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

E.M. Supko
Energy Resources International, Inc.
1015 18th St., NW, Suite 650, Washington, DC 20036, USA

J.H. Kessler
Project Manager, HLW and Spent Fuel Management Program
Electric Power Research Institute
1300 West W.T. Harris Blvd., Charlotte NC 28262, USA

ABSTRACT

The Yucca Mountain Final Environmental Impact Statement (YMEIS) included an analysis of the radiological impacts associated with the transport of spent nuclear fuel (SNF) from multiple locations across the US to Yucca Mountain for both incident-free and accident conditions.[1] While the transportation risks calculated in the YMEIS were small, it is important to recognize the many conservatisms that were utilized to calculate these risks. This paper examines radiological impacts under accident conditions assuming more realistic assumptions than those used in the YMEIS. While it is important to use conservative assumptions in the evaluation of the environmental impacts, it is equally important that the public and decision makers understand the conservative nature of the results presented in the YMEIS. This paper will provide that perspective regarding the calculation of accident risk and will summarize the results of a more detailed EPRI report on this subject, "*Assessment of Accident Risk for Transport of Spent Nuclear Fuel to Yucca Mountain Using RADTRAN 5.5*."[2]

INTRODUCTION

This paper describes the results of an evaluation of the accident risk associated with the transport of SNF to Yucca Mountain using the RADTRAN 5.5 computer model developed by Sandia National Laboratories. The objectives of the EPRI report were: (1) to examine the RADTRAN input parameters used in the YM EIS in order to determine which parameters employ conservative assumptions that result in an over prediction of radiological accident transportation risks; (2) to recommend alternative assumptions for use in development of a more realistic approach to assessing accident risk; and (3) 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.[2]

IDENTIFICATION OF CONSERVATIVE ASSUMPTIONS USED TO CALCULATE TRANSPORTATION ACCIDENT RISK

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.[1, 3] 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 transportation accident 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.

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. Those parameters for which conservative values were utilized to calculate accident dose risk in the YMEIS were identified, including:

- 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 U.S. Nuclear Regulatory Commission (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 loss-of-shielding (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 1×10^{-7} for assessing credible maximum reasonably achievable accidents and consequences rather than a threshold of 1×10^{-6}.

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

As the calculated impacts associated with transportation accident risk presented in the YM EIS were 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. The version of the YM EIS transportation database that EPRI obtained was write-protected. [3] 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 calculated the dose risks associated with the shipment of SNF from a single site to the proposed repository using RADTRAN and benchmarked these results against the results calculated in the YM EIS using the YM EIS transportation database.[3] By using the specific state-by-state shipment miles, population densities, accident rates, number of shipments, and package contents as input to RADTRAN, 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 was able to determine the effect of these changes on accident dose for shipments from a specific site.

Breathing Rate

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. NRC Regulatory Guide 1.109 [4] and the RISKIND user guide recommend a rate of 2.5E-04 m^3/sec.[5] EPRI evaluated the use of this latter value to determine the effect on the inhalation dose risk factors. 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, resulting in inhalation and resuspension unit risk factors that are 76% of the values utilized in the YM EIS. Table I 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. The 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 reduces in the dose risk associated with inhalation and resuspension exposure pathways. For example, the inhalation risk for the Mostly Truck scenario is reduced from 5.98E-03 person-rem to 4.554E-03 person-rem as shown in Table I. Thus, the overall dose risk is reduced by 2% for the Mostly Truck scenario and by 5% for the Mostly Rail scenario.

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

	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**

Urban Dose Risk Parameters

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. 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. This is 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. The standard RADTRAN parameters for these values are: BDF equal to 0.05, UBF equal to 0.9, USWF equal to 0.1, and a RPD equal to 6. [6] This results in the population density used for calculation of urban accident dose risk 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 dose risk must be calculated from each point of origin to the proposed repository using 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 [3] used to calculate accident risks for every route, it was not possible for EPRI to change one parameter (such as urban unit risk factors) to recalculate the overall dose risk. Instead, EPRI has examined the shipment of SNF from Maine Yankee, located in the southeast corner of the State of Maine, and from Humboldt Bay, located in northern California, 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 these sites.

Using the same RADTRAN parameters assumed in the YM EIS, EPRI calculated an accident dose risk of 0.015 person-rem using RADTRAN 5.5 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 II, 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. This results in a 20% reduction in overall dose risk from 0.015 person-rem to 0.012 person-rem for Maine Yankee SNF transport. A similar calculation of accident dose risk for transport of six (6) rail casks from Humboldt Bay to Yucca Mountain results in a dose risk of 0.00043 person-rem using the YM EIS input parameters as shown in Table II. This 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, UBF, USWF and RPD, resulting in the dose risk associated with urban populations being reduced from 0.00028 person-rem to 0.00018 person-rem, approximately 64% of the dose risk calculated in the YM EIS. This results in a 25% reduction in overall dose risk from 0.00043 person-rem to 0.00032 person-rem for Humboldt Bay SNF transport.

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

Route Segment	Shipment of SNF From Maine Yankee		Shipment of SNF From Humboldt Bay	
	YM EIS – Mostly Rail	Standard Urban Dose Risk Parameters	YM EIS – Mostly Rail	Standard Urban Dose Risk Parameters
	BDF = 1.0, UBF = 1.0 USWF = 0.0, RPD = 6	BDF = 0.05, UBF = 0.9 USWF = 0.1, RPD = 6	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	2.0E-05	2.0E-05
Suburban	6.6E-03	6.6E-03	1.2E-04	1.2E-04
Urban	8.1E-03	5.2E-3	2.8E-04	1.8E-04
Total Dose Risk	**1.5E-02**	**1.2E-02**	**4.3E-04**	**3.2E-04**

Effect of Crud Inventory on Accident Dose Risk

The YM EIS relied upon the methodology outlined in NUREG/CR-6672 [7] to determine the radionuclide inventory of activated corrosion products on SNF surfaces, referred to as “crud.” 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 YM EIS used the maximum values for surface concentration of crud and fuel assembly surface area, resulting in Co-60 crud inventories that are conservatively high. [1]

Using the lower bounding crud surface concentration identified in the YM EIS for PWR SNF, 2 µCi/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 µCi/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 µCi/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 µCi/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.

Assuming 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 III, the dose risk associated with using the lower bounding value for Co-60 surface concentration 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 dose risk associated with using the medium value for Co-60 surface concentration 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. 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.

Using the “low” and “medium” values for Co-60 inventories for BWR SNF identified above, 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 III, the dose risk associated with using the lower bounding value for Co-60 surface concentration 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 dose risk associated with using the medium value for Co-60 surface concentration 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. 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.

Table III
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)

	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**

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. [3] 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 IV, 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. Similarly, the reduction in cask external dose rate to 7 mrem per hour results in a LOS unit risk factor for LOS Severity Category 1 of 1.93E-5 person-rem, a 50% reduction. LOS unit risk factors for other Severity Categories remain unchanged.

EPRI also calculated the effect of the change in the LOS Category 1 unit risk factor on the overall accident dose risk associated with the rail shipment of six SNF casks from Humboldt Bay to the proposed repository. As shown in Table IV, 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 as discussed above. 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 there is no loss of shielding.

Table IV
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**

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. [1, 3] 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. [8] 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 V, 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.

Table V
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**

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.

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 urban, suburban and rural building shielding fractions discussed earlier. 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 earlier – that is, a suburban shielding fraction of 0.87 and an urban shielding fraction of 0.018 and a rural shielding fraction of 1.0.

As shown in Table VI, 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.

Table VI
The Effect of Changes to LOS Shielding Fractions on LOS Unit Risk Factors

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

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 VI. 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. 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 1.0. This 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.

Post Accident Parameter Options

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. EPRI examined the post-accident action level parameters for cleanup level, evacuation time, interdiction and evacuation using the standard RADTRAN values to determine how changes to these parameters might change the resulting calculation of accident dose risk.

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 $\mu Ci/m^2$ based on EPA guidelines. [9] 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. [9] The YM EIS assumes no evacuation occurred. [3] 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. [9]

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 proposed repository utilizing the standard RADTRAN parameters for CULVL, EVACUATION, INTERDICT, and CULVL. As shown in Table VII, 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, 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 – 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.

Table VII
Effect of Changes to Post Accident Parameters on Accident Risk Associated with Transport of SNF from Maine Yankee and Humboldt Bay (Person-Rem)

	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.

IDENTIFICATION OF REALISTIC RADTRAN PARAMETERS

EPRI 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 m^3/second. [4]

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. 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 considered 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 considered 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. EPRI calculated an average value for surface concentration of crud based on the values presented in the YM EIS in order to establish a reasonable value for Co-60 crud inventories.

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. It is likely that more than 40% of fuel shipped will have cooling times greater than 20 years over the range of possible shipping scenarios evaluated by the the Department of Energy’s (DOE) management and operating contractor (e.g., hottest fuel first, coldest fuel first, etc).[10] 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.[8] EPRI’s analysis assumed 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 regarding cask external dose rate was also utilized by EPRI in its assessment of realistic incident-free transportation impacts. [8]

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. A similar assumption was used by EPRI in its calculation of off-link dose in its reassessment of incident-free transportation risk. [8]

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, an urban shielding factor of 0.018, and a rural shielding factor of 1.0, even though this assumption is somewhat conservative. 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. [8]

The YM EIS assumed no evacuation, no cleanup and no interdiction in order to assess the maximum consequences of a transportation accident. 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 $\mu Ci/m^2$; an evacuation time of 24 hours; a threshold for interdiction of 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, consistent with recommended RADTRAN parameters. [9]

SUMMARY OF RESULTS

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 VIII, accident dose risk was calculated using the realistic parameters discussed above, assuming no interdiction or cleanup and the results are compared to the dose risk calculated in the YM EIS.

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 accounting for groundshine, cloudshine, inhalation, resuspension and LOS 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. 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 accounting for groundshine, cloudshine, inhalation, resuspension and LOS 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. 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. 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 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 and is dependent upon the percentage of miles traveled through urban areas.

Table VIII
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)

	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**

In order to determine the effect of interdiction on accident dose risk, EPRI calculated transportation accident dose risk using the realistic parameters discussed above, this time assuming evacuation, interdiction and cleanup as shown in Table IX. 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 accounting for groundshine, cloudshine, inhalation, resuspension and LOS 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. Thus, compared to the dose-risk calculated using EPRI's realistic RADTRAN assumptions shown in Table VIII, the dose-risk was further reduced by 50% when evacuation, cleanup and interdiction were assumed.

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 accounting for groundshine, cloudshine, inhalation, resuspension and LOS 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 VIII and Table IX, 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.

Table IX
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.

	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**

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. 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.

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 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.

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