

**USE OF DEDICATED TRAINS FOR TRANSPORTATION
OF HIGH-LEVEL RADIOACTIVE WASTE
AND SPENT NUCLEAR FUEL**

**Report to the Congress
March 2005**

The Mandate

Section 15 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (Pub. L. No. 101-615), amended section 116 of the Hazardous Materials Transportation Act (49 U.S.C. App. 1813) to read in part as follows:

- (a) **RAILROAD TRANSPORTATION STUDY** - The Secretary, in consultation with the Department of Energy, the Nuclear Regulatory Commission, potentially affected States and Indian tribes, representatives of the railroad transportation industry and shippers of high-level radioactive waste and spent nuclear fuel, shall undertake a study comparing the safety of using trains operated exclusively for transporting high level radioactive waste and spent nuclear fuel (hereinafter in this section referred to as 'dedicated trains') with the safety of using other methods of rail transportation for such purposes. The Secretary shall report the results of the study to Congress not later than one year after the date of enactment of this section.

- (b) **SAFE RAIL TRANSPORT OF CERTAIN RADIOACTIVE MATERIALS.** -Within 24 months after the date of enactment of this section, taking into consideration the findings of the study conducted pursuant to subsection (a), the Secretary shall amend existing regulations as the Secretary deems appropriate to provide for the safe transportation by rail of high-level radioactive waste and spent nuclear fuel by various methods of rail transportation, including by dedicated train.

Executive Summary

This report compares the relative safety of rail shipment alternatives for the transport of spent nuclear fuel (SNF) and high-level radioactive waste (HLRW). These alternatives involve the use of: (1) regular trains: operating without restrictions with the exception of current hazardous materials and rail safety regulations; (2) key trains: similar to regular trains but operating with a maximum speed limit of 50 miles per hour (mph) or 80.4 kilometers per hour (km/hr) and other handling restrictions; and (3) dedicated trains: operating with a maximum speed limit of 50 mph (80.4 km/hr) and additional operating restrictions.

In preparation for this report, the U.S. Department of Transportation's (DOT) Volpe National Transportation Systems Center (Volpe), a part of the DOT Research and Innovative Technologies Administration (RITA), under contract to the DOT Federal Railroad Administration (FRA), performed a study to provide a safety analysis on whether the FRA should require carriers to use dedicated trains for shipment of SNF and HLRW (Volpe Study). In preparation for this report, FRA preliminarily considered the relative cost implications of using dedicated trains and the additional opportunities for risk reduction associated with use of dedicated rolling stock.

The study was initiated once funding was appropriated for it in the Spring of 1992. Representatives from the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), potentially affected States and Native American tribes, the railroad industry, and SNF/HLRW shippers were invited to attend and consult with the FRA and the study contractor at a 2-day Dedicated Train Workshop held in Denver, Colorado, in September 1992.

In preparing this report, FRA coordinated closely with the DOT Pipeline and Hazardous Materials Safety Administration (PHMSA), which also issues regulations governing transportation of hazardous materials in all modes,¹ and with the DOT Office of the Secretary. In addition, FRA consulted with DOE and NRC. Although comments from other governmental agencies were incorporated, this report is ultimately the responsibility of the DOT.

As more fully explained later in this report, the transportation of SNF/HLRW is thoroughly regulated, and several agencies of government play active, highly coordinated roles in endeavoring to ensure its safety. Over the past 45 years, approximately 600 train movements of these materials have occurred by rail without any incidents occurring that

¹ FRA, in concert with PHMSA, develops hazardous materials regulations specifically applicable to the rail mode for issuance by PHMSA. FRA enforces hazardous materials regulations applicable to transportation by rail. Both agencies act by delegation from the Secretary of Transportation. Actions referred to in this report where PHMSA is referenced were taken by the Research and Special Programs Administration (RSPA). The PHMSA, created by P.L. 108-427, is the successor organization to RSPA for DOT's hazardous materials transportation and pipeline safety responsibilities and did not yet exist for purposes of this report.

have affected the integrity of the shipping package. At the discretion of the shipper/carrier parties involved, the majority of these shipments were made using "special" or dedicated trains.² The responsible agencies work to continually verify the safety of packaging, rolling stock, and procedures, and the training of personnel involved in transportation. The railroad industry also issued its own standard for movement of these commodities, that seeks to establish performance guidelines for a cask/car/train system transporting high-level radioactive material. These guidelines are designed to ensure safe transportation, minimize time in transit, and incorporate best available technology to minimize the potential for a rail accident.³ This report addresses one additional means by which a greater level of safety might be achieved, the use of dedicated trains.

The Volpe Study analyzed both non-incident risk from radiation emitted from the cask during transportation and accident risk. Non-incident risk from the entire future shipping campaign is estimated to be on the order of approximately one (1) latent cancer fatality (LCF) for every 40,000 shipments in non-dedicated trains and approximately one (1) LCF for every 50,000 shipments in dedicated trains. Using the number of rail shipments expected over the life of the shipping campaign, as stated in DOE's Environmental Impact Statement on Yucca Mountain as a measure, the potential expected LCF's would be appreciably less than one. Therefore, regardless of the type of train, the potential exposures are essentially benign when compared to a lifetime of normal background radiation exposure from the sun or heightened radiation exposure from flying in a commercial airliner at 30,000 feet. The potential exposures are also benign when compared to radiation risks associated with smoking tobacco. However, given public interest in the subject matter, the basis for these estimates is set forth below. As the results show, if there is a discernable difference in risk for affected populations, the risk is less using a dedicated train.

With respect to accident risk, safeguards are already in place — principally NRC package certification requirements, railroad industry key train requirements, and FRA's focused inspection program — that have reduced the potential, to an extremely low probability, that a cask could be damaged in rail transportation to the extent it might release radioactive material into the environment. However, further reducing the possibility of a train accident involving a SNF/HLRW cask is highly desirable, despite the very low probability that the cask might be compromised. It is also recognized that any train accident involving a cask shipment would degrade public confidence in the ability to safely transport this material, and the presence of a cask would greatly complicate emergency response and wreck clearance operations, thus compounding costs to responders and the railroad.

² As used in this report a special or dedicated train is a train that consists only of equipment and lading associated with the transportation of SNF/HLRW. That is, the train consists only of necessary motive power, buffer cars and cask car or cars, together with a car for escort personnel. Such a train does not transport other rail rolling stock or other revenue or company freight.

³ Association of American Railroads (AAR) Standard S-2043: Performance Standard for Trains Used to Haul High Level Radioactive Material; AAR Circular Letter C-9619 dated April 29, 2003.

Importantly, the study results support the conclusion that use of dedicated trains would reduce both the probability of a SNF/HLRW cask being involved in a train accident and the possibility that other hazardous materials might be involved that could subject a cask to a fire environment with possible loss of shielding. Although the study intentionally uses worst-case assumptions (e.g., minimum compliance with NRC fire exposure criteria) and should not be taken as an absolute measure of risk, on a comparative basis, it is apparent that a dedicated train strategy should have a favorable impact on any residual risk.

As the Volpe Center was finalizing the study effort underlying this report, FRA's Office of Safety, in concert with the Office of Railroad Development, was reviewing informally the economic and other practical issues associated with this public policy decision. Appropriate train make-up and the value of rolling stock that incorporates the latest lessons in derailment prevention and most advanced technology are clearly important. FRA also recognizes the improvements in quality and efficiency of inspection by the railroad and FRA that can be realized through use of dedicated consists. FRA further recognizes the utility of enhanced operating procedures and training that could further reduce the potential for collision or derailment. The risk of an accident that seriously compromises a cask is extremely small under current conditions. Avoiding any accident that gives rise to a concern over cask integrity should heighten public confidence in the ability to safely transport SNF and HLRW and hold down the cost of emergency response related to any events where the circumstances suggest the need for caution.

FRA preliminarily explored whether use of dedicated trains would result in higher costs to shippers or railroads, and found that use of special trains is, de facto, the current reality. Railroads cannot afford the disruption associated with any event involving apparent or possible compromise of an SNF/HLRW shipment. Shippers seek to use escort personnel efficiently, and having their cars switched en route degrades this efficiency, particularly given terminal dwell times for normal freight that often exceed 24 hours. FRA's own safety program for these shipments is greatly simplified by use of special trains and would be further simplified to the extent particular rolling stock is dedicated to this purpose. Accordingly, preliminary analysis suggests that overall costs to society by using dedicated trains is not materially in excess of those costs for general revenue trains or key trains. In concert with RSPA, FRA will further extend and refine this analysis in the coming months and will make a final determination regarding the need for further rulemaking regarding conditions of transportation for these materials.

FRA is aware that post-9/11, security looms large as a concern for all forms of transportation. Although this report does not address security issues in detail, FRA is aware that NRC and DOE are considering the security ramifications of this issue. At the same time, DOT is working with the Department of Homeland Security (DHS) on the wider scope of security for the transportation of all regulated hazardous materials, of which SNF/HLRW is but one area. Based upon FRA's general knowledge of the rail environment and information available to the agency as a result of its efforts with industry and other agencies of government, use of dedicated trains should enhance security for transportation of the SNF/HLRW. Dedicated trains will be provided priority

on the railroad and will be routed more directly to a destination with a minimum of interruptions to the journey. Security arrangements along the route can be executed with greater precision because the routing and scheduling will be more certain. Accordingly, while this report does not make final judgments regarding the role of dedicated trains in the security of these shipments, neither does FRA discern any reason why security concerns should be in conflict with the use of dedicated trains; and there may be significant synergy.

Background

SNF is fuel that has been withdrawn from a nuclear reactor following irradiation and has undergone at least one year's decay since being used as a source of energy in a power reactor. Further, reprocessing has not separated the constituent elements of SNF. This fuel includes: (1) intact, non-defective fuel assemblies; (2) failed fuel assemblies in canisters; (3) fuel assemblies in canisters; (4) consolidated fuel rods in canisters; (5) non-fuel components inserted in pressurized water reactor fuel assemblies; (6) fuel channels attached to boiling water reactor fuel assemblies; and (7) non-fuel components and structural parts of assemblies in canisters [42 U.S.C. § 10101(23), 40 CFR 191.02 and DOE Order 5820.2A].

HLRW results from the reprocessing of SNF in a commercial or defense facility. It includes liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation [42 U.S.C. § 10101(12), 10 CFR Part 72.3 and DOE Order 5820.2A]. HLRW meeting this definition has been shipped by modes other than rail.

SNF and HLRW are required to be transported in casks constructed to NRC requirements. Casks are secured to specially constructed rail cars capable of transporting the heavy load.⁴ This study assumes that the cask car(s) will be surrounded by two buffer cars and accompanied by an escort car. This complement of cars is referred to as the cask consist. A dedicated train is comprised of the cask consist and multiple locomotives. A regular or key train will include the cask consist, locomotive(s), along with any number of additional cars potentially containing other regulated hazardous materials, various other general cargo and/or empty rail cars.

Regular trains typically operate at allowable freight track speed, make numerous classification yard entries, and adhere to hazardous materials transportation regulations when transporting any regulated hazardous material, including SNF and HLRW. Since it was not possible to analyze all possible consist and operational arrangements of regular

⁴ A typical cask assembly weighs about 250,000 pounds, and a loaded cask car weighs about 394,500 pounds, in contrast to a typical rail load of 286,000 pounds. Like other cars constructed to carry heavy loads, cask cars use additional axles and span bolsters to distribute the weight over a larger portion of the track structure. Other special loads transported on the railroad include large transformers and specialized industrial equipment.

trains within the confines of this study, the model consisted of a generic regular train of 70 cars, with the cask consist in the middle of the train.⁵

In 2001, the Association of American Railroads (AAR) issued a Recommended Practice Circular defining any consist containing SNF or HLRW as a Key Train and routes with specified levels of hazardous materials including SNF and HLRW as Key Routes.⁶ Key trains are similar to regular trains in length and general operating rules except for the following:

- No consist restriction in excess of current regulatory requirements
- Cask is placed on a flatcar between two buffer cars
- Train has a railcar with escort personnel aboard who monitor/guard the shipment
- A 50 mph (80.4 km/hr) speed restriction
- Passing not restricted unless on lower than Class 2 Track
- All cars in the consist are equipped with roller bearings with rules about alarms
- Key Routes have hot bearing detection equipment at minimum intervals and the track must be inspected twice annually for internal flaws and geometry irregularities.

In the Volpe Study, by contrast, dedicated trains were assumed to operate according to the following:

- Consist is restricted - no freight other than SNF and/or HLRW is carried
- Cask is placed on a specially designed and equipped flatcar between two buffer cars
- Multiple locomotives
- Train has a railcar with escort personnel aboard who monitor/guard the shipment
- A 50-mph (80.4 km/hr) speed restriction. For completeness a 35 mph (56.3 km/hr) speed restriction was also analyzed although this restriction no longer applies since the publication of AAR circular OT-55-D
- Passing is restricted on all track classes-when a dedicated train is passed by another train, one of the trains remains still while the other train passes at a speed less than or equal to 50 mph (80.4 km/hr). Again, for completeness a 35-mph (56.3 km/hr) speed was also analyzed.

Between 1979 and 1997, there were over 1,300 shipments of commercial SNF and HLRW totaling over 1,102 tons (1,000 metric tons). Although only about 11 percent of the shipments were by rail, these accounted for over 75 percent of the tonnage [NRC,

⁵ FRA does not mandate specific placement of loaded and empty cars in trains except in the case of placarded cars carrying regulated hazardous materials in accordance with 49 CFR 174.85. However, industry guidelines and carrier rules exist to address train make-up in light of joint industry-government research. From the point of view of train-track dynamics, a heavy vehicle such as a cask car would typically require placement in the first third of the train.

⁶ AAR Recommended Practice Circular OT-55D, Recommended Railroad Operating Practices for Transportation of Hazardous Materials, 2001.

1998].⁷ To date, there have also been approximately 800 shipments of naval SNF and HLRW safely made in both regular trains and dedicated trains. In the future, DOE estimates that a total of between 11,000 and 17,000 casks of SNF and HLRW will need to be shipped by rail [DOE, 2002b].⁸ A shipment by rail can consist of a single movement of a single cask or a single movement of multiple casks with escort and buffer cars, as needed.

Safety Compliance Oversight

Regulations addressing hazard communication, training, security plans, packaging and modal operational requirements for transporting regulated hazardous materials, which includes SNF and HLRW, exist in 49 CFR Parts 100-185 (Hazardous Materials Regulations). Rail safety regulations in 49 CFR Parts 200-244 address safety requirements for railroad operations, including, for example: rail equipment, track, signal systems, communications, train crews, and grade crossings. These rail safety regulations apply regardless of whether there is any hazardous material being transported in a train.

The nation's rail carriers conduct their own inspections in their efforts to ensure compliance with all applicable regulations. The FRA and participating State agencies that have FRA Certified State inspectors continually use the resources available to them to the extent possible to conduct inspections of the nations rail carriers and to ensure that regulatory compliance is being achieved.

In addition to these efforts, the FRA developed and implemented the Safety Compliance Oversight Plan (SCOP),⁹ a coordination and inspection plan specific to all known rail shipments of SNF and HLRW. Implementation of the SCOP focuses available resources in order to ensure the safe and secure transportation of SNF and HLRW. The SCOP addresses what tasks the FRA and its FRA certified State inspection partners will perform for shipments of SNF and HLRW. The tasks cover all operational aspects of the rail transportation environment, as well as planning and coordination tasks with entities and agencies involved in the transportation of this material.

To date FRA has implemented the SCOP for each movement due to the infrequency of these shipments. However, FRA recognizes that as shipments "ramp up," which could be as early as 2007, it will become increasingly difficult to implement the SCOP tasks in their entirety as they currently exist for every shipment. Congress has recognized the

⁷ U.S. Nuclear Regulatory Commission. "Public Information Circular for Shipments of Irradiated Reactor Fuel." Washington, D.C.: NUREG-0725 Rev 13. October 1998.

⁸ U.S. Department of Energy. "Final Environmental Impact Statement for a Geological Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada." Washington, D.C.: Office of Civilian Radioactive Waste Management, DOE/EIS-0250 Vol. I and II. February 2002.

⁹ FRA's Safety Compliance Oversight Plan (SCOP), can be viewed and downloaded from FRA's web site at www.fra.gov/downloads/safety/scopfml.pdf

importance of ensuring that shipments of SNF and HLRW move safely and securely and provided FRA with the ability to add inspection personnel via the budget process. Regardless of the type of train used for this function, FRA and participating State agencies will continue to facilitate the safest possible transportation of SNF/HLRW by enforcing the railroad safety laws and regulations, and the Hazardous Materials Regulations. However, it is evident that FRA's task in this regard is greatly simplified and the likelihood of success is enhanced, where dedicated equipment is employed and the route is as direct and well suited to the mission as possible. Concentrating on the safety of a discrete subset of locomotives and cars, and surveying a route that avoids congested yards, will increase the likelihood that safety concerns are reliably identified and remedied before the shipment is accepted by the railroad.

Comparative Risk Assessment

The Volpe Study assumed two basic types of risks involved with transporting SNF and HLRW: (1) incident-free risks and (2) accident-related risks. The incident-free risks associated with normal emissions of very low radiation doses from the cask involved absolute risks of appreciably less than one LCF for the entire exposed population for the highest risk case-the regular train-over an entire shipping campaign. Primarily because of the reduced time in transportation, incident-free risk was lowest for dedicated trains (again appreciably less than one LCF for the shipping campaign). These estimates are higher than would be realized in actuality, as they assume the maximum allowed emissions from the casks in non-exclusive use transportation, rather than the generally lower emissions from actual shipments.¹⁰

Incident-free risks result from continuous emissions of low doses of radiation, which the cask shielding cannot totally contain. However, the emissions can and are limited to acceptable safe levels (a maximum of 10 millirems per hour (mrem/hr) at 3.3 feet (1 meter) from the surface of the package [49 CFR 173.441]). All individuals exposed to the radiation being emitted from the cask during transport, handling, loading and unloading are exposed to very low doses of incident-free radiation.

Accident-related risks result from the potential of exposure to radiation after an accident occurs. Radiological consequences were calculated for accidents where consequences vary with the use of a regular, key, or dedicated train service. For each accident type, incident durations from 3 to 72 hours were analyzed to account for a range of severities, and three locations types, urban, suburban, and rural, were analyzed. For the purposes of this study, accidents were broken down into four severity categories:

¹⁰ Prior to proffering a cask for shipment, the shipper must demonstrate compliance of the cask design with 10 CFR Part 71, as promulgated by the NRC. Experience has shown that radiation levels emitted by the package are generally below the maximum allowed by regulation for non-exclusive use shipments due to the shielding built into the packages and the efforts of the shipper to reduce the external radiation levels to be as low as possible. In addition, radiation levels are checked by State and Federal Government agencies prior to being offered into transportation and can also be monitored while in transportation. FRA recently secured additional staff to support this function.

- Category I Delay event - accident well within the Hypothetical Accident Conditions (HAC) modeled by the cask packaging test criteria of 10 CFR Part 71; dose rate assumed equivalent to the allowed non-exclusive use transport rate of 10 mrem/hr at 3.3 feet (1 m) from the cask surface. Accidents in Category I could result in an increased duration of exposure to certain individuals (such as crew and nearby population) due to the extended time required to clear the wreck scene and resume transport.
- Category II Serious accident - an accident close to the HAC, which could result in a hundredfold increase in radiation levels but no release of radioactive material occurs. The dose rate is assumed equal to 1 rem/hr (1,000 mrem/hr) at 3.3 feet (1 m) from the cask surface. Accidents in Category II could expose populations to higher doses of radiation for extended time periods.
- Category III Major accident - an accident that generates forces or temperatures that exceed the HAC. A greater loss of shielding or internal damage occurs but there is no release of radioactive material. The dose rate is assumed to be equal to 4.3 rem/hr (4,300 mrem/hr) at 3.3 feet (1 m) from the cask surface. Accidents in Category III could expose populations to higher doses of radiation for extended time periods.
- Category IV Severe accident - an accident resulting in forces or temperatures well in excess of the HAC. A significant loss of shielding or cask damage resulting in the release of some radioactive material. This category was not analyzed as it was considered equally unlikely for any of the shipping options and the consequences would not be substantially different.

The consequences of any of these four types of accidents are determined by: the environment in which the accident occurred; the potential for a second "event" such as a fire following the initial impact, puncture, or fall; and the time required to respond to the accident.

Incident-free and accident-related risks are analyzed for entire populations, and results are expressed as population doses (person-rem). These population doses are also converted into an estimate of health effects, i.e., LCFs. Doses for individuals (where applicable and possible) are expressed in units of millirem (mrem).

The use of LCF as a metric of deleterious health effect is based upon the assumption that any amount of radiation exposure may pose some risk. This is the linear, no-threshold (LNT) model, in which any increase in dose has an incremental increase in the risk of occurrence of cancer. LNT is the accepted model used in the U.S. as well as by international radiation protection bodies. The LCF rate for worker population is 0.0004,

while that for the general population is 0.0005 [NCRP 1993].¹¹ When the rates are applied to an individual, the units are for a lifetime probability of LCFs per rem (or 1,000 mrem) of radiation dose. When the rates are applied towards a population of individuals, the units are excess number of cancers per person-rem of radiation dose. The difference between the worker dose and the general public risk is attributable to the fact that the general population includes more individuals in sensitive age groups (that is, less than 18 years of age and over 65 years of age).

Calculating Risk

The total risk associated with transporting SNF and HLRW is the result of both incident-free risk and accident-related risk. The amount of the low-level exposure associated with Incident-free transport depends on the details of the number of shipments, specific routes and operating variations. Accident risks are associated with relatively low probability events. The accident probabilities are based on historical accident data independent of a specific route or location. Incident-free and accident-related risks of radiological exposure are calculated independently for regular, key, or dedicated train service. The results from these calculations are then compared against commonly accepted radiological exposures to put the calculated risk into perspective.

Incident-Free Risk

"Incident-free risk" involves calculating the total expected radiation dose to the public and other impacted populations for specific routes, assuming no accidents, and comparing that calculation to the incident-free risk for regular, key, and dedicated trains. A radiation level of 10 mrem/hr measured at 3.3 feet (1 m) from the package surface was used to calculate population exposures; this is the maximum level for radioactive material packages in non-exclusive use service. The results are also compared to the radiation received by a passenger on a four-hour airline flight. Regulations in 49 CFR 173.441 for exclusive-use shipments do allow for higher radiation levels to exist both at the package surface and at one meter from the package, and yet still allow the package to be transported, but only if additional safety measures are implemented. Experience with shipments of SNF and HLRW to date have shown the radiation levels are well within the prescribed lower regulatory limits for non-exclusive use shipments, and therefore are the norm.

Though SNF/HLRW casks are very well shielded by design, they continuously emit low levels of radiation throughout all phases of transportation. Hence, radiation exposure to crew, handlers, yard personnel, and the wayside population occurs even in the event that an accident does not occur. Therefore the probability of exposure is equal to one. The exposure of all affected populations during regular transport is defined as the incident-free risk. The radiological consequences of SNF/HLRW shipments are a function of the selected route, the cask design and material being transported, the size of the impacted

¹¹ National Council on Radiation Protection and Measurement (NCRP). "Limitation of Exposure to Ionizing Radiation." Bethesda, MD: NCRP Report No. 116, 1993.

populations, the population distance from the cask, the total exposure time, and the amount of shielding between the cask and the impacted populations.

RADTRAN 5, a set of computer models for the analysis of the consequences and risks of radioactive material transport, was used to calculate the incident-free risk. The package dose rate and the package-specific characteristics are used to model the transport cask as a point source for extended distances. For shorter distances, within two characteristic lengths of the cask, the package is treated as a line source. The transportation system characteristics are incorporated into a rail-specific model, with input parameters for population along the route and at stops, vehicle velocity and stop duration. The population density is defined by the user along each route segment. Inputs include the specific characteristics of sub-populations like the number of passengers, crews, and rail workers. The general population is broken into three sub-groups: urban, suburban, and rural.

The calculations were conducted for in-transit exposures (off-link and on-link) and exposures at stops. Off-link doses are defined as those received by persons on the ground within 875 yards (800 m) of a passing train. On-link doses are defined as doses received by persons on passing trains as well as by the escorts and crews onboard the cask-carrying train. Stop doses were calculated as doses received by persons on the ground as well as crew and escorts within 875 yards (800 m) of the train during a stop.

Six routes were chosen for analysis. These routes were chosen to cover a representative number of origination locations across the country with currently operating nuclear power plants or waste repositories that handle SNF or HLRW. The presumed destination point for all routes is Yucca Mountain in Nevada. Table 1 provides a breakdown of the length of each route as well as the associated average population densities along each route broken down into urban, suburban, and rural sub-groups. The selected routes are likely candidates and are representative in terms of their geographic location and length.

There are many designs and sizes of casks for transporting SNF and HLRW. For purposes of this study, it is assumed that the cask will be a large 125-ton (113-metric ton) multi-purpose rail cask [DOE, 1993].¹² The incident-free dose rate was taken as 10 mrem/hr at 3.3 feet (1 m). As described above the transport cask emission rate was modeled as either a point source or a line source depending on the distance of the exposed population from the transport cask.

¹² U.S. Department of Energy. MPS Conceptual Design. Draft 1993.

Table 1. Routes Used in the Analysis

Route Number	Origin	Length	Average Population Density Persons/sq mile (persons/sq km)		
			miles (km)	Urban	Suburban
1	Humboldt Nuclear Power Plant, CA	1,090 (1,754)	6,237 (2,408)	1,164 (449)	26 (10)
2	Crystal River Nuclear Power Plant, FL	2,988 (4,809)	5,641 (2,178)	976 (377)	38 (15)
3	Dresden Nuclear Power Plant Dock, IL	1,920 (3,090)	5,169 (1,996)	1,006 (389)	26 (10)
4	River Bend Nuclear Power Plant, LA	2,471 (3,977)	4,964 (1,917)	919 (355)	30 (12)
5	Seabrook Nuclear Power Plant, NH	3,086 (4,966)	6,109 (2,359)	1,028 (397)	28 (11)
6	Hanford Repository, WA	1,226 (1,973)	4,744 (1,832)	1,307 (505)	17 (7)

Source: 2000 U.S. Census

The exposed populations were broken down into the following categories:

- General population - individuals residing and working near rail lines (waysides) over which the cask passes as well as people who live near yards and sidings where the cask consist may stop temporarily
- Persons on trains sharing the route of the shipment
- Vehicle occupants at grade crossings along the shipment route
- Train crew located in the lead locomotive on the train transporting the SNF/HLRW
- Escorts on the train transporting the SNF/HLRW
- Railroad personnel who work in close proximity to the cask in classification yards and inspect the train at various points
- Other rail yard workers not in close proximity of the shipment.

Each of the different groups experience different exposure levels and durations. Wayside populations and passengers on passing trains will be exposed as the shipment passes. High-resolution population data was used from the 2000 U.S. Census to allocate population density along the length of each route in a one-mile wide corridor. Greater exposure will be calculated for longer routes that are highly populated. This is because exposure time is the determining factor in the amount of radiation members of a population group receive. Time spent near both moving and standing shipments affect exposure. Train operational restrictions such as train speed and run through operations impact exposure time both at stops and in transit.

The train density and train occupancy data derived from the Rail Garrison¹³ network studies were used to assign the number of persons likely to be sharing the railway with the shipment. The average passenger train density was used for the three general population sub-groups: urban at 0.4 trains/hr, suburban at 0.2 trains/hr, and rural at 0.14 trains/hr. The weighted average train speed for each type of train is the determining parameter for exposure. The faster the trains are allowed to travel, the shorter the exposure time.

Vehicle occupants at grade crossings on each side of the railroad can be exposed to emissions from passing shipments. The exposure to this sub-population was split into two different calculations: one for the general sub-population and the second for cars within a prescribed distance to the passing shipment. For the purposes of this study it was assumed that five vehicles would be occupying either side of the track during the passing of a shipment.

Members of the train crew and escorts are exposed for the full duration of the shipment and therefore experience the highest exposure levels of any sub-population. The exposures for these sub-populations are governed by distance from the source, length of route, and stops. Crew members on regular or key trains have the advantage of being further away from the cask consist than those on dedicated trains. However, the position of the escorts on any train type is the same.

During stops at yards or sidings, other railroad personnel will be exposed for the duration of the stop. Since train stops usually occur at rail yards, the population in and near a rail yard is modeled as a uniformly distributed population and the dose is integrated over this population. For rail stops, the public dose was calculated using the suburban population density. Greater exposure occurs for longer stop times and along routes that have more stops.

Exposure time for incident-free risk is determined by train speed, whether run-through operations are allowed, and the number of stops required at yards or sidings. The speed restrictions on the key and dedicated trains increase in-transit exposure time when compared to regular trains. However, the difference is greatly affected by such factors as the class of track over which the shipment traverses. Higher track classes allow for greater train speeds.

The last critical factor associated with exposure is the type of shielding factor that is applied to the various sub-populations to determine gamma radiation attenuation (absorption by physical structures). For the general wayside population different shielding factors were applied depending on the population density. Rural populations were assigned a shielding value of 1.0, which corresponds to no shielding. Suburban

¹³ Peacekeeper Rail Garrison Program, Rail Network Database developed by Earth Technology Corporation for the Department of the Air Force. Network not publicly available but similar network data available from National 1:100,000 scale Rail Network, distributed on the National Transportation Atlas Database produced by the Bureau of Transportation Statistics (BTS)

populations were assigned a shielding factor of 0.87 because of the presence of closely spaced structures generally constructed from wood and cinderblocks. The urban population had the highest shielding factor of 0.018 due to the concentration of buildings constructed from concrete and steel. Occupants at grade crossings, train passengers, escorts, and inspectors/handlers were assigned a shielding factor of 1.0 (no shielding). Crewmembers were assigned a shielding factor of 0.5 assuming that the intermediate locomotive(s) provides gamma radiation attenuation. General yard workers were assigned a shielding factor of 0.1 due to the mitigating effects of gamma radiation attenuation by rail cars and structures in the rail yard. The suburban shielding factor was used for the general population for all stops.

Risk to all population groups is strictly a function of the period of exposure, distance from the cask and the assumed level of shielding provided by intervening equipment or buildings. Transit time and time in yards becomes a major determinant when comparing service options.

Accident-Related Risk

"Accident-related risk" involves comparing the radiological exposure due to accidents with that for regular, key, and dedicated train service by using three components: accident involvement probability, accident severity probability, and expected consequences.

Accident-related risk is the second form of risk associated with the transport of SNF and HLRW along the national rail corridors between originations and final destination. Aggregate accident-related exposure is not calculated; aggregate accident probabilities, not specific to routes, are calculated. Potential accident related exposure is examined by predicting the accident likelihood for the three rail transport methods, and then assigning radiological consequences, broken down into four severity categories. The baseline accident probability is calculated for regular train transport using historical accident data from 1988 to 2001. Dividing the total number of accidents by reported train miles for each year normalized these historical accident rates. The rates were then adjusted to reflect the special constraints associated with key and dedicated trains.

Event schematic "trees" based on these probabilities were then constructed that show the probability of any mainline or yard accident for regular train service. During this 1988-2001 period the number of train miles varied from year to year but generally has risen. A long period was chosen to help determine the probability of extremely rare events such as major fires or high-speed collisions. The variation in accident probability in terms of train miles is not expected to noticeably change with the addition of dedicated trains in the future. Changes in operating practices and improvements in equipment and infrastructure maintenance should reduce these rates. For this analysis, the accident probability is assumed to be constant, as reflected by the event trees. These trees were then modified to reflect the effect of key and dedicated trains on accident probabilities. Aside from speed limits, the dedicated train modifications included operational restrictions, consist limits, and reduced visits to yards.

Radiological-related risks from accidents are based upon the following factors: the design of the cask and its ability to withstand mechanical, thermal, and combined mechanical and thermal accident loads, the likely level of loss-of-shielding (LOS) resulting from accident loads, and the effect of that radiation on crews, escorts, emergency response personnel and the general population surrounding an accident site.

A key assumption in the analysis was the response of the generic cask design. Analysis results were taken from a Sandia National Laboratories study performed on a bare cask with no impact limiters, impacting surfaces with varying hardness, at a range of impact speeds and in different orientations. Force-crush characteristics were taken from that study for the hypothetical 125-ton (113-metric ton) steel-lead-steel cask. These characteristics were then used as inputs into a simplified collision dynamics model to investigate residual cask impact speeds for secondary impacts. The conservative assumption was made that any impacts in the rail environment would be considered as impacts into a hard but not unyielding surface. The speed equivalent of the NRC required package certification HAC drop test criteria in 10 CFR Part 71 onto an essentially unyielding planar surface has been determined to be 30 mph.

There is substantial kinetic energy associated with a train in the event of a collision or derailment. This energy must be dissipated through various mechanisms prior to the train coming to a complete stop. Energy consumption through plastic deformations of colliding objects, plowing of rails and ballast, and emergency braking are only a few ways that the collision energy is absorbed. Of concern for this analysis is the consumption of energy through plastic deformations of rail equipment and the cask. Two collision types were studied: a primary impact against a heavy freight locomotive, and a subsequent secondary impact against the surrounding infrastructure or environment.

A transport cask impact with a heavy freight locomotive was chosen as a representative example of a worst case primary impact in the rail environment. Two impact load paths were assumed for crush of a generic freight locomotive. Using each crush trajectory, force-crush characteristics were developed based upon previous crashworthiness work. The force-crush characteristics of both the transport cask and the freight locomotive were used to establish LOS from a direct impact of the cask with a locomotive. LOS addresses the extent or degree that a SNF/HLRW cask may experience alteration of the radiation shielding component of the cask package, potentially resulting in increased radiation fields outside the cask package envelope. It was determined that cask damage could not occur for primary impacts with a heavy freight locomotive.

The second collision type studied was secondary impact of bare transport casks, without force limiters with the surrounding rail environment. The cask residual speed after a primary impact at various cask orientations and speeds was calculated for the following classes of collisions: head-on, rear-end, rail-rail crossings, and raking/corner impacts. Calculations were performed to determine scenarios where residual cask speeds exceeded the required NRC package certification drop test speed equivalent. This information was then used to estimate the accident consequences for the four severity categories.

Three event trees were constructed for regular train service: one for mainline incidents, one for yard incidents, and one for fires. Fires are treated independently, because they can be initiating events or a secondary event following one of the other accident scenarios. The distinction between mainline and yard accidents is made to account for the significant difference in the number of yard entries made by a regular/key train versus a dedicated train. There is a significant decrease in accident probability that results from this operational distinction. This information is used when modifying the accident rates for dedicated trains.

Each event tree begins with the overall train accident rate per train mile based upon the historical accident review. Accidents are further sub-divided into the following categories: collision, derailment, highway-rail grade crossing, fires/explosions, and miscellaneous. The probabilities for these sub-accident distinctions are reflected in the second level nodes on the event tree. These sub-accidents can result in a derailment, so the probability of a subsequent derailment is also calculated. Accident severity is calculated using the range of speeds that the derailment occurs at and is broken down into the four severity categories. The severity category is based upon the comparison of the final derailment speed to the required NRC package certification drop test speed equivalent.

Study Results

Incident-Free Risk

The total exposure during incident-free transport of SNF and HLRW is extremely low for all train service types (regular, key, and dedicated). In all of the examined representative routes, the expected number of LCFs incurred by any type of train service is less than one (1) for the total estimated number of shipments over the entire projected DOE shipping campaign.

The magnitude of radiation dosage to any population in incident-free shipping of SNF and HLRW is dependent on the total exposure time and the distance from the shipping cask. Exposure time, therefore, is heavily influenced by the amount of stop time (mostly in rail yards) and the amount of time the shipment is in transit.

Although all train service types have extremely low dose levels, there are measurable differences in radiological exposure due to the service type. Regular and key train service would result in higher potential doses to the general public, with estimates of 0.0235 person-rem to 0.0495 person-rem per single cask shipment. This translates into LCF estimates of 1.17×10^{-5} to 2.48×10^{-5} per single cask shipment; in the worst case, this is roughly one LCF for every 40,000 shipments. The DOE estimates that there are approximately 11,000 to 17,000 waste packages to be shipped by rail over the entire campaign [DOE 2002b]. Dedicated trains reduce this exposure range to 0.0177 person-rem to 0.0364 person-rem per shipment, or 8.85×10^{-6} to 1.82×10^{-5} LCF. The highest range of this estimate corresponds to approximately one LCF per 50,000 shipments. This

reduction is primarily due to the fact that dedicated trains do not stop in yards for classification, reducing the total exposure time.

The total radiation dose to a person standing 98.5 feet (30 m) from a train carrying a single SNF/HLRW car as it passes at 15 mph (24 km/hr) is calculated to be approximately 0.0004 mrem (this value is independent of train type). For comparison, the average dose received by a passenger on a four-hour jet flight is roughly 3 mrem, or four orders of magnitude greater than a cask shipment.

Rail worker doses are lower for dedicated trains than for key and regular trains. The total radiation dose to all rail workers through regular or key trains for the examined routes ranges from 0.0988 person-rem to 0.1755 person-rem per shipment, or 3.95×10^{-5} to 7.02×10^{-5} LCF. The highest range of this estimate corresponds to approximately one LCF per 14,000 shipments. Dedicated train single shipment doses ranged from 0.0496 person-rem to 0.0987 person-rem, which translates into 1.98×10^{-5} to 3.95×10^{-5} LCF. This small decrease in absolute dose value is primarily due to the reduced yard visits of dedicated trains.

Train crew doses are actually higher for dedicated trains than for the other service types due to the proximity of the cask car to the locomotive in a dedicated train consist; however, in all cases the radiation exposure of the train crew from a single cask shipment is multiple orders of magnitude less than the annual limits prescribed by Federal regulations (10 CFR 20). The highest exposure estimate of a dedicated train crewmember is 0.808 mrem per single cask shipment. For comparison, the regulatory maximum annual dose for non-radiation workers is 100 mrem, or over 100 single cask shipments in a year by the same crewperson for this worst-case dose estimate. The highest crewperson dose per single cask shipment for regular or key trains is less, approximately 0.016 mrem.

Accident-Related Risk

The assumptions used to analyze the accident consequences and probabilities make regular and key trains nearly identical in terms of risk.

The historical accident probabilities were sorted by the resulting radiological severity category. The consequences of category I, II, and III accidents are slight in terms of resulting LCF for all train service types. Analysis indicates that category II and III accidents are very unlikely events, regardless of service type.

The event trees constructed from historical accident data indicate that the most likely sources of category II accidents are derailment accidents and yard accidents. The probability of an accident that is more severe than the NRC HAC package certification regulatory test requirements (category III) is extremely low for all service types. Dedicated trains have the lowest accident probability due to the decreased stopping distance of the shorter consist, the fewer number of cars to derail, and fewer yard visits (decreasing yard accident probabilities). The probability of a fire engulfing the cask car

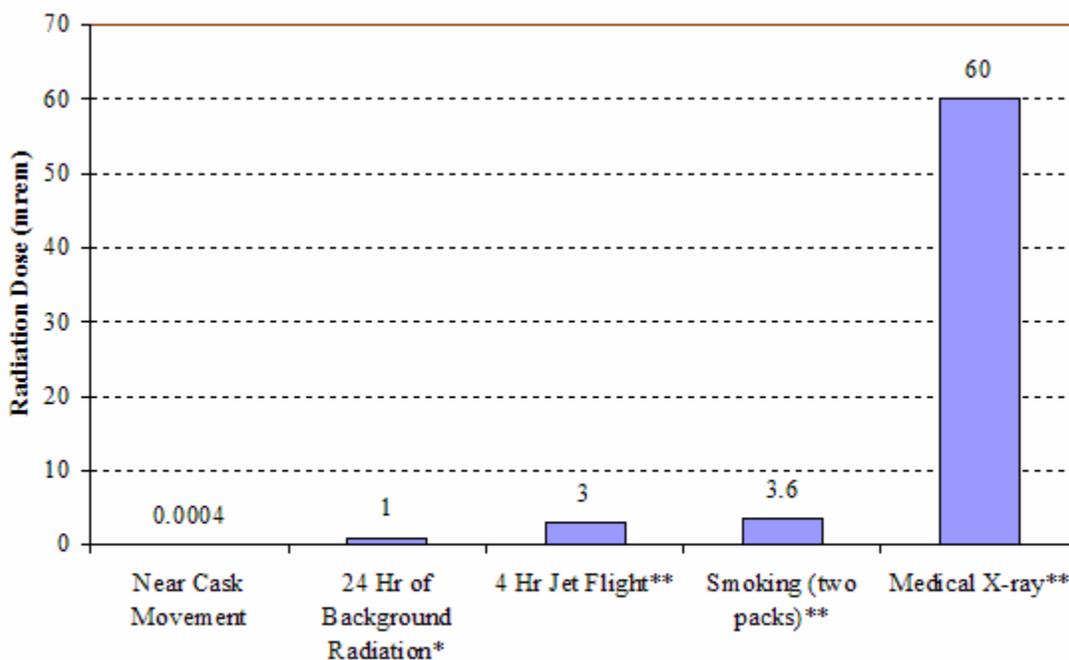
is lower for dedicated trains because cars carrying hazardous materials are restricted from the consist.

The predicted LCF consequences of category I, II, and III accidents are multiple orders of magnitude less than one per incident, regardless of service type. As with incident-free transport, differences in service are delineated in the results of this study. Regular or key trains involved in a category III accident are estimated to result in less than 0.03 LCF. The LCF prediction for dedicated trains involved in a category III accident is considerably lower: less than 0.009 LCF. The differential is due to the fact that the greater number of cars in regular and key trains requires more rerailling time. The accident consequences of category I and II accidents are substantially less severe, resulting in several orders of magnitude less than one LCF per incident.

Significance of Findings

The study concluded that the maximum individual radiological exposure resulting from an incident-free shipment of SNF or HLRW by regular, key, and dedicated trains is approximately equal to the exposure received in the first two seconds of a typical 4-hour airline journey. Figure 1 compares incident-free exposure rate with other common exposures.

Figure 1
Comparison of Incident-Free Exposure Rate vs. Other Common Exposures



Source:

* www.oerwm.doe.gov

** National Council on Radiation Protection (NCRP)

The dominant feature that differentiates the three types of service in the incident-free analysis is transit time. Although both key and dedicated trains have a 50 mph operating speed limit, dedicated trains will have the shortest transit times because they would spend less time in yards.

Dedicated trains would be expected to have lower collective population exposures because of the shorter transit times. Dedicated train crew exposures would be higher due to the cask being closer to the crew. The study did not take into account potential As Low As Reasonably Achievable (ALARA) radiation controls that could be used by train crews to further limit their potential exposure.

When considering the accident-related radiological risks there are three relevant issues: the likelihood of an accident, the severity of the accident, and the recovery time from the accident. When considering the accident risk, the likelihood of a category III accident, where cask damage exceeds regulatory limits but does not involve radioactive material release, dominates the analysis. For all types of service studied, the category III events are very rare. The resulting exposure would still result in a small fraction of one LCF.

Dedicated trains, compared to regular and key trains, reduce the potential radiation exposure in any accident, as accident clearing can be expedited with shorter trains. In addition, since there are no other hazardous materials in the consist, there would be little chance of a fire which would prolong the response and accident clearing duration.

Key trains, similar to dedicated trains, provide an increase in safety resulting from speed restrictions, but are more similar to regular trains in terms of overall risk. Key trains have a risk of high-speed impacts equal to or slightly greater than that of dedicated trains, which could result in cask damage that could potentially exceed the criteria to which it was certified. A severe fire involvement and yard accident probability of a key train is equal to the risk for regular trains. Given a derailment, the length of regular and key trains and the likely number of derailling cars will extend the time necessary to address an accident and increase the radiation dose to surrounding populations.

Analysis of the location and pattern of accident occurrences indicates that route specific factors, such as the number of yards encountered, can have a significant impact on risks. The use of dedicated trains will expedite shipments and will reduce the hazards associated with frequent yard visits, especially on long routes where multiple stops in yards are required. Use of dedicated trains also allows more flexibility to avoid higher-risk locations and to impose restrictions such as lower operating speeds.

In this study a consist of only one cask was assumed to be present in any of the transport options. Operating consists of multiple casks could be included in any of the trains changing the cumulative exposures to crewmembers and the general public. Multiple cask consists would in general reduce the cumulative radiation exposure for the incident-free case, but might slightly increase the probability of severe accidents due to a cask-to-cask collision.

Note on Total System Risk

Some analyses of the merits of dedicated trains suggest that their use would increase train miles and thus, overall, increase risk in rail transportation. FRA appreciates this perspective but believes this consideration is not dispositive for the following reasons:

- Any additional net increase in exposure is significantly less than that associated with the dedicated train. A conventional train would need to switch the shipping point, incurring risk similar to that incurred by the dedicated train. Depending upon the configuration of the rail facilities, including the industry track, additional risk might be introduced related to cars left on the main line (collision potential, roll-away potential) in the conventional train configuration. The same issues apply at destination
- As reflected in the Volpe Study, the more direct route taken by the dedicated train reduces both non-incident and accident-related risk associated with this type of shipment
- Under the new AAR Standard, the likelihood of derailment associated with transportation of the overweight cask car will be further mitigated through use of a state-of-the-art consist (Although defined in terms of key trains, this is actually a dedicated train concept and is wholly incompatible with a general manifest train)
- Use of Electronically Controlled Pneumatic (ECP) brakes by dedicated trains will reduce or greatly mitigate collision events, including highway-rail crossing collisions
- The principal element of exposure for all types of trains are highway-rail grade crossing accidents. This exposure, and it is the same for dedicated, key, and regular trains, is in decline due to improvements in engineering, education, and enforcement (when compared with the incident rate during earlier studies).¹⁴

It should also be noted that, as a society, some risks are tolerated more readily than others. Normal risks associated with rail transportation are more readily tolerated than the risk of a significant event involving a SNF/HLRW movement, in part because of limited public understanding regarding the safeguards provided. Where public tolerance is low, there is value (in the form of reduced anxiety and increased acceptance) in further reducing the already-low risk that a serious event will occur.

Summary and Conclusion

The Volpe Study indicates that risk to employees and the public from transportation of SNF/HLRW is low, but on a comparative basis dedicated trains appear to offer advantages over general consists. Several of these inherent advantages—avoiding yards, reducing derailment potential, and reducing the risk of involvement of other hazardous materials in an accident scenario—could be further exploited with careful attention to

¹⁴ Exposure related to trespassers on railroad property is a material issue, but it is by no means clear that the number of casualties varies by number of trains operated or by train miles.

conditions of transportation.

For instance, the recent AAR Standard S-2043,¹⁵ which was issued too late for formal consideration in the Volpe Study, calls for use of ECP brakes on trains carrying SNF/HLRW. ECP brakes have the capability of reducing stopping distances by 40-60 percent. Coupled with uniform composition of the consist, ECP brakes should significantly enhance the ability of the locomotive engineer to control in-train forces and mitigate the severity of collision with other trains and obstructions on the right of way, including vehicles at highway-rail crossings. In some cases, collisions may be avoided entirely. Use of the communications backbone provided by ECP brakes may also make possible the use of on-board sensors that can identify safety problems such as overheated bearings before they progress to failure. These kinds of engineering enhancements should be possible with equipment dedicated to these special trains. By contrast, such enhancements will not be implemented for some time on the general interchange fleet.

FRA's SCOP efforts are also much more likely to be successful if dedicated equipment and special trains are employed. While inspection processes are a proven, essential element of quality control, they work best as part of a total system approach. Being able to examine dedicated equipment at regularly-established shop locations and following the service history of the equipment to identify any propensities for wear or malfunction will increase the reliability of the inspection process both for the railroad and FRA.

Historically, the principal objection to use of dedicated trains was cost to the shipper. However, FRA's preliminary analysis indicates that use of dedicated trains should not result in significantly higher costs for these movements. Bypassing switching yards dramatically shortens transit times and lowers the cost of dedicated train operations. Dedicated trains comprised of state-of-the-art equipment maintained for this service and operated in small consists should incur many fewer mechanical malfunctions (e.g., broken coupler knuckles, unintended emergency brake applications) that could delay transportation and result in unexpected costs to shippers and the railroad.

A cost comparison of the six routes used in the study indicates that the operational and escort labor costs of dedicated train shipments of at least three casks or more are approximately equal to or less than if shipped by a train which would require yard switching. Thus the inherent cost of a dedicated locomotive and crew can be offset by the shorter transit time. Public costs should also be lower, since SCOP inspections can focus on a smaller number of route miles and fewer units of rolling stock.

Over the next 18 months, FRA will further explore in detail the costs associated with the use of dedicated trains and other special conditions of transportation that may further reduce the already low risks associated with transportation of SNF/HLRW, and determine whether further regulations governing transportation of these materials are required.

¹⁵ Association of American Railroads (AAR). "Performance Standard for Trains Used to Haul High Level Radioactive Material." Washington, D.C.: AAR Circular Letter C-9619 /AAR Standard S-2043, April 2003.