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# SPENT FUEL TRANSPORTATION RISK ASSESSMENT: OVERVIEW

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## ABSTRACT

The U. S. NRC is responsible for issuing regulations for the packaging of spent fuel (and other large quantities of radioactive material) for transport that provide for public health and safety during transport (Title 10 of the Code of Federal Regulations (10 CFR) Part 71, "Packaging and Transportation of Radioactive Waste," dated January 26, 2004). In September 1977, the NRC published NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," which assessed the adequacy of those regulations to provide safety assurance. In that assessment, the measure of safety was the risk of radiation doses to the public under routine and accident transport conditions, and the risk was found to be acceptable. Since that time there have been two affirmations of this conclusion for spent nuclear fuel (SNF) transportation, each using improved tools and information that supported the earlier studies. This report presents the results of a fourth investigation into the safety of SNF transportation. The risks associated with SNF transportation come from the radiation that the spent fuel gives off, which is attenuated—but not eliminate—by the transportation casks shielding, and the possibility of the release of some quantity of radioactive material during a severe accident. This investigation shows that the risk from the radiation emitted from the casks is a small fraction of naturally occurring background radiation and the risk from accidental release of radioactive material is several orders of magnitude less. Because there have been only minor changes to the radioactive material transportation regulations between NUREG-0170 and this risk assessment, the calculated dose due to the external radiation from the cask under routine transport conditions is similar to what was found in earlier studies. The improved analysis tools and techniques, improved data availability, and a reduction in the number of conservative assumptions has made the estimate of accident risk from the release of radioactive material in this study approximately five orders of magnitude less than what was estimated in NUREG-0170. The results demonstrate that NRC regulations continue to provide adequate protection of public health and safety during the transportation of SNF.

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## INTRODUCTION

Nuclear fission in power reactors produces a large amount of energy, which has been harnessed for the production of electricity. Fission also creates radioactive products that are contained in fuel rod pins in nuclear fuel assemblies. Therefore, spent nuclear fuel is very radioactive when first removed from a reactor, but it decays and becomes less radioactive over time. Because of this radioactivity, people have some concerns when spent fuel is moved in trucks and by rail over public roads and railroads.

Thirty-five years ago, the U.S. Nuclear Regulatory Commission (NRC) responded to these concerns by estimating the radiological impact of transporting radioactive materials, including spent fuel. This analysis resulted in NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," issued in 1977[1]. NUREG 0170 provided an environmental impact statement (EIS) for transportation of all types of radioactive material by road, rail, air, and water, and concluded the following:

- The average radiation dose to members of the public from routine transportation of radioactive materials is a fraction of their background dose.

- The radiological risk from accidents in transporting radioactive materials is very small compared to the non-radiological risk from accidents involving large trucks or freight trains.

On the basis of this EIS, NRC regulations in 1981 were considered "adequate to protect the public against unreasonable risk from the transport of radioactive materials[2]." However, the adequacy of these regulations continued to be questioned in part because the EIS was based on estimates of radiation dose and accident rates, for which not much data or information had been available. Among the questions not fully resolved: What constitutes "reasonable" risk and what are actual consequences should an accident happen?

This paper summarizes the work done for NUREG-2125[3], which used advanced models, risk assessment methods, and updated data to provide a current assessment of the risks and consequences of transporting spent nuclear fuel.

## HISTORY

All commodities that are transported by truck or rail can be involved in accidents. Trucks and railcars carrying spent nuclear fuel transportation casks are no exception. The NRC recognizes this, and it requires that spent fuel casks be designed and built to withstand severe transportation accidents. NUREG 0170 and later studies of casks have considered accident conditions more severe than those the regulations require the cask to demonstrate their ability to withstand. A 1987 study applied actual accident statistics to projected spent fuel transportation[4]. This study, known as the "Modal Study," also recognized that accidents could be described in terms of the strains they produced in the cask (for impacts) and the increase in cask temperature (for fires). Like NUREG 0170, the 1987 study based risk estimates on models because the limited number of accidents that had occurred involving spent fuel shipments was not sufficient to support projections or predictions. The Modal Study's refinement of modeling techniques and use of accident frequency data resulted in smaller assessed risks than had been projected by NUREG 0170.

A 2000 study of two generic truck casks and two generic rail casks analyzed the cask structures and response to accidents by using computer modeling techniques[5]. The study used semitrailer truck and rail accident statistics for general freight shipments because, even though more than 1,000 spent fuel shipments had been completed in the United States by 2000 and many thousands more had been completed safely internationally, there had been too few accidents involving spent fuel shipments to provide statistically valid accident rates.

Through a series of risk assessments, the release of radioactive material from a cask in an accident—and its subsequent dispersion—has been modeled with increasing refinement. NUREG 0170 assumed that most very severe accidents would result in release of all of the fuel particles created by the accident to the environment (the cask did not serve as a barrier to release). Although this engineering judgment overstated the release, it was nevertheless used because analytical capabilities at the time did not permit a more accurate assessment. The 2000 study analyzed the physical properties of spent fuel rods in a severe accident and revised estimates of material released to 1 percent or less of the NUREG 0170 estimates. Accordingly, risk estimates were revised downward. The 2000 study also verified that an accidental release of radioactive material could only be through the seals at the end of the cask where the lid is attached. In other words, an accident could cause seal failure, but would not breach the cask body[5].

## CASK SELECTION

The present study models certified cask designs (rather than generic casks) and the commercial spent nuclear fuel that these casks are certified to transport. It evaluated two rail casks and a truck cask. The casks chosen for analysis were the HI-STAR 100 steel shielded rail cask, the NAC STC lead shielded rail cask, and the GA-4 depleted uranium shielded truck cask. The HI-STAR 100 transports 24 spent PWR fuel assemblies within an inner welded canister. The NAC STC transports either 24 spent PWR assemblies within an inner welded canister or 26 PWR assemblies directly loaded into a basket within the cask. The GA-4 cask transports 4 spent PWR assemblies directly loaded into the cask. Figure 1 shows these three casks.

## ROUTINE TRANSPORTATION

Almost all spent fuel casks are shipped without incident. However, even this routine, incident free transportation causes radiation exposures because all loaded spent fuel casks emit some external radiation. The radiation dose rates for spent fuel shipments are measured before each shipment and must be maintained within regulatory limits. The radiation dose from this external radiation to any member of the public during routine transportation, including stops, is barely discernible compared to the public's natural background radiation. Figure 2 illustrates a typical rail cask and the way in which the radiation to a member of the public is modeled. One hundred times the dose at 1 meter (3.3 feet) from the cask measured in milliSeiverts/hour (the dose measured in millirem/hour) is known as the Transport Index, which is used to represent the amount of radiation coming from the cask during routine transportation.

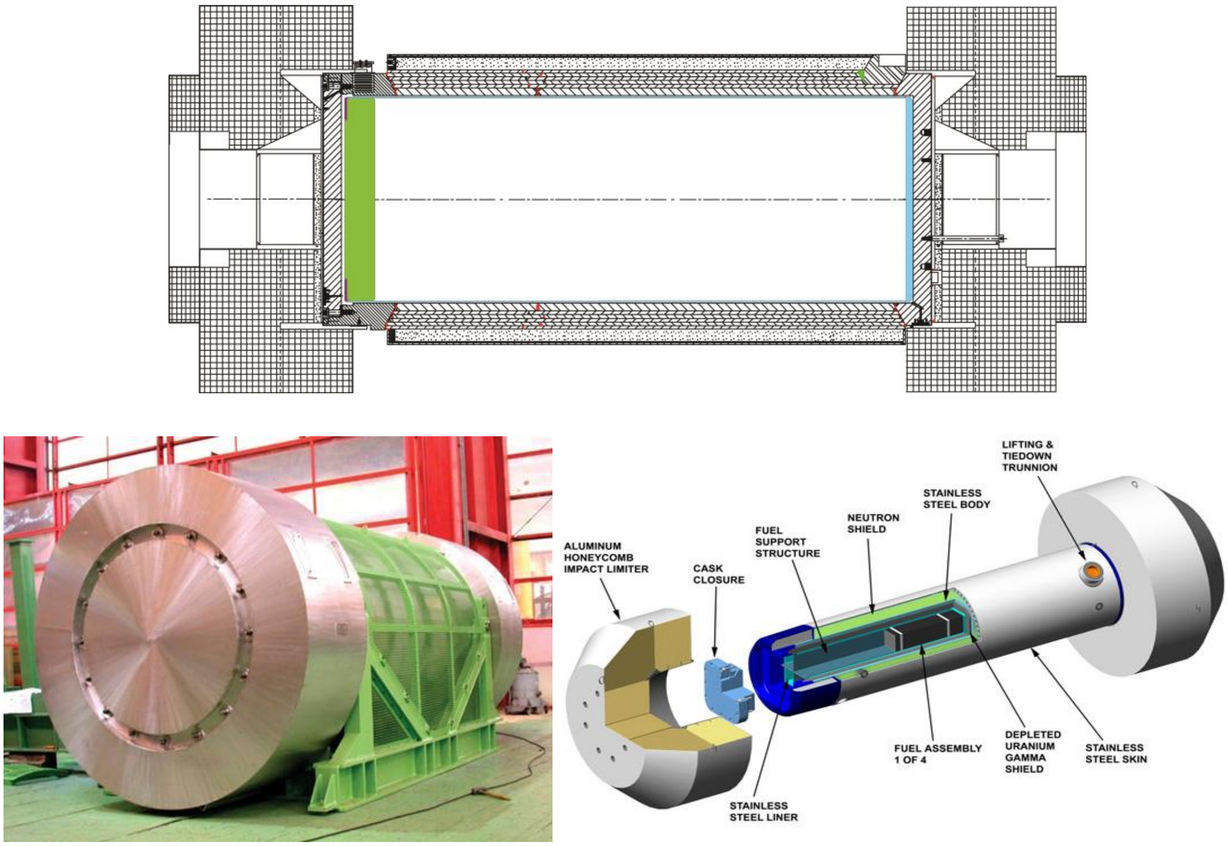



**Figure 1. The three casks modeled in this study**

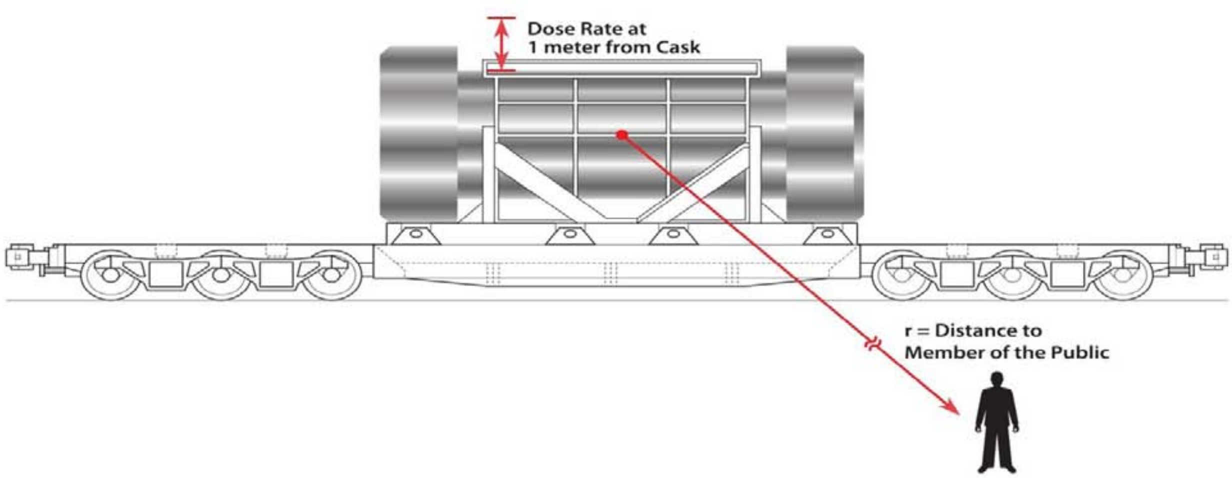



**Figure 2. Model of a spent fuel cask in routine, incident-free transportation and radiation dose to a member of the public. Relative sizes of the cask and member of the public are approximately to scale.**

The external radiation from the spent fuel cask results in a very small dose to each member of the public along the route traveled by the cask. The collective dose from routine transportation is the sum of all of these doses. This study examined several example transportation routes considered to be representative of possible cross country transport. No actual spent fuel transport has occurred, or is planned to occur, on the routes studied. Table 1 and Figure 3 show the possible total dose in person-sieverts (person-Sv) to all of the workers and members of the public who would be exposed to radiation along one of these routes—the truck shipment from the Maine Yankee Nuclear Power Plant to Oak Ridge National Laboratory. Table 1 and Figure 3 include the background radiation dose to exposed workers and members of the public during the time of the shipment.

**Table 1. Collective Dose from Routine Transport for the Truck Route from Maine Yankee Nuclear Power Plant to Oak Ridge National Laboratory (person-Sv) (1 Sv = 100,000 mrem)**

| Exposed Population | Rural | Suburban | Urban | Urban Rush Hour | Total |
|---|---|---|---|---|---|
| Residents near route | 0.0000050 | 0.000089 | 0.0000020 | 0.00000045 | 0.000096 |
| Traffic on the route | 0.00013 | 0.00024 | 0.000054 | 0.0000050 | 0.00046 |
| Residents near truck stops | 0.00000056 | 0.000012 | * | * | 0.000012 |
| Truck crew | 0.00059 | | 0.000076 | | 0.00067 |
| Escort | 0.000000047 | | 0.0000000043 | | 0.000000051 |
| Inspectors (10 inspections) | | | | | 0.0016 |
| People at truck stops | | | | | 0.00086 |
| Truck stop workers | | | | | 0.000013 |
| | Total dose from spent fuel shipment | | | | 0.0037 |
| Background | | | | | 7.56 |

* Most truck stops are located in rural or suburban areas.

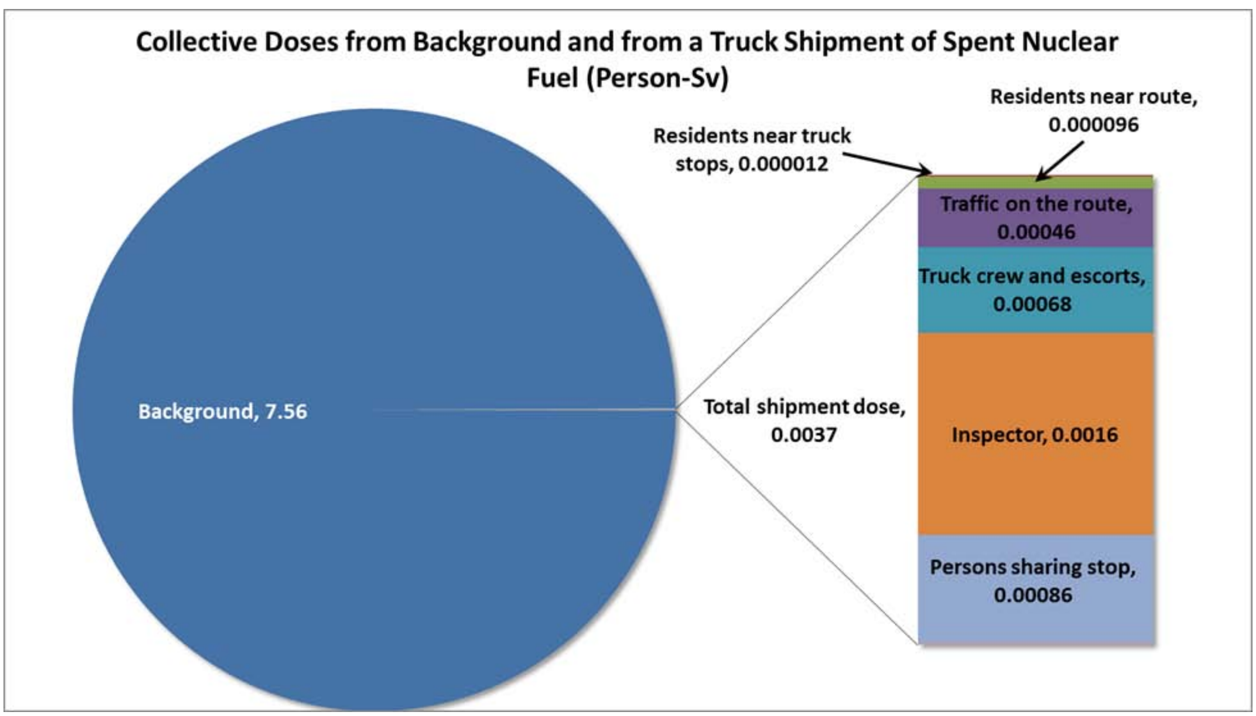



**Figure 3. Collective doses from background and from a truck shipment of spent nuclear fuel (person-Sv) (1 Sv = 100,000 mrem)**

The collective doses calculated for routine transportation are higher for this study than for either NUREG/CR 6672, "Re-examination of Spent Fuel Shipment Risk Elements[5]," or NUREG 0170[1], but still a very small fraction of background dose. Figure 4 compares the collective doses from truck transportation from the three studies. In NUREG 0170, the analysis was for a single route; in NUREG/CR-6672, the analysis was for 200 representative routes[5]; and in this study, the analysis is for 16 truck routes (as well as 16 rail routes). 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; the number of vehicles sharing the highways with the spent fuel transport is now much larger; and the number and length of refueling stops is much greater. These increases were somewhat offset by the greater vehicle speeds used in the present study.

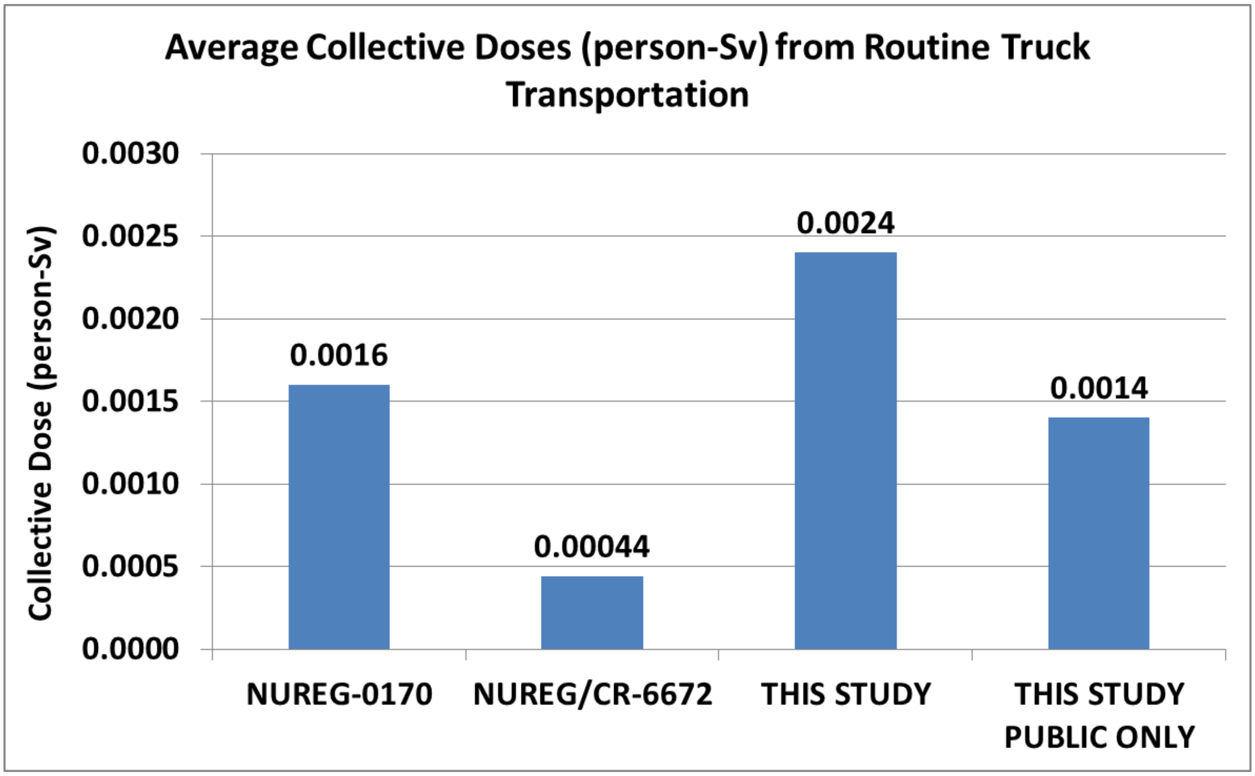



**Figure 4. Collective doses (person-Sv) from routine truck transportation**

## TRANSPORTATION ACCIDENTS

This study uses current (1991 to 2007) truck and rail accident statistics to determine the probability of an accident and the severity of that accident. Researchers performed detailed analyses to evaluate how the casks would respond to the accident scenarios. Figure 5 shows a cask response to one impact scenario, a 97 kilometer per hour (kph) (60 mile per hour (mph)) corner impact onto a rigid target, and the resulting deformations. Almost all of the deformation is in the impact limiter, a device that is added to the cask to absorb energy, much like the bumper of a car. Similar analyses were performed for impacts at 48 kph (30 mph), 97 kph (60 mph), 145 kph (90 mph), and 193 kph (120 mph) in end-on (lid down), corner, and side on orientations for two cask designs. These impact speeds encompass all accidents for truck and rail transportation.

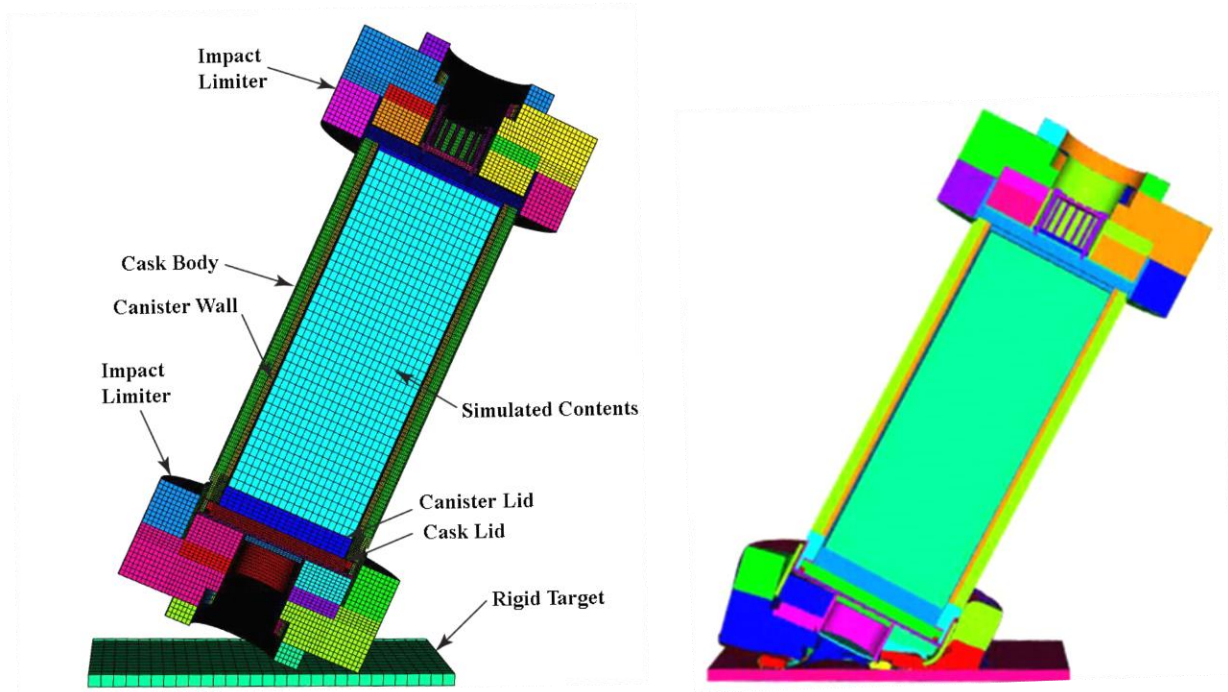



**Figure 5. Corner impact onto a rigid target at a 97-kph (60-mph) accident scenario for a spent fuel cask and the deformations produced by the impact**

Figure 6 shows one fire scenario, a 3-hour engulfing fire, and the resulting temperature distribution in the cask. Additional simulations were performed with the fire offset from the cask. These fires include all fire-related accidents in rail transportation. The longest duration for an engulfing fire during truck transportation is 1 hour because of the amount of fuel that is carried onboard a tanker truck.

Detailed impact simulations were performed for two spent fuel casks intended for transportation by railroad, the NAC STC and the HI STAR 100. In addition, the results for a third cask, the GA 4, which is intended for transportation by truck, were inferred from earlier analyses. Detailed fire simulations were performed for all three casks.

The impact and thermal analysis results indicate that no accident involving the truck transportation cask would result in the release of radioactive material or reduction in the effectiveness of the gamma shielding. The only radiological consequence of an accident would be exposure to external radiation from the cask because of the long-duration stop associated with the accident. The stop needs to be long enough for responders to clear the accident scene and to arrange for shipment to resume. During this stop, emergency responders could be fairly close to the cask. Because there is no loss in effectiveness of the gamma shielding, the radiation dose to these responders would be a small fraction of the allowed occupational dose.

For rail transport of spent fuel that is in an inner welded canister, this study shows that there would be no release of radioactive material. For casks using lead gamma shielding, the most severe accidents evaluated led to a reduction in the effectiveness of that shielding, which results in an elevated external radiation level. In addition, for rail transport of spent fuel that is not in an inner welded canister, some radioactive material is released following exceptionally severe and improbable accidents.

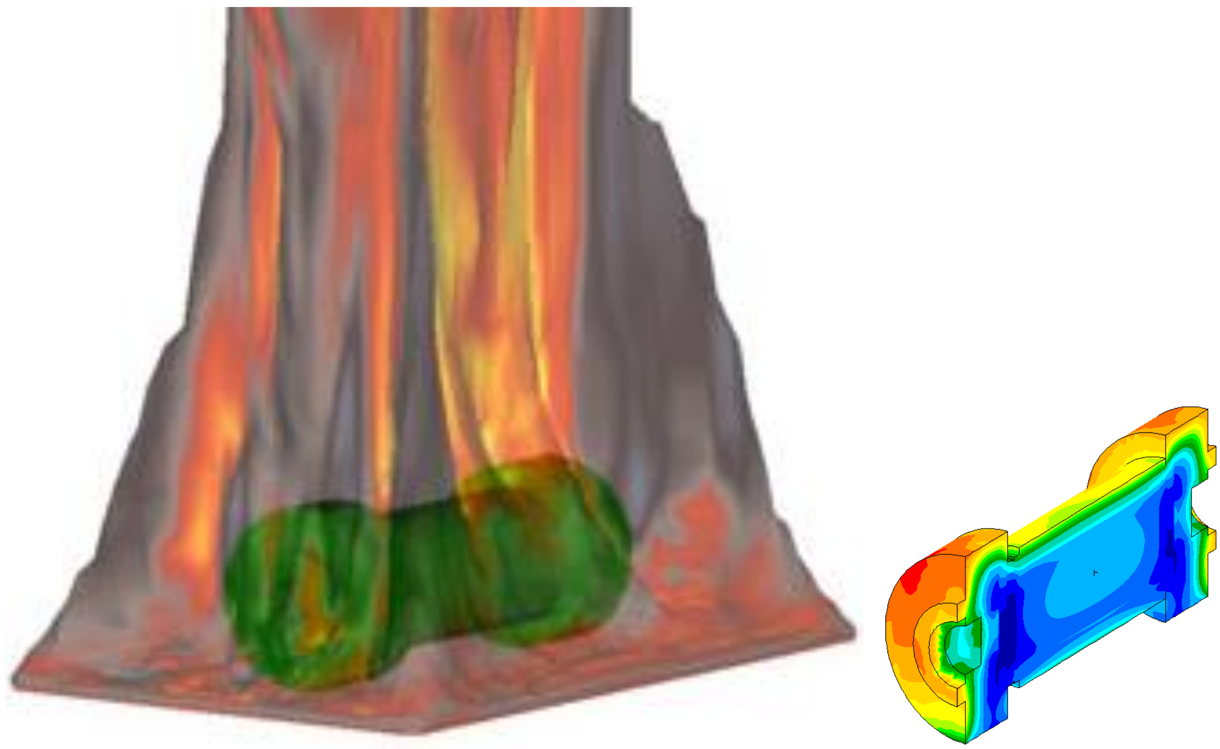


**Figure 6. Engulfing fire scenario and the temperature contours in the rail cask following a 3-hour fire duration. The transparency of the flames has been increased so the cask can be seen; in the actual fire simulation, and in a real fire, the flames are opaque.**

The calculated collective dose risk (the summation of dose to all exposed individuals times the probability of the accident) from accidents has decreased with each successive risk assessment. Figure 7 compares the average collective dose risks from releases and loss of lead shielding from the three studies (NUREG 0170 did not calculate loss of lead shielding). This study also considered accident doses from a source that was not analyzed in the prior studies—the dose that results from accidents in which there is neither release nor loss of lead shielding, but there is increased exposure to a cask that is stopped for an extended period of time. Figure 8 shows the average collective dose risks for this scenario for the three casks studied. This scenario is important because more than 99.999999 percent of all accident scenarios do not lead to either release of radioactive material or loss of shielding. Figure 9 provides a summary of all the accident probabilities and risks. The first pie chart shows that only about 1 in 1,000 trips would result in an accident. The second pie chart shows that if an accident occurs, only about 1 in 2,000 accidents is more severe than the regulatory accident conditions. The third pie chart shows that if an accident is more severe than the regulatory accident conditions, only about 3 in 1,000,000 will result in either loss of gamma shielding or release of radioactive material.

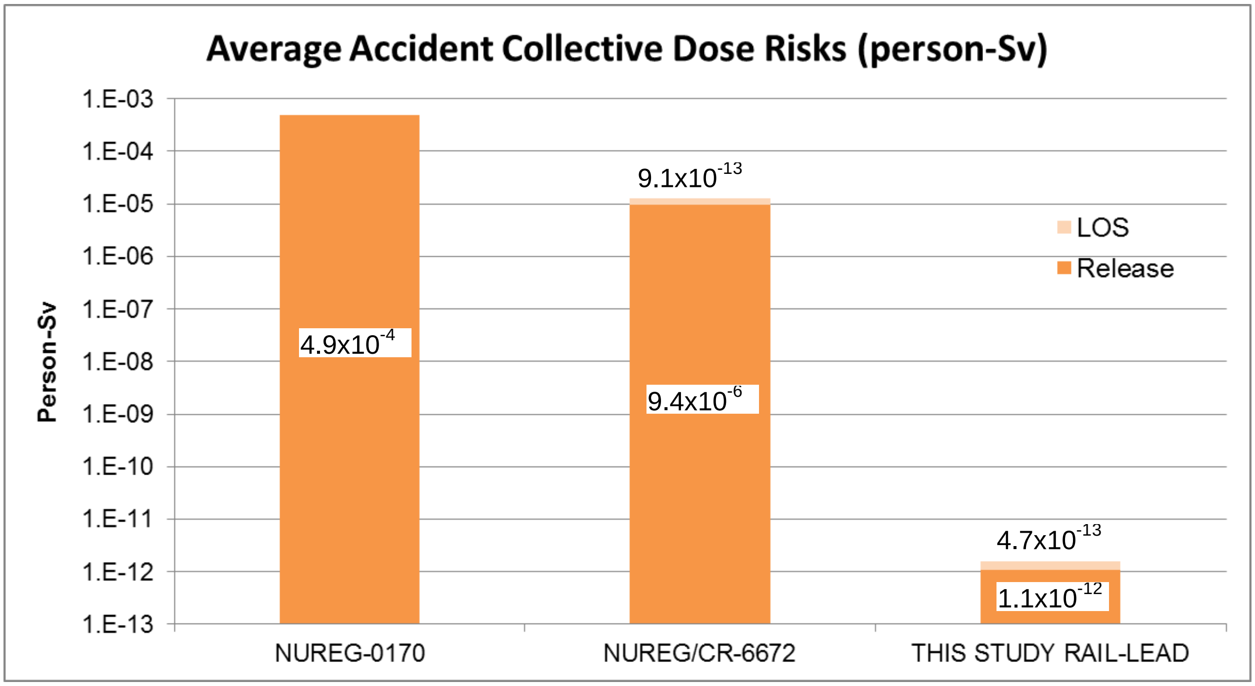



**Figure 7. Accident collective dose risks from release and loss-of-shielding accidents. The loss-of-shielding bar for NUREG/CR-6672 is not to scale.**

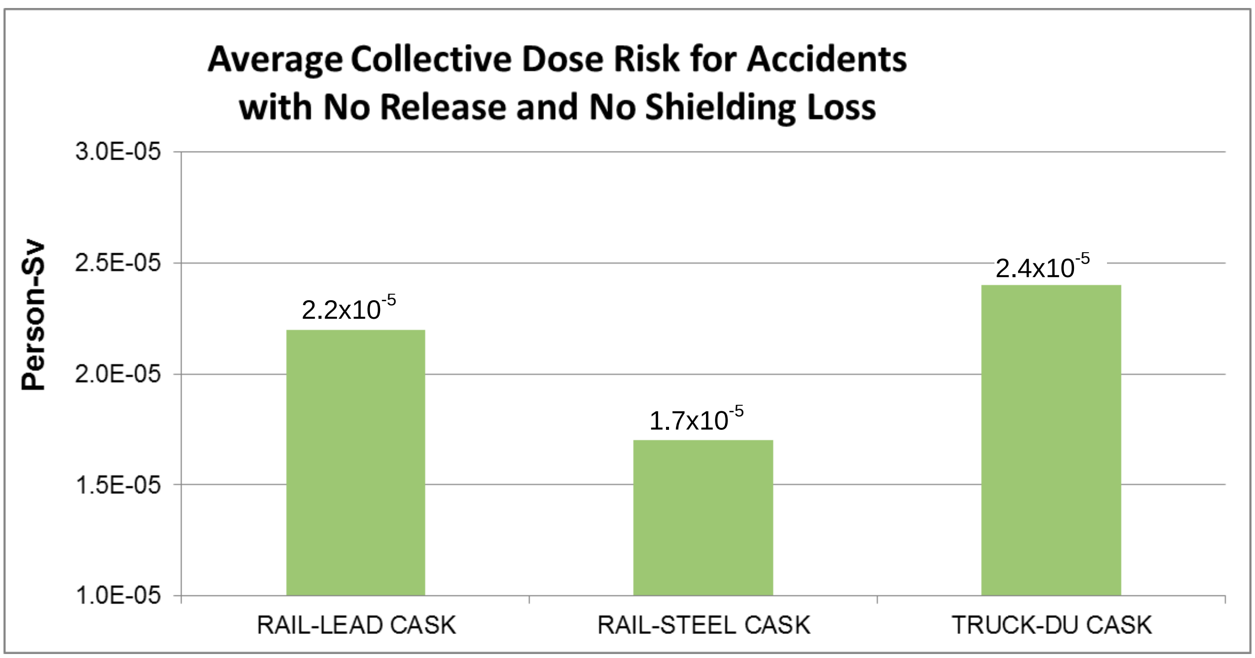
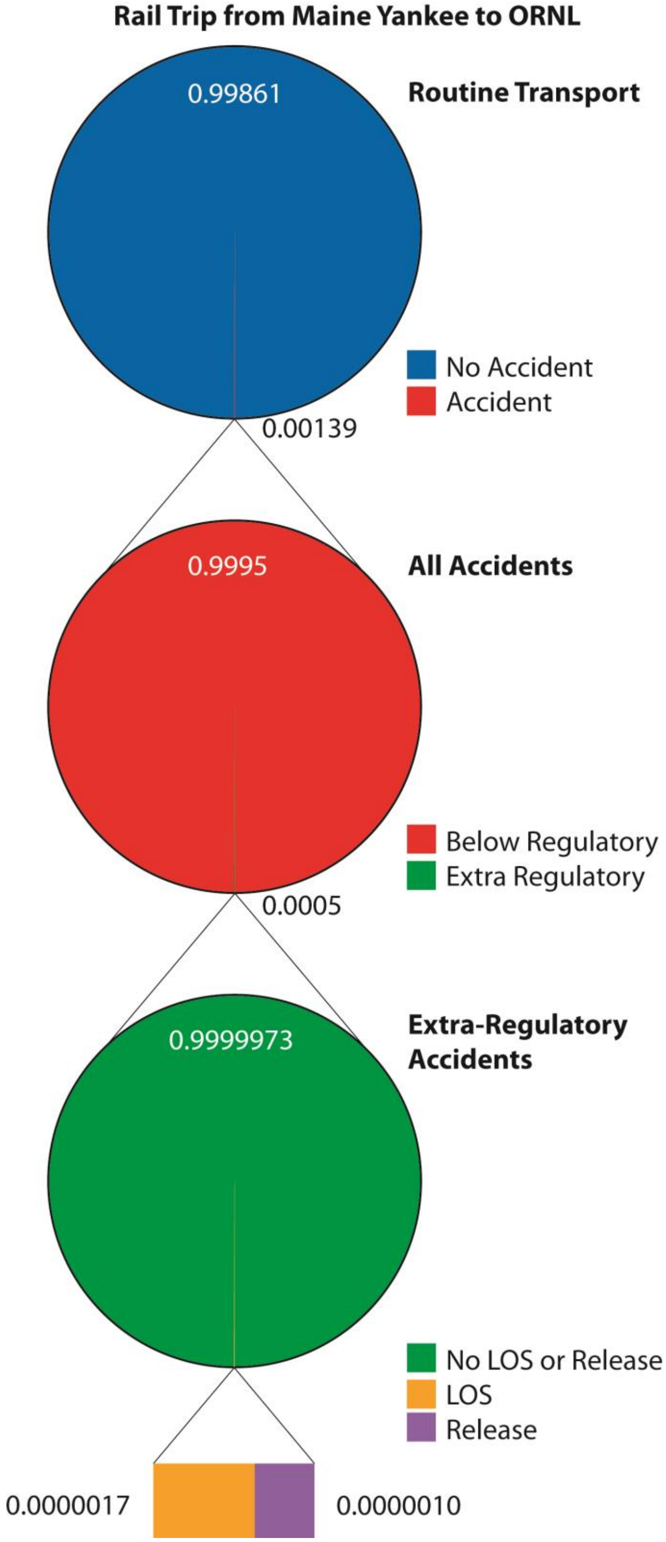



**Figure 8. Average collective dose risk from accidents that have no impact on the cargo**




**Most shipments are routine**

99.86% of shipments occur without accidents

Collective Dose from Routine Transportation: 2.3 Person-mSv

**Most accidents are less severe than the hypothetical accident casks are designed to withstand**

99.95% of accidents would not exceed regulatory requirements

Collective Dose Risk from 10-Hour Stop: 0.085 Person-mSv

**Casks provide safety well beyond the regulatory requirements**

99.99973% of accidents that are more severe than the regulatory hypothetical accident do not lead to release or loss of lead gamma shielding.

Collective Dose Risk from Loss of Lead Gamma Shielding: 2.5 $x10^{-10}$ Person-mSv

Collective Dose Risk from Release: 3.5 $x10^{-11}$ Person-mSv

Dose to a hypothetical maximally exposed individual (1.6 Sv) would not result in an acute fatality

**Figure 9. Accidents on the rail trip from Maine Yankee to ORNL in the rail-lead cask**

A final point of comparison between the studies is the maximum consequence of an accident. For NUREG 0170, this was about 110 person Sv; for NUREG/CR 6672, it was about 9,000 person Sv; and for this study, it is 2.2 person Sv. 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. This study estimated the effects of an accident on the maximally exposed individual (a hypothetical person located at the point of highest concentration of potentially released radioactive material for 10 hours). The estimate for such an individual is calculated to be a dose of 1.6 Sv, and would not cause an acute fatality.

## CONCLUSIONS

As noted above, the purpose of this analysis was to reproduce (and, in some cases, extend) risk analyses previously considered in NUREG 0170, the Modal Study, and NUREG/CR-6672 using updated models and methods. The study reached the following findings:

- The collective doses 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.
- The regulatory hypothetical accident conditions are more severe than 99.995 percent of all accidents.
- The certification process not only assures that casks will survive the hypothetical accident conditions, but that they also survive 99.9999 percent of more severe accidents. Therefore, 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 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.

## REFRENCES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