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TRANSPORTATION CASK FOR BARE HIGH BURNUP SPENT NUCLEAR FUEL

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ABSTRACT

In support of the U.S. Department of Energy's (DOE) "Spent Nuclear Fuel Transportation Cask Design Study," AREVA Federal Services LLC has developed a conceptual design of a reusable rail transportation cask (the 6625B-HB) capable of shipping high burnup pressurized water reactor (PWR) and boiling water reactor (BWR) spent nuclear fuel (SNF) that can be placed either bare into a basket or packaged in a damaged fuel can (DFC), which is then placed in a basket[1]. The purpose of the DOE study was to develop information and data on transportation cask options that could be used for shipment of SNF from commercial reactor sites to an Interim Storage Facility (ISF). The DOE study will be used to support the development of options for decision-makers on the design of an integrated waste management system.

The 6625B-HB would be capable of accommodating essentially the entire existing and future inventory of commercial light-water reactor SNF assemblies, including restrictive short-cooled, high-burnup SNF assemblies with a maximum burnup of 62.5 GWd/MTU and a minimum cooling time of 5 years. The 6625B-HB contains up to 24 PWR or 61 BWR SNF assemblies placed into baskets designed for holding either bare fuel or fuel packaged into DFCs.

The 6625B-HB cask has been designed such that there is reasonable assurance that it could be certified by the Nuclear Regulatory Commission (NRC) under 10 CFR Part 71, fabricated within existing facilities, used by most utilities, and transported by rail. The level of detail developed for the 6625B-HB is intended to support the analyses and planning activities that DOE is performing in laying the groundwork for an integrated waste management system, which includes preparing for future large-scale transport of SNF. The development of the cask design was based on lessons learned and past AREVA experience with design, testing and acquiring certification of transportation packages. This paper describes the 6625B-HB package features, certification approach, and design challenges including: transporting bare fuel packaged in DFCs, package weight restrictions, and accommodation of high burnup fuel, which introduces challenges related to shielding and decay heat.

INTRODUCTION

In accordance with the *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* [1], the U.S. Department of Energy (DOE) is laying the groundwork for an integrated waste management system, including planning for future large-scale transport of spent nuclear fuel

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[1]Under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare spent nuclear fuel. Acceptance of canistered spent nuclear fuel would require an amendment to the Standard Contract.

(SNF) to consolidated interim storage and disposal facilities when such facilities become available. To support these efforts, DOE is interested in studying a capability to ship SNF directly from Spent Fuel Pools (SFP) of nuclear power plants to an ISF. The Strategy includes activities to establish one or more ISFs and prepare for possible large-scale transport of SNF. It is expected that the capability to ship short-cooled high-burnup (HBU) SNF directly from nuclear power plant SFPs to an ISF may be desirable.

To prepare for this scenario, a study to examine design concepts for reusable transportation casks optimized for short-cooled HBU shipment from the SFPs to an ISF was sought by DOE, including a cask concept capable of being loaded with all assemblies enclosed in damaged fuel cans (DFCs).

To support the DOE study titled “Spent Nuclear Fuel Transportation Cask Design Study,” AREVA Federal Services LLC (AFS), associated with the Business Unit Logistics of AREVA, has developed a conceptual design of a reusable rail transportation cask (named the 6625B-HB) capable of shipping high-burnup pressurized water reactor (PWR) and boiling water reactor (BWR) SNF that can be placed either bare into a basket or packaged in a DFC, which is then placed in a basket. This paper describes the 6625B-HB package features, certification approach, and design challenges including: transporting bare fuel packaged in DFCs, package weight restrictions, and accommodation of high burnup fuel, which introduces challenges related to shielding and decay heat.

6625B-HB PACKAGE FEATURES

A conceptual cask system, the 6625B-HB, was designed by AREVA to be used for rail transport of SNF, including high burnup SNF, for the DOE under a task order arrangement [2]. The 6625B-HB packaging is designed for direct loading in a commercial nuclear power plant’s SFP. The package is designed to be transported singly, with its longitudinal axis horizontal, by rail or highway truck as an exclusive use shipment. When loaded and prepared for transport, the 6625B-HB package can contain up to 24 PWR or 61 BWR SNF assemblies. The package is 261.5 inches long, 126 inches in diameter (at the impact limiters), and has a nominal weight of 151.1 tons. Figure 1 and Figure 2 provide a general overview of the 6625B-HB and some of its principal dimensions.

The 6625B-HB utilizes bolted inner and outer lids that allow for it to be reused and credit taken for moderator exclusion under specific conditions as described in the certification approach section of this paper. By use of four different basket designs, this cask system is designed and optimized to be capable of handling the following SNF arrangements:

- Bare PWR SNF
- Bare BWR SNF
- PWR SNF placed in DFCs
- BWR SNF placed in DFCs

The 6625B-HB is designed to accommodate essentially the entire existing and future inventory of commercial light-water reactor SNF. Within the packaging, bare fuel or fuel in DFCs would be contained in the basket structures shown in Figure 3, which have been specifically designed for each fuel type to provide for heat rejection and criticality control.

As shown in Figure 4, the designed packaging system consists of a payload basket, a lead-shielded cask body, an inner closure lid with lead and steel gamma shielding, an outer steel lid, upper end structure, lower end structure with lead and steel gamma shielding, and upper and lower impact limiters. The packaging is designed to provide leak tight containment of the radioactive contents under all Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

The packaging is of conventional design and would utilize American Society of Mechanical Engineers (ASME) nickel alloy steel (NAS) as its primary structural material. Other materials would include the cast lead shielding between the containment boundary and inner shell, the elastomer O-ring seals, the borated resin neutron shield, and the carbon steel closure bolts. Socket head cap screws would be used to secure the inner and outer lids to the cask body. The body of the cask would consist of a 1.25 inch thick, 66.25 inch inside diameter, NAS inner (containment) shell and a 2.75 inch thick, 80.25 inch outside diameter, NAS structural shell which sandwich the 3.00 inch thick, cast lead shielding material. Lead shielding would also be located in the lower end structure and in the inner lid.

The 6625B-HB cask design includes a containment boundary consisting of the 66.25 inch diameter inner shell, a 1.25 inch thick bottom plate, an upper end structure, a 3.00 inch thick inner lid with a 3.50 inch thick shield plug with innermost seals and closure bolts, vent, and drain ports with closure bolts and seals, and containment welds. A 66.25 inch diameter, 182.00 inch long cavity is provided within the containment boundary as shown in Figure 2.

The design includes a redundant mechanical closure provided by the 2.50 inch thick outer lid with outermost seals and closure bolts, and the vent port with closure bolts and seals. The outer closure lid along with the space between the lids meets the design and manufacturing criteria such that it could be merged with the inner containment space to define an extended containment boundary. The extended containment boundary would be used only in the unlikely event that the boundary defined by the inner lid ceases to meet leak tight criteria. Both closure lids have been designed to perform the containment function with final qualification by leakage rate testing according to ANSI N14.5 [4].

The containment vessel is designed to prevent leakage of radioactive material from the cask cavity. It would maintain an inert atmosphere (helium) in the 6625B-HB cask cavity. Helium within the cavity would assist in heat removal and provide a non-reactive environment to protect fuel assemblies against fuel cladding degradation. To preclude air in-leakage, the cask cavity would be pressurized with helium to above atmospheric pressure.

CERTIFICATION APPROACH

The 6625B-HB packaging is designed as a Type B(U)F–96 shipping container in accordance with the provisions of 10 CFR Part 71. The conceptual cask design utilized materials and analysis methods with previous certification precedent in order to provide reasonable assurance that the cask system design can be certified by the NRC. Actual certification of this conceptual cask system by the NRC would require completion of detailed design calculations and certification testing, which were outside the scope of the study. Analytical evaluations or comparisons to previously certified designs were performed to ensure adequacy of the structural, thermal, containment, shielding, and criticality design features of the 6625B-HB transport package. A selection of specific certification requirements for the design is described below.

10 CFR 71.55(b) requires that a package must be designed so that it would be subcritical if water were to leak into the containment system, or liquid contents were to leak out of the containment system. To meet this requirement, burnup credit will be taken for PWR SNF, but will not be taken for BWR SNF. Taking credit for burnup reduces the system reactivity due to depletion of fissile material and growth of fission product poisons. Burnup credit is not required for NCT because the package is assumed to be dry, as it is leak tight under NCT.

For packages under HAC, 10 CFR 71.55(e) requires that a package must be designed so that when subjected to HAC testing the package would be subcritical. For this condition, moderator exclusion instead of burnup credit is used as the certification basis because the condition of the fuel is unknown. Burnup credit is not required because moderator exclusion results in a low reactivity. To ensure a robust design, 'defense-in-depth' cases are also performed in support of 10 CFR 71.55(e). In the defense-in-depth cases, reasonable fuel damage is assumed with fresh water moderation and burnup credit is applied. For these cases, the upper subcritical limit (USL) may be based upon an administrative margin of 0.02 (an administrative margin of 0.05 is used under all other conditions).

Moderator exclusion is employed as a certification basis to demonstrate compliance with the sub-criticality requirements of 10 CFR 71.55(e). The guidance and criteria provided in Interim Staff Guidance 19 (ISG-19) [3] are employed for this purpose. Specifically, 10 CFR 71.55(e)(2) states that to demonstrate sub-criticality under HAC, it must be assumed that "water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents." ISG-19 establishes criteria under which it is possible to demonstrate that the worst-case damaged condition of the package does not result in water in-leakage. This allows the HAC criticality calculations that form the certification basis to be performed assuming there is no water in-leakage.

DESIGN CHALLENGES

Design challenges for the packaging included accommodation of fuel packaged in DFCs, package weight restrictions, and accommodation of high burnup fuel. The goal of the package design was for it to be capable of transporting bare SNF or SNF loaded in DFCs. This unique constraint drove the design of the basket to provide duel capability while maximizing capacity. The DFC body is designed with a thin sheet metal body and a thicker reinforcement at the can lid to allow for closure and lifting. The thicker lid was integrated into the basket design with no additional space required or loss in basket capacity. This was achieved with removable sleeves which provided the additional clearance needed to insert the DFCs. The fuel compartment tubes are designed to be capped with the removable sleeve, which would be removed when a DFC is used, taking advantage of the DFC reinforcement to provide basket structural support for axial loads. This concept allowed the basket to accommodate the DFC without reducing fuel assembly capacity.

The main limitation for accommodating almost all of the commercial light water reactor SNF was the 125 ton limit for SFP cranes. This limit was established so that most site cranes currently in operation could be utilized for the 6625B-HB package. Once the weight limit had been established, it dictated a limiting diameter for the cask, which in turn established the maximum quantity of PWR fuel assemblies that could be placed within the cask. With this maximum quantity of PWR fuel assemblies (24 fuel assemblies), the thermal loading, assembly burn-up, and required cooling times were optimized to ensure this quantity of PWR fuel assemblies could be safely placed in the cask. The inclusion of DFCs did not have a penalty on the package capacity (i.e., no fuel assemblies had to be removed to meet the weight limit when DFCs were included). The cask was designed to accept a full load (i.e., 24 assemblies) of the heaviest type of PWR fuel. The next-highest capacity using a symmetric array (i.e., 32 assemblies) could accommodate more light fuel, but would need to be short-loaded (less than 32 assemblies) for much of the PWR fuel inventory of heaviest arrays.

High burnup fuel with short cooling times result in large gamma and neutron sources. The gamma source is shielded with a standard steel-lead-steel cask design. The neutron source is shielded with 6 inches of neutron shielding material between the impact limiters, and 5 inches of neutron shielding material is extended approximately 11 inches into the impact limiters (see Figure 2). Extending the neutron shield into the impact limiters is a novel design feature compared to similar existing designs. Also, the aluminum support rails (see Figure 3) are made of solid aluminum, which enhances shielding compared to a hollow rail design.

The high burnup fuel with the short cooling period before shipment would carry with it a high transportation heat load. Materials were selected to optimize the balance between rejecting the internal heat load during transportation conditions and minimizing the heat uptake from external transient heat loads such as in a transportation fire event. The large thermal mass of the package also would assist in mitigating transient events. Insulation would be placed within the packaging to protect and isolate the impact limiter material from the high temperatures of the cask. Both steady–state and transient thermal modeling were used to demonstrate that the design will accommodate the high thermal load of the payload.

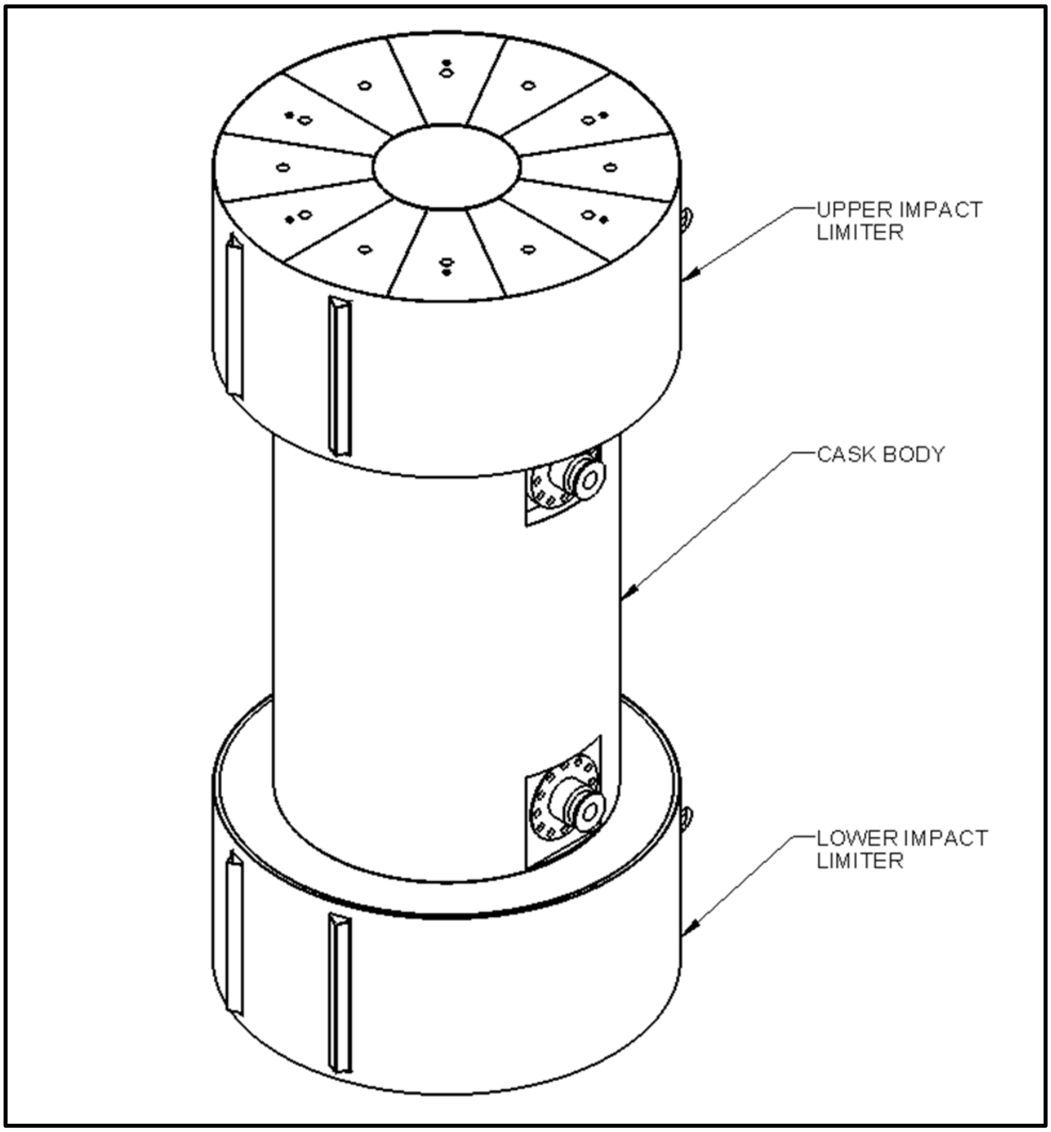

Figure 1. 6625B-HB Transport Cask

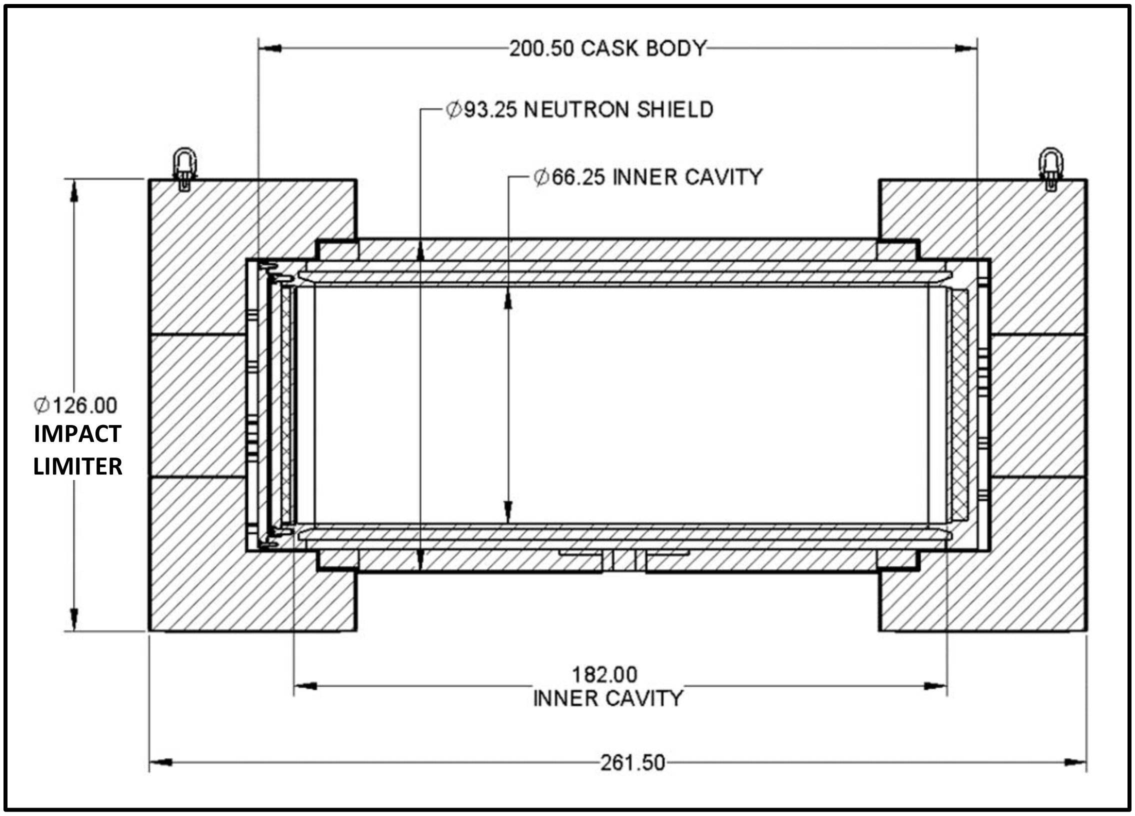

Figure 2. 6625B-HB Package Dimensions (inches)

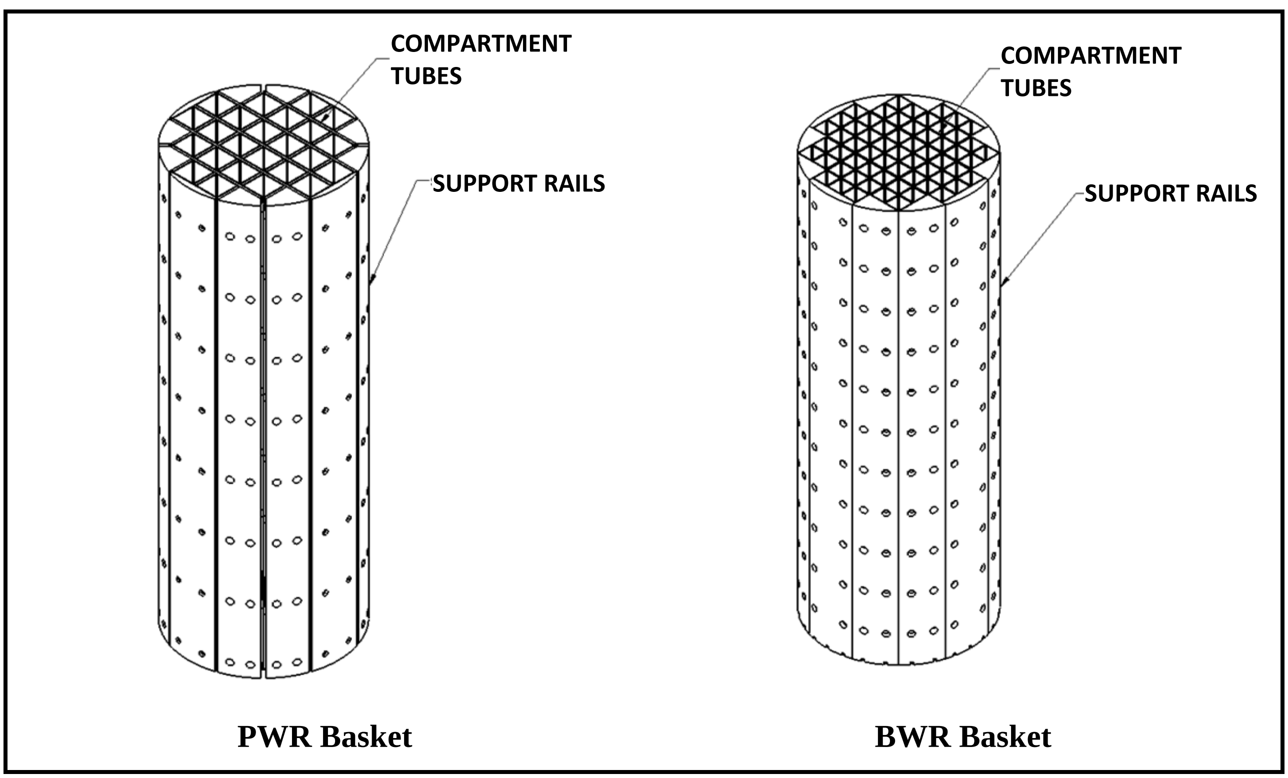

Figure 3. 6625B-HB 61 BWR Basket and 24 PWR Basket

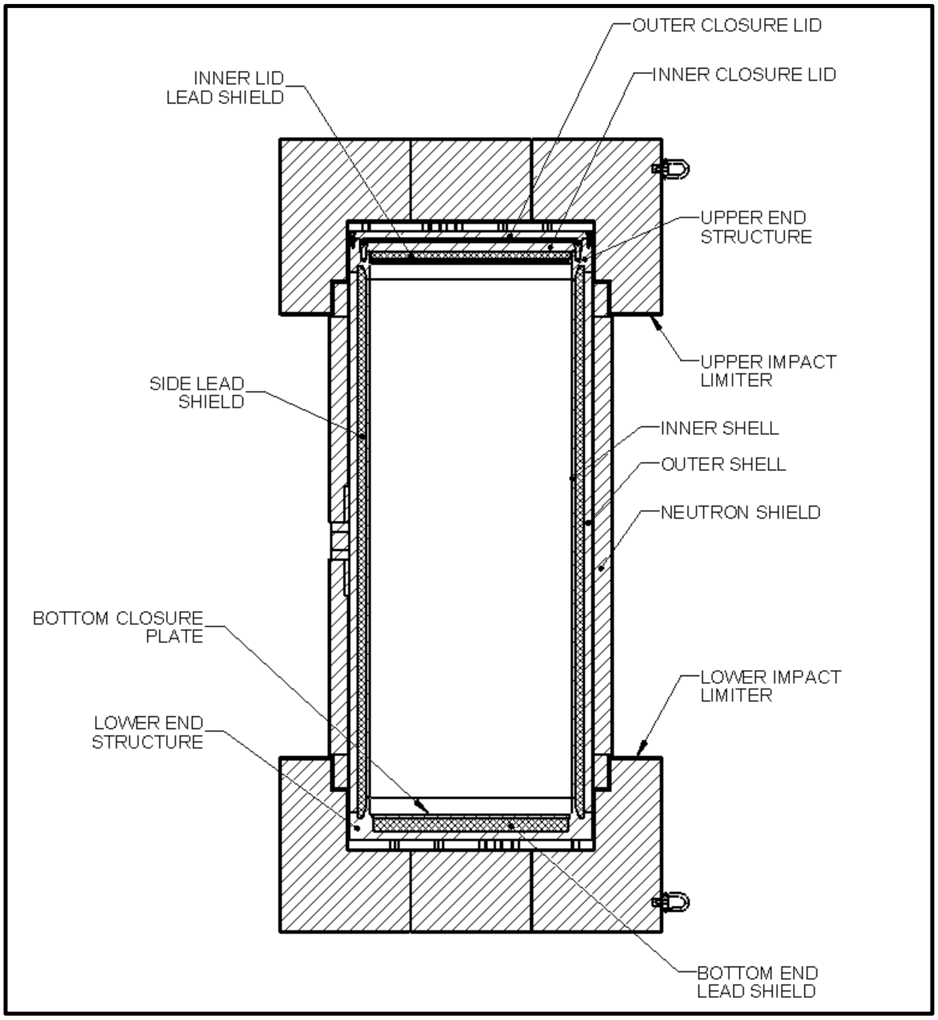

Figure 4. 6625B-HB Package Cross-Section

CONCLUSION

The 6625B-HB cask concept was designed by AREVA for rail transport of SNF, including high burnup SNF, for the DOE under a task order arrangement. The 6625B-HB conceptual design is based on current state-of-the-art industry designs that have been certified by the NRC. By using proven methodologies that have been utilized for previously certified casks, a high degree of confidence is obtained for this conceptual design. This approach provides reasonable assurance that the design will meet the regulatory requirements and provide safe transport of SNF. Although detailed analysis was not performed in all areas within the constraints of this conceptual design study, the configurations used in the design have been proven acceptable based on very detailed analysis and testing over the years. The design was developed using currently accepted industry practices with the goal of maximizing the package contents within the design basis restrictions, including a weight limit and required cavity length. The selected design was optimized for transporting high burnup fuel while continuing to meet thermal, shielding, criticality, and structural regulatory requirements and also limiting adverse impacts to: operations, the ability to fabricate the system, and fabrication costs.

REFERENCES

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2. AREVA Federal Services LLC, Report No. RPT-3011681-000, "Task Order 17 – Cask Design Study Final Report." March 2015.
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4. American National Standards Institute (ANSI), Inc., "American National Standard For Radioactive Materials – Leakage Tests on Packages for Shipment," ANSI N14.5–2014.