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Assessment of Accident Risk for Transport of Spent Nuclear Fuel to Yucca Mountain Using RADTRAN 5.5

Technical Report

Assessment of Accident Risk for Transport of Spent Nuclear Fuel to Yucca Mountain Using RADTRAN 5.5

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REPORT SUMMARY

This report evaluates the radiological impacts during postulated accidents associated with the transportation of spent nuclear fuel to the proposed Yucca Mountain repository, using the RADTRAN 5.5 computer code developed by Sandia National Laboratories. RADTRAN 5.5 can be applied to estimate the risks associated both with incident-free transportation of radioactive materials as well as with accidents that may be assumed to occur during transportation. Incident-free transportation risks for transport of spent nuclear fuel to Yucca Mountain were evaluated in EPRI report 1011821 using RADTRAN 5.5, September 2005.

Background

The Yucca Mountain Final Environmental Impact Statement (YM EIS), developed by the Department of Energy (DOE), included an analysis of the radiological impacts associated with transport of spent nuclear fuel under both incident-free and accident conditions. While the radiological risks calculated in the YM EIS, whose purpose was to bound potential environmental impacts, were small, it is important to recognize the many conservatisms employed in calculating these risks. This EPRI report examines the radiological impacts under postulated accident conditions using the RADTRAN model. The report is based on more realistic input assumptions than those used in the YM EIS for breathing rate, urban dose risk parameters, and commercial spent nuclear fuel cobalt-60 crud inventory. In addition, more realistic parameters for calculating loss-of-shielding (LOS) accident risk were taken into account, including cask external dose rate, maximum distance over which LOS accident dose is calculated, and LOS shielding factors. The YM EIS assumed that there would be no evacuation, cleanup, or interdiction in the event of a dispersal accident. EPRI examined the effect on accident dose risk of assuming the standard RADTRAN parameters for evacuation, cleanup, and interdiction.

Objectives

- To examine the RADTRAN input parameters used in the YM EIS in order to determine which parameters employ conservative assumptions that result in an overprediction of radiological accident transportation risks.
- To recommend alternative assumptions for use in development of a more realistic approach to assessing accident risk.
- To analyze the effects of changing RADTRAN input parameter assumptions on the calculation of accident risk and compare the results of this calculation to YM EIS results.

Approach

EPRI reviewed the YM EIS, its supporting calculational package, the YM EIS transportation database, and supporting RADTRAN input and output files in order to become familiar with the assumptions used to calculate accident risks in the YM EIS. Investigators used RADTRAN 5.5 to confirm that EPRI's analysis of transportation accident risk using the YM EIS RADTRAN input parameters would result in calculation of the same accident risk factors supporting the YM EIS. Once EPRI ensured that RADTRAN 5.5 results were the same as YM EIS results, the assumptions used for a range of RADTRAN parameters were changed from those in the YM EIS, and the effects on accident transportation dose risk were determined. EPRI then identified a realistic set of RADTRAN input parameters to use as the basis for assessing accident radiological risks for transport of spent fuel to the proposed repository.

Results

EPRI found that using more realistic assumptions to calculate accident dose—rather than the conservative assumptions used in the YM EIS—resulted in a reduction of overall accident dose risk to values that are 55–65% of the dose-risk calculated in the YM EIS, assuming no evacuation, no cleanup, and no interdiction. When EPRI incorporated the standard RADTRAN parameters for evacuation, cleanup, and interdiction in its analysis, the overall accident dose risk was reduced even further to approximately 30% of the dose risk calculated in the YM EIS. In addition, EPRI identified numerous conservative assumptions built into the RADTRAN model that cannot be quantified. Because of these conservative modeling assumptions, EPRI would expect that even the more realistic results calculated in this report are also conservative.

The YM EIS also relied on an overly conservative threshold to identify maximum reasonably foreseeable accidents—using a threshold of 1×10^{-7} accidents per year. Application of EPRI's more appropriate threshold of 1×10^{-6} accidents per year results in a population dose risk that is less than 1% of the population dose risk calculated for the maximum reasonably achievable rail accident in the YM EIS and 20% of the population dose risk for the maximum reasonably achievable truck accident.

EPRI Perspective

This document is the second of two reports to assess the risks of spent nuclear fuel transport based on more realistic assumptions than those used by the DOE in the YM EIS. The YM EIS incident-free transportation risks were previously evaluated by EPRI using RADTRAN 5.5 (report 1011821). While the radiological risks contained in the YM EIS were small, it is important to recognize the many conservatisms applied to calculate these risks. The use of conservative assumptions may be important in the context of preparing an EIS; however, it is equally important for regulators, decision makers, and the public to understand how these conservative assumptions inflate the identified risks. This report is intended to place the risks associated with transportation accidents into greater perspective.

Keywords

Spent Nuclear Fuel
Yucca Mountain
RADTRAN Code
Transportation Risks

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INTRODUCTION

The U.S. Department of Energy's (DOE) Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, (YM EIS)[1] included an analysis of the environmental impacts associated with the transport of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to the repository. The transportation-related impacts evaluated in the YM EIS included: radiological impacts under normal (or incident-free) conditions and under accident conditions; and non-radiological impacts – fatalities from vehicle emissions and fatalities caused by vehicle accidents. Incident-free transportation risks were examined in EPRI Technical Report 10011821, *Assessment of Incident-Free Transport Risk for Transport of Spent Nuclear Fuel to Yucca Mountain Using RADTRAN 5.5*, September 2005 (EPRI 2005). This report examines the radiological risks associated with postulated SNF transportation accidents.

The YM EIS described a "step-wise process" used to estimate the radiological impacts to the public and workers associated with the transport of SNF. This step-wise process used information from a wide range of sources as input to computer programs to calculate transport impacts. The computer programs used by DOE include the following:[2]

- CALVIN: used to estimate the number of shipments of spent nuclear fuel from commercial nuclear power plant sites.
- HIGHWAY: a routing program used to select highway routes that satisfy U.S. Department of Transportation (DOT) route selection regulations for shipment of SNF and HLW to the repository.
- INTERLINE: a routing program used to select rail routes for shipment of SNF and HLW to the repository.
- RADTRAN 5: a program used to estimate the radiological doses and dose risk to populations and transport workers resulting from incident-free transportation, and to the general population from accident scenarios.
- RISKIND: a program used to estimate the radiological doses to the maximally exposed individuals (MEI) for incident-free transportation, and to populations and maximally exposed individuals for accident scenarios.

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[1] DOE, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," Volumes I and II, DOE/EIS-0250F, February 2002,(YM EIS).

[2] Ibid. p. J-2.

The analysis of the YM EIS transportation risk assessment contained in this report examines the potential radiological impacts associated with the transport of SNF and HLW and does not include the assessment of non-radiological risks. This analysis includes an examination of the RADTRAN 5 input parameters used in the YM EIS to calculate radiological transportation risk under postulated accident conditions. The YM EIS RADTRAN 5 input parameters are compared to standard RADTRAN parameters and to parameters used in other risk assessments in order to identify those parameters for which conservative values were used in the YM EIS.[3] The standard RADTRAN 5 input parameters, described in the RADTRAN 5 User Guide, were developed by Sandia National Laboratories (SNL) scientists who developed the RADTRAN model.[4,5,6,7]

It should be noted that the examination of transportation accident risk discussed in this report uses the RADTRAN 5.5 model. The analysis contained in DOE's YM EIS utilized the RADTRAN 5 model. RADTRAN 5.5 was benchmarked against RADTRAN 5 by SNL and the results of this benchmark show good comparison between the results of the two models.[8] The main change to the RADTRAN 5.5 model was the addition of a third dispersion model in the code that uses the dispersion methodology of the RISKIND code. EPRI benchmarked the RADTRAN results that support the calculation of transportation accident risk for the YM EIS against the results calculated by EPRI using RADTRAN 5.5. EPRI's RADTRAN 5.5 results that used the same accident input parameters as contained in the YM EIS were identical to the RADTRAN 5 YM EIS results. Thus, EPRI concluded that it was appropriate to use RADTRAN 5.5 for the analysis contained in this report.

EPRI identified the RADTRAN parameter assumptions used in the YM EIS that it considers to be conservative and analyzed the effect on accident dose risk of changing individual parameters. This provided EPRI with a starting point for performing an analysis to quantify the conservatism in the Yucca Mountain RADTRAN 5 transportation risk analysis. It should be noted that the YM EIS also used the RISKIND program to estimate population dose and dose to the MEI for maximum reasonably foreseeable accidents. EPRI did not have access to the RISKIND model. However, the results of the RISKIND model were evaluated by EPRI to identify conservative assumptions.

Figure 1-1 provides a summary of the methodology and computer models used by DOE to analyze the radiological risk associated with transportation accident conditions.

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[3] Chen, S.Y., et al, Argonne National Laboratory, *A Resource Handbook on DOE Transportation Risk Assessment*, Prepared for U.S. DOE National Transportation Program, DOE/EM/NTP/HB-01, July 2002 (DOE Handbook 2002).

[4] Neuhauser, K. and FL Kanipe, 2003, RADTRAN 5 Users Guide, SAND2000-2354, Sandia National Laboratories (SAND2000-2354), July 7, 2003.

[5] Weiner, R.F., and G. Scott Mills, et al. RADTRAN/RADCAT User Guide, Rev 4, Sandia National Laboratories.

[6] Neuhauser, K.S.; Kanipe, F.L, and Weiner, R.F., RADTRAN 5 Technical Manual, SAND2000-1256, May 2000.

[7] Osborn, D.M.; Weiner R.F.; Hinojosa, D.; Mills, G.S.; Hamp, S.C.; O'Donnell, B.M.; Orcutt, D.J.; Heames, T.J.; RadCat 2.0 User Guide, SAND2005-0142, January 2005.

[8] Osborn, D.M., R.F. Weiner, G.S. Mills, and C.S. Hamp, Sandia National Laboratories, Verification and Validation of RADTRAN 5.5, SAND2005-1274, February 2005.

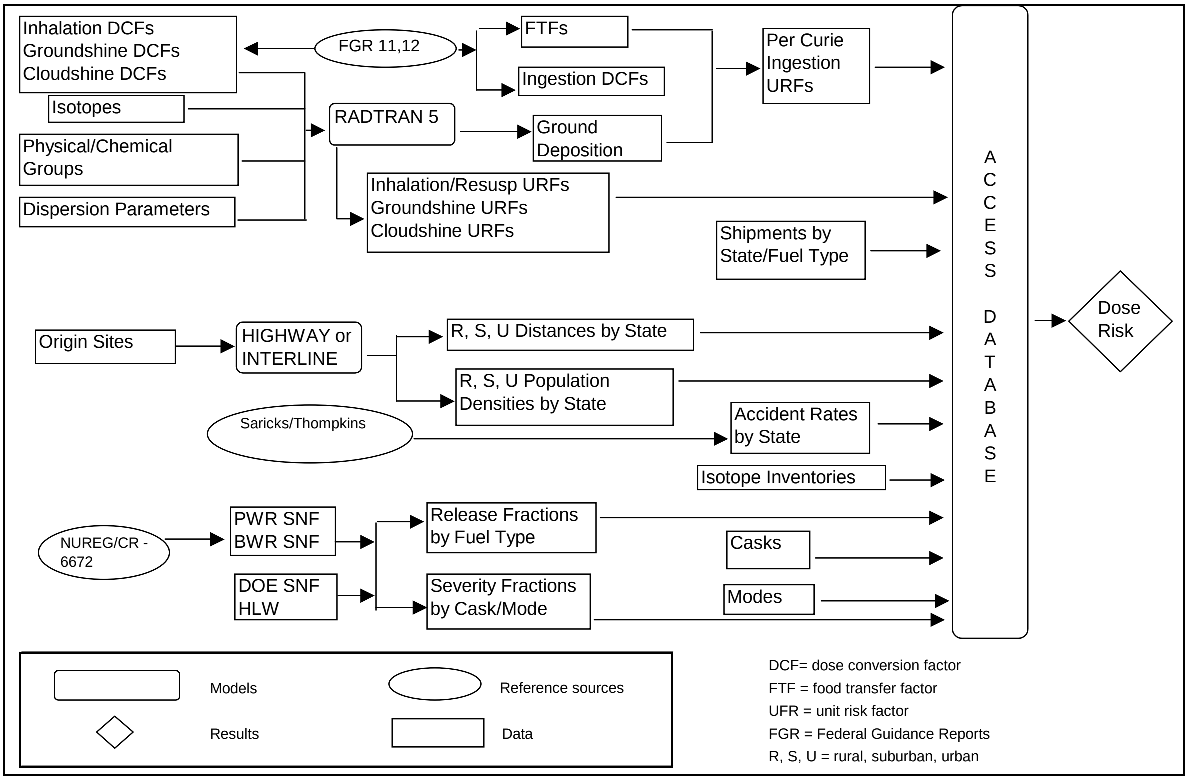

Figure 1-1
Diagram of Parameters and Information Flow for the Accident Dose Risk Calculation.[9]

As shown in Figure 1-1, the YM EIS used a wide range of data to calculate the radiological risks associated with a SNF transportation accident. Data input to the YM transportation database to calculate radiological risks associated with accidents along the transportation routes included per-curie unit risk factors; number of shipments by state and fuel type calculated from point of origin; rural, suburban and urban shipment distance by state; rural, suburban and urban population densities; accident rates by state; isotopic inventories per shipment based on fuel type; cask type (including various capacities for rail casks and truck cask); SNF and HLW isotopic inventories; shipment mode (rail, truck, barge and heavy-haul); release fractions by fuel type; and severity fractions by cask type and mode. The derivation of the data inputs that are important to the calculation of the radiological risks associated with transportation accidents is discussed in more detail in Section 3 of this report.

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[9] Jason Technologies Corporation, Transportation Health and Safety Calculation/Analysis Documentation in Support of the Final EIS for the Yucca Mountain Repository, CAL-HHS-ND-000003, Prepared for the U.S. Department of Energy, MOL.20020209.0097,December 2001, Figure 5-1, p. 120 (Jason 2001)

2

YUCCA MOUNTAIN EIS TRANSPORTATION RISK ASSESSMENT UNDER ACCIDENT CONDITIONS

As described in the YM EIS, the radiological risks associated with a transportation accident involving SNF could result from three possible types of accidents: (1) accidents in which there is no effect on the cargo (no release of material) and the package integrity is maintained; (2) accidents in which there is no breach of containment, but there is a loss of shielding because of lead shield displacement; and (3) accidents that release and disperse radioactive material. The YM EIS evaluated radiological impacts to populations and to hypothetical maximally exposed individuals (MEI) for transport of SNF and HLW under a Mostly Rail scenario and a Mostly Legal-Weight Truck (Mostly Truck) scenario. The YM EIS utilized the RADTRAN and RISKIND models, along with a transportation database developed in Microsoft Access™, to calculate accident risk and consequences. This section describes the results of the YM EIS transportation accident risk assessment.

2.1 Calculation of Accident Risk

As shown in Figure 1-1, the RADTRAN model was used in conjunction with the YM EIS transportation database to calculate transportation accident risks. RADTRAN was used to calculate unit risk factors (person-rem per person per square kilometer per curie) for the radionuclides being shipped. These per-curie unit risk factors (URF) were input to the YM EIS transportation database and combined with: conditional accident probabilities (also referred to as accident severity fractions); state-specific accident rates; and release fractions for each accident severity fraction. This was done for each mode of transportation, type of transport cask, and waste form (e.g., SNF, HLW). For each route from point of origin to destination, the results were combined with the urban, suburban and rural distances traveled and population densities as well as the number of shipments along the route and state-specific accident rates in order to calculate the dose risk along the routes for the Proposed Action considered in the YM EIS (e.g., transport of 70,000 MTU of SNF and HLW to the proposed Yucca Mountain repository).

The YM EIS utilized a complex methodology that included a series of database queries performed within the YM EIS transportation data base to calculate accident dose risk for a shipment, as described in the following excerpt from the YM EIS:

> The analysis first calculated unit risk factors for a shipment. This was done for the three types of population zones in each state and for each accident severity category. The unit risk factors were for one person per square kilometer per kilometer of route traveled. The unit risk factors were multiplied by the population densities (based on 1990 Census data) along the routes. These population densities are modeled as being within 800 meters (0.5 mile) of the routes. The accident dose risk calculation then assumed that the population density in the 800-meter band along the route is the same out to 80 kilometers (50 miles) from the route and multiplies the unit risk factor by this population density, yielding a dose risk in person-rem per kilometer of route for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The resultant dose risks (person-rem per kilometer) for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the dose risks per kilometer for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The resulting impacts were then multiplied by a scaling factor that is the ratio of the population in a state based on the 1990 Census to projected population in 2035. The results were summed to provide estimates of the accident dose risk (in person-rem) for a shipment.[10]

The collective radiological accident dose risk calculated in the YM EIS for the Mostly Truck scenario was approximately 0.46 person-rem for the population within 80 kilometers (50 miles) along the routes, as shown in Table 2-1. The collective radiological accident dose risk for the Mostly Rail scenario calculated in the YM EIS was approximately 0.89 person-rem for the population within 80 kilometers along the rail routes, as shown in Table 2-1. These collective dose risks are the total collective radiological dose risk associated with 24 years of shipping.

2.2 Consequences of Maximum Reasonably Foreseeable Accidents

The YM EIS also assessed the consequences of "maximum reasonably foreseeable accidents" for releases of material from a SNF cask during an accident. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur. In accordance with DOE EIS guidance documents, the YM EIS was required to examine accidents with a probability greater than 1×10^{-7} (1 chance in 10 million).[11] It should be noted that the 1 in 10 million accident probability is an order of magnitude lower than NRC guidance regarding "credible" accidents (1 in 1 million).[12] Thus, the

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[10] YM EIS, Appendix J, p. J-58.

[11] U.S. DOE, Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements, Office of NEPA Oversight, 1993 (DOE 1993).

[12] U.S. NRC, Memorandum and Order, In the Matter of Private Fuel Storage LLC, Docket No. 72-22-ISFSI, CLI-01-22, November 14, 2001 (CLI-01-22, 2001).

YM EIS analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of SNF and HLW evaluated consequences for accidents with a probability greater than 1×10^{-7} per year. The maximum reasonably foreseeable accident analysis was performed using the RISKIND code to estimate doses for individuals and populations.

The YM EIS evaluated the impacts of a maximum reasonably foreseeable accident scenario in urban and rural population zones for both the Mostly Truck and Mostly Rail scenario. For the Mostly Truck scenario, the maximum reasonably foreseeable accident was calculated to be a long-duration severe fire in which the cask was fully engulfed by the fire. The analysis conservatively assumed that the accident would occur under stable meteorological conditions in an urban area. Stable meteorological conditions tend to maximize the individual dose from an airborne release because it results in both the least amount of dilution of an airborne plume, and keeps the plume near the ground. This accident scenario has a probability of 2.3 in 10 million per year (see Table 2-1). The YM EIS calculated a population dose of 1,100 person-rem, with a corresponding incidence of 0.55 latent cancer fatalities (LCF). The analysis also calculated a dose of 3 rem to a maximally exposed individual with a corresponding LCF of 0.0015. The results are presented in Table 2-1.[13] The YM EIS converted collective dose to an estimated number of latent cancer fatalities by using a dose conversion factor of 0.0004 latent cancer fatalities per person-rem for radiation workers and 0.0005 latent cancer fatalities per person-rem for the public, as recommended by the International Committee on Radiological Protection.[14]

For the Mostly Rail scenario, the maximum reasonably foreseeable accident was calculated to be a long-duration severe fire in which the cask was fully engulfed by the fire. The analysis assumed that the accident would occur under stable meteorological conditions in an urban area. This accident scenario has a probability of 2.8 in 10 million per year. The YM EIS calculated a population dose of 9,900 person-rem, with a corresponding probability of 5 latent cancer fatalities. The analysis also calculated a dose of 29 rem to a maximally exposed individual with a corresponding LCF probability of 0.015. The results are provided in Table 2-1.[15]

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[13] YM EIS, p. 6-15, 6-47.

[14] *ibid.*, p. J-40.

[15] ibid., p. 6-15, 6-49.

Table 2-1
National Transportation – Radiological Accident Risk From Transporting 70,000 MTU of SNF and HLW Over a 24-year Period (from the YM EIS)[16]

Impact	Mostly Truck Scenario	Mostly Rail Scenario
Radiological Impacts for Maximally Reasonably Foreseeable Accident Scenario		
Frequency (per year)	2.3 in 10 million	2.8 in 10 million
Maximally exposed individual (rem)	3	29
Individual latent cancer fatality probability (a)	0.0015	0.015
Collective Dose (person-rem)	1,100	9,900
Latent Cancer Fatality Incidence (a)	0.55	5
Accident Dose Risk (person-rem)	0.46	0.89
Accident Risk (latent cancer fatalities) (a)	0.00023	0.00045

a. The risk of latent cancer fatalities is obtained by multiplying the dose risk (person-rem) by a conversion factor of 0.0005 fatal cancers per person-rem for the public. For nuclear industry workers, the conversion factor is 0.0004 fatal cancer per person-rem.[14]

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[16] ibid., p. 6-15.

3

RADTRAN INPUT PARAMETERS USED IN THE CALCULATION OF ACCIDENT DOSE RISK

RADTRAN utilizes a set of models to calculate the radiological risks associated with incident-free and accident conditions for transport of radioactive material. The models utilize (1) input parameters for which the user defines the input data; and (2) standard values contained within the RADTRAN model. For those parameters for which there are standard values, RADTRAN 5 will utilize standard values unless they are specifically overridden by the user. Section 3.1 describes the standard input parameters used in the calculation of transportation accident dose. Section 3.2 provides a summary of the user defined input parameters used in the calculation of accident dose and identifies the user-defined values utilized in the YM EIS.[17]

3.1 Standard Input Parameters for Transportation Accident Dose Calculations

Standard RADTRAN input parameters, described below, are available for many of the variables used in the calculation of transportation accident risk. The standard input parameter values that are recommended in the RADTRAN User Guide were used by DOE in the YM EIS for many of the input RADTRAN parameters in the calculation of transportation accident risks. As noted in the RADTRAN 5 Users Guide,[18] many of the variables that are important to the calculation of accident doses do not have standard values assigned. These variables include accident severity fractions, shielding degradation fractions for loss of shielding accidents, release fractions, aerosol fractions, and respirable fractions. The reason that these values are not specified is that release fractions are dependent upon the specific packages being transported, the package contents, and the type of accident being modeled. Recommended values for many of the user-defined variables are contained in a DOE handbook, *A Resource Handbook on DOE Transportation Risk Assessment*, Argonne National Laboratory, Prepared for U.S. DOE National Transportation Program, DOE/EM/NTP/HB-01, July 2002.[19]

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[17] SAND2000-2354, pp 52-62.

[18] Ibid pp 55-62.

[19] DOE Handbook 2002.

The input variable, BRATE, provides the breathing rate and is used for calculation of inhalation dose. The standard RADTRAN input parameter value is 3.30E-04 m^3/sec for a 70-kg adult male at light work. It should be noted that this value is somewhat higher than the breathing rate assumed in NRC Regulatory Guide 1.109, which utilizes a rate of 2.5E-04 m^3/sec.[20] The lower value contained in Regulatory Guide 1.109 is also the default value used in the RISKIND model.[21] The YM EIS utilized the standard RADTRAN input value for BRATE that would result in a more conservative (higher) risk associated with inhalation dose than would occur if the value recommended in NRC Regulatory Guide 1.109 were used.

3.1.1 Parameters Important to Urban Dose

There are several parameters that are used to calculate population dose risk in urban environments. These include BDF, Building Dose Factor; UBF, Urban Building Fraction; USWF, fractions of persons out of doors; and RPD, ratio of pedestrian density. The parameters are described in more detail below.

BDF – Building Dose Factor, describes the fraction of particles of an external aerosol that remain in aerosol form after passing through a building's ventilation system. The BDF is used in the calculation of inhalation dose to account for sheltering provided by building ventilation systems in urban structures. The standard input parameter value is 0.05 and according to SNL it represents a conservative average across a series of building types, including residential, office, and industrial structures. This BDF value will be dependent upon how much outside air can move into a building, whether windows are open or closed, and the rate of forced ventilation. Older urban buildings are likely to be less efficient at filtering air than newer urban office building due to differences in ventilation systems. The BDF is also dependent upon the type of radiological release. Noble gases would have a BDF of 1.0, meaning that no protection is provided by building ventilation. Large particulates that have higher deposition velocities would have lower BDFs than smaller particulates with lower deposition velocities.[22] The YM EIS utilized a BDF of 1.0, which results in no sheltering provided by building ventilation. This is a conservative assumption.

The input variable, UBF – Urban Building Fraction, represents the fraction of population that is in buildings. While the RADTRAN User Guide states that the standard input parameter value is 0.52, the value in the RADTRAN 5 model is actually 0.9 – meaning 90 percent of the urban population is assumed to be in buildings.[23] The YM EIS utilized a value of 1.0, meaning that 100% of the urban population is assumed to be indoors. While this may appear to be non-conservative as some portion of the urban population would be expected to be outside at any

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[20] U.S. NRC, Calculation of the Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, Regulatory Guide 1.109, Revision 1, October 1977 (RegGuide 1.109).

[21] DOE Handbook 2002, p. 125.

[22] DOE Handbook 2002, p. 88.

[23] SAND2000-2354, p. 59

time, it is actually conservative as the YM EIS assumed a BDF of 1.0, meaning that no protection is provided by building ventilation systems.

The input variable, USWF – Urban Sidewalk Fraction, specifies the fraction of the population that occupies sidewalks. The standard input parameter value is 0.1. The YM EIS assumed a value of 0.0 – this is consistent with the assumed UBF value of 1.0. (USWF= 1.0-UBF).

The input variable, RPD – Ratio of Pedestrian Density, is used to calculate the density of unshielded persons on sidewalks in urban areas by indexing it to the population density of the surrounding area. The standard input parameter value recommended by SNL is 6.0, which means that the pedestrian density is six times the residential population density. The RPD value was developed to support a review of transportation of radioactive materials in urban environments.[24] An RPD equal to 6.0 is considered to be a representative ratio of pedestrian density for a large city such as New York City. While the RADTRAN documentation recognizes that RPD values for other, smaller urban areas may be lower, no data exists to support a more general value – therefore an alternative to an RPD of 6 has not been recommended or used.[25] The use of an RPD of 6 will produce conservative results for that fraction of off-link dose associated with pedestrians in urban and suburban locations that have pedestrian densities lower than that of a large city, such as New York City. If the RPD is decreased, resulting in a lower pedestrian density, urban doses would decrease.

The above parameters are used in the calculation of urban dose risk by multiplying urban population density by the following equation in order to account for population inside and outside of urban buildings.

$$[(UBF * BDF) + (USWF * RPD)]$$

3.1.2 Rural, Suburban and Urban Shielding Factors

The RADTRAN model contains three shielding factors (RR- Rural Shielding Factor; RS-Suburban Shielding Factor; and RU – Urban Shielding Factor) that are used in the calculation of incident-free dose and non-dispersal accident dose (that is, loss-of-shielding dose). As the YM EIS did not use the RADTRAN loss-of shielding (LOS) model to calculate LOS dose, these shielding factors were not used in the calculation of accident dose for the YM EIS. As discussed in Section 3.2.7, the YM EIS used the RADTRAN STOP model to calculate LOS dose. Thus, the shielding factors in the STOP model are relevant to the calculation of non-dispersal accident dose. As such, changes to the values for RR, RS, and RU do not affect the calculation of accident dose in the YM EIS and will not be discussed further in this examination of accident risk. As EPRI will examine the effect of shielding factors on LOS dose risk in Section 5.4, the standard RADTRAN building shielding factors are discussed below.

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[24] Finley, N.C., et al, "Transportation of Radionuclides in Urban Environs – Draft Environmental Assessment", NUREG/CR-0743 (SAND79-0369), NRC, 1980

[25] SAND2000-1256, p. 40.

It should be noted, however, that if one chooses to utilize the RADTRAN LOS model to calculate LOS dose for non-dispersal accidents, the RADTRAN User Guide recommends the following standard values:

- RR – The standard input parameter recommended in RADTRAN is 1.0, which results in no shielding being assumed for rural areas. Therefore, the calculation of non-dispersal accident dose to rural populations assumes that rural residents are outside (i.e., unshielded) all of the time, which is a conservative assumption as most individuals spend some portion (e.g., 30%) of their time indoors during the day and nearly 100% of their time indoors at night. Decreasing the value of RR would result in a proportional change in the rural non-dispersal accident dose.
- RS – The standard input parameter value in RADTRAN is 0.87. This factor was developed to support earlier RADTRAN models and is based on assumed wood frame construction typically found in suburban homes, six inch thick walls, and buildings that are 45-foot square with approximately 100 feet between buildings.[26] An RS value of 0.87 recognizes that there is some shielding provided by homes along the route. Increasing or decreasing the value of RR would result in a proportional change in the suburban non-dispersal accident dose.
- RU – The standard input parameter value in RADTRAN is 0.018. This factor was developed to support earlier RADTRAN models and is based on assumed building construction with one-foot thick concrete walls, buildings in contiguous blocks that are 200 feet long, and 60 foot wide streets.[27] Increasing or decreasing the value of RU would result in a proportional change in the urban non-dispersal accident dose if the RADTRAN LOS model were utilized.

3.2 User Defined Input Parameters for Transportation Accident Risk

As noted previously, many of the variables that are important to the calculation of accident doses do not have standard values assigned. These variables include accident severity fractions, release fractions, aerosol fractions, respirable fractions; shielding degradation fractions for loss of shielding accidents; atmospheric dispersion model input parameters; package and package contents description; vehicle description; route segment information, and stop model information. The parameters that are important to the calculation of accident dose in the YM EIS are described below.

3.2.1 Accident Severity Fractions

Accident severity categories (SEVERITY) are used to provide severity fractions for up to three population density zones (NPOP) along a route (rural, suburban, urban). A severity fraction is the probability, assuming that an accident occurs, that it will be in a specific severity category. The severity of an accident will depend upon the impact speed, type of object impacted (e.g., hard or soft surface), and other characteristics of the accident (crush, puncture, fire, immersion).

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[26] SAND2000-1256, Table 3-1, p. 40.

[27] Ibid.

A release fraction is the fraction of radioactive material in the package that is assumed to be released from that package during an accident of a certain severity.

The accident severity fractions and release fractions used in the YM EIS were based on a methodology developed by SNL in an assessment of SNF transportation risk performed for the U.S. Nuclear Regulatory Commission (NRC).[28] NUREG/CR-6672 developed accident severity fractions as a function of two variables – the mechanical force that occurs in impacts as represented by the impact velocity, and the thermal energy, or the heat input to a cask engulfed by fire as represented by the midpoint temperature of a cask's lead shield wall. As all accident scenarios can be described as a function of mechanical and thermal force, any sequence of accident events can be assigned to the accident severity category associated with the applicable ranges for the two mechanical and thermal forces. The accident severity fractions developed in NUREG/CR-6672 are the conditional probabilities that, if an accident occurs, the accident will involve the impact speed and the heat energy in the ranges that apply to the categories.

NUREG/CR-6672 developed 21 rail accident severity fractions and 19 truck accident severity fractions.[29] The YM EIS reduced the 21 rail accident cases and the 19 truck accident cases by summing the probabilities of a range of accident severities to create six accident severity categories. Table 3-1 presents the resulting accident severity fractions for a steel-depleted uranium-steel legal weight truck used in the YM EIS. Table 3-2 presents the resulting accident severity fractions for a steel-lead-steel rail cask used in the YM EIS.

Table 3-1
Severity and Release Fractions for the Legal-weight Truck Transport of PWR SNF in the Steel - Depleted Uranium - Steel Truck Cask[30]

Severity Category	Severity Fraction	PWR Release Fractions				
		Kr	Cs	Ru	Particulates	Crud
1	0.99993	0.00000	0.00000	0.00000	0.00000	0.00000
2	6.06E-05	1.36E-01	4.09E-09	1.02E-07	1.02E-07	1.36E-03
3	5.86E-06	8.39E-01	1.68E-05	6.71E-08	6.71E-08	2.52E-03
4	4.95E-07	4.49E-01	1.35E-08	3.37E-07	3.37E-07	1.83E-03
5	7.49E-08	8.35E-01	3.60E-05	3.77E-06	3.77E-06	3.16E-03
6	3.00E-10	8.40E-01	2.40E-05	2.14E-05	5.01E-06	3.17E-03

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[28] Sprung, J.L, et al, Sandia National Laboratories, Reexamination of Spent Fuel Shipment Risk Estimates, Prepared for Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. NRC, NUREG/CR-6672, SAND2000-0234. March 2000 (NUREG/CR-6672.)

[29] Jason 2001, pp. 143-146.

[30] Ibid., Table 5-24, p. 147.

Table 3-2
Severity and Release Fractions for the Rail Transport of PWR SNF in the Steel-Lead-Steel Rail Cask[31]

Severity Category	Severity Fraction	PWR Release Fractions				
		Kr	Cs	Ru	Particulates	Crud
1	0.99993	0.00000	0.00000	0.00000	0.00000	0.00000
2	3.87E-05	1.96E-01	5.87E-09	1.34E-07	1.34E-07	1.37E-03
3	4.91E-05	8.39E-01	1.68E-05	2.52E-07	2.52E-07	9.44E-03
4	5.77E-07	8.00E-01	8.71E-06	1.32E-05	1.32E-05	4.42E-03
5	1.10E-07	8.35E-01	3.60E-05	1.37E-05	1.37E-05	5.36E-03
6	8.52E-10	8.47E-01	5.71E-05	4.63E-05	1.42E-05	1.59E-02

3.2.2 Accident Release Fractions

The parameter, RELEASE, is used to model the type of release, release fractions, aerosol fractions, shielding degradation fraction for loss of shielding accidents, and respirable fractions. These parameters are package specific and only apply to accident analyses. A release fraction is defined as the fraction of the radioactive material in a package that is assumed to be released during an accident of a certain severity and it is used to calculate radiological consequences along with the corresponding accident severity fractions and meteorological conditions.

Radiological consequences of SNF transportation accidents are a result of exposure to (1) material released from the transport package or (2) increased radiation exposure due to a reduction in package shielding (loss of shielding). Material that is aerosolized can be disbursed into the atmosphere and would be a source of external exposure (referred to as "cloudshine"). A respirable fraction of the aerosolized material would contribute to inhalation exposure. Aerosolized material that does not exhibit ideal gas behavior will eventually deposit on the ground. As such, it can remain a source of external exposure (referred to as "groundshine"); it may contaminate food supplies, which would result in ingestion exposure; and it could be "resuspended" in the atmosphere resulting in additional inhalation exposure or cloudshine exposure. [32]

The release fractions, REFRAC, for PWR spent fuel that correspond to the accident severity fractions used in the YM EIS are presented in Table 3-1 for transportation of PWR spent fuel by truck and in Table 3-2 for transport of PWR spent fuel by rail. The release fractions are presented for five GROUPS as represented by Kr (Krypton), Cs (Cesium), Ru (Ruthenium), Particulates and Crud under the six SEVERITY categories defined in the YM EIS. In addition to the parameter REFRAC, users also define: the aerosol fraction, AERSOL; respirable fraction RESP, and the deposition velocity, DEPVEL, within each GROUP. The release fractions will

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[31] Ibid., Table 5-26, p. 147.

[32] DOE Handbook 2002, p. 104.

vary depending upon the characteristics of the package and the physical form of the waste. Like the release fractions presented in Tables 3-1 and 3-2, the assumed numerical values for the additional parameters are based on the analysis contained in NUREG/CR-6672.

3.2.3 Atmospheric Dispersion Model Input Parameters

Two atmospheric dispersion models are available in RADTRAN 5, both of which contain standard values. The RADTRAN calculations used to calculate accident dose risk assumed national average meteorology for six Pasquill atmospheric stability classes. It should be noted that the RISKIND computer model was used to calculate accident risk associated with the maximally exposed individual and for the maximum reasonably foreseeable accident. As noted earlier, RADTRAN 5.5 includes a third atmospheric dispersion model – the model used in the RISKIND code.

The atmospheric dispersion model can be selected by the user, under the variable, IPSQSB, under the parameter PARM. If IPSQSB is set to 1, then six sets of standard Pasquill stability data are utilized (area, downwind distance, and time integrated concentrations). Pasquill probabilities, PSPROB, are entered under the keyword RELEASE. Six probabilities may be entered that correspond to the corresponding Pasquill stability class A, B, C, D, E, and F. Table 3-3 summarizes the national average meteorological conditions used in the YM EIS RADTRAN analysis. The wind speeds identified in Table 3-3 cannot be user defined but are contained in the default RADTRAN values if IPSQSB is set to 1. This methodology was used in the YM EIS to calculate per-curie unit risk factors. Due to the complexity of the calculation of radiological risk of an accident in the YM EIS, which considered rail, truck, and barge transport through more than 40 states over a 24-year period, EPRI considers the use of national average meteorological conditions to be appropriate.

Table 3-3
National Average Meteorological Conditions Used in RADTRAN Accident Analysis

Pasquill Stability Class	Fraction of Total Meteorology	Associated Wind Speed (m/sec)
A	0.011	1
B	0.068	2
C	0.114	3
D	0.472	4
E	0.121	2.5
F/G	0.214	1

RADTRAN can model five separate exposure pathways associated with dispersal accidents: inhalation, cloudshine, resuspension, groundshine and ingestion. The YM EIS used RADTRAN to calculate per-curie unit risk factors for inhalation, cloudshine, resuspension and groundshine exposure pathways. Ingestion unit risk factors were calculated through hand calculations and added as input to the YM EIS transportation database although the RADTRAN model does contain a ingestion risk module, COMIDA.

3.2.4 Package Description

Users must define the package, its gamma and neutron dose fractions, package dose rate, and radionuclides contained in the package for calculation of accident dose risk. Radionuclide properties (e.g., half life, photon energy, etc.) can be defined specifically by the user (using parameter DEFINE) or can be looked up for 60 common radionuclides in RADTRAN 5 – expanded to approximately 150 radionuclides in RADTRAN 5.5. It should be noted that the YM EIS defined the radionuclide properties used to calculate the per-curie unit risk factors as a large number of the radionuclides defined in the YM EIS were not contained in the RADTRAN 5 isotopic data files. While the RADTRAN 5.5 isotopic data files have been expanded to include more radionuclides, for the purpose of this analysis the radionuclides defined in the YM EIS analysis will continue to be used.

Package lengths used in the YM EIS are considered by EPRI to be reasonable and are based on typical package lengths for truck and rail casks. The YM EIS assumes that all packages have an external dose rate at the regulatory limit of 14 mrem/hour at one meter (equivalent to 10 mrem/hour at 2 meters). This is a conservative assumption since the package dose rate will vary as a function of fuel age, burnup and package design and will not exceed this value. This is an important factor in the calculation of LOS unit risk factors. The effect of changes to the package external dose is examined further in Section 5.4.1.

3.2.5 Vehicle Description

Users must also describe the vehicle being used to transport the package and associated parameters. Vehicle parameters include the vehicle length, number of crew members, distance of the crew from the package, crew view dimensions (which relate to the package diameter) and a crew shielding factor. The values associated with the dimensions of vehicles expected to transport the spent fuel packages as presented in the YM EIS are considered by EPRI to be reasonable.

3.2.6 Route Segment Information

Route segment information (LINK) for each section along the route must be defined by the user. Route specific information, such as population density, vehicle density, etc., can be obtained from TRAGIS, a routing program developed by Oak Ridge National Laboratory that has replaced HIGHWAY and INTERLINE models.[33] The YM EIS assumed that the parameters

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[33] Oak Ridge National Laboratory, Transportation Routing Analysis Geographic Information System (TRAGIS) User's Manual, ORNL/NTRC-006, Rev. 0, June 2003.

associated with population densities, vehicle densities, segment length, and accident rate in LINK are 1.0 to calculate "unit" risk factors. The total risk for each route segment is calculated by applying the unit risk factors to the route specific parameters from HIGHWAY and INTERLINE through the use of an ACCESS database that contained total kilometers traveled by population zone (rural, urban, suburban) for each mode (rail or truck) and for every route examined. Route-specific parameters are applied to the calculated unit risk factors as described previously in Section 2. EPRI considers this to be a reasonable approach for a complex evaluation of shipping spent fuel from multiple locations across the US along multiple routes using multiple transport modes to Yucca Mountain.

3.2.7 STOP Model to Calculate LOS Unit Risk Factors

The YM EIS utilized the RADTRAN STOP model to calculate unit risk factors associated with LOS accidents as well as accidents that had no LOS and no release of radioactive material but that resulted in the shipment being immobilized for some period of time. Input parameters for the RADTRAN STOP model include: an alphanumeric stop identifier, vehicle identification, stop time, population density or number of persons at stops, the minimum and maximum radius of area for the stop over which dose is calculated, and shielding fraction.

The YM EIS utilized a methodology developed in NUREG/CR-6672 to analyze the impacts of a LOS accident in which shielding material has been displaced, including accident severity probabilities for LOS accidents, the fraction of shield lost, the cask axis length of the unshielded area, diagonal length of the LOS area, source strength multiplier, and the radiation source (rem per hour at 1 meter). NUREG/CR-6672 explains that the STOP model, along with the VEHICLE description, is suited to modeling LOS scenarios as it requires dose rate, source dimension, and exposure duration that are used to model a point source to estimate radiation exposure. The values used in the STOP model and VEHICLE description that were developed from NUREG/CR-6672 are shown in Table 3-4.

For accidents in which there is no shielding displacement but the cask is immobilized until it can be recovered, the LOS model assumed that the cask external dose rate would be the maximum allowed by NRC transport regulations – 10 mrem per hour at 2 meters (14 mrem/hour at 1 meter). As discussed in EPRI 2005, the use of an external dose rate of 14 mrem/hr at 1 meter is a conservative assumption as not all spent fuel transport casks will be loaded with fuel with characteristics (burnup, enrichment and cooling time) that would result in the cask external dose rate being at the regulatory limit. While it can be expected that some portion of the casks may have doses that are equal to the regulatory limit, industry practice has always been to ensure that external doses are lower than the regulatory limits. In addition, much of the fuel that will be shipped to a repository at Yucca Mountain will be older fuel that does not have a high radiation source term and will, therefore, have cask external dose rates that are much lower than the regulatory limit. The analysis of incident-free transport risks using more realistic assumptions discussed in EPRI 2005 assumed that an external dose rate of 10 mrem/hour at 1 meter would more realistically represent the range of fuel characteristics to be transported.

Table 3-4
RADTRAN 5 Input Parameters Used to Calculate Unit Risk Factors and MEI Dose for LOS Accidents[34]

Accident Severity Category	Conditional Probability of LOS Category	Fraction of Shield Lost	Cask Axis Length Unshielded	Diagonal Length of LOS Area (b)	Source Strength Multiplier	Source (rem/hr @ 1m)
1 (a)	0.9999	0.0	0	0	1.0	0.014
2	6.4E-06	0.10	0.51	1.7	0.41	8.2
3	4.9E-05	0.029	0.15	1.7	0.12	2.4
4	4.5E-07	0.17	0.84	1.9	0.66	13.3
5	2.4E-05	0.034	0.17	1.7	0.14	2.9
6	5.2E-09	0.34	1.7	2.4	1.2	24.4

a. Accidents (99.99 percent) that would not result in LOS are grouped in Category 1.

b. The diameter of the radioactive source for all casks is assumed to be 1.65 meters, which is approximately the diameter of the pay-load cavity of a large cask.

3.3 Post Accident Parameter Options

RADTRAN contains several parameters association with post-accident options associated with evacuation and possible interdiction of areas affected by a dispersal accident. Changes to these parameters can affect public dose associated with an accident. As the YM EIS assumed no evacuation and no cleanup in order to assess the maximum consequences, these parameters will be examined to identify how interdiction might change the outcome of public dose in the event of an accident.

The input variable, CULVL, provides the clean-up level, which is the level to which contaminated surfaces must be cleaned up in the event of a dispersal accident. The standard input parameter value is 0.2 $\mu Ci/m^2$ based on EPA guidelines. The YM EIS assumes a value of 10^6 $\mu Ci/m^2$, meaning that no clean up of contaminated surfaces occurs. This results in a highly conservative calculation of accident risk.

The input variable, EVACUATION, represents the evacuation time in days following a dispersal accident. The standard input parameter value is 24 hours. While the YM EIS utilized the standard EVACUATION value of 24 hours to calculate accident per-curie unit risk factors, the calculation of accident dose risk performed within the transportation data base assumed that there was no evacuation during the 24-year period of the Proposed Action. This results in a highly conservative calculation of accident risk.

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[34] Jason 2002, Table 5-52, p. 170.

The variable, INTERDICT, specifies the threshold level for interdiction of contaminated land. The standard value in RADTRAN is 40 – that is, a value 40 times greater than CULVL, the clean-up level.

The variable, SURVEY, specifies the time (days) required to survey contaminated land after a dispersal accident. The standard value is set to 10 days, which the RADTRAN User Guide describes as "unrealistically brief, but radiologically conservative."[35] The YM EIS analysis to determine per-curie unit risk factors utilized the standard value.

The input variable, TIMENDE, provides the time, in days, required to evacuate following a non-dispersal accident such as a loss-of-shielding (LOS) accident. Values are required for each of three population-density zone (rural, suburban, and urban). The standard input parameter values are 0.67, 0.67, and 0.42 hours. DOE's calculation of unit risk factors for LOS accidents assumes values of 24 hours for each population zone. This appears to be an appropriate methodology for calculation of unit risk factors. Since the LOS model in RADTRAN was not used to calculate LOS dose risk, this parameter would not affect the LOS unit risk factors.

The RADTRAN User Guide describes the relationship of the above parameters in the following way:

- If the ground deposition (Ci/m3) exceeds the minimum clean-up level (CULVL), then the contaminated area is modeled as being evacuated at the end of time entered under keyword EVACATION.
- If the ratio of ground deposition to clean-up level exceeds the maximum threshold (INTERDICT), then the area is modeled as being permanently interdicted – that is, no residents return to the area and no additional dose is accumulated after the evacuation has taken place.
- If the CULVL threshold is exceeded, but the INTERDICT level is not exceeded, then the area is modeled as being cleaned to acceptable levels and returning populations are modeled being chronically exposed to residual contamination at the CULVL level. [36]

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[35] SAND2000-2354, p. 59.

[36] SAND2000-2354, p. 97.

4

SUMMARY OF YM EIS CONSERVATIVE ASSUMPTIONS FOR INCIDENT-FREE TRANSPORT

As discussed in the previous section, there are a number of conservative assumptions used by DOE for the input parameters to the RADTRAN 5 model for calculation of accident dose in the YM EIS, as summarized below. In addition, other conservative assumptions include: cask external dose rate in the LOS accident category in which no shielding is lost; fuel age and burnup considerations; LOS shielding fractions; post-accident interdiction; and the probability threshold for determining the maximum reasonably achievable accidents.

As noted earlier, the YM EIS utilized the RADTRAN 5 model to calculate incident-free and accident dose. SNL released an updated version of the model, RADTRAN 5.5, which EPRI has used in this analysis. EPRI has benchmarked the RADTRAN 5 results that support the calculation of accident risk for the YM EIS against the RADTRAN 5.5 model. RADTRAN 5.5 cases that utilized the same input parameters utilized in the YM EIS were identical to the YM EIS results. Thus, EPRI concluded that it was appropriate to use RADTRAN 5.5 for this analysis. The RADTRAN 5.5 model includes a third dispersion model, as discussed previously, and also an expanded radionuclide library. Since the YM EIS analysis, and EPRI's analysis summarized in this report, defined isotopes specifically rather than utilizing the RADTRAN isotope library, the additional radionuclide information in RADTRAN 5.5 does not affect the EPRI analysis.

4.1 Breathing Rate

In the calculation of accident dose, the YM EIS assumes that the breathing rate, BRATE, is 3.30E-04 m^3/sec for a 70-kg adult male at light work. This value is the standard value recommended in the RADTRAN user guide. This value is somewhat higher than the breathing rate assumed in NRC Regulatory Guide 1.109, which utilizes a rate of 2.5E-04 m^3/sec.[37] As noted earlier, this lower value contained in Regulatory Guide 1.109 is also the default value used in the RISKIND model.[38] The RISKIND user guide states that unless an individual is engaged in strenuous activity, the breathing rate should be near the average breathing rate.[39] The YM EIS utilized the standard RADTRAN input value for BRATE that would result in a more

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[37] RegGuide 1.109.

[38] DOE Handbook 2002, p. 125.

[39] Yuan, Y.C., et al, RISKIND – A Computer Program for Calculating Radiological Consequences and Health Risks From Transportation of Spent Nuclear Fuel, ANL/EAD-1, November 1995, p. G-15.

conservative (higher) risk associated with inhalation dose than would occur if the value recommended in NRC Regulatory Guide 1.109 were used. Section 5.1 examines the effect of breathing rate on the unit risk factors utilized to calculate inhalation dose in the YM EIS.

4.2 Conservative Assumptions Regarding Urban Dose Risk

As discussed in Section 3.1.1, the parameters that are used to calculate dose risk in urban environments include: BDF, Building Dose Factor; UBF, Urban Building Fraction; USWF, fractions of persons out of doors; and RPD, ratio of pedestrian density. The parameters are described in more detail below.

BDF – Building Dose Factor, describes the fraction of particles of an external aerosol that remain in aerosol form after passing through a building's ventilation system. The BDF is used in the calculation of inhalation dose to account for sheltering provided by building ventilation systems in urban structures . The standard input parameter value is 0.05 and according to SNL it represents a conservative average across a series of building types, including residential, office, and industrial structures. The YM EIS utilized a BDF of 1.0, which results in no sheltering provided by building ventilation. This is a conservative assumption.

UBF – Urban Building Fraction; represents the fraction of population that is in buildings. While the RADTRAN User Guide states that the standard input parameter value is 0.52, the value in the RADTRAN 5 model is actually 0.9 – meaning 90 percent of the urban population is assumed to be in buildings.[40] The YM EIS utilized a value of 1.0, meaning that 100% of the urban population is indoors. A related variable, USWF – Urban Sidewalk Fraction; specifies the fraction of the population that occupies sidewalks. If the standard value of UBF equals 0.90 then the standard value of USWF is 0.1, as:

$$USWF = 1.0 - UBF$$

The YM EIS assumed a value of 0.0 – this is consistent with the assumed UBF value of 1.0. As shown below, the use of a UBF of 1.0 and a USWF of 0.0 is conservative.

The final parameter used in the calculation of urban dose risk is the variable, RPD – Ratio of Pedestrian Density, which is used to calculate the density of unshielded persons on sidewalks in urban areas. The standard input parameter value recommended by SNL is 6.0, which means that the pedestrian density is six times the residential population density.

The above parameters are used in the calculation of urban dose risk by multiplying urban population density by the following equation in order to account for population inside and outside of urban buildings.

$$[(UBF * BDF) + (USWF * RPD)]$$[41]

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[40] SAND2000-2354, p. 59

[41] SAND2000-1256, p. 79.

Thus, the population density is multiplied by a value of 1.0 if it is assumed that:

- UBF=1.0
- BDF=1.0
- USWF=0.0
- RPD=6

If however, the standard RADTRAN values are used for these parameters, the population density would be multiplied by a value of:

$$(0.9) * (0.05) + (0.1) * (6) = 0.645$$

The per-curie unit risk factors associated with urban dose risk would decrease proportionally to the above value if the standard RADTRAN parameters are used. The effect of changes to the values used for UBF, BDF, USWF, and RPD on per-curie unit risk factors for urban dose risk is examined in more detail in Section 5.2

4.3 Package Description

EPRI considers the package descriptions utilized in the YM EIS to be reasonable as the package lengths are based on typical rail and truck casks. The YM EIS assumes that all packages have an external dose rate at the regulatory limit of 14 mrem/hour at one meter (equivalent to 10 mrem/hour at 2 meters). This is a conservative assumption as the package dose rate will vary as a function of fuel age, burnup and package design and will not exceed this value. This is an important factor in the calculation of LOS unit risk factors and effect of changes to this value are examined in Section 5.4.1.

The RADTRAN analysis used to calculate per-curie unit risk factors in the YM EIS defined 68 isotopes that might be contained in SNF or HLW. The package description of the materials to be transported assumed that one curie of each of the 68 isotopes would be transported in order to calculate per-curie unit risk factors for groundshine, cloudshine, inhalation, and resuspension dose. As described in Section 2, these per-curie unit risk factors were input to the YM EIS transportation database and combined with package-specific spent fuel characteristics for material to be transported from each point of origin to the proposed repository. For example, for the transport of SNF from the Humboldt Bay nuclear power plant, the per-curie unit risk factors would be multiplied by the number of curies of each isotope contained in a representative boiling water reactor (BWR) SNF assembly, the number of assemblies being transported in the package, etc. For the purposes of assessing radiological accident risk, the YM EIS assumed that a representative pressurized water reactor (PWR) assembly would have a burnup of 50 giga-watt days per metric ton of uranium (GWD/MTU), an enrichment of 4.3 weight-percent (%) U^{235}, and a decay time of 15 years. The representative BWR assembly would have a burnup of 40 GWD/MTU, 3.5 % enrichment, and a decay time of 14 years. The YM Draft EIS assumed fuel with lower burnups and longer decay times that would result in the calculation of lower radiological risks in the event of an accident (PWR SNF with 40 GWD/MTU burnup, 3.7% enrichment, and a decay time of 25.9 years; BWR SNF with 32.2 GWD/MTU burnup, 3.0% enrichment, and a decay time of 27.2 years.).

It should be noted that the use of the representative SNF isotopic inventory is a conservative assumption as not all spent fuel transport casks will be loaded with fuel with the "representative" characteristics (burnup, enrichment and cooling time) used in the calculation of accident risk. While the values utilized may be reasonable due to the fact that SNF will have a wide range of fuel burnup, enrichment and decay times, it is important to recognize that much of the SNF to be transported will, in fact, be decades old by the time the repository is operational. A study conducted by DOE's Management and Operating (M&O) contractor in September 2002 to examine the proposed design basis waste input for the repository shows a wide range of possible fuel ages being accepted for disposal. Depending upon the policy implemented for the shipment of spent fuel (i.e., ship the hottest fuel first (cooled for only five years) or the coldest/oldest fuel first) spent fuel shipments may contain fuel that has been cooled for an average of 11 years to 28 years prior to shipment resulting in a wide range of possible external dose rates.[42] Over the range of possible shipping strategies evaluated by DOE's M&O contractor, more than 40% of fuel shipped is likely to have been cooled for greater than 20 years.

Section 5.3 examines the effect of changes in the fuel burnup and age on the calculation of accident dose risk for a representative shipment of SNF from a nuclear power plant to the proposed repository. The YM EIS assumed that SNF casks would be uniformly loaded with SNF having the "representative" SNF characteristics. Section 5.3 also examines the impact on the calculation of accident risk associated with regional loading of SNF in a cask – that is, loading SNF with different SNF characteristics such as mixing SNF with both long and short decay times in one cask.

4.4 Loss of Shielding Accident Assumptions

As described in Section 3.2.7, the YM EIS utilized the RADTRAN STOP model to calculate unit risk factors associated with LOS accidents as well as accidents that had no LOS and no release of radioactive material but that resulted in the shipment being immobilized for some period of time. The LOS dose risk per shipment was then calculated using the unit risk factors using the following equation:

$$D_{LOS} = \sum_L (PD_L * ACC_L * DIST_L) * \sum_j (CP_j * URF_{LOS,j})$$

in which,

NSHIP, total number of shipments
PDL = population density along Lth route segment
ACC L = the accident rate along Lth route segment
DIST L = length of Lth route segment
CPj = jth LOS severity fraction
URFLOS, j = unit dose risk factor for jth LOS accident scenario

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[42] Bechtel SAIC Company, LLC, 2002 Design Basis Waste Input Report, TDR-CDW-SE-000022 Rev 00, September 2002, MOV.20021017.0001, (BSC 2002).

Input parameters for the RADTRAN STOP model include: an alphanumeric stop identifier, vehicle identification, stop time, population density or number of persons at stops, the minimum and maximum radius of area for the stop over which dose is calculated, and shielding fraction.

For accidents in which there is no shielding displacement but the cask is immobilized until it can be recovered, the LOS model assumed that the cask external dose rate would be the maximum allowed by NRC transport regulations – 10 mrem per hour at 2 meters (14 mrem/hour at 1 meter). As discussed in EPRI 2005, the use of an external dose rate of 14 mrem/hr at 1 meter is a conservative assumption since not all spent fuel transport casks will be loaded with fuel with characteristics (burnup, enrichment and cooling time) that would result in the cask external dose rate being at the regulatory limit. Section 5.4.1 examines the effect of assuming cask external dose rates that are lower than 14 mrem/hour at 1 meter for accidents in which the cask is immobilized but there is no LOS. The LOS risk factor for the accident in which there is no LOS would be reduced proportionally to the reduction in cask external dose rate.

Section 5.4 also examines the effect of stop time and shielding fractions on the calculation of LOS unit risk factors. As the RADTRAN LOS model was not used to calculate LOS dose risk, the building shielding fractions are not utilized. The YM EIS assumed that during a LOS accident (or an accident in which the cask is immobilized but there is no LOS), there is no shielding provided to residents in the vicinity of the accident. As the STOP model only contains one shielding factor for each stop, it would be necessary to calculate separate unit risk factors for urban, suburban and rural LOS accidents in order to apply shielding fractions that are similar to those described in Section 3.1.2. Use of STOP shielding factors that are lower than 1.0 would result in a proportional reduction in the LOS unit risk factors as summarized in Section 5.4.3.

4.5 Post Accident Parameter Options

As discussed in Section 3.5, RADTRAN contains several post-accident parameters with evacuation and possible interdiction of areas affected by a dispersal accident. Changes to these parameters can affect public dose associated with an accident. Since the YM EIS assumed no evacuation, no cleanup and no interdiction in order to assess the maximum consequences, Section 5.6 will examine the following parameters to determine how changes to these parameters, using the standard RADTRAN values or other values might change the resulting calculation of accident dose risk.

- CULVL – the level to which contaminated surfaces must be cleaned up in the event of a dispersal accident. The standard input parameter value is 0.2 µCi/m2 based on EPA guidelines. The YM EIS assumes a value of 1 million curies, meaning that no clean up of contaminated surfaces occurs.
- EVACUATION, represents the evacuation time in days following a dispersal accident. The standard input parameter value is 24 hours. While the YM EIS utilized the standard EVACUATION value of 24 hours to calculate accident per-curie unit risk factors, the calculation of accident dose risk performed within the transportation data base assumed that there was cleanup, interdiction or evacuation during the 24-year period of the Proposed Action. This results in a highly conservative calculation of accident risk.

- The variable, INTERDICT, specifies the threshold level for interdiction of contaminated land. The standard value in RADTRAN is 40 – that is, a value 40 times greater than CULVL, the clean-up level.
- The variable, SURVEY, specifies the time (days) required to survey contaminated land after a dispersal accident. The standard value is set to 10 days, which the RADTRAN User Guide describes as "unrealistically brief, but radiologically conservative."[43] The YM EIS analysis to determine per-curie unit risk factors utilized the standard value.

4.6 Probability Threshold for Maximum Reasonably Foreseeable Accidents

The YM EIS assessed the consequences of "maximum reasonably foreseeable accidents" for releases of material from a SNF cask during an accident using RISKIND. While EPRI did not have access to the RISKIND model to reassess the results in the YM EIS, EPRI was able to examine the methodology used in this assessment and has identified conservative assumptions from the YM EIS used to assess maximum reasonably foreseeable accidents.

The YM EIS and the associated transportation calculation package examined the frequency and consequences of the 21 rail severity fractions and the 19 truck accident severity fractions identified in NUREG/CR-6672. In accordance with DOE EIS guidance documents, the YM EIS considered any accident with a probability more than 1×10^{-7} (1 chance in 10 million) as "reasonably foreseeable."[44] Thus, the accident with a probability greater than 1×10^{-7} with the greatest consequence becomes the "maximum" reasonably foreseeable accident. As noted in Section 2, a 1×10^{-6} standard for "credible" accidents is utilized in other areas regulated by the NRC.[45] Thus, if the results of the RISKIND analysis are re-examined using a maximum reasonably foreseeable accident threshold of 1×10^{-6}, the result would find that less-severe accidents are the "maximum" reasonably foreseeable accidents resulting in lower population dose consequences and lower MEI doses. Section 5.6 examines the RISKIND results and reevaluates the maximum reasonably foreseeable accident using the 1×10^{-6} threshold.

4.7 Other Considerations

In addition to the use of conservative input parameters in the RADTRAN model identified above, there are conservative assumptions within the RADTRAN model and within DOE's transportation database. Given the complexity of the transportation data base used to calculate radiological risks associated with transportation accidents, EPRI recognizes that some of the conservative assumptions were necessary in order to simplify an already complex calculation of accident risk.

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[43] SAND2000-2354, p. 59.

[44] DOE 1993.

[45] CLI-01-22, 2001.

Thirty-three waste types that might be transported to Yucca Mountain were identified in the YM EIS. In order to reduce the complexity of the accident risk analysis, DOE grouped together waste types with similar characteristics and behaviors into ten groups. "Reference" fuel types were selected that 1) most closely resembles that of the specific SNF or HLW or (2) could result in larger potential releases in an accident than other fuels in the reference group.[46] Thus, the selection of these reference fuel types introduced conservatisms into the calculation of accident risk associated with accidents involving the non-reference fuel types in each group.

The population densities are modeled within 800 meters (0.5 mile) of the routes. The accident dose risk calculation then assumed that the population density in the 800-meter band along the route is the same out to 80 kilometers (50 miles) from the route. This extrapolated population density is then multiplied by the unit risk factors, yielding a dose risk in person-rem per kilometer of route for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The resulting impacts were then multiplied by a scaling factor that is the ratio of the population in a state based on the 1990 Census to projected population in 2035. The results were summed to provide estimates of the accident dose risk (in person-rem) for a shipment.[47] Assuming that the projected population in 2035 represents a reasonable estimate of the population in 2015 or 2025 or any other prior year is a conservative assumption. However, attempting to escalate population densities on a more frequent time interval would have added additional complexities to the YM EIS transportation database.

The YM EIS assumed that the population density within the 800 meter band along a route is the same as the population density to 80 kilometers. This assumption may be conservative in some instances and non-conservative in others. For example, the population density along routes in urban or suburban areas within 800 meters of the route may not be indicative of the population density for an area 80 kilometers away. The Washington DC area might serve as an example – the population density within the Washington DC beltway is much more dense than that 50 miles away in Frederick, Maryland – yet the YM EIS would assume a uniform density over the entire area even though much of it is suburban or rural.

The release fractions identified in Section 3.2.2 assume that in the event of an accident of a certain severity, the indicated amount of material will be released from the package. These release fractions are based on standard transportation casks and do not take into account that the latest announced DOE plans are to ship canistered SNF in dual-purpose canisters or transport, aging, and disposal (TAD) canisters. This plan was announced in 2006 and is still under development. If canistered SNF is shipped from reactor sites to the proposed repository, analysis by the U.S. NRC has shown that the canister would remain intact in the event of an accident, even one with a long-duration fire (the maximum reasonably foreseeable accident).[48] As such, the release fractions associated with the transport of canistered SNF could be zero. Thus, only LOS dose risk would be a factor that must be considered regarding transportation accident risk.

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[46] Jason 2001, pp.121-124.

[47] YM EIS, Appendix J, p. J-58.

[48] U.S. NRC, Spent Fuel Transportation Package Response to the Baltimore Tunnel Fire Scenario NUREG/CR-DRAFT, PNNL-15313, September 2005.

The YM EIS assumed that all radioactive isotopes that are released in an accident are dispersed in the air. All released and dispersed radioactive material are assumed to be aerosolized and respirable.[49] This is a conservative assumption as not all radionuclides that are released will be aerosolized or respirable.

The Pasquill stability classification methodology contained in the atmospheric dispersion model used to calculate unit risk factors in RADTRAN, utilized an idealized representation of topography and wind behavior. According to the RADTRAN Technical Manual, these idealizations are generally conservative for dose calculations. Another conservatism in the dispersion model is that the simple Gaussian plume dispersion calculation neglects factors such as surface roughness and shifting wind directions that would promote more rapid dilution of material.[50]

In addition, the RADTRAN atmospheric dispersion model assumes ground level releases. The RADTRAN Technical Manual notes that a "*ground-level release yields higher overall downwind concentrations and ground depositions than an otherwise comparable elevated release*."[51]

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[49] Jason 2001, p. 141.

[50] SAND2000-1256, p. 60.

[51] SAND2000-1256, p. 59.

5

EFFECT OF CHANGING RADTRAN INPUT PARAMETERS ON THE CALCULATION OF TRANSPORTATION ACCIDENT RISK

The potential radiological impacts associated with proposed transport of spent fuel to a repository at Yucca Mountain repository are very small – even with the conservative assumptions in the YM EIS. This section summarizes analyses performed by EPRI that examined the effect that changes to individual RADTRAN parameters have on the calculation of unit risk factors that were used in the YM EIS to calculate accident dose risk. This section also identifies more “realistic” values for several key RADTRAN input parameters than those used in the YM EIS.

As the calculated impacts associated with transportation accident risk presented in the YM EIS were very small, it would not be expected that a change to any one RADTRAN input parameter would result in a significant change in the calculated radiological accident dose risk. EPRI recognizes that it is important to use conservative assumptions in the evaluation of the environmental impacts associated with the proposed repository. However, it is equally important that the public and decision makers understand the conservative nature of the results presented. This chapter will provide that perspective regarding the assessment of radiological accident dose risk associated with the transport of SNF to the proposed Yucca Mountain repository.

The version of the YM EIS transportation database that EPRI obtained was write-protected. Thus, EPRI could not make changes to the database input parameters in order to recalculate accident risk to determine the effect of changing one or more parameters (e.g., changes to the per-curie unit risk factors). In order to demonstrate the effect of changing various RADTRAN input parameters, EPRI has calculated the dose risks associated with the shipment of SNF from a single site to the proposed repository using RADTRAN and has benchmarked these results against the results calculated in the YM EIS using the YM EIS transportation database. By using as input the specific state-by-state shipment miles, population densities, accident rates, number of shipments, and package contents, EPRI was able to replicate the transportation accident risks from the YM EIS transportation database using the RADTRAN model for rail shipment of SNF from the Humboldt Bay (CA) and Maine Yankee sites to the proposed repository for the Mostly Rail scenario. By changing specific RADTRAN input parameters, EPRI can determine the effect of these changes on accident dose for shipments from a specific site.

Note that EPRI’s reexamination of accident dose risk in Section 5 and Section 6 examines the dose risk components for groundshine, cloudshine, inhalation, resuspension and LOS dose risk. The YM EIS calculated the ingestion unit risk factors outside of the RADTRAN model. Thus, EPRI did not undertake to recalculate ingestion dose risk as it would have required state-by-state hand calculations in order to recreate the calculation of ingestion risk associated with routes traversing multiple states with varying food transfer factors, distances traveled and population densities. As described in Section 6, it appears that the dose risk via the ingestion pathway is likely to contribute only a few per cent to the overall dose risk. Thus, neglecting the ingestion pathway in this analysis is not likely to change the overall EPRI evaluation of the most important factors contributing to overall dose risk.

5.1 Breathing Rate

As discussed in Section 4.1, the YM EIS assumes that a breathing rate, BRATE, used to calculate inhalation dose risk, of 3.30E-04 m^3/sec, the standard value recommended in the RADTRAN User Guide. Since NRC Regulatory Guide 1.109 and the RISKIND user guide recommend a somewhat lower rate of 2.5E-04 m^3/sec, the use of this latter value will be evaluated to determine the effect on the inhalation dose risk factors.[52] As noted earlier, this lower value contained in Regulatory Guide 1.109 is also the default value used in the RISKIND model.[53]

Changing the breathing rate from 3.30E-04 m^3/sec to 2.5E-04 m^3/sec results in a reduction in the inhalation and resuspension unit risk factors that is proportional to the reduction in breathing rate. That is, a breathing rate of 2.5E-04 m^3/sec is approximately 76% of the standard RADTRAN value of 3.30E-04 m^3/sec. Thus, inhalation and resuspension unit risk factors would be 76% of the values utilized in the YM EIS. Table 2-1 presented the results of the YM EIS calculation of collective dose risks associated with transportation accidents for the Mostly Truck and the Mostly Rail scenarios, as 0.463 person-rem and 0.880 person-rem, respectively. As shown in Table 5-1, these collective dose risks are the sum of risks associated with groundshine risk, cloudshine risk (also referred to as immersion), ingestion risk, inhalation risk, resuspension risk, and loss of shielding risk. Changing the breathing rate to 2.5E-04 m^3/sec results in a reduction in the calculated per-curie unit risk factors for inhalation and resuspension which results in a proportional reduction in the dose risk associated with these exposure pathways. For example, the inhalation risk for the Mostly Truck scenario is reduced from 5.98E-03 person-rem to 4.54E-03 person-rem as shown in Table 5-1. As a result, the overall dose risk is reduced by 2% for the Mostly Truck scenario and by approximately 5% for the Mostly Rail scenario.

5.2 Urban Dose Risk Parameters

As discussed in Section 4.2, the YM EIS utilized conservative assumptions regarding the RADTRAN parameters used to calculate urban dose risk: BDF, Building Dose Factor; UBF, Urban Building Fraction; USWF, fractions of persons out of doors; and RPD, ratio of pedestrian density.

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[52] RegGuide 1.109.

[53] DOE Handbook 2002, p. 125.

Table 5-1
National Transportation – Reduction in Inhalation and Resuspension Risk Associated With Use of Reduced Breathing Rate (Person-Rem)

Parameters	YM EIS Mostly Truck	YM EIS Mostly Rail	Mostly Truck	Mostly Rail
Breathing Rate	**3.30E-04 m3/sec**		**2.5E-04 m3/sec**	
Groundshine Risk	5.23E-02	5.38E-01	5.23E-02	5.38E-01
Cloudshine Risk	1.33E-04	7.27E-04	1.33E-04	7.27E-04
Ingestion Risk	1.12E-02	8.03E-02	1.12E-02	8.03E-02
Inhalation Risk	5.98E-03	3.54E-02	4.54E-03	2.69E-02
Resuspension Risk	2.41E-02	1.43E-01	1.83E-02	1.09E-01
LOS Risk	3.69E-01	8.30E-02	3.69E-01	8.30E-02
Total Dose Risk	**0.463**	**0.880**	**0.455**	**0.838**

The YM EIS assumed a BDF of 1.0, which results in no sheltering provided by building ventilation; a UBF value of 1.0, meaning that 100% of the urban population is indoors; a USWF value of 0.0; and a RPD of 6.0. As discussed in Section 4.2, this results in the population density being multiplied by value of 1.0 – a conservative assumption since at least some of the urban population will be sheltered in buildings whose ventilation systems will provide some protection in the event of a radiological release.

EPRI utilized the standard RADTRAN parameters for these values in order to determine the effect on urban unit risk factors. EPRI assumed a BDF equal to 0.05, UBF equal to 0.9, USWF equal to 0.1, and a RPD equal to 6. This results in the EPRI population density that is 0.645 times the Yucca Mountain EIS value.

The per-curie unit risk factors associated with urban dose decreased proportionally to the above value, 0.645, as expected using the standard RADTRAN parameters. As the use of the standard RADTRAN parameters for BDF, UBF, USWF, and RPF only affect the calculation of the dose in urban populations, the results can not be directly applied to the calculated dose risks as EPRI was able to demonstrate in Table 5-1. The shipments from each point of origin to the proposed repository will have route-specific values for travel in urban areas through multiple states, with a wide range of population densities and different accident rates. Due to the complexity of the transportation database used to calculate accident risks for every route, it is not possible for EPRI to change one parameter (such as urban unit risk factors) to recalculate the overall dose risk. EPRI has examined the shipment of SNF from Maine Yankee, located in the southeast corner of the State of Maine, to the proposed repository to determine the effect of changing the urban dose risk parameters on the overall transportation risk associated with shipment of SNF from Maine Yankee.

Using the same RADTRAN parameters assumed in the YM EIS, EPRI calculated an accident dose risk of 0.015 person-rem using RADTRAN for the transport of fifty-five (55) rail casks containing SNF from Maine Yankee to Yucca Mountain. Note that this accident dose includes: groundshine, cloudshine, inhalation, and resuspension dose risk. The calculated dose risk is consistent with that calculated by the YM EIS transportation database. EPRI then calculated the accident dose risk using the standard RADTRAN input parameters for BDF (0.05), UBF (0.9), USWF (0.1) and RPD (6). As shown in Table 5-2, the dose risk associated with the rural and suburban populations does not change, but the dose risk associated with urban populations is reduced from 0.0081 person-rem to 0.0052 person-rem, approximately 64% of the dose risk calculated in the YM EIS. For the particular route associated with rail shipment of SNF from Maine Yankee to the proposed repository, this results in a 20% reduction in overall dose risk from 0.015 person-rem to 0.012 person-rem.

The effect of using the standard RADTRAN input parameters associated with urban dose risk will be dependent upon the distance that specific shipments travel through urban areas. In order to demonstrate this, a calculation of the dose risk associated with the transport of six rail casks from the Humboldt Bay Nuclear Power Plant in northwestern CA to the proposed repository was performed using RADTRAN and the input parameters used in the YM EIS transportation database. The dose risk was calculated to be 0.00043 person-rem as shown in Table 5-3, and is consistent with the dose risk calculated by the YM EIS transportation database for shipment of SNF from Humboldt Bay via rail. EPRI then calculated the accident dose risk using the standard RADTRAN input parameters for BDF (0.05), UBF (0.9), USWF (0.1) and RPD (6). As shown in Table 5-3, the dose risk associated with the rural and suburban populations does not change, but the dose risk associated with urban populations is reduced from 0.00028 person-rem to 0.00018 person-rem, approximately 64% of the dose risk calculated in the YM EIS. For the particular route associated with rail shipment of SNF from Humboldt Bay to the proposed repository, this results in a 25% reduction in overall dose risk from 0.00043 person-rem to 0.00032 person-rem.

Table 5-2
Accident Risk Associated with Transport of SNF from Maine Yankee to Yucca Mountain – Effect of Changes to Urban Dose Risk Parameters (Person-Rem)

Route Segment	**YM EIS – Mostly Rail** **Shipment of SNF From Maine Yankee**	**Standard Urban Dose Risk Parameters** **Shipment of SNF From Maine Yankee**
	BDF = 1.0 UBF = 1.0 **USWF = 0.0 RPD = 6**	**BDF = 0.05 UBF = 0.9** **USWF = 0.1 RPD = 6**
Rural	5.8E-04	5.8E-04
Suburban	6.6E-03	6.6E-03
Urban	8.1E-03	5.2E-3
Total Dose Risk	**1.5E-02**	**1.2E-02**

Table 5-3
Accident Risk Associated with Transport of SNF from Humboldt Bay to Yucca Mountain – Effect of Changes to Urban Dose Risk Parameters (Person-Rem)

Route Segment	**YM EIS – Mostly Rail** **Shipment of SNF From Maine Yankee**	**Standard Urban Dose Risk Parameters** **Shipment of SNF From Maine Yankee**
	BDF = 1.0 UBF = 1.0 **USWF = 0.0 RPD = 6**	**BDF = 0.05 UBF = 0.9** **USWF = 0.1 RPD = 6**
Rural	2.0E-05	2.0E-05
Suburban	1.2E-04	1.2E-04
Urban	2.8E-04	1.8E-04
Total Dose Risk	**4.3E-04**	**3.2E-04**

5.3 Package Description and Package Contents

As discussed in Section 4.3, EPRI considers the package descriptions utilized in the YM EIS to be reasonable as the package lengths are based on typical rail and truck casks. This section examines the effect of changes to the package radionuclide contents by comparing the risks associated with transport accidents involving SNF with the “representative” spent fuel characteristics used in the YM EIS to accidents involving SNF with lower burnup and longer cooling times. This comparison assumes that all SNF shipped in a package has uniform characteristics for burnup and SNF decay time. EPRI also examines how regional loading of SNF in a SNF transportation cask (e.g., loading SNF with short decay times and longer decay times in the same package) affect SNF transportation risk. In addition, as discussed below, the YM EIS used conservative assumptions regarding the Cobalt-60 (Co-60) inventories associated with activated corrosion products deposited on the surface of spent fuel assemblies during reactor operations (referred to as “crud”). The analyses in Section 5.3.1 and 5.3.2 utilize the conservative YM EIS methodology for calculating Co-60 crud inventories. Section 5.3.3 reexamines the results calculated in Section 5.3.1 and 5.3.2 to show the effect of utilizing minimum or average values for fuel surface areas and crud surface concentration. Note that the discussion of accident dose risk below examines the dose risk components for groundshine, cloudshine, inhalation and resuspension dose risk. The YM EIS calculated the ingestion unit risk factors outside of the RADTRAN model. Thus, it would require state-by-state hand calculations in order to recreate the calculation of ingestion risk associated with routes traversing multiple states with varying food transfer factors, distances traveled and population densities.

5.3.1 Comparison of Representative and Average PWR Fuel Characteristics and the Effect of Accident Dose Risk

For the purposes of assessing the transportation accident risk associated with shipping SNF to Yucca Mountain, YM EIS assumed that a representative PWR assembly would have a burnup of 50 GWD/MTU, an enrichment of 4.3 % U^{235}, and a decay time of 15 years. The representative BWR assembly was assumed to have a burnup of 40 GWD/MTU, 3.5 % enrichment, and a decay time of 14 years. This is a conservative assumption as not all spent fuel transport casks will be loaded with fuel with the “representative” characteristics (burnup, enrichment and cooling time) used in the calculation of accident risk. It is important to recognize that much of the SNF to be transported will, in fact, be decades old by the time the repository is operational. Over the range of possible shipping strategies evaluated by DOE’s M&O contractor in an analysis of possible waste streams for the repository, the average age of the SNF at the time of shipment was greater than 20 years for all of the scenarios evaluated and average burnups were 46 GWD/MTU for PWR SNF and 41 GWD/MTU for BWR SNF.[54] Thus, DOE’s assumption of “representative” SNF decay times of 15 years for PWR SNF and 14 years for BWR SNF is conservative and will result in the calculation of higher accident dose risk than if longer SNF decay times and/or lower burnups were utilized. In fact, the YM EIS also contained a description of what it referred to as “average” PWR and BWR fuel assemblies. The average PWR fuel assembly had a fuel burnup of 41.2 GWD/MTU, an enrichment of 3.75%, and a decay time of 23 years. The average BWR assembly had a fuel burnup of 33.6 GWD/MTU, an enrichment of 3.03% and a decay time of 23 years.[55]

In order to assess the effect of changes in the fuel burnup and age on the calculation of radiological accident risks, EPRI evaluated the radiological risks associated with the transport of 55 rail cask shipments of PWR SNF with both the “representative” PWR characteristics and the “average” PWR fuel characteristics as shown in Table 5-4 using the RADTRAN model.

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[54] BSC 2002, p.

[55] YM EIS, Appendix A, p. A-17.

Table 5-4
PWR Fuel Characteristics Used to Evaluate Effect of Fuel Age and Burnup on SNF Accident Risk

Parameters	YM EIS "Representative" PWR SNF Characteristics	YM EIS "Average" PWR SNF Characteristics
Fuel Burnup (GWD/MTU)	50	41.2
Fuel Enrichment (% U-235)	4.3	3.75
Decay Time (Years)	15	23

As shown in Table 5-5, the groundshine, inhalation, resuspension and cloudshine dose risk associated with transport of SNF from Maine Yankee to the repository was calculated using the "representative" PWR SNF characteristics as well as the "average" PWR SNF characteristics. A dose risk of 0.015 person-rem was calculated for the shipment of 55 rail cask shipments for SNF assuming "representative" PWR characteristics from Maine Yankee to the repository. EPRI then assumed that the radionuclide contents of the transport casks were consistent with SNF having a burnup of 41.2 GWD/MTU burnup and a decay time of 23 years, the "average" PWR fuel characteristics shown in Table 5-4. A dose risk of 0.0102 person-rem was calculated assuming these "average" PWR fuel characteristics, which is 65% of the dose risk associated with shipping SNF with the "representative" characteristics.

Table 5-5
Accident Risk Associated with Transport of SNF from Maine Yankee to Yucca Mountain – Effect of Changes to Fuel Age and Fuel Burnup (Person-Rem)

Parameters	Maine Yankee - Mostly Rail "Representative" PWR SNF	Maine Yankee - Mostly Rail "Average" PWR SNF
Groundshine Risk	1.1E-02	6.7E-03
Cloudshine Risk	1.7E-05	8.6E-06
Inhalation Risk	8.8E-04	6.7E-04
Resuspension Risk	3.6E-03	2.8E-03
Dose Risk **(Groundshine, Cloudshine, Inhalation, Resuspension)**	**1.5E-02**	**1.02E-02**

5.3.2 Effect of Regional Loading of SNF on Accident Dose Risk

The dose risk calculated in Table 5-5, assumed that all SNF assemblies would have either "representative" characteristics or "average" characteristics, that is, the calculation assumed that all SNF loaded in casks would have "uniform" SNF characteristics. Based upon transportation cask designs that are currently available and that are expected to be utilized to ship SNF to the repository, it is highly unlikely that SNF transportation casks would be uniformly loaded with SNF assemblies that all have the same fuel characteristics (burnup and cooling time). Dual-purpose SNF storage and transport casks being loaded at nuclear power plant sites today have been licensed to allow a mix of fuel burnups and decay times in order to efficiently manage SNF inventories – allowing hotter fuel to be placed in dry storage when mixed with older, less thermally hot SNF.

The radionuclide inventories for a single 50 GWD/MTU BWR assembly were calculated using the LWR Characteristics Data Base (RADDB), which calculates isotopic contents of SNF over a range of fuel burnups, enrichments and decay times.[56] EPRI assumed decay times of 5, 10, 15, 20 and 30 years. Cobalt-60 crud inventories were calculated by EPRI using the methodology described in the YM EIS, with Co-60 crud inventories being a function of fuel assembly surface area, crud surface concentrations for PWR and BWR SNF, and decay time.[57] As noted in the YM EIS, this methodology utilized the maximum values for both crud surface concentration and surface area, resulting in conservative results as discussed in more detail later in this section.

EPRI has evaluated the accident dose risk associated with the radionuclide inventory for BWR SNF assemblies with burnups of 50 GWD/MTU for decay times of 5, 10, 15, 20 and 30 years. Assuming a rail transport cask that can transport 68 BWR assemblies, using regional loading in which (1) 32 assemblies with decay heat of approximately 500 kilowatt (kW) per assembly can be loaded in the inner region of the package and (2) 36 assemblies with decay heat of approximately 0.275 kW can be loaded in the outer region of the package. Assuming a total package heat load of approximately 26 kilowatts and fuel burnup of approximately 50 GWD/MTU, this allows 32 5-year cooled assemblies to be loaded in the inner region and 36 30-year cooled assemblies to be loaded in the outer region. (Note that a mix of assembly burnup and cooling times can be loaded in order to stay within each region's decay heat limits and the package decay heat limits). These results are compared to the shipment of rail casks with uniform loading for the entire 68 assemblies with SNF characteristics of 50 GWD/MTU burnup and a decay time of 15 years as well as the shipment of rail casks with uniform loading of "representative" BWR assemblies with a burnup of 40 GWD/MTU and decay time of 14 years.

As presented in Table 5-6, EPRI calculated the dose risk associated with the transport of six 68-assembly BWR rail casks from Humboldt Bay to the repository using RADTRAN for three separate BWR fuel characteristic cases: (1) uniform loading of SNF with BWR fuel characteristics from the YM EIS; (2) uniform loading of BWR fuel with 50 GWD/MTU burnup and 15 years decay time; and (3) regional loading of BWR fuel 32 assemblies with 50

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[56] Oak Ridge National Laboratory, Characteristics Database System, LWR Radiological Database, DOE/RW-0184-R1, July 1992.

[57] YM EIS, pp. A-16 to A-20.

GWD/MTU burnup and 5 years decay time and 36 assemblies with 50 GWD/MTU and 30 years decay time. The accident risk associated with transport of 6 casks from Humboldt Bay to the repository using the YM EIS assumptions was calculated to be 0.00043 person-rem as shown in Table 5-6. If one assumed Uniform SNF Loading of 68 assemblies with 50 GWD/MTU burnup and 15 years decay time, the calculated accident risk associated with the shipment of 6 casks is 0.00052 person-rem – approximately 20% higher than shipping the same quantity of SNF with a lower 40 GWD/MTU burnup. In order to ship higher burnup SNF with relatively short decay times, SNF packages are being designed with regional loading that allows a mix of SNF with both short and long decay times such as that modeled in the third Regional SNF Loading case. In this scenario, 32 assemblies with 50 GWD/MTU burnup and 5 years decay time plus 36 assemblies with 50 GWD/MTU burnup plus 30 years cooling are transported in 6 rail casks resulting in a calculated accident dose risk of 0.00064 person-rem, approximately 49% higher than the shipping the same quantity of SNF with a uniform loading of 40 GWD/MTU and 14 years of cooling as assumed in the YM EIS. The accident dose risk for the Regional SNF Loading is approximately 23% higher than shipment of SNF under the Uniform SNF Loading scenario. While shipment of SNF with higher burnups and shorter decay times results in the calculation of somewhat higher accident risks than shipment of SNF with the longer decay times, it is important to recognize the very low risks associated with these shipments – essentially 0.1 person-millirem (or less) per shipment (0.00064 person-rem/6 shipments).

This analysis shows that the transportation accident risks associated with shipment of SNF, whether short-cooled SNF or older, longer-cooled fuel are small. In 2006, a National Academy of Sciences' Committee on Transportation of Radioactive Waste committee issued a finding that there were operational and safety advantages to be gained from shipping older (i.e., radiologically and thermally cooler) SNF first.[58] The Committee recommended that DOE should negotiate with commercial SNF owners to ship older fuel first to a federal repository. The above analysis demonstrates that while the radiological risks associated with shipment of "younger" SNF are somewhat higher than the risks associated with shipment of "older" SNF, the accident risks associated with the shipment of SNF are low no matter what the cooling time. Particularly when it is considered that in order to ship "younger" SNF in high capacity rail casks, current package designs require regional loading of SNF so that higher heat SNF can be mixed with SNF that has much lower heat loads.

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[58] NAS Committee on Transportation of Radioactive Waste, "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States", February 2006.

Table 5-6
Accident Risk Associated With Transport of SNF From Humboldt Bay to Yucca Mountain – Effect of Regional Loading Changes to Fuel Age and Fuel Burnup (Person-Rem)

Parameters	Humboldt Bay – Mostly Rail		
	YM EIS Results	Uniform SNF Loading	Regional SNF Loading
SNF Package Characteristics: **Burnup** **Assemblies per Cask/ Decay Time** **Total Assemblies per Cask**	40 GWD/MTU 68/14 years 68	50 GWD/MTU 68/15 years 68	50 GWD/MTU 32/5 years & 36/30 years 68
Groundshine Risk	3.6E-04	3.7E-04	5.0E-04
Cloudshine Risk	3.3E-07	3.8E-07	4.2E-07
Inhalation Risk	1.4E-05	2.8E-05	2.7E-05
Resuspension Risk	5.5E-05	1.2E-04	1.1E-04
Dose Risk	**4.3E-04**	**5.2E-04**	**6.4E-04**

5.3.3 Effect of Crud Inventory on Accident Dose Risk

The YM EIS relied upon the methodology outlined in NUREG/CR-6672 to determine the radionuclide inventory of activated corrosion products on SNF surfaces, referred to as “crud.” While crud generally contains eight radionuclides, all of the radionuclides decay after five or more years of storage except for Co-60.[59] Thus, only the concentration of Co-60 is important. The YM EIS explained that NUREG/CR-6672 estimated surface concentrations of 2 to 140 microcuries per square centimeter (μCi/cm^2) for PWR SNF and 11 to 595 μCi/cm^2 for BWR SNF. The YM EIS assumed the maximum values of 140 μCi/cm^2 for PWR SNF and 595 μCi/cm^2 per BWR SNF. NUREG/CR-6672 also estimated fuel assembly surface area values of 450,000 cm^2 for PWR assemblies and 170,000 cm^2 for BWR assemblies. These values yield Co-60 inventories of 63 Ci for PWR SNF (450,000 cm^2 x 140 μCi/cm^2) and 100 Ci for BWR SNF (170,000 cm^2 x 595 μCi/cm^2). When the Co-60 half-life of 5.27 years is factored in, the Co-60 inventory at a decay time of 15 years for PWR SNF is reduced to 9 Ci for a PWR assembly and at a decay time of 14 years for BWR SNF to 16 Ci. These Co-60 crud inventories were included in the package contents identified in the YM EIS and were factored into the YM EIS radiological risks associated with transportation accidents. The analyses summarized in Section 5.3.1 and 5.3.2, utilized the same methodology and assumptions regarding crud surface concentrations as the YM EIS, adjusting Co-60 crud inventory based on the appropriate decay times. As discussed above, the YM EIS notes that because DOE used the maximum values for surface concentration of crud and fuel assembly surface area, the resulting Co-60 crud inventories are conservatively high.[60] This section will examine the effect of using the lower bounding and an average surface

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[59] YM EIS, Volume II, pp. A-16.

[60] YM EIS, Volume II, pp. A-16 to A-22.

concentration for Co-60 crud on the calculation of SNF accident dose risk. In addition, it should be noted that the calculation of fuel assembly surface area does not account for the fact that there are a wide range of PWR and BWR fuel assembly designs with different surface areas. Modeling every fuel assembly design would have made the calculation of transportation accident risk in the YM EIS even more complicated, thus it is reasonable for DOE to have assumed one bounding value for PWR assemblies and one bounding value for BWR assemblies. However, it is also important to recognize that this introduced another conservativism in the calculation of accident dose risk.

As shown in Table 5-7, using the lower bounding crud surface concentration identified in the YM EIS for PWR, 2 $\mu Ci/cm^2$, results in a Co-60 inventory of 0.14 Ci for SNF with a 15 year decay time. Using a crud surface concentration that falls mid-way between the lower bound and upper bound identified in the YM EIS for PWR SNF, a value of 70 $\mu Ci/cm^2$, results in a Co-60 inventory of 4.4 Ci for PWR SNF with a decay time of 15 years. These values compare to the conservative Co-60 inventory of 9 Ci for PWR SNF calculated using the maximum crud surface concentration identified in the YM EIS.

Assuming a lower bounding crud surface concentration of 11 $\mu Ci/cm^2$ for BWR SNF, results in a Co-60 inventory of 0.3 Ci for BWR SNF with a decay time of 14 years. Assuming a crud surface concentration that is mid-way between the lower and upper bounds for BWR SNF, a value of 300 $\mu Ci/cm^2$, results in a Co-60 inventory of 8 Ci for BWR SNF with a decay time of 14 years. These compare to the conservative Co-60 inventory of 16 Ci for BWR SNF calculated using the maximum crud surface concentration identified in the YM EIS.

Using the above “low” and “medium” values for Co-60 inventories, EPRI calculated the dose risk associated with the transport of 26-assembly PWR rail casks for 55 shipments of SNF from Maine Yankee to the proposed repository and compared the results to the dose risk calculated in the YM EIS. As shown in Table 5-8, the dose risk associated with using the lower bounding value for Co-60 surface concentration (resulting in a Co-60 inventory of 0.14 Ci per assembly) was calculated to be 0.014 person-rem, a 7% reduction in dose risk compared to the dose risk calculated using the maximum Co-60 surface concentration assumed in the YM EIS. The Co-60 inventory of 0.14 Ci is less than 2% of the inventory assumed in the YM EIS. The dose risk associated with using the medium value for Co-60 surface concentration (resulting in a Co-60 inventory of 4.4 Ci) was calculated to be 0.0147 person-rem, a 4% reduction in dose risk compared to the dose risk calculated using the maximum Co-60 surface concentration assumed in the YM EIS. The Co-60 inventory of 4.4 Ci is approximately 50% of the Co-60 crud inventory assumed in the YM EIS for PWR SNF. Thus, while using the maximum Co-60 crud surface concentration for PWR fuel in the YM EIS was conservative, the conservatism results in an approximate 10% overestimate of dose-risk for the PWR case examined.

Table 5-7
Co-60 Crud Inventory for PWR and BWR Fuel Assemblies as a Function of Crud Surface Concentration.

Parameters	PWR SNF Assembly Values			BWR SNF Assembly Values		
Crud Surface Concentration	**Maximum YM EIS**	**Low**	**Medium**	**Maximum YM EIS**	**Low**	**Medium**
Fuel Surface Area (cm^2)	450,000	450,000	450,000	170,000	170,000	170,000
Crud Surface Concentration ($\mu Ci/cm^2$)	140	2	70	595	11	300
Co-60 Inventory at Discharge (Curies)	63	1.0	32	100	2	51
Decay Time	15	15	15	14	14	14
Co-60 Inventory at Decay Time (Curies)	9	0.14	4.4	16	0.3	8

Using the "low" and "medium" values for Co-60 inventories for BWR SNF identified in Table 5-7, EPRI calculated the dose risk associated with the transport of 68-assembly BWR rail casks for six shipments of SNF from Humboldt Bay to the repository and compared the results to the dose risk calculated in the YM EIS. As shown in Table 5-8, the dose risk associated with using the lower bounding value for Co-60 surface concentration (resulting in a Co-60 inventory of 0.3 Ci) was calculated to be 0.00027 person-rem, a 37% reduction in dose risk compared to the dose risk calculated using the maximum Co-60 surface concentration assumed in the YM EIS. The Co-60 inventory of 0.3 Ci is less than 2% of the inventory assumed in the YM EIS. The dose risk associated with using the medium value for Co-60 surface concentration (resulting in a Co-60 inventory of 8 Ci) was calculated to be 0.00035 person-rem, a 19% reduction in dose risk compared to the dose risk calculated using the maximum Co-60 surface concentration assumed in the YM EIS. The Co-60 inventory of 8 Ci is 50% of the Co-60 crud inventory assumed in the YM EIS for BWR SNF. Thus, using the maximum Co-60 crud surface concentration for BWR SNF could result an approximate 20% to 35% overestimate of dose-risk for shipment of BWR SNF.

5.4 Loss of Shielding Accident Assumptions

The YM EIS utilized the RADTRAN STOP model to calculate unit risk factors associated with LOS accidents as well as accidents that had no LOS and no release of radioactive material but that resulted in the shipment being immobilized for some period of time. The LOS dose risk calculation takes the following factors into account: number of shipments, population density along a route, accident rates along route, route length, LOS severity fractions, and LOS unit risk factors calculated using RADTRAN. Parameters used in the LOS stop model that are important to the calculation of LOS unit risk factors include: dose rate associated with LOS accident; stop time (the time that it takes to recover a damaged cask); minimum and maximum radius of the area over which the LOS dose-risk is calculated; shielding fraction. This section will examine how changes in the cask external dose rate, LOS accident stop time, maximum radius over which LOS dose risk is calculated and shielding fraction in the vicinity of LOS accidents affect the calculation of LOS unit risk factors as well as LOS dose-risk for transport of SNF from the Humboldt Bay site to the repository.

Table 5-8
The Effect of Co-60 Crud Inventory on the Calculation of Accident Risk Associated With Transport of SNF From Maine Yankee and Humboldt Bay to Yucca Mountain (Person-Rem).

Parameters	Maine Yankee – Mostly Rail			Humboldt Bay Mostly Rail		
	YM EIS Max Co-60	Low Co-60	Medium Co-60	YM EIS Max Co-60	Low Co-60	Medium Co-60
Co-60 Inventory (Curies)	9	0.14	4.4	16	0.3	8
Number of Casks Shipped	55	55	55	6	6	6
Groundshine Risk	1.1E-02	9.6E-03	1.0E-02	3.6E-04	2.1E-04	2.8E-04
Cloudshine Risk	1.7E-05	1.7E-05	1.7E-05	3.3E-07	3.3E-07	3.3E-07
Inhalation Risk	8.8E-04	8.6E-04	8.7E-4	1.4E-05	1.3E-05	1.3E-05
Resuspension Risk	3.6E-03	3.5E-03	3.6E-03	5.5E-05	5.0E-05	5.3E-05
Dose Risk	**1.53E-02**	**1.40E-02**	**1.47E-02**	**4.3E-04**	**2.7E-04**	**3.5E-04**

5.4.1 Effect of Cask External Dose Rate on LOS Unit Risk Factors and Accident Dose Risk

The majority of LOS accidents (99.999%) are accidents in which there is no shielding displacement but the cask is immobilized until it can be recovered. The unit risk factor associated with this LOS accident dominates the LOS unit risk factors for the other five LOS severity categories that were defined in the YM EIS. The YM EIS assumed that the cask external dose rate would be the maximum allowed by NRC transport regulations in an accident in which shielding is not lost but the cask is immobilized, e.g. 10 mrem per hour at 2 meters (14 mrem/hour at 1 meter). This is a conservative assumption as not all spent fuel transport casks will be loaded with fuel with characteristics (burnup, enrichment and cooling time) that would result in the cask external dose rate being at the regulatory limit.

As shown in Table 5-9, EPRI has calculated the resulting LOS unit risk factors associated with cask external dose rates of 10 mrem/hour at 1 meter and 7 mrem/hour at 1 meter and compared the results to the YM EIS LOS unit risk factors. Note that this calculation only affects the calculation for the LOS unit risk factor associated with LOS severity Category 1 in which no shielding is lost, but the cask is immobilized. The reduction in cask external dose rate to 10 mrem per hour results in a reduction to the LOS unit risk factor for LOS Severity Category 1 that is proportional to the reduction in cask external dose rate – that is, the external dose was reduced from 14 mrem/hour to 10 mrem/hour at 1 meter, a 29% reduction, and the resulting Severity Category 1 LOS unit risk factor was reduced from 3.86E-5 person-rem to 2.76E-05 person-rem, a 29% reduction. The reduction in cask external dose rate to 7 mrem per hour results in a reduction to the LOS unit risk factor for LOS Severity Category 1 that is proportional to the reduction in cask external dose rate, with the corresponding LOS unit risk factor of 1.93E-5 person-rem, a 50% reduction.

In addition to calculating the change in the LOS Severity Category 1 unit risk factors associated with a cask external dose rate that is lower than 14 mrem/hour at 1 meter for LOS accidents in which no shielding is lost but the cask is immobilized, EPRI calculated the effect of the change in the LOS Category 1 unit risk factor on the accident dose risk associated with the rail shipment of six SNF casks from Humboldt Bay to the proposed repository. As shown in Table 5-9, the dose risk associated with LOS accidents is dominated by LOS Severity Category 1 accidents in which no shielding is lost. The only change to the YM EIS LOS unit risk factors was to change the external dose rate associated with LOS Severity Category 1, a reduction in LOS Severity Category 1 unit risk factor of approximately 29% for a 10 mrem/hour external dose rate and of approximately 50% for a 7 mrem/hour external dose rate. The reduction in the total LOS risk associated with the shipment of SNF from Humboldt Bay to the proposed repository is proportional to the reduction in the LOS Severity Category 1 unit risk factor. That is, for the scenario in which the cask external dose rate is assumed to be 10 mrem/hour at 1 meter, the LOS Severity Category 1 unit risk factor is reduced to 71% of the value assumed in the YM EIS. No other severity category unit risk factors are changed. However, the total LOS dose risk associated with a cask external dose rate of 10 mrem/hour was calculated to be 1.94E-05 person-rem, a value that is 71% of the 2.71E-05 person-rem dose risk calculated in the YM EIS for Humboldt Bay. This shows that the most important contributor to LOS accident dose risk is an accident in which shielding is not lost.

Table 5-9
The Effect of Changes to Cask External Dose Rate on Calculation of LOS Unit Risk Factors and LOS Accident Dose Risk Associated With Transport of SNF from Humboldt Bay to Yucca Mountain.

LOS Severity Category	LOS Accident Severity Fractions	YM EIS TI = 14mre/hr @ 1 m	External Dose Case 1 TI = 10mre/hr @ 1 m	External Dose Case 2 TI = 7mre/hr @ 1 m
		LOS Unit Risk Factors (Person-Rem)		
1	1.0E+00	3.86E-05	2.76E-05	1.93E-05
2	6.4E-06	7.22E-03	7.22E-03	7.22E-03
3	4.9E-05	2.03E-03	2.03E-03	2.03E-03
4	4.5E-07	1.24E-02	1.24E-02	1.24E-02
5	2.4E-05	2.41E-03	2.41E-03	2.41E-03
6	5.2E-09	2.97E-02	2.97E-02	2.97E-02
Humboldt Bay – Mostly Rail **LOS Dose Risk (Person-Rem)**		**2.71E-05**	**1.94E-05**	**1.36E-05**

As more than 40% of fuel shipped is likely to have been cooled for times greater than 20 years over the range of possible shipping scenarios evaluated by the M&O contractor (e.g., hottest fuel first, coldest fuel first, etc), a cask dose rate of 10 mrem/hour at 1 meter (approximately 70% of the regulatory limit) was selected by EPRI as being a reasonable average cask external dose rate that could occur over the range of possible shipping strategies.[61] Average fuel ages ranged from 11 years to 28 years cooled for a range of spent fuel burnups and a range of possible external dose rates. Section 6 examines the effect that reducing the cask dose rate to 10 mrem/hour at 1 meters combined with changes to other RADTRAN input parameters will have on the unit risk factors and the resulting accident dose risk associated with transport of SNF to the proposed repository.

5.4.2 Effect of LOS Accident Recovery Time on LOS Unit Risk Factors and LOS Dose Risk

The YM EIS assumed that the time to recover a cask following a LOS accident would be 12 hours. EPRI considered the effect of the LOS accident recovery time on LOS unit risk factors and the calculation of LOS dose risk by evaluating two additional time periods – a LOS accident recovery time of 6 hours and a LOS accident recovery time of 24 hours. As shown in Table 5-10, changes to the LOS unit risk factors are directly proportional to the LOS accident recovery time specified in the RADTRAN STOP model. In LOS Recovery Case 1, reducing the LOS accident recovery time from the 12 hour assumption utilized in the YM EIS to 6 hours, results in a proportional reduction in the LOS unit risk factors for the six LOS severity categories shown in Table 5-10. Similarly, in LOS Recovery Case 2, increasing the LOS accident recovery time to 24 hours, results in a proportional increase in the LOS unit risk factors associated with the LOS severity categories.

EPRI calculated the accident dose risk associated with the rail shipment of six SNF casks from Humboldt Bay to the repository for the two LOS recovery cases discussed above. As shown in Table 5-10, for LOS Recovery Case 1 in which the LOS accident recovery time is reduced from 12 to 6 hours, the dose risk associated with transporting six SNF casks from Humboldt Bay to the repository decreases from 2.71E-05 person-rem to 1.35E-05 person-rem, a 50% reduction that is proportional to the decrease in the LOS recovery time. For LOS Recovery Case 2 in which the LOS accident recovery time is increased from 12 to 24 hours, the dose risk associated with the Humboldt Bay SNF transport increases from 2.71E-05 person-rem to 5.42E-05 person-rem, an increase that is proportional to the increase in the LOS recovery time.

It should be noted that the YM EIS assumed that LOS accidents that fall into the six severity categories would have the same LOS recovery times – 12 hours. In fact, the LOS recovery time may be dependent upon the type of LOS accident and the extent to which shielding is lost. For example, it appears to be reasonable that a LOS accident in which no shielding is lost but the SNF cask is immobilized could be recovered in a time period of 12 hours or shorter. Equipment would need to be brought to the site to lift the cask back onto a conveyance. For accidents in which shielding is lost, it is possible that the time to recover a cask could be somewhat longer than 12 hours if additional shielding would need to be put in place in order to protect workers

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[61] BSC 2002.

involved in the recovery operation. EPRI has examined the effect of using different recovery times for the six severity categories. EPRI assumed that a LOS Category 1 recovery time of 12 hours and LOS Categories 2 through 6 recovery times of 18 hours.

Table 5-10
The Effect of Changes to LOS Accident Recovery Time on Calculation of LOS Unit Risk Factors and LOS Accident Dose Risk Associated With Transport of SNF From Humboldt Bay to Yucca Mountain.

LOS Severity Category	LOS Accident Severity Fractions	YM EIS Recovery = 12 Hours	LOS Recovery Case 1 Recovery = 6 Hours	LOS Recovery Case 2 Recovery = 24 Hours
		LOS Unit Risk Factors (Person-Rem)		
1	1.0E+00	3.86E-05	1.93E-05	7.20E-05
2	6.4E-06	7.22E-03	3.61E-03	1.44E-02
3	4.9E-05	2.03E-03	1.01E-03	4.06E-03
4	4.5E-07	1.24E-02	6.21E-03	2.48E-02
5	2.4E-05	2.41E-03	1.20E-03	4.82E-03
6	5.2E-09	2.97E-02	1.48E-02	5.94E-02
Humboldt Bay – Mostly Rail **LOS Dose Risk (Person-Rem)**		**2.71E-05**	**1.35E-05**	**5.42E-05**

Table 5-11
The Effect of Using Different LOS Accident Recovery Times for LOS Severity Categories on Calculation of LOS Unit Risk Factors and LOS Accident Dose Risk Associated With Transport of SNF From Humboldt Bay to Yucca Mountain

LOS Severity Category	LOS Accident Severity Fractions	YM EIS Recovery = 12 Hours	LOS Recovery Case 3 Recovery LOS Sev Cat 1 = 6 Hours Recovery LOS Sev cat 2-6 = 18 Hours
		LOS Unit Risk Factors (Person-Rem)	
1	1.0E+00	3.86E-05	1.93E-05
2	6.4E-06	7.22E-03	1.08E-02
3	4.9E-05	2.03E-03	3.05E-03
4	4.5E-07	1.24E-02	1.86E-02
5	2.4E-05	2.41E-03	3.62E-03
6	5.2E-09	2.97E-02	4.46E-02
Humboldt Bay – Mostly Rail **LOS Dose Risk (Person-Rem)**		**2.71E-05**	**1.37E-05**

As shown in Table 5-11, applying a LOS recovery time of 6 hours to the LOS Category 1 accident results in a proportional decrease in the Category 1 LOS unit risk factor to 1.93E-05 person rem. Recovery times of 18 hours for LOS Category 2 through 6 accidents result in LOS unit risk factors that are 1.5 times those calculated in the YM EIS which assumed recovery times of 12 hours. EPRI used these LOS Recovery Case 3 unit risk factors that were calculated assuming different LOS recovery times to calculate the accident dose risk associated with the rail shipment of six SNF casks from Humboldt Bay to the repository. The dose risk associated with transporting six SNF casks from Humboldt Bay to the repository is 1.37E-05 person-rem, approximately 50% of the dose risk calculated in the YM EIS assuming that all accident categories had recovery times of 12 hours. The LOS Recovery Case 3 dose risk of 1.37E-05 person-rem is less than 2% higher than the LOS accident dose risk associated with LOS Recovery Case 1, in which all recovery times were assumed to be six hours. Again, this demonstrates that the most important contributor to LOS accident dose risk is an accident in which shielding is not lost but the cask is immobilized for some period of time. EPRI considers LOS recovery times that are dependent upon the LOS accident category, such as LOS Recovery Case 3, to be a reasonable approach and will examine this scenario in more detail in Section 6.

5.4.3 Changes to Maximum Radius Over Which LOS Dose Risk is Calculated

The YM EIS assumed a maximum radius of 800 meters over which LOS dose risk is calculated. In EPRI 2005, EPRI evaluated the impact of assuming maximum perpendicular distances of less than 800 meters over which the off-link incident free risk was calculated..[62] A decrease in the value of the maximum distance over which the LOS dose-risk is calculated (800 m) will decrease the calculated LOS dose risk as the integrated dose would be calculated over a shorter distance. EPRI examined the effect of two alternative maximum distances – 500 meters and 100 meters.

As shown in Table 5-12, changing the maximum radius over which LOS dose risk is calculated from 800 meters to 500 meters (62.5% of the YM EIS distance) results in LOS unit risk factors for LOS Distance Case 1 that are 86% of the LOS risk factors used in the YM EIS. In LOS Distance Case 2, reducing the maximum distance over which the LOS dose risk is calculated to 100 meters (12.5% of the YM EIS distance) results in LOS unit risk factors that are 37% of the LOS risk factors calculated in the YM EIS.

EPRI calculated the accident dose risk associated with the rail shipment of six SNF casks from Humboldt Bay to the repository using the unit risk factors for LOS Distance Case 1 (500 meters) and LOS Distance Case 2 (100 meters) and compared the results to the LOS accident dose risk calculated for Humboldt Bay rail shipments in the YM EIS transportation database. Under LOS Distance Case 1 in which the maximum distance is reduced to 500 meters, the dose risk associated with transporting six SNF casks from Humboldt Bay to the repository decreases from 2.71E-05 person-rem to 2.34E-05 person-rem, 86% of the YM EIS dose risk. For LOS Distance Case 2 in which the maximum distance is reduced to 100 meters, the dose risk associated with the Humboldt Bay SNF transport decreases from 2.71E-05 person-rem to 1.00E-05 person-rem, 37% of the YM EIS dose risk. A decrease in the maximum distance over which the LOS dose risk is calculated will result in a decrease in LOS dose risk that is inversely proportional to the square of the distance from the source.

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[62] EPRI 2005, pp. 5-13 – 5-14.

Table 5-12
The Effect of Changes to Maximum Distance Over Which LOS Dose-Risk Is Calculated on LOS Unit Risk Factors and LOS Accident Dose Risk Associated With Transport of SNF From Humboldt Bay to Yucca Mountain

LOS Severity Category	LOS Accident Severity Fractions	YM EIS Distance = 800 Meters	LOS Distance Case 1 Distance = 500 Meters	LOS Distance Case 2 Distance = 100 Meters
		LOS Unit Risk Factors (Person-Rem)		
1	1.0E+00	3.86E-05	3.33E-05	1.43E-05
2	6.4E-06	7.22E-03	6.24E-03	2.67E-03
3	4.9E-05	2.03E-03	1.75E-03	7.49E-04
4	4.5E-07	1.24E-02	1.07E-02	4.59E-03
5	2.4E-05	2.41E-03	2.08E-03	8.90E-04
6	5.2E-09	2.97E-02	2.56E-02	1.10E-02
Humboldt Bay – Mostly Rail **LOS Dose Risk (Person-Rem)**		**2.71E-05**	**2.34E-05**	**1.00E-05**

5.4.4 Effect of Shielding Fractions on LOS Unit Risk Factors and LOS Dose Risk

As the RADTRAN LOS model was not used to calculate LOS dose risk for the YM EIS, the building shielding fractions are not utilized in the calculation of LOS unit risk factors. The YM EIS assumed that during a LOS accident (or an accident in which the cask is immobilized but there is no LOS), there is no shielding provided to residents in the vicinity of the accident. As the STOP model used to calculate LOS unit risk factors only contains one shielding factor for each stop, it would be necessary to calculate separate unit risk factors for urban, suburban and rural LOS accidents in order to apply shielding fractions that are similar to those described in Section 3.1.2. This section analyzes the use of shielding fractions for calculating the dose to populations near a potential LOS accident. The shielding fractions evaluated are consistent with those used to calculate incident-free off-link dose described in Section 3.1.2 – that is, a suburban shielding fraction of 0.87 and an urban shielding fraction of 0.018. Rural shielding fractions used in RADTRAN assume no shielding is provided by buildings to rural populations, hence the shielding fraction is 1.0.

LOS Shielding Case 1 assumes a shielding factor of 0.87 in the RADTRAN STOP model used to calculate LOS unit risk factors. The decrease in the unit risk factors associated with LOS Shielding Case 1 is proportional to the decrease in the shielding factor from 1.0 to 0.87 – the resulting risk factors are 87% of those calculated in the YM EIS. LOS Shielding Case 2 assumes a shielding factor of 0.018 to calculate LOS unit risk factors. The LOS unit risk factors associated with LOS Shielding Case 2 are 1.8% of the LOS shielding factors calculated in the YM EIS. EPRI calculated the accident dose risk associated with the use of the LOS Shielding Case 1 LOS unit risk factors. Assuming a shielding factor of 0.87, the dose risk associated with transporting six SNF casks from Humboldt Bay to the repository decreases from 2.71E-05 person-rem to 2.36E-05 person-rem, 87% of the YM EIS dose risk. For LOS Shielding Case 2 in which a shielding factor of 0.018 was assumed, the dose risk decreases from 2.71E-05 person-rem to 4.88E-07 person-rem, 1.8% of the YM EIS dose risk. The decrease in dose risk is proportional to the decrease in shielding factors.

EPRI acknowledges that the use of three separate shielding factors for the calculation of LOS dose risk in the YM EIS would have made the YM EIS transportation database even more complex. However, it is overly conservative to assume that, in the event of a LOS accident in an urban or suburban area, no shielding is provided by buildings to the population in the vicinity of the accident. EPRI performed a hand calculation utilizing a rural LOS shielding factor of 1.0, a suburban LOS shielding factor of 0.87, an urban LOS shielding factor of 0.018 and the associated unit risk factors shown in Table 5-13. These unit risk factors were applied to the rural, urban and suburban distances associated with the shipment of six rail casks from Humboldt Bay to the repository using the formula shown in Section 4.4. The resulting dose risk associated with transport of six SNF casks from Humboldt Bay was calculated to be 8.0E-06 person-rem compared to 2.71E-05 person-rem calculated in the YM EIS using a shielding factor of 1. This is dose risk associated with using specific LOS shielding factors based on population density is 30% of that calculated in the YM EIS assuming no shielding. It seems reasonable to assume that the calculation of LOS dose risk should consider the use of shielding factors that are lower than 1.0 and consistent with urban and suburban shielding factors recommended in the RADTRAN model.

Table 5-13
The Effect of Changes to LOS Shielding Fractions on LOS Unit Risk Factors and LOS Accident Dose Risk Associated with Transport of SNF From Humboldt Bay to Yucca Mountain

LOS Severity Category	LOS Accident Severity Fractions	YM EIS Shielding = 1.0	LOS Shielding Case 1 Shielding = 0.87	LOS Shielding Case 2 Shielding = 0.018
		LOS Unit Risk Factors (Person-Rem)		
1	1.0E+00	3.86E-05	3.36E-05	6.95E-07
2	6.4E-06	7.22E-03	6.28E-03	1.30E-04
3	4.9E-05	2.03E-03	1.76E-03	3.65E-05
4	4.5E-07	1.24E-02	1.18E-02	2.24E-04
5	2.4E-05	2.41E-03	2.10E-03	4.34E-05
6	5.2E-09	2.97E-02	2.58E-02	5.34E-04
Humboldt Bay – Mostly Rail **LOS Dose Risk (Person-Rem)**		**2.71E-05**	**2.36E-05**	**4.88E-07**

5.5 Atmospheric Dispersion Models

According to a discussion in the RADTRAN Technical Manual regarding atmospheric dispersion, "the most commonly used mathematical representations of atmospheric dispersion are based on a Gaussian plume model, developed by Pasquill, in which gases or particles released into the atmosphere and dispersed exhibit ideal gas behavior."[63] This model is based on several principles:

- Gases, aerosols and particulates dispersed in the air move predominately downwind.
- The greatest concentration of the plume is along the plume centerline.
- Aerosols, gases and other materials in a plume diffuse spontaneously from regions of higher concentrations to regions of lower concentration.[64]

As discussed in Section 3.2.3, RADTRAN 5 contained two separate atmospheric dispersion models that can be used in the calculation of accident dose risk – the stability category method or the single-table method. If the Pasquill flag is set to 1 in the RADTRAN model, the stability category method is used in which six sets of tabular data (area, downwind distance, and time-integrated concentration) are called for six Pasquill atmospheric stability categories to which the user assigns a fractional probability of occurrence (see Table 3-3). The stability category method contains values for time integrated concentrations (X/Q) and isopleth areas assume an instantaneous ground-level release and a small-diameter source cloud.

If the Pasquill flag is set to 0, then a table of user definable areas and time-integrated concentration values is called up (referred to as the "Single-Table Method" in the RADTRAN Technical Manual).[65] RADTRAN includes default national average values that can be used, or the user can input values for isopleth areas, downwind centerline distances and time-integrated concentrations. The RADTRAN Technical Manual notes that the use of the national average data will generally yield acceptable results for routes longer than 500 kilometers (310 miles). The standard RADTRAN values are "*conservative because they represent a small-diameter (10 m) ground-level release and the lowest wind speed consistent with each stability category*."[66] The RADTRAN Technical Manual notes that a "*ground-level release yields higher overall downwind concentrations and ground depositions than an otherwise comparable elevated release*."[67]

The RADTRAN Technical Manual states that a limitation of both of the above methodologies is that the atmospheric dispersion models contain idealized representations of topography and wind behavior. These idealizations are generally conservative for dose calculations. Another

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[63] SAND2000-1256, p. 56.

[64] Ibid., p. 56.

[65] Ibid, p. 58.

[66] Ibid,, p.26.

[67] Ibid, p. 59.

conservatism is that the simple Gaussian plume dispersion calculation neglects factors such as surface roughness and shifting wind directions that would promote rapid dilution of material.[68]

The Pasquill stability category methodology was used in the YM EIS to calculate per-curie unit risk factors. EPRI analyzed the Single Table Method for atmospheric dispersion to determine the effect on the per-curie unit risk factors calculated in the YM EIS and found that while there were small differences associated with some unit risk factors for certain isotopes, there was generally good agreement between the isotopic unit risk factors and overall which would be expected since both models utilize national average weather conditions and model ground-level releases. Due to the complexity of the calculation of radiological risk of an accident in the YM EIS, which considered rail, truck, and barge transport through more than 40 states over a 24-year period, EPRI considers the use of national average meteorological conditions to be appropriate.

5.6 Post Accident Parameter Options

As discussed in Section 3.3, RADTRAN contains several parameters associated with post-accident options such as evacuation and possible interdiction of areas affected by a dispersal accident. The YM EIS assumed no evacuation, no cleanup and no interdiction in order to assess the maximum consequences. This section examines the following post-accident action level parameters to determine how changes to these parameters, using the standard RADTRAN values, might change the resulting calculation of accident dose risk. The parameters and their relationships to one another are described in more detail in Section 3.3.

Cleanup level (CULVL) is the level to which contaminated surfaces must be cleaned up in the event of a dispersal accident. The standard input parameter value is 0.2 μCi/m^2 based on EPA guidelines. The evacuation time (EVACUATION) is the time in days following a dispersal accident to evacuate the population in the vicinity of the accident. The standard input parameter value is one day. The YM EIS assumes no evacuation occurred.[69] A threshold for interdiction of contaminated land is set with the variable, INTERDICT. The standard value in RADTRAN is 40 – that is, a value 40 times greater than CULVL, the clean-up level. The time that would be required to survey contaminated land is identified by the variable SURVEY. The standard value is set to 10 days.

In order to determine the effect on accident dose risk associated with post-accident cleanup, EPRI analyzed the accident dose risk for the transport of spent fuel from Maine Yankee and Humboldt Bay to the repository utilizing the standard RADTRAN parameters for CULVL, EVACUATION, INTERDICT, and CULVL. As shown in Table 5-14, the resulting dose risk associated with groundshine, inhalation, resuspension and cloudshine exposure pathways is compared to the dose risk for these pathways calculated in the YM EIS. The use of post-accident interdiction, assuming the standard RADTRAN parameters discussed above, results in a reduction in accident dose risk for transport of SNF from Maine Yankee and Humboldt Bay to the repository. The dose risk associated with transport of SNF by rail from Maine Yankee to the repository, assuming post-accident interdiction, was calculated to be 0.0071 person-rem –

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[68] Ibid, p. 60.

[69] Jason 2001, p. 141.

approximately 47% of the dose risk calculated in the YM EIS assuming no post-accident evacuation or interdiction. The dose risk associated with the transport of SNF by rail from Humboldt Bay to the repository was calculated to be 0.00022 person-rem – approximately 51% of the dose risk calculated in the YM EIS assuming no post accident evacuation or interdiction. It should be noted that the reduction in dose risk associated with interdiction and cleanup is attributed to the groundshine and resuspension exposure pathways as shown in Table 5-14. Inhalation and cloudshine exposure pathways will not be affected by cleanup levels or interdiction level.

Table 5-14
Accident Risk Associated with Transport of SNF from Maine Yankee to Yucca Mountain – Effect of Changes to Fuel Age and Fuel Burnup (Person-Rem)

Parameters	Maine Yankee – Mostly Rail		Humboldt Bay – Mostly Rail	
	YM EIS No Interdiction	Post Accident Interdiction	YM EIS No Interdiction	Post Accident Interdiction
Groundshine Risk	1.1E-02	5.5E-03	3.6E-04	2.0E-04
Cloudshine Risk	1.7E-05	1.7E-05	3.3E-07	3.3E-07
Inhalation Risk	8.8E-04	8.8E-04	1.4E-05	1.4E-05
Resuspension Risk	3.6E-03	6.7E-04	5.5E-05	1.1E-05
Dose Risk	**1.5E-02**	**7.1E-03**	**4.3E-04**	**2.2E-04**

While the YM EIS assumed no evacuation, cleanup or interdiction in the event of a transportation accident that resulted in the dispersal of radioactive material in order to conservatively predict the dose risk, it must be recognized that these conservative assumptions may result in a doubling of the calculated accident dose risk.

5.7 Probability Threshold for Maximum Reasonably Foreseeable Accidents

The YM EIS and the associated transportation calculation package examined the frequency and consequences of the 21 rail severity fractions and the 19 truck accident severity fractions identified in NUREG/CR-6672. In accordance with DOE EIS guidance documents, the YM EIS considered any accident with a probability more than 1×10^{-7} per year (1 chance in 10 million) as "reasonably foreseeable."[70] Thus, the accident with a probability greater than 1×10^{-7} with the greatest consequence becomes the "maximum" reasonably foreseeable accident. As noted in Section 2, a 1×10^{-6} per year standard for "credible" accidents is utilized in other areas regulated by the NRC.[71] Thus, if the results of the RISKIND analysis are reexamined using a maximum reasonably foreseeable accident threshold of 1×10^{-6}, it would be determined that less-severe

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[70] DOE 1993.

[71] CLI-01-22, 2001.

accidents are the "maximum" reasonably foreseeable accidents resulting in lower population dose consequences.

Table 5-15 presents the frequency and consequences associated with rail accidents for commercial spent nuclear fuel in both urban and rural environments assuming stable atmospheric conditions (Pasquill stability class F) with a wind speed of 0.89 meters per second. The RISKIND model assumed that no shielding was provided to residents, a conservative assumption discussed earlier.

Using a maximum reasonably foreseeable accident threshold of 1 x 10^{-6}, it is evident that there are no "credible" urban accidents for commercial SNF in which the expected accident frequency is greater than 1 x 10^{-6}accidents per year. Examining the results of accidents in rural areas, the "Rail 20" accident has a frequency of 1.69x 10^{-6}accidents per year with a total exposure of 16.3 person-rem, less than 1% of the population dose risk associated with the maximum reasonably achievable rail accident in the YM EIS. DOE's maximum credible accident (Rail 20 in urban areas) had an expected frequency of 2.75 x 10^{-7} accidents per year with a population dose of 9,893 person-rem. Thus, the overly conservative threshold of 1 x 10^{-7} for credible accidents results in population dose risk that is 9,877 person-rem higher than accidents assessed against a credible accident threshold of 1 x 10^{-6} accidents per year.

If the truck accident frequencies and consequences in the YM EIS transportation calculation package are examined, the maximum reasonably foreseeable accident assessed against a credible accident threshold of 1 x 10^{-6}accidents per year would result in a maximum reasonably achievable truck accident with a frequency of 2.5 x 10^{-6}accidents per year and a population dose of 225 person-rem.[72] This is approximately 20% of the population dose associated with the maximum reasonably achievable truck accident in the YM EIS. The use of the conservative threshold of 1 x 10^{-7} for credible accidents required by the DOE EIS guidance documents results in population dose risk that is 1,083 person-rem, which is 858 person-rem higher than the result of a credible accident assessed against a credible accident threshold of 1 x 10^{-6}accidents per year.

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[72] Jason 2001, p. 179.

Table 5-15
Frequency and Consequence of Rail Accidents[73]

Case #	Expected Frequency (per year)	Total Exposure (person-rem)	Case #	Expected Frequency (per year)	Total Exposure (person-rem)
Urban Area – Stability Class F			**Rural Area – Stability Class F**		
Rail 19	7.67-19	254,377	Rail 19	4.71E-18	419
Rail 18	9.74E-17	173,447	Rail 18	5.99E-16	285
Rail 15	7.67E-16	254,377	Rail 17	8.63E-15	185
Rail 14	5.77E-15	242,817	Rail 15	4.71E-15	419
Rail 17	1.41E-15	112,468	Rail 14	3.54E-14	400
Rail 12	9.74E-14	173,447	Rail 12	5.99E-13	285
Rail 11	7.34E-13	171,358	Rail 9	8.63E-12	134
Rail 13	2.07E-13	230,214	Rail 11	4.51E-12	282
Rail 16	2.32E-12	220,788	Rail 13	1.27E-12	379
Rail 9	1.41E-12	81,049	Rail 8	6.47E-11	5.63
Rail 10	2.62E-11	149,279	Rail 16	1.43E-11	364
Rail 3	2.51E-11	219,698	Rail 10	1.61E-10	246
Rail 8	1.05-11	3,416	Rail 3	1.54E-10	361
Rail 6	6.16E-10	159,807	Rail 6	3.78E-09	264
Rail 7	3.79E-10	3,060	Rail 7	2.33E-09	5.04
Rail 5	4.61E-09	1,745	Rail 5	2.83E-08	2.88
Rail 2	3.18E-09	149,266	Rail 2	1.95E-08	245
Rail 1	4.59E-08	2,933	Rail 1	2.82E-07	4.83
Rail 20	2.75E-07	9,893	Rail 20	1.69E-06	16.3
Rail 4	1.66E-07	1,346	Rail 4	1.02E-06	2.22

Note: Source of rail accident cases: NUREG/CR-6672.

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[73] Jason 2001, p. 178.

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TRANSPORTATION ACCIDENT RISK – COMBINED REALISTIC ASSUMPTIONS

In addition to examining the effect of changing a single parameter at a time on the assessment of transportation accident risks, EPRI examined a “more realistic” case that combines a number of more realistic assumptions for RADTRAN input parameters. The results of this realistic case are compared to the results calculated in the YM EIS for transport of spent nuclear fuel from the Humboldt Bay and Maine Yankee sites. In addition, EPRI has provided an assessment of the effect of the realistic assumptions on the accident dose risk presented in YM EIS and summarized in Table 2-1.

6.1 Description of Changes to RADTRAN Input Parameters

As discussed in Sections 4 and 5, a number of conservative assumptions were made in the selection of RADTRAN input parameters that were used by DOE to calculate accident dose risk in the YM EIS. These conservative assumptions include:

- Assuming a breathing rate of 3.30E-04 m^3/second, as recommended in the RADTRAN User Guide, rather than the value recommended by the NRC in Regulatory Guide 1.109, 2.5E-04 m^3/second.
- Assuming that no sheltering is provided by building ventilation for urban populations. Standard RADTRAN input parameters include recommendations for the urban dose risk parameters, BDF, UBF, USWF, and RPD. Use of these parameters results in some sheltering of urban populations residing in buildings.
- Assuming a maximum Co-60 concentration for calculating the Co-60 crud inventory for both PWR and BWR SNF.
- Assuming that all spent fuel casks that are shipped to the repository would have a cask dose rate at the regulatory limit of 14 mrem/hour at 1 meter. This is a factor in the calculation of that fraction of dose risk attributed to LOS accidents in which a cask is immobilized but no shielding is lost.
- Assuming a maximum perpendicular distance of 800 meters over which the LOS accident dose risk is calculated.
- Assuming that no shielding is provided by buildings in urban and suburban areas in the vicinity of LOS accidents.

- Assuming no evacuation or interdiction of the areas affected by the dispersal of radioactive materials following a transportation accident.
- Assuming a probability threshold of 1 x 10^{-7} for assessing credible maximum reasonably achievable accidents and consequences rather than a threshold of 1 x 10^{-6}.

In addition to the above conservative assumptions that have been evaluated in this report, there are also other RADTRAN model assumptions whose impact on transportation risk cannot be easily quantified. These include: use of “reference” fuel types within ten groups of waste types identified in the YM EIS using the most conservative assumptions for fuel characteristics within a group’s fuel types; assuming that population densities projected to 2035 will be representative of population densities in the decades prior to 2035; the use of release fractions based on standard transportation casks for transport of canistered SNF; the atmospheric dispersion models used to calculate unit risk factors in RADTRAN provide an idealized representation of topography and wind behavior and neglect factors such as surface roughness and shifting wind direction which would promote dilution of material; and the atmospheric dispersion model assumes ground level releases which will produce conservative downwind concentrations and ground deposition.

Section 5 examined the effect of changing RADTRAN input parameters, one at a time, and the resulting impact on the calculation of transportation accident risk. These results were compared to the doses calculated in the YM EIS for shipment of SNF via rail from two sites – Maine Yankee and Humboldt Bay. It was shown that changes to the above conservative parameters would result in lowering the transportation accident risk by varying degrees. In order to understand how a combination of more realistic assumptions would affect the assessment of transportation accident dose risk, a “realistic” scenario has been developed by EPRI that combined changes to several RADTRAN input parameters in one scenario, as discussed below.

In the calculation of inhalation dose risk, the YM EIS assumed a breathing rate that is higher than the breathing rate recommended by the NRC in Regulatory Guide 1.109 although the rate used is the standard rate recommended in RADTRAN. EPRI assumed the breathing rate recommended by NRC in its guidance documents, 2.5E-04 m3/second.

As discussed earlier, the standard RADTRAN input parameters associated with the calculation of urban dose risk assume that some sheltering is provided to that fraction of urban populations who reside in buildings at the time of an accident. These RADTRAN parameters include: BDF, Building Dose Factor; UBF, Urban Building Fraction; USWF, fractions of persons out of doors; and RPD, ratio of pedestrian density. The YM EIS assumed that no sheltering is provided by urban building ventilation. EPRI utilized the standard RADTRAN parameters for these values in order to determine the effect on urban unit risk factors. EPRI assumed a BDF equal to 0.05, UBF equal to 0.9, USWF equal to 0.1, and a RPD equal to 6.

EPRI considers the selection of the “representative” SNF characteristics to be somewhat conservative as not all spent fuel transport casks will be loaded with fuel with the characteristics (burnup, enrichment and cooling time) used in the calculation of accident risk. However, EPRI considers the representative PWR and BWR SNF characteristics used in the YM EIS to calculate transportation accident dose risk to be reasonable assumptions, due to the fact that SNF will have a wide range of fuel burnup, enrichment and decay times when SNF is eventually shipped to the repository. While the SNF characteristics selected in the YM EIS are reasonable, EPRI considers the use of the maximum values for surface concentration of Co-60 crud and fuel assembly surface area to calculate Co-60 crud inventories to result in Co-60 crud inventories that are conservative.[74] EPRI calculated an average value for surface concentration of crud based on the values presented in the YM EIS and continued to use the maximum fuel assembly surface areas in order to establish a reasonable value for Co-60 crud inventories.

As more than 40% of fuel shipped is likely to have cooling times greater than 20 years over the range of possible shipping scenarios evaluated by the M&O contractor (e.g., hottest fuel first, coldest fuel first, etc), it is overly conservative to assume that all spent fuel casks that are shipped will have an external dose that is at the regulatory limit of 14 mrem/hour at 1 meter. Older fuel will have lower source terms and lower external cask doses. Evaluating the range of fuel ages that might be shipped under different fuel shipping scenarios, an average cask dose rate of approximately 10 mrem/hour at 1 meter (~71% of the regulatory limit of 14 mrem/hour at 1 meter) is a reasonable assumption considering the variability in possible fuel characteristics. The cask dose rate will depend upon not only the age of fuel being shipped but also the cask designs used to transport the fuel. The EPRI analysis presented here assumes that package dose rates will have an average external dose rate of 10 mrem/hour at 1 meter. This input parameter will only affect the LOS accident dose risk associated with LOS accidents in which a cask is immobilized but there is no degradation to package shielding. This same assumption was utilized by EPRI in its assessment of best estimate incident-free transportation impacts.[75]

The EPRI analysis assumed that the maximum radial distance over which the LOS dose risk is calculated is 500 meters instead of the 800 meter distance used in the YM EIS.

The LOS model used in the YM EIS assumed that no shielding was provided by buildings to residents in urban and suburban areas in the vicinity of a LOS accident. EPRI's LOS analysis utilized a suburban shielding factor of 0.87 and an urban shielding factor of 0.018. A rural shielding factor of 1.0 (no shielding) is assumed by EPRI, the same factor that is used by DOE in the YM EIS, even though this assumption is somewhat conservative as well. These values are consistent with the RADTRAN standard shielding factors for urban, suburban and rural buildings and are consistent with the shielding factors used by EPRI in its assessment of incident-free transportation risk.[76]

The YM EIS assumed no evacuation, no cleanup and no interdiction in order to assess the maximum consequences. In order to show the effect of including the standard RADTRAN parameters for these post-accident action levels, EPRI performed two separate analyses to calculate realistic transportation accident dose risk. The first analysis utilized the realistic parameters identified above but assumed no cleanup and no interdiction as was done in the YM EIS. The second also utilized the realistic parameters identified by EPRI but it assumed a cleanup level of 0.2 μCi/m2; an evacuation time of 24 hours; a threshold for interdiction of

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[74] YM EIS, Volume II, pp. A-16 to A-22.

[75] EPRI 2005, p. 6-2.

[76] Ibid.

contaminated land that is 40 times greater than the cleanup level; and sets the time that would be required to survey contaminated land to 10 days.

In addition, EPRI has reexamined the maximum reasonably foreseeable accidents using a threshold for determining the accidents that have the maximum consequences with accident frequencies of greater than 1 x 10-6 accidents per year.

6.2 Transportation Accident Risk – Reevaluated

In order to determine the overall effect of the changes in RADTRAN input parameters described above, EPRI examined the effect of changes to the identified input parameters on the transport of SNF via rail from two sites – Maine Yankee and Humboldt Bay, to the repository. As shown in Table 6-1, accident dose risk was calculated using the realistic parameters discussed in Section 6.1, assuming no interdiction or cleanup. The resulting dose risk is compared to the dose risk calculated in the YM EIS as shown in Table 6-1.

Table 6-1
Comparison of YM EIS Accident Dose Risk with Realistic Scenario, No Interdiction, for Transport of SNF from Maine Yankee and Humboldt Bay Sites to Yucca Mountain (Person-Rem).

Parameters	Maine Yankee – Mostly Rail		Humboldt Bay Mostly Rail	
	YM EIS	EPRI Realistic Scenario	YM EIS	EPRI Realistic Scenario
RADTRAN Input Parameter Assumptions				
Co-60 Inventory (Curies)	9	4.4	16	8
Number of Casks Shipped	55	55	6	6
Breathing Rate (m^3/second)	3.30E-04	2.5E-04	3.30E-04	2.5E-04
LOS Shielding	1.0	1.0 Rural 0.87 Suburban 0.018 Urban	1.0	1.0 Rural 0.87 Suburban 0.018 Urban
LOS Maximum Distance (kilometers)	800	500	800	500
LOS Cask External Dose Rate (mrem/hour @ 1 meter))	14	10	14	10
Accident Dose Risk (Person-Rem)				
Groundshine Risk	1.1E-02	8.3E-03	3.6E-04	2.2E-04
Cloudshine Risk	1.7E-05	1.4E-05	3.3E-07	2.5E-07
Inhalation Risk	8.8E-04	5.3E-04	1.4E-05	7.7E-06
Resuspension Risk	3.6E-03	2.2E-03	5.5E-05	3.0E-05
LOS Risk	1.0E-3	2.7E-4	2.7E-05	4.9E-6
Dose Risk	**1.7E-2**	**1.1E-2**	**4.6E-4**	**2.6E-4**

As discussed in Section 5, EPRI did not attempt to re-evaluate the portion of the YM EIS dose risk from the ingestion pathway. Using the transportation database that supported the YM EIS, EPRI was able to determine that the ingestion dose risk for the transport of spent fuel from the two nuclear power plants used as examples within Section 5 and 6, Humboldt Bay and Maine Yankee, represents between 2% and 8.5% of the total dose risk for transport of spent fuel from these plant sites. Ingestion dose risk for shipment of spent fuel from Humboldt Bay to the proposed repository was calculatd to be 0.000009 person rem – which is 2% of the total dose risk. Thus the total dose risk presented in Table 6-1 for Humboldt Bay, 0.00046 person-rem, would increase to approximately 0.00047 person-rem if ingestion dose risk were included in the total dose risk. The ingestion dose risk for shipment of SNF from Maine Yankee was calculated to be approximately .0015 person-rem, which is approximately 8.5% of the total dose risk for shipment of SNF from Maine Yankee. Thus, the total dose risk presented in Table 6-1 for Maine Yankee, 0.017 person-rem would increase to 0.018 person-rem if ingestion dose were included in the total dose risk. The reasons for the variations in ingestion dose risk are associated with the fact that ingestion dose is only calculated for rural populations and each state has a distinct set of food transfer factors that was used in the YM EIS. Given the relatively small contribution to overall dose from the ingestion pathways, EPRI determined that neglecting this pathway in this study will have an only minor impact on its conclusions.

Accident dose risk associated with transport of SNF from Maine Yankee via rail to the repository in the YM EIS was calculated to be 0.0170 person-rem (note that this value excludes inhalation dose risk). Using the realistic RADTRAN parameter assumptions identified above, the accident dose risk for transport of 55 rail casks from Maine Yankee was calculated to be 0.011 person-rem – 65% of the dose risk calculated in the YM EIS.

Examination of the effect that individual realistic parameters contributed to the reduction in dose risk shows that the greatest contributor is the reduction in LOS dose risk. Using realistic parameters associated with shielding, cask external dose rate and maximum distance over which LOS dose is calculated results in the LOS dose risk for Maine Yankee rail shipments being reduced to 0.00027 person-rem – 27% of the 0.001 person-rem calculated in the YM EIS. The reduction in LOS dose is attributed to the use of urban and suburban shielding factors and the use of a cask external dose rate of 10 mrem/hour at 1 meter for the LOS accident in which a cask is immobilized but no shielding is lost. Inhalation and resuspension dose risk are reduced to approximately 60% of the value calculated in the YM EIS. This is due primarily to a reduction in the breathing rate as well as the use of standard parameters for the calculation of urban dose risk (UBF, BDF, USWF, and RPD). Groundshine dose was reduced to approximately 75% of the dose calculated in the YM EIS for rail transport of SNF for Maine Yankee – use of the realistic parameters resulted in a groundshine dose risk of 0.0083 person-rem compared to 0.011 person-rem calculated in the YM EIS. The reduction in groundshine dose can be attributed to the use of standard parameters for the calculation of urban dose risk as well as the reduction of Co-60 crud inventory associated with using an average Co-60 surface concentration rather than the maximum Co-60 concentration used in the YM EIS. The reduction in cloudshine dose from 0.000017 person-rem to 0.000014 person-rem, 82% of the YM EIS dose, is attributed to the use of standard parameters for calculation of urban dose risk. The percentage reduction will be dependent upon the percentage of miles traveled along a given route through urban areas.

Accident dose risk associated with transport of SNF from Humboldt Bay via rail to the repository in the YM EIS was calculated to be 0.00046 person-rem (this value excludes inhalation dose risk). Using the realistic RADTRAN parameter assumptions identified above, the accident dose risk for transport of 6 rail casks from Humboldt Bay was calculated to be 0.00026 person-rem – 56% of the dose risk calculated in the YM EIS.

Examination of the effect that individual RADTRAN parameters contributed to the reduction in dose risk for rail transport of Humboldt Bay SNF shows that LOS dose risk provides the greatest reduction in overall risk. Using realistic parameters discussed above, the LOS dose risk for Humboldt Bay shipments is reduced to 0.0000049 person-rem – 17% of the 0.000027 person-rem calculated in the YM EIS. Inhalation and resuspension dose risk are reduced to approximately 55% of the value calculated in the YM EIS. This is due primarily to a reduction in the breathing rate as well as the use of standard parameters for the calculation of urban dose risk (UBF, BDF, USWF, and RPD). The percentage reduction is different from that calculated for shipments from Maine Yankee due to differences in the percentage of kilometers traveled through urban areas. Groundshine dose was reduced to approximately 61% of the dose calculated in the YM EIS for rail transport of SNF for Humboldt Bay - use of the realistic parameters resulted in a groundshine dose risk of 0.00022 person-rem compared to 0.00036 person-rem calculated in the YM EIS. The reduction in groundshine dose can be attributed to the use of standard parameters for the calculation of urban dose risk as well as the reduction of Co-60 crud inventory associated with using an average Co-60 surface concentration rather than the maximum Co-60 concentration used in the YM EIS. The reduction in cloudshine dose from 0.00000033 person-rem to 0.00000025 person-rem, 75% of the YM EIS dose, is attributed to the use of standard parameters for calculation of urban dose risk. The percentage reduction will be dependent upon the percentage of miles traveled along a given route through urban areas.

In order to determine the effect of interdiction on accident dose risk, EPRI utilized the same parameters utilized to calculate accident risk as summarized in Table 6-1, but also included the standard RADTRAN parameters for evacuation, cleanup and interdiction. The YM EIS assumed no evacuation, cleanup or interdiction, resulting in an overestimate of accident dose risk as shown in Table 6-2 for transport of SNF via rail from two sites – Maine Yankee and Humboldt Bay, to the repository. EPRI calculated transportation accident dose risk using the realistic parameters discussed in Section 6.1, this time assuming evacuation, interdiction and cleanup. The resulting dose risk is compared to the dose risk calculated in the YM EIS as shown in Table 6-2.

Accident dose risk associated with transport of SNF from Maine Yankee via rail to the repository in the YM EIS was calculated to be 0.0170 person-rem (note that this value excludes inhalation dose risk). Using the realistic RADTRAN parameter assumptions identified above and assuming the standard RADTRAN parameters for evacuation, cleanup and interdiction, the accident dose risk for transport of 55 rail casks from Maine Yankee was calculated to be 0.0055 person-rem – 32% [31%] of the dose risk calculated in the YM EIS. Comparing the EPRI Realistic Scenario results in Table 6-1 and Table 6-2, the assumption of evacuation, cleanup and interdiction resulted in the overall dose risk being reduced by an additional 0.011 person-rem. Thus, compared to the dose-risk calculated using EPRI's realistic RADTRAN assumptions, the dose-risk was further reduced by 50% when evacuation, cleanup and interdiction were assumed.

Table 6-2
Comparison of YM EIS Accident Dose Risk With Realistic Scenario, with Interdiction, for Transport of SNF From Maine Yankee and Humboldt Bay Sites to Yucca Mountain

Parameters	Maine Yankee – Mostly Rail		Humboldt Bay Mostly Rail	
	YM EIS	EPRI Realistic Scenario	YM EIS	EPRI Realistic Scenario
RADTRAN Input Parameter Assumptions				
Co-60 Inventory (Curies)	9	4.4	16	8
Number of Casks Shipped	55	55	6	6
Breathing Rate (m^3/second)	3.30E-04	2.5E-04	3.30E-04	2.5E-04
LOS Shielding	1.0	1.0 Rural 0.87 Suburban 0.018 Urban	1.0	1.0 Rural 0.87 Suburban 0.018 Urban
LOS Maximum Distance (kilometers)	800	500	800	500
LOS Cask External Dose Rate (mrem/hour @ 1 meter))	14	10	14	10
Accident Dose Risk (Person-Rem)				
Groundshine Risk	1.1E-02	4.2E-03	3.6E-04	1.2E-04
Cloudshine Risk	1.7E-05	1.4E-05	3.3E-07	2.5E-07
Inhalation Risk	8.8E-04	5.3E-04	1.4E-05	7.7E-06
Resuspension Risk	3.6E-03	4.4E-04	5.5E-05	6.2E-06
LOS Risk	1.02E-3	2.7E-4	2.7E-05	4.9E-6
Dose Risk	**1.7E-2**	**5.5E-3**	**4.6E-4**	**1.4E-4**

Accident dose risk associated with transport of SNF from Humboldt Bay via rail to the repository was calculated to be 0.00046 person-rem in the YM EIS (note that this value excludes inhalation dose risk). Using the realistic RADTRAN parameter assumptions identified above and assuming the standard RADTRAN parameters for evacuation, cleanup and interdiction, the accident dose risk for transport of 6 rail casks from Humboldt Bay was calculated to be 0.00014 person-rem – 30% of the dose risk calculated in the YM EIS. Comparing the EPRI Realistic Scenario results in Table 6-1 and Table 6-2, the assumption of evacuation, cleanup and interdiction resulted in the overall dose risk being reduced by an additional 0.00012 person-rem. Thus, compared to the dose-risk calculated using EPRI's realistic RADTRAN assumptions, the dose-risk was further reduced by 45% when evacuation, cleanup and interdiction were assumed.

6.3 Conclusions

Due to the complexity regarding the YM EIS transportation database and the large number of routes from more than 70 sites to the proposed repository that contribute to the overall accident dose risk calculated in the YM EIS, EPRI did not undertake a recalculation of the dose risk associated with all of the routes that made up the overall accident dose risk – 0.89 person-rem for the Mostly Rail scenario and 0.46 person-rem for the Mostly Truck scenario as summarized in Table 2-1. However, through the use of representative shipping campaigns for both PWR and BWR SNF via rail to Yucca Mountain, EPRI has demonstrated how individual conservative RADTRAN assumptions used in the YM EIS result in an overestimate of accident dose risk and put the risks associated with postulated transportation accidents associated with the transportation of SNF to a repository at Yucca Mountain into greater perspective for regulators, decision makers and the public.

In addition to examining the effect of changing a single parameter at a time on the assessment of transportation accident risks, EPRI examined a case that combines a number of more realistic assumptions for RADTRAN input parameters. As shown in Table 6-1, EPRI found that using more realistic assumptions to calculate accident dose results in a reduction of overall accident dose risk to values that are 55% to 65% of the dose-risk calculated in the YM EIS, assuming no evacuation, no cleanup and no interdiction. When EPRI utilized the standard RADTRAN parameters for evacuation, cleanup and interdiction, the overall accident dose risk was reduced even further to approximately 30% of the dose risk calculated in the YM EIS. EPRI would expect to calculate similar results for shipping campaigns from other nuclear power plant sites to the repository. Thus, the overall accident dose risk, summarized in Table 2-1, could be reduced from 0.89 person-rem in the YM EIS to 0.27 person-rem for the Mostly Rail scenario and from 0.46 person-rem in the YM EIS to 0.14 person-rem for the Mostly Truck scenario.

Using a maximum reasonably foreseeable accident threshold of 1 x 10^{-6}, the accident threshold typically required by the NRC, instead of the 1 x 10^{-7} used in the YM EIS, EPRI found the maximum reasonably foreseeable rail accident is an accident with a frequency of 1.69x 10^{-6}accidents per year with a total exposure of 16.3 person-rem, less than 1% of the population dose risk associated with the maximum reasonably achievable rail accident in the YM EIS. DOE's maximum credible rail accident had an expected frequency of 2.75 x 10^{-7} accidents per year with a population dose of 9,893 person-rem. Similarly, using a maximum reasonably foreseeable accident threshold of 1 x 10^{-6}accidents per year, the maximum reasonably foreseeable truck accident is one with a frequency of 2.5 x 10^{-6}accidents per year and a population dose of 225 person-rem, approximately 20% of the population dose risk associated with the maximum reasonably achievable truck accident in the YM EIS. The YM EIS' conservative threshold of 1 x 10^{-7} for credible accidents results in population dose risk that is 1,083 person-rem, which is 858 person-rem higher than the credible accident assessed against a credible accident threshold of 1 x 10^{-6} accidents per year.

EPRI recognizes that DOE has made a decision to implement transport, aging and disposal (TAD) canisters as part of the waste management system. Since the capacity of the TAD canisters (21 PWR assemblies and 44 BWR assemblies) is lower than the rail transport casks capacities assumed in the Mostly Rail scenario in the YM EIS (24/32 PWR assemblies and 52/68 BWR assemblies), EPRI would expect that the use of TAD canisters would result in an increase in the incident-free dose risk associated with the transport of SNF under the Mostly Rail scenario simply as a result of an increase in the number of shipments. If accident release fractions are modified to consider the effect of shipping SNF in welded canisters, EPRI would expect that accident dose risk for the Mostly Rail scenario may decrease. EPRI would expect that both the incident free and accident dose risk would remain small. EPRI would not expect any changes to the impacts calculated for the Mostly Truck scenario. EPRI would also not expect to change its conclusions regarding the identification of conservative RADTRAN input parameters, identified in this report, that were used by DOE to calculate accident dose risk in the YM EIS due to the introduction of TAD canisters for transport of SNF.

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