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The National Repository**

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STANDARDIZED DOE SPENT NUCLEAR FUEL CANISTER AND TRANSPORTATION SYSTEM FOR SHIPMENT TO THE NATIONAL REPOSITORY¹

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ABSTRACT

The U.S. Department of Energy's (DOE) National Spent Nuclear Fuel Program (NSNFP), located at the Idaho National Engineering and Environmental Laboratory (INEEL), has been chartered with the responsibility for developing spent nuclear fuel (SNF) standardized canisters and a transportation cask system for shipping DOE SNF to the national repository. The mandate for this development is outlined in the Memorandum of Agreement for Acceptance of Department of Energy Spent Nuclear Fuel and High-Level Radioactive Waste that states, "EM shall design and fabricate ... DOE SNF canisters for shipment to RW." (1) It also states, "EM shall be responsible for the design, NRC certification, and fabrication of the transportation cask system for DOE SNF canisters or bare DOE SNF in accordance with 10 CFR Part 71." (2) In fulfillment of these requirements, the NSNFP has developed four SNF standardized canister configurations and has conceptually designed a versatile transportation cask system for shipping the canisters to the national repository.¹

The standardized canister sizes were derived from the national repository waste package design for co-disposal of SNF with high-level waste (HLW). One SNF canister can be placed in the center of the waste package or one can be placed in one of five radial positions, replacing a HLW canister. The internal cavity of the transportation cask was derived using the same logic, matching the size of the internal cavity of the waste package. The size of the internal cavity for the transportation cask allows the shipment of multiple canister configurations with the application of a removable basket design. The standardized canisters have been designed to be loaded with DOE SNF, placed into interim storage, shipped to the national repository, and placed in a waste package without having to be reopened. Significant testing has been completed that clearly demonstrates that the standardized canisters can safely achieve their intended design goals. The transportation cask system will include all of the standard design features, with the addition of dual containment for the shipment of failed fuel. The transportation cask system will also meet the rigorous licensing requirements of the Nuclear Regulatory Commission (NRC) 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.

The standardization of the SNF canisters and the versatile design of the transportation cask system will eliminate a proliferation of designs and simplify the operations at the user sites and the national repository.

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INTRODUCTION

In accordance with the provisions of a Memorandum of Agreement between DOE's Office of Civilian Radioactive Waste Management (OCRWM) and DOE's Office of Environmental Management (EM), the NSNFP has been tasked with the responsibility to devise, design, and develop, as necessary standardized canisters and an optimized transportation system for shipping the standardized canisters or bare SNF. This presentation describes the standardized canisters and the transportation system that is being developed for the safe handling, storage, and transportation of DOE SNF to the national repository.

Development of the standardized canisters and the transportation system have been under way since 1997. The NSNFP worked with OCRWM, the INEEL, the Hanford Site, Oak Ridge National Laboratory, Argonne National Laboratory, and the Savannah River Site to develop the containers, referred to as the standardized DOE SNF canisters. These standardized canisters for DOE-owned SNF have the purpose of 1) providing a standard and easy-to-handle unit to confine DOE SNF; 2) providing durable units for storing SNF; 3) providing easily transportable units; and 4) ultimately, providing a unit for final disposal at the national repository, without the necessity of the DOE SNF being removed from the canister or reopening a sealed canister. The sizes of the standardized canisters are based on the internal dimensions of the repository waste package design for co-disposal of SNF with HLW. Once the sizes, materials, and configurations of the standardize canisters were established, full size prototypes were built and drop tested to ensure that the canisters would withstand handling accident conditions without failure. Computer modeling of accidental drops was first employed to ensure the adequacy of the design and then actual drop testing was performed to verify the accuracy of the models. Preliminary Design Specification for Department of Energy Standardized Canisters, DOE/SNF/REP-011, has been written to document the canister design (with drawings) as well as the basic loads and criteria necessary to achieve repository acceptance. (3)

The transportation system was developed based on the same repository waste package design for co-disposal. The internal cavity of the transportation cask is essentially the same as the waste package. This will allow a full waste package of material to be shipped to the repository in a single shipment. The transportation cask system concept is a rail cask with removable baskets that will allow for multiple configurations of canisters or bare SNF to be packaged for shipment by simply replacing the baskets. This feature will make the cask as versatile as possible. Using a rail cask will also significantly reduce the number of shipments required. The cask will incorporate conventional features that will facilitate the design and licensing of the system in accordance with the requirements of 10 CFR Part 71. A significant amount of analysis has been performed to ensure that the conceptual design will meet the structural, thermal, and shielding requirements. Recently, a procurement design specification was drafted for procurement of the design and licensing of the system. This document was sent to the user sites for review and comment. The conceptual design will be finalized based on the comments received, and the NSNFP will then be ready to proceed with the procurement of the design and licensing of the transportation system.

STANDARDIZED CANISTER DESIGN OBJECTIVE

One of the goals of the NSNFP was to develop a container for DOE SNF. The objective was to seal the many types and varied geometries of DOE SNF in a finite number of these containers to simplify handling during initial interim storage, then during transportation to the nation's repository, and finally during the efforts necessary to place the DOE SNF into the repository for final disposal.

To maintain simplicity, efficiency, and to keep costs low, the intent was to have these canisters envelop the SNF but not to provide numerous safety features, such as shielding. Other components (including the interim storage facilities, the transportation packagings, and the repository waste packages) could be relied on to provide these other safety functions.

Although the goal was to shift various safety functions onto other facilities or components, the potential still exists that when these canisters are being handled by themselves, they could be accidentally dropped. This means that the standardized DOE SNF canister has to be robust enough to withstand anticipated operational loads and at least confine the DOE SNF after an accidental drop event. Therefore, providing some means of protecting these canisters during potential drop events was an important design objective.

TRANSPORTATION SYSTEM DESIGN OBJECTIVE

The design objective for the transportation system is to devise an optimized system that will safely transport all spent nuclear fuel types in DOE-EM's inventory.

This objective statement contains significant key words, 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 design, 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. This is 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.” 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. (4) 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 Nuclear Regulatory Commission (NRC) Staff Reports (NUREGs) 1609 and 1617. (5)(6)(7) 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 DOE’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 large variations. In addition, 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 in between.

STANDARDIZED CANISTER DESIGN

During FY98 and FY99, the NSNFP developed the standardized DOE SNF canister design. The standardized DOE SNF canister design has two diameters (18 inch and 24 inch) and two lengths (10 ft and 15ft), and is made of 316L stainless steel. The nominal wall thickness is 3/8 inch for the 18-inch diameter canister and 1/2 inch for the 24-inch canister. Although a 50 psig internal pressure is established for design conditions (22 psig operational), the standardized DOE SNF canister actually has the capability of withstanding a much higher pressure limit (working pressure of about 350 psig). This is just one example of the robust design of the standardized DOE SNF canister. Maximum total loaded weight limits for all four canister geometries are listed in Table I.

Table I. Maximum allowable canister weights

Canister diameter (nominal)	Maximum weight of 10 ft canister (lb)	Maximum weight of 15 ft canister (lb)
18 inch	5,005	6,000
24 inch	8,996	10,000

This canister design incorporates an integral energy-absorbing skirt (Figures 1 and 2) that deforms on impact during an accidental drop event, providing a significant amount of protection to the actual pressure boundary or containment system of the canister. The skirt helps to protect the canister containment system in virtually all accidental drop events by absorbing impact energy. Only when the canister impacts in a horizontal (flat) orientation does the skirt not absorb significant energy. However, in horizontal orientations, the entire length of the canister is then able to absorb drop energy. This deformed skirt can be removed if necessary without disrupting the canister containment system, enhancing the canister's ability to still fit into other containers.

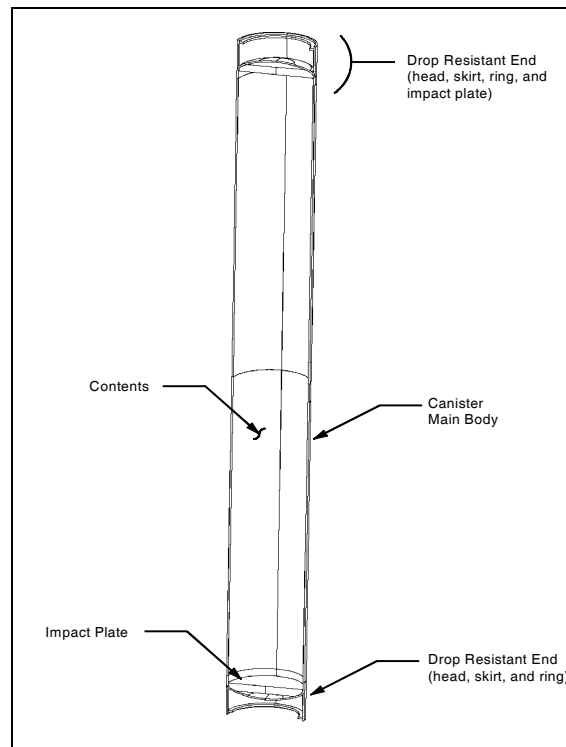


Figure 1. Standardized DOE SNF canister overall design (section view)

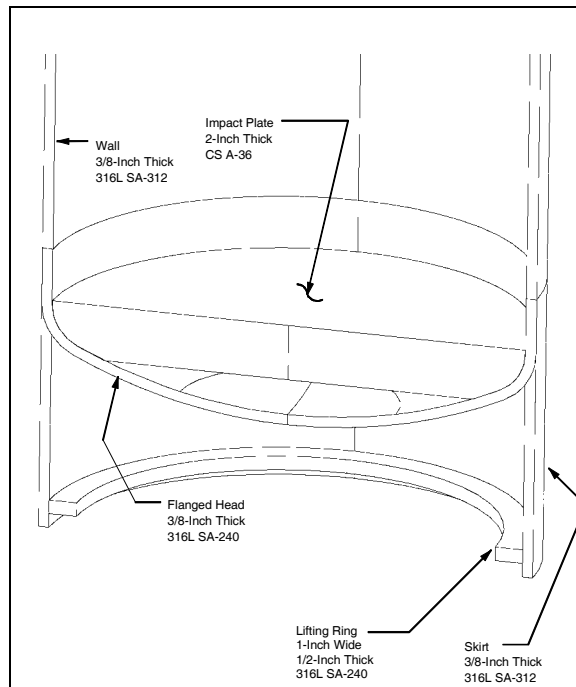


Figure 2. 18-Inch Canister Lower End

A preliminary design specification was written to document the canister design (with drawings) as well as the basic loads and criteria necessary to achieve repository acceptance. This document was not written to be the Design Specification as identified in Section III, Division 3 of the ASME Boiler and Pressure Vessel (B&PV) Code. (8) It was written to be used by various interim storage and transportation personnel (as applicable) as a basis for the generation of the standardized canister design specification and the following design report. However, the preliminary design specification performs the important function of providing the common design basis for all standardized DOE SNF canisters, regardless of how each standardized DOE SNF canister is used at the various DOE sites during initial SNF loading, interim storage, or transportation to the repository. Regardless of the individual use history of each standardized canister, the repository can be assured of receiving a standardized DOE SNF canister that properly interfaces with facility lifting fixtures, a canister that properly fits in designated places, and a canister that will perform as expected in case of an accidental drop or other significant loading event.

With a clear focus on the future, the preliminary design specification requires the standardized DOE SNF canister to be N-stamped per the criteria of the ASME B&PV Code, Section III, Division 3. The basis for this requirement is that the standardized DOE SNF canister can then function (if necessary) as the inner containment system for transporting damaged SNF, based on the guidance provided in Sections 4.4.1 and 4.5.1.3 in NUREG-1617. Because the current decision is to allow the various DOE sites to procure the standardized DOE SNF canisters on an as-needed basis over the next several decades, imposing ASME Section III criteria provides the added rigor of an authorized nuclear inspector (onsite) and proper Code fabrication techniques.

TRANSPORTATION SYSTEM CONCEPTUAL DESIGN

General Description

The system concept shown in Figures 3 and 4 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 based on site- and fuel-specific requirements.

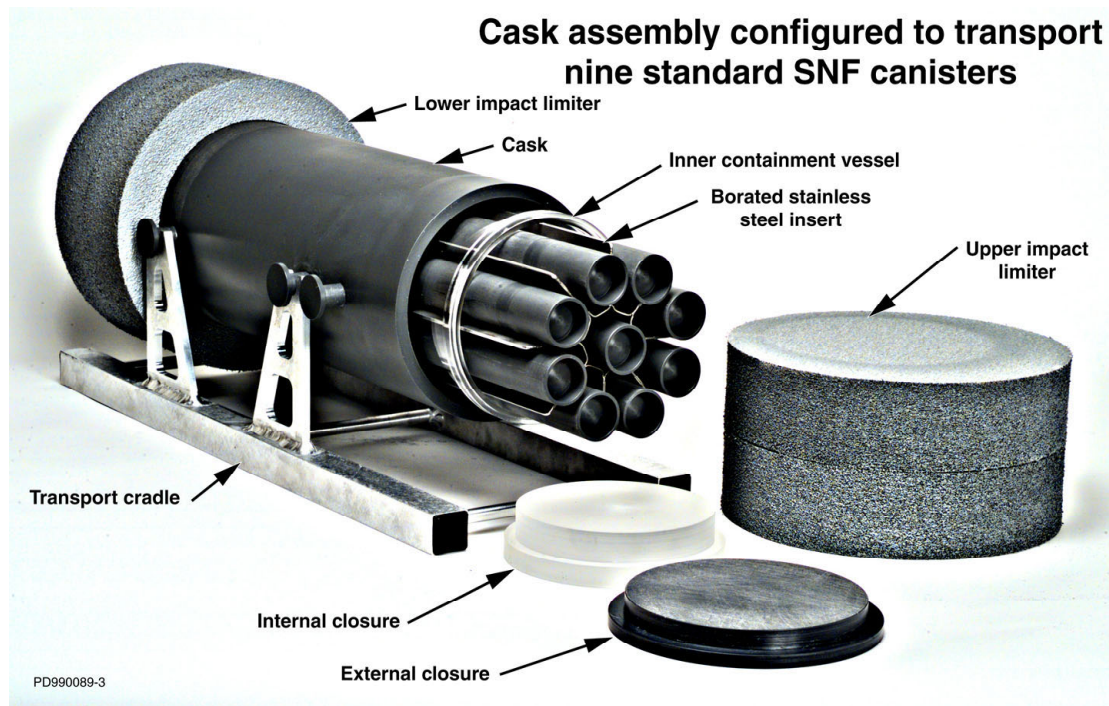


Figure 3. Conceptual design model.

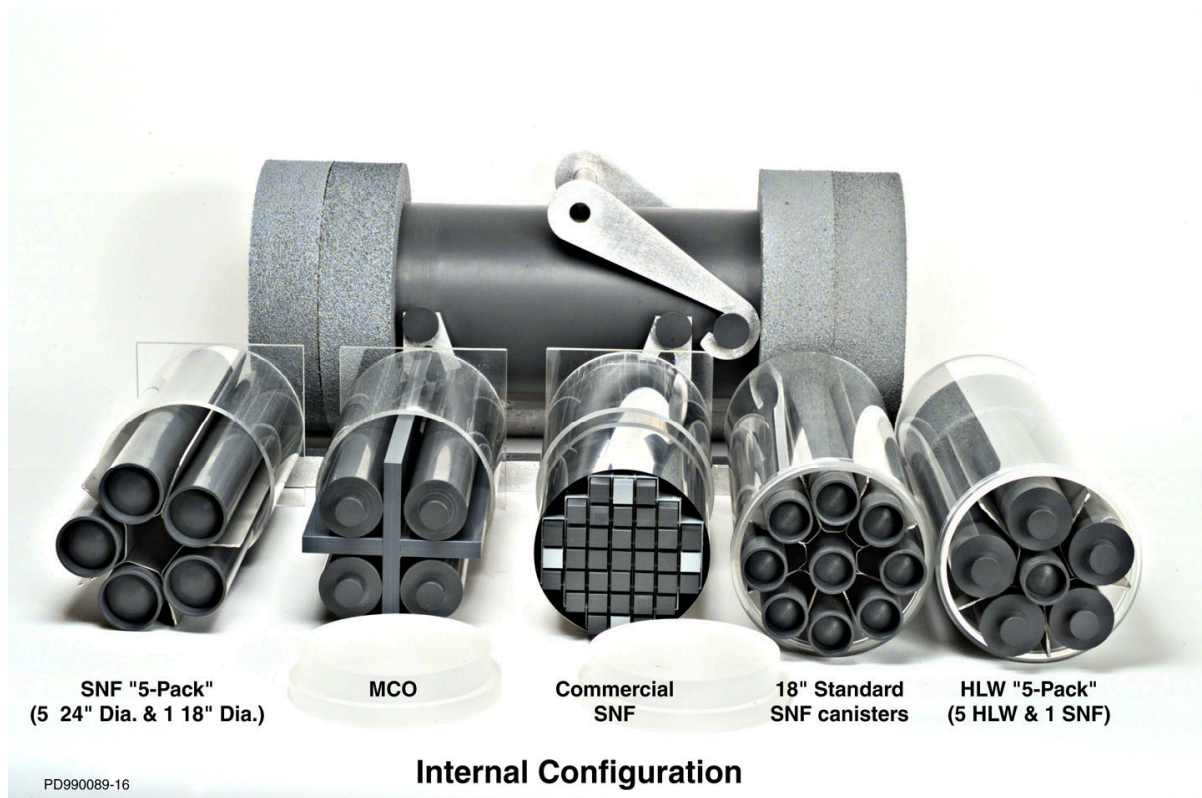


Figure 4. Cask assembled for shipment in transport cradle with impact limiters.

Despite the fact that DOE-owned fuels comprise a relatively small percentage of the total volume to be placed in the 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. In addition, as already noted in this document, a considerable number of the fuels are damaged and require some form of containerization (ie. standardized canisters).

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 BP&V 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. (9) 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 applicable 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. (10)

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 3, 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 3, 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 a 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 DOE 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. The repository has devised a disposal configuration consisting of five 610-millimeter (24-inch) diameter canisters of vitrified HLW in a circular array with a 451-millimeter (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 a 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 SNF, 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.

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.

STANDARDIZED CANISTERS AND TRANSPORTATION SYSTEM

The DOE storage site contractors will package most of the DOE SNF in the standardized canisters. Internal baskets will be designed for the various fuel types to facilitate loading and maintain configuration control. The baskets and SNF will be placed in the standardized canisters and the top of the canister will be welded on. There is a plug in the top of canister that allows for venting and testing during storage. Before final shipping to the repository, the canisters will be backfilled with helium, and the plug will be seal welded shut. When the canisters are accepted for shipment to the national repository, the appropriate basket will be placed in the transportation cask, and the canisters will be loaded in the specified configuration according to the NRC license. Once loaded, the transportation casks will be shipped by rail and/or heavy haul transportation to the national repository. The casks will be unloaded at the repository surface facility and packaged in the repository waste packages. The waste packages will then placed in

long-term storage in the repository, and the casks will be returned to the sites for reloading and shipment.

CONCLUSION

The repository has accepted the design of the standardized DOE SNF canister and has now incorporated it into their project documentation. The results of the drop testing performed to date clearly show that the design of the standardized DOE SNF canister is robust and that its containment system can indeed remain intact and functional, even after an accidental drop event. Helium leak testing has shown that leaktight conditions can be achieved. In addition, finite element computer analyses can be performed that adequately predict the structural responses of these canisters. This is important for future structural evaluations that were not specifically tested. Therefore, with the standardized DOE SNF canister, the NSNFP has provided the DOE complex with an important tool to safely store, transport, and dispose of DOE SNF. Due to its robust design and current acceptance by the repository, additional uses for the standardized DOE SNF canister may be proposed, including Greater-Than-Class C waste and other unique radioactive materials.

The NSNFP staff believes that the transportation system concept presented in this document will provide for the safe transportation of all spent nuclear fuels in the DOE Environmental Management's custody. The system is versatile and efficient, accommodating various configurations by using removable baskets and also optimizing the number of canisters that can be shipped in one shipment. By matching the cask internal cavity with the waste package internal cavity, this system could also be used for shipping HLW canisters. The NSNFP 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 NSNFP 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.

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