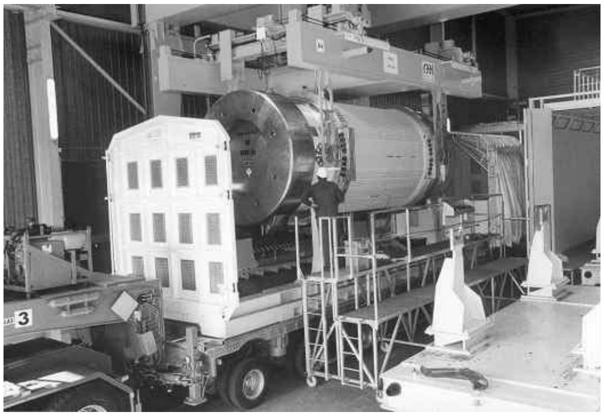
Spent Nuclear Fuel Transportation

An Overview

Technical Report



Spent Nuclear Fuel Transportation – An Overview

1009226

Final Report, February 2004

EPRI Project Manager
J. Kessler

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Energy Resources International, Inc.
Robert H. Jones, Consultant

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520, (800) 313-3774, press 2 or internally x5379, (925) 609-9169, (925) 609-1310 (fax).

Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

Copyright © 2004 Electric Power Research Institute, Inc. All rights reserved.

CITATIONS

This report was prepared by

Energy Resources International, Inc.
1015 18th Street, NW, Suite 650
Washington, DC 20036

Principal Investigator
E. Supko

Robert H. Jones, Consultant
P.O. Box 1510
Los Gatos, California 95031

Principal Investigator
R. Jones

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Spent Nuclear Fuel Transportation – An Overview, EPRI, Palo Alto, CA: 2004. 1009226.

REPORT SUMMARY

Spent nuclear fuel comprises a fraction of the hazardous materials packages shipped annually in the United States. In fact, at the present time, fewer than 100 packages of spent nuclear fuel are shipped annually. At the onset of spent fuel shipments to the proposed Yucca Mountain, Nevada, repository, the U.S. Department of Energy (DOE) expects to ship 400 – 500 spent fuel transport casks per year over the life of the facility. This study summarizes work on transportation cask design and testing, regulatory requirements, jurisdictional requirements, operational procedures and experience, and transportation risk assessments.

Background

While spent nuclear fuel has been transported safely for more than 40 years in the United States, the shipment of spent fuel to the proposed Yucca Mountain repository will involve significantly more cask shipments and longer shipment routes than previous shipping campaigns. Due to the increase in the projected number of shipments, there has been greater interest by the media, policy makers, and general public in the safety requirements for transporting spent nuclear fuel.

Objective

To summarize the technical and regulatory framework for transporting spent nuclear fuel.

Approach

The authors reviewed the technical and regulatory framework that presently exists to ensure the safe transport of spent nuclear fuel. They examined current regulations and identified research and analyses used to establish the adequacy of those regulations. They also evaluated operational experience with the package design, testing, fabrication, and shipping of spent nuclear fuel.

Results

This study shows that previous U.S. experience in transporting spent fuel and other radioactive materials will provide the DOE with a solid basis for developing its plan for transportation of spent nuclear fuel to the proposed Yucca Mountain repository. Furthermore, the study shows that current regulations and operational experience will ensure that future spent fuel transportation campaigns are conducted in a manner that protects public health and safety as well as the environment. The total volume of spent nuclear fuel projected for Yucca Mountain—although larger than heretofore shipped domestically—will involve a series of shipping campaigns with which the commercial spent fuel transport industry has ample experience.

Over the past 30 years, federal agencies and national laboratories have conducted research and test programs and performed analytical studies to assess the risks associated with transporting spent nuclear fuel. These documented risk assessments, studies, and cask testing programs provide a large body of evidence that validates the adequacy of regulations governing spent fuel transportation and shows that the transportation risks are small.

EPRI Perspective

The DOE’s spent fuel transportation planning will build on 40 years of commercial nuclear industry experience as well as other DOE transportation planning activities. These activities include foreign research reactor spent fuel transports, transport of transuranic waste to the Waste Isolation Pilot Plant, and transport of U.S. Navy spent nuclear fuel for storage in Idaho. It will also be important for the DOE to give serious consideration to international experience in shipping spent nuclear fuel and high level waste and apply the best practices to the proposed Yucca Mountain shipments. EPRI is confident that the resulting transportation system will safely and efficiently transport the projected volumes of radioactive material to the proposed Yucca Mountain repository.

Keywords

Spent Nuclear Fuel
High Level Radioactive Waste
Spent Fuel Transportation
Yucca Mountain

EXECUTIVE SUMMARY

Spent nuclear fuel has been shipped safely in the U.S. and in Europe for approximately 40 years. Spent nuclear fuel transport is a highly regulated activity – jointly regulated by the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Transportation (DOT). Spent nuclear fuel shipments have been by both civilian and government entities using highway, railroad, and sea transportation modes. A total of approximately 3,000 spent fuel casks have been shipped in the U.S., carrying approximately 2,400 metric tons of uranium (MTU) in the form of spent fuel, and traveling approximately 1.7 million cask-miles over this period. Internationally, approximately 85,000 MTU of spent nuclear fuel have been transported in an estimated 35,000 cask shipments by all modes of transport (road, rail, and sea).

Spent nuclear fuel comprises a fraction of the 300 million hazardous materials packages shipped annually in the U.S. At the present time, fewer than 100 packages of spent nuclear fuel are shipped annually. When shipments of spent fuel and high-level radioactive waste begin to the proposed repository, the U.S. Department of Energy (DOE) expects to ship between 400 and 500 spent fuel transport casks per year over the life of the facility. This will be only about one in a million of all hazardous materials packages transported in the U.S. on an annual basis.

This report summarizes the technical and regulatory framework that currently exists to ensure the safe transport of spent nuclear fuel; discusses research and analysis that has been conducted to validate the adequacy of current regulations; summarized the operational experience in package design, testing, fabrication, and shipping spent nuclear fuel; and relates this experience to future shipments to the proposed repository.

ES.1 Regulatory Framework

The transportation of spent nuclear fuel is perhaps the most comprehensively regulated of all hazardous materials, with oversight by both the NRC and DOT. The regulations governing the transport of spent nuclear fuel have evolved over four decades and include: requirements for shippers and carriers; packaging, including analysis or testing for both normal and accident conditions of transport; security and physical protection; training and emergency response; and inspection and quality assurance. These regulations, based on international standards, are continually reassessed by the NRC and DOT, as well as by international organizations such as the International Atomic Energy Agency.

NRC regulations require that shippers seek NRC approval of transportation routes, and further, they prescribe in-transit security measures. NRC regulations also require that spent nuclear fuel transport casks must be certified by the NRC prior to use and be able to meet NRC requirements related to containment of nuclear material, radiation control, and criticality control under both normal conditions of transport and hypothetical accident conditions.

The results of this comprehensive, multi-agency regulatory effort are transport casks that are designed and fabricated under strict design and quality assurance requirements and that are capable of withstanding severe transportation accident conditions.

ES.2 Validation of Regulations

More than forty years of operational experience in safely transporting spent nuclear fuel provides evidence that the regulations governing this activity are adequate to protect public health and safety and the environment. However, the NRC has not relied solely on this operational experience as validation for its regulations. Since the early 1970s, the NRC also has overseen numerous risk assessment analyses, analytical studies and cask testing programs to ensure that the regulations governing radioactive materials transport are adequate to protect the public. NRC risk assessments have found that the risks associated with transporting spent nuclear fuel are small. The risk assessments, studies and cask testing programs, as documented in scientific literature, combined with 40 years of operational experience provide a large body of evidence that validates the adequacy of the regulations that govern spent fuel transportation.

ES.3 Design, Licensing, Testing and Fabrication of Spent Fuel Casks

NRC regulatory oversight and review of spent fuel transportation casks occurs throughout the licensing, fabrication, operation, and maintenance of the cask. In addition, the entire design, licensing and fabrication process is performed in accordance with NRC regulations and national engineering standards by qualified cask design companies and cask manufacturers. Prior to a cask being used to transport spent nuclear fuel, the NRC must perform an independent safety evaluation and issue a certificate of compliance (COC) for the cask design to signify that all of the NRC safety requirements have been met. During the entire life of the cask, it is operated and maintained according to the requirements of its NRC COC and under a strict quality assurance program with approved procedures.

ES.4 Operational Experience in Transporting Spent Nuclear Fuel

Over the past forty years, civilian and government entities have embarked on spent nuclear fuel shipping campaigns for a number of reasons. In the past, the most prevalent reason was the transport of spent fuel from a nuclear reactor to a facility for the reprocessing of spent fuel. This resulted in frequent shipments of spent fuel during the 1960s through the 1980s as spent fuel was transported to and from reprocessing and storage facilities. However, large-scale domestic spent fuel shipping "campaigns" are no longer prevalent since there are no interim storage or disposal facilities available. Some of the large-scale shipping campaigns that have occurred are summarized below.

Since the late 1990s, DOE’s Foreign Research Reactor (FRR) Spent Fuel Acceptance Program has completed 25 shipments of FRR spent fuel, including 5,500 spent fuel assemblies from 27 countries. The U.S. Navy’s nuclear propulsion program continues to ship spent nuclear fuel to storage facilities in Idaho with more than 742 spent fuel casks shipped since 1957. During 1986 through 1989, a total of 43 cask shipments were made to transport the fuel debris via rail from Three Mile Island nuclear power plant to a DOE facility in Idaho. Since 1989, Progress Energy has been shipping spent nuclear fuel from its Brunswick and H.B. Robinson nuclear stations to its Shearon Harris station for interim storage shipping more than 200 casks during this time. During 1993 and 1994, the shipment of spent nuclear fuel from the Shoreham nuclear power plant in New York to Limerick nuclear power plant in Pennsylvania involved 33 round trip cask shipments using road, rail and barge transport modes.

ES.5 Emergency Management

Emergency preparedness and planning requirements have been established by DOT, NRC and the Federal Emergency Management Agency (FEMA) for radioactive material transport (as part of broader hazardous material regulations) to ensure that, in the event of a serious transportation accident, the public, workers and the environment are protected. Emergency preparedness and emergency response activities are shared by the shipper; the carriers that are transporting the material; state, local and tribal jurisdictions through which the material is traveling; and federal agencies.

FEMA and the DOE provide emergency response training and funding for state and local law enforcement officials, fire fighters, and rescue squads, covering preparedness planning and accident handling. This training, while specific to radioactive materials, supplements emergency response training conducted by state and local emergency response organizations associated with the transport of other hazardous materials.

ES.6 Transportation to the Proposed Yucca Mountain Repository

The shipment of spent fuel to the proposed Yucca Mountain repository will involve significantly more cask shipments and longer shipment routes than previous spent fuel shipping campaigns that occurred in the U.S. The proposed number of cask shipments are, however, the same order of magnitude as the number of shipments presently occurring internationally. The total volume of spent nuclear fuel and HLW projected for Yucca Mountain, although larger than heretofore shipped domestically, will be a series of shipping campaigns with which the transport industry has ample experience.

DOE's transportation planning efforts will build on forty years of commercial nuclear industry transportation as well as other DOE transportation planning activities such as the foreign research reactor spent fuel transports, transport of transuranic waste to the Waste Isolation Pilot Plant, and transport of U.S. Navy spent nuclear fuel for storage in Idaho. It will also be important for DOE to give serious consideration to the international experience in shipping spent nuclear fuel and HLW and apply the best practices of these shipments to those for Yucca Mountain. The resulting transportation system will safely and efficiently transport the projected volumes of radioactive material to the proposed Yucca Mountain repository.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

OVERVIEW OF SPENT NUCLEAR FUEL TRANSPORT

Every year, about 300 million packages of hazardous material are shipped in the United States (U.S.). Most of the hazardous material shipped —about 97 percent—is flammable, explosive, corrosive or poisonous. About 1 percent—three million packages—of the hazardous materials shipped annually contain radioactive materials, most of them from medical and industrial applications [Ref. 1-1].

Spent nuclear fuel comprises a fraction of the hazardous materials packages shipped annually in the U.S. At the present time, fewer than 100 packages of spent nuclear fuel are shipped annually. When shipments of spent fuel and high-level radioactive waste begin to the proposed Yucca Mountain repository, the U.S. Department of Energy (DOE) expects to ship between 400 and 500 spent fuel transport casks per year over the life of the facility. Despite the widespread attention that these proposed shipments have received, this will be only about one in a million of all hazardous materials packages transported in the U.S. on an annual basis.

1.1 What is Spent Nuclear Fuel?

The U.S. has 103 operating commercial nuclear power plants that supply approximately 20 percent of our nation's electricity without emitting any green house gases. Irradiated (or "spent") nuclear fuel, a highly radioactive material, is a byproduct of the production of electricity from nuclear power plants. Spent nuclear fuel has been safely stored at nuclear power plant sites for decades.

U.S. nuclear power plants use uranium oxide fuel in the form of solid ceramic fuel pellets that are placed inside metal fuel rods. These fuel rods are grouped together to form a fuel assembly. A typical fresh fuel assembly contains 0.18 to 0.46 metric tons of uranium (MTU). (See Figure 1-1) More than one hundred fuel assemblies are arranged in a fixed configuration in a water-filled vessel ("reactor") located within the highly reinforced containment structure of a nuclear power plant. In a nuclear power plant, the fission process splits the uranium atoms in a controlled chain reaction, producing heat energy that is used to produce steam. The steam drives a turbine to produce electricity. Following four to six years of use in the nuclear power plant, the nuclear fuel assembly is no longer efficient in generating electricity and is considered to be "spent." The assemblies are highly radioactive as a result of the fission process. The spent fuel is discharged from the nuclear reactor and placed into an adjacent steel-lined, water filled storage pool that provides radiation shielding and thermal cooling for the fuel. Nuclear power plants typically operate on 18 to 24 month refueling cycles, discharging between 30 MTU and 55 MTU per cycle into the spent fuel storage pool. On an annual basis, approximately 2,000 MTU of spent nuclear fuel is discharged from all U.S. nuclear power plants. As of December 31, 2002, approximately 47,000 MTU of spent fuel has been discharged from U.S. nuclear power plants and is in storage awaiting permanent disposal. In addition to commercial spent nuclear fuel, there will be approximately 2,500 metric tons of heavy metal of DOE-owned spent nuclear fuel that will require permanent disposal [Ref. 1-2].

High-level radioactive waste (HLW) is the highly radioactive material resulting from the reprocessing (i.e., chemical separation) of spent nuclear fuel. HLW contains the unusable radioactive fission-products separated from the spent fuel during reprocessing. Prior to shipment of HLW for disposal, this material will be contained in a solid vitrified glass matrix within metal canisters to provide immobilization. Most of the HLW in storage in the U.S. is a result of the reprocessing of navy nuclear propulsion fuel and other DOE-related fuels. Approximately 21,000 cubic meters of HLW is projected to require disposal in a repository [Ref 1-2]. HLW is currently stored at DOE facilities in Washington, Idaho, and South Carolina, and at the West Valley Demonstration Project in New York.

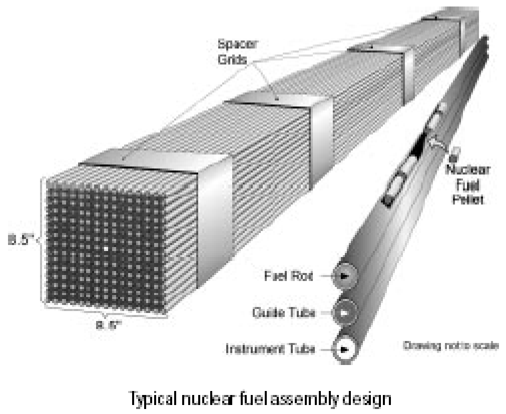


Figure 1-1
Pressurized Water Reactor Nuclear Fuel Assembly Design (assembly end fittings not shown)

Source: "Spent Nuclear Fuel Transportation", Brochure, U.S. DOE, www.ocrwm.doe.gov

1.2 History of Spent Fuel Transport

Spent nuclear fuel has been shipped in the U.S. and in Europe for approximately 40 years. Spent nuclear fuel transport is a highly regulated activity as discussed in Section 2 of this report. Shipments have been by both civilian and government entities using highway, railroad, and sea transportation modes. A total of approximately 3,000 spent fuel casks have been shipped in the U.S., carrying approximately 2,400 MTU of spent fuel and traveling approximately 1.7 million cask-miles over this period as shown in Figure 1-2 [Ref 1-3, 1-4].

Internationally, approximately 85,000 MTU of spent nuclear fuel have been transported. This is equivalent to approximately 35,000 cask shipments by all modes of transport (road, rail, and sea) [Ref 1-4]. Regarding U.S. shipments, approximately 75% of the total *tonnage* of domestic spent fuel has been shipped by railroad although the *number* of shipments by railroad is only about 19% of the total. This is because one large rail cask can accommodate roughly six times the amount of spent fuel as a truck cask. This capacity difference makes the railroad a significantly more efficient transportation mode. It is important to note that U.S. spent fuel statistics that are reported by the U.S. Nuclear Regulatory Commission (NRC) are provided by total number of "shipments" not the total number of "casks shipped". That is, a single shipment may involve more than one cask. In addition, NRC's statistics begin in 1979, not 1964 as presented in Figure 1-2. The result of these data handling variances is that the NRC statistics for the total "shipments" is somewhat less than the 3,000 cask shipments reported above [Ref 1-5].

The safety record of spent nuclear fuel shipping is enviable in the hazardous material transportation field. Domestically there have been a total of eight accidents involving spent nuclear fuel casks between 1971 and 2002.[1] All but one of these would be regarded as a minor incident. No radioactive material was released in any of the accidents, in fact, four of the accidents involved empty casks. Only one accident, in 1971, resulted in the cask being damaged. It is worth noting that the damaged cask was unloaded, inspected, repaired, tested, and returned to service.

Of the 300 million packages of hazardous material shipments that occur annually in the U.S., approximately 94% are transported by truck [Ref 1-6]. In March 2001, the U.S. Department of Transportation (DOT)'s Federal Motor Carrier Safety Administration released a study that examined the risks of transporting hazardous materials [Ref 1-7]. The study presented accident and incident likelihood and accident impact costs for all types of hazardous materials, including radioactive materials of which spent fuel is a fraction of one percent. The study found that less than 1% of all hazardous materials truck accidents and incidents involve trucks carrying radioactive materials. This is consistent with the fact that radioactive materials shipments make up approximately 1% of all hazardous materials shipments.

The concept of "relative risk" is important in the assessment of shipping spent nuclear fuel and high-level radioactive waste. A report prepared by Battelle Pacific Northwest Laboratories for Sandia National Laboratories [Ref. 1-8] examines a spectrum of societal risks, some natural and some man-made. A more detailed discussion of this report can be found in Appendix B. The report shows that the individual risk (i.e., probability of an individual dying from this cause in a given year) from spent fuel shipping is 4×10^7 times <u>less</u> than chlorine shipping, 7×10^7 times less than propane shipping, and 3×10^{11} times less than motor vehicle accidents. Other examples are cited. In other words, virtually all other well-recognized societal hazards are significantly more likely to impact an individual than the shipping of spent nuclear fuel and high-level radioactive waste.

Foreign shipping safety experience is comparable to that of the U.S. For international shipments, a comprehensive database of international accidents and incidents involving radioactive materials has not been implemented, although the International Atomic Energy Agency (IAEA) is working to develop such a database [Ref 1-4]. Individual countries track accidents and incidents involving radioactive materials within their borders. For example, the United Kingdom has tracked radioactive material transport accidents and incidents since 1958 [Ref. 1-9].

---

[1] Refer to Appendix A for more information regarding the eight accidents involving spent nuclear fuel casks since 1971 when NRC began tracking this data.

While there have been transportation accidents involving spent nuclear fuel casks both in the U.S. and in other countries, there have been no serious injuries to transport workers, emergency response personnel, or the general public as a result of the radioactive contents of the casks. The safety record of spent nuclear fuel and high-level radioactive waste shipments is due to the robust designs of the spent fuel casks, the effectiveness of the transportation regulations, and the professionalism of those engaged in this important activity.

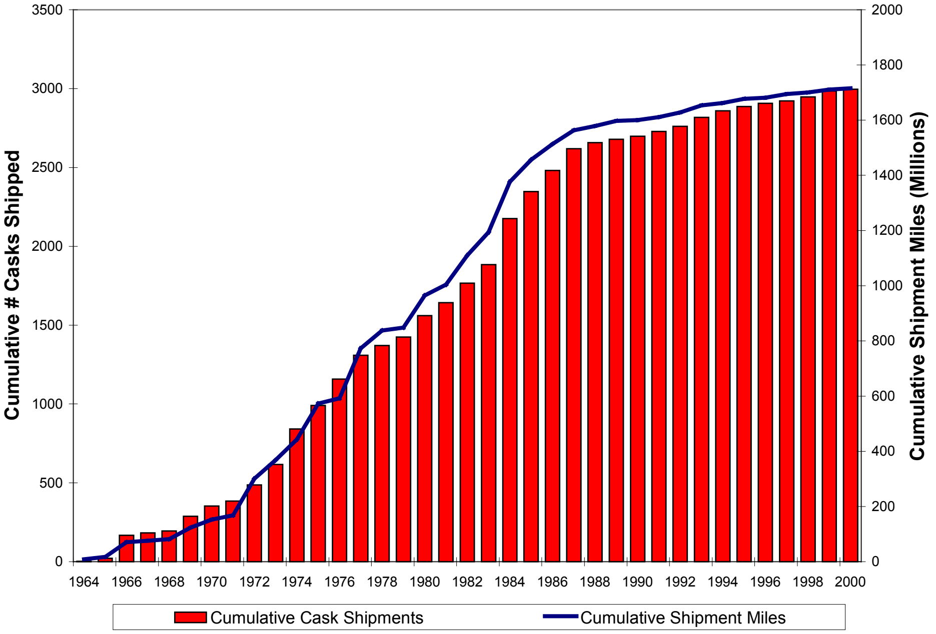


Figure 1-2
Cumulative U.S. Spent Nuclear Fuel Cask Shipments and Estimated Shipment Miles, 1964-2000 [Ref. 1-3]

1.3 Description of Typical Spent Fuel Transport Casks

Spent fuel transportation casks, as the shipping packages are called, are rugged containers that provide protection, containment, shielding, heat management, and nuclear criticality safety for the spent fuel contained within. Spent fuel transport casks are designed in a variety of sizes and configurations depending on the characteristics of the spent fuel to be transported. Figure 1-3 presents a cutaway view of a typical truck cask configuration. Figure 1-4 presents a cutaway view of a typical rail cask configuration.

The most common structural configuration for a spent fuel cask is a package body consisting of an inner and outer stainless steel structure (e.g., thick-walled cylinder) sandwiching the heavy metal (e.g., lead or depleted uranium) gamma shielding. However, some designs use a monolithic thick-walled steel cylinder that provides both gamma shielding and structure. Neutron shielding is generally exterior to the outer cylinder and consists of hydrogenous material such as polyethylene held in place by a thin-walled stainless steel structure. Internal to the body is a structure (referred to as a "basket") that provides support, positioning, criticality safety, and heat management for the spent fuel. In some cask designs, this basket structure is part of a thin-walled sealed canister that is separate from the main shielding and containment package. Cask closure mechanisms utilize metallic and/or elastomeric seals and a bolted, shielded lid. In cask designs that employ inner sealed canisters, the canisters are seal-welded. All contemporary spent fuel transport casks are equipped with removable external protective structures called impact limiters (also called energy absorbers) that reduce the mechanical forces imposed on the package under accident conditions. Cask interior air spaces are inerted with helium when loaded to improve heat transfer and to create a non-oxidizing environment for the spent fuel.

Spent fuel transport casks designed for highway transportation can weigh up to 26 tons and still meet the highway weight limits for legal weight shipping (i.e., gross vehicle weight (GVW) of 80,000 pounds). Over-weight truck (OWT) shipping with a GVW of about 110,000 pounds (i.e., 40-ton cask) is possible, but this mode requires special permits and may restrict vehicle movement on some roads. Packages designed for railroad transportation and/or intermodal barge shipping weigh up to 125 tons. The overall weight of spent fuel casks must also be compatible with the lifting capability of the cask handling crane at the nuclear power plant site and at the facility to which the spent fuel is being shipped. There is roughly a 6 to 1 fuel capacity advantage of rail casks over highway casks.

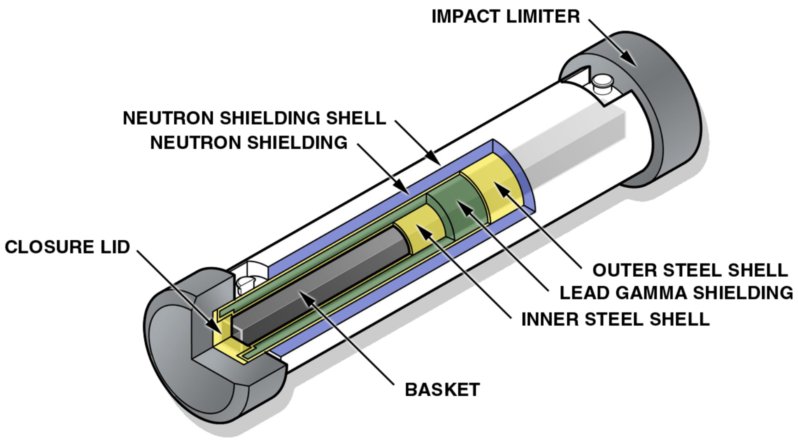


Figure 1-3
Generic Truck Cask for Spent Fuel (cutaway view)

Typical Specifications

Gross Weight (including fuel): 50,000 pounds (25 tons)
Cask Diameter: 4 feet
Overall Diameter (including Impact Limiters): 6 feet
Overall Length (including Impact Limiters): 20 feet
Capacity: Up to 4 PWR or 9 BWR fuel assemblies

Source:http://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-trans-cask-system.doc

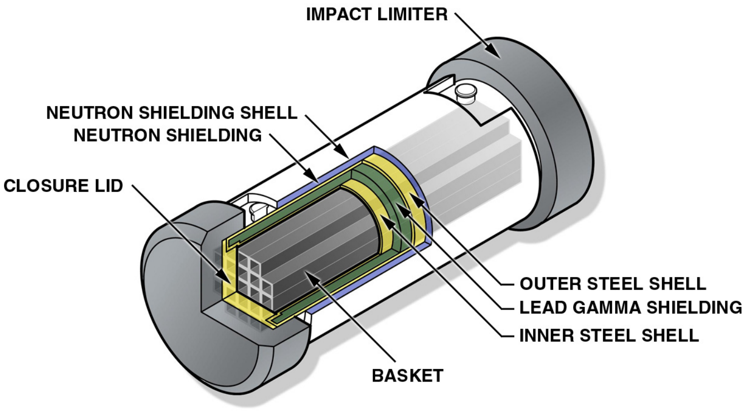


Figure 1-4
Generic Rail Cask for Spent Fuel (cutaway view)

Typical Specifications

Gross Weight (including fuel): 250,000 pounds (125 tons)
Cask Diameter: 8 feet
Overall Diameter (including Impact Limiters): 11 feet
Overall Length (including Impact Limiters): 25 feet
Capacity: Up to 26 PWR or 61 BWR fuel assemblies

Source:http://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-trans-cask-system.doc

1.4 Description of Transportation Equipment

Spent nuclear fuel can be transported by several modes – highway, railroad, or by barge or ship. In the U.S., shipping by barge would be conducted in conjunction with one of the other land-based transport modes, often referred to as multi-modal shipments.

Highway transportation uses specially designed trailers that provide integral tiedowns to fasten the cask to the conveyance. There is an incentive to keep the gross weight of a truck cask, trailer, and tractor below 80,000 pounds, which is the legal weight limit for interstate highway transport. Shipment weights that fall within the legal weight limit would not require heavy-load permits. To stay within this legal-weight limit, specialized tractor and trailer designs are often required. Figure 1-5 shows a truck cask loaded onto a truck for transport.

As with highway transport, railroad shipping requires specialized equipment. The 125-ton cask requires more than a 4-axle railcar due to the weight. Additionally, the Association of American Railroads (AAR) has prescribed unique design and testing requirements for railcar certification by AAR [Ref. 1-10]. Cask tiedowns are integral to the railcar. Figure 1-6 shows a cask loaded onto a rail car along with a personnel barrier.

In some designs the cask may be mounted on a shipping skid that has integral tiedowns. The skid may be moved with its attached cask from one mode of conveyance to another, for example, from a barge to a railcar. This eliminates the need to actually handle the cask separately at an off-site intermodal transfer facility. An example of intermodal transfer from rail to truck is shown in Figure 1-7.

All of these transport mode and equipment designs have been used to some extent over the past four decades, both domestically and internationally.

Figure 1-5
Truck Cask Ready for Transport

Figure 1-6
Rail Cask and Personnel Barrier Loaded on a Rail Car

Figure 1-7
Rail-to-Truck Intermodal Transfer Facility, Valognes, France

2

REGULATORY FRAMEWORK FOR SPENT FUEL TRANSPORT

2.1 Overview of Spent Nuclear Fuel Transportation Regulations

The IAEA is responsible for developing international transport safety standards for radioactive materials in conjunction with its Member States (which includes the U.S.). The safety standards are, in turn, adopted by international transport organizations, such as the International Maritime Organization, and are used by many IAEA Member States as the basis for their national transport regulations. The standards apply to all aspects of the transport of radioactive materials, including: design, manufacture, maintenance and repair of packaging; preparation, consignment, loading, carriage, and storage incident to transport; and unloading and receipt at the final destination. The IAEA transport safety standards are reviewed on a two year cycle and are revised as needed. Within the U.S., two federal agencies – the DOT and the NRC – jointly regulate the transportation of radioactive materials. U.S. transportation safety regulations for radioactive materials are revised periodically to take into account changes in the IAEA transport safety standards.

The Hazardous Materials Transportation Act of 1975 gave DOT the authority to establish standards for the safe transport of hazardous materials by any mode in interstate commerce. Within these broad hazardous material transport safety regulations, DOT is responsible for regulation of shippers and carriers of radioactive materials and transportation operations while the materials are in transit. DOT's regulations for radioactive material transport can be found within the hazardous materials regulations promulgated in Title 49, U.S. Code of Federal Regulations, Subchapter C, "Hazardous Materials Regulations" [Ref 2-1]. DOT responsibilities regarding radioactive material transport include:

- Regulation of shippers and carriers;
- Packaging requirements;
- Communication requirements for: shipping paper contents, package labeling and marking requirements, and vehicle placarding requirements;
- Training and emergency response requirements; and
- Highway routing requirements.

The Atomic Energy Act of 1954 gave NRC the authority to regulate the receipt, possession, use and transfer of radioactive materials. Regarding transportation of radioactive materials, the NRC is responsible for regulating users of radioactive materials and the design, manufacture, use, and maintenance of shipping containers for certain types of radioactive material shipments, including spent nuclear fuel. NRC's transportation related regulations can be found in Title 10, U.S. Code of Federal Regulations within Part 71, "Packaging and Transportation of Radioactive Material" (10CFR71). In addition, regulations for the safeguarding of spent fuel in transit are contained within Part 73, "Physical Protection of Plants and Materials" (10CFR73). NRC responsibilities governing radioactive material transport include:

- Certifying fissile material and Type B (including spent fuel) package designs;
- Approving package quality assurance programs;
- Providing technical support to DOT and ensuring consistency with respect to the transportation of radioactive materials;
- Establishing physical protection requirements for spent fuel in transit; and
- Conducting inspections in accordance with NRC requirements.

2.2 Spent Fuel Transport Cask Certification

Prior to use, spent nuclear fuel transport casks must be certified by the NRC in accordance with the regulations contained in 10CFR71. Designers of spent fuel packages submit an application to the NRC for review and approval. The application contains information as described in the *Standard Review Plan for Transportation Packages for Spent Fuel* (NUREG-1617) [Ref 2-2]. The application must address the safety and operational characteristics of the package, including design analysis for structural, thermal, radiation shielding, nuclear criticality, material content confinement, and analysis of the hypothetical accident conditions. In addition, the application must contain operational guidance, such as any testing and maintenance requirements, operating procedures, and conditions for package use. After performing an independent review of the application, if NRC determines that the spent fuel cask meets the 10CFR71 requirements, it issues a Safety Evaluation Report and a Radioactive Material Package Certificate of Compliance (COC) is issued to the cask designer. The COC allows any person to use the cask as long as it has a general or specific NRC license to *"… receive, possess, use, or transfer licensed material to a carrier for transport, transports the material outside the site of usage as specified in the NRC license, or transports that material on public highways."* In addition, such licensee must have a NRC-approved quality assurance plan that meets the requirements of 10CFR71, Subpart H, Quality Assurance.

The designers of spent fuel casks must demonstrate, either through physical testing or computer analysis, that the casks will meet NRC requirements related to containment of material, radiation control, and criticality control under both normal conditions of transport (as specified in 10CFR 71.71) and hypothetical accident conditions (as specified in 10CFR 71.73). Under normal conditions of transport, the radiation level does not exceed: (1) 200 mrem per hour at any point on the external surface of the package; and (2) 10 mrem per hour at any point 80 inches (2 meters) from the outer surface of the transport vehicle.

The hypothetical accident conditions require that the conditions be sequentially imposed on a cask design. Damage caused by the sequential accident conditions is cumulative and the evaluation of the ability of a package to withstand any one accident condition must consider the damage that resulted from the previous accident conditions. The 10CFR 71.73 accident conditions require that casks be subjected to all of the following accident conditions in the following sequence:

- Free Drop: A 30-foot (~9-meter) free drop of the cask onto a flat, unyielding, horizontal surface. The cask must strike the surface in a position for which maximum damage is expected.
- Puncture: A 40-inch (~1-meter) free drop of the cask onto a vertical steel bar, six inches in diameter, mounted on an unyielding, horizontal surface. The cask must strike the steel bar in a position for which maximum damage is expected.
- Thermal: Exposure of the cask in a fully-engulfing, hydrocarbon fuel/air fire with an average flame temperature of at least 1475°F (800°C) for a period of 30 minutes. The regulations specify the physical conditions of the fire including the dimensions of the hydrocarbon fuel source around the cask and the position of the cask relative to the surface of the fuel source.
- Immersion: Immersion under at least 3 feet (0.9 meters) of water.

Appendix C describes the regulatory accident conditions for spent fuel casks and how these accident conditions bound potential real-world transportation accidents.

As a separate accident condition, 10CFR 71.51 requires a deep immersion test for packages of spent nuclear fuel with activity greater than 1 million Curies (37 PBq). The regulations require that the package must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi (2 MPa) for a period of not less than one hour without collapse, buckling, or in-leakage of water. The pressure requirement of 290 psi is equivalent to 656 feet (200 meters) of water submersion and corresponds to the approximate depth of the continental shelf [Ref. 2-3].

NRC regulations allow cask designers to determine cask response to the hypothetical accident conditions either by physical test or by computer analysis. The regulations define the allowable radioactivity release and allowable external radiation dose from a package after being subjected to the hypothetical accident conditions. In addition, the package must be designed such that a criticality event cannot occur under normal conditions of transport or hypothetical accident conditions. The regulations are written to require that the cask structural integrity is "*effectively unimpaired*" after being subjected to the hypothetical accident conditions [Ref. 2-4].

2.3 Physical Protection of Spent Fuel in Transit

In addition to the requirements for cask design and certification contained in 10CFR71, NRC is also responsible for establishing physical protection requirements for spent fuel in transit. A system of security safeguards exists to ensure the safety of the public, handling personnel, and the environment before transport, during transport, and upon arrival of the transport package at its final destination. NRC regulations specified in 10CFR73.37 require the implementation of a physical security plan as part of an overall shipping campaign. These security plans and procedures are required to minimize the possibility of radiological sabotage and prevent the control of any shipment by unauthorized persons.

The NRC regulations require that the shipper of record perform the following security actions for shipments of used nuclear fuel.

- Provide advance written notification to the NRC prior to each shipment. In addition, the governor or his designee of each state through which the shipment passes must be notified in writing seven days in advance of the shipment.
- Establish a communications center for direct contact with the shipment to monitor the progress of the shipment and notify law enforcement agencies and other agencies as necessary. The communications center must be staffed on an around-the-clock basis.
- Ensure that a written log is maintained by the escorts and communications center for each spent fuel shipment describing shipment information and any events that occur during shipment.
- Make arrangements with local law enforcement agencies along the transport route for response to an emergency or request for assistance.
- Obtain advance route approval from the NRC of the security aspects of the transport routes for the shipments of the spent nuclear fuel for both rail and highway shipments.
- Ensure that escorts accompany the shipment at all times. The escorts must have a direct view of the shipment at all times. Armed escorts are required in heavily populated areas along a transport route and may be required throughout the shipment.
- Ensure that multiple and redundant forms of communications are used by the transport vehicle to report status to the communications center. Shipment escorts are required to report the status of the shipment to the communications center at least every two hours.
- Ensure that NRC-approved features are included in the transport vehicle to permit the immobilization of the vehicle so that the shipment can not be moved by unauthorized persons. These systems are activated, when necessary, by the vehicle driver.

While not a regulatory requirement, many shipments employ satellite tracking systems for continuous update on the progress of spent nuclear fuel shipments. For example, DOE tracks shipment of transuranic waste to the Waste Isolation Pilot Plant using satellite tracking devices.

In October 2002, the NRC issued Interim Compensatory Measures (ICMs) and Orders to licensees, imposing additional security requirements to supplement existing regulatory requirements related to security for the transport of spent fuel in quantities greater than 100 grams. Licensees had already implemented additional measures after September 11, 2001. The orders and ICMs are considered safeguards information, as is the list of NRC licensees who have received the orders; thus the details of the ICMs are not publicly available [Ref 2-5].

2.4 Routing Regulations for Highway Shipments

The Hazardous Materials Transportation Act provides DOT with the authority to regulate the routing of hazardous material shipments. DOT regulations contained in 49CFR397, Subpart D, "*Routing of Class 7 (Radioactive) Materials*", provide the requirements for determining routes for highway transport of spent nuclear fuel. The regulations require that spent fuel being transported by highway use "preferred routes," which are defined as interstate highways, including bypasses and beltways around cities, unless a state routing agency has designated an alternative route. DOT has published a set of guidelines to assist state agencies in designating routes that meet DOT requirements to minimize travel time, entitled, "*Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials*", DOT/RSPA/OHMT-89/01. Route selection factors include accident frequencies, traffic counts, average vehicle speed, population densities, and land use data along proposed routes. In addition, emergency response and/or evacuation capabilities and location of special facilities such as schools, hospitals, stadiums and nursing homes may also be considered.

Shipments of spent nuclear fuel by rail are not subject to federal routing regulations. However, it is standard practice to route rail shipments of spent nuclear fuel to: (1) minimize the distance over which the shipments must travel; (2) minimize the number of interchanges between railroad companies; and (3) maximize the use of mainline track [Ref. 2-6].

2.5 DOT Federal Railroad Administration – Track Inspection Criteria

In 1991, the DOT Federal Railroad Administration (FRA) established an enhanced inspection policy for rail movements of spent nuclear fuel and high-level radioactive waste [Ref 2-7]. The FRA inspection policy requires that prior to the first shipment of spent fuel along a given rail route, the entire track and signal system must be inspected. Track and signal inspectors must prepare a memorandum describing the condition of the route inspected, including sidings and yard tracks (if applicable), in addition to completing the routine inspection forms used while making the inspection. FRA inspectors conduct routine inspections along the route to be used to assure that train crews are complying with the rail carriers' current operating rules.

The policy requires that, prior to each shipment, FRA inspectors will conduct inspections of the locomotives, cask and buffer cars at the point of origin. In addition, hazardous materials inspectors will conduct inspections of the cask cars to assure compliance with placarding, shipping papers, crew notification, train placement and securement requirements.

The FRA policy requires that follow-up inspections for track, signal systems and operating practices must be conducted every six months, unless information is obtained that indicates that follow-up inspections should be conducted more (or less) frequently.

In August 1998, the FRA developed a *Safety Compliance Plan for Rail Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel* [Ref. 2-8]. The safety compliance plan was developed to address stakeholder issues such as mechanical equipment condition, infrastructure integrity, and high-rail grade crossing safety. The plan was developed in a coordinated effort between the FRA, DOE, AAR, railroad labor organizations, and state representatives. The FRA will periodically review, evaluate, and update the safety compliance plan to ensure that the latest technologies for the safe rail transport of spent nuclear fuel are considered.

2.6 State and Local Regulations

Many state and local governments have enacted laws addressing the transportation of radioactive material through their jurisdictions, particularly with respect to highway transport. States have authority in ensuring safe operation of motor vehicles, and conducting inspection and enforcement activities.

In addition, states have enacted laws that place additional requirements on spent nuclear fuel or hazardous materials transportation. Since Federal law generally preempts state and local laws in this area, these regulations must be consistent with Federal laws or they will be subject to preemption by Federal law. There have been several preemptive challenges to state and local regulations due to inconsistencies with Federal regulations. Typical State laws address registration and permit programs, notification, financial liability, emergency response planning and training, inspection and enforcement, and various shipment restrictions [Ref. 2-9].

2.7 Summary

The transportation of spent nuclear fuel is perhaps the most comprehensively regulated of all hazardous materials, with oversight by both the NRC and DOT. These regulations governing the transport of spent nuclear fuel have evolved over four decades and include: requirements for shippers and carriers; packaging, including analysis or testing for both normal and accident conditions of transport; security and physical protection; training and emergency response; and inspection and quality assurance. The regulations, based on international standards, are continually reassessed by the NRC and DOT, as well as by international organizations such as the IAEA. The results of this comprehensive, multi-agency regulatory effort are transport casks that are designed and fabricated under strict design and quality assurance requirements and that are capable of withstanding severe transportation accident conditions.

3

VALIDATION AND ADEQUACY OF REGULATIONS

More than forty years of operational experience in safely transporting spent nuclear fuel provides evidence that the regulations governing this activity are adequate to protect public health and safety and the environment. However, the NRC has not relied solely on this operational experience as validation for its regulations. The NRC also has performed analytical studies and conducted cask testing programs to ensure that the regulations governing radioactive materials transport are adequate to protect the public. This section will summarize several of the more significant risk assessments, accident analyses, and physical testing programs that have been conducted. These analyses and testing programs, as documented in scientific literature, combined with the 40 years of operational experience provide a large body of evidence that validates the adequacy of the regulations that govern spent fuel transportation.

3.1 Risk Assessments

Risk is defined as *the probability of an event occurring times the consequences of the event assuming that it has occurred.* Thus, to estimate the risk of spent nuclear fuel transportation accidents, the probability of an accident occurring must be considered along with the estimated consequences for the accident. Over the past four decades, numerous risk assessments associated with the transport of spent nuclear fuel and other radioactive materials have been conducted. The most significant studies are summarized below.

3.1.1 Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes

In December 1977, NRC issued a "*Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*", NUREG-0170 [Ref. 3-1]. The environmental statement was completed to assess the impacts associated with the transport of radioactive materials in the U.S. in order to ensure that NRC regulations continued to meet the goal of limiting radiological impacts to a level that is as low as reasonably achievable. In this study, the NRC evaluated the impact of regulated radioactive materials transport activities on public health and safety. The report assessed the potential impacts from transport of all licensed radioactive material, not just spent nuclear fuel. Transport modes evaluated included land, sea and air transport under both incident free and accident conditions. This study was a more comprehensive follow-on study to the 1972 Atomic Energy Commission document, WASH-1238, entitled, "*Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plants"* [Ref. 3-2]. WASH-1238 was produced in compliance with the National Environmental Policy Act of 1969 and it concluded that the risk to the public and transport workers was "*small.*"

Based on the evaluation performed in NUREG-0170, NRC staff determined that *"the environmental impacts of normal transportation of radioactive material and the risks attendant to accidents involving radioactive material shipments are sufficiently small to allow continued shipments by all modes. Because transportation conducted under present regulations provides adequate safety to the public, the staff concludes that no immediate changes to the regulations are needed at this time*" [Ref 3-1]. As noted in the summary and conclusions of NUREG-0170, many of the assumptions used in the assessment were very conservative, resulting in predictions of accident risk that are greater than more realistic assumptions would indicate. Despite its conservative assumptions, NUREG-0170 concluded that the total risk of transporting radioactive materials is small. The assessment performed in NUREG-0170 has become NRC's baseline for comparison with risk studies completed since that time.

It should be noted that despite the conclusion that the risks of transporting radioactive materials is small, the NRC policy is to evaluate its transportation on a regular basis. In fact, in February 2000 the NRC Commissioners concluded that "*prudence dictated that regulatory policy concerning transportation of radioactive materials be subject to close and continuing review*" [Ref 3-3].

3.1.2 Shipping Container Response to Severe Highway and Railway Accident Conditions (Modal Study)

As shipping campaigns were underway in the mid 1980s, public attention and concern regarding these shipments increased. One of the areas of concern dealt with public understanding of how the designated regulatory accident conditions (described in Section 2.2 and discussed further in Appendix C) might bound real-world transport accidents.

In 1987 as a result of this public concern, the NRC initiated a study*, "Shipping Container Response to Severe Highway and Railway Accident Conditions"*, NUREG/CR-4829 [Ref. 3-4], referred to as the "Modal Study", to evaluate and determine spent fuel cask response in real world accidents. The Modal Study compared the mechanical and thermal loads generated in actual truck and rail transportation accidents to the loads generated under the hypothetical accident conditions in 10CFR71. The Modal Study also included an assessment of the probabilities associated with the mechanical and thermal loads that had been calculated for the hypothetical accident conditions. The Modal Study found that the majority of thermal and mechanical accident loads evaluated from these real world accidents (99.4% of the truck accidents and 98.7% of the rail accidents) fell within the bounds of the loads associated with the regulatory accident conditions.

For those accident conditions that were near or exceeded the regulatory conditions, the Modal Study evaluated how a typical spent fuel cask would respond to these mechanical and thermal accident loads. This analysis used finite element computer modeling of generic cask designs to evaluate responses to accident conditions. In addition, the Modal Study evaluated the potential radiological hazard associated with the predicted cask response.

The conclusion of the Modal Study was that at least 99.4% of truck and train accidents involving a spent fuel shipment will result in negligible radiological hazards. Of the remaining (0.6%) of accidents, the Modal Study found that the risks associated with shipping spent fuel were small –

approximately one-third less than the risk estimated in NUREG-0170 [Ref 3-4]. This supports NRC's previous decision that there was no need to make changes to the regulatory bases for certifying spent fuel transport casks.

3.1.3 Reexamination of Spent Nuclear Fuel Risk Estimates

Despite the fact that the shipment of spent nuclear fuel in NRC-certified packages has an excellent safety record, NRC decided to reexamine the risks associated with the shipment of spent nuclear fuel by rail and truck. In March 2000, NRC released an updated assessment of spent fuel transportation risks, entitled, "*Reexamination of Spent Fuel Shipment Risk Estimates*", NUREG/CR-6672 [Ref. 3-5]. The reevaluation of transportation risks was prompted by the fact that: (1) the characteristics of the spent nuclear fuel and cask systems have changed; (2) more sophisticated analytical techniques are available than had been used in the Modal Study; and (3) NRC expects that there will be many shipments of spent nuclear fuel taking place over the next several decades. In addition, the prospect of increased shipments to an interim storage facility or a final repository once again focused public attention on spent fuel transport safety.

NUREG/CR-6672 calculated the risks for spent fuel shipments under both incident-free and accident conditions. The study took into account the characteristics of the spent fuel that will be shipped in the future (enrichment, burn-up, cooling time, etc.), the designs and capacities of spent fuel transport casks likely to be used in future shipments, and current population densities along road and rail routes. Many of these parameters had changed since the Modal Study and NUREG-0170 were completed. The study used finite element computer analysis to determine cask response to accident conditions.

The reexamination concluded that the "*results of this study show that the NUREG-0170 estimates of spent fuel transportation incident-free doses are somewhat conservative and the NUREG-0170 estimates of accident population risk are very conservative. …the fact that the incident-free doses estimated by this study are significantly smaller than the NUREG-0170 estimates and the accident dose risks estimated by this study are orders of magnitude smaller than those estimated by NUREG-0170 confirms that spent fuel transportation regulations adequately protect public health and safety*" [Ref 3-5].

3.1.4 Recent Assessments of Real Transportation Accidents

Since completion of the Modal Study, representatives from the State of Nevada identified additional rail and highway accidents that they classified as accidents that could result in thermal or mechanical loads imposed on a transport casks that may be greater than the accidents previously evaluated in the 1987 Modal Study [Ref 3.6]. In April 2003, DOE's Office of Environmental Management (EM) submitted a study to NRC performed by Sandia National Laboratories that reviewed and analyzed additional transportation accidents suggested by Nevada's representatives as being potentially severe enough to compromise the integrity of a spent fuel cask [Ref 3-7].

The study concluded that examination of these additional transportation accident scenarios "*revealed no accidents that were outside the event trees and accident severity already* *considered in NUREG/CR-6672. In most cases, the accidents were found to be within the regulatory test sequence limits described in 10CFR71.*" The report identifies one accident description that did not report the fire duration, thus it is possible that the 30-minute fire duration specified in 10CFR71 could have been exceeded. However, the report concluded that, even if the fire in this one accident was longer than 30 minutes, it would still have been within the range of extra-regulatory accident conditions considered in NUREG/CR-6672, such that the thermal loads and transport risks associated with this accident were bounded by this previous risk analysis.

In July 2001, derailment of a freight train and the associated fire in the Howard Street tunnel in Baltimore, Maryland, resulted in numerous parties speculating that, had a spent fuel cask been involved in the incident, the cask would not have withstood the thermal conditions without a breach of the cask containment system. NRC staff were directed by the NRC Commissioners to perform an evaluation of a hypothetical event involving a spent fuel transportation cask subjected to the fire environment that occurred during the Howard Street tunnel accident to determine if current regulations for shipping spent fuel by rail are adequate to withstand the thermal conditions experienced in the tunnel. NRC staff worked in coordination with the National Transportation Safety Board (NTSB) to determine the details of the train derailment and fire. NRC staff performed its technical analysis of the postulated event with assistance from the National Institute of Standards and Technology (NIST), the Center for Nuclear Waste Regulatory Analysis (CNWRA), and Pacific Northwest National Laboratory (PNNL). The NRC analysis included development of a detailed thermal model by NIST and analysis of materials from the tunnel and rail vehicles involved in the fire. The NRC staff concluded that if a 10CFR71-approved spent fuel transportation cask was subjected to the Howard Street tunnel conditions, no release of radioactive materials would have resulted from this postulated event, and the health and safety of the public would have been protected [Ref 3-8].

3.2 Cask Testing and Package Performance Study

During the 1970s, Sandia National Laboratories performed a series of physical tests on spent nuclear fuel shipping casks. The principal objective of these tests was to demonstrate the ability to analytically predict cask response to extreme accident conditions using computer models. Data from the tests were used to validate computer models used by industry and the NRC in cask design and certification [Ref. 3-9, 3-10]. Appendix D discusses the history of cask testing in the U.S. including the Sandia testing program and the role of cask testing in the design of spent fuel casks, and it identifies scientific literature available regarding cask testing programs.

Since the 1970s, cask designs and analytical techniques have continued to evolve and improve. NRC evaluated these new designs using the updated analytical techniques in NUREG/CR-6672. As a follow-on to NUREG/CR-6672, NRC has proposed a Package Performance Study to evaluate cask response to severe transportation accidents. The study is intended to examine the adequacy of the analytical methods and data that are used to predict the response of transportation casks to severe accident conditions. The Package Performance Study is intended to consider the use of physical testing to address certain issues. NRC conducted public consultation regarding the issues to be addressed in the proposed Package Performance Study during 1999 and 2000.

In February 2003, NRC released "*United States Nuclear Regulatory Commission Package Performance Study Test Protocols*" (Draft Test Protocol) for a 90-day public comment period. The Draft Test Protocol identifies the NRC's objectives in carrying out the testing program: (1) enhancing public confidence in the safety of spent fuel transport casks; (2) validating the cask models and analysis codes for extreme mechanical and thermal environments; and (3) providing data to refine dose risk estimates [Ref 3-11].

The nuclear industry determined that the testing program proposed by NRC staff in the Draft Test Protocol should be representative of real-world credible accidents. The tests proposed in the Draft Test Protocol involve testing to "extra-regulatory" conditions (beyond the physical test parameters required for cask certification). NRC provided information in the Draft Test Protocol that showed that the probability of a rail cask impacting an unyielding surface at the proposed 60 to 90 mph is 10^{-6} to 10^{-8} per year. With such low probabilities of occurrence for the proposed test conditions, it is clear that the proposed test speeds are not "realistic" and are not consistent with NRC's stated philosophy of risk informed regulation. The industry recommended that NRC justify any tests performed using a risk-informed, cost-benefit approach such that the tests performed are consistent with the real-world conditions that spent fuel transport casks might encounter during transport [Ref 3-12].

3.3 Summary

Due to continued public concern surrounding the transportation of spent nuclear fuel, the NRC Commissioners have committed to provide continuing review of regulatory policy related to spent fuel transport. The risks of transporting spent fuel and high-level radioactive waste have been under study for over 40-years. As analytical techniques and data gathering methods improve, more recent risk assessments continue to confirm that the original risk assessment presented in NUREG-0170 is conservative and that the risks associated with the transportation of spent nuclear fuel remain small. The probability of an accident occurring that is severe enough to violate the integrity of a spent fuel cask is extremely small. Thus, the risk to the general public from any credible accident is also extremely small.

4

DESIGN, LICENSING, TESTING, AND FABRICATION OF SPENT FUEL CASKS

Similar to the design and construction of packages used to transport other classes of hazardous materials, the design, licensing and fabrication of spent nuclear fuel transportation casks is a complex process that involves many technical disciplines (e.g., structural design, nuclear criticality safety and radiation shielding, heat transfer, quality assurance). However, where these spent fuel transport casks differ from other hazardous materials transport packages is in: (1) the strict regulatory requirements imposed by the NRC on package design to support a high level of safety (discussed in Section 2.2); (2) the regulatory oversight by NRC during package licensing, fabrication and operation; and (3) the rigorous quality assurance requirements applicable to cask design, fabrication, and operation. Spent nuclear fuel cask design, licensing, and fabrication, including relevant testing programs, are discussed in the following subsections.

4.1 Spent Fuel Cask Design and Testing

The design of casks to transport spent nuclear fuel and HLW requires the application of many disciplines. Most of these disciplines are technical, but others of equal importance deal more with logistical, operational, and regulatory considerations as discussed below.

4.1.1 Determining Cask Design Parameters

The first step in designing a spent fuel transportation cask begins with logistical planning to determine such things as package size, transport mode (i.e., rail versus truck), capacity (i.e., number of fuel assemblies), type and characteristics of the spent fuel to be transported, handling and operational requirements for both the shipping facility and the receiving facility, and economics. All of these considerations are combined to create a profile or design target for the spent fuel transport cask. In most cases, a complete transport system (i.e., the cask, impact limiters, transport cradle, ancillary equipment, and often transport vehicle) would be defined at this stage for subsequent technical development.

The cask design function involves numerous technical disciplines, including:

- Structural design and analysis including material properties, lifting and tie-down requirements, etc.;
- Thermal design and analysis, which deals with the efficiency of the design in transferring heat from the spent fuel;
- Containment system design;

- Radiation shielding design;
- Nuclear criticality design; and
- Operating procedures for cask loading, unloading, and preparation of loaded and empty casks for transport.

The design process is an iterative one. The cask designer must often adjust the system design requirements in order to comply with the regulatory requirements. Further, there are trade-offs between the various technical disciplines. For example, there are compromises between cask capacity and thermal, shielding and weight considerations. The result of this iterative design process is a cask system that meets all regulatory requirements and is the best combination of cask capacity, the types of spent fuel that can be transported, cask cost, and other system considerations. Additionally, the design is consistent with the operational requirements for the facilities that will be handling the cask and for off-site transportation. This process places regulatory requirements and worker/public safety at the forefront of the design, followed by package efficiency for the intended operational functions.

4.1.2 Regulations and Regulatory Guidance Documents

As discussed in Section 2, the NRC's regulations for packaging and transport of spent nuclear fuel, as contained in 10CFR71, are performance-based regulations. In this respect, the regulations define both normal shipping conditions and hypothetical accident conditions that spent fuel casks must be able to withstand, along with the acceptance criteria under these conditions. The NRC also publishes other documents that supplement the regulations to provide additional guidance to licensees and which must be taken into consideration during the design process. These documents include:

- *Standard Review Plan for Transportation of Spent Nuclear Fuel*, NUREG-1617 [Ref 2-2]. This is used by the NRC staff for cask technical review but is helpful to the applicant to aid in document content and formatting.
- Division 7 Regulatory Guides containing NRC clarification of the regulations such as:
  - Regulatory Guide 7.9, Standard Format and Content of 71 Applications for Approval of Packagings of Type B, Large Quantity and Fissile Radioactive Material, July 1979.
  - Regulatory Guide 7.10, Establishing Quality Assurance Programs for Packagings Used in the Transport of Radioactive Materials, January 1983.
- Numerous NRC technical (NUREG and NUREG/CR) publications such as those referenced in the *Standard Review Plan for Transportation of Spent Nuclear Fuel*, NUREG-1617. These include guidance documents on cask testing, fabrication criteria, analytical guidance, etc.
- NRC Interim Staff Guidance[2] documents establishing NRC staff positions on technical issues such as:

---

[2] NRC Interim Staff Guidance documents can be found at: http://www.nrc.gov/reading-rm/doc-collections/isg/spent-fuel.html

- ISG-1, Rev 1, Damaged Fuel
- ISG-8, Rev 2, Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks
- ISG-11, Rev 2, Cladding Considerations for the Transportation and Storage of Spent Fuel

The regulatory requirements for normal transportation conditions and hypothetical accident conditions that a spent fuel transport cask must be able to withstand make the design effort particularly challenging. Consequently, this has spawned the aforementioned substantial body of guidance material to assure design compliance with the applicable regulations.

4.1.3 Cask Design and Analysis

The actual design of a spent fuel transportation cask and its other transportation system components is a combination of "*design-by-analysis*" and "*design-by-test.*" These two approaches, or combination of approaches, have their roots in 10CFR 71.41, "Demonstration of Compliance". In §71.41 the NRC permits the use of test and/or *"another method of demonstration*," which the NRC has deemed to be analysis, to indicate cask compliance with the regulations. Supplementing the regulations is NUREG-1617, the *Standard Review Plan* for spent fuel casks, which refers to "Evaluation by Analysis" and "Evaluation by Test" in subsections 2.5.4.1 and 2.5.4.2 respectively.

Casks perform their safety functions primarily by: 1) their robust mechanical designs; 2) the application of substantial engineering safety margin; and 3) the use of protective features to mitigate the results of any physical impacts that might occur during transportation. Cask designers will use both analyses and tests to meet regulatory and operational objectives.

In the *design-by-analysis* phase of the cask design effort, the analytical tools used employ proven numerical methods (i.e., computer codes) that have been benchmarked against physical tests and validated through observation of the behavior of the casks after they have been put into service transporting spent nuclear fuel. Most of the structural and thermal computer codes (e.g., ANSYS, HEATING) are used in broad technical applications both inside and outside of the nuclear industry. These general purpose codes have decades of development, benchmarking and application behind them. They have been reviewed and accepted by the NRC as verified methods for structural and thermal use. The more specialized nuclear codes for criticality safety and shielding (e.g., KENO, MCNP, ORIGEN) have been developed and benchmarked over decades of use within the nuclear industry. All numerical methods are employed well within their demonstrated range of benchmarked capability, and the specific applications are thoroughly reviewed by NRC during the licensing process.

In the *design-by-test* phase of the cask design effort, the physical testing generally is conducted to provide physical evidence to support the analysis that will be submitted to the NRC for review during the licensing process. Testing might include material or specialized component testing when new materials are employed in a design, particularly for materials that might be used in impact limiters or cask seals. In addition, there are cases in which numerical methods may not be fully capable of accurately predicting behavior (this is particularly true for cask impact limiters), or where performance data are incomplete. In such instances, testing would be employed. Standardized material testing methods (e.g., ASTM, ASME standards), full-scale or partial-scale testing of components, and partial scale testing of the cask have all been applied over the past several decades. Full-scale testing of spent fuel casks is not considered to be necessary in light of the high precision of contemporary analytical methods. Appendix D contains additional information on cask testing programs. One referenced Sandia testing program concluded that, "*… both computational techniques and scale modeling are viable engineering approaches to studying accident environments and physical damage to shipping casks*."

The use of national standards such as the American Society of Mechanical Engineers (ASME), *ASME Boiler and Pressure Vessel Code (Section III, Division 3), Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste* (1998), assures substantial safety margins on structural design. The application of allowable stress and strain values for materials in the ASME Code assure structural integrity under analyzed conditions. Safety factors are inherent throughout the cask design process.

While spent fuel cask designs vary in a multitude of ways, all cask designs must meet the same regulatory requirements. As examples, casks use a variety of structural materials and design configurations, cask sizes differ depending upon the transport mode (rail versus truck), and cask handling restrictions can vary as a function of the potential users. However, all designs must comply with federal regulations.

4.2 Transport Cask Licensing Process

The products that result from the cask design effort are a total system design and a Safety Analysis Report – Packaging (SARP). The total system design describes the system and contains the necessary drawings, procedures, and specifications for fabrication, testing, and operation. The SARP is a document that contains all of the analytical analyses that demonstrate to the NRC that the system meets all mandated NRC safety requirements. Together, these two documents permit an independent assessment of the system by the NRC.

The NRC review of a cask design and associated safety analysis can take several years due to the agency's thorough review. The NRC generally recommends that potential licensees inform the NRC of their intention to file an application at least one to two years prior to doing so. NRC staff performs an acceptance review of the application to ensure that the application is complete and is sufficient to permit detailed technical review. The SARP must follow the standard format and content recommended by the NRC in its *Standard Review Plan* and be consistent with the other guidance documents that were discussed in Section 4.1.2.

The Standard Review Plan provides NRC staff with guidance for the review and approval of a spent fuel transport cask application. The NRC’s formal review process is thorough – with the NRC experts making written “requests for additional information” based on their independent review and the applicant responding via amendments to the SARP. NRC approval of an application is signified by the NRC issuance of a COC and a staff SER. The SER describes the NRC staff’s technical basis for determining that the cask design meets the regulatory requirements of 10 CFR 71. The COC for the cask design is essentially the "license" that permits its use under the conditions and with the contents specified.

The NRC provides an opportunity for the public to observe NRC's transportation cask approval process although there is no opportunity for formal public intervention. However, all interactions between an applicant for cask design approval and the NRC staff are filed in the NRC's public document room and are available for public review. Documents are available through an internet based document management system and meetings between an applicant and NRC are open to the public.

4.3 Spent Nuclear Fuel Cask Fabrication and Testing

The spent fuel transport cask system design includes all the necessary drawings, material specifications, tests, standards, and procedures necessary to fabricate one or more casks. Fabrication follows ASME national standards for pressure vessel construction and includes welding, bolting, materials, personnel qualifications, testing, quality assurance/quality control, and the other related activities. ASME Boiler & Pressure Vessel Code, Section III, Division 3, *Containment Systems and Transport Packagings for Spent Fuel and High Level Radioactive Waste*, [Ref. 4-1] contains the design rules for these types casks. Subpart H to 10CFR71 specifies the quality assurance criteria for packages. It should be noted that the 18 criteria in Subpart H are identical to those imposed on nuclear power plants under 10CFR50. All designers and fabricators must operate under quality assurance plans that have been approved by the NRC. Further, ASME Code in Article WA-4000 mirrors the QA criteria specified by the NRC.

Fabrication generally follows practices applied to large pressure vessel work. Some spent fuel transport casks use materials such as lead or depleted uranium for gamma shielding purposes, hydrogen-containing materials for neutron shielding, and/or boron-containing materials for nuclear criticality safety. These specialty materials are uniquely identified and specifically tested to assure that they have the material properties specified by the cask design. Material certification and testing, process and personnel qualification, and a rigid quality assurance/quality control plan combine to assure that the completed package is identical to the NRC-approved design. In fact, the design drawings are referenced in the cask COC to assure compliance. NRC inspections occur periodically throughout fabrication of a spent fuel cask to ensure compliance to the design drawings and manufacturing requirements.

Each completed cask must undergo acceptance testing prior to initial use that includes leak checking, hydraulic testing for integrity, shielding continuity testing, and thermal testing. Functional tests are also conducted to demonstrate successful handling and the interfacing with ancillary equipment. NRC regulations require that the cask fabrication records are audited for completeness and retained for the life of the package.

4.4 Quality Assurance

As discussed above, Subpart H of Part 71 contains the quality assurance (QA) requirements for spent fuel transport casks. ASME Code, Section III, Division 3 imposes criteria identical to those of the NRC. The QA requirements apply to not only the design and fabrication of the cask, but also the subsequent handling, shipping, storage, assembly, inspection, testing, operation, maintenance, repair, and modification of components that are important to safety. The prime responsibility for quality assurance lies with the designer and fabricator. As such, the quality assurance plan is created, implemented, and enforced by the designer/fabricator. NRC inspectors conduct periodic safety and compliance inspections of QA programs and their associated procedures to ensure that the programs are being implemented according to the requirements. ASME also audits fabricators as part of the process for qualifying a vendor under its Code.

There are eighteen criteria within Subpart H and Section III, Division 3, that must be addressed by an applicant. Some of the more important criteria include: quality assurance organization; quality assurance program; package design control; identification and control of materials, parts and components; internal inspection; test control; nonconforming materials, parts and components; corrective action; quality assurance records; and audits.

4. 5 Summary

The design, licensing and fabrication of spent fuel transportation casks is a highly regulated activity. There are numerous stringent design criteria and regulatory guidance documents that are imposed on cask designers. Regulatory oversight and review occurs throughout the licensing, fabrication, operation, and maintenance of the cask. In addition, the entire design, licensing and fabrication process is performed to federal regulations and national standards (e.g., ASME) by highly qualified cask design vendors and cask manufacturers. Prior to a cask being used to transport spent nuclear fuel the NRC must perform a safety evaluation and issue a NRC COC that signifies that all safety requirements have been met. During the entire life of the cask, it is operated and maintained according to the requirements of the COC and under a strict quality assurance program with approved procedures. No other hazardous material container undergoes the same level of scrutiny prior to transporting dangerous goods on U.S. highways and railways.

5

OPERATIONAL EXPERIENCE AND CURRENT PRACTICES

5.1 Historical Operational Overview

As presented in Section 1, spent nuclear fuel has been shipped in the U.S. and internationally for approximately 40 years. Shipments have been by both civilian and government entities using highway, railroad, and sea transportation modes.

Spent nuclear fuel shipments in the U.S. have occurred for a number of reasons. In the past, the most prevalent reason was the transport from a reactor to a facility for the reprocessing of spent fuel. Spent nuclear fuel has also been shipped to off-site storage facilities or to other nuclear power plants for interim storage. In addition, spent nuclear fuel has been shipped to research facilities for examination and/or for testing purposes. Future shipments of spent fuel in the U.S. will largely be for permanent disposal, presumably at the proposed Yucca Mountain repository. It is also expected that there may be spent fuel shipments to the proposed Private Fuel Storage facility in Utah for interim storage prior to permanent disposal.

Commercial reprocessing of spent fuel is no longer practiced in the U.S. although reprocessing continues in Europe. The U.S. government discontinued reprocessing military and government-owned spent fuel in 1992, but still retains a limited capability should the policy be reversed. Significant quantities of HLW from this country's past reprocessing of defense related spent nuclear fuel are stored at DOE sites in Idaho, South Carolina and Washington, all of which must be vitrified and packaged prior to being shipped for ultimate disposal. Since 1957 more than 742 casks containing spent fuel from the U.S. Navy's nuclear propulsion program have been shipped by the DOE to reprocessing and storage facilities in Idaho [Ref 5-1].

During the 1960s through the 1980s, spent fuel shipping was fairly frequent. General Electric Company (GE) shipped spent fuel from a number of nuclear power plants to its Morris, Illinois interim spent fuel storage facility. Spent fuel was also shipped to Nuclear Fuel Services Company’s West Valley, New York reprocessing plant. However, large-scale domestic spent fuel shipping "campaigns" have not been conducted for a decade or longer. A campaign is an organized shipping project from a designated site involving one or more shipments of spent fuel and the associated planning, logistics, and execution.

From the late 1990s to the present time, there have been a number of specific spent nuclear fuel shipping campaigns. DOE’s Foreign Research Reactor (FRR) Spent Fuel Acceptance Program has completed 25 shipments of FRR spent fuel, including 5,500 spent fuel assemblies from 27 countries [Ref 5-2]. These involved highway-transported packages that were moved by ship to both East Coast and West Coast ports and then either moved by truck or railroad to DOE facilities in South Carolina and Idaho. Highway-transported packages were used in a campaign that moved Brookhaven National Laboratory test reactor fuel by barge and highway from Long Island, New York, to the DOE's Savannah River Plant

In the commercial sector, Progress Energy has been shipping spent nuclear fuel from its Brunswick and H.B. Robinson nuclear stations to its Shearon Harris station for interim storage. Since 1989, Progress Energy has carried out 115 rail shipments with more than 200 casks traveling more than 21,000 miles [Ref 5-3]. In addition, commercial nuclear fuel suppliers transport irradiated fuel assemblies of advanced designs to hot cell facilities for performance examination; however, this is usually a single fuel assembly or even selected rods from a test assembly.

5.2 The Shoreham-to-Limerick Campaign

One of the more complicated shipping campaigns of the last decade was the transport of slightly irradiated fuel from the Shoreham nuclear power plant in New York to Limerick nuclear power plant in Pennsylvania. Project planning was begun in 1990 and the final shipment was completed in June 1994. The campaign involved the transfer of 560 partially-used boiling water reactor (BWR) fuel assemblies (102.5 MTU) from the Shoreham nuclear power station on the north shore of Long Island, which was being permanently shut down, to the Limerick nuclear power station west of Philadelphia. The purpose of the move was to allow the partially-used Shoreham fuel to be re-inserted into the compatible Limerick nuclear power plant to fully use the available energy in the fuel. The fuel was not as radioactive as fuel that has been resident in a reactor for two to three operating cycles. Nonetheless, the licensed transport casks were selected and the planning, logistics, and operations were conducted as if fully irradiated spent fuel was being transported.

What made this campaign unique is that it involved multi-modal transport: a 350-mile barge shipment, a 50-mile railroad shipment, and two intermodal transfers -- road-to-barge and barge-to-railroad. The former was an on-site heavy hauling activity to move the loaded cask from the Shoreham reactor building to the barge slip. The latter was a crane transfer at the end of the barge shipment to move the package from the barge to the railroad. The 50-mile railroad journey was from the crane transfer site to the Limerick nuclear power plant. This same process was reversed for the return of the empty transport cask. Thirty three such round-trip shipments were made using two 75-ton IF-300 rail casks shipped one at a time. The logistics called for one loaded cask/barge going to Limerick and one empty cask/barge returning to Shoreham for reloading. The first shipment departed Shoreham on September 25, 1993 and the last shipment was unloaded at the Limerick station on June 7, 1994. One of the keys to this project's success was a strong interaction with local and state officials and the public along the transportation corridors. The participating utility companies conducted informational meetings and media presentations. Stakeholders were given many opportunities to ask questions and provide input. Although no campaign can be conducted to everyone's satisfaction, the participation of the public and local officials created a generally positive attitude about the safety of the campaign. The Shoreham-to-Limerick shipments make an excellent model for defining the fundamentals of a spent fuel shipping campaign.

5.3 TMI Fuel Debris Shipments

The March 29, 1979, Three Mile Island reactor accident resulted in major damage to the nuclear fuel in the reactor core. As part of the cleanup effort, it was decided to canister the damaged fuel debris and ship it to a DOE facility in Idaho for study and interim storage. Railroad transport was chosen to minimize the number of shipments (i.e., 25 to 45 rail shipments vs. 250 highway shipments). Special casks, designated 125B, were designed and certified for this application. Three 125-ton transport casks were constructed along with their special heavy-duty flatcars. The shipments occurred using dedicated train service (i.e., no commodities on the train other than the 125B casks and their buffer cars), with one to three casks per train during a shipment. The first shipment began in July 1986 and the last one occurred in August 1989. A total of 43 cask-loads were moved in 20 rail shipments over the three year period. The canistered core debris was equivalent to 164 PWR fuel assemblies.

5.4 Shipping Campaign Fundamentals

Each spent fuel shipping campaign is unique but there are some fundamental steps that will apply to all campaigns. These steps are: Organization, Planning, Equipment Selection, Shipment Execution, and Campaign Close-out. A detailed discussion of each of these steps is contained in Appendix E.

5.5 Summary

This section identifies the broad range of activities that must be addressed in the course of planning a spent fuel shipping campaign, whether for the transport of a single spent fuel cask or for many casks over a period of years. In order to carry out a successful campaign, it is necessary to have a strong centralized management organization, skilled personnel, qualified equipment, precise planning and near-seamless execution. While planning and executing a spent fuel shipping campaign can be challenging, it is an activity that has been successfully performed for decades with about 35,000 cask shipments having taken place internationally. The outstanding safety record of spent fuel shipping is a testimony to the detailed planning and skilled staff involved in the shipping campaigns.

6

EMERGENCY MANAGEMENT

Emergency preparedness and planning requirements have been established by DOT, NRC and the Federal Emergency Management Agency (FEMA) for radioactive material transport (as part of broader hazardous material regulations) to ensure that, in the event of a serious transportation accident, the public, workers and the environment are protected. Emergency preparedness and emergency response activities are shared by the shipper of record (owner and/or generator of the material); the carriers that are transporting the material; state, local and tribal jurisdictions through which the material is traveling; and federal agencies.

FEMA and the DOE provide emergency response training for state and local law enforcement officials, fire fighters, and rescue squads, covering preparedness planning and accident handling. This training, while specific to radioactive materials, supplements emergency response training conducted by state and local emergency response organizations associated with the transport of other hazardous materials.

6.1 Emergency Response

In the event of an accident involving radioactive materials, the carrier has the responsibility for confining the spread of radioactive materials and for performing any cleanup activities. If the driver is not injured, then the driver (acting on behalf of the carrier) has initial responsibility for minimizing the consequences of the accident by directing traffic around the accident, confining suspected areas of contamination from access by people, and contacting and reporting the accident to appropriate authorities and the shipper of record.

First responders act to protect the people, property and the environment in the event of an accident. First responder duties are the responsibility of state and local government agencies, primarily through their police and fire departments. State and local governments can call on DOE for technical assistance in the event of a serious accident involving radioactive materials. DOE operates a Radiological Assistance Program, with eight regional offices that are staffed with experts who are available for immediate assistance to an accident involving radioactive materials.

In addition to assistance provided by federal agencies, the companies that operate nuclear power plants have entered into a voluntary mutual assistance agreement. Under this agreement, the company closest to the scene of a transportation accident responds on behalf of the company that shipped the radioactive materials, until emergency response personnel from the carrier and the company that owns the radioactive material arrive on the scene.

6.2 Emergency Preparedness

6.2.1 FEMA

FEMA is the lead federal agency for state and local radiological emergency response planning activities. FEMA coordinates the Federal Radiological Emergency Response Plan (FRERP), which outlines the responsibilities of federal departments and agencies in response to any type of peacetime radiological emergency, including transportation accidents involving radioactive materials. The FRERP identifies how each federal agency responds to specific kinds of radiological emergencies based on the location of the emergency, the potential impact on the public and environment, the size of the affected area and the source of the radioactive material involved. The key participants are FEMA, NRC, DOE, the Department of Defense, and the Environmental Protection Agency.

FEMA recently published detailed guidance for developing state and local response and preparedness plans for transportation accidents involving radioactive materials, *Guidebook for Radiological Response Planning and Preparedness.* According to FEMA, the guidebook has been distributed to all state emergency management agencies, state offices of radiological health and federal radiological emergency response agencies [Ref 6-1].

FEMA has also developed "*Guidance for Developing State, Tribal, and Local Radiological Emergency Response Planning and Preparedness for Transportation Accidents*" [Ref. 6-2].

The Federal Radiological Preparedness Coordinating Committee, which is administered by FEMA, is in the process of providing data on the detection and measurement capabilities of the modern and more commonly used radiation detection instruments. Responders to radiological emergencies associated with any facilities, transportation accidents or terrorist incidents need to know whether the instrument they are using can detect and measure the radiation emitted by the radioactive source. This database, when completed, would provide information to emergency responders regarding instrument detection and measurement capability and will assist in protecting the public health and safety, as well as emergency workers responding to a radiological incident [Ref 6-1].

6.2.2 Section 180(c) of the Nuclear Waste Policy Act

In accordance with Section 180(c) of the Nuclear Waste Policy Act (NWPA), DOE is required to provide "technical assistance and funds to States for training for public safety officials of appropriate units of local government and Indian Tribes through whose jurisdiction the Secretary plans to transport spent nuclear fuel or high-level radioactive waste…". The NWPA stipulates that training will include procedures development for safe routine transportation of spent nuclear fuel and high-level radioactive waste as well as procedures for dealing with emergency response situations.

Shipment of spent nuclear fuel and high-level radioactive waste to a geologic repository are not expected to begin until 2010, at the earliest. Therefore, DOE is not expected to begin implementation of Section 180(c) until it has started to develop its routing plan approximately three to five years prior to the first shipments [Ref 6-3]. Training of emergency responders too far in advance of shipments to the proposed repository would only result in the need to retrain responders along the transportation routes prior to the start of shipments due to turnover rates among these personnel. DOE's plan to begin implementation of Section 180(c) after routes have been identified appears to be a sensible approach.

6.2.3 Transportation Emergency Preparedness Program

Within the DOE Office of Environmental Management, the Office of Transportation is responsible for implementing DOE's Transportation Emergency Preparedness Program (TEPP) to provide technical assistance to federal, state, local and tribal authorities in emergency preparedness activities. Technical assistance has included: developing transportation emergency plans, training first responders, and assisting in emergency response drills. The TEPP has developed a number of planning tools to assist responders to prepare for transportation accidents involving radioactive materials. These include models for developing emergency plans, assessing readiness, and for developing operating procedures for responding to hazardous materials incidents. The tools also include scenarios that could serve as the basis for conducting emergency drills [Ref 6-4].

This assistance is associated with DOE Office of Environmental Management shipments (such as the return of foreign research reactor spent fuel) and should not be confused with training to be provided in accordance with Section 180(c) of the NWPA.

6.3 Funding for Emergency Response

Funding for emergency response activities is provided by federal sources including FEMA, DOT and DOE. In addition, states have the ability to impose reasonable fees on shippers for permits to transport hazardous materials through their jurisdictions.

6.3.1 Federal Funding

FEMA provides funding to states, tribes and local governments targeted to improving general emergency response capability for all types of emergencies.

The DOT's Research and Special Programs Administration (RSPA) administers the Hazardous Materials Emergency Preparedness (HMEP) grant program. HMEP is intended to provide financial and technical assistance as well as national direction and guidance to enhance state, territorial, tribal, and local hazardous materials emergency planning and training. The HMEP Grant Program distributes fees collected from shippers and carriers of hazardous materials to emergency responders for hazardous materials training and to Local Emergency Planning Committees (LEPCs) for hazardous materials planning activities. Approximately 40 percent of funds are for planning and 60 percent are for training. All grants go initially to the "grantee," i.e., one of the approximately eighty states, territories, or Indian tribes who receive the funds [Ref 6-5].

6.3.2 State Funding

Federal law requires that state-imposed fees on hazardous materials transportation within or through the state must be fair and used for a purpose related to transporting hazardous material. In accordance with 49CFR107, states may impose fees for enforcement, planning, developing, and maintaining a capability for emergency response. To date, twenty-four states have imposed fees associated with transporting certain radioactive materials within or through the state.

6.4 Summary

A well developed system for emergency preparedness and planning has been established by DOT, NRC and FEMA to ensure that, in the event of a serious transportation accident, the public, workers and the environment are protected. Federal agencies provide funding and emergency response training to state and local law enforcement officials, fire fighters, and rescue squads, covering preparedness planning and accident handling. Prior to shipments to a proposed repository, DOE will provide technical assistance and funds to states and tribes along proposed transportation routes for training for public safety officials.

7

EXTRAPOLATION OF EXPERIENCE TO DOE TRANSPORTATION TO THE PROPOSED YUCCA MOUNTAIN REPOSITORY

Section 5 discussed the U.S. government and private sector experience in transporting spent nuclear fuel. While shipment of spent fuel to the proposed Yucca Mountain repository will involve significantly more cask shipments and longer shipment routes, this cumulative domestic experience will provide DOE with a solid basis for developing its transportation plan for transport of spent nuclear fuel and HLW to Yucca Mountain. This section examines the historical experience and its relevance to the proposed logistics of moving the nation's spent nuclear fuel and HLW to the proposed Yucca Mountain repository. It demonstrates that the U.S. is fully capable of safely handling the projected future quantities of these materials.

7.1 Total Number of Shipments to the Proposed Repository

Section 6 and Appendix J of the Yucca Mountain Final Environmental Impact Statement (YM-FEIS) [Ref 7-1] discuss two scenarios for the shipment of spent fuel and high-level radioactive waste to the proposed Yucca Mountain repository. The two scenarios – the "Mostly Legal-Weight Truck" and the "Mostly Rail" scenarios – were selected by DOE to bracket the possible environmental effects of transportation. Since the NWPA imposes a statutory capacity limit of 70,000 MTU for the repository, the YM-FEIS evaluated two sets of spent nuclear fuel and HLW inventories: that for the Proposed Action (a 70,000 MTU repository) and Inventory Modules 1 & 2 (which included all potential inventories requiring geologic disposal). Under the Proposed Action, the 70,000 MTU of radioactive material would be shipped to the repository over a period of 24 years. If the Module 1 & 2 material is included, shipments would take place over a period of approximately 40 to 50 years. Since disposal of Module 1 & 2 inventories require Congressional approval and, if approved, will occur in the distant future they will not be addressed in this report. However, most of the conclusions reached on the Proposed Action scenarios are applicable to Modules 1 & 2. Tables 7-1 and 7-2 show both scenarios for information purposes.

As shown in Table 7-1, the Mostly Legal-Weight Truck scenario estimates 52,786 truck shipments and 300 single-cask rail shipments. As shown in Table 7-2, the Mostly Rail case conservatively estimates 9,646 single-cask rail shipments and 1,079 truck shipments. It should be noted that by the time DOE begins spent fuel acceptance at a geologic repository, the majority of U.S. nuclear power plants will have begun loading spent nuclear fuel into rail-compatible dual-purpose dry storage systems. It would not make operational or radiological sense to unload these rail-compatible systems and reload spent fuel into truck casks for transport to a repository. Because of this and based on the fact that rail transport is more efficient than truck transport, the

Mostly Rail scenario is likely to be the actual case. In addition, the YM-FEIS indicates that the Mostly Rail scenario is DOE's preferred approach for transport of spent fuel to the proposed Yucca Mountain Repository.

The plans for the transportation of spent fuel and HLW to the proposed Yucca Mountain repository have not yet been finalized by DOE. DOE has announced plans to release a transportation strategic plan at the end of 2003 that will be used as the baseline document for subsequent planning and logistical efforts. If most of the shipments to the proposed repository will be by rail, the shipping logistics would call for railroad service using mostly large (i.e., 125-ton class) casks, with highway transportation used for those few reactors where rail is not feasible. Intermodal transport using heavy-haul vehicles may be needed to transport the loaded rail cask to the nearest rail spur for some plants. There are a range of alternatives for rail transport to Yucca Mountain. Under one scenario during the early period of repository operation, rail casks would arrive at a Nevada rail facility and subsequently be transferred at an intermodal site to highway heavy-hauling vehicles for transport to Yucca Mountain. This scenario assumes that a rail line would eventually be constructed in Nevada to the Yucca Mountain site. A second scenario would involve the construction of a Nevada rail line prior to the start of repository operations at Yucca Mountain, thereby eliminating the need to transport via heavy-haul highway vehicle in Nevada. In either case, the Mostly Rail scenario will present fewer operational challenges since it will result in significantly fewer cask shipments than the Mostly Legal-Weight Truck scenario. Whether spent nuclear fuel is transported via truck or via rail, the environmental impacts will be small as determined in the Yucca Mountain FEIS.

Table 7-1
Estimated Cask Shipments for the DOE "Mostly Truck" Scenario

SHIPPING SCENARIO	MATERIAL TO BE SHIPPED	TOTAL NUMBER OF CASKS SHIPPED	
		PROPOSED ACTION	PROPOSED ACTION AND INVENTORY MODULES 1 & 2
YM FEIS **"Mostly Legal Weight Truck"**	Commercial Spent Fuel –Truck	41,001	79,684
	DOE & Navy Spent Fuel – Truck	3,470	3721
	DOE & Navy Spent Fuel – Rail	300	300
	HLW	8,315	22,280
	Greater-than-Class-C	0	1,096
	DOE Special Performance Assessment Material	0	1,763
TOTAL		53,086	108,844
Source: YM-FEIS, Table J-4, J-6, J-7, J-8, J-9			

Table 7-2
Estimated Cask Shipments for the DOE "Mostly Rail" Scenario

SHIPPING SCENARIO	MATERIAL TO BE SHIPPED	TOTAL NUMBER OF CASKS SHIPPED	
		PROPOSED ACTION	PROPOSED ACTION AND INVENTORY MODULES 1 & 2
YM FEIS "Mostly Rail"	Commercial Spent Fuel – Rail	7,218	12,989
	Commercial Spent Fuel – Truck	1,079	3,122
	DOE & Navy Spent Fuel	765	796
	HLW	1,663	4,458
	Greater-than-Class-C	0	282
	DOE Special Performance Assessment Material	0	410
TOTAL		10,725	22,057
Source: YM-FEIS, Table J-5, J-6, J-7, J-8, J-9			

Under the Mostly Rail scenario there would be approximately 450 rail cask shipments and 45 highway cask shipments per year during the 24-year shipping period. Since most nuclear power plants will load several casks per year for shipment to the proposed repository, it could be expected that three casks would be loaded on each train destined for the repository. This would result in approximately 150 train shipments per year. When combined with the highway cask shipments, this suggests that perhaps a total of three to four truck and train shipments per week would be moving somewhere in the country, less if a greater number of casks were transported on each train shipment.

7.2 Yucca Mountain – A Series of Shipping Campaigns

The number of different nuclear power plants and/or DOE waste sites from which spent fuel and HLW will be transported each year will vary depending on many factors including the amount of material shipped, location, and shipping mode(s). It would be reasonable to expect 20 or more sites to be shipping spent fuel to the proposed repository on an annual basis, some simultaneously and some serially. Each site represents a campaign as described in Section 5 and Appendix E of this report. The total volume of spent nuclear fuel and HLW projected for Yucca Mountain, although larger than heretofore shipped domestically, will be a series of campaigns with which the transport industry has ample experience. Shipping campaigns, as illustrated in Section 5 by the Shoreham-to-Limerick Project and the TMI Core Debris Shipping Campaign, are identical in composition to any of those projected for Yucca Mountain, only the total volume and the time periods over which shipments will occur are different.

The U.S. experience in spent nuclear fuel transportation has established the format for successfully conducting parallel and/or serial shipping campaigns. This format is completely applicable to the shipments to Yucca Mountain even though the volume of shipments will increase substantially. The shipment planning activity for Yucca Mountain will require sufficient time to acquire all necessary shipping casks and associated hardware, implement the campaign planning process, and establish the required infrastructure as discussed in Appendix E.

Before the first spent fuel shipping campaign to Yucca Mountain commences, DOE will have put in place an organization that will have responsibility for coordinating all transportation activities. In fact, DOE has already begun this organizational effort by establishing the Office of National Transportation within the Office of Civilian Radioactive Waste Management and by bringing in an experienced transportation manager from elsewhere in the DOE complex.

DOE's transportation planning efforts will build on those of the commercial nuclear industry and other DOE transportation planning activities such as the foreign research reactor spent fuel transports, transport of transuranic waste to the Waste Isolation Pilot Plant, and transport of U.S. Navy spent nuclear fuel for storage in Idaho. These DOE transportation planning efforts were recently summarized in a "best practices" report that summarized the best practices as outlined in DOE's "*Radioactive Material Transportation Practices Manual*" [Ref 7-2]. The Manual was developed to establish a set of standard transportation practices for DOE programs to use in planning and executing offsite shipments of radioactive materials or waste.

It will also be important for DOE to give serious consideration to the international experience in shipping spent nuclear fuel and HLW and apply the best practices of these shipments to those for Yucca Mountain. Section 5 indicates that the European shipping experience is roughly ten-times that of the U.S. The European shipping experience may be particularly useful in that the shippers must interface with multiple countries and regulatory authorities as shipments cross country borders and must plan and execute long-term shipping campaigns for shipment of spent nuclear fuel to reprocessing facilities and return of HLW to the countries of origin of the material. This campaign experience reasonably resembles that projected for Yucca Mountain and should be integrated, as applicable, into the DOE's planning process.

7.3 Summary

A well-developed spent fuel transportation planning basis and forty years of experience will form the basis upon which DOE plans its transportation program for shipments of spent nuclear fuel and HLW to the proposed Yucca Mountain repository. The resulting transportation system will safely and efficiently transport the projected volumes of radioactive material to the proposed Yucca Mountain repository.

8
ACRONYMS

10CFR71	Title 10, U.S. Code of Federal Regulations, Part 71
10CFR73	Title 10, U.S. Code of Federal Regulations, Part 73
AAR	Association of American Railroads
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BWR	Boiling Water Reactor
B( )F	Type B Fissile (package)
CFR	Code of Federal Regulations
CNWRA	Center for Regulatory Waste Regulatory Analysis
COC	Certificate of Compliance
DOE	United States Department of Energy
DOT	United States Department of Transportation
ERDA	Energy Research and Development Administration
FEMA	Federal Emergency Management Agency
FEIS	Final Environmental Impact Statement
FRERP	Federal Radiological Emergency Response Plan
FRA	Federal Railway Administration
FRR	Foreign Research Reactor
GE	General Electric
GVW	Gross Vehicle Weight
HazMat	Hazardous Material

HLW	High Level Radioactive Waste
HMEP	Hazardous Materials Emergency Preparedness
IAEA	International Atomic Energy Agency
ICM	Interim Compensatory Measures
ISG	Interim Staff Guidance
LEPC	Local Emergency Planning Committee
LWT	Legal-Weight Truck
MTU	Metric Tons of (initial) Uranium
NIST	National Institute for Standards and Technology
NRC	United States Nuclear Regulatory Commission
NTSB	National Transportation Safety Board
NWPA	Nuclear Waste Policy Act
OWT	Overweight Truck
PNNL	Pacific Northwest National Laboratory
PWR	Pressurized Water Reactor
QA	Quality Assurance
RAM	Radioactive Material
RMIR	Radioactive Material Incident Report
RSPA	Research and Special Programs Administration (DOT)
SARP	Safety analysis Report - Packaging
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratories
TEPP	Transportation Emergency Preparedness Program
TMI	Three Mile Island
YM	Yucca Mountain (NV)

9

REFERENCES

1-1 U.S. DOT, Research and Special Programs Administration, "*A Study of Hazards and Risks to Public Health and Safety, the Environment, and the Economy Associated with the Transportation of Hazardous Materials*," Final Report, June 18, 2002.

1-2 U.S. DOE, *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250, February 2002, Appendix A.

1-3 Supko, Eileen, Energy Resources International, Inc.

1-4 Pope, Ronald; Bernard-Bruls, Xavier; and Brittinger, M.; International Atomic Energy Agency, "*A Worldwide Assessment of the Transport of Irradiated Nuclear Fuel and High-Level Radioactive Waste*", PATRAM 2001, September 3-7, 2001 Chicago, Illinois.

1-5 U.S. NRC, "*Public Information Circular for Shipments of Irradiated Reactor Fuel*", NUREG-0725, Rev. 13, October 1998.

1-6 U.S. DOT, "*Hazardous Materials Shipments,*" Office of Hazardous Materials Safety, Research and Special Programs Administration, October 1998

1-7 Battelle Columbus, Prepared for the Federal Motor Carrier Safety Administration, "*Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents*", March 2001.

1-8 R.E. Rhodes, A.L. Franklin, J.C. Lavender, "*Evaluation of Methods to Compare Consequences From Hazardous Material Transportation Accidents*," SAND86-7117, Prepared for Sandia National Laboratories by Battelle Pacific Northwest Laboratories, October 1986.

1-9 Hughes, J S, and Shaw, K B, *Accidents and Incidents Involving the Transport of Radioactive Material in the U.K., from 1958 to 1994, and Their Radiological Consequences*, NRPB-R282, 1996.

1-10 Association of American Railroads, *Performance Specification for Trains Used to Carry High-Level Radioactive Material,* Standard S-2042, Effective May 1, 2003.

2-1 U.S. Department of Transportation:

49CFR171, "General Information, Regulations, and Definitions";
49CFR172, "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information and Training Requirements";
49CFR173, "Shippers – General Requirements for Shipments and Packagings";
49CFR174, "Carriage by Rail";
49CFR 175, "Carriage by Aircraft";
49CFR176, "Carriage by Vessel";
49CFR177, "Carriage by Public Highway".
49 CFR397, Routing Regulations for Certain Radioactive Materials, Including Spent Nuclear Fuel.

2-2 U.S. NRC, *Standard Review Plan for Transportation Packages for Spent Fuel*, NUREG-1617, March 2000.

2-3 U.S. NRC, *Draft Regulatory Analysis of Major Revision of 10 CFR 71, Proposed Rule, Draft Report for Comment*, NUREG/CR-6713, April 2002.

2-4 U.S. NRC, *Shipping Container Response to Severe Highway and Railway Accident Conditions: Main Report*, Lawrence Livermore National Laboratory, NUREG/CR-4829, February 1987.

2-5 U.S. NRC, *In the Matter of All Power Reactor Licensees, Research and Test Reactor Licensees, and Special Nuclear Material Licensees Who Possess and Ship Spent Nuclear Fuel; Order Modifying License, Effective Immediately*, Federal Register, Volume 67, No. 197, October 10, 2002.

2-6 U.S. DOE, *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250, February 2002.

2-7 U.S. DOT, Federal Rail Administration, *High-Level Nuclear Waste Rail Transportation Inspection Policy,*

http://www.fra.dot.gov/safety/hazmat/hlvwste.htm.

2-8 U.S. DOT, Federal Rail Administration, *Safety Compliance Oversight Plan for Rail Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel*, August 1998, http://www.fra.dot.gov/downloads/safety/scopfnl.pdf.

2-9 Reed, James, National Conference of State Legislatures, *The State Role in Spent Fuel Transportation Safety: Year 2000 Update*, January 2000, No. 14.

3-1 U.S. NRC, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*", NUREG-0170, December 1977.

3-2 U.S. Atomic Energy Commission, *Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plants,* WASH-1238.

3-3 Travers, William D., Executive Director for Operations, U.S. NRC, Memo to the Commissioners, *RE: Transportation Risk Studies*, SECY-00-0042, February 17, 2000.

3-4 U.S. NRC, *Shipping Container Response to Severe Highway and Railway Accident Conditions*, Lawrence Livermore National Laboratory, NUREG/CR-4829, February 1987.

3-5 U.S. NRC, *Reexamination of Spent Fuel Shipment Risk Estimates, Sandia National Laboratories*, NUREG/CR-6672, March 2000.

3-6 Halstead, R J, *Comments of Robert J. Halstead on Behalf of the State of Nevada Agency for Nuclear Projects Regarding the U.S. Nuclear Regulatory Commission Study Assessing Risk of Spent Nuclear Fuel Transportation Accidents (Modal Study Update), Presented at the Public Meeting in Henderson, Nevada, December 18, 1999.*

3-7 U.S. DOE, National Transportation Program, Office of Environmental Management, *Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk*, Douglas J. Ammerman, et al, Sandia National Laboratories, April 8, 2003, NRC ADAMS Accession # ML031140370, Submitted April 14, 2003.

3-8 U.S. NRC, Evaluation of the Effects of the Baltimore Tunnel Fire on Rail Transportation of Spent Nuclear Fuel*, SECY-03-0002, January 6, 2003.*

3-9 Robert M. Jefferson, H. Richard Yoshimura*, Crash Testing of Nuclear Fuel Containers*, SAND77-1462, Sandia National Laboratories, February 1978.

3-10 Michael Huerta, Analysis*, Scale Modeling, and Full-Scale Testing of a Railcar and Spent-Nuclear Fuel Shipping Cask in a High-Velocity Impact Against a Rigid Barrier*, SAND78-0458, Sandia National Laboratories, June 1981.

3-11 U.S. NRC, Package Performance Study Test Protocols, Draft Report for Comment, *NUREG-1768, February 2003.*

3-12 Kraft, Steven P, Nuclear Energy Institute, Letter to U.S. NRC, RE: Request for Comments on United States Nuclear Regulatory Commission Package Performance Study Test Protocols, Draft Report For Comments*, NUREG-1768, May 30, 2003.*

4-1 *American Society of Mechanical Engineers, ASME Boiler & Pressure Vessel Code, Section III, Division 3,* Containment Systems and Transport Packagings for Spent Fuel and High Level Radioactive Waste, *New York, NY, 1998.*

5-1 Doherty, D., *U.S. Naval Nuclear Propulsion Program*, presented to the NRC Advisory Committee on Nuclear Waste, Transportation Working Group, November 20, 2002.

5-2 Clapper, Maureen, U.S. DOE*, “Transport Safety Record and Measures Taken for the United States Foreign Research Reactor Spent Nuclear Fuel Acceptance Program*”,IAEA-CN-101/34, International Conference on the Safety of Transport of Radioactive Material, Contributed Papers, July 7-11, 2003, Vienna, Austria.

5-3 Kunita, Robert, Progress Energy, “*Summary of Utility Experience*”, presented to the NRC Advisory Committee on Nuclear Waste, Transportation Working Group, November 20, 2002.

6-1 Baughman, Bruce, Office of National Preparedness, Federal Emergency Management Agency, *Statement before the Committee on Transportation and Infrastructure Subcommittee on Highways and Transit and Subcommittee on Railroads*, *U.S. House of Representatives*, April 25, 2002.

6-2 Federal Emergency Management Agency, *Guidance for Developing State, Tribal, and Local Radiological Emergency Response Planning and Preparedness for Transportation Accidents*, FEMA-REP-5, Rev. 1, June 1992.

6-3 U.S. DOE, *Transporting Spent Nuclear Fuel and High-level Radioactive Waste to a National Repository, Answers to Frequently Asked Questions*, Office of Civilian Radioactive Waste Management, December 2002.

6-4 McNeil, E.B., U.S. DOE, Office of Environmental Management, *Transportation Emergency Preparedness Program,* IAEA-CN-101/113, International Conference on the Safety of Transport of Radioactive Material, Contributed Papers, July 7-11, 2003, Vienna, Austria.

6-5 U.S. DOT, Research and Special Programs Administration, Report to Congress on the Hazardous Materials Emergency Preparedness (HMEP) Grants Program*, August 1998.*

7-1 U.S. DOE, Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250, February 2002.*

7-2 SAIC, Best Practices and Findings for DOE Programs Transporting Spent Nuclear Fuel, Report for the National Transportation Program*, Department of Energy, Albuquerque, Final Draft, January 2003, by Science Applications International Corporation Energy Solutions Group.*

A

U.S. TRANSPORTATION ACCIDENTS INVOLVING SPENT NUCLEAR FUEL TRANSPORT CASKS

A.1 Summary

Sandia National Laboratories (SNL) manages the Radioactive Materials Incident Report (RMIR) database. The RMIR was developed in 1981 to support SNL's research and development activities for the DOE. The database contains information about radioactive materials transportation accidents and incidents that have occurred in the U.S. since 1971. Table A.1 summarizes the transportation accidents that have occurred in the U.S. involving spent nuclear fuel casks since 1971.

It is useful to note that as a result of these accidents, there have been no serious injuries to transport workers, emergency response personnel, or the general public as a result of the radioactive contents of the casks.

Table A-1
U.S. Transportation Traffic Accidents Involving Spent Nuclear Fuel Casks

Date	Location	Mode	Description	
12/1971	Tennessee	Highway	Truck driver left road during rain storm to avoid near head-on collision with car. Truck rolled and cask was thrown free landing in a ditch. Driver killed.	Cask was not damaged. No release of contents.
3/1974	North Carolina	Rail	Rail tank car derailed and struck cask on another track.	Superficial damage to cask. No release of contents. *Empty cask.*
2/1978	Illinois	Highway	As cask crossed rail road tracks at a grade crossing, extra stress caused trailer to collapse due to broken weld.	Cask was not damaged. No release of contents.
8/1978	New Jersey	Highway	As empty cask was being placed on trailer, the trailer deck failed due to broken weld.	Cask was not damaged. No release of contents *Empty cask.*
12/1983	Indiana – Illinois border	Highway	Tractor separated from trailer holding spent fuel cask.	Cask was not damaged. No release of contents
3/1987	Missouri	Rail	Train struck automobile at railroad crossing.	No damage to train or casks. No release of contents.
1/1988	Illinois	Rail	Train derailed.	No damage to train or casks. No release of contents. *Empty cask*
12/1995	North Carolina	Rail	Railway car derailed – four of eight wheels slipped off track. Car was stable and upright.	No damage to train or casks. No release of contents. *Empty casks.*

Source:

Cashwell, C E, and McClure, J D, Sandia National Laboratories*, Transportation Accidents/Incidents Involving Radioactive Materials (1971 – 1991),* Presented at the PATRAM '92, 10th International Symposium on the Packaging and transportation of Radioactive Materials, September 12-18, 1992, Yokohama City, Japan

McClure, J D, Sandia National Laboratories, *Historical Safety Performance of Spent Fuel Transportation,* Presented before the U.S. Nuclear Waste Technical Review Board, November 19, 1997

B

A DISCUSSION OF RELATIVE RISK OF TRANSPORTATION OF HAZARDOUS MATERIALS

It is often difficult and frequently misleading to examine the concept of societal risk associated with a specific activity in an absolute sense. The fact is that risk is relative. To examine the risk of spent fuel transportation by itself, for example, implies that all other activities are risk-free or, at best, not of enough importance to consider.

In 1986, Battelle Pacific Northwest Laboratories performed a study that compared the consequences of hazardous materials transportation accidents [Ref. 1-8]. The report included data on the risks associated with a number of societal activities and compared these risks on a common basis, including natural and man-made phenomena and activities. The study examined the transportation of many common hazardous materials such as explosives, chlorine, and propane and the associated risks. As a precursor to the study, a number of approaches to defining risk were identified and three were accepted based on accuracy, ease of data application, and the ability to reasonably communicate the results. In the final analysis, a risk assessment methodology was used to compare the various risks. Risk assessment in its fundamental format is that "risk" is the probability of an event times the consequences of that event. In the case of the Battelle study, the consequences were stated as fatalities due to the hazardous nature of the material being shipped. Injuries and damage costs were not considered in order to make an easily understood comparison among the different classes of hazardous materials being evaluated.

Examination of the results presented in Figure B-1 and Table B-1 clearly show that the societal risk, measured by the chances of a fatality in a given year, are extremely small for spent nuclear fuel when compared to other common hazardous materials such as explosives, propane, and chlorine. Further, when compared to other aspects of life such as motor vehicle and industrial accidents and natural phenomena, the risk of spent nuclear fuel shipping is even smaller. The report shows that the individual risk (i.e., probability of an individual dying from this cause in a given year) from spent fuel shipping is 4×10^7 times <u>less</u> than chlorine shipping, 7×10^7 times less than propane shipping, and 3×10^{11} times less than motor vehicle accidents.

The conclusion of this risk comparison is consistent with other risk assessments on the transportation of spent nuclear fuel and high-level radioactive waste. The societal risk is extremely small on either a relative basis or an absolute basis.

Table B-1
Comparison of Risks from Various Sources [Ref. 1-8]

ACCIDENT TYPE	FATALITIES/YEAR	INDIVIDUAL RISK*
All Accidents	115,821	1 in 2,000
Motor Vehicle Accidents	55,511	1 in 4,000
All Industrial Accidents	14,100	1 in 6,000
Falls	15,506	1 in 13,000
Drowning	7,152	1 in 29,000
Fires	6,503	1 in 32,000
Poisoning	5,335	1 in 40,000
Airplane Crashes	1,668	1 in 130,000
Railway Accidents	789	1 in 250,000
Lightning	160	1 in 1,300,000
Tornadoes	90	1 in 2,300,000
Dam Failures	35	1 in 5,700,000
Propane Transportation Accidents	11	1 in 15,000,000
Chlorine	9.4	1 in 22,300,000
Air Crashes (persons on ground)	6	1 in 33,000,000
Explosives	0.16	1 in 10^9
Spent Fuel	3E-9	1 in 10^{15}
* Probability of an individual at risk of dying from this cause in a given year		

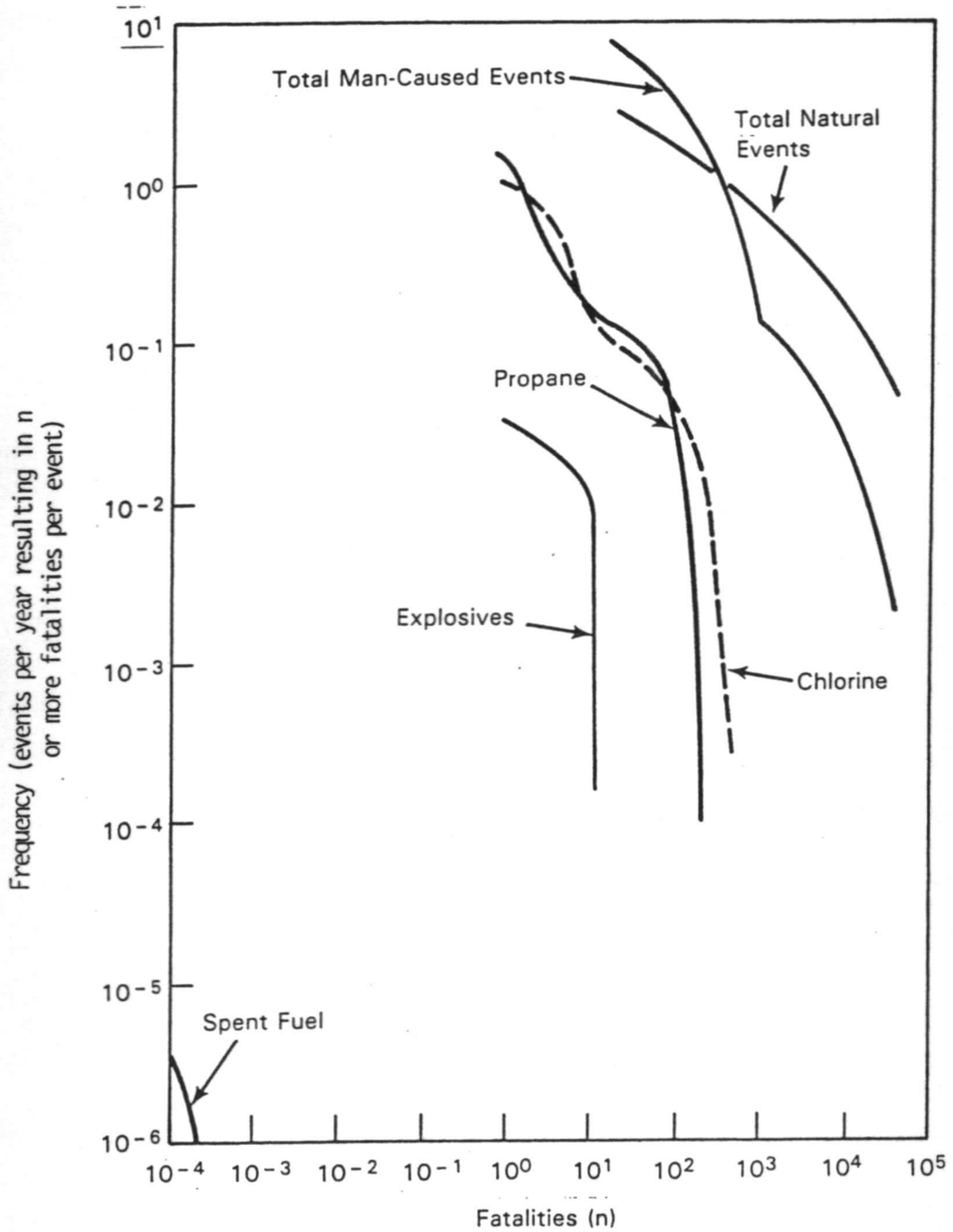


Figure B-1
Comparison of Risk Curves for Various Activities [Ref 1-8]

C

HYPOTHETICAL ACCIDENT CONDITIONS COMPARED TO REAL WORLD ACCIDENTS

C.1 Introduction

As discussed in Section 3, as shipping campaigns were underway in the mid 1980s, public attention and concern regarding these shipments increased. One of the areas of concern dealt with public understanding regarding how the designated regulatory accident conditions might bound real-world transport accidents. In response to this concern, the NRC initiated a study, *"Shipping Container Response to Severe Highway and Railway Accident Conditions"*, NUREG/CR-4829 [Ref. 3-4], referred to as the "Modal Study", to evaluate and determine spent fuel cask response in real world accidents. The Modal Study compared the mechanical and thermal loads generated in actual truck and rail transportation accidents to the loads generated under the hypothetical accident conditions in 10CFR71. The Modal Study concluded that the risks associated with transporting spent nuclear fuel are small.

Despite the results of the Modal Study and the additional risk assessment conducted since then (described in Section 3), there continues to be concern by the public regarding how the NRC's regulatory accident conditions for spent fuel casks compare to real-world accident conditions. For example, questions are asked such as: are there potential accident fires that will "burn hotter" than the regulatory accident thermal conditions? are there drop accidents that might be more severe than the regulatory free drop conditions? This section will discuss the regulatory hypothetical accident conditions and how they relate to real world accident conditions.

C.2 Regulatory Hypothetical Accident Conditions

Spent nuclear fuel transportation casks are designed to be able to withstand severe transportation accident conditions without a release of the radioactive contents. NRC regulations provide cask designers with performance criteria for the casks in the form of the regulatory accident conditions contained in 10CFR 71.73. The accident conditions require that casks be subjected to the following accident conditions in sequence to determine the cumulative effect on the spent fuel cask.

Free Drop: A 30 foot (~9 meter) free drop of the cask onto a flat, unyielding, horizontal surface. The cask must strike the surface in a position for which maximum damage is expected.

Puncture: A 40-inch (~1 meter) free drop of the cask onto a vertical steel bar, six inches in diameter, mounted on an unyielding, horizontal surface. The cask must strike the steel bar in a position for which maximum damage is expected. The dimensions of the bar are specified by the regulation.

Thermal: Exposure of the cask in a fully-engulfing, hydrocarbon fuel/air fire with an average flame temperature of at least 1475°F (800°C) for a period of 30 minutes. The regulations specify the physical conditions of the fire including the dimensions of the hydrocarbon fuel source around the cask and the position of the cask relative to the surface of the fuel source.

Immersion: Immersion under at least 3 feet (0.9 meters) of water.

As a separate accident condition, 10CFR 71.51 requires a deep immersion test for packages of spent nuclear fuel with activity greater than 1 million Curies (37 PBq). The regulations require that the package must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi (2 MPa) for a period of not less than one hour without collapse, buckling or in-leakage of water.

These performance criteria, in the form of the hypothetical accident criteria, remove the need for cask designers and the NRC to predict specific accident events. These hypothetical accident criteria make it possible to duplicate tests, compare test results for different designs, and be assured of consistent results as additional tests are performed. The duplication of accident conditions would not be easily accomplished if one were to test casks under real world conditions since more test variables and uncertainties would be introduced.

C.3 Free Drop Accident Condition

The hypothetical accident conditions require that a cask be able to withstand a 30-foot free drop onto an unyielding surface, striking the unyielding surface in a position for which maximum damage is expected. There are virtually no natural or manmade structures that a cask would encounter during transportation that can be classified as unyielding [Ref. C-1, C-2]. In fact, to construct an unyielding surface requires "*a block of concrete that weighs 10 times the weight of the cask (that is, about 500,000 pounds for a truck cask and 2,000,000 pounds for a rail cask) that is topped with a 4-inch thick plate of steel*" [Ref C-3]. Real-world surfaces that a cask might encounter during a transportation accident will yield and absorb a substantial amount of the energy of the impact. In other words, the 30-foot drop onto the unyielding target, which has an impact velocity of approximately 30 mph, is equivalent to higher impact velocities with real world surfaces – for example, more than a 120 mph end impact with a concrete slab; more than a 150 mph end impact with soil [Ref. C-4]. The reason for this velocity difference is that real surfaces deform (i.e., bend, shatter, compress) and in the process absorb impact energy and consequently reduce impact forces on the cask. In contrast, the impact with an unyielding surface forces the cask to absorb all of the energy from the impact.

C.4 Thermal Accident Condition

The hypothetical accident conditions require that a cask be exposed to a fully-engulfing, hydrocarbon fuel/air fire with an average emissivity coefficient of 0.8, with an average flame temperature of 1475°F for 30 minutes. The regulations also specify that the absorptivity coefficient must be 0.8 or greater and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. While the regulatory requirement is for a 30-minute fire at 1475°F, the additional regulatory conditions (emissivity and absorptivity) bound fires for fuels which may burn at higher temperatures (normally lasting only a very short time at very high temperatures), or at lower temperatures for longer periods of time.

The emissivity coefficient refers to the amount of heat that the flames are assumed to radiate (90%) compared to the theoretical amount that could be radiated by an ideal flame source. The cask absorptivity coefficient specified – 80% – results in the cask being completely enveloped in the thermal environment so that it absorbs all of the heat with little being conducted or radiated away [Ref C-1].

In a real fire, the fire temperature is not uniform and the cask is not completely engulfed. In order to fully engulf a cask, the cask would have to be suspended approximately four feet above the surface of the fuel. [Ref C-2] In a real world scenario, the cask would likely be in contact with the ground or the transport vehicle providing a pathway for heat removal from the cask to the ground or vehicle. In addition, in real world fires, the temperature would not be uniform, but would fluctuate depending upon the amount of fuel and the ventilation. The higher the emissivity, the greater the flame thickness will be. However, increasing flame thickness for an open fire will reduce the ventilation to the fire and lower the flame temperature [Ref C-1]. Thus, as concluded in a recent study by Sandia National Laboratories, "it is difficult to justify any fire that could be more severe than a fully-engulfing fire" [Ref C-5].

References:

C-1 U.S. Congress, Office of Technology Assessment, Transportation of Hazardous Materials, July 1986

C-2 Jefferson, Robert, Sandia National Laboratories, Transporting Spent Reactor Fuel, Allegations and Responses, SAND82-2778, TTC-0403, Reprinted November 1984

C-3 U.S. DOE, National Transportation Program, Office of Environmental Management, "Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk", Douglas J. Ammerman, et al, Sandia National Laboratories, April 8, 2003, NRC ADAMS Accession # ML031140370, Submitted April 14, 2003

C-4 U.S. NRC, Reexamination of Spent Fuel Shipment Risk Estimates, Sandia National Laboratories, NUREG/CR-6672, March 2000, Tables 5.10 to 5.13

C-5 U.S. DOE, National Transportation Program, Office of Environmental Management, "Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk", Douglas J. Ammerman, et al, Sandia National Laboratories, April 8, 2003, NRC ADAMS Accession # ML031140370, Submitted April 14, 200

D
SUMMARY OF CASK TESTING PROGRAMS

D.1 Introduction

Before examining cask testing programs, it is instructive to discuss how radioactive material shipping packages are classified. Under NRC and DOT regulations there are essentially two classifications, Type A and Type B packages. Generally, Type A packages contain limited amounts of radioactive material (RAM) and must meet regulatory criteria for normal conditions of transportation. Type B packages contain RAM in excess of Type A quantities (including spent nuclear fuel and high level radioactive waste) and must meet regulatory criteria for both normal conditions of transportation and hypothetical accident conditions. Within these two classifications are fissile and non-fissile. All fissile packages, whether Type A or Type B, must meet both normal and accident criteria. DOT regulations also address other types of radioactive material packages of much lower hazard (i.e., low specific activity, industrial). IAEA transport safety standards address and classify this same spectrum of packages in an identical fashion.

For purposes of this discussion the focus will be on Type B packages, or casks as they are commonly called, and the testing programs that apply to them. Type B packages range in size from a few hundred pounds to over 100 tons. Transport casks for spent nuclear fuel and HLW are typically in the 25-ton to 125-ton range depending on the mode of transportation (i.e., highway or railroad). Spent nuclear fuel and HLW casks are generally classified as Type B fissile, designated as B(U)F or B(M)F. The designation of (U) and (M) mean *unilateral* or *multilateral* respectively; these are international approval designations and are not germane to this discussion.

Many testing programs of Type B casks that were not designed to transport spent nuclear fuel or HLW still have application to spent fuel and HLW casks, since all must meet the normal transport and accident criteria of federal regulations.

D.2 Historical Perspective

Cask and cask component testing have been employed by the government and industry from the beginning of the nuclear era. In the early years of spent fuel cask development, testing was generally used to confirm analysis, which was important in the early days since computer models were relatively crude compared to today's standards. Small casks were often tested in full scale while larger casks were frequently tested by scale modeling. Analysis showed that scale models as small as one-eighth scale were found to be valid, although one quarter scale was more often used. In testing performed in the early years, instrumentation ranged from none to a full compliment of strain gauges and accelerometers. Additionally, component testing for seal performance, closure designs, or impact limiter behavior was often used to augment the analytical effort.

Periodically this testing information was shared by those in the various cask-related disciplines. Sandia Corporation (now Sandia National Laboratories) organized the Sandia Packaging Symposium to discuss programs and technical studies associated with radioactive material packaging and shipping. This was held October 21-23, 1957. A workshop entitled Working Meeting on Shipping Container Testing Programs was conducted at John Hopkins University on May 2-3, 1962. At this meeting were reports on fire, impact and model testing of Type B packages. In December 1962, the AEC sponsored a Symposium On Packaging and Regulatory Standards for Shipping Radioactive Materials. This gathering drew an international audience and addressed drop, fire, model testing and analytical methods for RAM packages. In late 1964, the first PATRAM (International Symposium on the Packaging and Transportation of Radioactive Materials) was held. This international gathering has been continued on a roughly 4-year cycle since that time, with the last one being held in Chicago in 2001. PATRAM has brought the world's packaging experts together to share knowledge and experience. A significant number of the PATRAM presentations have been made regarding both U.S. and international cask testing programs and related analyses.

The history of RAM shipping cask development is charted by a continuing quest for greater knowledge of the behavior of packages under mechanical and thermal stresses, and the development of methods for analyzing and mitigating the consequences. NUREG/CR-0366, "*Shipping Containers for Nuclear Material: A Descriptive Bibliography*", Sandia National Laboratories, May 1979, [Ref D-1] contains over 100 pages of brief descriptions of testing and analysis documents; there are over 250 cited reports. Since 1979 the pace in testing and analysis has continued with packaging design and analysis reaping the benefits of this collective data.

Perhaps the most comprehensive analysis and testing program was begun in 1975 at Sandia Laboratories under the sponsorship of the Energy Research and Development Agency (ERDA) the predecessor to the Department of Energy.

D.3 Sandia Cask Testing Program

The Sandia/ERDA cask study brought analysis, model testing, and full size testing together to examine how well these combine in predicting spent nuclear fuel shipping cask behavior under real-world accident conditions involving both high-speed impact and fire. A summary of this program is contained in SAND77-1462C, "*Crash Testing of Nuclear Fuel Shipping Containers*", February 1978 [Ref D-2]. The abstract best summarizes the program:

> *"In an attempt to understand the dynamics of extra severe transportation accidents and to evaluate state-of-the-art computational techniques for predicting the dynamic response of shipping casks involved in vehicular system crashes, the Environmental Control Technology Division of ERDA undertook a program with Sandia to investigate these areas. This program, which began in 1975, encompasses the following major distinct efforts. The first of these utilizes computational methods for predicting the effects of the accident environment and, subsequently, to calculate the damage incurred by a container as the result of*

> *such an accident. The second phase involves the testing of 1/8-scale models of transportation systems. Through the use of instrumentation and high-speed motion photography, the accident environments and physical damage mechanisms are studied in detail. After correlating the results of these first two phases, a full scale event involving three selected test scenarios have been completed. Results of the program to this point indicate that both computational techniques and scale modeling are viable engineering approaches to studying accident environments and physical damage to shipping casks*." [emphasis added]

This landmark program used actual spent fuel casks that had been removed from service but had been fully licensed under federal regulations. There were two truck casks weighing about 25 tons and one rail cask weighing roughly 75 tons. The truck system (i.e., cask and vehicle) weighed 40 tons and the rail cask system (i.e., cask and railcar) weighed approximately 150 tons. One truck cask system was crashed into a near-immovable barrier at 62 mph and then at 81 mph after refurbishment of its impact limiter. The second truck cask system was subject to a simulated grade crossing accident and was struck by a 205-ton locomotive traveling at 81 mph. The rail cask system was impacted against the near-immovable barrier at 81 mph. Following the impact test, the damaged rail cask system was subjected to a 90-minute engulfing petroleum fire. The analytical methods used by the program accurately predicted the results of all assaults. In addition, the program demonstrated that casks designed to meet federal regulations are able to sustain the extreme accident environment and still retain their containment integrity. This program still stands nearly 30 years later as a confirmation of the validity of numerical methods and model testing to demonstrate cask compliance with federal packaging safety regulations.

D.4 Contemporary Testing

The enormous advancements in analytical methods for structural, thermal, and nuclear parameters has reduced the need for extensive confirmatory testing programs. Nevertheless, the proceedings of PATRAM 2001 [Ref D-3] show a continuing interest in testing. There are more than a dozen reported testing programs examining such topics as: lid bolt behavior under drop conditions, real-world accident conditions vs. regulatory conditions, impact limiter behavior under drop conditions, open fire characteristics, one-quarter scale cask impacts, and multi-layered cask wall response to impact.

It is important to note that physical testing, although sounding like the ultimate proof of cask safety, can introduce variables that negatively affect the outcome. There are many opportunities for error ranging from environmental parameters such as wind gusts during the drop to instrumentation failures. Further, there are a limited number of test articles available to be tested (i.e., often one cask and several sets of impact limiters for different orientations) so statistical data cannot be gathered. Additionally, testing comes after the design is completed so the designer must invariably depend on numerical methods for essentially all of the effort hence the emphasis on precise analysis.

In terms of contemporary cask designs, the GA-43 spent nuclear fuel truck cask was perhaps the last domestic package that was tested (circa 1993) using an exact scale representation. The GA-4 was drop and puncture tested in one-half scale in a series of damaging orientations (e.g., center of gravity (CG)-over-corner, side, slapdown). The design of this cask also included component testing of impact limiters and the seal/flange assembly. Other contemporary designs have performed scale testing of impact limiters but the cask itself was simulated by a structure that preserved geometric and dynamic similitude but did not replicate the cask details.

This reduced emphasis on full and scale testing can be attributed to the rise in precision of the numerical methods available to the designer. Another contributor is the use of design rules and national standards (i.e., ASME Code) that provide engineering safety margin. Component testing and testing for the purpose of benchmarking numerical methods has been found to be far more cost-effective than full or scale testing of a cask, with essentially no sacrifice in safety.

D.5 Conclusions

As evidenced by the literature, testing continues as an embedded part of the advances in cask design and analysis. The content and emphasis of the testing has changed with time as analytical techniques have improved. The full or scale testing of detailed cask designs of decades ago has been replaced by component testing and testing designed to confirm the accuracy of contemporary numerical methods. The net results are designs that fully comply with regulatory safety requirements, are technically defendable, and are cost-effective.

References:

D-1 Sandia National Laboratories, *Shipping Containers for Nuclear Material: A Descriptive Bibliography,* NUREG/CR-0366, May 1979

D-2 Sandia National Laboratories, *Crash Testing of Nuclear Fuel Shipping Containers*, SAND77-1462C, February 1978

D-3 PATRAM 2001, *13th International Symposium on the Packaging and Transportation of Radioactive Materials*, Chicago, Illinois, September 2-7, 2001

E
SHIPPING CAMPAIGN FUNDAMENTALS

Each spent fuel shipping campaign is unique but there are some fundamental steps that will apply to all campaigns. These steps are: Organization, Planning, Equipment Selection, Shipment Execution, and Campaign Close-out. Each of these steps are discussed in detail below.

E.1. Organization

A shipping campaign utilizes a large number of resources and requires many different skills. It is essential for success to have a centralized organization with a strong management structure. The elements of this organization must have clearly defined responsibilities and seamless communication links. While the organization requires strong centralized management, there are certain operational elements for which it is vital that the decision-making process be “decentralized” in order to continue project momentum once the campaign is underway. For example, tugboat ingress and egress at Shoreham was affected by the tide (i.e., water depth), thus real-time depth measurements and decisions were needed in order to not lose 12 hours on the schedule. Despite the need for this flexibility, there must be continuous project oversight from a centralized position throughout the campaign. All campaigns must begin with a strong organizational structure in place.

Additionally, it is essential that the organization’s key personnel have experience in radioactive materials transport activities and be fully knowledgeable regarding the regulations governing spent fuel transport. In order to have an efficient shipping campaign, the “learning curve” must be short and this can only occur with experienced personnel. Due to public interest and concern surrounding spent fuel transport operations, it is essential that the process be carried out in a reasonably transparent manner by an experienced organization. For safeguards and security purposes, some details of the shipping activity must remain closely held.

E.2 Planning

Planning for a spent fuel shipping campaign should begin several years in advance of the first shipment. Planning activities have two distinct parts, on-site and off-site.

On-site planning activities start with an assessment of the nuclear power plant site(s) for the shipping campaign (i.e., receiving, loading, dispatching, and tracking a cask). It is a complex task. A site assessment is required to assure that the cask, transport equipment, and ancillary equipment are compatible with the facility. Shipping "windows" must be arranged so that there is no interference with the facility's prime function of power generation. These windows will generally avoid cask loading activities during a site’s maintenance and refueling outages. On-site planning is not strictly an equipment issue. Planning activities also include training and qualification of personnel, and the development of procedures for cask receipt, loading and dispatch as well as fuel selection and fuel handling. These on-site planning activities must be accomplished within the strict regulatory requirements associated with fuel and cask handling and spent fuel transport. Facility reconfiguration and temporary staffing changes are often needed to accommodate the shipment of spent fuel and these changes must be incorporated into the on-site plan.

The off-site planning involves the state and local governments, the general public, spent fuel transport cask carriers (e.g., trucking companies and railroads), transfer facilities, emergency response personnel along the shipping route, and federal agencies (NRC, DOT, etc.). Contingency planning associated with problems that could occur along the transportation route can be challenging since off-site issues are the most difficult to foresee and are likely to involve a range of parties. Mode of transport and route selection are critical off-site planning activities since they lead to the planning for equipment, carrier selection and qualification, notifications, security, emergency planning and response, shipment tracking, inspections, safe parking, public outreach and communications, and all related in-route considerations. Once a shipment leaves the nuclear power plant site, it enters the “public domain” – that is, no longer within the bounds of a regulated site. While spent fuel shipments represent a small fraction of all hazardous materials shipments in the U.S., the public scrutiny and concern expressed regarding spent fuel shipments is high. This requires that the off-site planning process be conducted in a reasonably transparent manner, involving state and local decision-makers in the process. It is also important that emergency response personnel have received the appropriate training in advance of the start of shipments.

E.3 Equipment Selection

The modal options for transporting spent fuel in the U.S. include: highway, railroad, and barge (as part of an intermodal shipment). The planners of a shipping campaign must consider which transport mode or modes will provide the most efficient and cost-effective means for carrying out the campaign within the regulatory requirements. Issues that must be considered in the selection of the cask and associated equipment include:

Cask handling crane limitations at the nuclear power plant site,

Near-site modal capabilities such as availability of a rail spur, ability to use barge or heavy-haul truck to a rail spur, nearby roadway limitations, and bridge restrictions.

Cask weight or size limitations such as those due to structural constraints or facility equipment hatch sizes.

All of these considerations affect the selection of the transport cask and associated hardware. The use of large rail-compatible transport casks is the most efficient since these casks can transport between 24 and 62 spent fuel assemblies compared to a truck cask which can transport from 1 to 9 assemblies. However, due to the limitations discussed above, some sites do not have the physical capability to handle the large rail casks at this time. Therefore, there is and will continue to be a need to transport some amount of spent fuel in highway-transported casks.

Barge or highway heavy-hauling, in conjunction with an intermodal transfer, may allow some nuclear power plant sites to utilize large rail casks that otherwise would have to use the less-efficient truck casks .

Other equipment considerations include cask lifting and handling components, pre-shipment cask preparation items, and post-loading testing and acceptance equipment. The transportation equipment must meet DOT, including the Federal Railway Administration (FRA), safety and inspection requirements. In addition the carriers (e.g., trucking companies and railroads) may have equipment standards that must be met (e.g., the Association of American Railroads Standard S-2043, "Performance Specifications for Trains Used To Carry High Level Radioactive Material," May 2003).

E.4 Shipment Execution

The operational phase of the campaign is where the organization, planning, and equipment selection come together. The entire process is a highly choreographed activity where the matching of interfaces is vital to success. One or more on-site dry runs is conducted with the empty transport cask before the first increment of spent fuel is loaded. This ensures that the cask handling crew is familiar with the equipment and procedures and that the equipment works as planned. Prior to shipment, a "table top" exercise of the entire route control system is generally conducted to assure that there is continuity among all elements of the shipping campaign and participants.

Cask loading and preparation for shipment must be coordinated with the carrier (e.g., railroad, trucking company) to ensure that the cask can be transported off-site on schedule. Advance notification must be given to the NRC and to the governor of any state through which the spent fuel will be transported as required by NRC regulations. Prior to the start of a shipment, the shipment tracking function must be put into action and the communications center must be operational. Escort and security functions must be activated in accordance with NRC regulations. Communications activities are initiated in order to respond to questions from state and local officials, the public and the media.

As required by NRC regulations, the shipping campaign's communications center, which must be manned around the clock, is responsible for keeping in direct contact with each shipment along the entire route to monitor the progress of the shipment and notify law enforcement agencies and other agencies as needed. While satellite tracking is not required by 10CFR73, it is used by DOE for current spent fuel shipments and it is likely that satellite tracking will be employed on every shipment to Yucca Mountain. Routing specialists check for circumstances (e.g., weather, detours, right-of-way problems) along the route of travel and are prepared to make route adjustments if necessary. There must be very close coordination among all parties involved in shipment operations, which is the reason for the strong centralized organization. Control and monitoring of the movement of spent nuclear fuel between shipping and receiving points is not unlike air traffic control in the aviation field, but more centralized. The amount of documentation needed to execute a campaign is enormous, due in part to the stringent quality assurance requirements for everything from training to equipment certification to shipping papers. In addition a written log is prepared for each shipment which is maintained by the escorts and communications center. It describes shipment information and any events that occur during shipment.

E.5 Campaign close out

Once the shipping campaign is complete and all of the spent fuel has been transported to its final destination, the project must be demobilized. This final phase of the campaign involves both paperwork filing and transmittal, and equipment/facility tasks. The latter involves the restoration of the reactor facilities to the pre-campaign configuration such as dismantling of the package decontamination scaffolds and equipment that were temporarily erected to support the cask loading activities. The transportation casks and associated equipment must also undergo demobilization following a campaign. From the cask owners perspective, the end of one campaign means that the cask may have to be sent to a maintenance facility for inspection and refurbishment or reconfiguration before being dispatched to another facility for use. Cask COCs may require certain periodic actions or certain maintenance activities. For example, periodic testing, new seal installation, internal decontamination, and damage/deterioration inspection are activities that take place on a periodic basis. Cask transporters and ancillary equipment also require maintenance, testing, and inspection.

Program:
Nuclear Power

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

© 2004 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc.
EPRI. ELECTRIFY THE WORLD is a service mark of the Electric Power Research Institute, Inc.

Printed on recycled paper in the United States of America

1009226

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com