DISCUSSION DRAFT

An Updated View of Spent Fuel Transportation Risk

A Summary Paper for Public Meetings

Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission

Preface

In this summary of the Nuclear Regulatory Commission's (NRC's) newly-released study of spent fuel shipment risks, there are references to and comparisons with a baseline study, completed in 1977, and other studies. This synopsis offers a thumbnail sketch of the various studies, including specific citations for further reading, as well as a glimpse of future NRC plans.

1977: NRC completed The "Final Environmental Statement on the Transport of Radioactive Materials by Air and Other Modes" (NUREG-0170). The Commission considers this the baseline study on radioactive material transport risks in general, and on spent fuel transport risks in particular. On the basis of this study, the Commission concluded, "existing regulations governing the shipment of radioactive materials were adequate to protect the public." In this summary, NUREG-0170 is referred to it as the "baseline," "1977," or "prior" study.

1980: The "Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment," NUREG/CR-0743, SAND79-0369 is published. This study is aimed at assessing transportation risk in areas of significantly higher population density than considered in the baseline study. New York City was the example. This is referred to as the "Urban Study" in this summary.

1987: A study titled "Shipping Container Response to Severe Highway and Railway Accident Conditions" (NUREG/CR-4829) added assurances of cask capability to withstand accident forces. This study used modern structural and thermal calculations and developed prototype event trees that depict the sequence of events that define an accident scenario. This report is referred to as the "Modal Study."

2000: The "Reexamination of Spent Fuel Shipment Risk Estimates," (NUREG/CR-6672) was released in March 2000. This document is the primary subject of this summary. This publication refers to NUREG/CR-6672 as the "current," "Year 2000 risk study," or "new" study.

2000 – 2005: The NRC is planning an "Update of the Spent Fuel Transportation Package Performance Study." This study will revisit, in part, the 1987 Modal Study. Public meetings have been held in Bethesda, Maryland and in Pahrump and Henderson, Nevada to gather public opinion to help define the scope of the work. Additional meetings will be held in Nevada and Bethesda in Fall 2000.

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Summary

Recently, the Nuclear Regulatory Commission (NRC) released a study of spent fuel shipment risks. The March 2000 study, "Reexamination of Spent Fuel Shipment Risk Estimates" (NUREG/CR-6672), evaluated both highway and rail shipments of spent fuel. It shows that the risks from accident-free shipments and from shipments where accidents occur are very low. The study reveals that the estimated risk of future spent fuel shipments is less than was estimated in the 1977 study. In addition, current NRC safety standards for spent fuel transportation remain valid and require no major changes.

This publication compares a recent study of spent fuel shipment risks and a baseline study done in 1977. The "Final Environmental Statement on the Transport of Radioactive Materials by Air and Other Modes" (NUREG-0170) was published in late 1977. That report examined risks of transporting a wide variety of radioactive materials, including spent fuel. The report looked at shipments of radioactive material typical in 1975 and at those projected to occur in 1985. Based in part on the results of this study, NRC concluded that the "existing regulations governing shipment of radioactive materials were adequate to protect the public."

At the same time, the Commission set a regulatory policy that the safety of spent fuel transportation would be subject to ongoing review. The current study, "Reexamination of Spent Fuel Shipment Risk Estimates," (NUREG/CR-6672), is an element of that continuing review.

Because spent fuel transportation occurs in the public domain, shipments continue to raise considerable interest. NRC anticipates public concern will increase with greater numbers of shipments per year likely to be moving on United States (U.S.) highways and railroads in the next 30 years.

Three developments prompted the current study:

- the likelihood that spent fuel shipments will increase over current levels,
- use of routes and casks that differ from those considered in the baseline study, and
- better risk assessment and spent fuel cask response modeling technology.

Spent fuel shipments never reached the 1500 highway or 650 rail shipments projected by the baseline study for 1985. During the mid-1980s, highway and rail shipments totaled less than 200 per year. At present, they are less than 20 per year. In the U.S., from 1979 through 1995, the nuclear industry completed about 1300 commercial spent fuel shipments. Of those, 1045 were by highway and 261 by rail. Although four highway shipments and four rail shipments were involved in accidents between 1971 and 1995, none of the accidents damaged the spent fuel casks or compromised shielding or caused any release of radioactive material. There were no injuries, deaths, or non-routine doses due to release of radioactive material or compromise of shielding.

The Nuclear Waste Policy Act and its Amendments project a future in which the Nation's spent fuel will be moved to a repository. It could take as many as 2500 truck or 100 rail cask loads a year to move fuel now stored at reactors to a repository. While future shipping levels are not much different from those analyzed in the 1977 report, the shipments themselves differ in some key respects. For example, the fuel in future shipments will be much older than that considered in the 1977 report. Older (longer out of the reactor) spent fuel produces less residual heat and radiation. As a result, new spent fuel packages, or casks, can be designed to contain larger numbers of spent fuel assemblies than casks considered earlier.

Risks to populations along routes were evaluated in the 1977 report on a generalized, U.S. average basis. The new study more accurately divides routes into rural, suburban, and urban segments for assessing risk. Similarly, computer models allow a much more detailed evaluation of the response of casks and spent fuel to accident forces and fires. Thus, estimates of possible releases of radioactive material from the cask and impacts on persons are more realistic.

As in the 1977 study, the new report estimates risks to the public from transporting spent fuel in two categories:

- "accident-free risk" – the total of all radiation doses received by all persons during shipments that are completely routine, and
- "accident risk" – the total of all doses to all individuals exposed in an accident multiplied by the chance that the accident producing the dose might occur.

Risk in the Year 2000 risk study is measured in units called "person rem." Scientists and doctors use rem as the unit of dose that measures the effect of radiation energy deposited in human cells. Most people in the U.S. are exposed to radiation in the amount of 200 to 400 millirems per year (a millirem is one thousandth of a rem) from natural radioactive materials in the environment and cosmic rays. Regulations and industry practice attempt to limit doses to as low a level as reasonable. Studies indicate that added doses up to a tenth of background (10 to 40 millirem) have no discernable effect on human health.

The risks for future shipments, estimated using modern technology in the Year 2000 study, are well within the range estimated in the 1977 NRC report for the 1970s and 1980s. The total accident-free risk is about half of that estimated in the baseline report for highway and about one-tenth for rail shipments.

The Year 2000 risk study confirms that earlier estimates of risk to the public are unlikely to be exceeded in the foreseeable future. Therefore, NRC will continue to use the 1977 report as its benchmark assessment of the radiological impact for the transportation of radioactive materials, including spent fuel.

The Commission continues to invite the public's involvement in this important work.

1. BACKGROUND

As the principal regulator of cask design and use, NRC demands continuing assurance that spent fuel transport is safe. NRC uses risk studies as one of its tools in evaluating safety. In this publication, the Commission compares the results of a new study, completed in March 2000, to those in a 1977 report, which established a risk baseline. This publication also briefly addresses the significance of other studies completed between 1977 and the present. The Year 2000 risk study is the latest effort in assuring that risk standards are met. NRC funded this study to learn how expected changes in spent fuel transport to a permanent spent fuel repository or interim storage facility would impact risk estimates.

The NRC and the U.S. Department of Transportation (DOT) share regulatory responsibility for shipment of radioactive materials in commerce within the U.S. The DOT regulates shippers and carriers of radioactive material and transport operations while a radioactive material package is in transit. The NRC regulates users of radioactive material and the design, manufacture, use, and maintenance of shipping containers for certain types of radioactive material shipments, including spent fuel. In this role, the NRC allows shipments of spent fuel on a continuing basis based on:

- confidence in NRC regulations (which mirror those used internationally);
- cask certification procedures used by NRC staff;
- consistent regulation application by its licensees; and
- the safety record for spent fuel shipments in the U.S. and around the world.

Nuclear reactor operations produce spent fuel. Nuclear fuel powers a reactor over a period of years until the fuel's energy production potential is spent. Operators currently store virtually all spent fuel on-site in cooling ponds or dry storage casks. This spent fuel will be shipped to a national repository or interim storage facility in the first third of this century. These shipments are likely to occur at rates higher than current levels. This has prompted NRC to reexamine the risks for such shipments.

The NRC first evaluated spent fuel shipments in its 1977 report, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes." That study examined the risks of shipping about three dozen different radioactive materials. One was spent fuel. Scientists trying to analyze spent fuel cask damage from severe accidents found they could not easily do so. To compensate for the lack of information about how much material might be released, they used a fixed release amount. Based in part on the results of the 1977 study, the Commission concluded in 1981 that "present regulations are adequate to protect the public from unreasonable risk from the transport of radioactive material and that no immediate changes in the regulations were needed to improve safety."

The NRC funded other studies that examined in detail the ability of spent fuel cask designs of the 1970s and 1980s to survive severe rail and highway accidents and limit release of radioactive material. One study, usually called the "Modal Study," used computer techniques not available in 1977. This 1987 analysis confirmed that casks should contain spent fuel material in all but the most severe accidents. It also showed that the risks of shipping spent fuel were about one-third of those estimated in the 1977 study.

In March 2000, NRC published the current study to provide a best estimate of spent fuel transportation risk. The Year 2000 risk study extended the Modal Study methods for cask analysis and used improved risk assessment methods. NRC funded the study to consider these factors:

- Spent fuel will be less radioactive and produce less heat than expected and allow more fuel to be shipped in each cask.
- Computer programs can better assess cask behavior and leakage potential.
- Numbers of shipments per year that are higher than actual shipment rates undertaken in the U.S. in the last two decades.
- More route-specific information is available today for improved risk assessment.

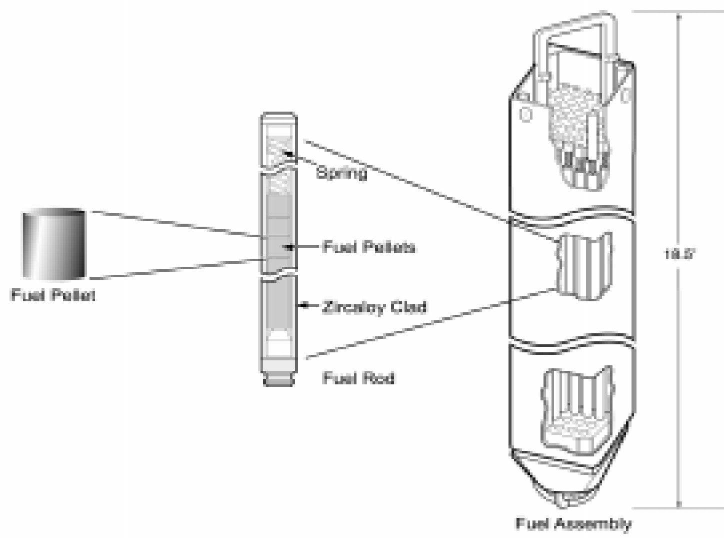
The Year 2000 risk study considered these factors to the extent they could be addressed with modern analytic methods. No physical testing was performed.

Because spent fuel transportation occurs on highways and rail systems in the public domain, shipments raise considerable interest. NRC expects the public to be concerned with the larger numbers of shipments likely to be moving on U.S. highways and railroads in the next 30 years.

The new report focuses on these concerns. It also provides a factual basis for the public to understand the risks presented by these activities and to decide if shipments are safe, considering the benefits. Also, the public can judge whether adequate resources are devoted to this issue.

The remainder of this publication provides a comparison of the Year 2000 risk study, with earlier studies. Basic information on risk and exposure concepts is provided. In addition, there is an overview of risk estimation methods, characteristics of spent fuel and spent fuel casks, and methods used to estimate the damage to casks from accident forces. Finally, there is a discussion of the study results with a comparison to other studies and the significance attached by NRC to the results.

2. SPENT FUEL: WHAT IS IT? HOW IS IT SHIPPED?



Commercial nuclear power plants licensed by NRC produce power from fuel assemblies containing uranium fuel. When the fuel value of the assembly is used up, it becomes "spent fuel." Spent fuel is a hazardous material, but it contains no liquid and cannot explode. A spent fuel assembly must be contained and shielded because it is intensely radioactive. NRC licensees must comply with NRC and other agency's regulations that assure that a spent fuel shipment is prepared for shipment and transported safely.

Casks used to move the spent fuel are designed to withstand severe accidents while maintaining shielding, containment integrity, and subcriticality. U.S. and international regulations require that casks be shown to perform these functions after a series of hypothetical accident tests designed to produce damage observed in severe accidents.

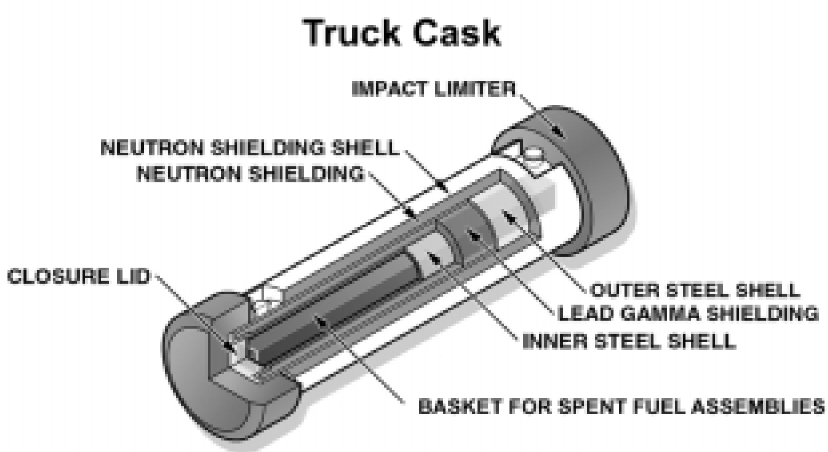
The fuel loaded into a nuclear reactor is made up of uranium oxide fuel pellets about one-half inch in diameter and about the same height. The pellets are stacked in a tube (cladding) about 12 feet long called a fuel rod. Fuel rods are held in an array by series of metal grids to form a fuel assembly.

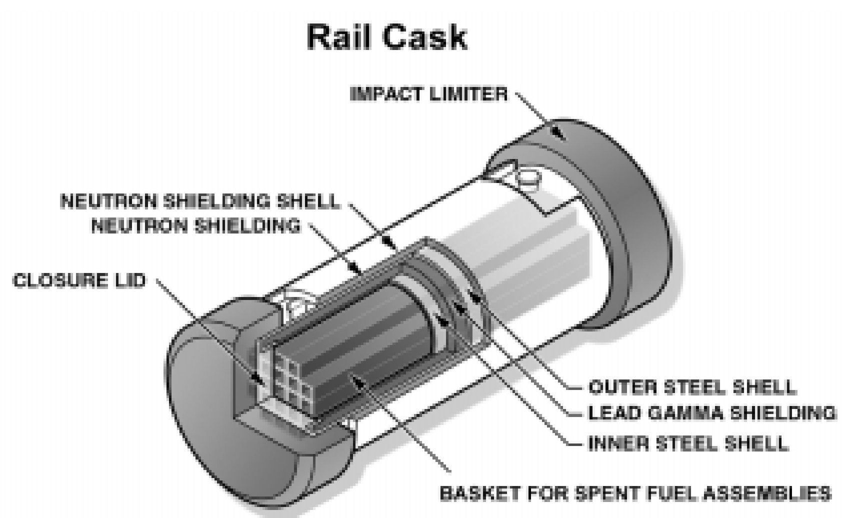
During reactor operation, fission products slowly accumulate in the fuel material. When the fuel is "spent," that is, it no longer produces energy efficiently, operators remove the fuel from the reactor. Spent fuel assemblies are highly radioactive and are always shielded when out of the reactor. The spent fuel emits radiation and heat at a rate that decreases with time after removal from the reactor. Radiation from the assembly or release and dispersal of the pellet material from the rods into the air or water would produce a significant hazard. In the power plant, in transportation, and in a storage or repository facility, regulations assure that shielding and leak-tight containment are maintained.

Spent fuel casks are designed to be leak-tight and shield their surroundings from most radiation. It is not possible to eliminate all radiation using shielding, but package designers can reduce emissions to levels that are safe. Regulations limit radiation levels to a dose rate of 10 millirem/hour at a distance of about 6.5 feet from the edge of the truck bed or railcar to which a cask is attached.

Radiation interacts with living cells. To measure of the effect of the radiation, scientists use a unit called a rem. For many situations, scientists use an even smaller unit, the millirem. (One thousand millirem equals one rem.) Natural radiation background ranges from 200 to 400 millirem per year in the U.S.

The spent fuel cask provides protection of public health and safety during transport. The cask has a passive design that does not depend on truck or railway crew actions to assure public safety. Casks achieve this goal by being relatively simple, without moving parts, and without reliance on external active systems (like fire suppression sprays).





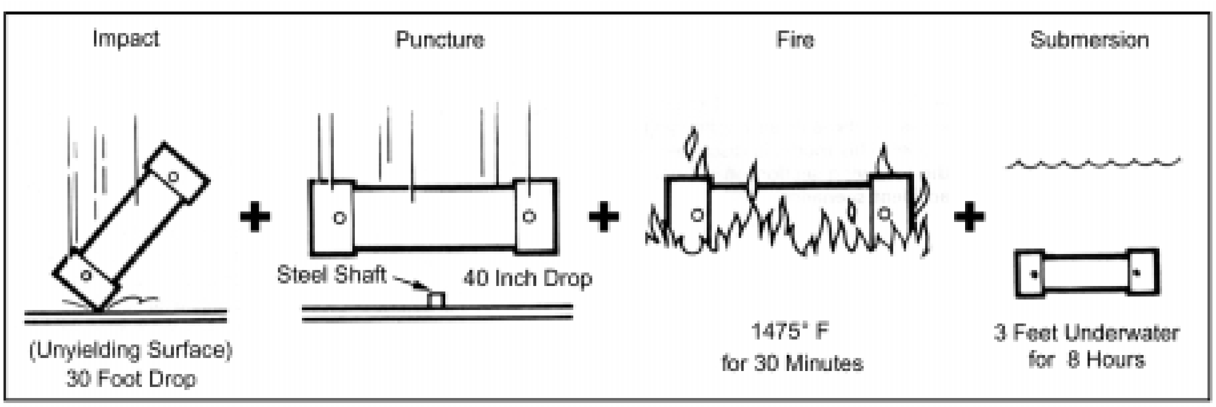
Examples of casks are as shown in the drawings above. Typically, casks are cylindrical with walls 5 to 15 inches thick, depending on the shielding material – and a massive lid at one end for loading. Truck casks weigh about 25 tons and contain one to two tons of spent fuel. Rail casks weigh about 100 tons and transport 15 to 20 tons of spent fuel. Both ends of the cask are encased in structures called impact limiters, which crush if the cask is involved in an accident. Thus, they limit the impact forces on the cask and spent fuel. This reduces damage to the cask base, lid, and seal areas and the spent fuel.

NRC reviews and certifies spent fuel cask designs. Certification assures that the design meets specific performance standards and that the cask can survive most severe transportation accidents. Package designers must demonstrate to the NRC that the cask can survive a sequence of four hypothetical accident tests:

- Impact: a 30-foot drop onto an **unyielding** surface in a direction to cause maximum damage (equal to 30 mph speed);
- Puncture: a 3-foot drop onto a 6-inch-diameter steel shaft to cause maximum damage;
- Fire: exposure to an all-engulfing fuel fire for 30 minutes; and
- Submersion: a tested cask is held underwater at 3-feet depth for 8 hours (relates to criticality control.)

After the tests, the external dose rate may not increase to more than 1 rem/hr at 3.3 feet from the cask surface. The gas leak rate must be below the test required to demonstrate sealing of food cans.

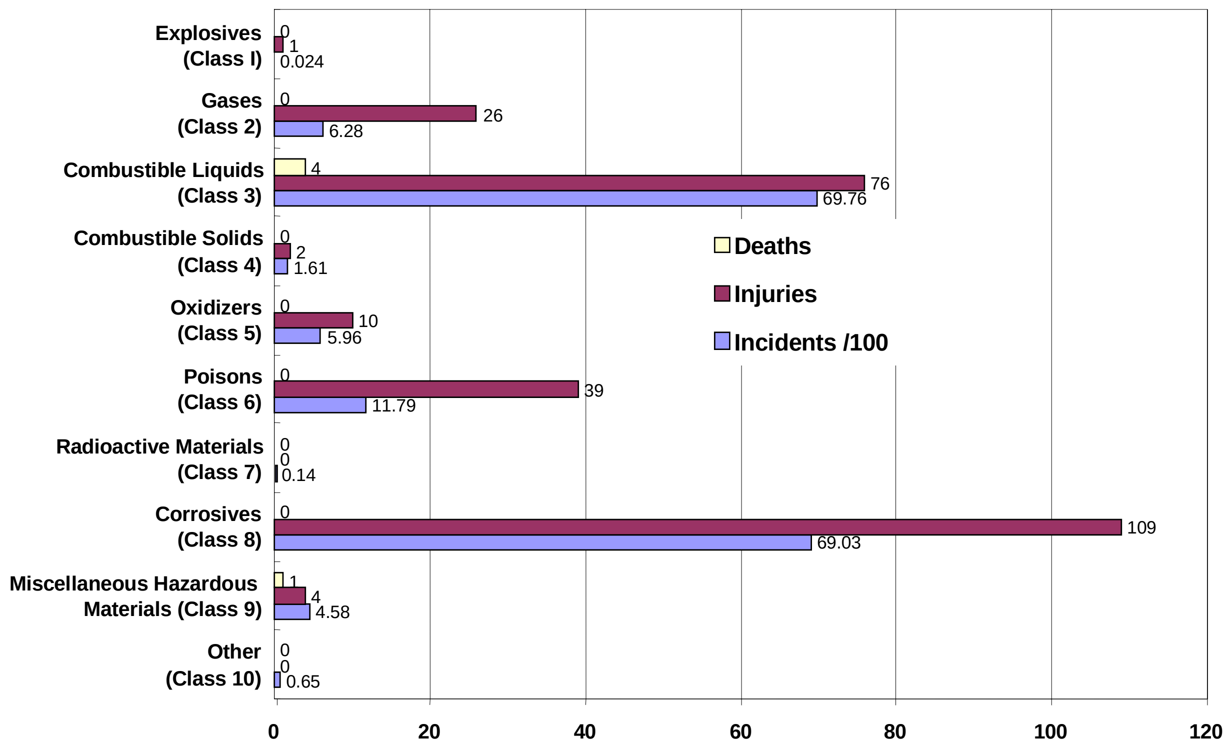
The NRC receives many comments from the public about the likelihood of real events exceeding the impact speed and fire intensity used in these tests. Analysis shows that these test environments are exceeded in less than a few tenths of a percent of all severe accidents. At first glance, a 30-mile-per-hour impact speed seems low. However, the **unyielding** surface simulates a collision with an identical package going the same speed in the opposite direction where the combined closing speed is 60 mph. Vehicles do move faster than 30 mph in real life, but an impact on a truly unyielding surface is very rare. Transportation fires occasionally last longer than 30 minutes. However, rarely are they large enough or in the right place to fully engulf a large cask.



Hypothetical Accident Tests

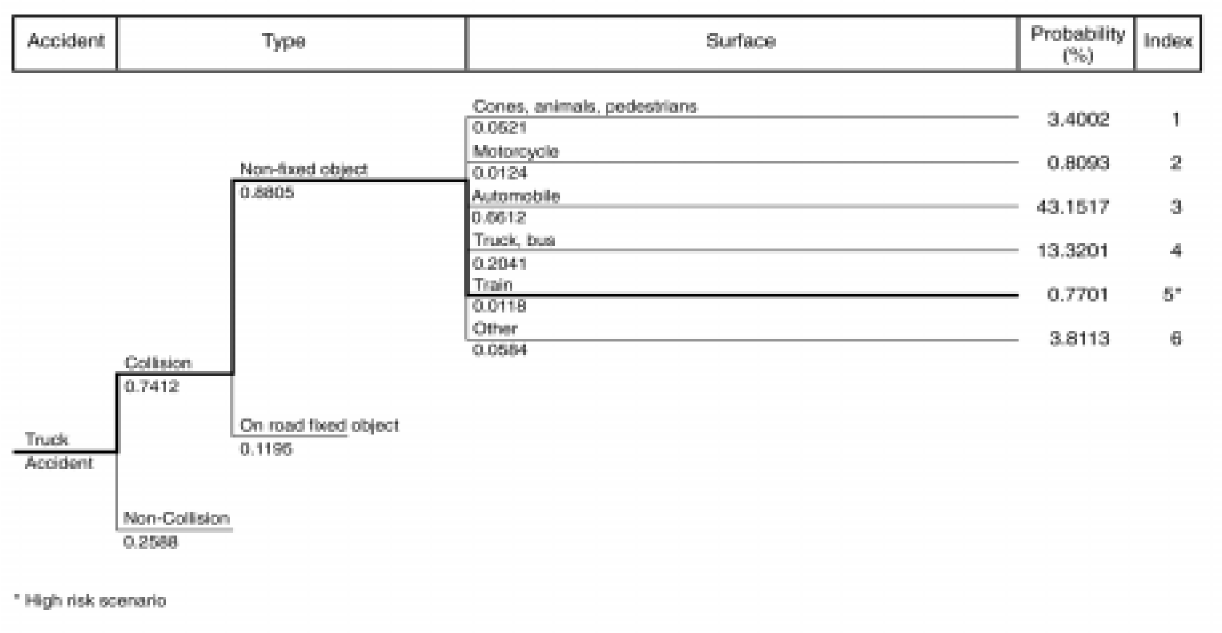
Only casks with a Certificate of Compliance from NRC may be used to transport spent fuel. The casks are designed, fabricated, and used under an NRC-approved Quality Assurance Program for the Transportation of Radioactive Materials. This program is subject to direct NRC inspection and enforcement.

Shipment packages for other classes of hazardous material are not required to withstand the forces developed in accidents. The risk from shipping hazardous materials is low. There are 3 to 4 million radioactive material packages shipped per year. A few hundred of these are spent fuel or similarly packaged. The graph below shows the release incidents and damages produced for all classes of hazardous material. While there are relatively few radioactive material shipments compared to gasoline (Class 3), the death and injury results show an advantage to the packages used for radioactive materials (Class 7) on a total as per incident basis.



Summary of 1999 Hazardous Material Incident System (HMIS) Report

3. RISK ASSESSMENT METHODS



Risk is a familiar term in modern life. Risk assessment provides an estimate of risk by numerically representing the answers to three basic questions: (1) What could happen? (2) How likely is it? (3) How serious are its consequences? Risk estimates for the shipment of spent fuel in the Year 2000 risk study used event trees to identify accident scenarios and standard dose estimation methods. In the Year 2000 risk study, researchers used a risk assessment computer program to calculate risk. Accident scenarios and other data for risk assessments were obtained from prior analyses and published data sources. Where data was not precise, researchers selected values that yielded overestimates of risk. The computer program and the data sets used in this study are available to the public on the Internet.

Risk is a term used frequently in everyday conversation. We often define it as "the chance of injury, damage, or loss." This implies that risk is a chance of something, usually unpleasant, happening. To risk assessors, the term has a more formal definition, in which chance is only one part. Risk is the consequence of an event multiplied by its likelihood of occurrence.

Usually, risk assessments deal with three questions:

- What can go wrong?
- How likely is it?
- If something goes wrong, what are the consequences?

In the new study, researchers noted two risk components: accident-free risk and accident risk. Total risk from spent fuel transport is the sum of accident-free risk and accident risk.

For accident-free, or routine, transportation, there are radiological consequences (doses) because the cask emits radiation continuously at a low rate. Thus, accident-free risk is simply the total of all doses received by all exposed persons expressed in person-rem.

The accident risk analysis in the current study looks at a large number of things that could go wrong and the possible chance of occurrence for each incident. Analysts use an “event tree” for accident-related consequences to trace things that could go wrong as a result of an accident. A path that selects various choices in the tree is called a scenario.

Accident consequence is the sum of all radiological doses received by all persons exposed from each specific kind of accident. The result of multiplying this consequence by chance provides accident risk resulting from a scenario as a single numeric value. That value can be added to those for all other scenarios to find the total accident risk.

As the table below illustrates, the consequence for an accident scenario typically becomes larger as its chance of occurrence becomes smaller. The table also shows that the chance gets smaller faster than the consequence gets larger. As a result, the contribution to total risk from larger consequence events becomes very small.

Models and event trees cannot be used without data. Some data, such as the estimated number of shipments per year, is relatively easy to obtain. Other data, such as the amount of spent fuel particles produced by an impact of a given intensity, may be unavailable or difficult to find or estimate. In that case, the data used would be chosen to yield an overestimate of risk.

Researchers developed three different sets of route data for the study. This data was used to estimate both accident and accident-free risk.

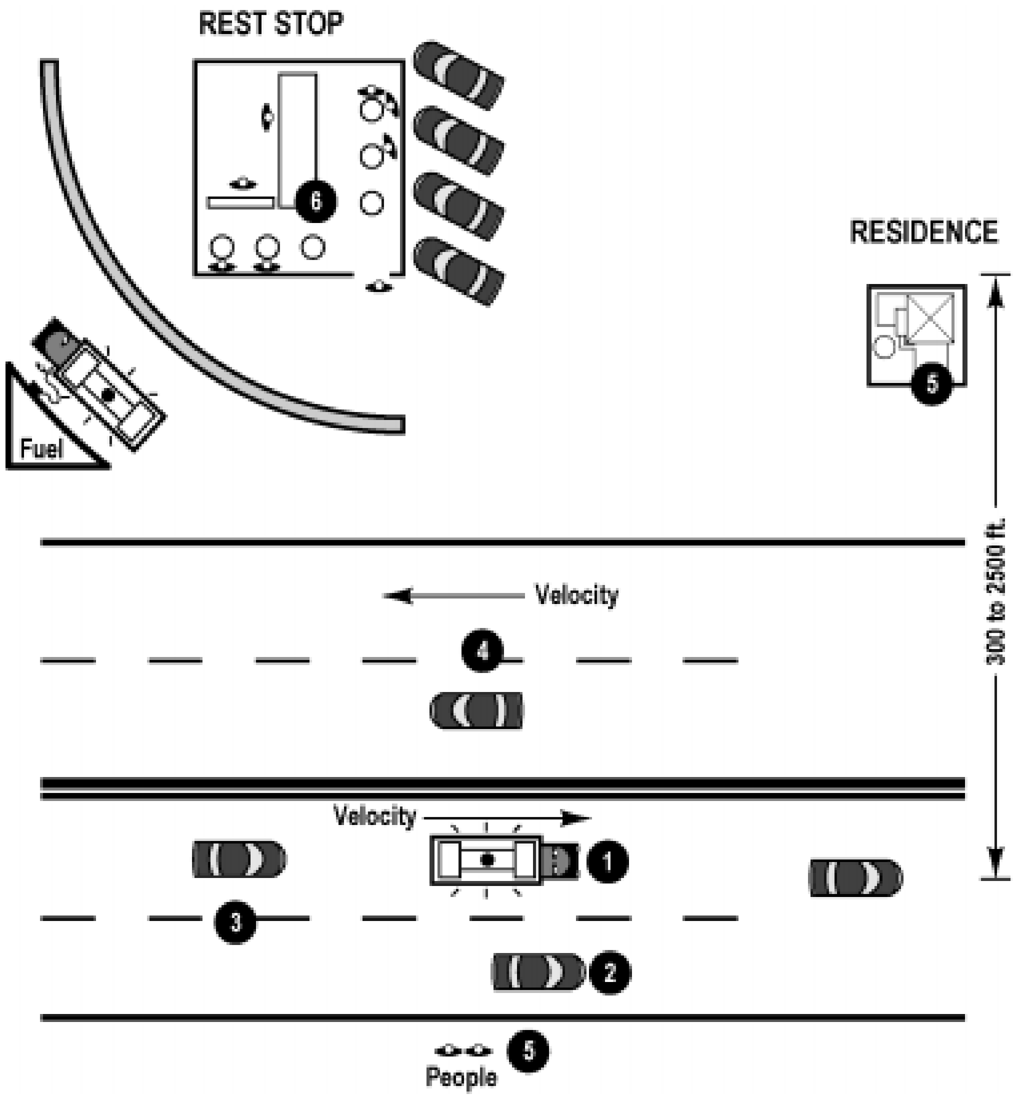
- Pooled Routes – A generalized ensemble of 200 routes, connecting all the places from which spent fuel might come and go. The data were developed by pooling route data for 741 interstate highway routes or mainline rail routes connecting locations where spent fuel is stored to nine sites where interim or permanent storage sites may be located.
- Illustrative Routes – This data represents four specific highway and four rail routes for comparison to pooled routes. These are transcontinental in scope and pass through most regions of the country.
- 1977 Route Data - This data is from the prior study. It specifies a generic route that might have been used in the mid-

Scenario	Chance of Occurrence (per year)	Consequence (person rem)	Risk Contribution (person-rem)
1	0.00000001	10	0.0000001
2	0.000000001	100	0.0000001
3	0.00000000001	1000	0.00000001
4	0.000000000000001	10000	0.00000000001
Etc.			

1970s.

All of the input data for the current study is accessible through TRANSNET, an NRC and Sandia National Laboratories information sharing facility supported by the DOE National Transportation Program. Individuals can make calculations similar to those in the current study with different data sets using the RADTRAN program. For access, go to: http://tdd.sandia.gov/risk/transnet.htm.

4. ACCIDENT-FREE RISK ASSESSMENT



The risk to the public from accident-free transportation results from a low-level radiation field that surrounds the cask containing spent fuel. The public alongside transportation routes, as well as using the route (as passengers in cars or trains), receives a very low dose of radiation from a nearby cask. While the dose received by any individual is minuscule, many persons can be exposed. The radiological risk of the shipments is represented by the sum of all doses to all individuals (in person-rem).

Accident-free risk results from radiation emitted by the cask during its journey. NRC regulations require that the dose rate from the cask be below a specific value. Required quality assurance procedures confirm that these values are met before the cask enters the public domain. Analysts estimate the total dose by considering people exposed in different situations relative to the cask.

A person near a cask receives a radiation dose. The dose depends on how close he or she is to the cask, how long the exposure lasts, and how much shielding material is between the person and the cask. If the cask is moving past a person, dose decreases with speed. In addition to those in the public exposed to the low radiation levels during transport, workers associated with the trip are also exposed. Workers include the truck or train crew, escorts, and inspectors. Together, they comprise three groups:

- **Persons Sharing the Transport Link** are those on or near the highway or rail line with the spent fuel shipment. (Bold numbers indicate groups in the diagram.) There are four principal subgroups.
  - the truck driver **(1)**, the relief driver, any escort in the truck cab (highway only), and persons traveling at the same speed in adjacent lanes **(2)**;
  - other persons traveling in the same direction as the shipment **(3)**; and
  - persons in vehicles moving in the opposite direction **(4)**.
- **Bystanders Near the Transport Link** are people who live in one-half-mile strips on both sides of the highway or rail line **(5)**.
- **Persons at Places Where a Shipment Stops** for refueling, changing drivers, or inspections. Persons eating at a rest stop or workers where the spent fuel truck stops are an example of this group **(6)**.

In each case, the analyst sums the dose received by every individual to obtain the dose received by all persons.

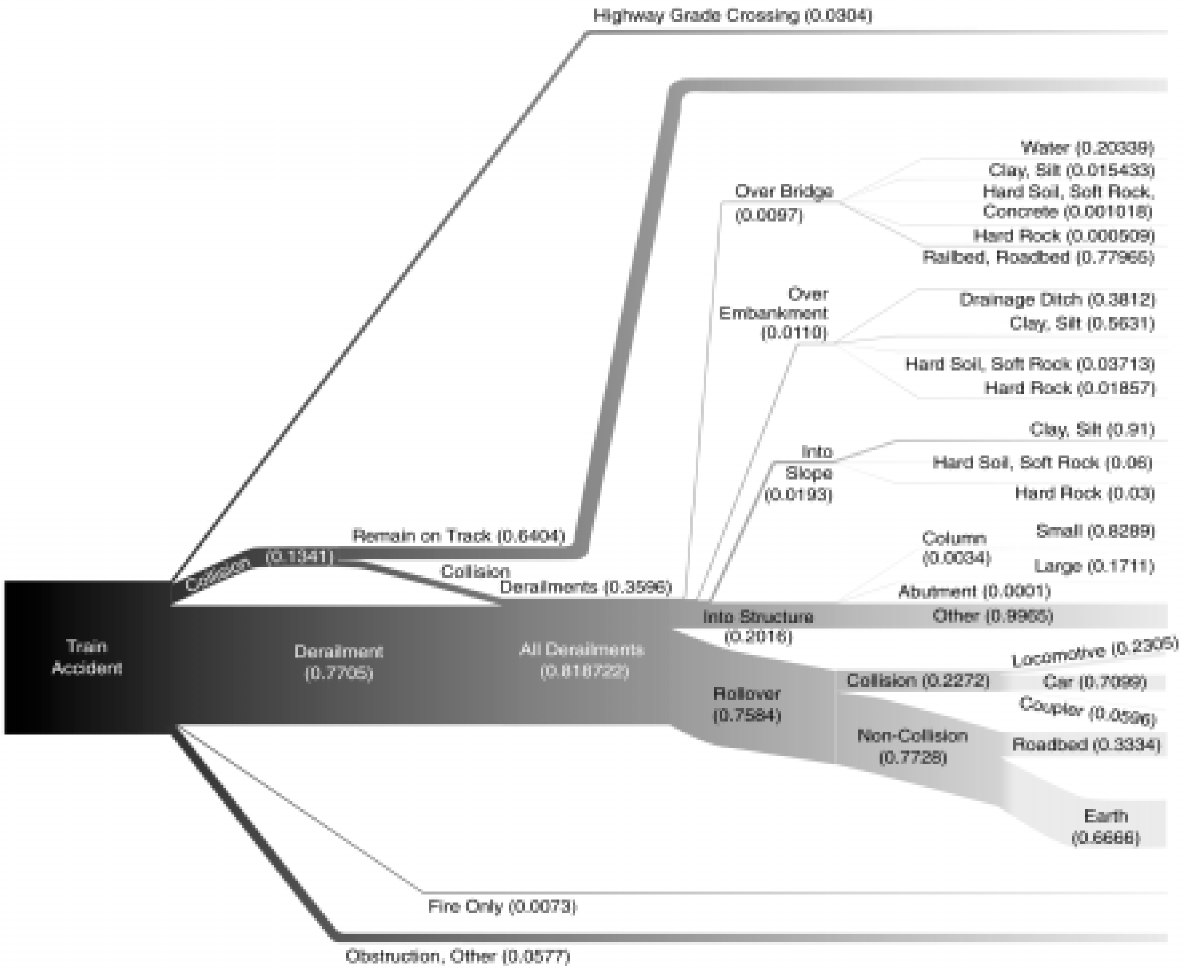
People in vehicles located next to the shipment for a long time (as in a traffic jam) might experience a dose rate as high as 10 millirems per hour. If they remain close to the cask for a few hours, they might receive a dose of 10 millirems. The few people stuck near the cask during a shipment will not receive a dose larger than the driver, because the driver is with the shipment for the entire time. The driver's dose is about 80 percent of the small dose received by persons sharing the transport link. The dose to persons driving along side the cask is even smaller.

People at truck stops who are away from parking and fueling areas (in restaurants or coffee shops) are generally too far from the cask to receive a significant dose.

Because rail shipments of spent fuel will travel almost exclusively on main lines and highway shipments almost exclusively on interstate highways, the average speed of these shipments is known, as well as the average speed of other trains or other vehicles.

Census data provides information on the number of people alongside the shipping routes. Researchers evaluate this data to obtain an aggregate estimate of the total exposed population. For one of the illustrative highway routes evaluated, there were approximately 840,000 persons in the mile-wide strip around a route connecting a site in Maine to a destination in Utah. Because the total population dose for the route was 0.1 person-rem, the average dose received by any person was about 0.0001 millirem. (That is equivalent to about 10 seconds exposure to natural background radiation). A person standing close to the highway (or railway) watching a cask pass by at 40 mph would receive a dose of approximately 0.001 millirem.

5. ACCIDENT RISK ASSESSMENT



Most transportation accidents that could involve a spent fuel cask will not lead to release of spent fuel materials because of the robust cask design. However, accident severity can become extreme if things were to go perfectly wrong and several unusual events occurred sequentially. A four-step accident risk assessment technique used in the Year 2000 risk study addressed these unusual events and their influence on cask behavior. That analysis yielded estimates of releases, consequences, and chances of occurrence. The resulting accident risks are significantly below estimates in the 1977 study.

Accidents involving a spent fuel cask in transportation are unlikely to produce a release of radioactive material. The NRC package standards and certification process described earlier assure that a cask will not leak, even in a severe accident. Fewer than one percent of accidents will produce more severe accident environments (larger impact forces, longer fires, or more penetrating punctures) than are covered by the certification standards. These situations are the focus of a four-step accident risk assessment.

Step 1 uses event trees (above) to find critical accident scenarios that could lead to very severe environments. Critical scenarios involve impact with relatively rigid and massive surfaces (rock, hard soil, concrete abutments, pillars, etc.) and fires, either alone or in combination with impact.

Step 2 identifies impact and fire conditions that are severe enough to cause both a cask leak and failure of the spent fuel rods. Without fuel rod failure, a leak in the cask has little impact.

A sophisticated computer model estimates how the various parts of the cask distort and what forces on the fuel rods could cause them to break. This is done for impacts on a rigid target at various speeds and orientations. Another model calculates the temperature of the cask seals and spent fuel from exposure to long-duration fires. From those results, researchers calculate the number of rods that fail and size of any leak in the cask caused by impact or fire.

In addition, these results help to determine how much pulverized spent fuel pellet material there would be, and how much might get out of the cask in each impact or fire situation.

Step 3 links the impact and fire calculations in Step 2 with possible real-life events in Step 1. Real-life impact accidents occur at many speeds and involve hitting different surfaces at differing angles. Effects of the impact can be markedly different depending on speed, surface hardness, and angle. For instance, researchers know that a steel/lead/steel cask hitting clay or silty soil at 60 miles an hour is damaged about as much as the same cask hitting a rigid surface (like a massive rock) at 30 mph. Hitting substantial concrete structures at 40 mph also gives about the same damage, but none are severe enough to cause a cask to leak.

Researchers match accident scenarios, which identify surfaces hit and accident speeds, with results from Step 2 to determine the likely damage to the cask and fuel rods and any release of spent fuel material. The chance of each release occurring comes from the event probability, combined with speed and fire duration statistics.

In **Step 4**, researchers used a computer program called RADTRAN to calculate the radiological consequences from the release and their corresponding chances of occurrence to produce risk estimates. The program takes the accident rates as well as expected numbers of shipments, route data (like population density), weather data (to estimate how the release would be spread by the winds), and radiological dose data to produce a person-rem estimate for each potential accident. RADTRAN calculates risks, which are summed to give an overall estimate for an accident.

The table below shows an example of how researchers estimate chance and consequence fractions. To achieve this 1100 person-rem consequence, seven unlikely events had to occur in sequence. Larger-consequence events require even more unlikely sequences of events.

Sample of a Very Severe Accident Sequence

	Event or Condition	Chance of Occurrence	Overall Chance of Occurrence/Trip	Dose Consequence of Accident
1	A 3000-mile highway shipment is underway.	1	1	0
2	An accident occurs.	6 in 10 million miles	18 in 10 thousand	0
3	Shipment is in an urban population zone.	2 in 100	36 in a million	0
4	The accident involves a collision.	75 in 100	27 in a million	0
5	The collision is with a fixed object.	12 in 100	3 in a million	0
6	The object is a bridge railing.	6 in 100	2 in 10 million	0
7	The cask falls from the bridge onto its side on a rail roadbed.	77 in 100	1.5 in 10 million	0
8	The impact speed is more than 85 mph (More than 200-foot drop). As a result, 10 percent of rods fail.	3 in 1000	5 in 10 billion	0
9	A fire lasting more than one hour engulfs the cask. (Seal degradation opens a leak path and gas expansion carries material out of cask)	1 in 1000	5 in 10 trillion	1100 person-rem (risk contribution of this sequence is 0.000000055 person rem)

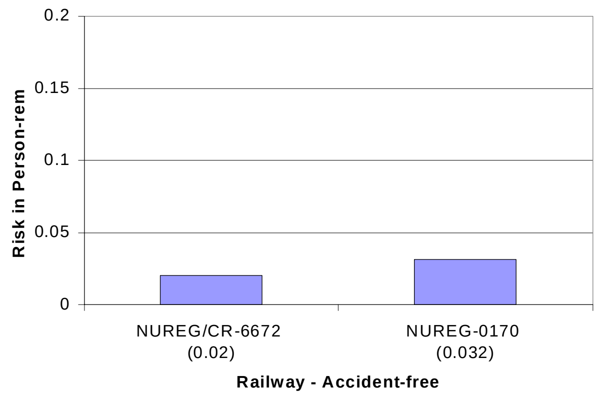
6. RISK ASSESSMENT RESULTS

The risk assessment results for the current study assure that the risks from shipping spent fuel are significantly below those estimated in the baseline study. Both accident-free and accident risk are lower both on a single shipment basis and for the total number of shipments included in each study.

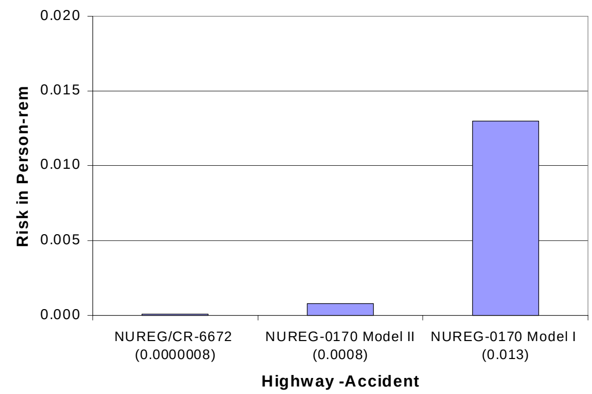
The risk assessment results for the Year 2000 risk study that are highlighted in this summary for one particular type of cask (steel/lead/steel), but are typical of the results for other types of casks. The primary results contained in the current study are for an average of 200 generalized "routes" that were developed from a much larger set of potential routes for spent fuel shipments. The results show that the risks from foreseeable future spent fuel shipments are expected to be small. In fact, the risks are significantly smaller than those estimated in the 1977 study.

The figures below present the accident-free and accident risks from the Year 2000 risk study and from the prior study for comparison. The results are presented for a single shipment. However, the results reported in the current study for the total number of shipments per year compared to total shipments risk in the 1977 study show the same relationship.

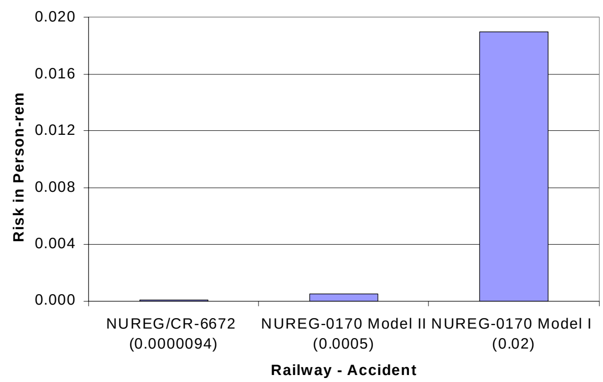
The bottom line is that the risk per year and risk per shipment estimated in the Year 2000 risk study for both railway and highway shipments are lower than those estimated in 1977. This fact provides confidence that the anticipated increase in spent fuel shipments from reactors to an interim storage facility or to a geologic repository will not entail a greater risk to the public than that considered acceptable in the 1977 study.



Risk Results for Rail Transport Mode

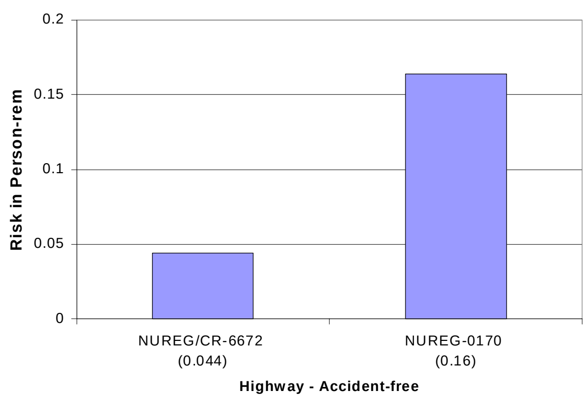


Risk Results for Highway Transport Mode



Risk Results for Rail Transport Mode

For the rail shipment mode, the accident-free risk in the Year 2000 risk study is about 44 percent less than the 1977 result. For accident risk, the result is more dramatic. Rail accident risk is only 2 percent of the estimate in the prior study.



Risk Results for Highway Transport Mode

The risk results for highway shipment show a trend similar to that for rail. Accident-free highway shipment risk in the Year 2000 risk study is 73 percent less than that reported in the prior study. Accident risk for highway shipment is sharply lower, just 0.1 percent of the 1977 estimated risk value.

Better casks or lower cask radiation levels did not cause these results. The governing regulations in 2000 and 1975 were basically the same. The marked reductions in risk for rail and highway shipment, especially for accident situations, results from the significant improvement in computer power for predict-ing fire and impact effects on casks, fuel rods, and fuel assemblies. Computers available for the baseline study were comparable to today's mid-range PCs and computer programs were much less capable than those available today.

The 1977 results reflected two accident release models. The first (Model I) greatly overstated the potential for a cask release; the second (Model II) was more realistic. Neither evaluated the details of fuel release. In the current study, researchers modeled the mechanisms for fuel failure, release of specific radionuclides to the cask interior, and deposit of the materials inside the cask. Predicting these effects strongly decreased the risk per shipment and total risk estimates relative to the 1977 study.

For the accident-free results, the risks per rail shipment are comparable to the prior risk assessment. This reflects the similar rail shipment conditions (speeds, stops per journey, cask radiation level) between the two studies. For highway shipments, the risk per shipment is significantly smaller in the current study. This results primarily from a more realistic representation of the number of stops made by a highway shipment in the current study. The 1977 study assumed sleep stops for the truck crew every 200 miles, but today crews typically drive continuously from origin to destination. For a 2000-mile trip, this greatly reduced the number of stops and reduced stop impacts by about a factor of 10.

About 1300 spent fuel shipments have been completed in the U.S. since 1977 without serious incident. During the same period, many more shipments have been completed safely internationally under the same basic regulatory framework. These safety records are consistent with the low risks estimated in the prior study and the lower risks estimated in the current study.

7. RISK RESULTS PERSPECTIVE

The results of the risk assessment performed in the Year 2000 risk study show that the risks from anticipated future spent fuel transport are less than those estimated in the 1977 study. While this document considered only highway and rail shipments in lead-shielded casks, similar results were obtained for other cask types and are described in detail in the new study. As a result, the NRC has determined that adequate levels of public safety will exist during the shipment of spent fuel to interim storage facilities and ultimately to a repository. In addition, the full report provides significant information on the details of data use and results of cask response to impact and fire accidents.

The goal for the Year 2000 risk study was to reevaluate the risks of shipping spent fuel as reported in 1977. The current report contributes to the Commission's pledge to continually evaluate transportation safety in light of expressed public concern about spent fuel shipments. It also provides a vehicle for further communication with the public on spent fuel transport risk.

Because NRC accepted the risk estimates in the 1977 study as protective of public safety, it was important to establish a comparative level of risk for the anticipated future shipments. In producing these results, the Year 2000 risk study used more modern computer technology and information than used in the 1977 study. The report included:

- advanced analysis methods for cask and fuel response to accident forces,
- Realistic uniform shipment rate over 30 years,
- more modern cask designs that are consistent with older fuel and which are expected to be available for the shipments, and
- more extensive and detailed transportation route data.

As a result, many features of the baseline study were made more realistic for the current study. Though many features of the prior report that led to overestimates were removed, the current study still overestimates risks. Even with these factors, the estimated risks in the Year 2000 risk study were much below that determined in the prior study.

The results from the new study show that the estimated total annual risks for expected future shipments are well below those estimated in 1977. This is true for both accident-free and accident risk for both rail and highway modes of transportation. Thus, risks to the public from future shipments of spent fuel — even with doubling the number of spent fuel shipments per year — will be well below the risk levels established in the 1977 report. As a result, the baseline report (NUREG-0170) remains valid as a primary source on which National Environmental Policy Act analyses of transportation risk are based.

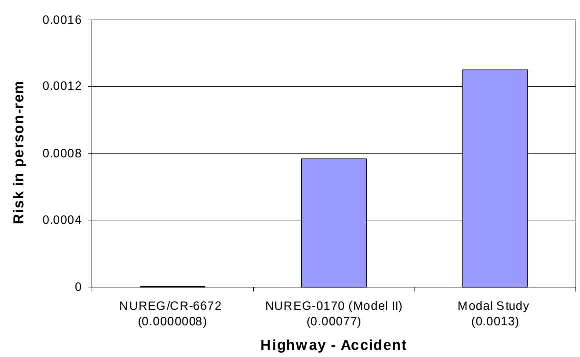
Accident-free transportation risks are quite small, amounting to about 100 person rem per year for highway and about 2 person rem per year for rail. These population doses are spread over a significant fraction of the U.S. population. As a result, average doses to individuals are virtually undetectable.

A person living at the edge of a roadway into a repository, who saw (and was exposed by) all trucks carrying spent fuel, would receive only about 3 millirem per year. As a maximum individual dose, this is well within the 100 millirem-per-year allowable dose standard for individuals, or the 25-millirem-per year standard used for long-term population exposures. Dose to individuals near a rail facility would be even smaller because of the lower number of rail shipments per year.

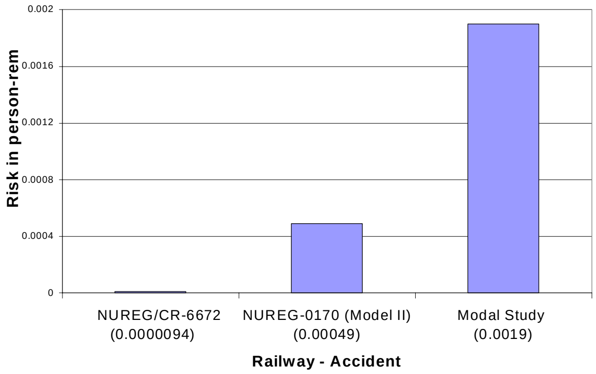
The risk from accidents in transportation is significantly smaller than the accident-free risk because of the very low chance of an accident that could produce a release. The most likely accidents produce population doses which are comparable to accident-free population risk, but even the most likely accident might be expected no more than once in 1000 years of shipping. As a result, accident risk in rail or highway modes is extremely small.

Other Studies – The charts below compare accident risk results with the Modal Study of 1987.

In the mid-1980s, NRC evaluated the response of truck and rail spent fuel casks to accident forces. No accident-free estimates were made in this work, referred to as the Modal Study. The Modal Study developed much of the accident event tree information used in the new study. It was the first to apply sophisticated computer models to find out how casks responded to impacts and fires. The Modal Study did not explicitly evaluate risk, but concluded that an accident risk estimate would be about one-third of that estimated in the 1977 study. The values shown in the figures for the Modal Study were estimated as part of the current study.



Highway Risk Comparison



Rail Risk Comparison

Every day, people must compare risks and benefits. In the case of spent fuel shipments, the benefits are on a national scale. They relate to enabling continued production of electricity and successful completion of the nuclear waste management program. An NRC risk standard was established in 1977 and determined that no unreasonable risk is posed by spent fuel shipments conducted in accordance with regulations. The new study demonstrates that those risks are not exceeded. Thus, NRC concludes that spent fuel shipments as analyzed are safe to continue.

8. REFERENCES

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