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SPENT FUEL TRANSPORTATION RISK ASSESSMENT: CONCLUSIONS

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ABSTRACT

The NRC has recently completed an updated Spent Fuel Transportation Risk Assessment, NUREG-2125. The study reached the following findings:

- The collective dose risks from routine transportation are vanishingly small. These doses are about four to five orders of magnitude less than collective background radiation doses.
- The routes selected for this study adequately represent the routes for spent nuclear fuel transport, and there was relatively little variation in the risks per kilometer over these routes.
- Radioactive material would not be released in an accident if the fuel is contained in an inner welded canister inside the cask.
- Only rail casks without inner welded canisters would release radioactive material, and only then in exceptionally severe accidents.
- If there were an accident during a spent fuel shipment, there is less than one in a billion chance the accident would result in a release of radioactive material.
- If there were a release of radioactive material in a spent fuel shipment accident, the dose to the maximally exposed individual would be less than 2 Sv (200 rem), and would not cause an acute fatality.
- The collective dose risks for the two types of extra-regulatory accidents (accidents involving a release of radioactive material and loss of lead shielding) are negligible compared to the risk from a no-release, no-loss-of-shielding accident.
- The risk of loss of shielding from a fire is negligible.
- None of the fire accidents investigated in this study resulted in a release of radioactive material.

Based on these findings, this study reconfirms that radiological impacts from spent fuel transportation conducted in compliance with NRC regulations are low. In fact, this study's

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radiological impact estimates are generally less than the already low estimates reported in earlier studies. Accordingly, with respect to spent fuel transportation, this study reconfirms the previous NRC conclusion that the regulations for transportation of radioactive material are adequate to protect the public against unreasonable risk.

INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) first assessed the health and safety impacts of spent fuel transportation in NUREG 0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," published in 1977[1]. Based on NUREG-0170, the Commissioners concluded that the regulations in force at the time of the environmental impact statement were "adequate to protect the public against unreasonable risk from the transport of radioactive materials[2]". NUREG-2125[3] (the present study) presents the most recent NRC assessment of the risks of transporting commercial spent nuclear fuel (SNF). Both NUREG-0170 and NUREG-2125 estimate the radiological impact for spent fuel transport conducted in compliance with 10 CFR Part 71 regulations. Other NRC studies, including the Modal Study[4] and NUREG/CR-6672[5], also provided spent fuel shipment risk assessments.

Regulations and regulatory compliance analyses are different from risk assessments. A regulation must be conservative because its purpose is to ensure safety, and 10 CFR Part 71, which regulates transportation, requires a conservative estimate (i.e., overestimate) of the damage to a cask in an accident and the radiation emitted from the cask during routine transportation. The original environmental assessment for 10 CFR Part 71, NUREG 0170, was also conservative, but for a different reason: only limited data were available to perform the assessment. Therefore, NUREG-0170 deliberately used conservative parameter estimates. The NRC's conclusion was that NUREG-0170 showed that even with conservative assumptions transportation of radioactive materials provide adequate public safety.

When an assessment is used to inform regulation, it should be as realistic as possible to provide information necessary to confirm or revise the regulations it informs. Realistic assessment depends on data availability and accurate and precise modeling techniques, which have become increasingly available since 1977. Consequently, the Modal Study and NUREG/CR 6672 made progress in assessing transportation risks more realistically. As a result, both the calculated consequences and risks of radioactive materials transportation decreased. The decrease in risk means that the regulations provide for a greater level of safety than previously recognized.

NUREG-2125 is more accurate than previous analyses. Certified spent fuel casks were analyzed, rather than generic designs. Recent (2005 or later) accident frequency and population data were used in the analyses and the modeling techniques also were upgraded. The Spent Fuel Transportation Risk Assessment is another step toward building a complete picture of SNF transportation radiological safety. It also presents the current state of art for such analyses. The results of NUREG-2125 are compared with preceding risk assessments in the figures that follow.

ROUTINE TRANSPORTATION

Figures 1 and 2 show results of routine truck and rail transportation of a single shipment of SNF using the single example route from NUREG-0170, the average of the 200 routes from NUREG/CR-6672, and the average of the 16 truck or rail routes from the present study.

Figure 1 plots average collective radiation dose (person-Sv) from truck transportation, and Figure 2 plots average collective radiation dose from rail transportation. These average doses include doses to the population along the route, doses to occupants of vehicles sharing the route, doses at stops, and doses to vehicle crew and other workers. Doses without the crew and worker dose (labeled public only) are also shown.

Collective doses from routine transportation directly depend on the population along the route and the number of other vehicles that share the route, and, inversely, on vehicle speed. Doses to occupants of vehicles that share the route depend inversely on the square of the vehicle speed.

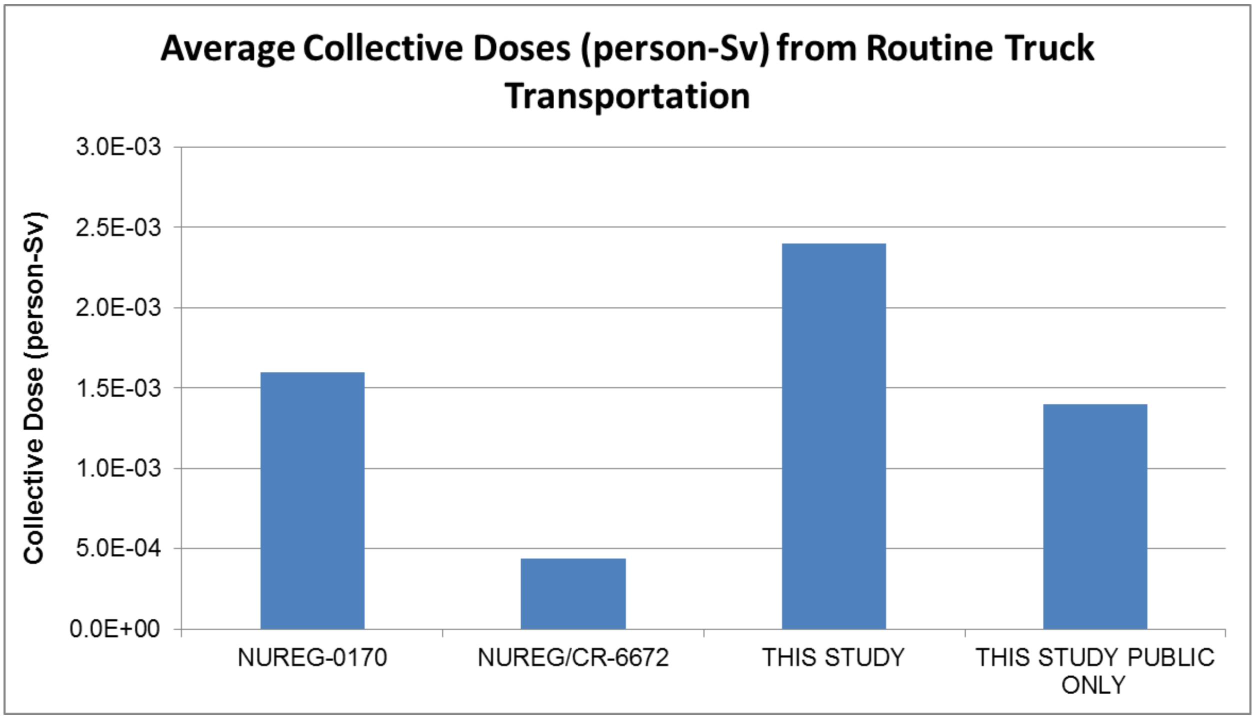

Figure 1. Collective doses (person-Sv) from routine truck transportation

NUREG-0170 results for truck transportation were based on a single long route; constant values of rural, suburban, and urban population densities; different and conservative vehicle speeds on rural, urban, and suburban roads; a fixed rate of vehicle stops; and 1975 estimates of vehicle density (vehicles per hour), all of which led to conservative results. NUREG/CR 6672 used more realistic distributed route lengths, population densities, vehicle occupancy and density, vehicle dose rate and stop time, and the means of the distributions as parameters.

Figure 1 shows that the conservatism was decreased by more than a factor of three.

The collective average dose in the present study is larger than the NUREG/CR 6672 result because present populations are generally larger, particularly along rural routes, and vehicle densities are much greater. The higher vehicle speeds used in the present study offset these increases. The largest contributor to higher doses in this study is the parameters used for stops. In this study, stops were assumed to occur every 845 kilometers versus 1,290 kilometers and last for 50 minutes versus 30 minutes. The combination of these two factors results in a 2.5 times increase in the stop dose. This is especially significant because the greatest contributor to the public collective dose is from people sharing truck stops with the cask (56 percent of the collective dose). The second largest contributor is from people sharing the highway with the cask (38 percent of the collective dose). Residents along the route only receive 6 percent of the collective dose and residents near truck stops only receive 1 percent.

Figure 2 shows the differences between NUREG 0170, NUREG/CR-6672, and the present study for calculating average doses to the public for routine rail transportation.

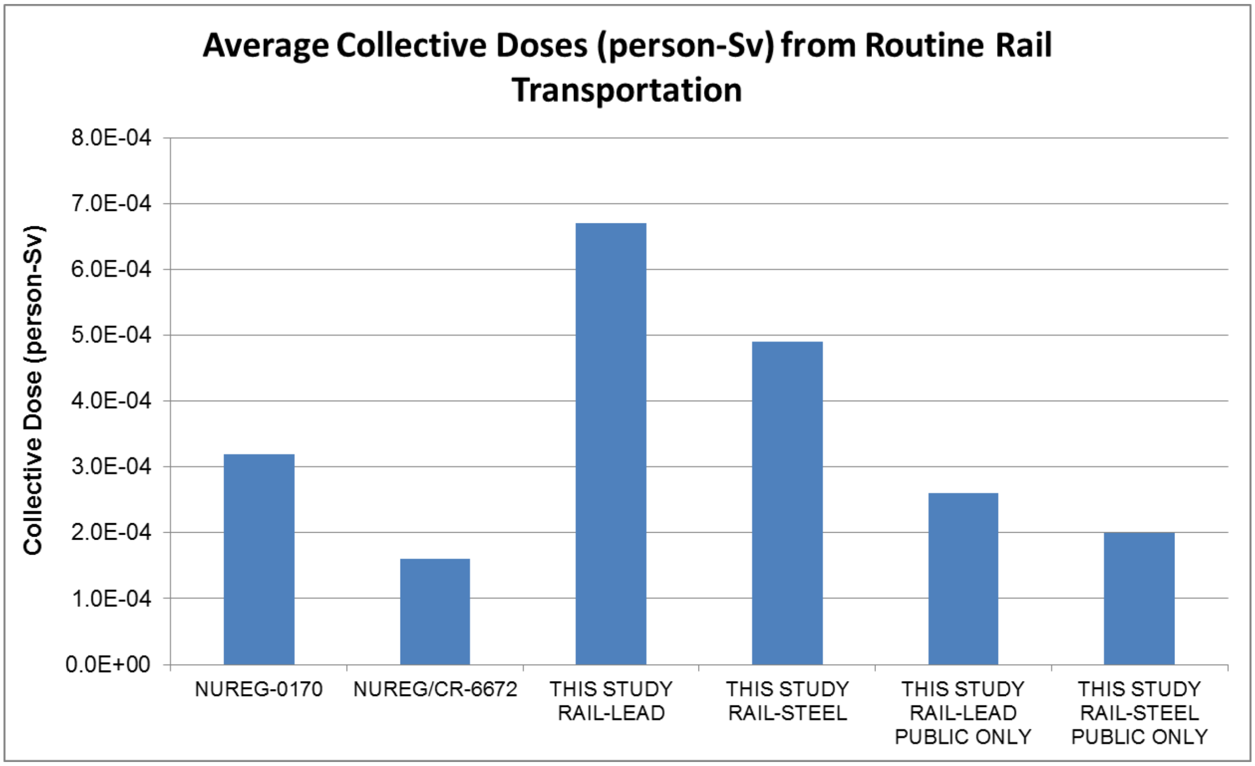

Figure 2. Collective doses (person-Sv) from routine rail transportation

The difference in dose between the Rail-Lead cask and the Rail-Steel cask occurs because the latter cask has a smaller external dose rate (Chapter 2). The differences in crew doses between the studies reflect the considerable difference between the methods the different studies used.

Differences in the collective doses from routine transportation between the cited studies are not the result of differences in external radiation from the spent fuel casks. The 1975 version of 10 CFR Part 71 specified the same limit on external radiation (the TI) as Part 71 specifies today. Instead, these differences reflect improvements to modeling methods and the increase in population and traffic levels. Also the groups of people exposed that various studies considered has changed. For example, this study includes inspector doses not included in the other two studies. The differences in results are primarily due to vehicle speed, population and vehicle densities, and differences in calculating train crew and railyard worker doses.

Dose to the MEI is a better indication than collective dose of the radiological effect of routine transportation. The same event results in different collective doses depending on the population affected, which varies by location and the consideration of rush hour. The MEI dose is shown in Figure 3 for NUREG-0170 and for the three cask types of this study. NUREG/CR-6672 did not calculate this dose for routine transportation. The reduction is because of the higher speeds this study used.

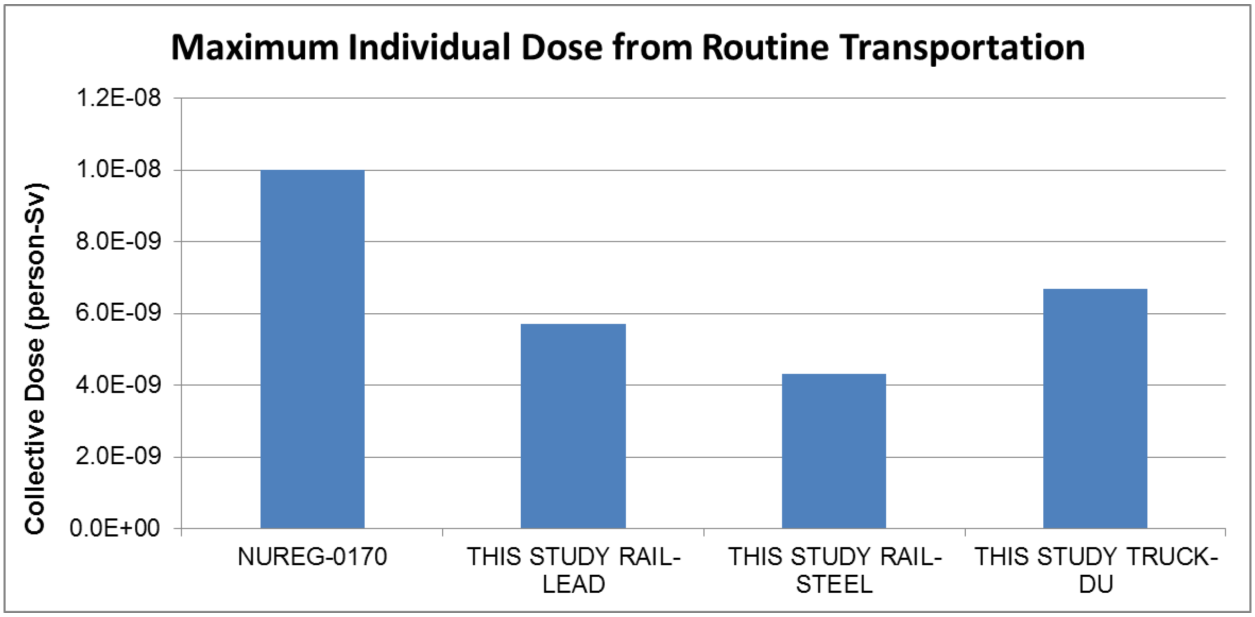

Figure 3. Maximum individual dose (Sv) from routine transportation

TRANSPORTATION ACCIDENTS

Radiological accident risk is expressed in units of "dose risk" that include the probability of an accident and the conditional probability of certain types of accidents. Dose units (Sv) are used because probability is a unitless number. The dose risk to a population (as distinct from the dose risk to an individual) is collective dose risk, which has units of person-Sv. NUREG-0170, NUREG/CR-6672, and this study all used the RADTRAN version available at the time of the study to calculate dose risk, but the input parameters differed significantly. These parameters were based primarily on the detail and precision of the assessment of package performance, modeling improvements, and the availability of accident and population data. In addition, improvements in RADTRAN and other modeling codes described in earlier chapters resulted in a more accurate analysis of cask behavior in an accident.

The results shown in Figure 4 and Figure 5 for this study are averages over the 16 rail routes studied. A lead-shielded rail cask, the Rail-Lead cask in this study, is the only cask type of the three studied that indicated either release of radioactive material or loss of lead gamma shielding in an accident.

The results in Figure 4 reflect the different amounts of radioactive material released and the different amounts of lead shielding lost as estimated in the respective studies. NUREG-0170 used a scheme of 8 different accident scenarios; 4 postulated release of the entire releasable contents of the cask, 2 postulated no release, 1 postulated a 10 percent release, and 1 postulated a 1 percent release. The range of conditional probabilities ranged from 1×10^{-5} for the most severe

(100 percent release) accident to 80 percent for the 2 no-release scenarios. The NUREG 0170 "universe" of accidents and their consequences was primarily based on engineering judgment, which was clearly conservative.

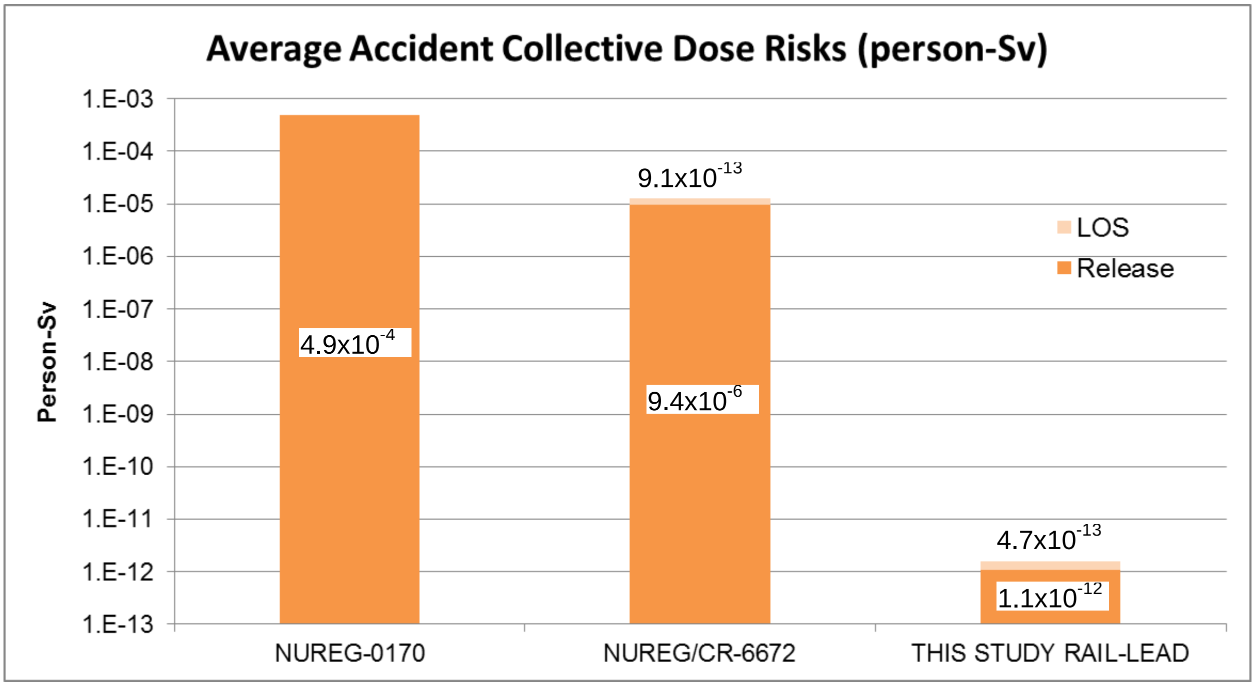

Figure 4. Accident collective dose risks from release and loss-of-shielding accidents. The loss-of-shielding bar for NUREG/CR-6672 is not to scale.

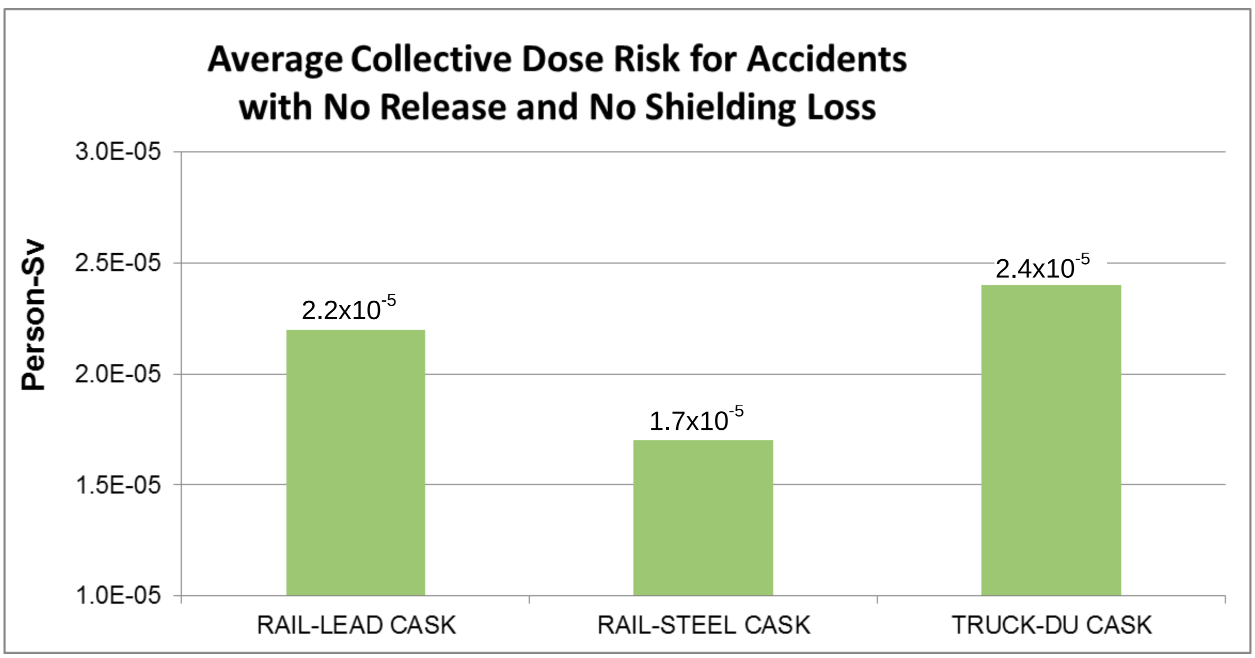

Figure 5. Average collective dose risk from accidents that have no impact on the cargo

NUREG/CR-6672 analyzed the structural and thermal behavior of four generic cask designs—two truck and two rail casks—in great detail, and analyzed the behavior of the five groups that best describe the physical and chemical nature of the radioactive materials potentially released from SNF through the casks. These five groups are particulate matter, semi volatile substances, ruthenium, gas, and CRUD. The spent fuels considered were high burnup and low burnup PWR and BWR fuel. That analysis resulted in 19 truck accident scenarios and 21 rail accident scenarios, each with an attendant possibility, including a no-release scenario, which had better than 99.99 percent probability.

The present study followed the analytical outline of the NUREG/CR 6672 analysis, but analyzed the structural and thermal behavior of a certified lead-shielded cask design loaded with the fuel that the cask is certified to transport. Instead of the 19 truck scenarios and 21 rail scenarios that included potential releases of radioactive material, the current study resulted in only 7 rail scenarios that included releases. The seals are the only parts of the cask structure that could be damaged enough to allow a release. Release could take place through the seals only if the seals fail and if the cask is carrying uncanistered fuel. No potential truck accident scenario resulted in seal failure, nor did any fire scenario. In the present study, only the Rail-Lead cask response to extremely severe accident conditions resulted in a release. A comparison of the collective dose risks from potential releases in this study to both NUREG-0170 and NUREG/CR-6672 is appropriate, since the latter two studies considered only potential releases. The collective dose risks decrease with each succeeding study as expected, since the overall conditional probability of release and the quantity of material potentially released decreases with each successive study. The decrease in release is primarily because of the replacement of conservative estimates of cask performance in an accident with FE analyses of cask performance in an accident. Basically, in succeeding studies, the calculated performance of the cask is better (it releases less) than estimated previously.

The collective dose risk from a release depends on dispersion of the released material, which either remains suspended in the air, producing cloudshine, or is deposited on the ground, producing groundshine, or is inhaled. All three studies used the same basic Gaussian dispersion RADTRAN model, although the RADTRAN 6 model is much more flexible than the previous versions and can model elevated releases. NUREG-0170 only calculated doses from inhaled and resuspended material. NUREG/CR-6672 included groundshine and cloudshine as well as inhaled material, but overestimated the dose from inhaled resuspended material. The combination of improved assessment of cask damage and dispersion modeling has resulted in the decrease in collective dose risk from releases shown in Figure 4.

Frequently, public interest in the transportation of SNF focuses solely on the consequences of possible accidents without regard to the likelihood that an accident will occur. The maximum estimated consequence, based on average population density, from the accident with the largest release is 2.18 person-Sv (218 person-rem). This consequence is orders of magnitude less than the 110 person-Sv (11,000 person-rem) in NUREG 0170 and the 9,000 person-Sv (900,000 person-rem) estimated in NUREG/CR-6672 Figure 8.27. The reduction in consequence is the result of using the actual spent fuel being shipped, a smaller release fraction, and improvements in the RADTRAN model. The maximum estimated dose to any person from this accident is 1.6 Sv (160 rem), and would not cause an acute fatality.

NUREG-0170 did not consider a loss of spent fuel cask lead shielding, which can result in a significant dose increase from gamma radiation emitted by the cask contents. NUREG/CR 6672 analyzed 10 accident scenarios in which the lead gamma shield could be compromised and then calculated a fractional shield loss for each. An accident dose risk was calculated for each potential fractional shield loss.

The present study followed the same general calculation scheme, but with a more sophisticated model of gamma radiation from the cask due to the damaged shield and using 18 potential accident scenarios instead of 10. Most of the difference between the NUREG/CR-6672 dose risks from shielding loss and this study is the inclusion of accident scenarios that have a higher conditional probability (i.e., accidents that are more likely to happen) than any scenarios in NUREG/CR-6672. The consequence of a loss of lead shielding estimated in NUREG/CR-6672 Table 8.13 is 41,200 person-Sv (4,120,000 person-rem), about 100 times the 690 person-Sv (6,900 person-rem) estimated in this study because of the more conservative loss of lead shielding model used in NUREG/CR-6672 and the overestimation of the amount of lead slump in that study. Loss of lead shielding clearly affects only casks with a lead gamma shield; casks using DU or thicker steel shielding would not be affected.

More than 99.999999 percent of potential accident scenarios do not affect the cask at all and would not result in a release of radioactive material or an increased dose from loss of lead shielding. However, these accidents would result in an increased external radiation dose from the cask to the population near the accident because the cask would remain at the accident location until it could be moved. A nominal 10 hour delay in moving the cask was assumed for this study. The resulting collective dose risk is shown in Figure 5 for all three cask types studied. Even including this additional consequence type, the accident collective dose risk from this study is less than that reported in either NUREG-0170 or NUREG/CR-6672.

For the most probable accident, one that does not involve either loss of shielding or release of radioactive material, the most significant consequence, in addition to any nonradiological consequence of the accident itself, is the external dose from a cask immobilized at the accident site.

Figure 5 shows the average collective dose risks from this type of accident for the 16 truck routes and 16 rail routes studied. The most significant parameters contributing to this dose risk are the accident frequency and the length of time that the cask sits at the accident location. Even in this case, the significant parameter in the radiological effect of the accident is not the amount or rate of radiation released, but the exposure time.

Each of the three transportation risk assessments conducted for the NRC show that the NRC regulation of transportation casks ensures safety and health. The use of data in place of engineering judgment shows that accidents severe enough to cause a loss of shielding or release of radioactive material are improbable and the consequences of such unlikely accidents would require mitigation, but would not result in large radiation doses to even the maximally exposed individual. Moreover, these consequences depend on the size of the population exposed rather than on the radiation or radioactive material released.

FINDINGS AND CONCLUSIONS

The following findings are reached from this study:

- The collective doses from routine transportation are very small. Theses doses are about four to five orders of magnitude less than collective background radiation doses.
- The routes selected for this study adequately represent the routes for SNF transport, and there was relatively little variation in the risks per kilometer over these routes.
- Radioactive material would not be released in an accident if the fuel is contained in an inner welded canister inside the cask.
- Only rail casks without inner welded canisters would release radioactive material and only then in exceptionally severe accidents.
- If there were an accident during a spent fuel shipment, there is only about a one in a billion chance that the accident would result in a release of radioactive material.
- If there were a release of radioactive material in a spent fuel shipment accident, the dose to the MEI would be less than 2 Sv (200 rem) and would not result in an acute lethality.
- The collective dose risks for the two types of extra-regulatory accidents (accidents involving a release of radioactive material and loss of lead shielding accidents) are negligible compared to the risk from a no-release, no-loss of shielding accident.
- The risk of loss of lead shielding from a fire is negligible.
- None of the fire accidents investigated in this study resulted in a release of radioactive material.

Based on these findings, this study reconfirms that radiological impacts from spent fuel transportation conducted in compliance with NRC regulations are low. They are, in fact, generally less than previous, already low, estimates. Accordingly, with respect to spent fuel transportation, this study reconfirms the previous NRC conclusion that regulations for transportation of radioactive material are adequate to protect the public against unreasonable risk.

REFRENCES

1> U.S. Nuclear Regulatory Commission, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," NUREG 0170, Washington, DC, 1977.

2> *Federal Register*, Vol. 46, p. 21629, April 13, 1981.

3> U.S. Nuclear Regulatory Commission, "Spent Fuel Transportation Risk Assessment: Draft Report for Comment," NUREG-2125, Washington, DC, 2012.

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