Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

ASSESSMENT OF ACCIDENT RISK FOR TRANSPORT OF SPENT NUCLEAR FUEL TO YUCCA MOUNTAIN USING RADTRAN 5.5

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ABSTRACT

The Yucca Mountain Final Environmental Impact Statement (YMEIS) included an analysis of the radiological impacts associated with the transport of spent nuclear fuel for transport under both incident-free and accident conditions.[1] Using RADTRAN 5.5, 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] EPRI 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 determined 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 Yucca Mountain 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.

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

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 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 and Maine Yankee sites to the 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. RADTRAN parameters examined by EPRI included:

- breathing rate and its effect on inhalation and resuspension dose risk;
- urban dose risk parameters and the effect on calculated urban dose;
- SNF characteristics such as burnup, regional loading of SNF with different burnup and age characteristics, and Co-60 concentration in "crud" and the effect on accident dose risk;
- loss-of-shielding (LOS) accident assumptions including cask external dose rate, accident recovery time, distance over which dose risk is calculated, and use of shielding fractions and the effect of these assumptions on LOS dose risk; and
- post accident cleanup and interdiction assumptions on the effect on accident dose risk. [5]

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 the Maine Yankee and Humboldt Bay sites. 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. [1],[6]

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

Department of Energy's (DOE) management and operating contractor (e.g., hottest fuel first, coldest fuel first, etc).[9] 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.[7] 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. [7]

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. [7]

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. [7]

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. [8]

SUMMARY OF RESULTS

EPRI examined the effect of changes to the identified input parameters on the transport of SNF via rail from two nuclear power plant sites – Maine Yankee and Humboldt Bay – to the repository. As shown in Table 1, 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 EPRI's 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 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)

	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 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 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 1, 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 1 and Table 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.

Table 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.

	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

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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