ENERGY
RESOURCES
INTERNATIONAL, INC.

ERI-2030-1101

Overview of High-Level Nuclear Waste Materials Transportation: Processes, Regulations, Experience and Outlook in the U.S.

ENERGY
RESOURCES
INTERNATIONAL, INC.

ERI-2030-1101

Overview of High-Level Nuclear Waste Materials Transportation: Processes, Regulations, Experience and Outlook in the U.S.

Prepared For:

Blue Ribbon Commission on America's Nuclear Future

Prepared by:

Eileen M. Supko
Michael H. Schwartz

January 2011

1015 18th Street, NW, Suite 650
Washington, DC 20036
USA
Telephone: (202) 785-8833
Facsimile: (202) 785-8834

Blue Ribbon Commission on America's Nuclear Future: Disclaimer

This material was prepared at the request of the Blue Ribbon Commission on America's Nuclear Future ("the BRC"). The contents herein do not necessarily reflect the views or position of the BRC, its Commissioners, staff, consultants, or agents. Reports and other documents reflect the views of the authors, who are solely responsible for the text and their conclusions, as well as the accuracy of any data used. The BRC makes no warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed, or represents that the use of any information would not infringe privately owned rights. Any reference to a specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or preference by the BRC.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Every year, more than 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 contains radioactive material, most of them from medical and industrial applications. [DOT 1998b]

Spent nuclear fuel comprises a very small fraction of the hazardous materials packages shipped annually in the U.S. At the present time, fewer than 50 packages of spent nuclear fuel are shipped annually. The U.S. Department of Energy (DOE), prior to the termination of the proposed Yucca Mountain repository program, had expected to eventually ship between 400 and 500 spent fuel transport casks per year during the first twenty years of the repository's operation. Despite the widespread attention that those proposed shipments had received, this would have been only about one in a million of all hazardous materials packages transported in the U.S. on an annual basis.

Section 2 provides an overview of the U.S. experience in the transport of high-level nuclear waste materials and describes the types of materials and transportation packages that are used to ship these materials. It describes the types of nuclear waste materials that exist today and that may result from implementation of future fuel cycle alternatives and nuclear waste management scenarios including: commercial irradiated nuclear fuel, which is referred to as spent nuclear fuel (SNF) and/or used nuclear fuel; naval reactor SNF; DOE-owned SNF; DOE high-level radioactive waste (HLW); commercial vitrified HLW; other waste streams from reprocessing; greater-than-Class C low-level radioactive waste (GTCC waste); and GTCC-like waste. An estimate of the number of cask shipments for each of these materials is also provided. A summary of U.S. SNF transport experience is included as well as a discussion of international experience with regard to transport of SNF and HLW. Transport of low-level radioactive waste (except for GTCC waste) is not addressed in this report.

Section 3 provides an overview of the regulatory framework for transport of nuclear waste, including the roles of Federal, State, Tribal and local governments. It describes the Federal regulations that govern the transport of radioactive materials – both SNF and HLW – including regulations and orders promulgated by the U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Transportation (DOT), U.S. Department of Homeland Security (DHS), and the U.S. Department of Energy (DOE). The roles that State, Tribal and local governments play in the transport of nuclear waste are also summarized.

Section 4 provides an overview of the process and regulations for the design and certification of transportation casks for SNF and HLW. It also includes an overview of the process and expected timing associated with procurement and fabrication of transportation equipment, including transportation casks, cask handling equipment, and transportation equipment, to support a large-scale, long-term transportation system. Technical issues associated with nuclear waste transportation that must be addressed in the future are described, including: approval of burnup credit for transport of SNF using high-capacity rail casks; resolution of technical and regulatory issues associated with transport of high-burnup SNF (e.g., burnups > 45 gigawatt day per metric ton of uranium [GWD/MTU]); confirmation of fuel condition after very long term storage; and transportation cask testing programs.

Section 5 provides an overview of the process for planning nuclear waste material transportation campaigns from commercial nuclear power plant sites and DOE sites to a central waste management facility. Existing programs for emergency planning and emergency response training are summarized. The types of information that will be needed to assess near-site transportation needs are described, such as need for heavy-haul capability from nuclear power plants to the nearest rail line. Interactions that will be needed between the shipper and State, Tribal and local governments regarding near-site and national route planning, emergency response training, and campaign planning are summarized assuming that the shipper could be either a private company or a Federal agency.

Section 6 describes several scenarios for the transportation of U.S. SNF and HLW as part of a future central waste management system, including: estimated shipments on an annual basis and total program basis; required transport cask fleet and transportation equipment needs consistent with the scenarios presented; and technical and institutional issues that may arise regarding the various scenarios.

Section 7 provides a summary of observations and considerations associated with the development of a large-scale, national program to transport SNF and HLW for central interim waste management and/or disposal. This includes a summary of the materials that will require transport, technical issues that may need to be addressed, transportation planning activities and timelines, logistical issues associated with transport, and a summary of observations regarding the transportation scenarios presented in Section 6.

2. OVERVIEW OF U.S. NUCLEAR WASTE MATERIALS TRANSPORT EXPERIENCE

This section provides an overview of U.S. experience in the transport of high-level nuclear waste materials and describes the types of materials and transportation packages that are used to ship these materials. It describes the types of nuclear waste materials that exist today and that may result from implementation of future fuel cycle alternatives and nuclear waste management scenarios including: commercial SNF; naval reactor SNF; DOE-owned SNF; DOE HLW; commercial vitrified HLW; other waste streams from reprocessing; GTCC waste; and GTCC-like waste. This section also includes a summary of U.S. SNF transport experience; a description of typical packages (i.e., casks) used to transport SNF and HLW; number of shipments; relative size of expected shipments; and, to provide further perspective, a discussion of international experience with regard to transport of SNF and HLW.

2.1 Types of Nuclear Waste Materials

There are various types of nuclear waste materials that arise from the operation of commercial nuclear power plants and U.S. government defense activities that will need to be transported for further processing and/or permanent disposal. Commercial nuclear waste includes: SNF assemblies and associated non-fuel hardware, limited quantities of commercial HLW from the West Valley Demonstration Project, and GTCC waste. U.S. government defense waste includes: naval reactor SNF, DOE-owned SNF, DOE HLW, and DOE GTCC-like waste. If the nuclear fuel cycle policy of the U.S. evolves from the current once-through fuel cycle to an alternative fuel cycle, additional waste streams might include commercial vitrified HLW and GTCC waste from reprocessing activities – primarily the activated fuel assembly hardware. Transport of low-level radioactive waste, other than GTCC-waste, is not addressed in this report. Each of these different types of nuclear waste materials is described briefly below.

2.1.1 Commercial Spent Nuclear Fuel

Irradiated nuclear fuel, which is commonly referred to as spent nuclear fuel or SNF, is highly radioactive and a byproduct of the production of electricity from nuclear power plants. The U.S. presently has 104 operating commercial nuclear power plants that supply approximately 20 percent of the nation’s electricity. The spent nuclear fuel assemblies that are discharged from these nuclear power plants have been safely stored at the power plant sites for decades.

The fresh (i.e., unirradiated) fuel assemblies that are loaded into the reactor core of U.S. nuclear power plants use ceramic uranium oxide fuel pellets that are typically stacked 12 feet high, and sometimes higher, inside long metal fuel rods. These fuel rods are bundled together in square lattices (e.g., 10x10 rods, 14x14 rods, 17x17 rods) to form individual fuel assemblies that may each be comprised of hundreds of fuel rods. A typical fresh fuel assembly contains between approximately 0.18 metric tons of uranium (MTU) for boiling water reactors (BWR) to approximately 0.46 MTU for pressurized water reactors (PWR), depending upon the specific design. Figure 2.1 provides an illustration of a fuel pellet, fuel rod and fuel assembly.

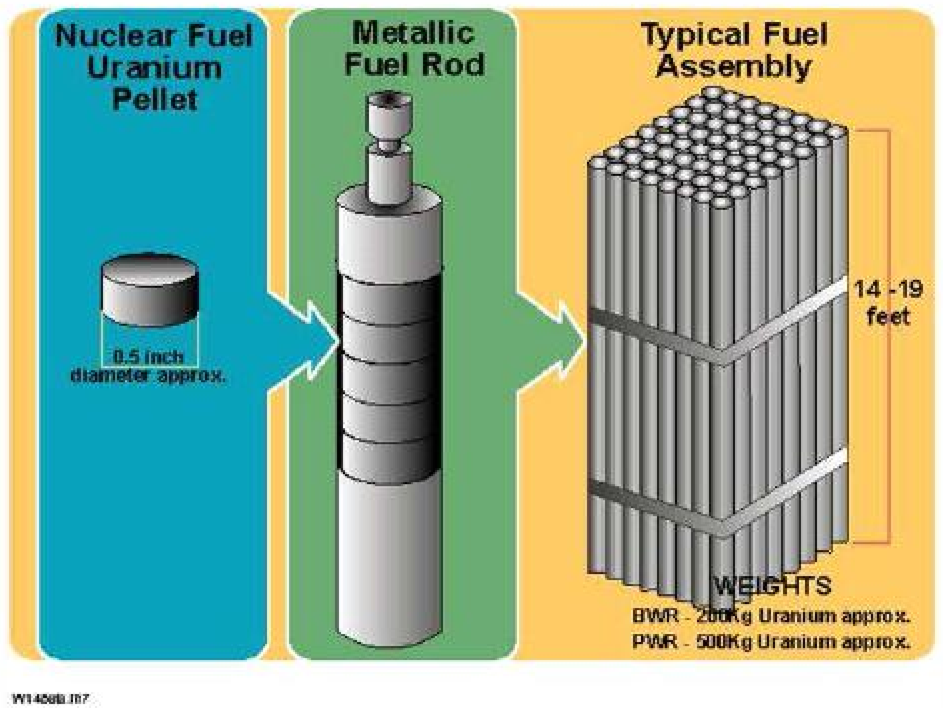


Figure 2.1 Pressurized Water Reactor Nuclear Fuel Assembly Design [DOE 2009a]

A water-filled reactor vessel is located within the highly reinforced containment structure of each of these nuclear power plants. The reactor core, depending upon the design, is itself comprised of between 100 and 1,000 fuel assemblies arranged in a fixed configuration. In a nuclear power plant, the fission process splits some of the uranium atoms in a controlled chain reaction, producing heat energy that is ultimately used to produce steam. The steam drives a turbine generator to produce electricity.

Nuclear power plants in the U.S. typically operate on 18 to 24 month operating cycles. After residing in the reactor core, producing energy for four to six years (i.e., typically two or three operating cycles), a nuclear fuel assembly must be replaced with a fresh fuel assembly to maintain the chain reaction that results in production of heat and generation of electricity by the nuclear power plant. At this point the discharged fuel assembly is considered to be “spent.” These SNF assemblies are highly radioactive as a result of the fission process that had been taking place while they were in the reactor core. The discharged SNF assemblies are immediately transferred to a steel-lined, water filled storage pool that is located within the nuclear power plant. The SNF storage pool provides radiation shielding and thermal cooling for the SNF.

Approximately 2,000 MTU of SNF are discharged from U.S. nuclear power plants each year. As of December 31, 2010, approximately 64,000 MTU of SNF has been discharged from U.S. nuclear power plants and is in storage awaiting permanent disposal. Assuming that the 104 presently operating nuclear power plants continue to operate under extended licenses for 60 years each, the total SNF inventory is projected to reach approximately 133,000 MTU by 2055, as shown in Figure 2.2. If SNF is not removed from nuclear power plant sites prior to each plant reaching the end of its extended operating license, then all SNF remaining in storage pools at that time is expected to be transferred into onsite dry storage as also shown in Figure 2.2. ERI estimates that approximately 11,800 dry storage systems would be needed to store the entire 133,000 MTU inventory of SNF. This assumes that nuclear operating companies will continue to utilize high-capacity dual-purpose storage and transport technologies, which are described in more detail in Section 2.4.

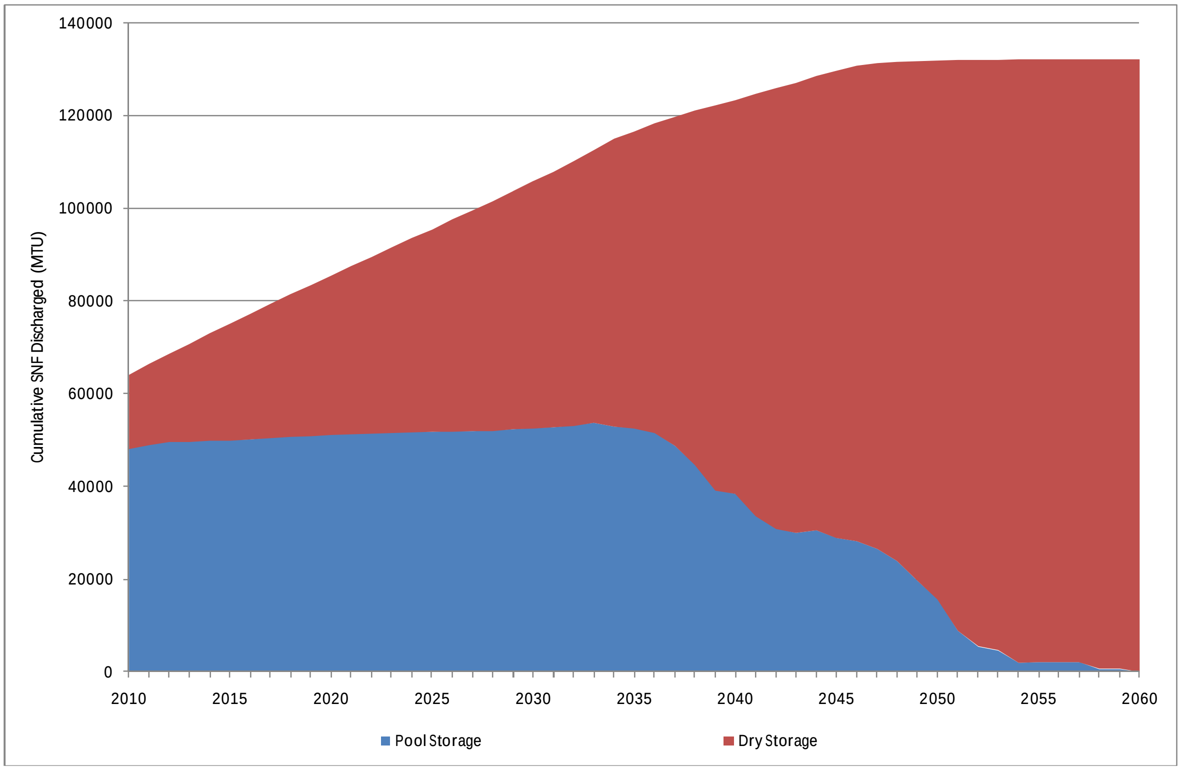


Figure 2.2 Projected Cumulative SNF from Commercial Nuclear Power Plants in Pool Storage and Dry Storage, 2010 – 2060 [ERI Analysis, December 2010]

A number of nuclear operating companies have submitted license applications to the NRC to construct and operate new nuclear power plants. A typical 1,000 megawatt-electric (MWe), which is equivalent to one Gigawatt-electric (GWe), nuclear power plant would discharge approximately 1,500 MTU of SNF over a 60-year operating period. An inventory of 1,500 MTU of SNF could be transported in 120 to 150 cask shipments (assuming 10 to 13 MTU per rail cask).

Since all U.S. commercial nuclear power plants are expected to implement onsite dry storage of SNF during the next ten years, it is expected that the vast majority of commercial SNF will eventually be shipped in sealed dual-purpose canisters (DPCs) that are certified by the NRC for both storage and transport. DPCs are described in more detail in Section 2.3.

2.1.2 Commercial HLW and Other Reprocessing Waste Streams

Commercial reprocessing operations at the Nuclear Fuel Services plant near West Valley, New York, generated a small amount of HLW between 1966 and 1972, at which time reprocessing operations ceased. That site is presently owned by the New York State Energy Research and Development Authority. In 1980, Congress passed the West Valley Demonstration Project Act. This Act authorized DOE to conduct, in cooperation with the New York State Energy Research and Development Authority, a demonstration of solidification of HLW for disposal and the decontamination and decommissioning of demonstration facilities. [DOE 2002b]

The West Valley Demonstration Project generated 275 canisters of HLW. [Bower 2008] The solidified HLW is the result of a vitrification process, which can be used to convert a material into a glass or glassy substance. This is usually accomplished by a thermal process. The resulting glass is a rigid, non-crystalline material that has a relatively low porosity. [EPA 1992] The stainless-steel canisters in which the HLW is stored have a nominal outside diameter of 2 feet (0.61 meters) and a nominal height of 10 feet (3 meters). They contain approximately 7,060 cubic feet (ft^3) (200 cubic meters [m^3]) of vitrified HLW. According to DOE, the estimated total mass of this HLW is between 595 and 694 tons (540 and 630 metric tons). [DOE 2002b] DOE estimates that 5 canisters of HLW can be transported in a rail cask. Thus, it is estimated that 55 rail cask shipments will be needed to transport the HLW from the West Valley site. [DOE 2008a]

A 2009 presentation regarding reprocessing waste streams by Areva identified the waste streams that would result from reprocessing of SNF in a reprocessing and recycling facility with an annual throughput of 800 MTU per year. Processing 800 MTU of commercial SNF per year would result in 560 canisters of vitrified HLW (with a nominal height of 1.34 meters [4.4 ft] and a diameter of 0.43 meters [1.4 ft]), 560 canisters of irradiated fuel assembly hardware which would be classified as GTCC waste, and other low-level radioactive waste (LLW). [AFS 2009] TN International has two casks for transport of HLW, the TN-81 and TN-85. These HLW transport casks can transport 28 canisters of HLW. Thus, the 560 canisters of HLW and 560 canisters of GTCC waste produced annually could be transported for disposal in 40 TN-85 transport cask shipments. [Areva 2007]

2.1.3 Commercial GTCC Waste

NRC regulations for the land disposal of radioactive waste are contained in Title 10, U.S. Code of Federal Regulations, Part 61 (10CFR61), *Licensing Requirements for Land Disposal of Radioactive Waste*. Within 10CFR61, Section 61.55 classifies LLW for near surface land disposal. The waste classifications for LLW are determined by the specific radionuclides and the radionuclide concentration in the waste requiring disposal and are defined as: Class A, Class B, Class C, and GTCC waste, with Class A waste having the lowest concentrations of radionuclides and GTCC waste having the highest. Class A, B and C wastes are generally acceptable for near-surface disposal. According to Section 61.55, GTCC waste is “not generally acceptable for near-surface disposal” and therefore, it may require disposal in a geologic repository.

GTCC waste that is generated by commercial nuclear power plants arises primarily from metal components from reactor internals that become activated due to exposure to neutron flux during nuclear power plant operation. These components can include the core shroud, top fuel guide assembly components, core support plates, the lower core barrel, thermal shields, and lower grid plate components. GTCC waste from these reactor components would be generated as nuclear power plants are dismantled as part of the decommissioning process. [SNL 2007] Minimal quantities of commercial GTCC waste may also be generated during operation of nuclear reactors; items such as contaminated filters and resins, and irradiated “non-fuel components” (e.g., control rods and other incore components) may be classified as GTCC waste.

The overall quantities of GTCC waste at shutdown nuclear power plants and projected quantities of GTCC waste from operating plants have been estimated by DOE contractors to support an Environmental Impact Statement (EIS) regarding the disposal of GTCC waste that is being prepared by DOE’s Office of Environmental Management (DOE EM). [DOE 2005a] In a study released in 2007 to support this EIS, Sandia National Laboratories (SNL), a DOE contractor, estimated the maximum volume of GTCC waste arising from commercial nuclear power plants, when these plants eventually are shut down and dismantled, was estimated to be 30,760 ft^3 (871 m^3) according to SNL. [SNL 2007] According to a report by DOE EM, if the approximate 871 m^3 of GTCC waste were packaged in Transport, Aging and Disposal (TAD) canisters, which are similar in size to the dual-purpose canisters that are being used to store SNF, then a total of 398 TAD canisters would be needed, requiring approximately 398 shipments of commercial GTCC from nuclear power plant sites. [Joyce 2008]

2.1.4 DOE Spent Nuclear Fuel

In addition to commercial SNF, there will be approximately 2,750 tons (2,500 metric tons) of heavy metal of DOE-owned SNF, including naval reactor SNF, that will require permanent disposal. [DOE 2002b] DOE presently stores most of its spent nuclear fuel at three primary locations: the Hanford Site in Washington State, the Idaho National Laboratory (INL) in Idaho, and the Savannah River Site (SRS) in South Carolina. In addition, some DOE-owned SNF is stored at the Fort St. Vrain dry storage facility in Colorado. DOE and its predecessor agencies have generated approximately 250 different types of spent nuclear fuel from weapons production, nuclear propulsion, and research missions. [DOE 2002b]

DOE and naval reactor SNF will be packaged in standard canisters. INL reports that it would use a combination of 18- and 24-inch (46- and 61-centimeter)-diameter stainless-steel canisters for its disposition of SNF. SRS reports that it would use 18-inch canisters, and Hanford would use 25.3 inch (64 centimeter) multi-canister overpacks and 18-inch canisters. There are two conceptual canister designs for naval fuel: one with a length of 212 inches (539 centimeters) and one with a length of 187 inches (475 centimeters). Both canisters would have a maximum diameter of 67 inches (169 centimeters). [DOE 2002b] DOE estimates that a total of 784 rail cask shipments will be needed to remove DOE-owned SNF from DOE sites. [DOE 2008a]

2.1.5 DOE HLW

The majority of HLW in storage in the U.S. is a result of the reprocessing of navy nuclear propulsion fuel and DOE nuclear materials related to plutonium and tritium production. DOE stores high-level radioactive waste at the Hanford Site, SRS, and INL. DOE is in the process of immobilizing its HLW into a solid matrix within metal canisters.

DOE plans to vitrify the HLW that is at Hanford into a borosilicate glass matrix and pour it into stainless-steel canisters prior to shipment to a repository. DOE estimated the volume of Hanford HLW will require as many as 9,700 canisters, nominally 15 feet (4.5 meters) long with a 2 foot (0.61 meter) diameter. [DOE 2002b, DeLeon 2009]

Most of the HLW at INL is in the form of calcined solids. INL plans to use a hot isostatic pressing (HIP) process to transform the calcined solids into a glass-ceramic matrix. [Ramsey 2010] DOE expects to load approximately 6,600 canisters with HLW from INL, with a nominal height of 10 feet (3 meters) and a diameter of 2 feet (0.51 meter). [DOE 2002b, DeLeon 2009]

The HLW at the SRS consists of wastes generated from the reprocessing of SNF. SRS is expected to generate an estimated 6,300 canisters of HLW, with a nominal height of 10 feet (3 meters) and a diameter of 2 feet (0.61 meters). [DOE 2002b, DeLeon 2009]

DOE expects that a total volume of 21,000 m^3 of HLW from the three sites, which will be stored in approximately 22,600 canisters, will require transport and disposal. [DeLeon 2009] DOE estimates that 5 canisters of HLW can be transported in a rail cask. Thus, it is estimated that 4,520 rail cask shipments will be needed to transport the HLW from the Hanford, INL, and SRS sites. [DOE 2008a]

2.1.6 DOE GTCC-Like Waste

DOE possesses wastes with characteristics that are similar to GTCC LLW and are referred to as “DOE GTCC-like waste.” This waste includes activated metals, sealed sources and other waste, such as LLW and transuranic waste. The total volume for the existing and projected inventory of DOE GTCC-like waste is 105,950 ft^3 (3,000 m^3). [SNL 2007] If

DOE’s GTCC-like waste were packaged in TAD canisters, a total of approximately 816 canisters would be needed, requiring approximately 816 cask shipments of DOE GTCC-like waste from DOE sites. [Joyce 2008]

2.1.7 Other GTCC Waste

GTCC waste that does not originate at commercial nuclear power plants or DOE sites, includes sealed sources and waste from generators such as industrial research and development firms, fuel fabrication and irradiation research (burnup) laboratories, research nuclear reactors, and sealed source manufacturers, including sealed source waste, glove boxes. The total projected volume of this other GTCC waste is approximately 63,570 ft^3 (1,800 m^3) and it would require approximately 460 TAD canisters to transport this material for disposal. [Joyce 2008]

2.2 History of SNF Transport

Transport of spent nuclear fuel is a highly regulated activity, which has been taking place in the U.S. and in Europe for more than 50 years. Both government and civilian shipments have occurred over the years, using highway, railroad, and sea modes of transportation. An estimated 3,200 shipments carrying SNF from commercial nuclear power plants and research reactors have been shipped in the U.S., carrying approximately 3,290 MTU of SNF as shown in Figure 2.3. In addition to the commercial and research reactor SNF shipments shown in Figure 2.3, there have been more than 800 cask shipments of naval reactor SNF to INL.

NRC's data regarding SNF shipments, as depicted in Figure 2.3, begins in 1979. [NRC 2010h] Data prior to 1979 are based on research sponsored by the DOE. [Pope 1991] It is important to note that SNF transport statistics for the U.S., as reported by the NRC, are provided by total number of “shipments” not by the total number of “casks shipped”. Many of the rail "shipments" from 1979 to 2007 involved multiple casks; thus, the actual number of casks shipped will be higher than the 3,200 shipments reported. Almost 90% of the historical cask shipments were shipped via truck. However, regarding shipments to a central waste management facility, the majority of future SNF from commercial nuclear power plants is expected to be shipped in rail-capable dual-purpose storage and transport casks. DOE's "mostly rail" transportation planning for shipment of SNF and HLW to the Yucca Mountain repository assumed that the majority of SNF and HLW would be transported by rail and that at least three transport casks would be transported in each rail shipment.

In the U.S. approximately 75% of the total *tonnage* of domestic SNF has been shipped by railroad. However, the *number* of shipments by railroad has accounted for only about 13% of the total shipments made to date. This disparity is due to the fact that a single large rail cask can accommodate roughly six times the amount of SNF as a truck cask. This capacity difference makes the railroad a much more efficient transportation mode. As noted in Section 2.1, most commercial SNF will be loaded into rail transportable DPCs and is expected to be transported by rail to a central waste management facility in the future.

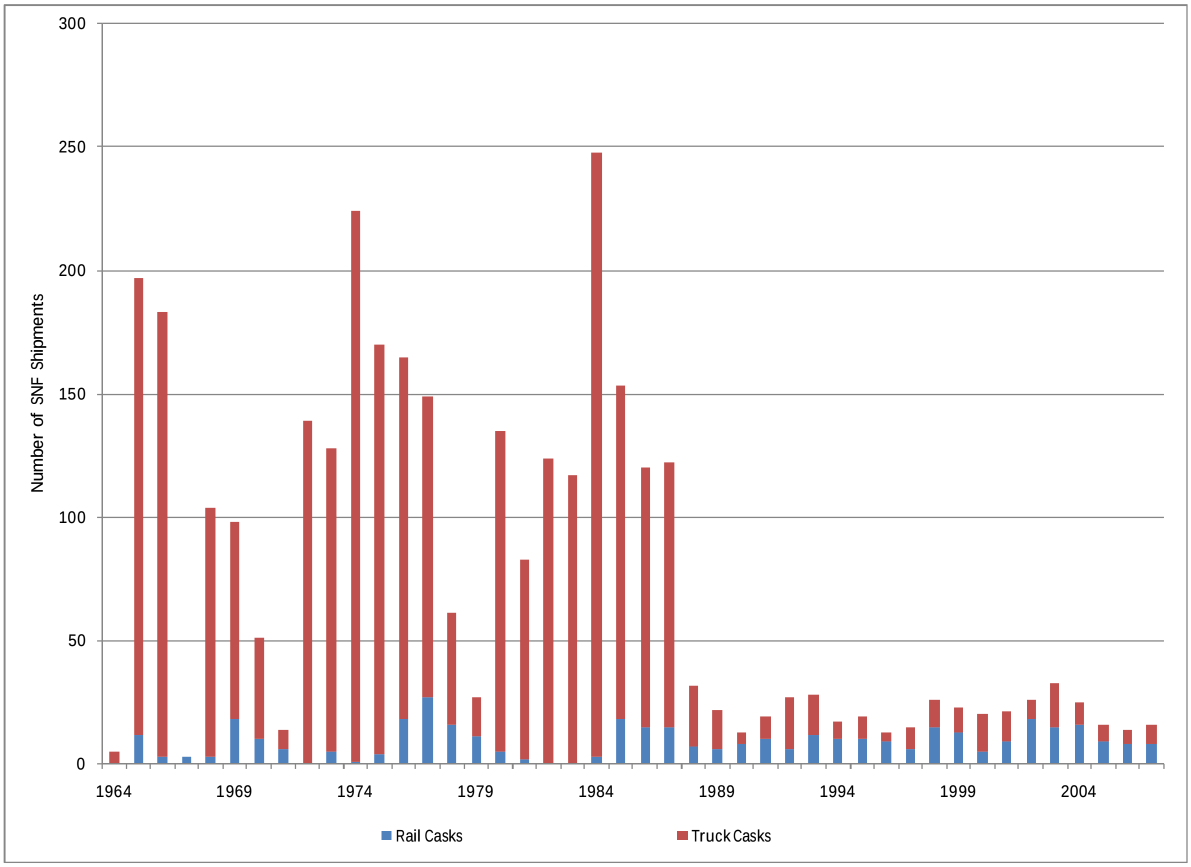


Figure 2.3 Historical Shipments of SNF from Commercial Nuclear Power Plants and Research Reactors, 1964-2007 [Pope 1991, NRC 2010h]

Worldwide, it is estimated that approximately 73,000 to 98,000 MTU of SNF and HLW have been transported, which is equivalent to approximately 24,000 to 43,000 cask shipments by all modes of transport. [Pope 2001]

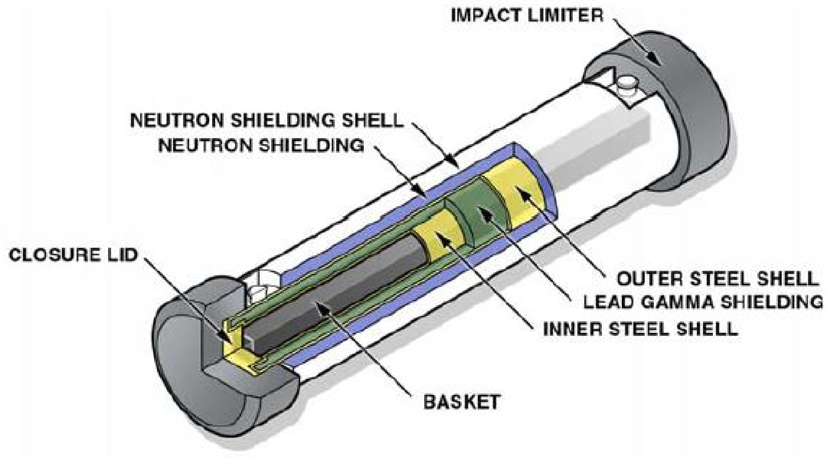
The transport of SNF has established an outstanding safety record within the hazardous material transportation field. Within the U.S., there have been a total of nine accidents involving SNF casks between 1971 and 2006. [NAS 2006] All but one of these accidents would be regarded as a minor traffic accident and the radioactive contents of the SNF cask have never been released in any of the accidents. In fact, five of the accidents involved empty casks. Only one accident, in 1971, resulted in the cask being damaged. In that case, the damaged cask was unloaded, inspected, repaired, tested, and returned to service.

While a comprehensive database of international accidents and incidents involving radioactive materials has not been implemented, 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. [Hughes 1996, HPA 2010]

The enviable safety record of SNF and HLW shipments is due to the robust designs of the SNF casks, the effectiveness of the transportation regulations, and the professionalism of those engaged in this important activity.

2.3 Description of Typical SNF Transport Casks

SNF and HLW is shipped in sturdy containers that provide physical protection, containment, shielding, heat management, and nuclear criticality safety for the SNF and HLW contained within. These containers are referred to as transport casks. In the U.S., the NRC is responsible for certification of SNF and HLW casks in accordance with NRC regulations contained in 10CFR71, *Packaging and Transport of Radioactive Materials* [NRC 2009a], discussed in more detail in Section 3.3. SNF and HLW transport casks are designed in a variety of different sizes and configurations in order to best handle the characteristics of the different types of SNF and HLW that will be transported and the mode of transportation (e.g., rail or truck transport). Figure 2.4 presents a cutaway view of a typical truck cask configuration. Figure 2.5 presents a cutaway view of a typical rail cask configuration. The cask basket internals can be configured to transport SNF or HLW.



Generic Truck Cask for Spent Fuel

Figure 2.4 Generic Truck Cask for SNF (cutaway view) [NRC 2010i]

Typical specifications for a truck cask that will be used for SNF shipment are:

- 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

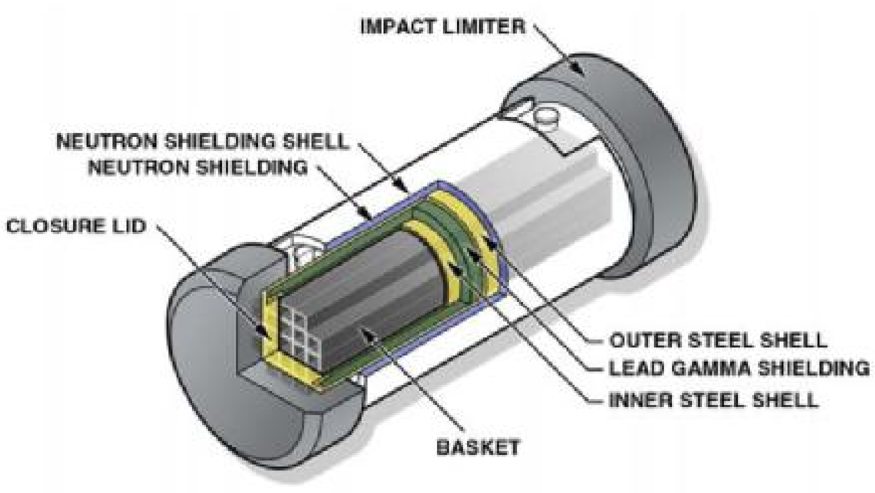


Figure 2.5 Generic Rail Cask for SNF (cutaway view) [NRC 2010i]

Typical specifications for a rail cask that will be used for SNF transport are:

- 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 37 PWR or 87 BWR fuel assemblies

Typically, a SNF cask is comprised of a package body consisting of an inner and outer stainless steel structure (e.g., thick-walled cylinder), which encloses 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. Within the package body is a structure referred to as a "basket" that provides support, positioning, criticality safety, and heat management for the SNF or HLW canisters. Neutron shielding is generally exterior to the outer cylinder of the package body and consists of hydrogenous material such as polyethylene held in place by a thin-walled stainless steel structure. In some cask designs, the basket structure is part of a thin-walled sealed canister that is separate from the main shielding and containment package. Metallic and/or elastomeric seals and a bolted, shielded lid are used in cask closure mechanisms. In cask designs that employ inner sealed canisters, the canisters are seal-welded. All contemporary SNF 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. Helium is used to fill interior void spaces in the cask. Use of an inert gas such as helium improves heat transfer and also creates a non-oxidizing environment for the SNF. [EPRI 2004]

Packages designed for railroad transportation and/or intermodal barge shipping weigh up to 125 tons. SNF 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. The overall weight of SNF 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 SNF is being shipped. There is roughly a 6 to 1 fuel capacity advantage of rail casks over highway casks. [EPRI 2004]

2.4 Dual-Purpose Storage and Transport Casks

The first dry storage systems licensed in the U.S. were storage-only technologies, licensed under NRC regulations contained in 10CFR72, *Licensing Requirements for the Independent Storage of Spent Nuclear fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.* [NRC 2009e] In the late 1990s, nuclear operating companies began to consider dual-purpose storage and transport technologies to meet their onsite SNF storage requirements. Dual-purpose technologies are certified by NRC under 10CFR71 for transport and 10CFR72 for storage. One of the benefits of dry storage using dual-purpose technologies for onsite dry storage is that, once SNF has been loaded into the sealed dual-purpose casks or canisters, it is hoped that the individual SNF assemblies would not have to be handled again prior to their eventual transport offsite to a Federal waste management system. SNF loaded into dual-purpose storage and transport technologies may have to be repackaged for disposal.

With a storage-only system, SNF is transferred from the SNF storage pool to a dry storage system; the SNF is stored in an onsite dry storage facility for an indefinite period of time; the storage system may need to be transferred back to the pool to be unloaded; and SNF is then reloaded into a transportation cask for transport offsite. If storage-only systems are relied on for onsite dry storage, the SNF storage pool may need to be maintained in operating condition in order to transfer fuel from storage-only systems to transportation casks for transport off-site at some point in the future. The development of dual-purpose dry storage technologies has been particularly important for shutdown nuclear power plants that have off-loaded SNF to dry storage, allowing those nuclear power plants, including the SNF storage pools, to be to dismantled and decommissioned. [EPRI 2010a]

With the prospect of very long-term dry storage at nuclear power plant sites, the majority of onsite dry storage facilities that have been commissioned since 2000 have loaded SNF into dual-purpose dry storage technologies. Even those companies that began dry storage facility operation in the 1980s and 1990s have transitioned from storage-only technologies to dual-purpose technologies. There are two primary types of dual-purpose technologies – cask based systems and canister based systems. Dual-purpose casks are similar in design to the rail cask designs described in Section 2.3. The basket that holds the individual fuel assemblies is generally integral to the cask assembly. Dual-purpose casks are certified under 10CFR71 and 10CFR72. Canister-based dual-purpose technologies utilize a sealed metal canister that is certified under 10CFR71 and 10CFR72. The dual-purpose storage system includes the DPC, a storage overpack, and related equipment. The dual-purpose transport system includes the same DPC, a transport overpack (e.g. transport cask), and related equipment. As noted above, nuclear operating companies are expected to continue to utilize high-capacity dual-purpose technologies for onsite storage for the foreseeable future. Industry activities to examine issues associated with extended storage of SNF in dual-purpose technologies and deferred transportation following extended storage are discussed in Section 4.3.3.

2.5 Description of Transportation Equipment

Several modes of transport are available to ship SNF and HLW: highway, railroad, 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. The transfer of a SNF or HLW cask from one mode of transport to another, such as from heavy-haul truck or barge shipment to rail transport is referred to as inter-modal transfer.

Specially designed trailers that provide integral tiedowns to fasten the cask to the conveyance are used for highway transport. 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 as discussed in Section 2.3. 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 2.6 shows a schematic of a truck cask loaded onto a truck for highway transport. Shipment weights that are over this legal-weight limit require that the shipper receive heavy load permits from the States and local jurisdictions with responsibility for the roads over which the shipment will be transported. Receipt of heavy load permits to support SNF shipments is an area of potential delay that should be considered in the transportation planning process.

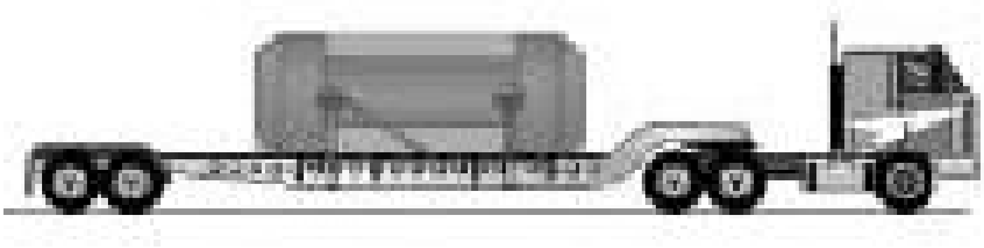


Figure 2.6 Truck Cask Ready for Transport [DOE 2002b]

Railroad transport also requires specialized equipment. Transport of the 125-ton SNF 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, as discussed in more detail in Section 4.2. Figure 2.7 shows a cask loaded onto a rail car along with a personnel barrier.

Figure 2.7 Rail Cask with Personnel Barrier Loaded on a Rail Car [DOE 2008c]

In some designs the cask may be mounted on a transport skid that has integral tie-downs. 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 2.8.

Figure 2.8 Rail-to-Truck Intermodal Transfer Facility, Valognes, France

For rail transport, in addition to the cask transport system (cask, impact limiters, transport skid, and auxiliary equipment), special rail equipment will be needed to ship loaded SNF casks from nuclear power plant sites to a central waste management facility: rail locomotives, rail cask cars, rail escort cars, and rail buffer cars (i.e., flatbed rail cars that are required by regulation to separate SNF cask cars from the locomotive and escort cars). Each rail shipment is assumed to include one locomotive, one escort car, and two buffer cars and cask cars. The number of cask cars will depend upon the number of SNF casks that are being shipped.

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

3. OVERVIEW OF THE REGULATORY FRAMEWORK THAT GOVERNS WASTE TRANSPORTATION

This section provides an overview of the regulatory framework for transport of nuclear waste, including the roles of Federal, State, Tribal and local governments. It describes the Federal regulations that govern the transport of radioactive materials – both SNF and HLW – including regulations and orders promulgated by the NRC, DOT, and the DOE. The roles that State, Tribal and local governments play in the transport of nuclear waste are also summarized.

3.1 Spent Nuclear Fuel Transportation Regulatory Background

The International Atomic Energy Agency's (IAEA) governing rules authorize the IAEA to establish international safety standards, including transport safety standards, which can be implemented by IAEA Member States in their national safety regulations. In 1961, the IAEA first published "*Regulations for the Safe Transport of Radioactive Material,*" Safety Series No. 6. [WNTI 2006] Since that time, the IAEA, in conjunction with its Member States, has periodically reviewed and revised the transport safety standards. The current version of the IAEA transport safety standards is embodied in "*Regulations for the Safe Transport of Radioactive Material*," 2009 Edition, Safety Requirements, No. TS-R-1. [IAEA 2009] The IAEA transport safety standards are used as a basis for national regulations in many IAEA Member States, including the U.S., and they are incorporated by international transport organizations, such as the International Civil Aviation Organization and the International Maritime Organization, in their regulatory instruments. [WNTI 2006]

In the U.S., the DOT has been designated as the U.S. Competent Authority[1] and serves as the official liaison with the IAEA Transport Safety Standards Committee (TRANSSC). The DOT and NRC jointly regulate the transport of radioactive materials. The two agencies signed a memorandum of understanding (MOU) in 1979 that outlines their respective responsibilities regarding the regulations for safety of radioactive materials transportation. [DOT/NRC 1979] The regulation of radioactive material transportation within DOT currently resides in the Pipeline and Hazardous Materials Safety Administration (PHMSA).

Under the DOT/NRC MOU, each agency conducts an inspection and enforcement program within its jurisdiction to assure compliance with its requirements. The NRC carries out enforcement actions for violations of the requirements of NRC and DOT regulations by NRC licensees and licensee-shipper-private carriers. The DOT carries out enforcement actions for violations of its hazardous materials transport regulations by carriers of radioactive materials and shippers of radioactive materials from agreement States, DOE

---

[1] Competent Authority means a national agency that is responsible, under its national law, for the control or regulation of a particular aspect of some aspect of hazardous materials (dangerous goods) transportation. [49 10CFR 171.8 (DOT 2009a)]

contractors, or any other shippers otherwise not subject to NRC requirements. [DOT 2008a]

The Nuclear Waste Policy Act, as amended (NWPAA), requires that transportation of commercial SNF under the NWPAA be subject to licensing and regulation by the NRC and the DOT. However, DOE is responsible for transport of DOE SNF and HLW. DOE has signed a memorandum of understanding with both NRC and DOT that DOE will comply with DOT regulations found in 49CFR171 through 49CFR178, and 49CFR397 and NRC regulations found in 10CFR71. [DOE 2002a] DOE implements these agreements through DOE Orders 460.1C, *Packaging and Transportation Safety* [DOE 2010a], and 460.2A, *Departmental Materials Transportation and Packaging Management.* [DOE 2004a]

3.2 U.S. Department of Transportation

DOT's authority to regulate the safety of hazardous materials transport, including radioactive materials transport, was established by the Hazardous Materials Transportation Act of 1975. The hazardous materials regulations are contained in 49CFR Subchapter C, *Hazardous Materials Regulations*, Parts 171 through 178, and Part 397. [DOT 2009b] Regarding SNF and HLW transport, DOT is responsible for the regulation of shippers and carriers of radioactive materials while the materials are in transit including highway route selection, vehicle condition and placarding, driver training, packaging marking, labeling, and other shipping documentation. [NRC 2010a]

3.2.1 Overview of DOT Regulations

DOT regulations governing hazardous materials transport, including radioactive materials transport, are provided in:

49CFR171, General Information, Regulations and Definitions: This part addresses the applicability of the hazardous materials regulations to packages that are used for the transportation of hazardous materials and to pre-transportation and transportation functions (such as preparing a package for loading, preparation of shipping papers, movement of packages, unloading, etc.).

49CFR172, Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information and Training Requirements: This part lists and classifies hazardous materials for purposes of transportation and prescribes the requirements for shipping papers, package marking, labeling, and transport vehicle placarding applicable to the transport of these materials.

49CFR173, Shippers – General Requirements for Shipments and Packagings**:** This part provides definitions of hazardous materials for transportation purposes; identifies requirements to be observed in preparing hazardous materials for shipment by air, highway, rail, or water, or any combination thereof; and identifies inspection and testing responsibilities for containers used in the transportation of hazardous materials.

49CFR174, Carriage by Rail: This part provides additional requirements that are applicable to the transportation of hazardous materials by rail, including additional requirements for the transport of certain radioactive materials (Section 174.700).

49CFR175, Carriage by Aircraft: This part provides additional requirements that apply to the transportation of hazardous materials aboard aircraft. Subpart C, *Specific Regulations Applicable According to Classification of Material*, includes additional requirements for the transport of radioactive material by aircraft including separation distance requirements between packages and passengers and other cargo, plutonium shipments, and radioactive contamination.

49CFR176, Carriage by Vessel: This part provides requirements that apply to the transport of hazardous materials by vessel. Subpart M provides additional requirements for transport of radioactive material including stowage requirements, segregation distances, contamination control, and special requirements transport of irradiated nuclear fuel, plutonium or HLW in international transport.

49CFR177, Carriage by Public Highway: This part provides requirements that apply to the transport of hazardous materials by motor vehicles on public highways. Section 177.842 provides additional requirements for radioactive materials including setting vehicle and package dose rates.

49CFR397, Transportation of Hazardous Materials, Driving and Parking Rules: These regulations are administered by the Federal Motor Carrier Safety Administration within DOT. Subpart D provides highway routing requirements for the transport of highway route controlled quantities (HRCQ) of radioactive materials, which would include SNF and HLW.

3.2.2 DOT Routing Regulations for Highway Shipments

The Hazardous Materials Transportation Act (HMTA) 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 SNF 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 1992]

Route selection factors include accident frequencies, traffic counts, average vehicle speed, population densities, time in transit, 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.

3.2.3 Federal Railroad Administration

In August 1998, the Federal Railroad Administration (FRA) developed a *Safety Compliance Oversight Plan for Rail Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel* (Plan). [DOT 1998b] The 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, Association of American Railroads (AAR), railroad labor organizations, and State and Tribal representatives. The FRA periodically reviews, evaluates, and updates the Plan to ensure that the latest technologies for the safe rail transport of spent nuclear fuel are considered. Key elements of Plan include (1) coordinated planning of the most appropriate and viable routes, (2) ensuring appropriate training of railroad employees and emergency responders, and (3) enhancing and focusing FRA's safety inspections and monitoring activities on all facets of the rail shipments of SNF and HLW. [Rutter 2004]

Under route-planning provisions of the Plan, FRA works with DOE, electric utility companies, or other shippers, and the involved railroad companies in planning and selecting the routes, emphasizing the selection of the highest classes of track. In addition, FRA prepared an accident-prediction model for the highway-rail grade crossings along the intended route and uses this model to assist the shipper in coordinating with appropriate State, local, and Tribal agencies in route-planning activities. FRA coordinates with other Federal agencies, local law enforcement representatives, and intelligence communities on security matters. FRA also reviews the emergency response plans of the shipper and the rail carrier to ensure that they adequately address the actions to be taken along the route in the unlikely event of an accident or incident involving the train. [DOT 1998b]

Appendix A to the FRA Plan contains FRA's High Level Nuclear Waste Rail Transportation Inspection Policy. The policy requires that the rail track and signal system to be inspected prior to the first shipment of SNF and HLW along a given rail route. Track and signal inspectors must prepare a memorandum describing the condition of the route inspected, including sidings and yard tracks, in addition to completing the routine inspection forms used while making the inspection. 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. [DOT 1998b]

In December 2008, DOT's PHMSA implemented a final rule that would require railroads that transport certain hazardous materials, including SNF, to perform a comprehensive safety and security risk analysis in order to determine and select routes that pose the least overall risk. Twenty-seven risk factors must be considered in route selection in order to assess the safety and security risk analysis of routes, including: rail traffic density, time and distance in transit, track class and conditions, environmentally-sensitive or significant areas, population density, emergency response capability, past incidents, availability of practicable alternatives, and other factors [DOE 2009a, DOT 2008c] The railroads have completed two years of conducting risk analyses of the primary routes in compliance with this new rule. The Rail Corridor Risk Management System (RCRMS), a web-based software tool, has been developed to assist the railroads in analyzing routes for shipment of certain hazardous materials.

3.3 U.S. Nuclear Regulatory Commission

NRC's authority to regulate the receipt, possession, transfer and use of source materials, byproduct materials and special nuclear materials is provided by the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974. In the context of the transportation packages used to ship certain types of radioactive materials, including SNF and HLW, the NRC is responsible for

- Establishing the regulatory requirements for package design;
- Certification of manufacture, use, and maintenance of packages; and
- Inspection of these transportation packages.

NRC regulations governing transport of radioactive material are found in 10CFR71. [NRC 2009a] In addition, NRC regulations for the safeguarding of SNF in transit are contained within 10CFR73, *Physical Protection of Plants and Materials.* [NRC 2009b, NRC 2010b] In this regard, the NRC is responsible for:

- Certification of packaging, specifically fissile material and Type B package designs, which include SNF and HLW packages;
- Approval of quality assurance programs for package design, manufacture and use;
- Development of physical protection requirements for SNF in transit;
- Conduct of inspections in accordance with NRC requirements; and
- Providing technical support to DOT in accordance with the agreement between the two agencies.

3.3.1 NRC SNF Transport Cask Certification

In accordance with 10CFR71, SNF transport cask designs must be approved by the NRC prior to the cask being used for transport. An applicant seeking certification of a SNF transport cask would submit an application to the NRC in accordance with Regulatory Guide 7.9, "*Standard Format and Content of Part 71 Applications for Approval of*

Packages for Radioactive Material" [NRC 2005a] and its "*Standard Review Plan for Transportation Packages for Spent Fuel* (NUREG-1617). [NRC 2000a]

The application must address the safety and operational characteristics of the package, including design analysis for structural, thermal, radiation shielding, nuclear criticality, and material content confinement. In addition, the application must include operational guidance, such as any testing and maintenance requirements, operating procedures, and conditions for package use. [NRC 2010c]

The applicant for a SNF transport cask 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 must 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. [NRC 2009a, EPRI 2010a]

The hypothetical accident conditions require that the conditions be sequentially imposed on the transport package and that any damage caused by the sequential accident conditions is cumulated. That is, evaluation of package's ability 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 (15 centimeters) 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.

As a separate accident condition, 10CFR 71.61 requires a deep immersion test for SNF packages 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 (2 MPa) is equivalent to 656 feet (200 meters) of water submersion and corresponds to the approximate depth of the continental shelf.

The severe physical conditions imposed sequentially by these hypothetical accident conditions in 10CFR71.73 would not be encountered in real world accidents. Real world impact accidents may occur at higher velocities than those encountered in the hypothetical free drop accident. However, the severity of the hypothetical free drop accident conditions is a result of the regulatory requirement that the impacting surface be "unyielding", which results in all of the forces of the impact being absorbed by the cask and not the unyielding surface. In real world accidents, energy would be absorbed by the cask conveyance and impacting surface as well as the cask. Thus, under real world conditions, the surface of impact would not be unyielding and the impact not as severe as the impacts imposed by the 10CFR71.73 free drop accident conditions. While some real world fires may be at higher temperatures than the 1,475° F thermal accident conditions, real world fires are not "fully engulfing." The thermal test conditions require a cask be fully engulfed in an optically dense fire for 30 minutes and that cask be essentially suspended above the fuel source for the fire. In a real world accident, a cask would likely be resting on the ground or conveyance and therefore would be neither fully engulfed nor suspended above the fire source. Thus, the impact of a real world fire would not be as severe as the impacts imposed by the 10CFR71.73 thermal accident conditions. [OTA 1985, Ammerman 2003]

NRC regulations allow cask designers to determine cask response to the hypothetical accident conditions either by physical test or by computer analysis. Cask vendors may perform quantitative safety analyses using computational modeling software, scale-model testing of casks or cask components, and testing of materials used in the cask design. Testing of full-scale transportation casks is not required for package certification. 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.

Each transportation package Certificate of Compliance (CoC) is issued for a period of five years, and may be renewed for a new five year period. In order to renew a CoC, the CoC holder would submit a request to the NRC with any necessary supporting information describing the capability of the package design to continue to meet technical requirements. After reviewing this information, the NRC will determine whether to grant a CoC renewal.

After NRC completes its review of an application, it issues a safety evaluation report (SER) and a 10CFR71 CoC to the cask designer. The CoC allows any licensee to use the cask as long as the licensee 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, the licensee must also have a NRC-approved quality assurance plan that meets the requirements of 10CFR71, Subpart H, Quality Assurance.

SNF transport casks that are currently certified for use in the U.S. are identified in Table 3.1 along with the cask vendor, valid 10CFR71 CoC number, and date of issuance. Those packages that are also certified for storage of spent nuclear fuel under NRC regulations contained in 10CFR72 are identified, along with the 10CFR72 CoC number and date of issuance of the storage CoC.

Cask Vendor	Transport Cask Model	Certificate of Compliance	Date of Issuance
BNG Fuel Solutions	FuelSolutions	Transport :71-9276	10/31/2007
		Storage: 72-1026	2/15/2001
General Atomics	GA-4	Transport: 71-9226	2/5/2009
Holtec International, Inc.	HI-STAR 100	Transport: 71-9261	5/8/2009
		Storage: 72-1008 Storage: 72-1014	10/4/1999 6/1/2000
NAC International, Inc.	NAC-LWT	Transport: 71-9225	3/23/2010
	NAC-UMS	Transport: 71-9270	10/29/2007
		Storage: 72-1015	11/20/2000
	NAC-MPC	Transport: 71-9235	6/12/2009
		Storage: 72-1025	4/10/2000
Transnuclear, Inc.	TN-FSV	Transport: 71-9253	9/14/2009
	MP 187	Transport: 71-9255	11/25/2008
		Storage: 72-1004 Storage: 72-1029	1/23/1995 2/5/2003
	MP-197	Transport 71-9302	8/30/2007
		Storage: 72-1004	1/23/1995
	TN-68	Transport: 71-9293	2/10/2006
		Storage: 72-1027	5/28/2000
Sources: U.S. Nuclear Regulatory Commission, http://www.nrc.gov/waste/spent-fuel-storage/designs.html http://rampac.energy.gov/certificates/certificate_retrieval_page.htm			

Table 3.1 List of SNF Transport Casks with Valid NRC Certificates of Compliance

3.3.2 Physical Protection of SNF in Transit

NRC is responsible for establishing physical protection requirements for SNF in transit. NRC regulations for the physical protection of SNF during transportation are found in 10CFR73.37. Following the events of September 11, 2001, NRC imposed Interim Compensatory Measures (ICMs) and Orders on its licensees that resulted in additional security requirements to supplement existing regulatory requirements related to security for the transport of SNF in quantities greater than 100 grams. The order was issued to licensees who had shipped or received spent nuclear fuel within three years and who planned to ship or receive spent nuclear fuel in the foreseeable future. [NRC 2009c]

In October 2010, the NRC published a proposed rule in the Federal Register that would amend its security regulations for transport of SNF. This proposed rulemaking would establish generically applicable security requirements similar to those previously imposed by Commission orders to licensees. The proposed rulemaking would establish the acceptable performance standards and objectives for the protection of spent nuclear fuel shipments from theft, diversion, or radiological sabotage.

The revised NRC regulations [NRC 2010b] require that a shipper perform the following security-related actions for the transport of SNF:

- Preplan and coordinate SNF shipments, including
    - Provide instructions to the armed escorts for the transport campaign;
    - Preplan and coordinate shipment itineraries with the receiver;
    - Ensure written certification of transfer of custody of the SNF;
    - Make arrangements with local law enforcement authorities along routes to provide emergency response if necessary;
    - Obtain advance approval from NRC regarding road and rail routes, or any U.S. ports used for transport, in addition to the routing requirements specified in DOT regulations; and
    - Document all preplanning and coordination activities.
- Provide advance written notification to the NRC in accordance with 10CFR 37.72. In addition, provide advance notification to the governor or his designee for each State through which the shipment will transit. This notice must be made in writing seven days in advance of the shipment.
- Establish a physical protection system that includes armed escorts to protect the SNF shipments. Armed escorts accompany the shipment at all times and are required to report on the status of the shipment to the movement control center at least every two hours.
- Establish a movement control center to monitor and control shipments and to communicate with local law enforcement agencies. The control center must be manned continuously when a SNF shipment is in progress.
- Develop contingency and response procedures to address threats, thefts, and radiological sabotage related to SNF in transit.
- Equip transport vehicles and escorts with redundant communication capabilities that allow for communication between the transport vehicle, escort vehicle, the movement control center, and local law enforcement agencies.
- Ensure that NRC-approved features are included in the transport vehicle that allow immobilization of the truck cab during highway transport or the cargo-carrying portion of the vehicle.
- Ensure that the shipment is continuously and actively monitored by a tracking system that reports to the movement control center.

Under 10CFR 73.38, the NRC establishes new requirements for licensees to establish an access authorization program that would apply to any individual. This program requires determination of individuals:

- Who will have unescorted access to SNF in transit;
- Responsible for implementing a licensee's physical protection program, including armed escorts;
- With access to SNF shipment information that its considered to be Safeguards information. [NRC 2010b]

3.4 State and Local Regulations

While Federal regulations set by DOT and NRC govern SNF and HLW transport safety, State, local and Tribal governments have some authority over shipments that transit their jurisdictions. States cannot prohibit the transport of SNF and HLW through their jurisdictions, but States can enact laws that are not in conflict with Federal laws and that address areas that are not covered by the Federal regulations. States enforce the Federal transportation safety standards and have authority to determine driver qualifications, ensure safe operations of motor vehicles, and conduct inspection and enforcement activities.

Numerous States and local governments have enacted laws that govern the transport of SNF and HLW, as well as other radioactive or hazardous materials, through their jurisdictions. 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. Typical State laws address:

- Registration and permit programs that may require the payment of registration or permit fees;
- Inspection and enforcement activities for shipments that transit States;
- Notification requirements to provide data for routing, planning and emergency response activities;
- Financial liability in the event of an accident; and
- Emergency preparedness training, planning activities and response to a radioactive materials accident. States may assess emergency response fees for shipments that transit their jurisdictions. [NCSL 2000, NCSL 2004]

As of January 2010, twenty-seven States have enacted laws that require permits and/or registration fees for transport of SNF and HLW, and other radioactive materials. These fees are charged for SNF and HLW shipments, radioactive materials shipments, as well as the shipment of other hazardous materials. Such fees include annual permit or registration fees, vehicle fees, fees charged per shipment or per package of material shipped, and emergency response fees charged per package. [NCSL 2010]

States can designate routes for the transport of SNF in accordance with 49CFR397, discussed in Section 3.2.2. States that have currently have designated routes for highway transport of SNF include: Alabama, Arkansas, California, Colorado, Iowa, Kentucky, Nebraska, New Mexico, Tennessee and Virginia.

State, Tribal, and local governments, along with the Federal government and shippers, have a responsibility for emergency response and emergency preparedness activities. The roles that various jurisdictions play in emergency response and emergency preparedness are discussed in more detail in Section 5.

4. PROCESS AND REGULATIONS ASSOCIATED WITH DESIGN, CERTIFICATION, PROCUREMENT AND FABRICATION OF TRANSPORTATION EQUIPMENT

This section provides an overview of the process and regulations for the design and certification of transportation casks for SNF and HLW. It also includes an overview of the process and expected timing associated with procurement and fabrication of transportation equipment, including transportation casks, cask handling equipment, and transportation equipment, to support a large-scale, long-term transportation system. Technical issues associated with nuclear waste transportation that must be addressed in the future will be described, including: approval of burnup credit or moderator exclusion for transport using high-capacity rail casks; resolution of technical and regulatory issues associated with transport of high-burnup SNF (e.g., burnups > 45 GWD/MTU); confirmation of fuel condition after very long term storage; and the need for transportation cask testing programs.

4.1 Process for Transportation Cask Design, Certification, and Manufacture

The design, certification and manufacture of SNF transportation casks is a complex process that involves numerous technical disciplines (e.g., structural design, nuclear criticality safety and radiation shielding, heat transfer), rigorous quality control and quality assurance, and strict oversight by the NRC during package certification, manufacture, and operation.

4.1.1 Transportation Cask Design Process

With the majority of U.S. nuclear operating companies storing SNF in dual-purpose storage systems for onsite dry storage, the design of SNF transportation casks must be coordinated with the design for SNF storage. Most dual-purpose technologies that have been deployed at Independent Spent Fuel Storage Installations (ISFSI) in the U.S. are canister-based systems that employ a sealed metal DPC with an internal basket for housing the SNF, separate overpacks for storage and transport, and a metal transfer cask to transfer the sealed DPC from the SNF storage pool into the storage overpack and from the storage overpack to the transport overpack (e.g., transport cask) for shipment off-site as described in Section 2.4. The following discussion assumes that in the future the majority of SNF will be transported in dual purpose systems, since it is likely that the majority of the projected inventory of SNF – approximately 133,000 MTU – will be placed in dry storage prior to being transported.

When designing a SNF transport cask or a dual-purpose system, a cask designer identifies the type of SNF to be transported (i.e., PWR or BWR]); the SNF characteristics (i.e., discharge burnup, as loaded enrichment assay, cooling time since discharge); the handling and operational requirements for both the shipping facility and the receipt facility; and gives consideration to the mode of transport (i.e., rail versus truck), and cask capacity (i.e., number of fuel assemblies). While design of the storage systems have been the primary focus of recent dual-purpose system development, cask designers must also ensure that features important to transport are considered in the design of the dual-purpose canister. Cask design 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 SNF;
- 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.

As discussed in Section 3, the NRC's regulations for certification of SNF transport casks define normal conditions of transport that must be met as well as hypothetical accident conditions that SNF 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 such as the Standard Review Plan (SRP) for Transportation Packages of Spent Nuclear Fuel [NRC 2000a]; Interim Staff Guidance Documents (ISGs) developed by NRC's Division of Spent Fuel Storage and Transportation, and Regulatory Guides [NRC 2010d]; and Division 7, Transportation, of NRC's regulatory guide series. [NRC 2010e] Additional technical publications are referenced in the SRP.

In preparing the Safety Analysis Report (SAR) that will provide the technical basis for certification of a transportation cask design, cask vendors may perform quantitative safety analyses using computational modeling software, scale-model testing of casks or cask components, and testing of materials used in the cask design. Testing of full-scale transportation casks is not required for certification of the package by NRC. (Section 4.3.4 discusses NRC proposals to conduct a full-scale test of a SNF transportation cask as part of a Package Performance Study). Any computational modeling software used to support transportation cask safety analyses must be benchmarked and validated against other codes or published data from physical tests, and must be approved by NRC staff for its intended use. The cask design effort must be carried out under an NRC-approved quality assurance (QA) program.

The process for the design of a SNF transport cask and development of the cask SAR will typically take between 12 and 24 months and will cost a cask designer several million dollars. The length of time to develop a SNF transport cask will depend upon whether or not the cask vendor has prior experience with transport cask design, and the complexity of the computational modeling needed to support the safety analysis. High-capacity SNF transport casks that will transport SNF with high-burnups and short cooling times will require more complex computational modeling software and will therefore require additional resources to develop.

4.1.2 SNF Transport Cask Certification Process

As noted above, the end result of the SNF transport cask design process is the development of a SAR and an application for a 10CFR71 CoC. Upon receipt of an application for a 10CFR71 CoC, NRC staff performs an administrative review of an application to determine the completeness of the application and to identify any significant omissions of information in accordance with internal NRC procedures. 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 SAR must follow the standard format and content recommended by the NRC in its SRP and be consistent with the other guidance documents.

The SRP, as supplemented by ISGs, provides NRC staff with guidance for the review and approval of a SNF transport cask application. During the review process, NRC staff may issue a Request for Additional Information (RAI) to the applicant if additional information or analysis is needed for NRC to complete its review of the SAR. Once NRC staff has completed its technical review of an application, it will issue a draft SER and draft 10CFR71 CoC for cask design. Following review of these draft documents by the cask vendor, NRC staff will issue a final SER and 10CFR71 CoC. The SNF transportation cask certification process typically takes between 12 and 24 months. An amendment to an existing 10CFR71 CoC may take 6 to 12 months for minor amendments or 12 months or longer for a complex amendment.

4.1.3 SNF Transportation Cask Manufacturing Process

The lead time for SNF transportation cask manufacturing is approximately 36 months to allow for ordering of long-lead time items and manufacture of the cask and support equipment. The SNF transport cask design includes all of the necessary drawings, material specifications, tests, standards, and procedures needed for cask manufacture. The manufacture of SNF transport casks is performed in accordance with American Society of Mechanical Engineers (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*, contains the design rules for these types casks. The QA requirements for SNF transport packages are contained in 10CFR71, Subpart H. Cask designers and manufacturers must operate under quality assurance plans that have been approved by the NRC. 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.

Fabrication generally follows practices applied to large pressure vessel work. Some SNF transport casks use materials such as lead or depleted uranium to provide gamma shielding, hydrogen-containing materials for neutron shielding, and/or boron-containing materials for nuclear criticality safety. These specialty materials are tested to ensure 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 meets the requirements of the cask 10CFR71 CoC. NRC performs periodic inspections of cask designers and manufacturing facilities throughout the fabrication process to ensure compliance with the design drawings and manufacturing requirements.

Each completed cask must undergo acceptance testing at the fabrication facility prior to initial use. Acceptance testing includes visual inspection of the cask; structural and pressure testing; load testing of the cask lifting trunnions; leak testing of the containment boundary; testing of components such as valves, gaskets, and impact limiters; continuity testing of shielding materials and neutron absorbing materials; and functional tests 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. [EPRI 2004, NRC 2000a]

4.2 Process for Procurement and Fabrication of Transportation Equipment

In order to embark on a nation-wide program to transport SNF from commercial nuclear power plant sites to a central facility for storage, disposal or reprocessing, it will be necessary to procure not only a SNF transport cask system, but also the transportation equipment needed to transport the casks. Since all U.S. commercial nuclear power plant sites are expected to have SNF in dry storage prior to the start of any transportation activities associated with DOE long-term storage and disposal, this report assumes that all commercial SNF will be transported by rail in large capacity dual-purpose systems such as those presently being deployed in at-reactor ISFSIs. While it is possible that a small amount of SNF would be transported in standard truck or rail casks, similar to those described in Section 2.4, the same processes would be used for procurement and fabrication of those systems.

The transportation equipment, also referred to as rolling stock, includes rail cask cars that would carry the SNF cask system (cask, impact limiters, and shipping cradle); rail escort cars for carrying the security escorts, and rail buffer cars. The buffer cars will separate the cask cars from the security escort car and the locomotive. Locomotives will also be needed, which can be purchased or leased from the railroad companies. Each shipment is assumed to include one locomotive, one escort car, two buffer cars to separate the locomotive and escort cars from the cask cars, and cask cars as shown in Figure 5.1. The number of cask cars will depend upon how many SNF casks are being transported in a single rail shipment.

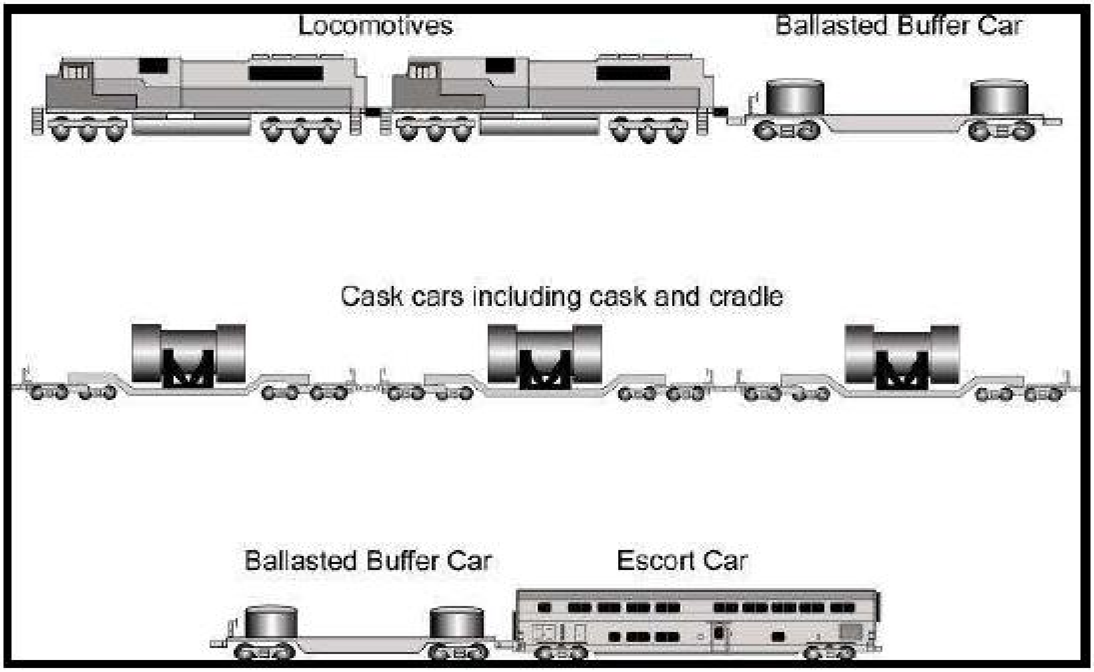


Figure 4.1 Rolling Stock, Escort and Buffer Car Schematic [DOE 2009a]

It is assumed that all rolling stock will be designed and tested to meet the AAR Standard, AAR S-2043. [AAR 2003] This performance standard provides specifications for a cask/car/train system to ensure safe transportation of SNF casks in the railroad operating environment and to allow trains carrying SNF to travel at 55 mph rather than at reduced speeds required for trains that do not meet the performance standard. Trains that meet this standard also would not have restrictions requiring the train to stand still when meeting or passing other trains when in transit. If existing rail car designs that meet AAR S-2043 and could be adapted for transport of SNF do not exist, it would be necessary to develop a prototype rail car, perform acceptance testing of the prototype in accordance with S-2043, and submit the testing results to AAR for approval of the design. According to DOE planning documents, this process could take four to five years. [Jones 2004] Once the design has been approved, DOE expected that it would take four to five years until the rolling stock fabrication is complete. Thus, if new rail car designs are necessary to meet AAR S-2043, the lead time for completion of these activities and fabrication of rolling stock is expected to be eight to nine years, as shown in Figure 4.2. To the extent it exists, off-the-shelf rolling stock could be purchased in approximately four years. [Lanthrum 2007]

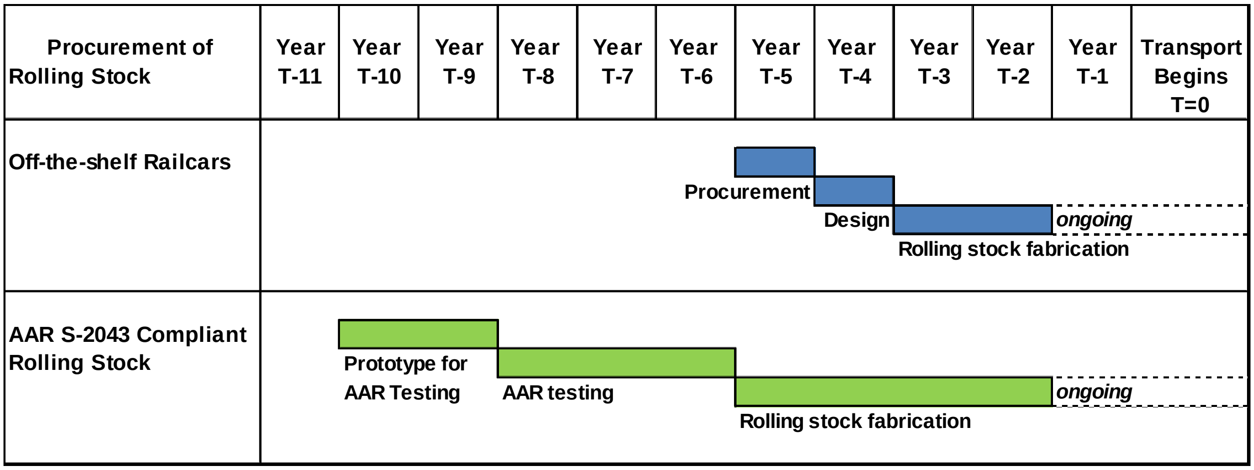


Figure 4.2 Timeline for AAR S-2043 Compliant Rolling Stock Testing and Procurement [Lanthrum 2007]

4.3 SNF Transportation Technical Issues

There are a number of technical issues that must be addressed before embarking on a nation-wide program to transport SNF from commercial nuclear power plant sites to a central facility for storage, disposal or reprocessing. As noted above, SNF from commercial nuclear power plants is expected to be stored primarily in large-capacity dual purpose dry storage systems. Technical issues that may need to be addressed in order to transport this SNF include resolution of regulatory issues associated with the transport of high-burnup SNF (e.g, burnups in excess of 45 GWD/MTU); approval of full burnup credit to support the criticality safety analyses for these SNF transport casks; confirmation of the condition of the SNF after extended storage of SNF; consideration of the need for a SNF cask testing program to support public acceptance of a nation-wide program to transport SNF.

4.3.1 Burnup Credit

The criticality safety analyses that support SNF transport cask certification have historically assumed that the SNF is unirradiated, referred to as a "fresh fuel" assumption. If the criticality safety analyses can take "credit" for the reactivity reduction associated with depletion of uranium and the build up of neutron poisons in the SNF, criticality safety can be more readily demonstrated for high-capacity SNF transport casks, such as 32-PWR capacity dual-purpose systems being loaded today for at-reactor storage. While NRC has issued an ISG that would allow partial burnup credit based on the depletion of fissile uranium, a technical basis must be developed to allow credit for the buildup of neutron-poisoning fission products in the SNF. While there has been progress on this issue over the past ten years, additional technical work must be completed to develop a validation approach that can be used as a basis for SNF criticality safety evaluations. [NRC 2002b, Wagner 2009]

4.3.2 Transport of High Burnup SNF

NRC ISG-11, Revision 3, Cladding Considerations for the Transportation and Storage of Spent Fuel was issued in November 2003. In that guidance document, NRC staff noted that it was "*reevaluating the technical basis for the transportation of spent fuel including assemblies with average assembly burnups exceeding 45 GWd/MTU. The staff is reviewing data and technical reports to further understand the mechanical and fracture toughness properties of spent fuel cladding in relation to the transportation of high burnup fuel under 10 CFR 71.55. Therefore, until further guidance is developed, the transportation of high burnup commercial spent fuel will be handled on a case-by-case basis using the criteria given in 10 CFR 71.55, 10 CFR 71.43(f), and 10 CFR 71.51.*" [NRC 2003a] Thus, until further NRC guidance is issued on this topic, there is not a generic approach for approval to transport SNF with burnups in excess of 45 GWD/MTU.

ERI estimates that average discharge burnups for PWR SNF have been in excess of 45 GWD/MTU since approximately 1999 and that average discharge burnups for BWR SNF will be in excess of 45 GWD/MTU by approximately 2015, as shown in Figure 4.3. This means that more than one-half of the projected commercial SNF inventory (more than 60,000 MTU of SNF) will have discharge burnups in excess of 45 GWD/MTU. Until there is a generic approach for NRC approval to transport of high burnup SNF that does not require "case-by-case" approval, it may be difficult to design the type of large-scale transportation program that would be needed to sustain a federal waste management system.

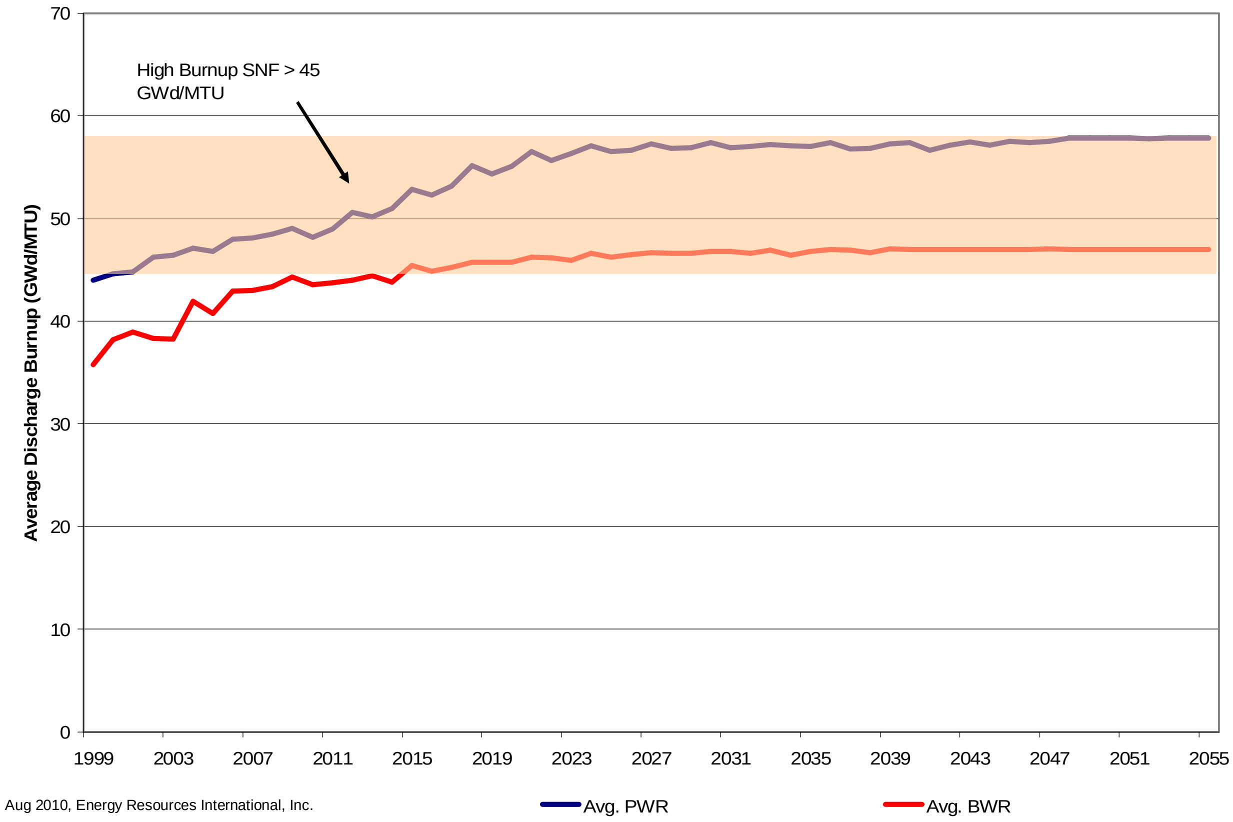


Figure 4.3 Historical and Projected SNF Discharge Burnups [ERI Analysis, December 2010]

4.3.3 Transport of SNF Following Extended Storage

With the prospect of SNF being stored at reactor sites for the foreseeable future, the nuclear industry, NRC and DOE are beginning to examine the issues associated with extended storage of SNF and deferred transportation after long-term storage.

Recognizing the likelihood that SNF will have to be stored at nuclear power plant sites for many decades, the Electric Power Research Institute (EPRI) has embarked on an extended storage collaborative research program to define the research and analysis needed to ensure very long-term safe storage, transportation, and monitoring. EPRI held a workshop in November 2009 that brought together representatives from EPRI, nuclear operating companies, the regulatory community, government agencies, SNF storage vendors, and other stakeholders that began to define critical gaps and research needs. [EPRI 2010b]

Similarly, NRC staff have embarked on a review of NRC's regulatory programs for SNF storage and transportation to identify regulatory gaps in these regulations associated with very long-term storage. This "gap" analysis will be used to form the technical basis for any changes to existing regulations. [NRC 2009d, NRC 2010f]

At some unknown time in the future, SNF will need to be transported away from nuclear power plant sites after extended wet or dry storage. It will be necessary to demonstrate that the SNF can be safely transported in accordance with NRC regulations. Dry storage safety related functions must be maintained during extended storage to ensure that SNF can later be transported. These safety functions include SNF thermal performance, radiological protection, confinement, sub-criticality, and ready retrievability.

EPRI envisions that due to the expected long-term durations of SNF storage, detailed investigation may be required into a host of potential issues, including:

- Condition of the fuel in dry casks and of the fuel baskets in sealed canisters;
- Condition of the fuel and pools in wet storage;
- Environmental and handling conditions that could compel repackaging;
- Repackaging at sites where reactor decommissioning has taken place (loss of wet pool storage, requirements for dry transfer);
- Long-term lead cask testing of high burnup fuel;
- Long-term monitoring requirements; and
- Effect of long-term storage on transportability.

The EPRI program has been split into three phases. During Phase 1, participants will review the current technical basis for SNF storage and perform a gap analysis to gain an understanding regarding the time periods covered by existing analyses of storage systems; identification of existing data and operational issues; identification of open items (i.e., the "gaps"), and provide suggested pathways for filling the gaps. This is currently ongoing. During Phase 2, the program will identify and coordinate experiments, field studies, and additional analyses needed to address the gaps that were identified. During Phase 3, the program will coordinate the collaborative research program that results in a demonstration involving at least one licensed dry storage system loaded with high burnup fuel. [EPRI 2010b]

NRC's research activities associated with long-term waste management are being coordinated with similar programs being conducted by other organizations, such as DOE, national laboratories, utilities, fuel and storage system vendors and EPRI's Extended Storage Collaboration Program. [NRC 2010f, NRC 2010g]

4.3.4 Transportation Cask Testing

In February 2003, NRC staff released NUREG-1768 for public comment, "*U.S. Nuclear Regulatory Commission Package Performance Study Test Protocols*" (PPS Test Protocol). [NRC 2003b] In February 2004, NRC staff presented options to the NRC Commissioners for full-scale testing of SNF transportation casks. [NRC 2004a] In May 2004, the Commission approved testing of a full scale, NRC certified rail transportation cask and authorized NRC staff to purchase a single rail cask, develop a realistically conservative test, include sufficient instrumentation to collect data to validate analytical methods including scaling, and include a fully engulfing fire as part of the test. NRC staff was instructed to develop a test plan for Commission approval, for a realistically conservative demonstration test. [NRC 2004b] NRC staff submitted a plan to the Commission in 2005 for a cask demonstration test that would utilize a full-scale cask tied to and supported on a carrier railcar that would be impacted by a train approaching from a 90-degree angle at a simulated rail crossing. This would be considered an “extra-regulatory” test since it would be a test that is not required by 10CFR71 for package certification. [NRC 2005b] The Commission directed the staff to include a fire test scenario in the demonstration test plan in which the same rail cask used for the impact test would be subjected to a fully engulfing, optically dense, hydrocarbon fire for a duration of one-half hour post-collision. [NRC 2005c]

While the Package Performance Study never proceeded due to delays in the DOE’s Yucca Mountain program, consideration should be given to whether a SNF cask testing program of some nature should be performed prior to embarking on a long-term, nation-wide program to transport SNF. There may be a continued benefit to collecting data through testing to validate analytical methods used in cask safety analyses. In addition, a cask testing program could have an additional benefit of boosting public confidence in transportation cask safety.

4.3.5 Transport of High-Burnup, Short-Cooled SNF

Many of the advanced DPC dry storage systems that have been certified by the NRC for storage allow nuclear operating companies to load high burnup SNF assemblies that have cooling times as short as five years. PWR DPC dry storage systems have been certified with package heat loads that include: several 24 PWR assembly capacity DPCs with total package heat loads ranging from 23 to 40 kilowatts (kW) for storage; and several 32 PWR assembly capacity DPCs with total package heat load ranging from 34 to 40 kW for storage. BWR DPC systems have been certified with package heat loads that range from: a 61 BWR assembly capacity DPC with a total package heat load of 32 kW to an 87 BWR assembly capacity DPC with a total package heat load of 33 kW. Many of the 10CFR72 certified DPC storage systems allow for both uniform loading of SNF (that is, all SNF assemblies loaded have similar burnups and cooling times), and regional loading of SNF (allowing higher heat load SNF assemblies to be loaded in certain regions of the dry storage basket, and requiring lower heat load SNF assemblies in other regions). The total heat load of all assemblies loaded must be within the total package heat load limits.

In contrast, the allowable total package heat loads for transporting these same DPCs are lower than the storage heat loads described above. This means that a high burnup SNF assembly may be qualified for storage in a large capacity DPC after it has cooled for five years, but that same assembly may not be able to be transported in that DPC until it has cooled for a longer time period – possibly for 10 to 15 years, depending upon the package design and the mix of SNF assemblies that have been loaded. Already loaded DPCs with high-burnup, short-cooled SNF may have to be stored until these DPCs qualify for transport. If commercial SNF will be kept in long-term onsite storage, the SNF cooling time may not be an issue for transport.

However, if there is a need to transport high burnup, short-cooled SNF (e.g., SNF with 5 to 15 years of cooling) to a central waste management facility in the future, it may be necessary to design a transport cask with a smaller capacity in order to be able to transport this SNF. Cask designers may be able to amend their transport cask designs to allow transport of shorter-cooled SNF. Several transport cask designs associated with DPC systems that are currently used for storage are undergoing NRC review to allow transport of higher burnup SNF. Current DPC designs may also be able to be derated – that is, the package would not be fully loaded prior to transport.

If new transport casks are designed or derated, package capacities may require reductions of 20% to 40% depending upon the transport package design and the SNF burnup and cooling time. For example, if a 20% reduction in capacity is needed, SNF could be loaded into a 26 PWR assembly package instead of a 32 PWR assembly package, or a 32 PWR assembly package could be derated by loading only 26 PWR assemblies. If a 40% capacity reduction is needed, a 20-PWR assembly package may be necessary.

The use of lower-capacity, or derated, transport casks would result in the need for a greater number of SNF casks to be transported. These lower capacity systems would not be necessary for the entire inventory of SNF since much of the SNF will have cooled for many decades prior to transport. But, if commercial SNF can be transported while nuclear power plants are still operating or if SNF from shutdown nuclear power plant sites can be transported within five to ten years of plants permanently ceasing operation, it is possible that 20% or more of the commercial SNF inventory could be transported with cooling times of ten years or less. Planning associated with transport of high burnup, short-cooled SNF will have to be done well in advance of the need to transport this SNF so that transport casks will be available to ship this material if necessary.

5. INSTITUTIONAL INTERACTIONS ASSOCIATED WITH PLANNING LARGE-SCALE, LONG-TERM TRANSPORTATION OF NUCLEAR WASTE MATERIAL

This section provides an overview of the process for planning nuclear waste material transportation campaigns from commercial nuclear power plant sites and DOE sites to a central waste management facility. Existing programs for emergency planning and emergency response training are summarized. The types of information that will be needed to assess near-site transportation needs are described, such as need for heavy-haul capability from nuclear power plants to the nearest rail line. Interactions that will be needed between the shipper and State, Tribal and local governments regarding near-site and national route planning, emergency response training, and campaign planning are summarized assuming that the shipper could be either a private company or a Federal agency.

5.1 Emergency Preparedness and Emergency Response

In the event of an accident involving radioactive materials, the carrier has the responsibility for confining the spread of those 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, Tribal and local governments, primarily through their police and fire departments. State, Tribal and local governments can call on DOE for technical assistance in the event of a serious accident involving radioactive materials.

5.1.1 DOE Emergency Preparedness Programs

DOE's National Nuclear Security Administration (NNSA) operates a Radiological Assistance Program (RAP), with eight regional offices that are staffed with experts to provide immediate assistance to first responders in the event of an accident involving radioactive materials. RAP provides resources (trained personnel and equipment) to evaluate, assess, advise, isotopically identify, search for, and assist in the mitigation of actual or perceived nuclear or radiological hazards. [NNSA 2010]

DOE EM operates a Transportation Emergency Preparedness Program (TEPP) that provides an integrated program for DOE's transportation emergency planning and preparedness activities. The TEPP mission is to ensure that Federal, State, Tribal, and local responders have access to the plans, training, and technical assistance necessary to safely, efficiently, and effectively respond to transportation accidents involving DOE-owned radioactive materials. 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. [DOE 2010b]

For SNF shipments that occur under the NWPAA, Section 180(c) of the Act requires that DOE 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 NWPAA 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.

5.1.2 Other Emergency Preparedness Programs

The DHS Federal Emergency Management Agency (FEMA) is the responsible Federal agency for incident response. FEMA oversees the National Incident Management System (NIMS) which provides a national system for response to emergencies and incidents, including a transportation accident involving nuclear material under the National Response Framework. [FEMA 2008a] The National Response Framework includes a Nuclear/Radiological Incident Annex (NRIA) that describes the policies, situations, concepts of operations, and responsibilities of the Federal departments and agencies governing the immediate response and short-term recovery activities for incidents involving release of radioactive materials to address the consequences of the event. [FEMA 2008b]

The Emergency Response Guidebook was developed jointly by Transport Canada, the DOT, the Secretariat of Transport and Communications of Mexico, and with the collaboration of CIQUIME (Centro de Información Química para Emergencias) of Argentina, for use by fire fighters, police, and other first responders to a scene of a transportation incident involving dangerous goods. [DOT 2008b]

The DOT's PHMSA 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 Native American Tribes who receive the funds. [DOT 2010a]

In addition to assistance provided by Federal agencies, nuclear operating companies through their membership in the Institute for Nuclear Power Operations (INPO) have established 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. [EPRI 2004]

5.2 Facility and Near-Site Infrastructure Assessment

Well in advance of embarking on a large-scale, nation-wide SNF transportation program, facility and near-site infrastructure assessments will need to be performed to assess: existing infrastructure at nuclear power plant sites and DOE sites to handle transportation cask and associated equipment; and the capability of rail lines, roads, bridges, and other infrastructure near sites to accommodate rail shipments.

As noted earlier, all commercial nuclear power plants are expected to load SNF into dry storage using high-capacity dual purpose dry storage technologies, with weights of 100 to 125 tons. These heavy packages will have to be transported by rail, possibly with inter-modal heavy haul of the transport cask from plant sites for transfer to a rail car at the nearest rail line. For canister based dual-purpose technologies, the loaded DPCs will have to be transferred from the storage systems to the transport systems. Nuclear power plant sites that have permanently ceased operation and are in the process of decommissioning or have been completely dismantled may no longer have onsite capability to lift heavy loads, such as a SNF transport cask. It may be necessary to install portable cranes at these sites to enable loaded DPCs to be transferred to the transport casks, and to lift the loaded cask, impact limiters, and transport skid onto the rail car or heavy-haul vehicle for shipment off site. Several commercial nuclear power plants are loading SNF into dual-purpose casks (such as the TN-40 and TN-68 casks) which will have to be lifted onto transport skids and rail cars or heavy haul vehicles for transport off site. In the early 1990s, DOE performed preliminary assessments of the infrastructure at commercial nuclear power plant sites including each site’s on-site capability to ship SNF, including an evaluation of crane lifting capability, plant infrastructure, on-site rail or barge infrastructure, and operational constraints that might impede loading SNF for transport off site. This preliminary information would need to be updated well in advance of any SNF transport to ensure that adequate time is included in the schedule for on-site infrastructure upgrades. Similar assessments will need to be conducted at DOE sites that will ship DOE-owned SNF and HLW. [DOE 2009a, ORNL 1992]

In order to transport the these large casks from commercial nuclear power plant sites to the nearest rail line, it may be necessary to upgrade near-site rail infrastructure (e.g., abandoned rail spurs at the nuclear power plant sites), upgrade near-site roads or bridges to allow heavy haul of rail casks to the nearest rail line, or upgrade of barge facilities at plant sites. In the early 1990s, DOE performed preliminary assessments of the infrastructure near nuclear power plant sites including the capabilities for highway, road, bridge, railroad and barge access to each site. This preliminary information would need to be updated well in advance of any SNF transport to ensure that adequate time is included in the schedule for transportation infrastructure upgrades. Similar assessments will need to be conducted at DOE sites that will ship DOE-owned SNF and HLW in the future. [DOE 2009a]

The on-site infrastructure assessments and the near-site infrastructure assessments would be necessary to develop site-specific transportation campaign plans for each commercial nuclear power plant site and each DOE site. These site-specific plans would identify each step in the process needed to complete transport of SNF from sites where SNF and HLW are currently stored to a central waste management facility. [DOE 2009a] Site-specific campaign plans would include:

- Identification of the transport cask and associated equipment needed at a site in order to transport previously loaded DPCs or dual-purpose casks.
- Identification of on-site infrastructure capabilities, such as crane capacities, the need for heavy lifting capability, etc.
- Identification of the haul path to be used on site for transfer of the empty and loaded SNF transport casks.
- Detailed plans for transport of the loaded SNF transport system from the plant site to the nearest rail line, including the need for heavy-haul or barge transport, intermodal transfer of the cask, etc. This would be coordinated with transport companies and railroads, as needed.
- Coordination of the near-site transportation routing with national routes, in accordance with NRC regulations for SNF transport. The near-site routing would be coordinated with State, Tribal and local governments near the shipping site.

5.3 Interactions with State, Tribal and Local Governments

Well in advance of embarking on a large-scale, nation-wide SNF transportation program, the shipper will need to begin interactions with State, Tribal and local governments regarding near-site and national route planning, emergency response training, and transportation campaign planning. These interactions will also need to address issues associated with security of SNF while in transit, communications and information access, transportation safety and risk assessment, and protection of workers and the public.

5.3.1 Routing

As previously noted, it is assumed that all commercial SNF will be loaded into rail-capable dual-purpose storage and transport systems. Thus, this discussion regarding transportation routing focuses on identification of rail routes, including near-site heavy-haul or barge inter-modal shipments, from shipping sites to a central waste management facility.

As noted in Section 3.2.3, under the DOT's regulations for the rail routing [DOT 2008c], selection of rail routes for the transport of SNF would require discussions between the shipper (a Federal agency or private company), rail carriers, and stakeholders such as State Tribal and local governments. While the DOT regulations do not specify preferred routes for rail shipments of SNF and HLW, the regulations do require rail carriers of certain hazardous materials, including SNF and HLW, to analyze safety and security risks along rail routes, assess alternative routing options, and make routing decisions based on those assessments to select the safest and most secure practicable route. Many factors are to be considered in the safety and security risk analysis of routes, including rail traffic density, time and distance in transit, track class and conditions, environmentally-sensitive or significant areas, population density, emergency response capability, past incidents, availability of alternatives, and other factors.

Truck transport of SNF and HLW, if any occurs in the future, would follow the DOT's routing regulations in 49CFR397, as discussed in Section 3.2.2.

During DOE's preliminary transportation planning process, DOE planned to identify a suite of national routes for transportation. Prior to embarking on a national campaign to transport SNF and HLW, it will be necessary for the shipper to develop near-site and national routes to transport SNF and HLW from commercial nuclear power plant sites and DOE sites to a central waste management facility. These route planning activities will have to take place in accordance with DOT regulations for determining rail and highway transportation routes. Route planning will also require a collaborative and consultative process that involves interested stakeholders, including the nuclear operating companies; DOE sites; State, Tribal and local government agencies; carriers; and transportation cask vendors. Other issues that may need to be addressed through a collaborative process include security of SNF while in transit, emergency response planning, communications and information access, transportation safety and risk assessment, protection of workers and the public, and training. [DOE 2003a] Lessons learned during past and current DOE transportation planning activities should be considered, including route planning for DOE shipments of transuranic (TRU) waste to the Waste Isolation Pilot Plant and for DOE shipments of foreign research reactor SNF.

National and regional route planning efforts in the future could also take into account the considerable work done by several State regional organizations, through grants from DOE, to prepare planning guides for the shipment of SNF and HLW, such as the Council of State Governments, Midwestern and Eastern Regional Conferences, and the Western Governors Association. [CSG 2006, CSG 2009, WGA 2008]

In order to ensure appropriate emergency response planning along regional and national transportation routes, route planning should begin well in advance of national shipping campaigns. State regional groups estimate that transportation planning should begin 9 to 12 years in advance of a national-wide transportation program. Transportation planning to support transport of SNF from a limited number of sites could be accomplished in a shorter time period since there would be fewer stakeholders involved in a more limited shipping campaign. [Janairo 2010]

5.3.2 Emergency Planning

Section 180(c) of the NWPAA requires that DOE "*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 [to an NWPAA-authorized facility]. Training shall cover procedures required for safe routine transportation of these materials, as well as procedures for dealing with emergency response situations.*" In October 2008, DOE issued for public comment a revised proposed policy for implementing Section 180(c). DOE had intended to conduct a pilot program for implementation of the Section 180(c) grant process. At that time, DOE envisioned issuing Section 180(c) grants to State and Tribal governments approximately four years prior to the start of shipments through any of those jurisdictions. Grants would have included emergency response assessment and planning grants and annual training grants. [DOE 2008b]

For SNF and HLW shipments that occur in accordance with the NWPAA, the Section 180(c) process to provide technical assistance and funding emergency response training would have to be restarted. Future activities should take into account DOE's 2008 policy for Section 180(c) implementation as well as feedback provided by stakeholders, State regional organizations, and should integrate Section 180(c) assistance with existing training programs designed for State, Tribal and local emergency responders.

5.3.3 Transportation Campaign Planning

Planning a national transportation system will be done in conjunction with the site-specific transportation plans discussed in Section 5.2. Site specific transportation plans would be developed for each commercial nuclear power plant site and DOE site (i.e., the Shipping Site) that will ship SNF, HLW, and other nuclear waste material to a central waste management facility (i.e., the Destination Site). The site-specific transportation plans include [DOE 2006a]:

- Specifications for transportation cask system (cask, ancillary equipment, impact limiters, transport skid) to be used at the Shipping Site. Transportation cask systems must be certified to transport previously loaded DPCs.
- Specifications to support delivery of other needed equipment (e.g., portable cranes for lifting heavy loads at shutdown nuclear power plant sites).
- Preparation of site-specific procedures for cask receipt, cask loading, cask sealing, installation of impact limiters and transfer to transport equipment.
- Development of training plans and inspection procedures including dry runs of cask loading and transfer operations.
- Schedules for delivery of transportation equipment to Shipping Site and for departure of loaded cask system from Shipping Site;
- Identification of any site specific limitations (e.g., haul path limitations, lifting capability)

- Identification of near-site and national transportation routes, including requirements for heavy haul to the nearest rail line and intermodal transfer equipment needs. This would be done in consultation with stakeholders identified in Section 5.3.2.
- Prior planning for security and emergency response capability along the entire route from the Shipping Site to the Destination Site.

The individual site-specific transportation plans would be developed in conjunction with regional and national transportation planning efforts and would be consistent with operational guidelines developed for national transportation operations. [DOE 2009a] The national transportation plan would identify, on an annual basis:

- Number of cask shipments from each Shipping Site to the Destination Site;
- Dates for delivery of transportation equipment to Shipping Sites and the number and types of equipment needed (e.g., transportation cask systems, rolling stock)
- Dates for departure of loaded casks from Shipping Sites to the Destination Site;
- Inspection requirements prior to departure and along transportation routes;
- Notification of NRC and State and Tribal agencies in accordance with NRC procedures;
- Intermodal transfer requirements including equipments needs;
- Carriers responsible for transport from Shipping Sites to Destination Site;
- Security and monitoring requirements for transport from Shipping Sites to Destination Site; and
- Emergency response points of contact along each shipping route.

The Destination Site would be prepared to receive each shipment from the Shipping Sites, remove the transportation cask system from the vehicle conveyance, unload and decontaminate the transportation cask system, and forward the vehicle conveyance and transportation cask system for reuse at another Shipping Site.

This national transportation plan would allow the shipper, whether a Federal agency or private company, to determine transportation cask system needs (e.g., number and types of various SNF transport casks and equipment) and rolling stock requirements; to contract with carriers for near-site and national transportation needs; and to coordinate with State, Tribal and local governments in planning safe and secure shipments.

A national SNF transportation system will require long-term planning by a well-managed transportation system operator to coordinate: transportation cask systems, rolling stock, carriers, security, notification, coordination with Shipping Sites and Destination Site, coordination with State, Tribal and local governments, tracking of SNF and HLW in transit, and management of the paperwork that must accompany each shipment.

5.4 NWPAA Shipments versus Private Shipments

Transportation of SNF and HLW to an interim storage or reprocessing facility that is owned and operated by a private company would be carried out under the same NRC and

DOT regulations as a Federal SNF transportation program being carried out under the NWPAA. The shipper would have to consult with State, Tribal and local governments for route planning, in accordance with highway routing regulations discussed in Section 3.2.2 and railroad routing discussed in Section 3.2.3.

The requirement to provide technical assistance and funding to State and Tribal governments under Section 180(c) of the NWPAA for emergency response planning and training would only apply to a Federal transportation program. Shipments of SNF and HLW by a private company associated with a private interim storage or reprocessing facility would not take place under the NWPAA and the provisions of Section 180(c) would not apply. A private entity has no legal requirement to provide financial assistance to communities along its planned transportation routes to support emergency response planning and training. State, Tribal and local governments would continue to be eligible for DOT's HMEP grant program that provides financial and technical assistance to State, Tribal and local governments for emergency response training associated with hazardous materials transportation.

6. POSSIBLE SCENARIOS FOR TRANSPORT OF NUCLEAR WASTE MATERIAL IN THE FUTURE

This section describes several scenarios for the transportation of U.S. SNF and HLW as part of a future central waste management system, including: estimated shipments on an annual basis and total program basis; required transport cask fleet and transportation equipment needs consistent with the scenarios presented; and technical and institutional issues that may arise regarding the various scenarios.

6.1 Quantities of Nuclear Waste Materials to be Transported

Section 2 of this report identified the existing quantities of commercial SNF and HLW, DOE-owned SNF and HLW, GTTC waste, and DOE GTCC-like waste that will require eventual transport for interim storage, further processing, and/or disposal. The existing or projected quantities of waste, and the estimated number of casks needed to transport this waste are summarized in Table 6.1. Additional information regarding the assumptions for the estimated quantities is provided in Section 2.1. All waste is assumed to be shipped via railroad in the future, with the transport of multiple casks on each rail shipment as discussed in more detail in Sections 6.2 and 6.3.

Waste Description	Estimated Quantity of Waste	Projected Number of Casks to be Shipped
Commercial SNF (a)		
Projected Inventory Existing Plants	133,000 MTU	11,800
Projected Inventory Per New Plant	1,500 MTU	~120 to 150
DOE SNF (b)	2,500 MTHM	784
HLW		
DOE (c)	22,600 canisters	4,520
West Valley (d)	275 canisters	55
GTCC Waste (e)		
Commercial Nuclear Power Plants	871 m^3	398
Other (Sealed Sources, etc)	1,800 m^3	460
DOE GTCC-Like Waste (e)	3,000 m^3	816
Total Number of Shipments		**18,833**
Sources: **(a) ERI Analysis, December 2010** **(b) DOE 2008a** **(c) DOE 2008a, DeLeon 2009** **(d) Bower 2008, DOE 2008a** **(e) Joyce 2008**		

Table 6.1 Quantities of Waste to be Transported and Estimated Cask Shipments

The steady-state annual SNF acceptance capacity for commercial SNF at the Yucca Mountain repository had been established as 3,000 MTU of SNF per year, with the annual acceptance rate ramping up to that steady-state rate over a five-year period. The shipments of DOE-owned SNF and HLW were expected to be in addition to the annual 3,000 MTU of commercial SNF. While the 3,000 MTU steady state rate may have been a reasonable rate of acceptance for a waste management system that started transport of SNF while nuclear power plants were still operating, a higher acceptance rate may be needed in the future if one of the goals of the waste management system is to remove SNF from shutdown nuclear power plant sites in a timely manner so that the sites can be dismantled and the land can be repurposed.

Nuclear industry surveys conducted by ERI in the early 1990s indicated that commercial nuclear power plants could ship as much as 6,000 MTU per year. Since the majority of SNF is expected to be stored in transport-ready dual-purpose technologies, a much higher rate of acceptance could be achievable since the operations needed at nuclear power plant sites to transfer loaded DPCs to transport casks or to ready a previously loaded dual-purpose cask for transport will take considerable fewer resources compared to loading individual SNF assemblies into transport casks.

6.2 Scenario 1: SNF Shipped In Accordance with OFF Priority to a Central Waste Management Facility

Scenario 1 assumes that SNF will be transported from nuclear power plant sites based on the oldest fuel first priority ranking, as provided for in the Standard Contract. The *Standard Contract for Acceptance of Spent Nuclear Fuel and/or High-Level Radioactive Waste* (10CFR960) states that the priority ranking for assigning SNF and acceptance rights is based on the age of the SNF as determined from the date that the SNF was permanently discharged from the Contract Holders' nuclear power plant(s). This priority ranking methodology is typically referred to as "Oldest Fuel First" or "OFF." The Standard Contract also allows DOE to grant priority for any SNF or HLW removed from a nuclear power plant that has reached the end of its useful life or has been permanently shutdown. Scenario 1 assumes that SNF is shipped from the nuclear power plant sites on which the OFF priority ranking is based, but it does not specifically assume that the oldest SNF will be shipped from those sites. This assumption results in a conservative (high) estimate of the number of sites from which SNF might be shipped in any given year.

While the OFF priority ranking allocates acceptance rights to a nuclear operating company based on the age of SNF, a nuclear operating company may utilize its acceptance rights to ship any SNF (not just the oldest SNF) from any of its nuclear power plant sites (not just the site from which the allocations originate). Thus, it is difficult to predict what the actual pattern of SNF transport would be under an OFF priority ranking. For example, assume that Company A operates two nuclear power plant sites. Site A1 has an allocation of 20 MTU in 2035 and Site A2 has an allocation of 30 MTU in 2035. Under Scenario 1, Company A would ship 20 MTU from Site A1 in 2035 and 30 MTU from Site A2 in 2035 (but, not necessarily the oldest SNF). However, Company A could choose to use the two allocations to ship SNF from the same site, 50 MTU in 2035 from Site A1 (or Site A2).

For this scenario, the transportation system needs are examined, such as estimated number of transport casks, rolling stock, and an estimated number of nuclear power plant sites that would be shipping SNF on an annual basis. Two overall SNF acceptance rates are examined, the 3,000 MTU steady-state rate that was the planned rate for the Yucca Mountain repository and a 6,000 MTU steady-state rate, that ramps up to a steady-state capacity of 6,000 MTU over an eight year period. In addition to examining the requirements for shipment of commercial SNF, the requirements for transport of other waste quantities are also calculated. As summarized in Table 6.1, this includes 784 cask shipments of DOE-owned SNF, 4,575 cask shipments of HLW, and 1,674 cask shipments of GTCC waste and GTCC-like waste.

At an annual steady-state acceptance rate of 3,000 MTU per year, it would take approximately 47 years to transport the 133,000 MTU of SNF from commercial nuclear power plants. At an annual-steady-state acceptance rate of 6,000 MTU per year, it would take approximately 28 years to transport this inventory.

6.2.1 Scenario 1: Transport System Requirements

The following analysis assumes that one or more facilities for central management of SNF will be available in the future which will allow for transport of SNF from nuclear power plant sites to begin. A date for the start of central waste management facility operations is not assumed in this analysis – dates are referred to as Year 1, Year 2, etc. In addition to examining the transport requirements for shipment of commercial SNF, Scenario 1 also identifies the transport equipment needed for transport of DOE-owned SNF and HLW, GTCC waste, and GTCC-like waste.

6.2.1.1 Scenario 1a: 3,000 MTU Steady State SNF Transport

Scenario 1a assumes that SNF will be shipped from nuclear power plant sites under an OFF priority ranking at a steady-state rate of 3,000 MTU per year. As shown in Figure 6.1, the steady-state rate of 3,000 MTU per year is assumed to be reached in the fifth year of transport. This shipping rate is maintained through Year 47 when the 133,000 inventory of commercial SNF has been transported. During the years in which SNF is shipped at the 3,000 MTU steady-state rate, an average of 58 sites are shipping SNF in any given year. Transport of DOE-owned SNF, HLW, GTCC waste and GTCC-like waste, is assumed to be conducted at a steady rate over this 47 year period.

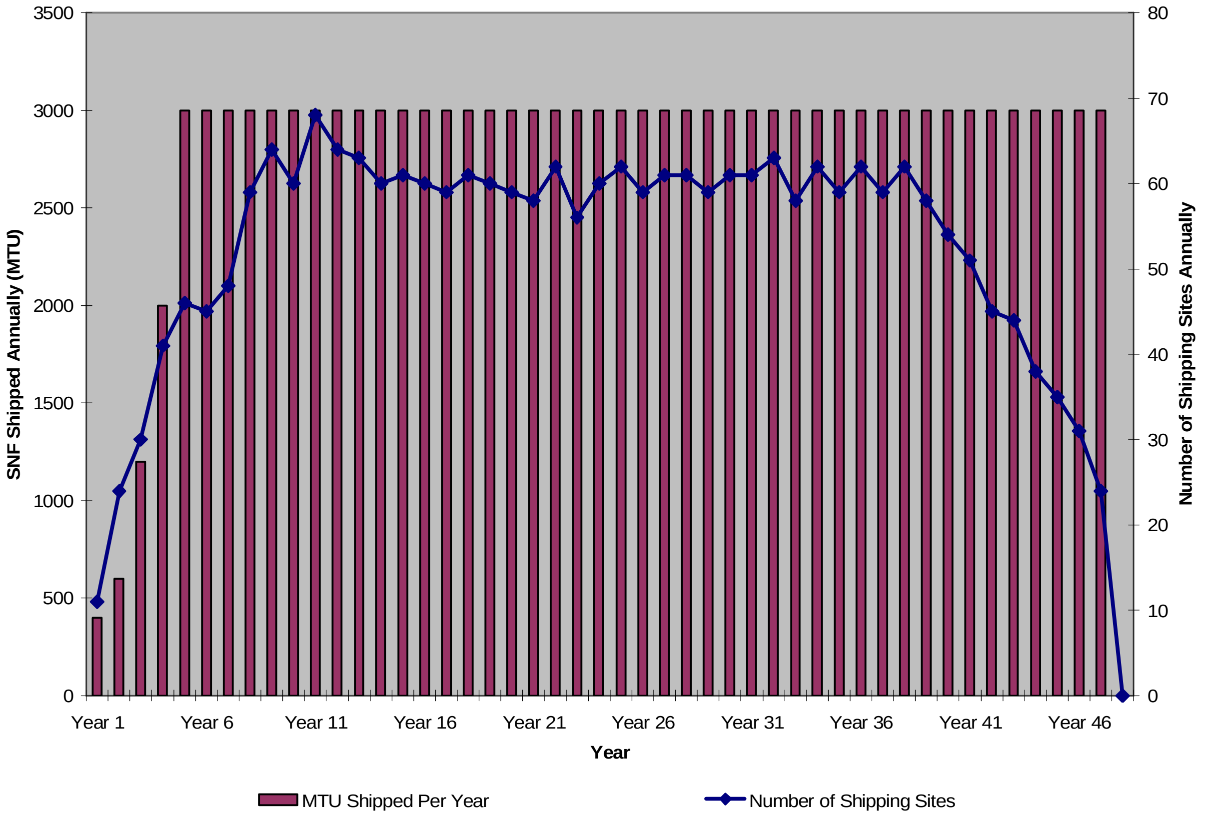


Figure 6.1 Scenario 1a, Annual SNF Shipments and Shipping Sites Assuming a 3,000 MTU Annual Acceptance Rate [ERI Analysis, December 2010]

ERI has estimated the equipment needed to transport loaded SNF casks from reactor sites at a steady-state rate of 3,000 MTU per year to a central waste management facility. ERI assumed a transport cask turnaround time of 10 weeks per rail cask. This assumes two weeks in transit to the Shipping Site, three weeks at the Shipping Site, two weeks in transport from the Shipping Site, and three weeks to unload the casks, perform cask maintenance and return the casks to service. Multiplying the cask capacity (11 MTU) by 52 weeks in a year and dividing by the cask turn-around time results in each transport cask being able to ship 57 MTU of commercial SNF annually.

In addition, it is unlikely that one standard transport cask design can be used to transport the variety of dual-purpose systems that are expected to be used for onsite storage at nuclear power plant sites. Therefore, ERI assumed a 50% increase in the cask fleet size in order to address the fact that not all commercial SNF casks in the cask fleet can be deployed to any site for transport of SNF. Thus, if 3,000 MTU of SNF are transported annually using casks that can each transport 57 MTU of commercial SNF annually, and applying a 50% increase for cask fleet inefficiencies, a fleet of 79 casks would be needed, as shown in Table 6.2. Accordingly, approximately 272 casks are transported annually in approximately 55 rail shipments.

In addition to the commercial SNF, it is assumed that a total of 4,575 cask shipments of HLW are made over a 47 year period, resulting in 98 cask shipments per year. Assuming a 10 week cask turnaround time, this results in a HLW transport cask fleet of 19 casks. Since all DOE HLW is expected to be placed in canisters of similar dimensions, ERI did not adjust the fleet size upward.

Annual SNF Shipped (MTU)	**Cask Capacity (MTU)**	**Transport Cask Turn-Around Time (Weeks)**	**MTU Shipped Per Year by Cask (MTU/year/Cask)**	**Cask Fleet Size (# Casks)**
Transport Cask Requirements: Commercial SNF				
(a)	(b)	(c)	(d) = [(b)*52 weeks]/(c)	[(a)/(d)*1.5]
3,000	11	10	57	79
Transport Cask Requirements: DOE-Owned SNF, HLW, GTCC Waste, and GTCC-Like Waste				
Waste Transported	**Total Cask Shipments of Other Waste**	**Annual Cask Shipments**	**Transport Cask Turn-Around Time (Weeks)**	**Cask Fleet Size (# Casks)**
HLW	4,575	98	10	19
DOE SNF	784	17	10	3
GTCC Waste & GTCC-Like Waste	1,674	36	10	10

Table 6.2 Scenario 1a, Transportation Cask Fleet Assumptions to Transport 3,000 MTU

A total of 784 cask shipments of DOE-owned SNF are expected to be made over a 47 year period, resulting in 17 cask shipments per year. Assuming a 10 week cask turnaround time, this results in a DOE-owned SNF transport cask fleet of three casks. Since all DOE-owned SNF is expected to be placed in standard canisters, ERI did not adjust the fleet size upward.

A total of 1,674 cask shipments of GTCC waste and GTCC-like waste are expected to be made over a 47 year period, resulting in 36 cask shipments per year. A 10 week cask turnaround time is assumed. Since GTCC waste and GTCC-like waste may be packaged in different sizes of canisters, ERI assumed a 50% increase in the cask fleet size. This results in ten casks for transport of GTCC waste and GTCC-like waste.

Table 6.3 presents the number of escort cars, buffer cars and locomotives needed to transport SNF assuming that 3,000 MTU of SNF are transported annually. ERI assumed that each train will include: one locomotive, five rail cask cars, two buffer cars, and an escort car. This means that there will be two buffer cars for every five rail cask cars, and one locomotive and one escort car for every five rail cask cars. Assuming 3,000 MTU shipped annually in casks with a capacity of 11 MTU per cask, results in a total of 272 cask shipments per year. If five casks are shipped in each rail shipment, the cask fleet of 79 casks could be used for as many as 16 rail shipments at any time. Rolling stock needed to support 16 rail shipments would include 79 cask cars, 32 buffer cars, 16 locomotives, and 16 escort cars, as shown in Table 6.3. The rail equipment needed to transport HLW, DOE-owned SNF, GTCC waste and GTCC-like waste is also summarized. An additional 32 rail cask cars, 14 buffer cars, 7 escort cars, and 7 locomotives would be needed to transport these additional wastes over a 47 year period.

Annual SNF Shipped (MTU)	Rail Cask Fleet and Rail Cars	Buffer Cars	Locomotives	Escort Cars
Commercial SNF 3,000 MTU/Year	79	32	16	16
HLW	19	8	4	4
DOE SNF	3	2	1	1
GTCC Waste and GTCC-Like Waste	10	4	2	2
Total	111	46	23	23

Table 6.3 Scenario 1a, Transportation Rail Equipment Needs to Transport 3,000 MTU

6.2.1.2 Scenario 1b: 6,000 MTU Steady State SNF Transport

Scenario 1b assumes that SNF will be shipped from nuclear power plant sites under an OFF priority ranking at a steady-state rate of 6,000 MTU per year. As shown in Figure 6.2, the steady-state rate of 6,000 MTU per year is assumed to be reached in the eighth year of transport. This shipping rate is maintained through the Year 26 when the entire 133,000 inventory of commercial SNF has been transported. During the years in which SNF is shipped at the 6,000 MTU steady-state rate, an average of 61 sites are shipping SNF in any given year. Transport of DOE-owned SNF, HLW, GTCC waste and GTCC-like waste, is assumed to be transported at a steady rate over this 28 year period.

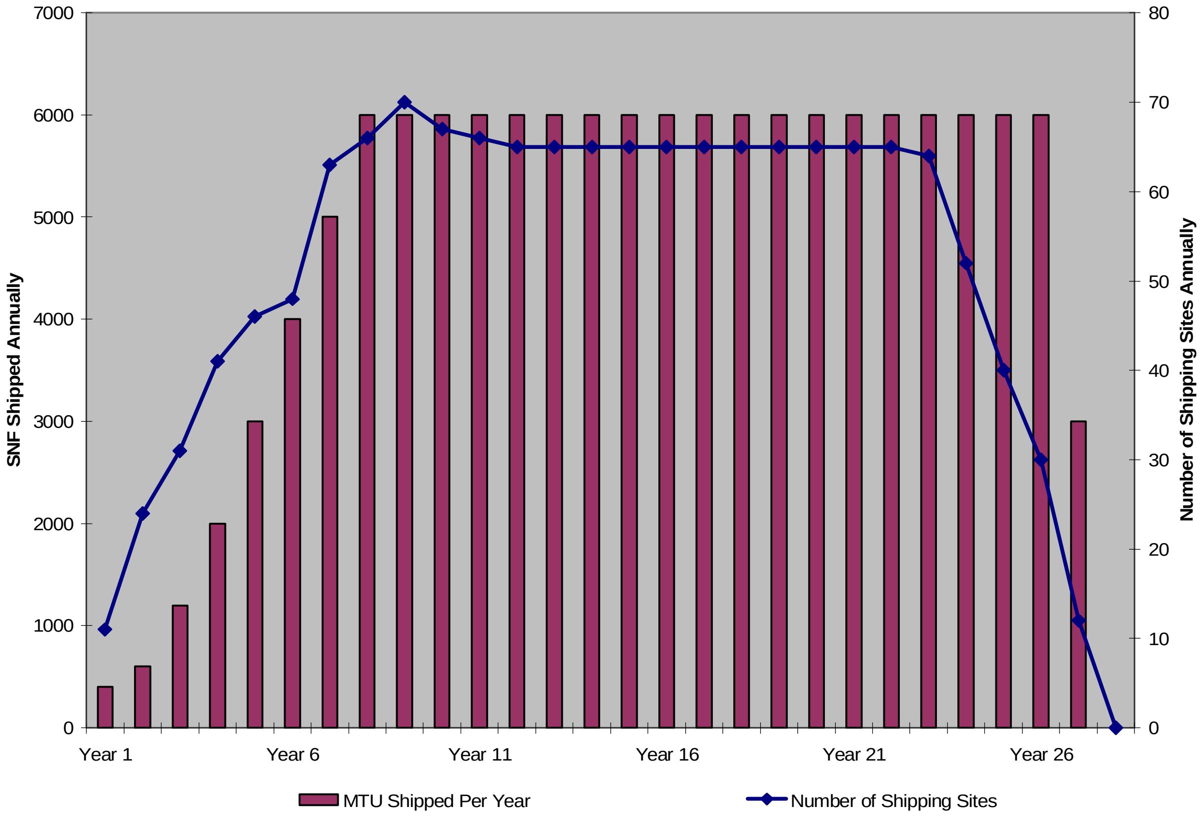


Figure 6.2 Scenario 1b, Annual SNF Shipments and Shipping Sites Assuming a 6,000 MTU Annual Acceptance Rate [ERI Analysis, December 2010]

ERI has estimated the equipment needed to transport loaded SNF casks from nuclear power plant sites at a steady-state rate of 6,000 MTU per year to a central waste management facility. ERI assumed a transport cask turnaround time of 10 weeks per rail cask. This assumes two weeks in transit to the Shipping Site, three weeks at the Shipping Site, two weeks in transport from the Shipping Site, and three weeks to unload the casks, perform cask maintenance and return the casks to service. Multiplying the cask capacity (11 MTU) by 52 weeks in a year and dividing by the cask turn-around time results in each transport cask being able to ship 57 MTU of commercial SNF annually.

ERI assumed a 50% increase in the cask fleet size in order to address the fact that not all commercial SNF casks in the cask fleet can be deployed to any site for transport of SNF. Thus, if 6,000 MTU of SNF are transported annually using casks that can each transport 57 MTU of commercial SNF annually, and applying a 50% increase for cask fleet inefficiencies, a fleet of 157 casks would be needed, as shown in Table 6.4. Accordingly, approximately 545 casks are transported annually in approximately 109 rail shipments.

It is assumed that a total of 4,575 cask shipments of HLW are made over a 28 year period, resulting in 163 cask shipments per year. Assuming a 10 week cask turn around time, this results in a HLW transport cask fleet of 31 casks. Since all DOE HLW is expected to be placed in canisters of similar dimensions, ERI did not adjust the fleet size upward.

Annual SNF Shipped (MTU)	Cask Capacity (MTU)	Transport Cask Turn-Around Time (Weeks)	MTU Shipped Per Year by Cask (MTU/year/Cask)	Cask Fleet Size (# Casks)
Transport Cask Requirements: Commercial SNF				
(a)	(b)	(c)	(d) = [(b)*52 weeks]/(c)	[(a)/(d)*1.5]
6,000	11	10	57	157
Transport Cask Requirements: DOE-Owned SNF, HLW, GTCC Waste, and GTCC-Like Waste				
Waste Transported	**Total Cask Shipments of Other Waste**	**Annual Cask Shipments**	**Transport Cask Turn-Around Time (Weeks)**	**Cask Fleet Size (# Casks)**
HLW	4575	163	10	31
DOE SNF	784	28	10	5
GTCC Waste & GTCC-Like Waste	1,674	60	10	17

Table 6.4 Scenario 1b, Transportation Cask Fleet Assumptions to Transport 6,000 MTU

A total of 784 cask shipments of DOE-owned SNF are expected to be made over a 28 year period, resulting in 28 cask shipments per year. Assuming a 10 week cask turnaround time, this results in a DOE-owned SNF transport cask fleet of five casks. Since all DOE-owned SNF is expected to be placed in standard canisters, ERI did not adjust the fleet size upward.

A total of 1,674 cask shipments of GTCC waste and GTCC-like waste are expected to be made over a 28 year period, resulting in 60 cask shipments per year. A 10 week cask turnaround time is assumed. Since GTCC waste and GTCC-like waste may be packaged in different sizes of canisters, ERI assumed a 50% increase in the cask fleet size. This results in 17casks for transport of GTCC waste and GTCC-like waste.

Table 6.5 presents the number of escort cars, buffer cars and locomotives needed to transport SNF assuming that 6,000 MTU of SNF are transported annually under an OFF priority ranking. ERI assumed that each train will include: one locomotive, five rail cask cars, two buffer cars, and an escort car. This means that there will be two buffer cars for every five rail cask cars, and one locomotive and one escort car for every five rail cask cars. Assuming 6,000 MTU shipped annually in casks with a capacity of 11 MTU per cask, results in a total of 545 cask shipments per year. If five casks are shipped in each rail shipment, a cask fleet of 157 could be used for as many as 32 rail shipments at any time.

Rolling stock needed to support 32 rail shipments would include 157 rail cars, 64 buffer cars, 32 locomotives, and 32 escort cars, as shown in Table 6.5. The rail equipment needed to transport HLW, DOE-owned SNF, GTCC waste and GTCC-like waste is summarized. An additional 53 rail cars, 24 buffer cars, 12 escort cars, and 12 locomotives would be needed to transport these additional wastes over a 28 year period.

Annual SNF Shipped (MTU)	Rail Cask Fleet and Rail Cars	Buffer Cars	Locomotives	Escort Cars
Commercial SNF 6,000 MTU/Year	157	64	32	32
HLW	31	14	7	7
DOE SNF	5	2	1	1
GTCC Waste and GTCC-Like Waste	17	8	4	4
Total	210	88	44	44

Table 6.5 Transportation Rail Equipment Needs to Transport 6,000 MTU

6.2.2 Logistical Issues Associated with Scenario 1

As illustrated by Scenario 1a and Scenario 1b, when transport of SNF begins to a central waste management facility, a transport system of unprecedented capacity for the U.S. nuclear industry would have to be put in place to move the quantities of commercial SNF, DOE-owned SNF and HLW, GTCC waste, and GTCC-like waste that will require long-term management and eventual disposal. Commercial SNF would be transported from an average of 58 sites over a period of 47 years under a steady-state transport rate of 3,000 MTU per year. Under a steady-state rate of 6,000 MTU per year, commercial SNF would be transported from an average of 61 sites over a period of 28 years.

Whether the transport system is designed to transport 3,000 MTU per year over a 47 year period or 6,000 MTU per year over a 28 year period, the U.S. has not transported these large quantities of SNF in the past. Transporting 3,000 MTU of commercial SNF per year would result in 272 cask shipments per year, plus an additional 151 cask shipments of the other nuclear waste described in Table 6.1. Transporting 6,000 MTU of commercial SNF per year would result in 545 cask shipments per year, plus an additional 251 cask shipments of other nuclear waste. As discussed in Section 2, U.S. experience in transporting SNF amounts to several hundred metric tons per year – not thousands of metric tons. However, the U.S. transports several hundred million packages of hazardous materials annually. Thus, an additional 400 to 800 hazardous materials shipments should be able to be accommodated within the U.S. transportation system.

In order to move 3,000 to 6,000 MTU of SNF annually, the U.S would need a robust transportation management system to ensure that the transportation route planning, emergency response planning, and campaign planning are carried out in a safe and efficient manner. As shown in Figure 6.3, planning activities associated with transport of SNF to one or more central waste management facilities would have to begin a minimum of 11 years in advance of transport operations. The schedule assumes that all transportation planning activities needed for the start of SNF transport would be completed one year prior to the year that transport operations would begin, which is Year "T=0" in Figure 6.3. As discussed in Section 4.1, SNF transport cask design, certification and fabrication are expected to take approximately seven years, assuming that new cask designs must be certified. Additional transport casks would be fabricated to make up the cask fleet. Procurement and fabrication of a prototype for rolling stock testing is assumed to take two years, followed by an approximate three year period for the rolling stock prototype to go through AAR testing and approval, as discussed previously in Section 4.2. Rolling stock fabrication for the start of transport operations would take approximately four years, with additional rolling stock fabrication taking place after that time until the needed equipment has been manufactured. [Lanthrum 2007]

As discussed previously in Section 5.3.1, transportation planning activities would likely need to begin nine to twelve years in advance of the start of transport. Facility and near-site infrastructure assessments would need to start approximately 11 years in advance of the start of transport operations and would take approximately three years to perform the assessments needed for the initial sites transporting SNF at the start of transport operations. Additional facility and near-site assessments would take place after the first three years as more sites prepare to transport SNF. Once the facility and near-site assessments are complete for the initial sites transporting SNF, route identification activities would take place in consultation with stakeholders. Route identification and approval for the initial sites is assumed to take approximately three years, with additional routes being approved after that time. Following identification and approval of the initial routes, emergency response training would take place along the initial routes. This initial emergency response training is assumed to begin approximately four prior to the start of transport operations, with additional training taking place after that time on additional routes to support transport from additional sites.

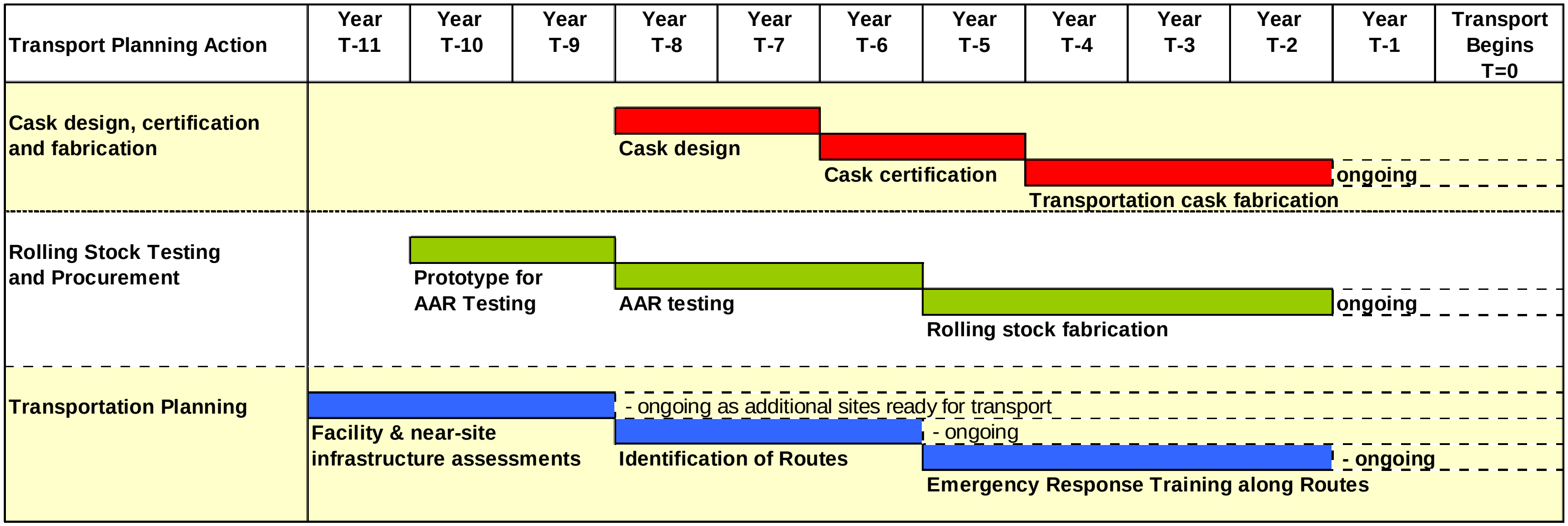


Figure 6.3 Timeline for Transportation Planning Activities for a Large-Scale SNF Transportation Program [Lanthrum 2007, Jones 2004, Janairo 2010]

As shown in Table 6.6, under Scenario 1a, during the first five-year planning period, Years 1 through 5 of transport, there would be between 11 and 46 sites transporting SNF – with the number of sites increasing as the system capacity ramps up to the steady-state rate of 3,000 MTU per year. An average of 1,440 MTU of SNF would be transported annually during that time period. During the second five-year planning period, there would be between 45 and 60 nuclear power plant sites shipping SNF, with 3,000 MTU shipped annually. By the third five-year planning period 60 to 68 sites would be shipping SNF, with 3,000 MTU shipped annually. The total number of nuclear power plant sites, including operating and shutdown reactor sites, is 74.

SNF Shipping Scenario	**Transport Period Periods**				
	Years 1-5	**Years 6-10**	**Years 11-15**	**Years 16-20**	**Years 21-25**
Scenario 1a **SNF Shipped within 5 Years**					
# Sites Shipping During Period	11 - 46	45 - 60	60 - 68	59 - 61	56 - 62
Average MTU Shipping Annually	1,440	3,000	3,000	3,000	3,000
Scenario 1b **SNF Shipped within 10 Years**					
# Sites Shipping During Period	11 - 46	47 - 70	65 - 66	65	44 - 65
Average MTU Shipping Annually	1,440	5,400	6,000	6,000	6,000

Table 6.6 Estimated Number of Shipping Sites and Average Amount of SNF Shipped for 5-Year Planning Periods

Under Scenario 1b, during the first five-year planning period, there would be 11 to 46 sites transporting SNF in any given year with average annual shipments of 1,440 MTU. During the second five-year, there would be between 47 and 70 sites shipping SNF as the system capacity ramps up to the steady-state rate of 6,000 MTU per year. By the third five-year planning period 65 to 66 sites would be shipping SNF annually.

6.2.3 Technical Issues Associated with Scenario 1

As discussed in Section 4.3.5, depending upon when a central waste management facility is available for transport of SNF from commercial nuclear power plant sites, transportation system planning and transport cask designs may need to be adjusted to account for age of the SNF when it is transported.

Nuclear operating companies are loading high burnup, short-cooled SNF into dual-purpose storage technologies with high package heat loads for onsite storage. Many of these storage systems are certified to allow high heat load SNF to be stored with as little as five years of cooling. In contrast the allowable total package heat loads for transporting these same dual-purpose technologies are lower than the allowable heat loads for storage. This means that a high burnup SNF assembly may be qualified for storage in a large capacity DPC after it has cooled for five years, but that same assembly may not be able to be transported in that DPC until it has cooled for a longer time period – possibly for 10 to 15 years.

As noted in Section 4.3.5, if commercial SNF can be transported to a central waste management facility while nuclear power plants are still operating, it is possible that lower capacity transport casks will need to be designed, certified and manufactured to transport high burnup, short-cooled SNF. Alternatively, current dual-purpose technologies could be derated, but nuclear operating companies would have to be notified well in advance of loading these systems for storage. The need to utilize lower capacity or derated casks may also be a consideration in the transport of SNF from shutdown nuclear power plant sites as discussed in more detail in Section 6.3.4.

6.3 Scenario 2: Transport of SNF from Shutdown Nuclear Power Plant Sites

Scenario 2 assumes that SNF will be transported from shutdown nuclear power plant sites. For this scenario, the transportation system parameters are examined, such as estimated number of transport casks, rolling stock, and the number of shutdown plant sites that would be shipping SNF on an annual basis. For the purposes of this analysis, a shutdown nuclear power plant site is a site at which all commercial nuclear power plants have permanently ceased operation.

The Scenario 2 analysis that is presented in this report assumes that SNF will be shipped from shutdown nuclear power plants instead of under an OFF priority ranking. This analysis is presented for illustrative purposes to demonstrate the transportation system requirements if SNF transport does not begin until after nuclear power plants permanently cease operation. The transport of other nuclear waste materials is not specifically analyzed in Scenario 2, but they would be similar to the number of shipments and the transport system requirements analyzed for Scenario 1b, above.

6.3.1 Scenario 2: SNF Inventory at Shutdown Nuclear Power Plant Sites

At the present time, there are nine shutdown nuclear power plant sites in the U.S. with ten shutdown nuclear power plants, as shown in Table 6.7. Many of these plants ceased operation several decades ago. As shown in Table 6.7, all of the SNF at these nine shutdown nuclear power plant sites has been transferred to dry storage or is expected to be transferred to dry storage in the future. A number of the shutdown plant sites also have GTCC waste stored in dual-purpose canisters as noted in the table.

As noted below, most of the DPC systems that are being used for SNF storage have related transport cask designs that have been certified under 10CFR71 or are in the process of 10CFR71 certification. However, several of the 10CFR71 CoCs will require amendments to add the DPCs used for storage at specific sites. It should be noted that none of these transport cask designs have been manufactured. Thus, in order to transport SNF that has been loaded into DPC systems for storage, it will be necessary to manufacture transport casks and associated equipment.

Reactor Name	Year of Shutdown	Amount of SNF Stored (MTU)	Number of DPC Systems	DPC Storage System Model	On-Site Dry Storage Status
Humboldt Bay	1976	29	5 SNF 1 GTCC	Holtec HI-STORM	5 SNF In Storage 1 GTCC Planned
LaCrosse	1987	38	5 SNF	NAC MPC	Planned
Rancho Seco	1989	228	21 SNF 1 GTCC	NUHOMS 24P	In Storage
Yankee Rowe	1991	127	15 SNF 2 GTCC	NAC MPC	In Storage
Trojan	1992	359	34 SNF	Holtec MPC TranStor Overpack	In Storage
Haddam Neck	1996	412	40 SNF 3 GTCC	NAC MPC	In Storage
Maine Yankee	1997	542	60 SNF 4 GTCC	NAC UMS	In Storage
Big Rock Point	1997	58	7 SNF 1 GTCC	FuelSolutions	In Storage
Zion 1 & 2	1998	1,018	65 SNF	NAC MAGNASTOR	Planned
Total:		2,811	237 SNF 12 GTCC		

Table 6.7 Summary of SNF Storage at Shutdown Nuclear Power Plant Sites

The following DPC systems are used to store or are expected to be used to store SNF and GTCC waste at shutdown nuclear power plant sites:

- Holtec International’s HI-STORM system is used for storage, along with the Holtec MPC-HB canister at the Humboldt Bay site. The Holtec MPC-24 canister is used in conjunction with TranStor concrete storage overpacks at the Trojan site. Holtec has received a 10CFR71 CoC to transport for the HI-STAR 100 transport cask; however a CoC amendment is needed to add the MPC-HB canister to the approved contents.
- NAC International’s NAC MPC is used for storage of SNF and GTCC waste at the Haddam Neck and Yankee Rowe sites. LaCrosse plans to load NAC MPCs for storage in the future. NAC has received a 10CFR71 CoC for the NAC MPC transport cask. An amendment to the NAC MPC 10CFR71 CoC would be needed to transport the LaCrosse dual-purpose canisters.
- The NAC UMS system is used for storage of SNF and GTCC waste at the Maine Yankee site. NAC has received a 10CFR71 CoC for the UMS transport cask. The

UMS transport cask is certified to transport the Maine Yankee dual-purpose canisters.
- Transnuclear, Inc.'s NUHOMS-24P system is used for storage of SNF and GTCC waste at the Rancho Seco site. The NUHOMS MP-187 transport cask is certified to transport the NUHOMS-24P dual-purpose canisters.
- EnergySolutions' FuelSolutions system is used for storage of SNF and GTCC waste at the Big Rock Point site. EnergySolutions received a 10CFR71 CoC for the FuelSolutions transport cask. The transport cask is certified to transport the Big Rock Point dual-purpose canisters.
- NAC's MAGNASTOR system is planned for storage of SNF at the Zion site. The MAGNASTOR transport cask has not yet been licensed by the NRC, but NAC plans to submit an application for transport certification in the near term.

It should be noted that there are an additional four shutdown nuclear power plants at sites that have operating nuclear power plants (Dresden 1, Indian Point 1, San Onofre 1, and Millstone 1). Dresden 1, Indian Point 1, and Millstone 1 are in "safe storage" and are expected to be decommissioned along with the operating units at those sites in several decades when the operating units reach the end of their extended licenses. San Onofre 1 is in the process of being decommissioned. Dresden 1, Indian Point 1 and San Onofre 1 have transferred SNF into onsite dry storage facilities that utilize DPC systems.

Currently operating nuclear power plants will begin to reach the end of extended operating licenses in 2029, assuming that plants operate for 60 years. As shown in Figure 6.4, the majority of nuclear power plants at U.S. sites will begin to reach the end of their operating licenses in the time period between 2029 and 2050. In most years, two or three sites reach the shutdown site status. Two sites will reach the shutdown site status after 2050, Comanche Peak in 2053 and Watts Bar in 2074 (this assumes that Watts Bar 2 begins operating in 2014). This analysis has not factored in the recent decision by Exelon Generation to shut down the Oyster Creek plant in 2020, ten year prior to the end of its extended license in 2030.

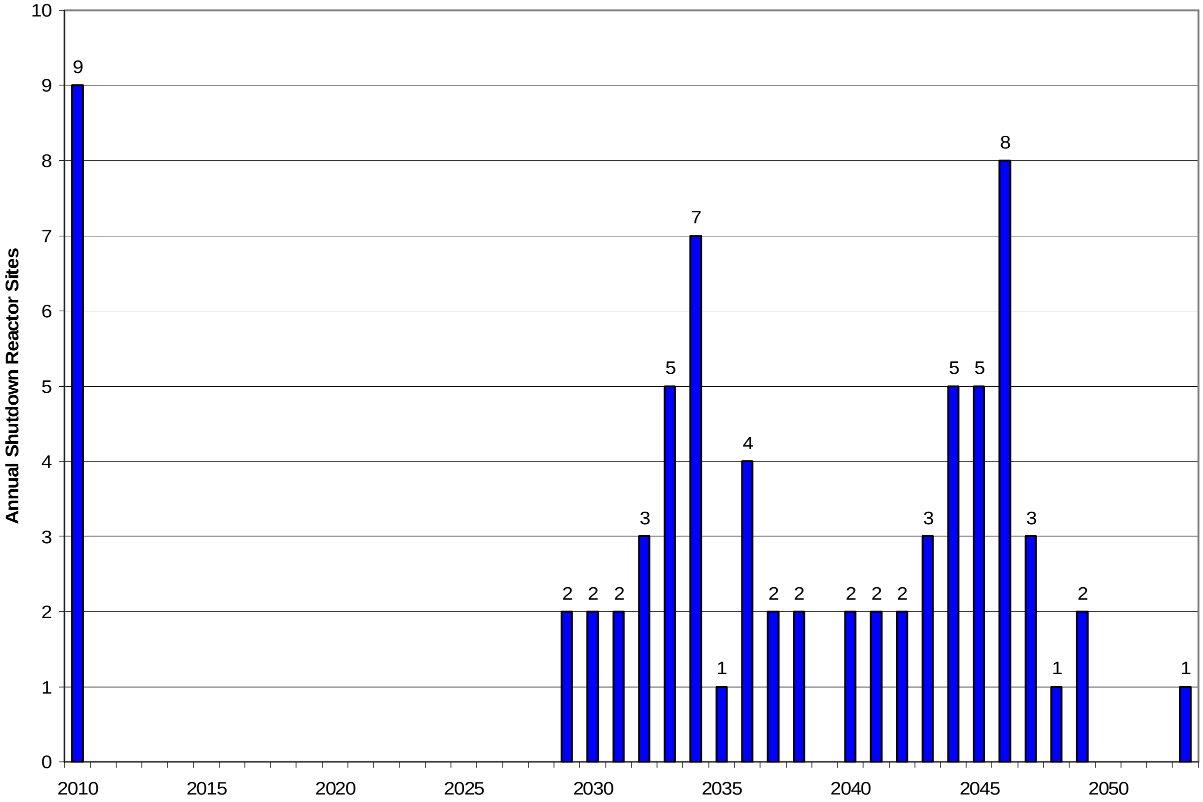


Figure 6.4 Number of Nuclear Power Plant Sites that are Shutdown Each Year [ERI Analysis, December 2010]

Figure 6.5 presents the cumulative inventory of SNF at shutdown nuclear power plant sites. The SNF inventories are included in the cumulative when the final unit at each site reaches the end of its operating license. For example, if the nuclear power plants at a two unit site reach the end of their extended operating licenses in 2034 and 2036, the inventories from these two plants would be added to the cumulative inventory in 2036. By approximately 2053, almost the entire 133,000 MTU of SNF will be stored at shutdown plant sites. As noted above, the SNF inventories assume that Watts Bar 2 will begin operating in 2014 – thus the SNF inventory for the Watts Bar site would not be added to the shutdown plant site inventory until Watts Bar 2 reaches the end of an extended operating license in 2074.

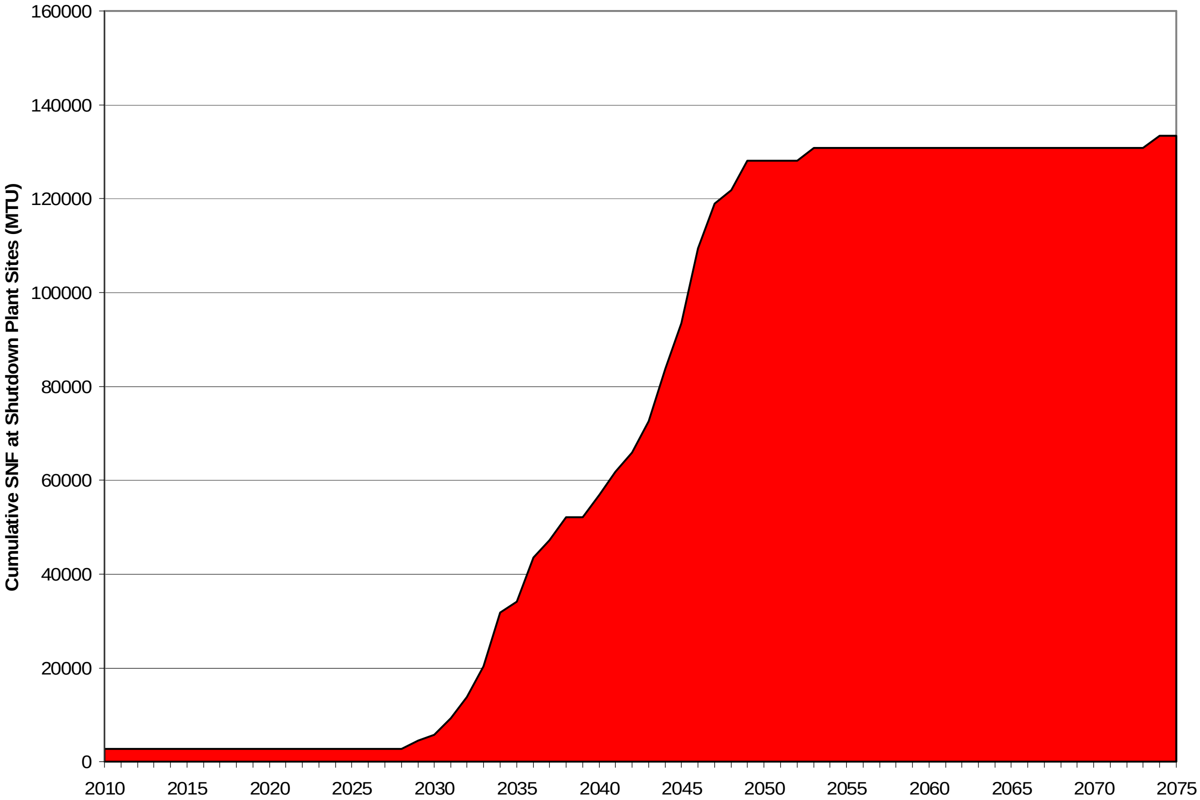


Figure 6.5 Cumulative SNF in Storage at Shutdown Nuclear Power Plant Sites [ERI Analysis, December 2010]

6.3.2 Scenario 2: Transport System Requirements

The following analysis assumes that one or more facilities for central management of SNF will be available by approximately 2029 to begin transport of SNF from shutdown nuclear power plant sites. This date was chosen to demonstrate that if central waste management facilities can be deployed prior to the large increase in shutdown site SNF inventories as shown by the steep curve in Figure 6.5, it may be possible to transport SNF from shutdown plant sites and allow the sites to be decommissioned without the need for indefinite long-term dry storage of SNF and the associated costs.

6.3.2.1 Scenario 2a: SNF Shipped From Shutdown Sites Within 5 Years

The first shutdown plant site SNF transport scenario examined assumes that SNF will be shipped from each shutdown nuclear power plant site within five years of the final plant reaching the end of its operating license. If the nuclear power plants at a two unit site reach the end of their extended operating licenses in 2034 and 2036, the SNF inventories at this site will be transported to a central waste management facility by 2041. SNF at the existing shutdown plant sites that were identified in Table 6.1 is assumed to be transported beginning in 2029.

Assuming that all SNF is transported from shutdown nuclear power plant sites within 5 years of the final plant at each site reaching the end of its operating license, ERI calculated the amount of SNF that would have to be transported annually. As shown in Figure 6.6, the amount of SNF to be transported annually varies from several hundred MTU around 2030 to more than 10,000 MTU around 2049. The average amount of SNF that would be transported annually is approximately 6,000 MTU per year. The number of Shipping Sites on an annual basis varies from two to 24 sites, as shown in Figure 6.6. The average number of Shipping Sites is approximately 12.

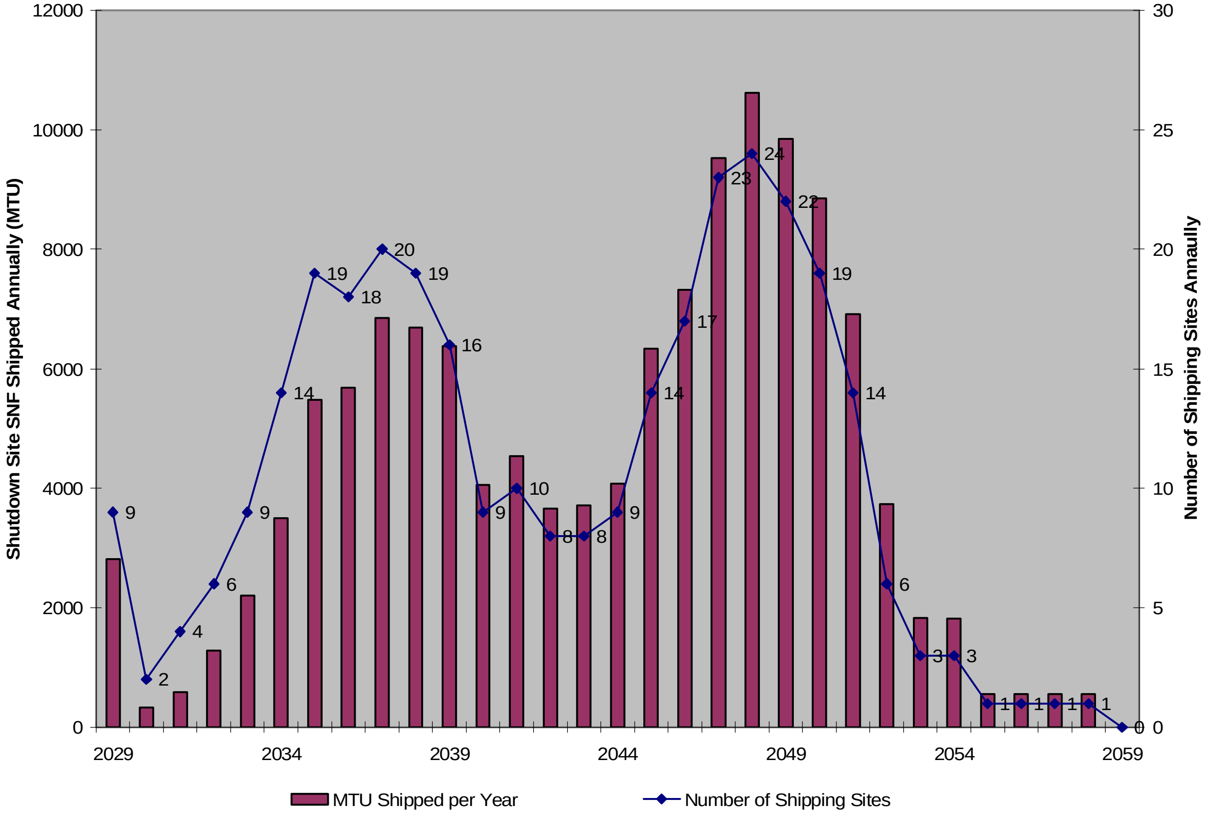


Figure 6.6 Annual SNF Transport Requirements Needed to Remove SNF from Shutdown Plant Sites Within Five Years of Site Shutdown [ERI Analysis, December 2010]

Figure 6.6 assumes that SNF would be transported after nuclear power plant sites shutdown. In order to operate an efficient transport system, it would be necessary to begin transport at some sites in advance of the final nuclear power plants shutting down. A SNF transport rate of 6,000 MTU is needed by approximately 2036, and the system would be required to maintain that annual rate of acceptance until approximately 2054 in order to remove SNF from shutdown plant sites approximately five years after the last plant at each site permanently ceases operation.

The equipment needed to transport loaded SNF casks from nuclear power plant sites to a central waste management facility include: rail casks and associated equipment, rail cars, rail locomotives, escort cars, and buffer cars. ERI estimated the cask fleet size based upon an annual transport rate of 6,000 MTU. ERI assumed a transport cask turnaround time of 10 weeks per rail cask. This conservatively assumes two weeks in transit to the Shipping Site, three weeks at the Shipping Site, two weeks in transport from the Shipping Site, and three weeks to unload the casks, perform cask maintenance and return the casks to service. Multiplying the cask capacity (11 MTU) by 52 weeks in a year and dividing by the cask turn-around time results in each transport cask being able to ship 57 MTU of SNF annually.

In addition, it is unlikely that one standard transport cask design can be used to transport the variety of dual-purpose systems that are expected to be used for onsite storage at nuclear power plant sites. Therefore, ERI assumed a 50% increase in the cask fleet size in order to address the fact that not all casks in the cask fleet can be deployed to any site for transport of SNF. Thus, if 6,000 MTU of SNF are transported annually using casks that can each transport 57 MTU of SNF annually, and applying a 50% increase for cask fleet inefficiencies, a fleet of 157 casks would be needed, as shown in Table 6.8.

Annual SNF Shipped (MTU)	**Cask Capacity (MTU)**	**Transport Cask Turn-Around Time (Weeks)**	**MTU Shipped Per Year by Cask (MTU/year/Cask)**	**Cask Fleet Size (# Casks)**
(a)	(b)	(c)	(d) = [(b)*52 weeks]/(c)	[(a)/(d)*1.5]
6,000	11	10	57	157

Table 6.8 Scenario 2a, Transportation Cask Fleet Assumptions, 6,000 MTU/Year

Table 6.9 presents the number of escort cars, buffer cars and locomotives needed to transport SNF to a central waste management facility, assuming that 6,000 MTU of SNF are transported annually. ERI assumed that each train will include: one locomotive, five SNF rail cars, two buffer cars, and an escort car. This means that there will be two buffer cars for every five rail cask cars, and one locomotive and one escort car for every five rail cask cars. Assuming 6,000 MTU shipped annually in casks with a capacity of 11 MTU per cask, results in a total of 545 cask shipments per year. If five casks are shipped in each rail shipment, the cask fleet could be used for as many as 32 rail shipments at any time. Rolling stock needed to support 32 rail shipments would include 157 rail cask cars, 64 buffer cars, 32 locomotives, and 32 escort cars, as shown in Table 6.9. There would also be additional cask shipments and transportation system requirements associated with the DOE owned SNF and HLW, GTCC waste, and GTCC-like waste, as described in Table 6.5.

Annual SNF Shipped (MTU)	Cask Capacity (MTU)	Rail Cask Fleet and Rail Cars	Buffer Cars	Locomotives	Escort Cars
6,000	11	157	64	32	32

Table 6.9 Scenario 2a, Transportation Rail Equipment Needs to Transport 6,000 MTU

6.3.2.2 Scenario 2b: SNF Shipped From Shutdown Sites Within 10 Years

The second scenario, Scenario 2b, associated with transport of SNF from shutdown plant sites assumes that SNF will be shipped from each shutdown nuclear power plant site within 10 years of the final plant at the site reaching the end of its operating license. If the nuclear power plants at a two unit site reach the end of their extended operating licenses in 2034 and 2036, the SNF inventories at this site will be transported to a central waste management facility by 2046. SNF at the existing shutdown plant sites that were identified in Table 6.7 is assumed to be transported beginning in 2029.

Assuming that all SNF is transported from shutdown nuclear power plant sites within 10 years of the final plant at each site reaching the end of its operating license, ERI calculated the amount of SNF that would have to be transported annually. As shown in Figure 6.7, the amount of SNF to be transported annually varies from several hundred MTU in approximately 2030 to more than 7,000 MTU in about 2049. The average amount of SNF that would be transported annually is approximately 5,000 MTU per year. The number of Shipping Sites on an annual basis varies from two to 33 sites, as shown in Figure 6.7. The average number of Shipping Sites over the period 2029 to 2064 is approximately 19.

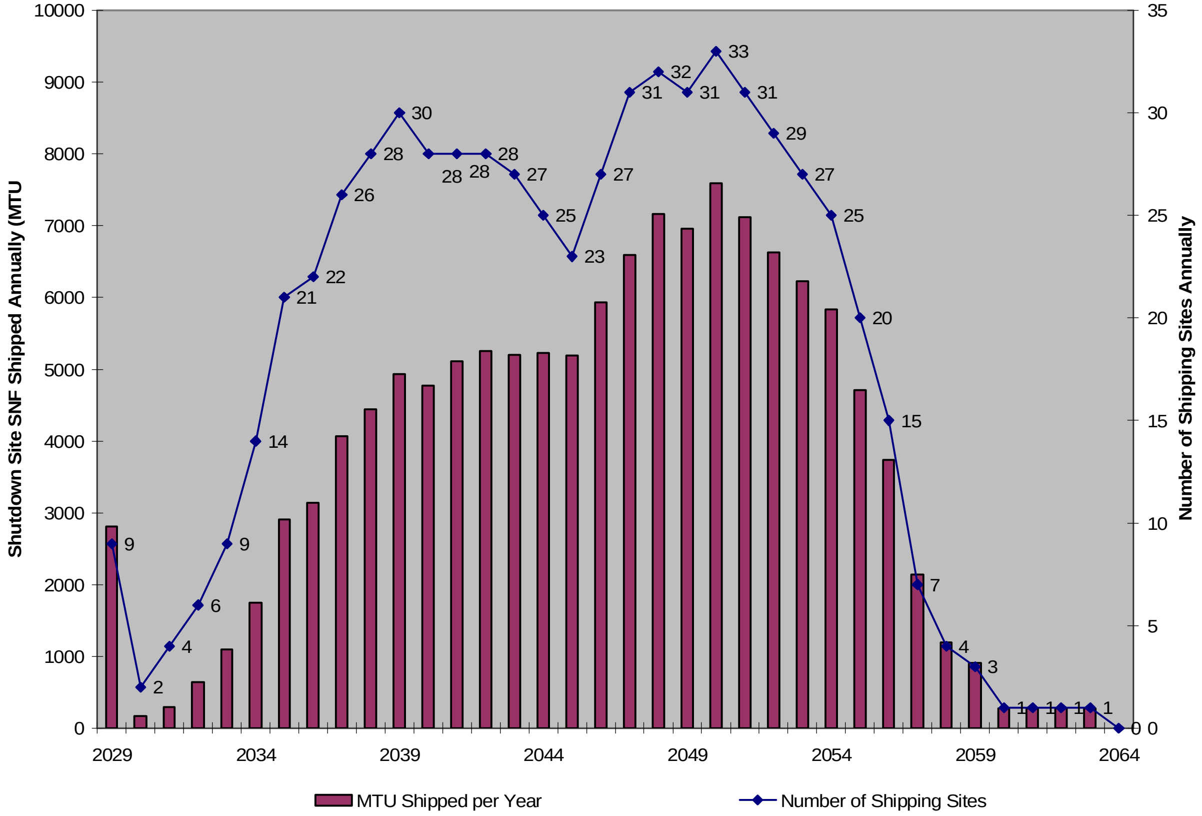


Figure 6.7 Annual SNF Transport Requirements Needed to Remove SNF from Shutdown Plant Sites Within 10 Years of Site Shutdown [ERI Analysis, December 2010]

Figure 6.7 assumes that SNF would be transported after nuclear power plant sites shutdown. In order to operate an efficient transport system, it would be necessary to begin transport at some sites in advance of the final nuclear power plants shutting down. A SNF transport rate of 5,000 MTU is needed by approximately 2038, and the system would be required to maintain that annual rate of acceptance until approximately 2059 in order to remove SNF from shutdown plant sites approximately 10 years after the last plant at each site permanently ceases operation.

ERI estimated the cask fleet size based upon an annual transport rate of 5,000 MTU. ERI again conservatively assumed a transport cask turnaround time of 10 weeks per rail cask. This assumes two weeks in transit to the Shipping Site, three weeks at the Shipping Site, two weeks in transport from the Shipping Site, and three weeks to unload the casks, perform cask maintenance and return the casks to service. Multiplying the cask capacity (11 MTU) by 52 weeks in a year and dividing by the cask turn-around time results in each transport cask being able to ship 57 MTU of SNF annually.

It is unlikely that one standard transport cask design can be used to transport the variety of dual-purpose systems that are expected to be used for onsite storage at nuclear power plant sites. Therefore, ERI assumed a 50% increase in the cask fleet size in order to address the fact that not all casks in the cask fleet can be deployed to any site for transport of SNF. Thus, if 5,000 MTU of SNF are transported annually using casks that can each transport 57 MTU of SNF annually, and applying a 50% increase for cask fleet inefficiencies, a fleet of 131 casks would be needed, as shown in Table 6.10.

Annual SNF Shipped (MTU)	**Cask Capacity (MTU)**	**Transport Cask Turn-Around Time (Weeks)**	**MTU Shipped Per Year by Cask (MTU/year/Cask)**	**Cask Fleet Size (# Casks)**
(a)	(b)	(c)	(d) = [(b)*52 weeks]/(c)	[(a)/(d)*1.5]
5,000	11	10	57	131

Table 6.10 Scenario 2b, Transportation Cask Fleet Assumptions, 5000 MTU/Year

Table 6.11 presents the number of cask cars, escort cars, buffer cars and locomotives needed to transport SNF to a central waste management facility assuming that 5,000 MTU of SNF are transported annually. ERI assumed that each train will include: one locomotive, five SNF rail cars, two buffer cars, and an escort car. This means that there will be two buffer cars for every five rail cask cars, and one locomotive and one escort car for every five rail cask cars. Assuming 5,000 MTU shipped annually in casks with a capacity of 11 MTU per cask, results in a total of 455 cask shipments per year. If five casks are shipped in each rail shipment, the cask fleet could be used for as many as 26 rail shipments at any time. Rolling stock needed to support 26 rail shipments would include 131 rail cask cars, 52 buffer cars, 26 locomotives, and 26 escort cars, as shown in Table 6.11.

Annual SNF Shipped (MTU)	**Cask Capacity (MTU)**	**Rail Cask Fleet and Rail Cars**	**Buffer Cars**	**Locomotives**	**Escort Cars**
5,000	11	131	52	26	26

Table 6.11 Transportation Rail Equipment Needs to Transport 5,000 MTU Annually

6.3.3 Logistical Issues Associated with Scenario 2

As illustrated by Scenario 2a and Scenario 2b, if SNF transport does not begin until 2029 or later, when currently operating nuclear power plants begin to reach the end of their extended operating licenses, a transport system of unprecedented capacity for the U.S. nuclear industry would have to be put in place to ensure that shutdown plant sites can be decommissioned without the need for indefinite long-term dry storage of SNF and the associated costs. Transport system capacities of 5,000 to 6,000 MTU per year would be needed to remove SNF from shutdown nuclear power plant sites within five to ten years of the last nuclear power plant at each site shutting down. As shown in Figure 6.5, by 2040, there would be more than 57,000 MTU in storage at shutdown plant sites. This would more than double by 2050, growing to 128,000 MTU of SNF.

Transporting 5,000 to 6,000 MTU of SNF on an annual basis for a 25 to 30 year duration has never been done before. Transporting 5,000 to 6,000 MTU per year would result in 450 to 550 cask shipments of commercial SNF per year, assuming cask capacities of 11 MTU, plus an approximate 251 cask shipment of other types of nuclear waste described in Table 6.1. While the U.S. has never transported this level of SNF and HLW annually, an additional 700 to 800 hazardous materials shipments should be able to be accommodated within the U.S. transportation system.

In order to move 5,000 to 6,000 MTU of SNF annually, the U.S would need a robust transportation management system to ensure that the transportation route planning, emergency response planning, and campaign planning are carried out in a safe and efficient manner. One possible benefit of focusing on the transport of SNF from shutdown nuclear power plant sites is that a relatively small number of sites would be shipping SNF on an annual basis. As shown in Figure 6.6, if it is assumed that SNF is shipped from shutdown plant sites within approximately five years of the site reaching shutdown site status, an average of 12 shutdown plant sites would be shipping SNF in any given year – with a maximum of 24 sites shipping SNF during the period 2047 through 2050. As shown in Figure 6.7, if it is assumed that SNF is shipped from shutdown plant sites within approximately 10 years of a site reaching shutdown site status, an average of 19 shutdown plant sites would be shipping SNF in any given year – with a maximum of 33 sites shipping SNF during the period 2047 through 2052. Servicing a smaller number of sites each year would allow transportation planning activities to focus on a smaller number of shipping campaigns, transportation routes and emergency planning.

Planning activities associated with transport of SNF to one or more central waste management facilities would have to begin nine to 12 years in advance of transport operations, as shown in Figure 6.3. This would include activities such as SNF transport cask design, certification and fabrication; design, testing, and fabrication of rolling stock; facility and near-site infrastructure assessments; route identification and approval, and emergency response training along approved routes.

As shown in Table 6.12, during the first five-year planning period, Years 1 through 5 of transport (in this case 2029 to 2033), there would be two to nine sites transporting SNF in any given year under Scenario 2a. An average of 1,450 MTU of SNF would be transported annually during that time period. During the second five-year planning period, there would be between 14 and 20 sites shipping SNF, with an average of 5,600 MTU shipped annually. By the third five-year planning period 8 to 16 sites would be shipping SNF, and an average of 6,000 MTU would be shipped annually. Transporting SNF from shutdown sites within five years of shutdown would result in the maximum steady-state rate of 6,000 MTU being reached before the second 5-year planning period, but the number of sites from which SNF in being transported any given year is lower than the number of sites in Scenario 2b.

SNF Shipping Scenario	**Transport Period Periods**				
	Years 1-5	**Years 6-10**	**Years 11-15**	**Years 16-20**	**Years 21-25**
Scenario 2a					
SNF Shipped within 5 Years					
# Sites Shipping During Period	2 - 9	14-20	8 -16	9 24	3 - 22
Average MTU Shipping Annually	1,450	5,600	6,000	6,000	6,000
Scenario 2b					
SNF Shipped within 10 Years					
# Sites Shipping During Period	2 - 9	14 - 28	27 - 30	23 - 32	27 - 33
Average MTU Shipping Annually	1,000	3,300	5,000	5,000	5,000

Table 6.12 Estimated Number of Shipping Sites and Average Amount of SNF Shipped for 5-Year Planning Periods

Under Scenario 2b, during the first five-year planning period, there would be two to nine sites transporting SNF in any given year with average annual shipments of 1,000 MTU. During the second five-year planning period, there would be between 14 and 28 sites shipping SNF, with an average of 3,300 MTU shipped annually. By the third five-year planning period 27 to 30 sites would be shipping SNF, and an average of 5,000 MTU would be shipped annually. Thus, spreading the shipment of SNF from shutdown sites over a longer time period (e.g., 10 years) results in the maximum steady-state rate of 5,000 MTU being reached during the third 5-year planning period, but there are a greater number of sites that ship SNF in any given year , compared to Scenario 2a.

6.3.4 Technical Issues Associated with Scenario 2

As discussed in Section 4.3.5, if a central waste management facility is available by approximately 2029 and SNF is transported from shutdown nuclear power plant sites, transportation system planning and transport cask designs may need to be adjusted to account for cooling time of the SNF when it is transported.

Nuclear operating companies are loading high burnup, short-cooled SNF into dual-purpose storage technologies with high package heat loads for onsite storage. Many of these storage systems are certified to allow high heat load SNF to be stored with as little as five years of cooling. In contrast, the allowable total package heat loads for transporting these same dual-purpose technologies are lower than the allowable heat loads for storage. This means that a high burnup SNF assembly may be qualified for storage in a DPC after it has cooled for five years, but that same assembly may not be able to be transported in that DPC until it has cooled for a longer time period – possibly for 10 to 15 years.

If commercial SNF from shutdown nuclear power plant sites can be transported within five to ten years of the last plants at each site permanently ceasing operation, it is possible that 20% or more of the commercial SNF inventory from shutdown plants would need to be transported with cooling times of ten years or less. This would include SNF from the final reactor core and the last several discharge batches of SNF. In order to transport this high burnup, shorter cooled SNF, lower capacity transport casks would need to be designed, certified and manufactured. Alternatively, current dual-purpose technologies could be derated, but nuclear operating companies would have to be notified well in advance of loading these systems for storage.

As shown in Table 6.13, assuming that 20% of the commercial SNF inventory, or approximately 26,600 MTU, is transported in casks with a 30% lower capacity (e.g., 8 MTU instead of 11 MTU), this would result in an increase of 866 cask shipments over a 30 to 35 year transport period. The annual increase in cask shipments would be an increase of 25 to 30 cask shipments per year for the Scenario 1b and Scenario 1a, respectively.

Transport Cask Capacity	**20% of SNF Inventory (MTU)**	**Number of Cask Shipments**
11 MTU	26,000	2,364
8 MTU	26,000	3,250
Total Increase in Cask Shipments		866
Annual Increase in Cask Shipments		25 - 30

Table 6.13 Impact of Reduced Transport Cask Capacity on Number of SNF Shipments

6.4 Other Transport Considerations

Scenario 1 and Scenario 2 were used to calculate the requirements for transportation equipment assuming that commercial SNF, DOE-owned SNF, HLW, GTCC waste and GTCC-like waste are transported only once to a central waste management facility, such as a repository. If commercial SNF and other wastes are transported to one or more interim storage facilities for storage and later transported to a repository, the total number of shipments would double. If a repository began operation while the interim storage facility was also receiving waste, this could double the number of shipments that occur in some years.

A more likely scenario would be for one or more interim storage facilities to accept nuclear waste materials, store those materials for some period of time, and later ship those waste materials to a repository for disposal. Under these conditions, the number of waste shipments estimated for Scenario 1 and Scenario 2 would occur a second time when the waste is transported to a repository for disposal. Depending upon the status of the 10CFR71 CoCs associated with the cask designs that make up the casks in the fleet that are used to transport nuclear waste materials to interim storage, it may be necessary to procure and fabricate a new cask fleet if the package certifications can no longer be renewed.

6.5 Summary of Non-Reprocessing Scenarios

ERI evaluated two scenarios for transport of the 18,833 casks of commercial SNF, DOE owned SNF and HLW, GTCC waste, and GTCC-like waste identified in Table 6.1. Scenarios 1a and 1b assume that SNF is transported based on an OFF priority ranking and Scenarios 2a and 2b assume that SNF is transported from shutdown nuclear power plant sites once the last plant at each site reaches the end of its operating license. All scenarios assume that existing plants will operate under extended licenses for 60 year license terms.

Scenarios 1a and 1b assume SNF is transported from nuclear power plant sites to a central waste management facility in accordance with an OFF priority ranking at two overall steady state acceptance rates, 3,000 MTU and 6,000 MTU per year, respectively. A transport system that is designed to transport 3,000 MTU per year will take approximately 47 years to remove 130,000 MTU of SNF from commercial nuclear power plant sites in 11,800 cask shipments. On average 58 nuclear power plant sites would be shipping SNF on an annual basis if SNF were shipped from sites based on an OFF priority ranking. As summarized in Table 6.14, at the steady-state rate of 3,000 MTU per year, approximately 423 cask shipments would be required annually (272 cask shipments of commercial SNF plus 151 cask shipments of other nuclear waste materials). Assuming that these shipments would take place by rail, this would result in 87 rail shipments with five casks per shipment on an annual basis. A cask fleet of approximately 111 casks would be needed to transport commercial SNF, DOE owned SNF and HLW, GTCC waste and GTCC-like waste over this 47 year period.

A transport system that is designed to transport 6,000 MTU per year, assuming an OFF priority ranking, will take approximately 28 years to remove 130,000 MTU from commercial nuclear power plant sites in 11,800 cask shipments. On average 61 nuclear power plant sites would be shipping SNF on an annual basis if SNF were shipped from sites based on an OFF priority ranking. As summarized in Table 6.14, at the steady-state rate of 6,000 MTU per year, approximately 796 cask shipments would be required annually (545 cask shipments of commercial SNF plus 251 cask shipments of other nuclear waste materials). Assuming that these shipments would take place by rail, this would result in 160 rail shipments with five casks per shipment on an annual basis. A cask fleet of approximately 210 casks would be needed to transport commercial SNF, DOE owned SNF and HLW, GTCC waste, and GTCC-like waste.

Scenario 2 assumes SNF is transported from shutdown nuclear power plant sites to a central waste management facility in accordance with SNF being transported once plants reach the end of their operating licenses and SNF has cooled for a minimum of five years. Scenario 2 examined two cases – one in which SNF is assumed to be shipped from each shutdown nuclear power plant site within five years of the final plant at each site reaching the end of its operating license, Scenario 2a. And a second case, Scenario 2b, assumes that SNF is shipped within ten years of the final plant at each site reaching the end of its operating license.

Under Scenario 2a, an average of 6,000 MTU of SNF must be transported on an annual basis over an approximately 28 year period in order to remove SNF from shutdown plant sites within five years following shutdown of the last plant on each site. The number of sites that would be shipping SNF on an annual basis varies from two to 24 sites, with an average of 12 shutdown plant sites shipping SNF annually. As summarized in Table 6.14, assuming a steady-state rate of 6,000 MTU of SNF transported annually, approximately 796 cask shipments would be required annually (545 cask shipments of commercial SNF plus 251 cask shipments of other nuclear waste materials). Assuming that these shipments would take place by rail, this would result in 160 rail shipments with five casks per shipment on an annual basis. A cask fleet of approximately 210 casks would be needed for transport of nuclear waste materials over this period.

Under Scenario 2b, an average of 5,000 MTU of SNF must be transported on an annual basis over an approximate 35 year period in order to remove SNF from shutdown plant sites within ten years following shutdown of the last plant on each site. The number of sites that would be shipping SNF on an annual basis varies from two to 33 sites, with an average of 19 shutdown plant sites shipping SNF annually. As summarized in Table 6.14, assuming a steady-state rate of 5,000 MTU of SNF transported annually, approximately 656 cask shipments would be required annually (455 cask shipments of commercial SNF plus 201 cask shipments of other nuclear waste materials). Assuming that these shipments would take place by rail, this would result in 133 rail shipments with five casks per shipment on an annual basis. A cask fleet of approximately 170 casks would be needed to transport nuclear waste materials over this period.

Scenario Description	# Years To Transport Waste Inventory	Maximum Annual MTU Shipped	Number Cask Shipments per Year	Number of Rail Shipments per Year	Average Number of Sites Shipping Per Year	Cask Fleet Size
1a: OFF Priority, 3000 MTU	47	3,000	423	87	58	111
1b: Off Priority, 6000 MTU	28	6,000	796	160	63	210
2a: Shutdown plant priority, SNF removed with 5 years of site shut down	28	6,000	796	160	12	210
2b: Shutdown plant priority, SNF removed with 10 years of site shut down	35	5,000	656	133	19	170

Table 6.14 Summary of Transportation Parameters for SNF Transportation Scenarios

As shown in Table 6.14, a SNF transportation system that accepts SNF based on an OFF priority ranking, such as Scenarios 1a and 1b, may result in an average of 58 to 63 nuclear power plant sites shipping SNF on an annual basis. In contrast, a SNF transportation system that accepts SNF assuming priority for transport of SNF from shutdown nuclear power plant sites, such as Scenarios 2a and 2b, may result in an average of 12 to 19 nuclear power plant sites shipping SNF on an annual basis. Whether the transportation system is designed to transport 3,000 MTU per year over a 47 year planning period or 6,000 MTU per year over a 28 year period, the U.S. has not transported these large quantities of SNF in the past on an annual basis. A total of 423 to 796 cask shipments would be made annually, assuming 3,000 MTU or 6,000 MTU annual acceptance, respectively. Assuming that SNF, HLW and other waste is shipped via rail with five casks per rail shipment, this results in only 87 to 160 rail shipments annually. As noted in Section 6.2, the U.S. transports several hundred million packages of hazardous materials annually. The transport of an additional 400 to 800 hazardous materials packages annually, or 87 to 160 rail shipments annually, should be able to be accommodated within the transportation system.

Under both Scenario 1 and Scenario 2, between 3,000 MTU and 6,000 MTU of SNF would be transported annually – thus a robust transportation management system would be necessary to ensure that transportation route planning, emergency response planning and transportation campaign planning would be carried out in a safe and efficient manner. However, the transportation planning associated with transport of SNF from an average of 58 to 63 sites annually would be more complex than a system that must transport SNF from an average of 12 to 19 sites annually.

While a transport system based on OFF priority ranking appears to be less efficient than one based on priority for transport of SNF from shutdown reactor sites, it should be recognized that nuclear operating companies can utilize their OFF acceptance rights to ship SNF from any of their nuclear power plant sites. In order to ship SNF from nuclear power plant sites more efficiently and minimize the impact on their own nuclear power plant operations, it is reasonable to expect that a nuclear operating company would utilize its SNF acceptance rights to ship larger quantities of SNF in campaigns from selected nuclear power plant sites rather than shipping small quantities from each site annually. Whether priority for transport of SNF is based on OFF or some other methodology, it is clear that there would be system efficiencies if SNF is transported from nuclear power plant sites in shipping campaigns that allow resources associated with route planning and emergency response training along routes to be done in an efficient manner.

If the transport campaigns associated with transport of SNF under Scenario 2, which assumes priority for shutdown nuclear power plants, take longer than the five to ten years assumed in Scenarios 2a and 2b, respectively, then the result will be a less efficient transport system. Longer shipping campaigns will result from either shipping beginning later in time or the size of the transport system not being large enough. If, for example, SNF transport campaigns from shutdown nuclear power plant sites are designed such that all SNF will be transported from these sites over a 20 year period from the time when the last plant on a site reaches the end of its operating license (rather than over a 10 year period as in Scenario 2b), then an average of 40 shutdown plant sites would be transporting SNF on an annual basis (rather than average of 19 sites per year in Scenario 2b). Thus, the improved efficiency of the transport campaigns in Scenario 2 relative to Scenario 1 are due in large part to the assumptions regarding when shipping of SNF from shutdown plant sites will begin (i.e., 2029, prior to shutdown of currently operating nuclear power plants) and the high steady state acceptance rate of 5,000 to 6,000 MTU per year. This results in the relatively small number of shutdown sites that are shipping SNF during the short shipping campaign durations (e.g., 5 and 10 years) that have been assumed in these scenarios.

6.5 Transport Associated with Reprocessing

If commercial SNF is transported for reprocessing and recycle, reprocessing waste streams would have to be transported for disposal. These are likely to include HLW and GTCC waste that would result from processing of the irradiated fuel assembly hardware. These shipments would be in addition to the shipments of fuel to the reprocessing facility, which would be the same as those calculated above for shipments of fuel to a repository or storage facility.

As noted in Section 2.1.2, processing 800 MTU of commercial SNF per year would result in 560 canisters of vitrified HLW, 560 canisters of irradiated fuel assembly hardware which would be classified as GTCC waste, and other LLW. [AFS 2009] TN International has two casks for transport of HLW, the TN-81 and TN-85. These HLW transport casks can transport 28 canisters of HLW. Thus, the 560 canisters of HLW and 560 canisters of GTCC waste produced annually could be transported for disposal in 40 TN-85 transport cask shipments, as shown in Table 6.15. [Areva 2007]

Assuming that a reprocessing facility had a 3,000 MTU per year, ERI estimated the number of annual HLW shipments that would result from the reprocessing of 3,000 MTU of commercial SNF per year using the above assumptions. A total of 2,100 canisters of vitrified HLW and 2,100 canisters of irradiated hardware (GTCC waste) would result from reprocessing 3,000 MTU of SNF annually. Assuming that a transport canister with a capacity to transport 28 HLW or GTCC waste canisters, results in 150 cask shipments of HLW and GTCC waste annually. This would require an estimate cask fleet size of 20 casks, if a seven week cask turnaround time is assumed. This assumes that the shipments will take place between one reprocessing facility transporting HLW and GTCC waste to a single repository.

Annual Reprocessing Throughput (MTU/Year)	Canisters of HLW	Canisters of GTCC Waste	HLW & GTCC Waste Cask Shipments Per Year	Estimated Cask Fleet
800	560	560	40	6
3,000	2,100	2,100	150	20

Table 6.15 Estimated Shipments of HLW from Reprocessing and Estimated Cask Fleet Size

Assuming a cask fleet size of 20 casks and five casks per rail shipment, would result in the need for the following rail equipment: 20 rail cask cars, eight buffer cars, four escort cars, and four locomotives.

As indicated above, the 150 cask shipments per year and the associated equipment would be in addition to the cask shipments calculated for commercial SNF in Scenario 1a and 2b, above, which under such a scenario would have been used to transport the SNF from the nuclear power plant sites to the reprocessing facility.

7. SUMMARY OF OBSERVATIONS AND CONSIDERATIONS REGARDING TRANSPORT OF SNF AND HLW

This Section provides a summary of observations and considerations associated with the development of a large-scale, national program to transport SNF and HLW for central interim waste management and/or disposal. This includes a summary of the materials that will require transport, technical issues that may need to be addressed, transportation planning activities and timelines, logistical issues associated with transport, and a summary of observations regarding the transportation scenarios presented in Section 6.

7.1 Quantities of Waste Materials to be Transported

As summarized in Section 2.1, approximately 64,000 MTU of SNF has been discharged from U.S. nuclear power plants as of December 31, 2010, and is in storage awaiting permanent disposal. Assuming that the 104 presently operating nuclear power plants continue to operate under extended licenses for 60 years each, then the total SNF inventory is projected to reach approximately 133,000 MTU by 2055. ERI estimates that approximately 11,800 dry storage systems would be needed to store the entire 133,000 MTU inventory of SNF. Since the majority of nuclear operating companies are utilizing high-capacity dual-purpose storage and transport casks for onsite dry storage, ERI estimates that there will be approximately 11,800 cask shipments of commercial SNF.

The West Valley Demonstration Project generated 275 canisters of HLW. Assuming that five canisters of HLW can be transported in a rail cask, it is estimated that 55 rail cask shipments will be needed to transport HLW from the West Valley site. [Bower 2008, DOE 2008a]

Shutdown nuclear power plant sites have loaded GTCC waste into canister-based systems that are similar to the DPC systems used for onsite storage of SNF. It is estimated that approximately 398 rail cask shipments of commercial GTCC waste will be needed to transport this material from nuclear power plant sites. [Joyce 2008]

There are approximately 2,500 MTHM of DOE-owned SNF that will require permanent disposal. [DOE 2002b] DOE estimates that a total of 784 rail cask shipments will be needed to remove DOE-owned SNF from DOE sites. [DOE 2008a]

DOE expects that the HLW from SRS, INL and Hanford will be stored in approximately 22,600 canisters. [DeLeon 2009] Assuming that 5 canisters of HLW can be transported in a rail cask, it is estimated that 4,520 rail cask shipments will be needed to transport HLW for eventual disposal. [DOE 2008a]

If DOE GTCC-like waste is packaged in canisters similar to those used for onsite storage of commercial SNF, it is estimated that approximately 816 cask shipments of GTCC-like waste would be needed to transport this material from DOE sites. Other GTCC waste that does not originate from commercial nuclear power plants or DOE sites would require approximately 460 cask shipments to transport this waste material for disposal. [Joyce 2008]

7.2 Transportation Technical Issues

As discussed in more detail in Section 4.3, there are a number of technical issues that must be addressed before embarking on a nation-wide program to transport SNF from commercial nuclear power plant sites to a central facility for storage, disposal or reprocessing. SNF from commercial nuclear power plants is expected to be stored primarily in large-capacity dual purpose dry storage systems. Technical issues that may need to be addressed in order to transport this SNF include resolution of regulatory issues associated with approval of full burnup credit to support the criticality safety analysis for SNF transport casks; transport of high-burnup SNF (e.g, burnups in excess of 45 GWD/MTU); confirmation of the condition of the SNF after extended storage of SNF; consideration of the need for a SNF cask testing program to support public acceptance of a nation-wide program to transport SNF; and transport of high-burnup, short-cooled SNF.

Regarding burnup credit for SNF transport casks, NRC has issued interim staff guidance that would allow partial burnup credit based on depletion of fissile uranium in SNF. However, in order to support the transport of high-capacity rail casks, the technical basis for full burnup credit must be developed to allow credit for the buildup of neutron-poisoning fission products in the SNF. While there has been progress on this issue over the past ten years, additional technical work must be completed to develop a validation approach that can be used as a basis for SNF criticality safety evaluations.

Average discharge burnups for PWR SNF have been in excess of 45 GWD/MTU since approximately 1999 and average discharge burnups for BWR SNF will be in excess of 45 GWD/MTU by approximately 2015. At the present time, NRC regulatory guidance only allows transport of high burnup SNF on a case-by-case basis. Until there is a generic approach for NRC certification of transport of high burnup SNF that does not require "case-by-case" approval, it may be difficult to design the type of large-scale transportation program that would be needed to sustain a federal waste management system.

With the prospect of SNF being stored at nuclear power plant sites for the foreseeable future, the nuclear industry, NRC and DOE are beginning to examine the issues associated with extended storage of SNF and deferred transportation after long-term storage. At some unknown time in the future, SNF will need to be transported away from nuclear power plant sites after extended wet or dry storage. It will be necessary to demonstrate that the SNF can be safely transported in accordance with NRC regulations. Dry storage safety related functions must be maintained during extended storage to ensure that SNF can later be transported. These safety functions include SNF thermal performance, radiological protection, confinement, sub-criticality, and ready retrievability. Continued coordination among the nuclear industry, through EPRI's Extended Storage Collaboration Program, NRC, DOE, and the national laboratories will be needed to address these long-term storage and transport issues.

NRC's Package Performance Study was a program that would have performed full scale demonstration tests on a NRC certified rail transport cask. The tests were to include sufficient instrumentation to collect data to validate analytical methods including scaling, and include a fully engulfing fire as part of the tests. While the Package Performance Study never proceeded due to delays in the DOE's Yucca Mountain program, consideration should be given to whether a SNF cask testing program of some nature should be performed prior to embarking on a long-term, nation-wide program to transport SNF. There may be continued benefit to collecting data through testing to validate analytical methods used in cask safety analyses. In addition, a cask testing program could have an additional benefit of boosting public confidence in transportation cask safety

If commercial SNF will be kept in long-term onsite storage, then it is likely that SNF will have sufficient cooling time to enable transport of the SNF in the large-capacity DPC systems that are currently being deployed for dry storage of SNF. However, if there is a need to transport high burnup, short-cooled SNF (e.g., SNF with 5 to 15 years of cooling) to a central waste management facility in the future, then it may be necessary to design a transport cask with a smaller capacity in order to be able to transport this SNF. Cask designers may be able to amend their transport cask designs to allow transport of shorter-cooled SNF. Current DPC designs may also be able to be derated – that is, the package would not be fully loaded prior to transport. If new transport casks are designed or existing packages are derated, package capacities may require reductions of 20% to 40% depending upon the transport package design and the SNF burnup and cooling time. The use of lower-capacity, or derated, transport casks would result in the need for a greater number of SNF casks to be transported. These lower capacity systems would not be necessary for the entire inventory of SNF since much of the SNF will have cooled for many decades prior to transport. Advance planning will be needed to transport high burnup, short-cooled SNF to ensure that nuclear operating companies have been notified well in advance of loading DPC systems for onsite storage.

7.3 Transportation Planning Considerations

Section 5 summarized the institutional interactions associated with planning a large-scale, long-term transportation program for transport of SNF and HLW. Such planning efforts will require the assessment of facility and near-site infrastructure requirements; interactions between the shipper and State, Tribal and local governments regarding near-site and national route planning; emergency response training; and regional and national transportation campaign planning.

As discussed in more detail in Section 5.2, well in advance of embarking on a large-scale, nation-wide transportation program, facility and near-site infrastructure assessments will need to be performed to assess: existing infrastructure at nuclear power plant sites and DOE sites to handle transportation cask and associated equipment; and the capability of rail lines, roads, bridges, and other infrastructure near sites to accommodate rail shipments. These infrastructure assessments would be necessary to develop site-specific transportation campaign plans for each commercial nuclear power plant site and each DOE site. These site-specific plans would identify each step in the process needed to complete transport of SNF from sites where SNF and HLW are currently stored to a central waste management facility.

As discussed in more detail in Section 5.3, well in advance of the start of transportation operations, the shipper will need to begin interactions with State, Tribal and local governments regarding near-site and national route planning, emergency response training, and transportation campaign planning. These interactions will also need to address issues associated with security of SNF while in transit, communications and information access, transportation safety and risk assessment, and protection of workers and the public. State regional groups estimate that transportation planning should begin nine to 12 years in advance of a national-wide transportation program.

7.4 Observations Regarding Transportation Scenarios Evaluated

In Section 6, ERI evaluated two scenarios for transport of the 18,833 casks of commercial SNF, DOE owned SNF and HLW, GTCC waste, and GTCC-like waste. Scenarios 1a and 1b assume that SNF is transported based on an OFF priority ranking and Scenarios 2a and 2b assume that SNF is transported from shutdown nuclear power plant sites once the last plant at each site reaches the end of its operating license. All scenarios assume that existing plants will operate under extended licenses for 60 year license terms.

Scenarios 1a and 1b assume SNF is transported from nuclear power plant sites to a central waste management facility in accordance with an OFF priority ranking at two overall steady state acceptance rates, 3,000 MTU and 6,000 MTU per year, respectively. A transport system that is designed to transport 3,000 MTU per year will take approximately 47 years to remove 130,000 MTU of SNF from commercial nuclear power plant sites in 11,800 cask shipments. On average 58 nuclear power plant sites would be shipping SNF on an annual basis if SNF were shipped from sites based on an OFF priority ranking. A transport system that is designed to transport 6,000 MTU per year, assuming an OFF priority ranking, will take approximately 28 years to remove 130,000 MTU from commercial nuclear power plant sites in 11,800 cask shipments. On average 61 nuclear power plant sites would be shipping SNF on an annual basis if SNF were shipped from sites based on an OFF priority ranking.

Scenarios 2a and 2b assume SNF is transported from shutdown nuclear power plant sites to a central waste management facility in accordance with SNF being transported once plants reach the end of their operating licenses and SNF has cooled for a minimum of five years. Scenario 2a assumes that SNF is shipped from each shutdown nuclear power plant site within five years of the final plant at each site reaching the end of its operating license. Scenario 2b assumes that SNF is shipped within ten years of the final plant at each site reaching the end of its operating license.

Under Scenario 2a, an average of 6,000 MTU of SNF must be transported on an annual basis over an approximately 28 year period in order to remove SNF from shutdown plant sites within five years following shutdown of the last plant on each site. The number of sites that would be shipping SNF on an annual basis varies from two to 24 sites, with an average of 12 shutdown plant sites shipping SNF annually. Under Scenario 2b, an average of 5,000 MTU of SNF must be transported on an annual basis over an approximate 35 year period in order to remove SNF from shutdown plant sites within ten years following shutdown of the last plant on each site. The number of sites that would be shipping SNF on an annual basis varies from two to 33 sites, with an average of 19 shutdown plant sites shipping SNF annually.

A SNF transportation system that accepts SNF based on an OFF priority ranking, such as Scenarios 1a and 1b, may result in an average of 58 to 63 nuclear power plant sites shipping SNF on an annual basis. In contrast, a SNF transportation system that accepts SNF assuming priority for transport of SNF from shutdown nuclear power plant sites, such as Scenarios 2a and 2b, may result in an average of 12 to 19 nuclear power plant sites shipping SNF on an annual basis. Scenarios 2a and 2b assume that SNF acceptance at a central waste management facility begins by 2029, when currently operating nuclear power plants begin to reach the end of their extended operating licenses. If a central waste management facility is not available to transport by 2029 or shortly thereafter, it will be more difficult to design a SNF transport system that could efficiently transport SNF from shutdown nuclear power plant sites within five or 10 years of the nuclear power plants reaching the end of their operating licenses.

Under both Scenario 1 and Scenario 2, between 3,000 MTU and 6,000 MTU of SNF would be transported annually – thus a robust transportation management system would be necessary to ensure that transportation route planning, emergency response planning and transportation campaign planning would be carried out in a safe and efficient manner. However, the transportation planning associated with transport of SNF from an average of 58 to 63 sites annually would be more complex than a system that must transport SNF from an average of 12 to 19 sites annually.

While a transport system based on OFF priority ranking appears to be less efficient than one based on priority for transport of SNF from shutdown reactor sites, it should be recognized that nuclear operating companies can utilize their OFF acceptance rights to ship SNF from any of their nuclear power plant sites. In order to minimize the impact on their own nuclear power plant operations, it is reasonable to expect that a nuclear operating company would utilize its SNF acceptance rights to ship larger quantities of SNF in campaigns from selected nuclear power plant sites rather than shipping small quantities from each site annually. Whether priority for transport of SNF is based on OFF or some other methodology, it is clear that there would be system efficiencies if SNF is transported from nuclear power plant sites in shipping campaigns that allow resources associated with route planning and emergency response training along routes to be done in an efficient manner.

If the transport campaigns associated with transport of SNF under Scenario 2 take longer than the five to ten years assumed in Scenarios 2a and 2b, respectively, then the result will be a less efficient transport system. Longer shipping campaigns will result from either shipping beginning later in time or the limitations on the amount of SNF that can be shipped on an annual basis. If, for example, SNF transport campaigns from shutdown nuclear power plant sites are designed such that all SNF will be transported from these sites over a 20 year period from the time when the last plant on a site reaches the end of its operating license (rather than over a 10 year period as in Scenario 2b), then an average of 40 shutdown plant sites would be transporting SNF on an annual basis (rather than an average of 19 sites per year in Scenario 2b). Thus, the improved efficiency of the transport campaigns in Scenario 2 relative to Scenario 1 is due in large part to the assumptions regarding when shipping of SNF from shutdown plant sites will begin (i.e., 2029, prior to shutdown of currently operating nuclear power plants) and the high steady state acceptance rate of 5,000 to 6,000 MTU per year. This results in the relatively small number of shutdown sites that are shipping SNF each year during the short shipping campaign durations (e.g., 5 and 10 years) that have been assumed in these scenarios.

REFERENCES

AAR 2003, Association of American Railroads, *AAR Manual of Standards and Recommended Practices Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material*, Standard S-2043, Effective: May 1, 2003.

AFS 2009, Davidson, Dorothy, VP Strategic Programs, Areva Federal Services (AFS) LLC, presentation to the U.S. Nuclear Waste Technical Review Board, September 23, 2009.

Ammerman 2003, Douglas J. Ammerman et al., Sandia National Laboratories, *Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk*, April 8, 2003.

Areva 2007, Blachet, L., C. Otton, D. Sicard, Areva TN International, *European Experience in Transport in Transport/Storage Cask for Vitrified Residue*, Waste Management Conference 2007, Tucson, Arizona, February 25-March 1, 2007.

ASME, 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.

Bower 2009, Bryan Bower, U.S. DOE, Office of Environmental Manager, Director – WVDP, DOE High-Level Waste Corporate Board Meeting, Savannah River Site, April 1, 2008

CSG 2006, Council of State Governments, Eastern Regional Conference, Northeast High Level Radioactive Waste Transportation Project, NE Task Force, *Rail Work Progress Report*, TEC Presentation - September 13, 2006.
http://www.csgeast.org/radwaste/resources

CSG 2009, Council of State Governments, Midwestern Office and the Midwestern Radioactive Materials Transportation Committee, *Planning Guide for Shipments of Radioactive Materials through the Midwestern States*, Revision 3B, December 2009

DeLeon 2009, Gary DeLeon, DOE, EM, Office of Nuclear Materials Disposition, *Status of DOE Spent Nuclear Fuel and High Level Waste,* Nuclear Waste Technical Review Board Meeting, June 11, 2009

DOE 2002a, U.S. DOE, DOE Transportation Risk Assessment Working Group Technical Subcommittee, Prepared for DOE National Transportation Program, *A Resource Handbook on DOE Transportation Risk Assessment*, DOE/EM/NTP/HB-01, July 2002

DOE 2002b, U.S. DOE, Office of Civilian Radioactive Waste Management, *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nevada,* DOE/EIS-0250F, February 2002.

DOE 2003a, U.S. DOE, *Strategic Plan for the Safe Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste to Yucca Mountain: A Guide to Stakeholder Interactions*, November 18, 2003.

DOE 2004a, U.S. DOE, *Departmental Materials Transportation and Packaging Management,* DOE Order 460.2A, Dec 22, 2004, https://www.directives.doe.gov

DOE 2005a, U.S. DOE, Office of Environmental Management, *Advance Notice of Intent To Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste*, FR/ Vol. 70, No. 90, May 11, 2005.

DOE 2006a, U.S. DOE, Office of Civilian Radioactive Waste management, *Transportation System Concept of Operations,* DOE/RW-0584, April 2006.

DOE 2008a, U.S. DOE, Office of Civilian Radioactive Waste Management, *Analysis of the Total System Life Cycle Cost (TSLCC) of the Civilian Radioactive Waste Management Program*, DOE/RW-0591, July 2008.

DOE 2008b, U.S. DOE, Office of Civilian Radioactive Waste Management, *Safe Routine Transportation and Emergency Response Training; Technical Assistance and Funding*, Notice of revised proposed policy and request for comments, Federal Register, Vol. 73, No. 212, October 31, 2008.

DOE 2008c, U.S. DOE, Office of Civilian Radioactive Waste Management, *Report from AREVA, NC Site Visit and Interview*, Spring 2007, March 2008

DOE 2009a, U.S. DOE, Office of Civilian Radioactive Waste Management, *National Transportation Plan*, DOE/RW-0603, Revision 0, January 2009.

DOE 2010a, U.S. DOE, *Packaging and Transportation Safety*, DOE Order 460.1C, May 14, 2010, https://www.directives.doe.gov

DOE 2010b, U.S. DOE, Office of Environmental Management, *Transportation Emergency Preparedness Program*, http://www.em.doe.gov/TEPPPages/TEPPHome.aspx

DOT 1992, U.S. DOT, Research and Special Programs Administration, *Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials*, DOT/RSPA/HMS/92-02, 1992.

DOT 1998a, U.S. DOT, Research and Special Programs Administration, Office of Hazardous Materials Safety, *Hazardous Materials Shipments*, October 1998.

DOT 1998b, U.S. DOT, Federal Rail Administration, *Safety Compliance Oversight Plan for Rail Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel*, August 25, 1998.

DOT 2008a, U.S. DOT, Pipeline and Hazardous Materials Safety Administration, *Radioactive Material Regulations Review*, December 2008.

DOT 2008b, U.S. DOT, et al, *Emergency Response Guidebook 2008, A Guidebook for First Responders During the Initial Phase of a Dangerous Goods/Hazardous Materials Transportation Incident*, http://www.phmsa.dot.gov/hazmat/library/erg

DOT 2008c U.S. DOT, PHMSA, *Hazardous Materials: Enhancing Rail Transportation Safety and Security for Hazardous Materials Shipments; Railroad Safety Enforcement Procedures; Enforcement, Appeal and Hearing Procedures for Rail Routing Decisions; Final Rules,* 49 CFR Parts 172, 174, 209, U.S. Federal Register, Vol. 73, No. 229, November 26, 2008.

DOT 2009a, U.S. DOT, U.S. Code of Federal Regulations,
Title 49, Transportation, Part 105, *Hazardous Materials Program Definitions and General Procedures,* Revised October 1, 2009

DOT 2009b, U.S. DOT, U.S. Code of Federal Regulations, Title 49, Revised October1, 2009:
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, *Transportation of Hazardous Materials, Driving and Parking Rules.*

DOT 2010a, U.S. DOT, PHMSA, Hazardous Materials Emergency Preparedness Grant Program, http://phmsa.dot.gov/hazmat/grants

DOT/NRC 1979, U.S. DOT, U.S. NRC, *Transportation of Radioactive Materials, Memorandum of Understanding*, 44 FR 38690, July 2, 1979.

EPA 1992, Environmental Protection Agency, *Vitrification Technologies for the Treatment of Hazardous and Radioactive Waste*, Handbook, EPA/625/R-92/002, May 1992.

EPRI 2004, Electric Power Research Institute, *Spent Nuclear Fuel Transportation, An Overview*, #1009226, February 2004.

EPRI 2010a, Electric Power Research Institute, *Industry Spent Fuel Storage Handbook*, # 102048, July 2010.

EPRI 2010b, Electric Power Research Institute, *Used Fuel and HLW Extended Storage Collaboration Program: November 2009 Workshop Proceedings*, #1020780, February 2010.

FEMA 2008a, Federal Emergency Management Agency, *National Incident Management System,* December 2008, http://www.fema.gov/emergency/nims/AboutNIMS.shtm

FEMA 2008b, Federal Emergency Management Agency, *National Response Framework, Nuclear/Radiological Incident Annex*, current as of June 2008. http://www.fema.gov/pdf/emergency/nrf/nrf_nuclearradiologicalincidentannex.pdf

HPA 2010, HPA Centre for Radiation, Chemical and Environmental Hazards, *Radiological Consequences Resulting from Accidents and Incidents Involving the Transport of Radioactive Materials in the U.K.,* 2009 Review, July 2010.

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

IAEA 2009, International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series No. TS-R-1*, 2009.

Janairo 2010, Lisa R. Janairo, Senior Policy Analyst, The Council of State Governments, Midwestern Office, November 2, 2010.

Jones 2004, Jay Jones, U.S. DOE, OCRWM, Office of National Transportation, "*Office of Civilian Radioactive Waste Management Update Presented to: High-Level Radioactive Waste Transportation Task Force, Eastern Regional Conference, Council of State Governments*, June 3, 2004.

Joyce 2008, James Joyce, U.S. DOE, Office of Environmental Management, email to Jane Summerson, U.S. DOE, OCRWM, S*ubject: Transmittal of Updated GTCC Inventory and TAD estimates*, March 13, 2008.

Lanthrum 2007, Gary Lanthrum, U.S. DOE, OCRWM, Office of Logistics Management, *Office of Logistics Management Transportation Strategic Plan*, Presented to the Nuclear Waste Technical Review Board, January 24, 2007

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

NCSL 2004, Jennifer A.D. Smith and James Reed, National Conference of State Legislatures, *Spent Fuel Transportation History, Status and State Involvement*, March 2004.

NCSL 2010, National Conference of State Legislatures, State Permits and Fees (annual) for the Transportation of Radioactive Materials, January 2010.
http://www.ncsl.org/default.aspx?tabid=13213

NNSA 2010, Regional Assistance Program, NNSA web site,
http://nnsa.energy.gov/aboutus/ourprograms/emergencyoperationscounterterrorism/respondingtoemergencies/firstresponders/radi

NRC 2000a, U.S. NRC, *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, Initial Report*, NUREG-1617, March 2000.

NRC 2002a, U.S. NRC, *Issuance of Orders Modifying Security Requirements*, RN-02-051, October 3, 2002. ML022760551.

NRC 2002b, U.S. NRC, Spent Fuel Project Office, *Interim Staff Guidance – 8, Rev. 2—Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks*," September 27, 2002.

NRC 2003a, U.S. NRC, Spent Fuel Project Office, *Interim Staff Guidance-11, Revision 3, Issue: Cladding Considerations for the Transportation and Storage of Spent Fuel*, November 17, 2003.

NRC 2003b, U.S. NRC, *U.S. Nuclear Regulatory Commission Package Performance Study Test Protocols*, Draft Report for Comment, NUREG-1768, February 2003.

NRC 2004a, U.S. NRC, *Options for Full-Scale Spent Nuclear Fuel Transportation Cask Testing Under the Package Performance Study*, SECY-04-0029, February 23, 2004.

NRC 2004b, U.S. NRC, *Options for Full-Scale Spent Nuclear Fuel Transportation Cask Testing Under the Package Performance Study*, Staff Requirements – SECY-04-0029, May 11, 2004.

NRC 2005a, U.S. NRC, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*, Regulatory Guide 7.9, Revision 2, March 2005.

NRC 2005b, U.S. NRC, *Details and Projected Cost of a Demonstration Test of a Full-Scale Spent Nuclear Fuel Rail Transportation Cask under the Package Performance Study*, SECY-05-0051, March 28, 2005.

NRC 2005c, U.S. NRC, . Staff Requirements – SECY-05-0051 - *Details and Projected Cost of a Demonstration Test of a Full-Scale Spent Nuclear Fuel Rail Transportation Cask under the Package Performance Study*, SECY-05-0051, June 9, 2005.

NRC 2009a, U.S. NRC, U.S. Code of Federal Regulations, Title 10, Part 71, *Packaging and Transportation of Radioactive Materials,* Revised October 1, 2009.

NRC 2009b, U.S. NRC, U.S. Code of Federal Regulations, Title 10, Part 73, *Physical Protection of Plants and Materials,* Revised October 1, 2009.

NRC 2009c, U.S. NRC, Memorandum from R.W. Borchardt, Proposed Rule: 10CFR 73.37, *Physical Protection of Irradiated Fuel in Transit* (RIN 3150-AI64), SECY-09-0162, October 31, 2009.

NRC 2009d, U.S. NRC, Memo from Commission Dale E. Klien, to Chairman Jaczko and Commissioner Svinicki, Subject: *Revisiting the Paradigm for Spent Fuel Storage and Transportation Regulatory Programs,* COMDEK-09-001, August 3, 2009.

NRC 2009e, U.S. NRC, U.S. Code of Federal Regulations, Title 10, Part 72, *Licensing Requirements for the Independent Storage of Spent Nuclear fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste,* Revised October 1, 2009.

NRC 2010a, U.S. NRC, *Public Information Circular for Shipments of Irradiated Reactor Fuel*, NUREG-0725, Rev 15, May 2010.

NRC 2010b, U.S. NRC, *Physical Protection of Irradiated Reactor Fuel in Transit*, 10CFR Part 73, Proposed Rule Federal Register, Vol. 75, No. 197, Page 62695-62716, October 13, 2010, RIN-3150-AI64 [NRC-2009-0163].

NRC 2010c, U.S. NRC, *Nuclear Materials Transportation Package Certification*, http://www.nrc.gov/materials/transportation/certification.html

NRC 2010d, U.S. NRC, Interim Staff Guidance Documents for NRC's Division of Spent Fuel Storage and Transportation, http://www.nrc.gov/reading-rm/doc-collections/isg/spent-fuel.html

NRC 2010e, U.S. NRC, Division 7, Transportation, Regulatory Guides, http://www.nrc.gov/reading-rm/doc-collections/reg-guides/transportation/rg/

NRC 2010f, U.S. NRC, *Revisiting the Paradigm for Spent Fuel Storage and Transportation Regulatory Programs*, Staff Requirements, COMDEK-09-0001- February 18, 2010.

NRC 2010g, U.S. NRC, *Project Plan for the Regulatory Program Review to Support Extended Storage and Transportation of Spent Nuclear Fuel*, COMSECY-10-0007, June 15, 2010.

NRC 2010h, U.S. NRC, *Public Information Circular for Shipments of Irradiated Reactor Fuel,* NUREG-0725, Rev. 15, May 2010.

NRC 2010i, Typical Spent Fuel Transportation Casks, http://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-trans-cask-system-2.pdf

ORNL 1992, Oak Ridge National Laboratory, *Facility Interface Capability Assessment (FICA) Summary Report*, ORNL/Sub/86-97393/7, May 1992.

OTA 1985, Office of Technology Assessment, U.S. Congress, Managing the Nation's Commercial High-Level Radioactive Waste, OTA-O-171, March 1985.

Parkyn 2006, John Parkyn, Private Fuel Storage LLC, *Interim Storage Update*, Midwest Council of State Governments, November 15, 2006

Pope 1991, R.B. Pope, M.W. Wankerl, Martin Marietta Energy Systems, Inc., Research Sponsored by the U.S. DOE, *Historical Overview of Domestic Spent Fuel Shipments - Update,* CONF-910435-60, Presented at the 1991 International High-Level Radioactive Waste Management Conference, April 28-May 3, 1991, Las Vegas, Nevada.

Pope 2001, Ronald B. Pope, Xavier Bernard-Bruls, M.T.M. Brittinger, *A Worldwide Assessment of the Transport of Irradiated Fuel and High-Level Waste*, 13th International Symposium on Packaging and Transportation of Radioactive Material, 2001.

Ramsey 2010, Ron Ramsey, CDP Project Manager, Idaho National Laboratory, *Calcine Disposition Project,* Presented To: The NWTRB Meeting, June 29, 2010.

Rutter 2004, Allan Rutter, U.S. DOT, Administrator, Federal Rail Administration, *Testimony regarding Transportation of Nuclear Waste,* Before the Subcommittee on Railroads, Committee on Transportation and Infrastructure, March 5, 2004.

SNL 2007, Sandia National Laboratories, *Greater-Than-Class C Low-Level Radioactive Waste and DOE Great-Than-Class C-Like Waste Inventory Estimates,* Prepared for the U.S. Department of Energy, Office of Environmental Management, July 2007.

Wagner 2009, John C. Wagner, Cecil V. Parks, Don E. Mueller, and Ian Gauld, Oak Ridge National Laboratory, *Review of Technical Studies in the United States in Support of Burnup Credit Regulatory Guidance*, International Workshop on Advances in Applications of Burnup Credit for Spent Fuel Storage, Transport, Reprocessing, and Disposition, Cordoba, Spain, October 27-30, 2009

WGA 2008, Western Governors' Association, *WIPP Transportation Safety Program Implementation Guide,* July 2008.

WNTI 2006, World Nuclear Transport Institute, *Radioactive Materials Transport, The International Safety Regime, An Overview of Safety Regulations and the Organisations Responsible for their Development,* WNTI Review Series No. 1, Revised July 2006.

ACRONYMS

AAR	Association of American Railroads
ASME	American Society of Mechanical Engineers
BWR	Boiling water reactor
CIQUIME	Centro de Información Química para Emergencias
CoC	Certificate of Compliance
CSG	Council of State Governments
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DOE EM	U.S. Department of Energy, Office of Environmental Management
DOE OCRWM	U.S. DOE, Office of Civilian Radioactive Waste Management
DOT	U.S. Department of Transportation
DPC	Dual-purpose canister
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERI	Energy Resources International, Inc.
FEMA	Federal Emergency Management Agency
FRA	Federal Railroad Administration
GTCC	Greater-than-Class C
GWD/MTU	Gigawatt-day per metric ton of uranium
GWe	Gigawatt-electric
HLW	High-level radioactive waste
HMEP	Hazardous Materials Emergency Preparedness
HMTA	Hazardous Materials Transportation Act
HRCQ	Highway route controlled quantity
IAEA	International Atomic Energy Agency
ICM	Interim Compensatory Measures
INPO	Institute for Nuclear Power Operations
ISFSI	Independent spent fuel storage installation
ISG	Interim Staff Guidance
INL	Idaho National Laboratory
LEPC	Local Emergency Planning Committees
LLW	Low-level radioactive waste

MOU	Memorandum of understanding
MTU	Metric ton of uranium
MWe	Megawatt-electric
NAS	National Academy of Sciences
NCSL	National Conference of State Legislatures
NIMS	National Incident Management System
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
NRIA	Nuclear/Radiological Incident Annex
NWMPAA	Nuclear Waste Policy Act, As Amended
OFF	Oldest fuel first
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment
OWT	Over-weight truck
PHMSA	Pipeline and Hazardous Materials Safety Administration
PPS	Package performance study
PWR	Pressurized water reactor
QA	Quality assurance
RAI	Request for additional information
RAP	Radiological Assistance Program
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SFST	U.S. NRC, Division of Spent Fuel Storage and Transportation
SNF	Spent nuclear fuel
SNL	Sandia National Laboratories
SRS	Savannah River Site
TAD	Transportation, aging and disposal canister
TEPP	Transportation Emergency Preparedness Program
TRANSSC	IAEA Transport Safety Standards Committee
TRU	Transuranic waste
WGA	Western Governors' Association
WNTI	World Nuclear Transport Institute