks are estimated for the total shipping campaign, which is defined by the total number of shipments required to transport the material. Total risks associated with the campaign are independent of the number of years over which the shipments take place. Maximum annual risks are also estimated for the six-year and four-year campaigns. The maximum annual risk represents the maximum estimate for risk associated with a single year of each campaign.

This risk assessment only addresses the transportation risks of the proposed shipping campaign. The risks addressed in this report are:

- radiological risks under incident-free conditions,
- radiological risks under accident conditions, and
- nonradiological risks (traffic accidents and exhaust emissions).

The RADTRAN 4 computer code has been used to quantify the handling and transportation risks. National-average data used in many previous risk studies are used to develop estimates of the risks to the general public and workers from shipments of the N-Reactor

wastes to an on-site burial facility. The shipping campaign would take place entirely on the Hanford Reservation, so there would be no incident-free risk to the public. Incident-free risk to site workers is estimated for handlers, workers at both the N-Reactor site and the 200-W burial site, the conveyance crews, and site workers sharing the transportation route with the waste shipments.

The radioactive solid waste would consist of two major groups: wastes taken from the N-Reactor fuel handling basins, and wastes taken from other parts of the entire N-Reactor facility. The N-Basin wastes are of two types: approximately 178 m³ of N-Basin fuel-handling equipment contaminated with activation products created by neutron penetration into the metal lattice, and approximately 12 m³ of radioactive contaminated sludge removed from the water of the N-Basins. Other waste materials include approximately 1284 m³ of wastes such as tools, ladders, filters, and clothes; approximately 285 m³ of fuel spacers that have become activated; approximately 37 m³ of mixed radioactive wastes; approximately 1 m³ of contaminated batteries; and approximately 184 m³ of contaminated lead. The volumetric quantities of radioactive material included in the transportation risk assessment are estimates of the actual quantities to be transported to the 200-W burial grounds. The N-Basin sludge would be shipped in a special Type B container. The N-Basin fuel handling equipment would be shipped in Type A concrete burial boxes or similar type boxes. The other waste would be shipped in Type A containers appropriate for each waste form, including 55-gal steel drums, wooden burial boxes, and concrete burial boxes.

The incident-free risk assessment is largely dependent on the number of shipments and would not be affected by changes in the volume of material shipped as long as the number of shipments did not change from the number incorporated in this analysis. Accident-related risks would change if there were changes in radionuclide inventories associated with larger or smaller volumes of material.

The waste packages would be loaded onto truck or rail transport at the N-Reactor site and shipped to the burial disposal facility in the 200-W Area. Truck shipments would be via the N-Reactor access road to Hanford Rt. 4 North, south on Rt. 4 North to Hanford Rt. 11A,

west on Rt. 11A to the 200-W Area burial site access road, and then to the 200-W Area via the access road. Rail shipments would be via the government railroad, which runs south by southwest from the N-Reactor site directly into the 200-W Area.

The results of this study are presented in terms of total risks from the proposed shipping campaign. In the case of radiological impacts under accident conditions, the probabilities of accidents (events for the entire campaign) are multiplied by the consequences of those accidents to the general public (person-rem/event) to arrive at a measure of risk (person-rem for the entire campaign).

The expected radiological risks from the proposed shipping campaign are summarized in Tables E-1 and E-2. The nonradiological risks are summarized on Table E-3. The following conclusions resulted from the risk study.

- The shipment of N-Reactor-stabilization radioactive wastes to the 200-W Area is expected to result in insignificant incident-free radiation exposure to site workers.
- The estimated projected radiological risks under accident conditions are small, in the range of 50-year Committed Effective Dose Equivalents for each of the proposed shipping campaigns.
- There are no significant nonradiological risks from truck or rail traffic accidents, and there are no measurable risks associated with vehicle exhaust emissions for either mode for the proposed shipping campaign.

The results indicate that the impacts of the transportation of N-Reactor-stabilization radioactive wastes are small. Detailed RADTRAN 4 output is presented in Appendix B.

Potential radiological impacts from accidents were predicted using accident severity classification schemes and associated probabilities of occurrence derived from NUREG-0170 and listed in Table E-4. Accident severity categories define the seriousness of an accident in

Table E-1. Expected Dose Impacts Associated With Proposed Action

Total Risk - Person-Rem								
Shipping Campaign	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total	Accident Total
				Off Link	On Link			
Total Campaign	Truck	9.400E-03	4.03E+00	5.900E-05	3.010E-03	1.260E-02	4.052E+00	2.910E-06
	Rail	1.320E-01	4.03E+00	7.550E-05	0.000	1.260E-02	4.1710E+00	9.42E-7
Six-Year Campaign Maximum Year ^a	Truck	1.999E-03	7.758E-01	1.237E-05	6.320E-04	2.586E-03	7.810E-01	4.850E-07
	Rail	2.536E-02	7.758E-01	1.580E-05	0.000	2.586E-03	8.038E-01	1.570E-08
Four-Year Campaign Maximum Year	Truck	2.924E-03	1.180E+00	1.808E-05	9.240E-04	4.031E-03	1.188E+00	9.700E-07
	Rail	3.532E-02	1.180E+00	2.270E-06	0.000	4.031E-03	1.220E+00	3.140E-08
^a The maximum year represents the largest number of shipments required in any one year to meet the desired six- or four-year shipping campaign. The total number of shipments required, 241, does not divide evenly by six or four. Thus, for at least one year of either a four- or six-year shipping campaign, maximum yearly shipping rates would be 42 shipments for a six-year campaign and 64 for a four-year campaign.								

Table E-2. Expected Latent Cancer Fatality (LCF) Impacts Associated With Proposed Action^a

Total Risk - LCFs								
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total	Accident Total
				Off Link	On Link			
Total Campaign	Truck	3.816E-06	1.610E-03	2.360E-08	1.12E-06	5.040E-06	1.621E-3	1.455E-09
	Rail	5.276E-04	1.610E-03	3.02E-08	0.000	5.040E-06	1.668E-03	4.710E-10
Six-Year Campaign Maximum Year	Truck	7.995E-07	3.103E-04	4.950E-09	2.528E-07	1.035E-06	3.124E-04	2.425E-10
	Rail	1.014E-05	3.103E-04	6.330E-09	0.000	1.035E-06	3.215E-04	7.850E-11
Four-Year Campaign Maximum Year	Truck	1.170E-06	4.721E-04	7.234E-09	3.697E-07	1.612E-06	4.752E-04	4.850E-10
	Rail	1.413E-05	4.721E-04	9.08E-09	0.000	1.612E-06	4.878E-04	1.570E-11
^a BEIR V conversion factors of 5E-4 LCFs/person-rem for general population and 4E-4 LCFs/person-rem for workers are used.								

Table E-3. Total Nonradiological Accident Risks Associated With Shipping Campaign

Nonradiological Accident Risks - Fatalities				
Population Group	Mode	Total Campaign	Maximum Year	
			6-Year Campaign (42 Shipments)	4-Year Campaign (64 Shipments)
Crew	Truck	1.16E-04	2.01E-05	3.07E-05
	Rail	7.95E-04	1.38E-04	2.11E-04
Site Workers	Truck	4.10E-04	7.21E-05	1.09E-04
	Rail	1.16E-04	2.02E-05	3.08E-05

Table E-4. Accident Frequencies and Severity Category Probabilities

Transportation Mode and Zone	Accident Frequency	Severity Category	Severity Probability
Truck, Rural	1.37E-7/km	1	0.4620
		2	0.3020
		3	0.1760
		4	0.0403
		5	0.0118
		6	0.0065
		7	0.0006
		8	0.0001

terms of mechanical and thermal (fire) loads and influence the potential amount of radioactive material released from a package during an accident. NUREG-0170 specified eight severity categories for each transportation mode. The first accident category (designated 1) is defined to be less serious than the accident performance capabilities of a Type A container and is not expected to result in any release of radioactive material. The

remaining seven categories are postulated to involve increasingly severe accidents. The second accident severity category could result in the failure of a Type A container, but would involve accident conditions less severe than the accident performance standards for Type B containers. The remaining accident severity categories involve accident environments that would result in failure of a Type A container and could fail a Type B container.

The highway accident frequency of $1.37\text{E-}07$ accidents/km was applied to the entire proposed transportation route. Thus, an accident resulting in a release of radioactive material from the shipping container could potentially occur at any point along the route.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is currently assessing the potential environmental impacts associated with a proposal to place the N-Reactor facility at the Hanford Reservation in a radiologically and environmentally stable condition until decontamination and decommissioning are initiated. This transportation risk assessment will support the environmental impact assessment of the N-Reactor Stabilization Program (USDOE, 1993) to assist DOE in determining the appropriate level of National Environmental Protection Act (NEPA) environmental analysis and documentation.

The radioactive solid waste material generated by the stabilization program would be shipped by truck or rail from the 100-N Area to the burial disposal facility in the 200-W Area of the Hanford Reservation, a distance of 19 km by truck and 13 km by rail. The general nature of the radioactive material, the packagings to be used, and shipping campaign are shown in Table 1-1.

The proposed truck route for transporting the waste is to leave the N-Reactor site via the access road to Hanford Rt. 4 North, then to travel south on Rt. 4 North to Hanford Rt. 11A, then west on Rt. 11a to the access road for the 200-W Area burial site, and south on the access road to the burial site. The proposed rail route would be the government railroad which runs south by south west from the N-Reactor site to the 200-W Area.

The objective of this risk assessment is to determine the radiological and nonradiological transportation risks to workers and the public. The scope of this risk assessment includes estimating the risks associated with in-transit operations (during the highway or rail segments of the transportation campaigns) and loading and unloading activities at N-Reactor and the burial site.

Risks are identified as radiological or nonradiological depending on the source of the risks. Radiological risks are further classified under incident-free and accident conditions. A description of these risks follows.

Table 1-1. N Reactor Stabilization Radioactive Waste Shipping Campaign

	Approximate Volume (m ³)	Packaging (Capacity)	1 Meter Dose Rate (mrem/hr)	Number of Packages	Total Number of Shipments (Packages/ shipment)	Shipments/Year by Campaign
N-Basin RAD/TRU	178	Concrete Burial Box (2268 kg)	0.5	5	5 (1)	Six Yr - 1 Four Yr - 2
N-Basin Sludge	11.9	Type B Cask	0.5	47	6 (8)	Six Yr - 1 Four Yr - 2
Contaminated Tools and Clothes	1284	Wooden Burial Box (7200 kg)	0.5	405	203 (2)	Six Yr - 34 Four Yr - 51
Fuel Spacers	285	Concrete Burial Box (2268 kg)	0.5	7	1 (4 or 3)	Six Yr - 1 Four Yr - 1
Mixed Radioactive Waste	37	Steel 55-Gallon Drum (450 kg)	0.5	177	5 (40)	Six Yr - 1 Four Yr - 2
Contaminated Batteries	1	Steel 55-Gallon Drum (450 kg)	0.5	5	2 (2 or 3)	Six Yr - 1 Four Yr - 1
Contaminated Lead	184	Steel 55-Gallon Drum (450 kg)	0.5	698	18 (40)	Six Yr - 3 Four Yr - 5
Total	1981.60			1339	241	Six Yr - 42 Four Yr - 64

- Radiological Risks - Risks expected during performance of the transportation activities that result from the radioactive nature of the cargo being transported.
 - Incident-Free Conditions - Impacts to the general public and workers under incident-free conditions.
 - Accident Conditions - Risks to the public and workers under accident conditions that do not result in the release of radiological contents of the cargo to the environment, and accident conditions that do result in the release of radiological contents of the cargo to the environment.
- Nonradiological Risks - Risks expected during performance of the transportation activities that are independent of the radioactive nature of the cargo being transported. These risks include injuries and fatalities from in-transit traffic (truck and train) accidents and from vehicle-exhaust emissions.

The radiological exposure risks (person-rem for the entire campaign) are estimated under incident-free and accident conditions for the public and workers. These risks are calculated by the RADTRAN 4 (Neuhauser and Kanipe, 1992) computer code.

Nonradiological risks are calculated for the transportation campaign. These risks include injuries and fatalities resulting from accidents during truck transport. Latent cancer fatalities (LCFs) from truck or train exhaust emissions were not calculated because the risk parameters for such impacts are immeasurably small and inconsequential for rural and urban population zones, as illustrated in Table 4-1.

This risk assessment uses methodology first developed by Sandia National Laboratories (SNL) and now widely used in transportation risk studies for the U.S. Nuclear Regulatory Commission (NRC), DOE, and Department of Defense (DoD). Recent projects using this methodology include the Waste Isolation Pilot Plant Final Supplemental Environmental Impact Statement (USDOE, 1990), the Mixed Waste Disposal Operations Study at the

Nevada Test Site (USDOE, 1991a), and the Environmental Assessment of the Risks of the Taiwan Research Reactor Spent Fuel Project (USDOE, 1991b).

The balance of this report consists of three sections. Section 2.0 provides cargo and transportation details. Section 3.0 presents the radiological risks of the transportation campaign and Section 4.0 presents the nonradiological risks of the transportation campaign. Appendix A presents the radiological source term and transportation parameters, and Appendix B presents the RADTRAN 4 computer input and output data.

2.0 CARGO AND TRANSPORTATION DETAILS

This section describes the cargo (radioactive wastes and transportation packagings) and scope of the transportation campaign.

2.1 Radioactive Waste

The radioactive wastes generated from the N-Reactor stabilization program have been separated into seven different types:

- N-Basin solid radioactive waste (including transuranic (TRU) waste),
- N-Basin sludge,
- contaminated tools and clothes,
- fuel spacers from outside the N-Basins,
- mixed radioactive wastes,
- contaminated batteries, and
- contaminated lead.

The underwater N-Basin equipment has become radiologically contaminated over the course of the reactor's life. This equipment includes mining carts used to transfer fuel underwater to adjacent basins, fuel baskets used to store the fuel during the initial cool-down period, equipment used to examine and package fuel for transfer to the plutonium-extraction plant (PUREX), fuel-storage cubicles, various tools used to manipulate the fuel, fuel spacers, and other underwater items. This metallic material accounts for approximately 178 m³ of special form, or nondispersable waste.

The N-Basin water is radiologically contaminated with a very fine sludge accumulated over the life of the N-Reactor. This water was circulated through a filtration and ion-exchange treatment facility during reactor operation. This process partially removed the contamination in the water; however, it was discontinued in 1991 and is no longer available to remove the remaining contamination. The sludge has a density very close to that of water, and must be

centrifuged to reduce the amount of moisture in the waste. This will produce approximately 12 m³ of damp sludge.

An assortment of tools, supplies, work clothing, and equipment contaminated at facilities throughout the N-Reactor site must also be disposed of. These items account for approximately 1284 m³ of low-level waste (LLW).

Fuel spacers from outside the N-Basins have become radioactive from exposure to irradiated fuel. These metal components that have become activated account for approximately 285 m³ of special-form radioactive waste.

Mixed-waste forms containing both hazardous and radioactive materials make up the remaining three waste groups. Mixed radioactive wastes removed from the N-Reactor plant account for approximately 37 m³ of mixed waste. There is also approximately 1 m³ of contaminated batteries and approximately 184 m³ of contaminated lead.

2.2 Transportation Packaging System

Radioactive waste material would be identified and packaged in accordance with U.S. Department of Transportation (DOT) requirements for transporting the type of waste involved, as specified in 49 CFR 100 to 199 (USDOT, 1990). Waste would be transported by truck in accordance with all applicable DOT regulations regarding placarding, labeling, and securing of packages. All waste packages would meet the surface radiation exposure and package exposure rate requirements of 49 CFR 173.441. Specific packagings for each waste group are discussed in the following subsections.

2.2.1 N-Basin Equipment

The N-Basin equipment qualifies as special form material for the purposes of packaging under 49 CFR 173.403. The equipment will be packaged in Type A concrete burial boxes

measuring 7.3 m x 4.0 m x 1.8 m. Only one burial box would be loaded per truck trailer or rail car.

2.2.2 N-Basin Sludge

The N-Basin sludge would be packaged in a shipping container satisfying Type B packaging requirements in 10 CFR 173.416. The sludge would be packaged in absorbent materials within the containers. A specific cask design has not yet been selected, but it is expected that the capacity of the container would be 0.25 m³, and that the size and weight would be such that eight casks could be shipped on a single truck trailer or rail car. This would result in a shipping campaign of six total shipments at the rate of one per year.

2.2.3 Contaminated Tools and Clothing

The contaminated tools and clothing would be packaged in wooden burial boxes satisfying Type A packaging requirements. Each box would be of plywood construction measuring 1.2 m x 1.2 m x 2.4 m with a gross capacity of 7200 kg. The burial boxes would be loaded two to a truck trailer or rail car.

2.2.4 Fuel Spacers

The fuel spacers would be packaged in concrete burial boxes satisfying Type A packaging requirements. Each box would measure 7.3 m x 4.0 m x 1.8 m and would have a gross capacity of 2268 kg. Up to four boxes could be loaded onto a truck trailer or rail car.

2.2.5 Mixed Radioactive Wastes

The mixed radioactive wastes would be packaged in steel 55-gal drums satisfying Type A packaging requirements. Each drum would measure 0.851 m high and 0.622 m across and have a gross capacity of 450 kg. The drums would then be placed in wooden burial boxes (four drums per box) like those described in Section 2.2.3. The boxes would be loaded onto

truck trailers or rail cars in single tiers, arranged in two rows of five boxes for a total of ten boxes and forty drums per shipment.

2.2.6 Contaminated Batteries

The contaminated batteries would be packaged in 5 steel 55-gal drums satisfying Type A packaging requirements. The drums would measure 0.851 m high and 0.622 m across and have a gross capacity of 450 kg. The drums would then be placed in wooden burial boxes like those described in Section 2.2.3. This analysis conservatively models two shipments: one shipment of three barrels and one of two barrels per truck or rail car.

2.2.7 Contaminated Lead

The contaminated lead would be packaged in steel 55-gal drums satisfying Type A packaging requirements. Each drum would measure 0.851 m high and 0.622 m across and have a gross capacity of 450 kg. The drums would then be placed in wooden burial boxes (four drums per box) like those described in Section 2.2.3. The boxes would be loaded onto truck trailers in single tiers, arranged in two rows of five boxes for a total of ten boxes and forty drums per shipment.

2.3 Transportation Campaign

The entire transportation campaign would entail shipment of 1981.6 m³ of waste in 1339 packages. The packages would be shipped in 241 shipments over one of two possible time frames: six years or four years. The maximum expected number of shipments made in any calendar year would be 42 shipments for the six-year campaign and 64 for the four-year campaign option. The truck transportation route would start at the N-Reactor site gate, proceed along the N-Reactor access road to Hanford Rt. 4 North, south along Rt. 4 North to Hanford Rt. 11A, then west on Rt. 11A to the access road for the 200-W Area burial site (Figure 2-1). The total distance is 19 km. The rail transportation route option would be the government railroad, which runs south by southwest from the N-Reactor site to the 200-W

Area (Figure 2-1). The rail distance is 13 km. Shipments would occur during normal operating hours of the Hanford Reservation N-Reactor and 200-W Area facilities.

Figure 2-1. Map of Hanford Reservation With Proposed Shipment Route

3.0 RADIOLOGICAL RISKS OF THE TRANSPORTATION CAMPAIGN

This section discusses the radiological exposure risks associated with the transportation of radioactive wastes from the N-Reactor stabilization program. Handling and highway transportation of the waste have the potential for radiological exposure of workers and the general public. The radiological risks associated with incident-free and accident conditions are addressed in Sections 3.1 and 3.2, respectively. Incident-free conditions model the routine shipment of packages from their point of origin to their destination without any release of their contents to the environment. These radiological risks are measured in terms of acute radiation exposures to persons at the Hanford site. The general public is not at risk for incident-free waste transportation since no release of radioactive material that might be dispersed off-site would occur under these conditions, and the entire shipping campaign is confined to the Hanford Reservation. Under certain accident conditions, there is a potential for release of radioactive contents of the cargo to the environment. The radiological risks associated with such accidents are based on the calculation of 50-yr committed effective dose equivalent (CEDE) exposure to both the public and workers. Both of these radiological risks are expressed in person-rem for the entire campaign. Person-rem dose estimates are also converted to LCFs using the BEIR V (NAS, 1990) and ICRP 60 (ICRP, 1991) and conversion factors of $5\text{E-}04$ LCFs/person-rem for the general public and $4\text{E-}04$ LCFs/person-rem for workers.

The radiological risks associated with the truck shipments are assessed using the RADTRAN 4 computer code (Neuhauser and Kanipe, 1992). RADTRAN was originally developed by SNL to support preparation of the Final Environmental Statement of the Transportation of Radioactive Material by Air and Other Modes (USNRC, 1977). RADTRAN I initially evaluated occupational and nonoccupational doses from direct radiation exposure during incident-free transportation and accident-related exposures by various pathways. Subsequent revisions to the code have enhanced the incident-free and accident models, expanded the number of exposure pathways evaluated, increased the number of accident-severity categories

that may be considered, incorporated an internal radionuclide-data library, and improved its route-specific analysis capability. RADTRAN 4 is the most current version of the code.

RADTRAN 4 calculates the radiological exposure risk to individuals under incident-free conditions. This requires characterization of: the package dose rate or transportation index (TI) (highest radiation dose-rate [mrem/hr] at 1 m from external surface of package); modes of transport (e.g., ship, truck); and potentially exposed populations (crew, cargo handlers, bystanders). RADTRAN 4 allows exposures to crewmen to be separated out on the basis of exclusive-use and nonexclusive-use shipments. Supplemental calculations present maximum individual (occupational and nonoccupational) exposure scenarios specific to transportation operations. This includes evaluation of maximum crew member exposures, taking into consideration crew resources and utilization, the number of shipments in a campaign, and origin/destination locations. These supplemental calculations also consider other recurring or one-time exposure scenarios for vehicle servicing, truck inspections, and bystander circumstances.

RADTRAN 4 models radiological risks under accident conditions for both internal and external exposure pathways. Inhalation constitutes the primary internal exposure pathway and results from breathing contaminants in a volatilized or respirable particulate form. The code also determines the internal exposure due to resuspension, which results from the inhalation of deposited contaminants that become resuspended into the air by various surface weathering mechanisms, such as wind. The internal exposure from ingestion of contaminated food products can also be evaluated. External exposure pathways analyzed by RADTRAN 4 include groundshine and cloudshine. Groundshine results from the exposure to ionizing radiation emitted by radioactive contaminants that settle out as released material diffuses downwind. This exposure pathway diminishes with time (radioactive decay) and may be reduced by cleanup efforts. Cloudshine results from external exposure to penetrating radiation from released contaminants and has an exposure duration corresponding to the time the contaminants take to cloud pass. The exposure is expressed in terms of a 50-yr CEDE.

A key parameter for analyzing accidents is the estimated fraction of radioactive material escaping to the environment. Gaseous or particulate contaminant releases can result from impacts during accidents that damage the packaging containment and fracture the radioactive material, or from fires that can entrain impact-generated particulates, cause off-gassing of volatile radionuclides, or thermally degrade the material. To calculate release fractions for very severe accidents, it is necessary to characterize the radioactive material being transported, the response of the shipping containers to the accident conditions, and the release mechanisms that might result in the escape of radioactive material. Details of the source term and release mechanism are presented in Appendix A. Appendix B details the code input and output for the RADTRAN 4 analysis of the transportation campaign.

The RADTRAN 4 calculations of the radiological risks associated with accident conditions incorporate the probabilities of a spectrum of potential accidents spanning accident severity from high probability/low consequence incidents to low probability/high consequence events. Table 3-1 presents the accident categories and severity probabilities used for the RADTRAN 4 analysis. Only rural parameters were used in this analysis since the entire shipment campaign would occur on the Hanford Reservation. The on-site working population of the Hanford Reservation, including the N-Reactor site workers and the 200-W Area burial grounds, and surrounding off-site populations are accounted for in the accident risk assessment by the rural population zone model used in the risk calculations. Radiological risks associated with accident conditions are calculated on an exposed population (public and workers) basis and are identified by severity category; population zone (only rural for this study); radionuclide; and exposure pathway. Early fatality risks associated with accident conditions are also evaluated by the code. The accident severity categories in Table 3-1 are discussed in more detail in Section 3.2.1.

Table 3-1. Accident Frequencies and Severity Category Probabilities

Transportation Mode and Zone	Accident Frequency	Severity Category	Severity Probability
Truck, Rural	1.37E-7/km	1	0.4620
		2	0.3020
		3	0.1760
		4	0.0403
		5	0.0118
		6	0.0065
		7	0.0006
		8	0.0001

3.1 Radiological Risks: Incident-Free Conditions

3.1.1 Modeling Considerations

Radiological risks to the Hanford Reservation workers under incident-free conditions have been estimated for the truck crew, Hanford workers sharing the transportation route with the shipments, the package handlers (both at N-Reactor and at 200-W Area), and other N-Reactor site workers who would be exposed to radiation during handling of the packages at the N-Reactor site. Under incident-free conditions, no radioactive materials are released from the packages. The packages on each shipment are modeled as a radiation point source or line source. Radiation exposure from the point or line source is modeled for the following groups of people:

- N-Reactor site workers,
- cargo handlers at both the N-Reactor and 200-W Area,
- truck crew, and
- Hanford workers traveling on the roadways at the same time as the billet shipment.

The two transportation route options, truck and rail, were divided into distinct route segments or links.

Truck Links

- The stop link at the N-Reactor site, where the packages would be handled during loading onto the transport trucks, exposing both N-Reactor site workers and package handlers to radiation.
- The 2-km access road between N-Reactor and Rt. 4 North, for which the speed limit was modeled as 56 km/hr, exposing both the truck crew and site workers sharing the road with the shipments.
- The 13.2-km road link from the point where the N-Reactor access road intersects Rt. 4 North, south to Rt. 11A, west on Rt. 11A to the intersection with the access road to the east entrance of 200-W Area, for which the speed limit was modeled as 88 km/hr, exposing both the truck crew and site workers sharing the road with the shipments.
- The 3.8-km road link, continuing west on Rt. 11A and then south on the access road to the north entrance and gate of the 200-W Area, for which the speed limit was modeled as 56 km/hr, exposing both the truck crew and site workers sharing the road with the shipments.
- The stop link at 200-W Area, where the packages would be handled during unloading prior to burial, exposing the 200-W Area handlers. No other 200-W Area workers were assumed to be in the vicinity of the burial site during off-loading of the wastes.

Railroad Links

- The stop link at the N-Reactor site, where the packages would be handled during loading onto rail cars, exposing both N-Reactor site workers and handlers.
- The 13-km rail distance from N-Reactor to the 200-W Area disposal site, along which the train speed was modeled as 40.2 km/hr (25 m/hr), exposing the train crew.
- The stop link at 200-W Area, where the packages would be handled during unloading prior to burial, exposing the 200-W Area handlers. No other 200-W Area workers were assumed to be in the vicinity of the burial site during off-loading of the wastes.

The parameter values used to model the five truck links and three rail links are detailed in the RADTRAN 4 input files in Appendix B and are summarized below:

1. The population at risk during incident-free transportation along the highway and rail routes is modeled by using a rural population density along these routes. The population density is modeled by using the national average (RADTRAN 4 suggested value) for rural zones (6 persons/km²). The N-Reactor site population is 100 workers. This is the population at risk to incident-free dose during loading of the material for shipment at the N-Reactor site. The 200-W Area burial site population is accounted for in the handling model for the 200-W Area stop link. The N-Reactor and 200-W Area workers are distinctly modeled for incident-free analysis only. For the accident risk analysis, no distinction is made between workers and the general population. The population at risk for accidents is modeled by using the national average population density for rural zones extended over a 50-mi radius.

2. The site population potentially exposed to external radiation from incident-free shipments is the population within 800 m (0.5 mi.) of either side of the transportation route.
3. The transportation campaign will consist of 241 one-way truck or rail shipments between N-Reactor and the 200-W Area burial site.
4. Truck crews consist of two persons per truck; rail crews consist of five persons per train.
5. Exposures are calculated for occupants of passenger cars driving beside, in front of, and behind a truck. The vehicle density for traffic sharing the roadway with the shipments is the RADTRAN 4 default value of 470 vehicles/hr for rural traffic. Each vehicle modeled contains two occupants. This vehicle density is believed to be a very conservative model for the traffic flow along the proposed route. No rail traffic is expected to share the rail route with the proposed shipments, so no on-link exposure is expected for site workers.
6. Stops for resting and refueling are not modeled. It is assumed that no vehicle inspections are conducted after the vehicles are loaded, by agencies other than DOE, since the shipments would be entirely on the Hanford Reservation.

3.1.2 Incident-Free Condition Results

The radiological risks associated with incident-free conditions were estimated with the RADTRAN 4 computer code and are summarized in Table 3-2 for dose risk and Table 3-3 for LCFs expected from the dose risks shown in Table 3-2. The radiation exposure to Hanford Reservation site workers would be low for the total shipping campaign. The risk was estimated to be 4.05 person-rem for workers for the entire campaign. The maximum annual risk (the risk associated with the highest rate of shipments for the proposed campaign) to Hanford Reservation workers is:

Table 3-2. Expected Dose Impacts Associated With Proposed Action

Total Risk - Person-Rem								
Shipping Campaign	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free	Accident
				Off Link	On Link		Total	Total
Total Campaign	Truck	9.400E-03	4.03E+00	5.900E-05	3.010E-03	1.260E-02	4.052E+00	2.910E-06
	Rail	1.320E-01	4.03E+00	7.550E-05	0.000	.260E-02	4.052E+00	9.42E-7
Six-Year Campaign Maximum Year	Truck	1.999E-03	7.758E-01	1.237E-05	6.320E-04	2.586E-03	7.810E-01	4.850E-07
	Rail	2.536E-02	7.758E-01	1.580E-05	0.000	2.586E-03	8.038E-01	1.570E-08
Four-Year Campaign Maximum Year	Truck	2.924E-03	1.180E+00	1.808E-05	9.240E-04	4.031E-03	1.188E+00	9.700E-07
	Rail	3.532E-02	1.180E+00	2.270E-06	0.000	4.031E-03	1.220E+00	3.140E-08

Table 3-3. Expected Latent Cancer Fatality Impacts Associated With Proposed Action

Total Risk - LCFs								
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free	Accident
				Off Link	On Link		Total	Total
Total Campaign	Truck	3.816E-06	1.610E-03	2.360E-08	1.12E-06	5.040E-06	1.621E-3	1.455E-09
	Rail	5.276E-04	1.610E-03	3.02E-08	0.000	5.040E-06	1.668E-03	4.710E-10
Six-Year Campaign Maximum Year	Truck	7.995E-07	3.103E-04	4.950E-09	2.528E-07	1.035E-06	3.124E-04	2.425E-10
	Rail	1.014E-05	3.103E-04	6.330E-09	0.000	1.035E-06	3.215E-04	7.850E-11
Four-Year Campaign Maximum Year	Truck	1.170E-06	4.721E-04	7.234E-09	3.697E-07	1.612E-06	4.752E-04	4.850E-10
	Rail	1.413E-05	4.721E-04	9.08E-09	0.000	1.612E-06	4.878E-04	1.570E-11

- 0.781 person-rem yr⁻¹ for the six-year campaign, and
- 1.19 person-rem yr⁻¹ for the four-year campaign.

3.2 Radiological Risks: Accident Conditions

3.2.1 Modeling Considerations

Accidents occurring during transportation of the radioactive waste could potentially result in radiological risks to the population (workers and off-site public). These risks would result from radiological exposures to the population following a release to the environment of some of the radioactive material being transported.

The evaluation of radiological risks under accident conditions requires estimation of the amounts of material potentially released to the environment in various accident severities. The primary mechanisms for material release include: the release of particulates associated with material fracture resulting from impacts, entrainment of impact-generated particulates by fires, and combustion of metallic waste material in a fire. The release-fraction parameter determines the fraction of radioactive material released to the environment and available for atmospheric dispersion downwind from the accident site. Inhalation is the primary internal exposure pathway for humans. Aerosolized particles less than 10 microns in diameter are assumed to be respirable. In addition to the inhalation pathway, the particles in the air can also result in exposures to external radiation. This pathway is typically referred to as "cloudshine." The particulate material will also eventually settle to the ground as it moves downwind. These particles present a pathway for personnel exposure, known as "groundshine." Finally, some of these "settled" particles will undergo natural weathering processes and may be resuspended in the air by the wind and be inhaled by people; this pathway is known as "resuspension." The sum of exposure from each pathway represents the total exposure resulting from an accidental release.

For this analysis, the ingestion pathway was not assessed. The ingestion pathway represents the ultimate human consumption of contaminated food plants, dairy products, or meat-

producing animals. This path was not considered because there is no agricultural production within the Hanford Reservation where the majority of any deposition would occur; because of its relatively low contribution; typically one or two orders of magnitude below inhalation, and because of the potential to identify and condemn any contaminated foodstuffs prior to consumption.

The radiological impacts under accident conditions are calculated as dose risks. Risk is defined here as the product of the probability of occurrence of an accident involving the release of radioactive material to the environment and the radiological consequence of the accident. Consequence is defined here as the potential dose or health effects resulting from a release of radioactive isotopes from the transportation package and the resultant exposure of the population (both off-site public and on-site workers) to radiation.

RADTRAN 4 was used to evaluate the radiological impact for the cloudshine, groundshine, inhalation, and resuspension pathways. The atmospheric dispersion of radioactive material releases was conservatively modeled as Gaussian dispersion of a ground-level release to estimate a 50-yr CEDE for the population. Potential exposures to emergency response and decontamination crews were not calculated.

The evaluation of the radiological risks under accident conditions also requires the use of an accident-severity classification scheme and associated probabilities of occurrence. Accident-severity categories define the seriousness of an accident in terms of mechanical and thermal (fire) loads and influence the potential amount of radioactive material released during an accident. NUREG-0170 specified eight severity categories for each transportation mode. The first accident category is defined to be less serious than the accident performance capabilities of a Type A packaging and is not expected to result in the release of the radioactive material. The remaining seven categories involve increasingly severe accidents that result in the release of radioactive material to the environment.

The potential accident scenarios considered, based on the severity classification, are:

Category 1: A minor vehicular accident resulting in no breach of package containment and therefore no increase in package dose rate or release of radionuclides.

Categories 2-8: Accidents of increasing severity, all of which have the potential to expose the radioactive material to a fire and have the potential for release of radioactive material. The amount of material assumed to be released for a particular accident-severity category increases as the severity category number increases.

Probability-versus-consequence curves for five of the seven specific types of radioactive material in the shipping campaign defined in Table 1-1 are shown in Figures 3-1 through 3-3. No curves are shown for the N-Basin RAD/TRU waste form or fuel spacers. These materials are nondispersable; therefore, there are no dispersions accident risks associated with transporting them.

3.2.2 Accident Radiological Risk Estimates

The radiological risks associated with accident conditions were estimated using the RADTRAN 4 computer code and are summarized in Tables 3-2 and 3-3. The risks to the off-site public and the on-site workers are low, estimated as $2.91\text{E-}06$ person-rem for the truck option and $9.42\text{E-}7$ person-rem for the rail option. These risk estimates are for the entire on-site and surrounding public populations. No distinction is made between public and worker populations for accident conditions. Both groups are accounted for in the population density within the potentially contaminated area.

For each of five material types (N-Basin sludge, contaminated tools and clothing, fuel spacers, mixed radioactive waste, contaminated batteries, and contaminated lead) three curves were generated. These curves illustrate the maximum annual accident risks for a four-year campaign, maximum annual accident risks for a six-year campaign, and risks associated with the total proposed campaign. These curves illustrate both the potential consequences associated with the range of possible accident environments modeled in the eight accident-

Figure 3-1. Probability Consequence Plot: Maximum Annual for Four-Year Campaign

Figure 3-2. Probability Consequence Plot: Maximum Annual for Six-Year Campaign

Figure 3-3. Probability Consequence Plot: Total Campaign

severity categories and the associated probabilities. These probability-versus-consequence results illustrate the constituent components of the material-specific risk estimates that were summed over the five material types to estimate the total risk estimates shown in Table 3-2. Probability-versus-consequence plots which can only be generated for the individual materials, cannot be generated for the total risk estimates for the entire shipping campaign.

4.0 NONRADIOLOGICAL RISKS OF THE TRANSPORTATION CAMPAIGN

This section discusses the nonradiological risks associated with transport of the N-Reactor radioactive material. Nonradiological consequences are those injuries or fatalities that could result from traffic accidents and vehicle-exhaust emissions during transportation of the waste. These risks are not associated in any way with the radioactive nature of the cargo, and are the estimated injuries and fatalities that could occur during transport of any type of cargo. In this risk assessment, the nonradiological accident rates associated with this campaign are modeled as being similar to the accident rates associated with general truck and rail transportation of nonradioactive heavy commodities in the United States.

4.1 Modeling Considerations

The model for the nonradiological consequences includes the truck and rail links of each trip of the campaign. As in the analysis in Section 3.0, the population along the route was modeled entirely as rural. The shipping distance for nonradiological impact analysis is double the shipment distance used for radiological analyses. This is because the nonradiological impacts must be assessed for the return portion of the vehicles' trip. Nonradiological risk parameters are presented in Table 4-1. The parameters are defined according to the methodology developed in Wilmot (1983) and Rao (1982).

4.2 Nonradiological Risk Results

The expected number of nonradiological injuries and fatalities is the sum of the products of the unit-risk factor for the rural population zone and the total kilometers traveled. The results of the nonradiological risk calculations are summarized in Table 4-2. The total nonradiological risks for the entire shipping campaign are insignificant. The risks for the truck option to the truck crews and site workers sharing the roadway with the shipments are estimated to be $1.16\text{E-}04$ fatalities among the crew and $4.10\text{E-}04$ fatalities among site workers for the entire campaign from accidents and are immeasurably small for normal incident-free activities. For the rail option, the results are similar, $7.95\text{E-}04$ fatalities for the

Table 4-1. Nonradiological Risk Parameters--Incident-Free (LCFs/km)

Population Zone	Occupational	Nonoccupational
Rural (Truck and Rail)	€	€
Suburban (Truck and Rail)	€	€
Urban (Truck/Rail)	€/€	1.00E-07/6.50E-07
Population Zone	Accident Parameters (Fatalities/km) Occupational	Nonoccupational
Rural		
Truck	1.50E-8	5.30E-08
Rail	1.27E-7	1.85E-08
Suburban		
Truck	3.70E-09	1.30E-08
Rail	1.27E-07	1.85E-08
Urban		
Truck	2.1E-9	7.50E-09
Rail	1.27E-07	1.85E-08

Table 4-2. Nonradiological Accident Fatality Risks

Nonradiological Accident Risk				
Population Group	Mode	Total Campaign	Maximum Year	
			6-Year Campaign (42 Shipments)	4-Year Campaign (64 Shipments)
Crew	Truck	1.16E-04	2.01E-05	3.07E-05
	Rail	7.95E-04	1.38E-04	2.11E-04
Site Workers	Truck	4.10E-04	7.21E-05	1.09E-04
	Rail	1.16E-04	2.02E-05	3.08E-05

crew and $1.16\text{E-}04$ fatalities for site workers, and immeasurably small for normal incident-free activities.

5.0 SENSITIVITY ANALYSIS OF INCREASED PACKAGE DOSE RATES

A sensitivity analysis was conducted to assess the risk associated with a range of potential package dose rates. The package dose rate is a measure of the intensity of radiation at 1 m from a radioactive material transportation package. This feature of a radioactive material package is also referred to as the Transportation Index, or TI. The package dose rate is used in the RADTRAN 4 incident-free models to determine the expected exposure to all relevant worker groups and the public during incident-free transportation.

The package dose rate is restricted by regulatory statute to a maximum of 10 mrem/hr for a package, except for packages shipped by exclusive-use vehicles, as specified in CFR 173.443. The regulatory limit for packages in exclusive-use vehicles is equivalent to a dose rate of approximately 13 mrem/hr at 1 m. The proposed transportation campaign associated with the stabilization of N-Reactor could easily be conducted so that all shipments would be exclusive use. The sum of the package dose rates for a single shipment of several packages may not exceed 50 mrem/hr.

Since the proposed shipping campaign is expected to be done using exclusive use vehicles, it was assumed that the package dose rate for each package could exceed 10 mrem/hr. If package dose rates were to increase significantly, the regulatory limit of 50 mrem/hr for an entire conveyance could prevent meeting the proposed number of shipments as shown in Table 1-1. The number of shipments required to move the waste material from N-Reactor to 200-W Area would increase as it became necessary to place fewer packages on each shipment to meet the 50 mrem/hr limit for an entire conveyance. However, the potential doses received by the various worker population groups during incident-free transportation is not dependent on the number of shipments, but rather the number of packages transported. Thus, even if the number of shipments required to transport the material was to increase, the crucial factor in estimating the incident-free doses would be the number of packages shipped and their associated package dose rates.

The package dose rates used for the base case analysis are shown in Table 5-1. The base-case package dose rates are much lower than the nonexclusive-use regulatory limit of 10 mrem/hr and the exclusive-use limit of 13 mrem/hr. However, to establish a comprehensive range of potential incident-free doses, the sensitivity analysis assessed the expected doses for several package dose rates up to the maximum case, in which each package would have a package dose rate of 13 mrem/hr. It should be noted that this sensitivity analysis examines solely the sensitivity of the expected population doses to changes in the package-dose-rate parameter value. There was no attempt to assess what might be the maximum possible dose rate that could be achieved for each particular waste material based on the radionuclide inventories of each material.

The package dose rates were varied by factors of 10, 20, and 26. For the fuel-spacer waste material, which has a package dose rate of 1.5 mrem/hr for the base case, the package dose rate was held equal to 13 mrem/hr for all three sensitivity assessments. The summary results of the sensitivity analysis are shown in Table 5-2. More detailed results for each worker population group and for LCF risks converted from the dose estimates are shown in Tables 5-3 through 5-8. As can be seen from the results in Table 5-2, the expected dose impacts of incident-free transportation are linearly related to changes in the package dose rate.

It should be noted that the higher potential package dose-rates modeled in the sensitivity analysis have no correlation to any potentially higher accident risk. This sensitivity analysis assesses only potential impacts related to changes in the shielding properties of the packagings used to transport the waste material. No sensitivity analysis was performed on potential variations of the radionuclide inventory.

Table 5-1 Base Case Package Dose Rates for Each Material

Waste Material	Base Case Package Dose Rate (mrem/hr)
N-Basin TRU	0.5
N-Basin Sludge	0.5
Contaminated Tools	0.5
Fuel Spacers	1.5
Contaminated Mixed Waste	0.5
Contaminated Batteries	0.5
Contaminated Lead	0.5

Table 5-2. Summary of Sensitivity Analysis on Package Dose Rate

Total Incident-Free Dose - Person-Rem					
	Mode	Base Case Package Dose Rate	Base Case x 10 ^a	Base Case x 20 ^b	Base Case x 26 ^c
Total Campaign	Truck	4.052E+00	40.23	24.21	101.5
	Rail	4.171E+00	41.41	80.87	104.6
Six-Year Campaign Maximum Year	Truck	7.810E-01	7.643E+00	14.20	18.14
	Rail	8.038E-01	7.866E+00	14.62	18.67
Four-Year Campaign Maximum Year	Truck	1.188E+00	11.71	22.34	28.72
	Rail	1.220E+00	12.02	22.93	29.48
^a The base case package dose rate of 1.5 mrem/hr for the fuel spacer waste material is scaled by 8.667 to achieve the regulatory maximum allowable dose rate of 13 mrem/hr. ^b The base case package dose rate of 1.5 mrem/hr for the fuel spacer waste material is scaled by 8.667 to achieve the regulatory maximum allowable dose rate of 13 mrem/hr. ^c The base case package dose rate of 1.5 mrem/hr for the fuel spacer waste material is scaled by 8.667 to achieve the regulatory maximum allowable dose rate of 13 mrem/hr.					

Table 5-3. Dose Impacts for Sensitivity Analysis - Base Case TI x 10

Total Risk - Base Case TI x 10 - Person-Rem							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident Free Total
				Off Link	On Link		
Total Campaign	Truck	9.418E-02	40.00	5.83E-04	2.98E-02	1.248E-01	40.23
	Rail	1.310E+00	40.00	7.45E-04	0.000	1.248E-01	41.41
Six-Year Campaign Maximum Year	Truck	1.929E-02	7.59	1.19E-04	6.10E-03	2.51E-02	7.64
	Rail	2.482E-01	7.59	1.53E-04	0.000	2.51E-02	7.87
Four-Year Campaign Maximum Year	Truck	2.855E-02	11.6	1.77E-04	9.02E-03	3.96E-02	11.71
	Rail	3.478E-01	11.6	2.22E-04	0.000	3.96E-02	12.02

Table 5-4. Mortality Impacts for Sensitivity Analysis - Base Case TI x 10

Total Risk - Base Case TI x 10 - LCFs							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total
				Off Link	On Link		
Total Campaign	Truck	3.767E-05	1.600E-02	2.33E-07	1.190E-05	4.993E-05	1.609E-02
	Rail	5.239E-04	1.600E-02	2.98E-07	0.000	4.993E-05	1.656E-02
Six-Year Campaign Maximum Year	Truck	7.716E-06	3.040E-03	4.780E-08	2.440E-06	1.004E-05	3.057E-03
	Rail	9.927E-05	3.040E-03	6.110E-08	0.000	1.004E-05	3.146E-03
Four-Year Campaign Maximum Year	Truck	1.142E-05	4.650E-03	7.060E-08	3.610E-06	1.582E-05	4.686E-03
	Rail	1.391E-04	4.650E-03	8.86E-08	0.000	1.582E-05	4.810E-03

Table 5-5. Dose Impacts for Sensitivity Analysis - Base Case TI x 20

Total Risk - Base Case TI x 20 - Person-Rem							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total
				Off Link	On Link		
Total Campaign	Truck	1.804E-01	78.1	1.12E-03	5.700E-02	2.421E-01	78.55
	Rail	2.558E+00	78.1	1.43E-03	0.000	2.421E-01	80.87
Six-Year Campaign Maximum Year	Truck	3.406E-02	14.10	2.110E-04	1.080E-02	4.527E-02	14.20
	Rail	4.611E-01	14.10	2.700E-04	0.000	4.527E-02	14.62
Four-Year Campaign Maximum Year	Truck	5.257E-02	22.20	3.250E-04	1.080E-02	7.416E-02	22.34
	Rail	6.604E-01	22.20	4.070E-04	0.000	7.416E-02	22.93

Table 5-6. LCF Impacts for Sensitivity Analysis - Base Case TI x 20

Total Risk - Base Case TI x 20 - LCFs							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total
				Off Link	On Link		
Total Campaign	Truck	7.210E-05	3.120E-02	4.460E-07	2.280E-05	9.684E-05	3.142E-02
	Rail	1.023E-03	3.120E-02	5.71E-07	0.000	9.684E-05	3.235E-02
Six-Year Campaign Maximum Year	Truck	1.362E-05	5.640E-03	8.440E-08	4.31E-06	1.811E-05	5.680E-03
	Rail	1.845E-04	5.640E-03	1.080E-07	0.000	1.811E-05	5.847E-03
Four-Year Campaign Maximum Year	Truck	2.103E-05	8.880E-03	1.30E-07	6.650E-06	2.967E-05	8.937E-03
	Rail	2.642E-04	8.880E-03	1.63E-07	0.000	2.967E-05	9.173E-03

Table 5-7. Dose Impacts for Sensitivity Analysis - Base Case TI x 26

Total Risk - Base Case TI x 26 - Person-Rem							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total
				Off Link	On Link		
Total Campaign	Truck	2.322E-01	10.1	1.440E-03	7.33E-02	3.124E-01	101.5
	Rail	3.307	10.1	1.840E-03	0.000	3.124E-01	104.6
Six-Year Campaign Maximum Year	Truck	4.292E-02	18.0	2.660E-04	1.360E-02	5.736E-02	18.14
	Rail	5.889E-01	18.0	3.400E-04	0.000	5.736E-02	18.67
Four-Year Campaign Maximum Year	Truck	6.698E-02	28.50	4.140E-04	2.12E-02	9.493E-02	28.72
	Rail	8.480E-01	28.50	5.190E-04	0.000	9.493E-02	29.48

Table 5-8. Mortality Impacts for Sensitivity Analysis - Base Case TI x 26

Total Risk - Base Case TI x 26 - LCFs							
	Mode	Crew	Handlers	Site Workers		100-N Area Workers	Incident-Free Total
				Off Link	On Link		
Total Campaign	Truck	9.288E-05	4.040E-02	5.75E-07	2.930E-05	1.250E-04	4.062E-02
	Rail	1.323E-03	4.040E-02	7.350E-07	0.000	1.250E-04	4.182E-02
Six-Year Campaign Maximum Year	Truck	3.649E-05	7.210E-03	1.060E-07	5.430E-05	2.295E-05	7.254E-03
	Rail	2.356E-04	7.210E-03	1.360E-07	0.000	2.295E-05	7.467E-03
Four-Year Campaign Maximum Year	Truck	2.679E-05	1.140E-02	1.660E-07	8.470E-05	3.797E-05	1.149E-02
	Rail	3.392E-04	1.140E-02	2.080E-07	0.000	3.797E-05	1.179E-02

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APPENDIX A

RADIOLOGICAL SOURCE TERM AND TRANSPORTATION ASSUMPTIONS

This Appendix describes the assumptions used to estimate the radiological source term for the release of material for the various accident categories. The source-term estimation determines the quantity of radioactive material that may be released in a respirable, airborne form following an accident. Large particles are not analyzed, since they are excluded from the body and consequently do not contribute significantly to the estimated health effects. The source term magnitude is dependent on the amount of material at risk in the accident; the accident conditions (e.g., intensity and duration of fire, impact energy which can be reflected in the severity categories); the material-release mechanism(s); and the level of containment of the shipping containers. Therefore, the two primary factors that require evaluation are: the response of the Type A and Type B packagings to accident conditions and the release mechanisms associated with the applicable accident severity.

Both impact and thermal release mechanisms may lead to respirable releases of radionuclides under accident conditions. Potential release mechanisms include: fragmentation of the waste material by impactation and subsequent aerodynamic entrainment of particles, and aerosolization of particles by combustion or heating of contaminated surfaces.

Transportation accidents can result in fires, typically caused by burning fuels, which could engulf the waste packages. The waste materials themselves might sustain oxidation or combustion. The extent of the release would be dependent on duration of the fire, temperatures attained, physical form of the waste, and amount of material involved. In addition, heating of noncombustible, contaminated surfaces could result in the thermally driven suspension of radioactive material. Impact energy in an accident, i.e., a drop, fall, collision, etc., could lead to fragmentation or particle formation of waste material, which may subsequently be entrained by aerodynamic forces, such as wind.

Potential radiological impacts from the accident were predicted using the accident severity classification schemes and associated probabilities of occurrence derived from NUREG-0170 and listed in Table 3-1. Accident severity categories define the seriousness of an accident in terms of mechanical and thermal (fire) loads and influence the potential amount of radioactive material released from a package during an accident. NUREG-0170 specified

eight severity categories for each transportation mode. The first accident category (designated category 1) is defined to be less serious than the performance capabilities of a Type A container and is not expected to result in any release of radioactive material. The remaining seven categories are postulated to involve increasingly severe accidents. The second accident-severity category could result in the failure of a Type A container, but would involve accident conditions less severe than the performance standards for Type B containers. The remaining accident-severity categories involve accident environments that would result in failure of a Type A container and could fail a Type B container.

APPENDIX B

RADTRAN 4 RADIONUCLIDE INVENTORIES

B.1 Radionuclide Inventory of Material to be Shipped

B.1.1 N-Basin Sludge

<u>Radionuclide</u>	<u>Curies</u>
Am ²⁴¹	7.50E-02
Be ¹⁰	4.82E-05
C ¹⁴ GAS	7.62E-04
Ce ¹⁴⁴	1.40E-01
Cm ²⁴²	3.82E-05
Cm ²⁴⁴	8.96E-04
Co ⁵⁷	1.87E-02
Cs	2.54E+00
H ³ - Water	4.17E-02
Mn ⁵	2.85E-01
Ni ⁵⁹	1.29E-03
Ni ⁶³	1.10E-01
Pu ²³⁸	2.21E-02
Pu ²⁴¹	5.46E+00
Sb ¹²⁵	9.02E-03
Sr ⁸⁹	2.31E-01
Sr ⁹⁰	6.01E-01
U ²³⁴	1.36E-03
U ²³⁵	2.36E-04
U ²³⁸	1.10E-03
Zn ⁶⁵	1.43E-02

B.1.2 Contaminated Tools, Mixed Radioactive Waste, Contaminated Batteries, and Contaminated Lead

<u>Radionuclide</u>	<u>Curies</u>
Mn ⁵⁴	1.00E-10
Co ⁶⁰	4.60E-09
Ni ⁵⁹	4.09E-15
Ni ⁶³	2.00E-10
Zn ⁶⁵	1.25E-17
Sr ⁹⁰	5.80E-08
Y ⁹⁰	4.39E-08
Cs ¹³⁷	1.21E-07
Eu ¹⁵⁴	6.80E-09
Eu ¹⁵⁵	4.30E-09
U ²³⁴	4.61E-12
U ²³⁵	1.33E-08
U ²³⁸	8.42E-08
Pu ²³⁸	2.39E-07
Pu ²³⁹	3.45E-08
Pu ²⁴⁰	5.10E-07
Pu ²⁴¹	3.16E-07
Am ²⁴¹	2.30E-08

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