MASTER

CONCEPTUAL DESIGN OF A SHIPPING CASK FOR
RAIL TRANSPORT OF SOLIDIFIED HIGH LEVEL WASTE

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

by
R. E. Rhoads
P. L. Peterson

May 1978

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Prepared for the
U.S. Department of Energy
under Contract EY-76-C-06-1830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONCEPTUAL DESIGN OF A SHIPPING CASK FOR RAIL TRANSPORT OF SOLIDIFIED HIGH LEVEL WASTE

R. E. Rhoads and P. L. Peterson
Battelle, Pacific Northwest Laboratories

Reprocessing of spent fuel from commercial light water reactors (LWR's) has been deferred indefinitely while the international safeguards issues associated with plutonium extraction and recycle are being debated. If it is eventually decided to proceed with the reprocessing option, much work remains to be done to develop commercial facilities and equipment to solidify the high level liquid waste (HLLW) produced during chemical reprocessing of LWR fuel; to transport the waste from the reprocessing plant to a federal radioactive waste repository; and to isolate the waste from the environment until the radioactivity has decayed to nonhazardous levels. The Department of Energy has conducted a variety of research activities in these areas to insure that reprocessing and waste disposal technology will be available if the decision to use this technology is made.

A shipping cask uniquely designed to transport solidified high level waste (SHLW) from reprocessing spent LWR fuel has not yet been developed. Battelle, Pacific Northwest Laboratory (PNL) has conducted a program for the Department of Energy to develop a conceptual design for a rail cask for transporting SHLW, and to produce models and graphical displays based on the conceptual design for use at technical meetings and in public information displays. The results of this work are summarized in this paper.

The design of a shipping container for radioactive materials is dependent on a variety of factors or design constraints, including federal regulations, the characteristics of the material to be transported, limitations of the transport mode, and operating considerations. Economics and logistics considerations dictate that a shipping cask should be able to transport the maximum volume of SHLW possible within these design constraints. The general approach used to develop the conceptual cask design was to:

- Review current technology in high-level waste solidification.
- Select a reference or baseline canister design and associated characteristics based on the current technology.
- Establish design constraints due to SHLW properties, the railroad transportation environment, and requirements for handling or storing the canisters.
- Identify design constraints imposed by current federal hazardous material transportation regulations.
- Review current technology in spent-fuel casks.

FIGURE 1. Conceptual Solidified High-Level Waste Shipping Cask and Railcar

The cask body is a series of concentric shells. The inner wall, constructed of 1.9-cm thick stainless steel, is surrounded by a lead gamma radiation shield 20-cm thick. The gamma shield is contained by a 5-cm thick stainless steel structural wall. A 10-cm thick borated water neutron shield surrounds the other structural wall. The neutron shield water is divided among four compartments. Each compartment is connected to a 100 $\pm$ expansion tank that permits the water to remain at a pressure of about 1 atmosphere over the maximum range of temperatures expected during normal operation. Each compartment is also supplied with a pressure relief valve that prevents the neutron shield water pressure from exceeding 5 atmospheres. Ethylene glycol is added to the shield water to prevent freezing when the cask is shipped empty. The cask body is completed by a 1.2-cm thick stainless steel outer wall and a series of radial cooling fins 1.2-cm thick and 10-cm thick.

The stainless steel cask lid is constructed in two pieces. Double lid construction has been used on some large spent fuel casks. This concept provides a stronger closure since more area is available for attaching the head bolts. The inner lid of the conceptual cask contains a 12.7-cm thick layer of depleted uranium for gamma radiation shielding. Depleted uranium is used to provide additional strength in the lid if the cask is involved in an accident. The outer lid contains a 7.6-cm thick layer of solid hydrogenous material for neutron shielding. The stainless steel fins on the outer lid function as impact absorbers in an accident. Each lid is attached to the cask body by twenty 5-cm diameter stainless steel bolts. A metallic o-ring gasket is used to seal the outer lid to the cask body. The cask bottom is not removable, but is otherwise similar to the lid. Four 18-cm diameter trunnions are mounted on the cask. The trunnions extend 14 cm from the cask body and support the cask during handling and shipping.

The cask tiedown and handling systems are permanently mounted on the railcar. The tiedowns consist of four massive columns that support the cask during shipment. The trunnions on the cask body rest on the support columns. The cask is clamped in place at each end by a steel semicircular retaining ring 2.5-cm thick that is bolted to the top of the support columns. Energy-absorbing impact fins are welded to the steel rings. A support pad is located under the front and rear of the cask to provide additional restraint if the cask and tiedown assembly is subjected to large axial accelerations during shipment.

FIGURE 2. Conceptual Solidified High Level Waste Shipping Cask Structural Details

The cask is unloaded from the railcar by removing the retaining rings, lifting the cask with the installed hydraulic jacks so that the forward set of trunnions clears the support column, and attaching a specially designed lifting cradle suspended from a large crane to the trunnions. The cask rotates about the rear trunnions while it is lifted to the vertical position with the crane.

The depressed center railcar shown in Figure 1 is a standard design with some modifications to accommodate the conceptual cask. The deck of the car is steel to facilitate attachment of tiedown equipment and permit easy cleanup of any radioactive contamination that might occur. The support columns and associated bracing and the hydraulic jacks and auxiliary equipment are permanently mounted on the car. An expanded metal cage covers the cask during shipment. This cage keeps debris off the cask and prevents people from contacting the heated outer surface of the cask. The cage is constructed in two pieces that slide back onto the car deck during cask loading and unloading operations.

BASES FOR REFERENCE DESIGN

Much of the cask design is defined by the constraints discussed previously. Design alternatives are available for satisfying many of these constraints. The choice among design alternatives is usually dictated by economics. The task of the designer is to satisfy the design constraints in the most cost-effective manner. A detailed economic analysis was beyond the scope of this study, so the choice of design approaches and construction materials is based primarily on historical experience with spent fuel casks. In some instances, the choice was based on simplicity or clarity for the models that were subsequently produced. The major areas

of consideration in developing a SHLW cask design are cask structure, heat dissipation, radiation shielding, and cask mounting and handling. The bases for the designs selected in these areas are outlined briefly below.

The primary determinant of cask structural strength requirements are the Type B package accident test criteria. The conceptual design relied on the basic shell configuration used for spent fuel casks that have been shown to meet these test criteria. Preliminary calculations have been made that indicate that the conceptual cask design would survive the puncture test and the 9-m drop test. Calculations were not made for the crush and immersion tests because it was felt that these tests produce much lower stress levels in the cask than the puncture and 9-m drop tests.

The conceptual cask is supplied with energy-absorbing impact fins on the ends and on the retaining rings that hold the cask to the support columns during shipment. These fins are designed to minimize damage in a severe transportation accident. The radial cooling fins would also function as energy absorbers in an accident. Impact absorbers used on large casks for carrying radioactive materials are generally balsa wood, steel fins, or rolled steel shapes. Fins were used for the conceptual SHLW cask design primarily for the simplicity and resulting clarity in a visual display. Internal impact absorbers fabricated from an aluminum honeycomb material were also added at each end of the SHLW canisters because the canisters are readily adaptable to this type of additional protection.

A compatible thermal environment must be provided for the SHLW canisters during both normal transit and under accident conditions. A passive heat dissipation system is preferred because it simplifies the design and construction of the cask and is generally easier to license. The design approach to develop an effective passive heat dissipation system was to minimize all air gaps within the cask. The problem of asymmetric heat transfer due to the canisters being inserted in an oversize hole in the aluminum magazine in the center cavity was minimized by providing a spring-loaded three-piece positioner around each canister as shown in Figure 2. The aluminum magazine was designed such that differential thermal expansions would minimize the gap between the magazine and the inner wall of the cask shell as the temperature rose. Cooling fins were provided on all outside surfaces to facilitate heat transfer.

A thermal analysis of the conceptual cask under normal operating conditions and postulated accident conditions was performed. Two cases were analyzed: 1) a steady state analysis to determine temperatures at key positions in the cask during normal operation, and 2) a transient analysis to determine temperatures in the cask as a function of time if the cask were exposed to a 1000°C fire for one hour. Results of these calculations are summarized in Table 2.

The steady-state analysis shows that the waste centerline temperature, canister surface temperature, and lead shielding temperature could be maintained at acceptable levels in the conceptual cask. The analysis also shows that the cask surface temperature during normal operations will generally be 15-25°C higher than the regulatory guideline of 80°C. This condition is also present in many spent fuel casks currently in use. This necessitates installation of the screen shown in Figure 1 to keep personnel away from the hot surface of the cask.

The transient thermal analysis showed that the SHLW would maintain its containment integrity during exposure to a 1000°C fire for one hour. The analysis assumed that the neutron shield water would be released through the pressure release device soon after the fire began. Because the waste has a relatively low heat generation rate and the cask body has a large heat capacity, the temperature of the waste does not change significantly during exposure to a 1000°C fire for one hour. Some melting of the outer layers of the lead shield may occur at the end of the one-hour fire, but this would not significantly affect the radiation dose rate at the surface of the cask. The analysis indicates that the conceptual cask would remain undamaged during the thermal test required by NRC and DOT regulations (800°C fire for 30 minutes).

Typical shielding materials used in large shipping casks are lead, iron and depleted uranium. Because of the many factors that must be considered, the choice of a shielding material usually involves trade-offs with other cask design parameters. Detailed economic, engineering and safety analysis studies are required to select the optimum shielding material for a

TABLE 2. Results of Thermal Analysis of Conceptual Cask Design

Location Within Cask	Steady State Temperature ^(a) (°C)	Temperature (°C) During Exposure to 1000° Fire		
		20 min ^(b)	40 min ^(b)	60 min ^(b)
Center of SHLW ^(c)	450	450	450	450
Canister Surface ^(c)	415	415	415	415
Lead Shielding	190	200	240	305
Neutron Shield ^(d)	125	--	--	--
Cask Surface	105	1000	1000	1000

(a) Ambient air temperature is 50°C.

(b) Time after start of fire

(c) Hottest canister

(d) The neutron shield is assumed to be released through the pressure relief device in an extended fire.

particular cask. Such studies are beyond the scope of efforts performed for a conceptual design. The shielding material selections were based on past experience with spent fuel cask designs and engineering judgment of a reasonable balance between the many competing factors.

Lead was selected for the gamma shield material in the shell of the cask because 1) it is generally the least expensive gamma shield material, 2) the temperature during operation was well below the melting point (330°C), 3) the thermal analysis showed that significant melting with the resultant loss of shielding did not occur during exposure to a 1/2-hour fire at 800°C, and 4) the strength of the shielding material was not critical to cask integrity. Depleted uranium was selected for the closed end and lid of the cask body because of its inherently greater strength and resultant resistance to axial impact or puncture forces. The use of uranium in the ends of the cask body has the additional advantage of serving as a neutron reflector.

EFFECT OF CHANGES IN WASTE CHARACTERISTICS

The conceptual cask system is based on a reference SHLW canister with fixed physical characteristics. The design developed in this study provides some flexibility to accommodate SHLW canisters with different configurations and properties, but significant changes in some waste properties would require a different design. The SHLW characteristics identified as most influential on cask design are the heat generation rate and the gamma radiation level. These characteristics establish the heat dissipation and shielding requirements.

The heat generation rate in the SHLW declines significantly during the first few years after the fuel from which the waste is created is removed from the reactor. The conceptual SHLW cask system described in this paper can dissipate up to 50 kw of decay heat with a passive heat dissipation system. If the age of the waste were less than approximately three years, an active system such as those based on spent fuel casks would be required to maintain the same shipping capacity. Higher thermal flux due to either younger waste or a stronger composition might also require the use of materials other than lead as a gamma shielding material because operating temperatures in the shield for a passive heat dissipation system would approach the melting temperature of lead.

Other waste characteristics can also significantly impact cask design. The volume of the canister assembly per unit volume of SHLW can change significantly from the reference value used

if a protective overpack is added to the canister before shipment or if the HLLW is diluted with larger quantities of inert material during solidification. Steel protective overpacks could add up to 15 cm to the diameter of the 30-cm diameter reference canister. The outer protective barrier would decrease the allowable heat flux from a basic 30-cm diameter canister. Overpacks adding more than 2 to 5 cm to the canister diameter would significantly reduce the capacity of a multiple-canister cask due to both greater shielding weight (the shielding layer would be at a great diameter) and constraints on the overall diameter to comply with railroad clearances.

The conceptual cask design is based on a reference SHLW canister diameter of 30 cm. Canister diameters ranging from 15 cm to 60 cm are being considered in HLLW solidification studies. The conceptual cask could be used to transport waste canisters of different diameters from the reference canister by fabricating a new aluminum magazine and inserting it in the cask cavity. The effect of alternative canister diameters on the cask design parameters is shown in Table 3. Larger canister diameters produce the most efficient shipping system because more waste can be transported per shipment and loading and unloading operations would be simplified with fewer canisters in each shipment. Further analysis would be required to determine if the conceptual cask had sufficient shielding and heat removal capacity to accommodate three 60-cm diameter canisters of 5-year-old waste, but this canister size would be favored on the basis of transportation system efficiency.

TABLE 3. Comparison of Alternative Canister Sizes

Canister Diameter (cm)	Maximum Number Of Canisters in Reference Cask	Waste Volume ^(a) Per Shipment (m ³)	Heat Generation Rate ^(b) (kw)
30	9	1.58	46
45	4	1.58	46
60	3	2.10	63
23	15	1.48	44
15	27	1.18	36

(a) 80% of theoretical canister volume

(b) Based on 5-year-old reference waste