DEPARTMENT OF ENERGY SPENT NUCLEAR FUEL TRANSPORTATION SYSTEM CONCEPT FOR THE 21st CENTURY[1]

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ABSTRACT

The Department of Energy's (DOE) National Spent Nuclear Fuel Program (NSNFP), located at the Idaho National Engineering and Environmental Laboratory (INEEL), is chartered with the responsibility for developing a transportation system for the various spent nuclear fuels (SNF) owned by the Department. In accordance with the provisions of the Nuclear Waste Policy Act of 1982, as amended, the system must be licensed under the regulations of the US Nuclear Regulatory Commission (NRC). The transportation system components, commonly known as shipping casks, are expected to withstand extreme conditions of accidents while safely maintaining containment of the radioactive contents. The casks, some weighing as much as 150 tons when fully loaded, incorporate radiation shielding and must exhibit prescribed degrees of resistance to impacts due to high speed accidents, drops in various orientations from differing elevations, hydrocarbon fuel fire, and immersion under water. The casks are subjected to rigorous licensing proceedings and evaluations to ensure that the design and the methods of fabrication employed will result in a shipping cask that will safely contain the radioactive materials under all credible accident scenarios.

As opposed to SNF owned by commercial entities with small variations among their dimensions, fissile material and fission product concentrations, the DOE owns SNF of virtually every type ever produced for any purpose and, also, SNF that have been subjected to destructive testing or damaged by reactor accidents. Therefore the proposed system, in addition to satisfying the rigorous requirements imposed by the NRC, must also retain sufficient flexibility to accommodate the diversity of sizes, geometric configurations, fissile material and fission product concentrations found among the DOE SNF. This presentation describes the current status and objectives of the development of a system of transportation casks that meets these requirements yet provides sufficient flexibility to accommodate the diverse needs of the DOE.

INTRODUCTION

In accordance with the Nuclear Waste Policy Act of 1982, as amended, the disposition of spent nuclear fuel (SNF) and vitrified high-level waste (HLW) is one of the major tasks facing the Department of Energy (DOE) in the 21st century. The size of the task is truly awesome. The oft-cited TMI-2 damaged core transportation program pales by comparison. That program transported essentially one entire reactor core packaged into 49 shipments. By comparison, and depending on the mode of transportation used, the shipments to a central repository will carry the equivalent of well over a 1,000 reactor cores in shipments numbering in the several thousands.

A small, but highly complex, subset of this national inventory is the SNF in DOE Environmental Management's (EM's) custody. Although representing a small percentage of the total national inventory, the large variety of SNF in DOE-EM's custody represents the entire spectrum of nuclear fuels. Consequently, a transportation system designed specifically to accommodate the large variations of shapes, sizes, enrichments, and conditions of fuels is required for shipment of the fuels from the consolidation sites, DOE's Idaho National Engineering and Environmental Laboratory (INEEL), the Hanford Site (HS), and the Savannah River Site (SRS) to a repository.

In accordance with the provisions of a Memorandum of Agreement executed between DOE's Office of Civilian Radioactive Waste Management (OCRWM) and EM, it is EM's responsibility to provide a transportation system for DOE SNF. The National Spent Nuclear Fuel Program (NSNFP) was tasked with the responsibility to devise, design, and develop, as necessary, such a system for use by the consolidation sites. This presentation describes a transportation system concept developed by the NSNFP to safely transport DOE SNF from the consolidation sites to a central location or disposal facility.

The various constraints and requirements impacting the development of the transportation system concept and imposed by external elements and regulations are still evolving. Consequently, the design of the transportation system is also subject to changes in response to the evolution of the various external requirements and constraints. Although changes are anticipated, most are expected to be minor and restricted to dimensional alterations only; none of them are expected to alter or negate the concept presented here. Furthermore, in order to minimize complexities in licensing, the design of the transportation cask follows conventional philosophies in configuration, fabrication, materials, and fittings as well as the requirements and practices established by consensus codes.

In order to aid visualization, in addition to various drawings and illustrations prepared as part of this development, reduced scale models (1:18 and 1:87 scale) were also fabricated. The models were used for demonstration of the system concept and will continue to be used in the future as the consolidation sites are preparing their facilities, equipment, and procedures necessary for their respective shipment programs. Ultimately, the models may also be used as training aids for maintenance and operations personnel.

Cognizant personnel from throughout the DOE complex were requested to examine the concept with the objective of providing critical evaluations in an attempt to identify any SNF, either as bare assemblies or in canisterized form, that may have been overlooked during the development of the system. As of the date of this document, no SNF type has been identified that could not be safely transported by this system. Considering the transportation of damaged SNF to be the enveloping condition for all radioactive materials then, by extension of this argument, it is probably safe to hypothesize that, other than constraints due to size, there is no radioactive material in the domestic inventory that could not be safely transported by this system.

DESIGN OBJECTIVE

The design objective of the National Spent Nuclear Fuel Program (NSNFP) is to **devise an optimized system that will safely transport all spent nuclear fuel types in DOE-EM's inventory.**

This objective statement contains highly significant key words, in no specific order of importance the first of which is "**an optimized system.**" Devising a system for a specific fuel type is a relatively simple requirement. Devising a system for all fuel types, sizes, configurations, and enrichments is a challenge. This requires an intelligent compromise among the diverse requirements, and the resulting system, while ideal for a few of the nuclear fuel types, will only be adequate for all others. On the other hand, building unique systems for each of the fuels would be prohibitively costly in terms of the cost of licensing, acquisition, and in the complexities of handling gear and operations. The system concept described here is adequate for the transportation of all fuels in DOE's inventory. Although not always achieving the highest transportation efficiency, the most painstaking search of DOE's inventory failed to identify a single fuel type that could not be shipped by this system. The team working on the concept recognized in the early stages of development that in order to achieve an optimum, versatility must be a key aspect of the system. Accordingly, the cask has removable and interchangeable internal components, sometimes referred to as baskets, that can be custom-tailored to each specific fuel type or fuel container. These baskets can be changed out to meet a particular shipper's demands. The requirement for five different basket configurations have been identified to date, others are highly possible. The advantage of this approach is that, should the need arise to ship a previously unidentified material requiring the use of an internal basket different from those listed in the licensing documents, the cost of a full licensing review, estimated at several millions of dollars is avoided because, the resulting change can be accomplished by a relatively simple amendment to the cask's existing license. The resulting system may still not be ideal, but an acceptable compromise will have been achieved.

Another equally important set of key words is "**safely transport**." As noted elsewhere in this document, the transportation of SNF is conducted according to the regulations provided in Title 49, Part 173, Subpart I of the Code of Federal Regulations, using packages that satisfy the requirements set forth in Part 71 of Title 10 of the Code of Federal Regulations, 49 CFR 173 Subpart I and 10 CFR 71 respectively. The safety of the transportation casks and their ability to withstand certain specified events under normal handling and accident conditions are detailed in 10 CFR 71 while the related supporting requirements and guidance are provided in Regulatory Guide Series 7 (Reg. Guides) and in NRC Staff Reports (NUREGs) 1609 and 1617. The first of the two NUREGs applies to all Type B packages while the latter is specific to casks used for the transportation of SNF.

The regulatory and guidance documents place high reliance on consensus codes and standards developed by the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), and the American Society for Testing and Materials (ASTM). The objective of the application of all of the requirements is to ensure that the resulting package will safely transport the specified contents and will safely withstand the consequences of credible events attributable to handling and/or accidents.

The final key words to consider are "**all spent fuel types.**" As noted earlier, DOE has some amount of virtually every type of nuclear fuel ever used in the United States. The configurations range from short, slender fuel pins to robust fuel assemblies consisting of arrays of fuel pins or plates. With a height of nearly 508 cm (200 inches), canisters containing six High Temperature Gas Cooled Reactor fuel elements from the Fort St. Vrain reactor represent the tallest items in the Department's inventory. At the opposite end of the scale are small fuel fragments and sections of fuel pins. The uses of the fuels are as varied as their configurations, ranging from isotope production, irradiation, to power generation. The materials of construction and levels of enrichments are also subject to similarly large variations. Additionally, many of the fuels are damaged, most often as consequences of deliberate events for studying fuel behavior under various normal and extreme operating conditions. However, the inventory also includes fuels damaged by accidents such as the Three Mile Island Unit 2 event or by less than ideal conditions of storage. A significant portion of the spent fuels owned by the Department falls into the damaged category. The transportation system concept was designed to accommodate these extremes as well as all others between.

DESIGN BASIS

The dimensions of the transportation system concept are predicated on those of the waste disposal container designed for repository emplacement of HLW and SNF. The internal dimensions of the larger of the two types of waste disposal containers at approximately 175.7 centimeters (69.2 inches) diameter by 461.7 centimeters (181.8 inches) deep were used as the internal dimensions for the transportation system. The dimensions of the repository waste containers are based on the proposed requirement for co-disposal of five vitrified HLW canisters and one canister of DOE SNF (Figure 1), conventionally referred to as the "five-pack", in either 10 or 15 meter lengths and illustrated in Yucca Mountain Project (YMP) sketch numbers SK-0069 and SK-0070, Rev. 00 dated March 9, 1998 (Figure 2).

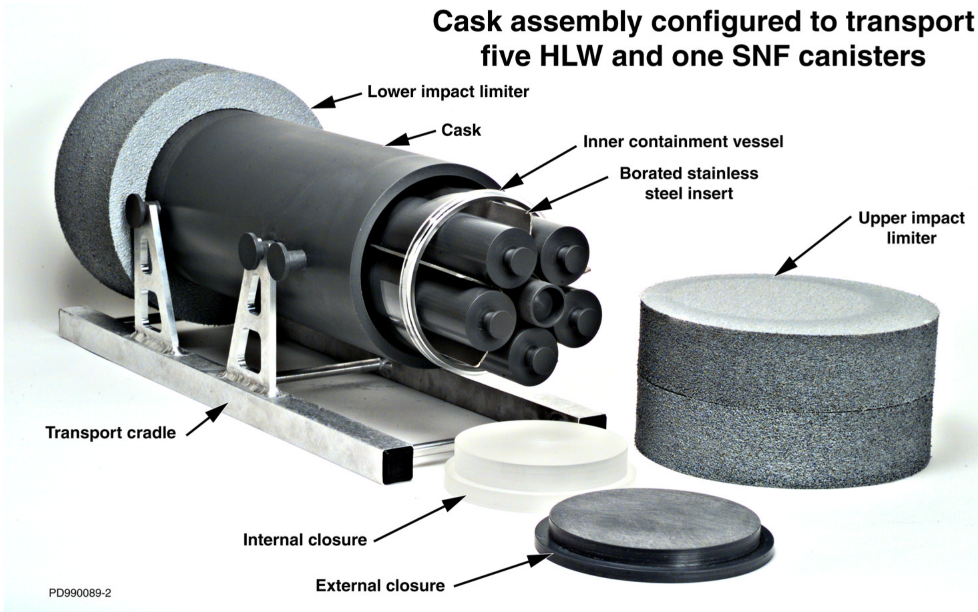
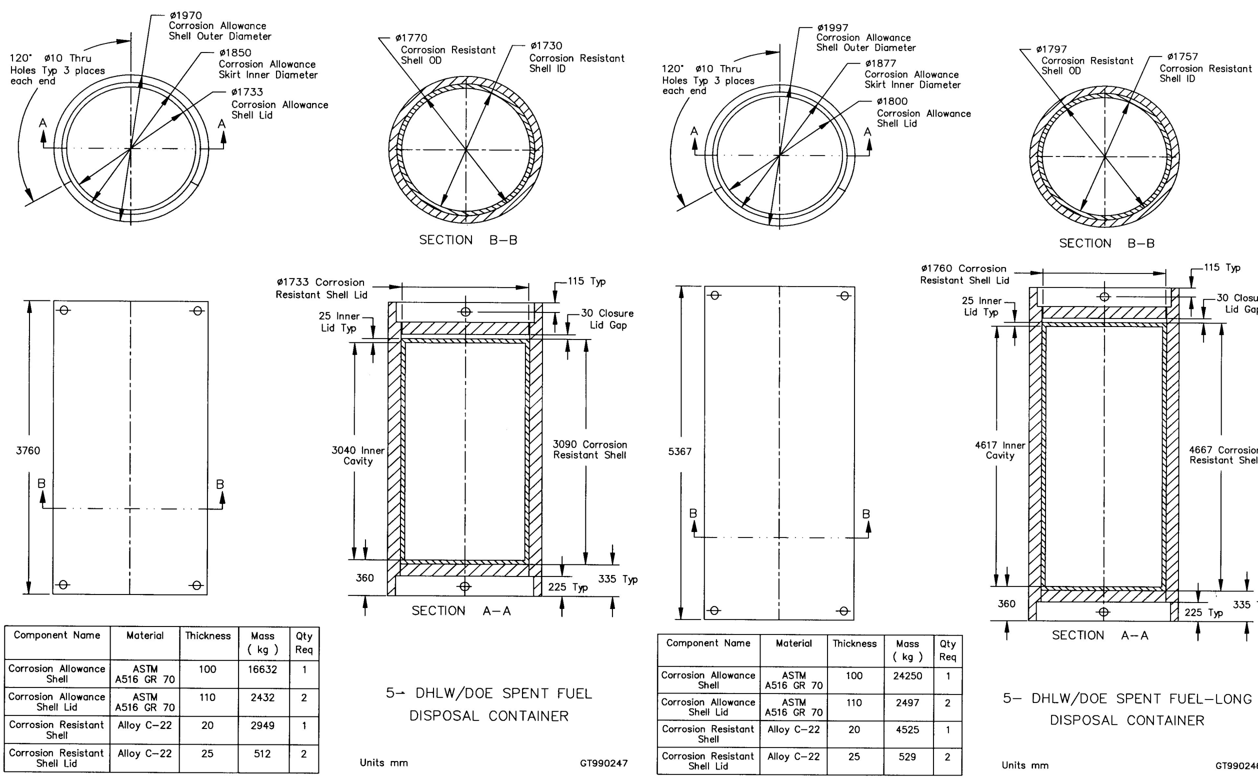


Figure 1. Cask Assembly Configured to Transport Five HLW + 1 SNF Canisters



Component Name	Material	Thickness	Mass (kg)	Qty Req
Corrosion Allowance Shell	ASTM A516 GR 70	100	16632	1
Corrosion Allowance Shell Lid	ASTM A516 GR 70	110	2432	2
Corrosion Resistant Shell	Alloy C–22	20	2949	1
Corrosion Resistant Shell Lid	Alloy C–22	25	512	2

Component Name	Material	Thickness	Mass (kg)	Qty Req
Corrosion Allowance Shell	ASTM A516 GR 70	100	24250	1
Corrosion Allowance Shell Lid	ASTM A516 GR 70	110	2497	2
Corrosion Resistant Shell	Alloy C–22	20	4525	1
Corrosion Resistant Shell Lid	Alloy C–22	25	529	2

Figure 2. Five DHLW + One DOE SNF Canister 10 Meter & 15 Meter Long Disposal Containers
(Source: YMP Sketch Numbers 0069 and 0070, Rev. 00, dated March 9, 1998)

The rationale for using the dimensions of the waste disposal container for the transportation system is to enhance the efficiency of the entire program by matching the size of the shipments delivered to the size and capacity of the disposal system on an approximately one-for-one basis. The expected result will be reductions in the amount of time needed to load and transfer waste containers into the repository and minimization of the amount of lag storage required at the repository surface facilities. Such reductions are translatable into costs saved or avoided, an essential consideration for a facility that is expected to operate on a throughput production basis.

However, as noted in the introduction to this document, all aspects of the system development are subject to changes in response to external influences and requirements and as the results of engineering analyses that will have to be performed as part of the final design and licensing effort. The changes anticipated as the consequences of external developments and as the results of engineering analyses, however, are expected to be minimal. They will probably be limited to fractional increases or decreases in the dimensions and weights of the transportation cask. Barring extraordinary developments, it is assumed that all dimensions and specifications provided in this document are within approximately 5% or closer to those anticipated for the final cask system.

DESIGN PHILOSOPHY

The NRC has voiced the opinion, that, while innovations in the development of a transportation system are welcome, drastic departures from standard designs and materials may prove counterproductive. Major deviations from established design practices, materials, and system specifications require the NRC to learn the peculiarities of the new design and the result may be delays in licensing. The concept proposed by the National Spent Nuclear Fuel program is well within mainstream design practices and, except for dimensions, strongly approximate those of the 125-B casks used for the TMI-2 damaged core shipment program.

The significance of the ASME requirements pertinent to all aspects for providing a system acceptable to the NRC is a cornerstone of the design effort. There are, however; significant questions of pertinence still outstanding, criticality control being the salient among them. The most convenient material currently envisioned for the purpose of criticality control is borated stainless steel with the boron acting as the neutronic poison or absorber because of its large thermal neutron capture cross-section (app. 3,800 barns). Other borated materials such as boroflex™, a flexible neutron poison material, or borated aluminum were also considered, however, their use entails considerable complexities in fabrication. The single problem that currently exists with using borated stainless steel arises from the lack of code for welding such materials and guidance in this area from the ASME is viewed as a need.

REGULATORY BASES

In accordance with the requirements specified in the Nuclear Waste Policy Act of 1982, as amended, all deliveries of HLW and SNF to a repository must be made using transportation casks licensed according to the regulations of the United States Nuclear Regulatory Commission (USNRC or NRC). The NRC regulations also incorporate by reference those of the United

States Department of Transportation (USDOT or DOT) and the requirements of various state regulatory bodies exercising authority over the transportation of HLW and SNF through their domains. The pertinent requirements of all of these regulatory bodies form the bases governing the design, development, construction, related engineering tests and analyses, and operation of the transportation system and, accordingly, they were factored into the development of the system concept in their respective entireties.

U.S. Nuclear Regulatory Commission

The design, construction, testing, and licensing of SNF transportation packages are governed primarily by the regulations promulgated in Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71). Additional supporting, clarifying, and explanatory information is provided in NRC Staff Reports 1609 and 1617 (NUREGs 1609 and 1617) and in Series 7 of the Regulatory Guides (Reg. Guides). The primary objective of the compendium of information provided by the NRC is aimed at the safety requirements pertinent to the design, construction, testing, and licensing of packaging used for the transportation of all radioactive materials rather than the actual act of their transportation. All aspects of the conceptual system were devised in accordance with the NRC documents cited herein.

U.S. Department of Transportation

The regulations governing the transportation of all radioactive materials (Class 7), including HLW and SNF, are provided in Title 49, Part 173, Subpart I, of the Code of Federal Regulations (49 CFR 173). While the NRC is concerned primarily with the safety and security of nuclear materials in transit and with the design, construction, testing, and licensing of packaging used for the shipment of all radioactive materials, the requirements of the DOT are aimed at the factors governing the actual act of transportation outside the shipper's facilities. Thus the DOT regulates the means and methods of hazard communications via shipping papers, labeling, and plackarding of shipments and, to a lesser extent, the specifications of the packaging itself, therefore, their regulations have less impact on the conceptual design.

The two regulatory bodies, the NRC and the DOT, mirror each other's requirements for radiation safety, radioactive contamination levels and radiation limits while in transit. By appropriate cross-references, the regulations of the NRC and DOT frequently invoke, incorporate by reference, and/or complement each other's requirements. Certain additional sections of Title 49 (Subpart K, 174.700 et seq.) govern specific aspects of the transportation of radioactive materials by rail and they were incorporated as appropriate. As the transportation of the casks by aircraft or surface vessel is not an envisioned possibility, the respective pertinent requirements specified in 49 CFR 175.700 – 705 and in 49 CFR 176.700 – 715 are not considered applicable. The two sets of regulations, 10 CFR 71 and 49 CFR 173 Subpart I, jointly form the regulatory bases for the design, construction, testing, licensing, and operations of packaging used for the shipment of HLW and SNF and, accordingly, they are regarded as the basic requirements to be observed in the development of this conceptual design.

State Regulations

The transportation of radioactive materials, to a certain extent, is also subject to the statutory authorities of the various states. The regulations pertain exclusively to hazard communication requirements and to verifying that the radiation and contamination limits specified by both the U.S. DOT and NRC are met. The pertinent requirements of the federal regulatory requirements are nominally incorporated into the states' regulations either by reference or by verbatim adoption into the states' code of rules and regulations; however, none of the states have regulations governing the design, construction, and licensing of transportation packages.

Additionally, states also exercise statutory authority over the mechanical safety of the transportation equipment operating within their domains. However, the primary thrust of the exercise of such authority is public highway safety and, consequently, because the system described herein is intended for transportation by rail, state regulations are expected to have little to no impact on the design of the system itself. Generally speaking, the authorities at the county, parish, or city levels have no jurisdiction over the transportation of radioactive materials. However, under the derived authority of "home rule" they frequently seek involvement at the notification levels. Such involvement, however, also has no impact on the design of the transportation system.

Other Regulations

The NRC has proposed that, to the extent practical and applicable, domestic licensees of radioactive materials shall also observe the regulations of the International Atomic Energy Agency (IAEA). Accordingly, the conceptual design effort also took into consideration the requirements of the IAEA, as promulgated in document ST-1 (formerly Safety Series 6), despite the fact that the transportation system described in this document is not expected to be used in international commerce. The most important of the applicable requirements of the IAEA that has been adopted by the NRC is that casks transporting irradiated (spent) nuclear fuel must be able to withstand an external water pressure of 2 MPa (290 psi) for one hour without collapse, buckling, or inleakage of water (10 CFR 71.61). An external pressure of 2 MPa is approximately equivalent to immersion under a depth of 200 meters (600 feet) of water.

GENERAL DESCRIPTION

The system concept shown in Figure 3 and described in greater detail hereafter, was developed based on the key assumption that all shipments from the DOE consolidation sites to the proposed repository will be made by rail or by rail heavy-haul combination intermodal transport. The repository expressed the preference for shipment by rail with a view toward minimizing the number of handling operations and transportation from the shippers' sites. The primary system consists of a cylindrical lead or depleted uranium shielded external vessel with impact limiters at both ends, nested in a transport cradle with appropriate lifting, tie-down, and pivoting trunnions. Cask and payload weight, without impact limiters, is expected to be under the 150 U.S. ton limit currently proposed by the repository. Using appropriate interfacing equipment, the cask can be loaded and unloaded in either wet or dry environments in facilities with clear lifting heights of approximately 15 meters (45 feet) or higher and with crane capacities of 150 U.S. tons or greater. Special handling gear such as lifting yokes, transfer casks, and loading collars will have to be developed on site- and fuel-specific bases.

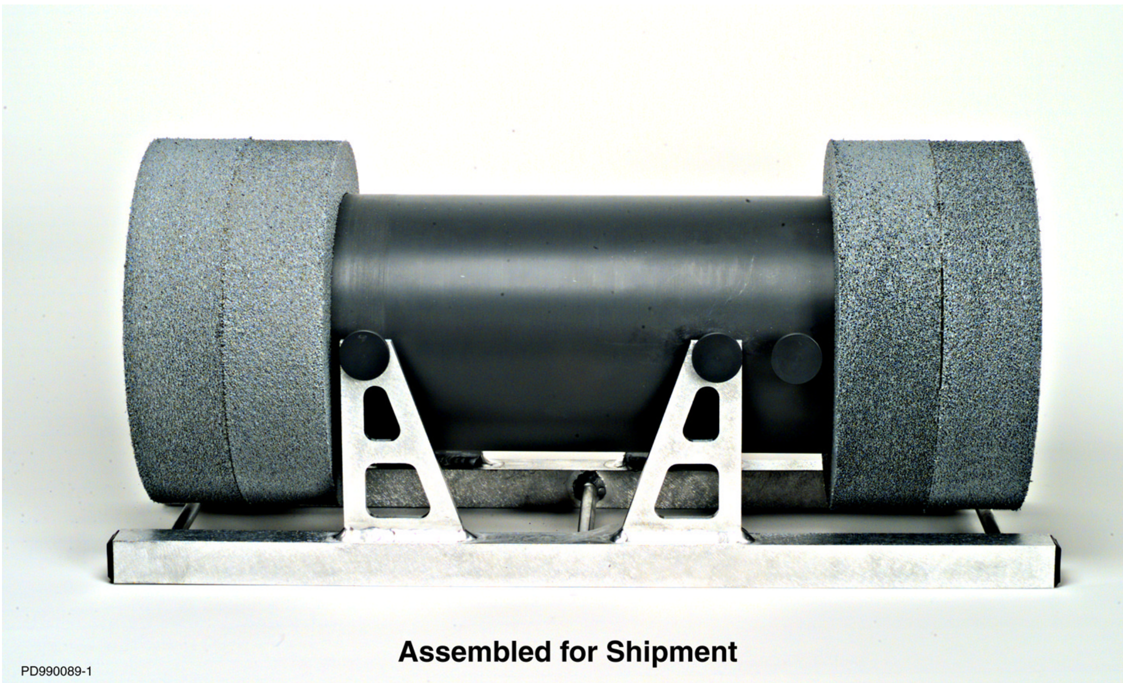


Figure 3. Cask Assembled for Shipment in Transport Cradle with Impact Limiters.

Despite the fact that DOE owned fuels comprise a relatively small percentage of the total volume to be placed in a repository, the actual number of individual spent fuel assemblies, pins, pieces and fragments number well over 100,000 and are grouped into about 250 categories. The sheer numbers of items would impose a significant handling burden on a repository that is expected to be operating as a production facility where cask turn-around times are of the essence. Additionally, as already noted in this document, a considerable number of the fuels are damaged and require some form of containerization.

Concurrent with the development of the transportation system concept described in this document, the NSNFP is in the process of finalizing the design of a standardized canister that is expected to be used by all of the consolidation sites for packaging their fuels. Spent fuels thus containerized reduce the number of handling operations during storage, transportation, and transfer to the repository and provide confinement for damaged assemblies and fuel components. Such reductions in handling are linearly and directly translatable into costs saved and personnel exposure avoided. The transportation system concept was designed to accommodate the standardized canisters developed by the NSNFP as well as spent fuels of commercial origin.

DESIGN DETAILS

Applicable Codes

In addition to withstanding the impacts imposed by normal conditions of transport as specified in 10 CFR 71.71, the casks must be designed and built such that they will also survive the hypothetical accident scenarios described in 10 CFR 71.73. The designers/builders of casks must show by tests and analyses that the packaging will maintain containment of the materials under a set of specified conditions. Without elaborating here on the specifics contained in the regulations, it is important to discuss how such level of assurance of safety is achieved.

The NRC places strong emphasis on the application of established codes and consensus standards. Primary among these is the requirement that the containment system be designed, fabricated, examined, and tested according to the various applicable sections and divisions of the ASME Boiler and Pressure Vessel Code as specified in Tables 1-1 and 1-2 of NUREG 1617. These requirements are the foundation of all activities performed in providing the system described herein. In addition to the applicable code sections, the cask must also be leak tested in accordance with ANSI 14.5 after each assembly or maintenance activity. The DOE SNF cask system is expected to be in full compliance with the requirements specified in NUREG 1617 and, consequently, with the applicable sections of the various codes (e.g. ANSI, ASME, ASTM).

Materials of Construction

The primary materials of construction are expected to be 304L-type stainless steel plates and forgings. A singular feature of the cask closure is the use of bore seals made of neoprene rather than the more conventional face seals used in the past. Bore seals provide greater assurance of the cask maintaining leak-tight integrity under accidental conditions of transport. The need for unilateral (U) or multilateral (M) approval status has not yet been evaluated. However, in an effort to bring the system closer in line with current NRC philosophy, it is expected to be designed and analyzed to meet the requirements of the International Atomic Energy Agency's safety standards for transportation packages (ST-1, formerly Safety Series 6) thus earning a "–85" designation signifying compliance thereto.

The external vessel or cask, its closure, and impact limiters provide the shielding, thermal, and impact protection for the contents. The inner and outer shells of the external vessel will be fabricated from stainless steel with a layer of either lead or depleted uranium between the shells for gamma shielding. The use of borated stainless steel for the inner shell to act as neutron shielding is also under consideration. The closure and lower end of the cask are anticipated to be stainless steel forgings with sufficient thickness to provide shielding equivalent to that of the shell.

Containments

As shown in figure 1, the proposed transportation system concept consists of an external cask with clear internal dimensions of approximately 5.285 meters (208 inches) deep by 1.822 meters

(71.7 inches) in diameter. The entire assembly of components is referred to as the primary containment vessel (PCV). Also as shown in figure 1, inside the PCV is an optional removable inner, or secondary containment vessel (ICV), made of approximately 1 inch thick borated stainless steel. The ICV's clear inside dimensions are approximately 4.8 meters (189 inches) deep by 1.75 meters (68.9 inches) in diameter.

The closure of the ICV is expected to be made of a single stainless steel forging of sufficient thickness to provide shielding equivalent to the walls of the PCV. The ICV's sole function is to maintain containment of the materials in shipment. Around the sides and the bottom, the ICV, in and of itself, provides only modest amount of gamma shielding and thermal rejection and therefore, it is not expected to be taken credit for in the analysis. The closure of the ICV, however, is expected to provide sufficient shielding to allow hands-on performance of leak testing after maintenance or upon assembly of the inner vessel after the cask is loaded for shipment.

Both the PCV and ICV are equipped with bolted closures. Subject to the results of the analyses to be performed, the PCV closure is bolted in place using 36 1.5 inch diameter ASTM Grade A-320 6-UNC-2A bolts torqued to about 500 foot-pounds and, also subject to confirmation via engineering analyses, the ICV closure is expected to be bolted in place using 32 0.75 inch diameter ASTM Grade A-320 6-UNC-2A bolts torqued to about 250 foot-pounds, in both cases lubricated and preloaded to about half of the final torque values. As noted before in this document, the closures are equipped with bore seals (rather than face seals) and, therefore, torquing of the bolts is not a critical requirement.

> Note: The regulations in 10 CFR 71.63 require that shipments of certain forms of plutonium and materials containing more than 20 curies of plutonium be made in a cask featuring two levels of containment. For virtually all instances, the cladding of intact fuel assemblies is regarded as the first level of containment with the cask providing the second level of containment and therefore, the requirement for two levels of containment is satisfied. However, this is not the case where the cladding is damaged and, consequently, cannot be considered as a level of containment. As noted before, a significant portion of the fuels owned by the Department is damaged and, in the absence of proof that the fuels contain less than 20 curies of plutonium, a second level of containment is required. Under the regulations of the NRC promulgated in section 4.4.1 of NUREG 1617, in order for a container to be called a containment, it has to be fabricated according to ASME Section III, Division 3 requirements and, after closure, leak tested according to the requirements of ANSI 14.5. As the radiation level around canisters loaded with spent fuel is in the lethal range, the operations of final closure welding and subsequent leak testing would have to be performed remotely. The cask system designers took into consideration the extreme complexity of attempting to meet these requirements with the use of internal canisters individually welded closed and leak tested according to ASME Section III, Division 3, and ANSI 14.5 respectively, and concluded that providing an inner containment vessel as a part of the transportation packaging is a simpler and safer route to compliance with the dual containment requirements of 10 CFR 71.63 and the applicable sections of NUREG 1617.

It is important to consider the bases for the internal dimensions of the cask. As shown in figures 1 and 2 of this document, the repository has devised a disposal configuration consisting of five 61 centimeter (24 inch) diameter canisters of vitrified HLW in a circular array with a 46 centimeter (18 inch) diameter standard SNF canister in the center position. The resulting array of canisters requires a waste disposal package with internal diameters in the approximate range of 1.73 to 1.76 meters (68.1 to 69.3 inches). Depending on their sources of production (e.g. INEEL, Hanford, or Savannah River Site), the HLW canisters are in lengths of 3 or 4.5 meters (120 or 180 inches). In order to maximize production efficiency at the repository, the internal dimensions of the waste disposal package for the longer 4.5 meter (180 inch) canisters were adopted for the internal dimensions of the transportation system also. This would allow the shippers to deliver the equivalent of one waste package load of materials to the repository, an important consideration for a production-type facility with limited capability for onsite short-term storage and with the need to maximize the periodic rate of throughput.

Shielding and Criticality Control

One of the most important features of all Type B packages is the requirement for them to shield the external environment from the contents. Regardless of their energies, the emission of alpha and beta particles are of no concern because of their low abilities to penetrate even modest amount of shielding. Similarly, fast neutrons pose no problems as they are incapable of interacting with matter while traveling at relativistic speeds. The concerns are slow or thermal neutrons and gamma radiation emitted by spent nuclear fuel, each requiring a different kind of shielding. Gamma rays are shielded by high density materials such as lead or depleted uranium while the most expedient method for stopping thermal neutrons is with the use of neutronic poisons, boron being the most common among them. As noted before, the present view is that the appropriate parts of the cask internals will be made with stainless steel incorporating a neutronic poison such as boron although, the use of gadolinium, as an alternate to boron is currently under intensive study. Either lead or depleted uranium may be used for shielding of gamma radiation. The present status of the design admits to either of the two materials for gamma shielding and changing from one to the other would not be considered a major impact at this stage of the development.

> Note: The use of lead as gamma shielding is supported by tradition, relative ease of manufacture, and reasonable availability. However, as it is a D-listed Resource Conservation and Recovery Act (RCRA) hazardous heavy metal, its use and future disposition are likely to entail problems. The use of depleted uranium generally avoids the RCRA problem, however, its use and manufacture entails certain complexities normally not encountered with lead fabrication.

The additional problem is that thermal neutrons may cause a nuclear reaction to occur within the cask or among casks containing spent nuclear fuel. This could be the case if a cask were filled with water during an accident. The water in the cask would slow fast neutrons to thermal speeds possibly resulting in a criticality. Materials with large thermal neutron capture cross-sections, such as boron, hafnium, or gadolinium are used for criticality control. This is the additional reason for incorporating one of these neutronic poisons within the internals, commonly referred to as the baskets, used in the transportation cask. The present view is that borated stainless steel will be used for the fabrication of the baskets.

One of the objectives of the design is to maintain radiation exposures as low as reasonably achievable (ALARA). In keeping with that philosophy, and despite the higher limit allowed by the regulations, the design objective is to provide sufficient shielding to reduce the radiation on contact to 10 mR/hr or less. The rationale for the lower limit is that facilities handling only a few shipments per year can afford the exposure resulting from a higher contact dose. However, the personnel at the repository, operating as a production facility and handling two or more casks on a daily basis, would receive unacceptably high cumulative doses.

Payload Configurations (Authorized Contents)

The internal baskets (inserts) are removable and interchangeable with others custom tailored for specific applications and payloads. The baskets are fabricated from borated stainless steel for criticality control. The following payload configurations are presently envisioned (five of the payload configurations are shown in figure 4, others are possible):

1. Repository short "five-pack" equivalent of five 0.61 m. (24 in.) diameter by 3.0 m. (120 in.) standard SNF canisters with one 0.457 m. (18 in.) diameter by 3.0 m. (120 in.) standard SNF canister in the center. (Requires use of internal shoring plug.)

2. Repository long "five-pack" equivalent of five 0.61 m. (24 in.) diameter by 4.5 m. (180 in.) standard SNF canisters with one 0.457 m. (18 in.) diameter by 4.5 m. (180 in.) standard SNF canister in the center.

3. Repository short "five-pack" equivalent of five 0.61 m. (24 in.) diameter by 3.0 m. (120 in.) WVDP/DWPF type HLW canisters with one 0.457 m. (18 in.) diameter by 3.0 m. (120 in.) standard SNF canister in the center. (Requires use of internal shoring plug.)

4. Repository long "five-pack" equivalent of five 0.61 m. (24 in.) diameter by 4.5 m. (180 in.) Hanford type HLW canisters with one 0.457 m. (18 in.) diameter by 4.5 m. (180 in.) standard SNF canister in the center.

5. Four Multicontainer overpack (MCO) type canisters. (Requires the use of internal shoring plug.)

6. Nine 0.457 m. (18 in.) diameter by 3.0 m. (120 in.) standard SNF canisters. (Requires use of internal shoring plug.)

7. Nine 0.457 m. (18 in.) diameter by 4.5 m. (180 in.) standard SNF canisters.

8. Up to 37 commercial PWR SNF assemblies with 0.216 m. (8.5 in.) pitch by 4.42 m. (174 in.) long. (Configuration requires the use of internal shoring plugs and is weight limited.)

9. Other commercial fuels may be transported using shoring plugs and sleeves.

10. Special configuration for up to nine Fort St. Vrain-type SNF canisters.

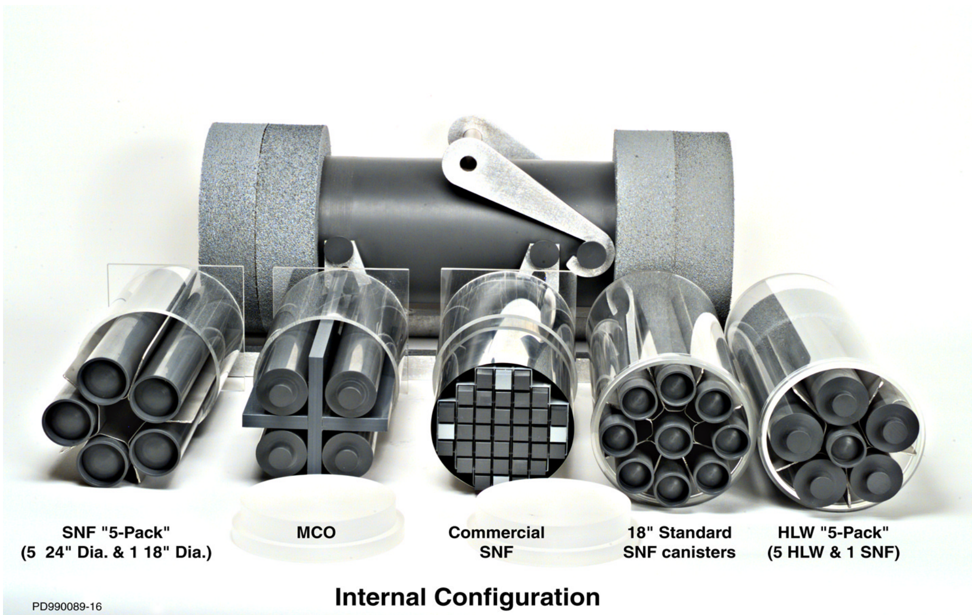


Figure 4. Payload configurations.

Miscellaneous Features

Transport Cradle. The entire cask, when assembled for shipment, is nested in a transportation cradle mounted on a railcar or other suitable heavy-haul conveyance (see figure 3). The cask is equipped with six, permanently attached trunnions arranged in three pairs. Two of the pairs are the attachment points to the transportation cradle while the remaining pair of trunnions is used for pivoting and raising the cask out of the transport cradle. The cask pivots on the lower pair of trunnions. The inclusion of an additional set of lifting trunnions to provide greater flexibility for handling is also under consideration as an option, however, exercising this option is not expected to have an impact on the overall design.

Test, Vent, Inerting, and Sampling Ports (Figure 5). Both the primary containment vessel (PCV) and the inner containment vessel (ICV) are equipped with fittings for leak testing, venting, inerting, and sampling of the cask. In order to minimize the complexity and possible maintenance problems, the design of the fittings avoids the use of valves and relies on seals and bolts instead. This approach minimizes the number of movable parts and possible leakage paths. An important aspect is that the leak-testing, venting, inerting, and sampling fittings cannot be leak tested after closure, however, their design precludes the possibility of assembling the cask for shipment and inadvertently leaving one of these ports open.

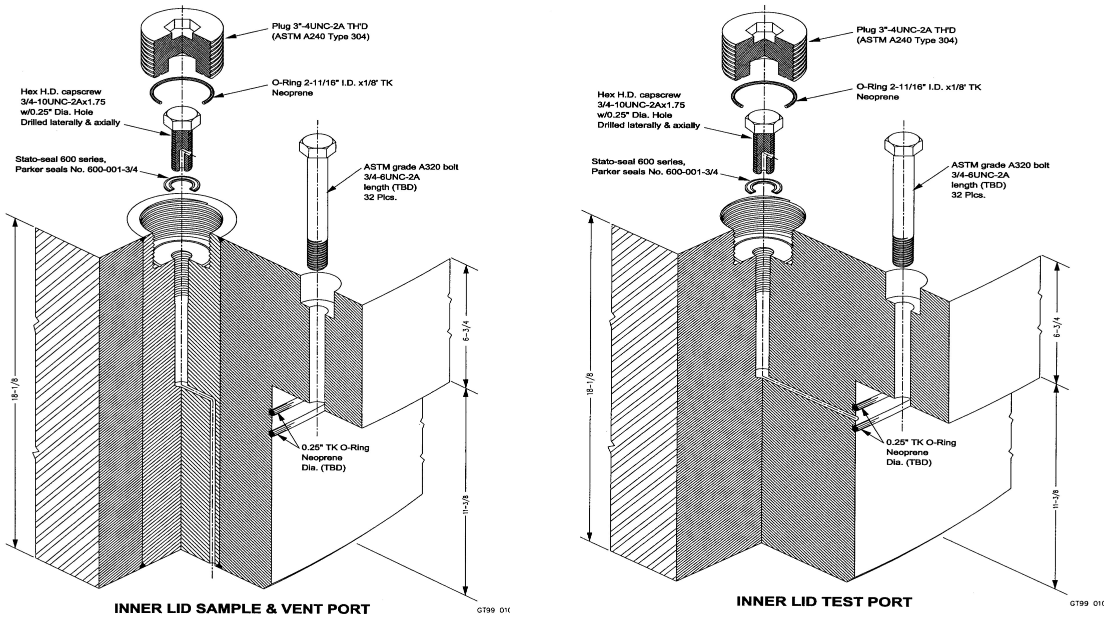


Figure 5. Sampling, Vent, and Assembly Test Port Configurations

Pressure Relief. Consideration is being given to the installation of frangible disks for pressure relief. Should future analyses indicate that the maximum internal pressure of the cask may exceed 700 kilopascals per square centimeter (100 psi) under normal conditions of transport (10 CFR 71.73), both the PCV and ICV closures will be equipped with frangible disks set to relieve the internal pressure upon reaching some predetermined level (150 psi nominal estimated). Although not an envisioned possibility, in accordance with 10 CFR 71.4 and 49 CFR 403, any Type B transportation cask whose normal operating pressure may exceed 700 kilopascals per square centimeter (100 psi) or is equipped with a relief device to allow release of the radioactive contents under accident conditions of transport is designated as a Type B(M) cask requiring that multilateral approvals be secured prior to transportation in international commerce.

Interchangeable Internal Baskets (Inserts). The conceptual design features a set of interchangeable internal baskets each custom tailored for a specific payload category. The various payload combinations identified to date are listed in the section titled "7.5 Payload Configurations" (Authorized Contents) five of which are also shown in figure 4. The importance of this feature is that the ability to remove and exchange the internal baskets permits the transportation of various payload configurations with relatively simple amendments to the cask's license (Certificate of Compliance) rather than having to go through the much more expensive design and licensing process for a new cask. This feature also permits the addition of more shielding should the radioactivity of the payload exceed the shielding ability of the cask, a rather unlikely event. Presently, the baskets are expected to be constructed of borated stainless steel for criticality control; however, other materials incorporating neutronic poisons are also under evaluation.

QUALITY ASSURANCE

The quality assurance aspects of the design, engineering, and construction of transportation casks licensed by the NRC is governed by the requirements imposed by 10 CFR 71.101 through 10 CFR 71.137 inclusive. Without specific elaboration here, the specifics generally mirror those of ASME Nuclear Quality Assurance (NQA-1) requirements and they will form the basis of quality of all aspects of the design, engineering and fabrication of the transportation packages described in this document.

According to Appendix B of the Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Requirements and Description (QARD) document, DOE/RW-0333P, the transportation system is not subject to the quality assurance requirements imposed by the repository.

> Note: The designers have taken into consideration the fact that certain repository-specific requirements, primarily those pertaining to the handling of heavy loads (critical lifts) will have an impact on the transportation system, the cask, and its various components and these will be factored into the design of the system.

CONCLUSION

The NSNFP staff believes that the system concept presented in this document is satisfactory for the safe transportation of all spent nuclear fuels in the Department of Energy Environmental Management's custody. The staff is also of the opinion that there are no SNF types in the entire United States inventory that could not be safely transported using this system. Furthermore, the staff believes that the dimensions provided here are within a few percent of what the ultimate final design is going to be and the licensing of the system, based on precedent, should not encounter insurmountable difficulties. The staff further submits that the design is subject to changes in response to external driving forces, however, the concept appears to be sound and has survived all challenges to date.

FOOTNOTES

1 - Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management under DOE Idaho Operations Office Contract DE - AC07-99ID13727.