Development of the GA-4 and GA-9 Legal Weight Spent Fuel Casks*

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INTRODUCTION

GA is nearing the completion of the final design of two legal weight truck spent fuel shipping casks, the GA-4 Cask for PWR fuel and the GA-9 Cask for BWR fuel. GA is developing the casks under contract to the U.S. Department of Energy (DOE) Field Office, Idaho, as part of the Office of Civilian Radioactive Waste Management (OCRWM) Cask Systems Development Program (CSDP). The casks will transport intact spent fuel assemblies from commercial nuclear reactors sites to a monitored retrievable storage facility or a permanent repository. The DOE initiated the Cask Systems Development Program in response to the Nuclear Waste Policy Act of 1982 which made DOE responsible for managing the program for permanent disposal of spent nuclear fuel and high-level waste. This paper describes developmental and design verification testing programs, and the present status of the GA-4 and GA-9 Cask designs.

CASK DESIGN GOALS

OCRWM selected designs which would enhance the overall safety and efficiency of the nuclear waste transportation system. GA's approach was to design two dedicated casks that would maximize payload and minimize the number of shipments, thereby minimizing life-cycle costs. The GA-4 Cask has the length and shielding necessary to carry four PWR assemblies with burnups up to 35,000 MWd/MTU and cooling times of ten years or more. The GA-9 Cask, which is approximately ten inches longer than the GA-4 Cask, will carry nine BWR assemblies with burnups of up to 30,000 MWd/MTU and cooling times of ten years or more. A common-use cask that could carry both of these spent fuels would have a capacity of three PWR or seven BWR assemblies at best. Both casks can be down loaded to carry fewer elements with higher burnups or shorter cooling times. GA is performing shielding analysis at this time to quantify the relationship between capacity, burnup and cooling time. This approach results in a legal-weight truck transportation system with the fewest number of shipments, lowest life-cycle costs, and most importantly, the greatest degree of public safety.

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Cask Arrangement

Figures 1 and 2 show the GA-4 Cask arrangement and the fuel support structure (FSS). The GA-9 Cask arrangement is very similar to that of the GA-4 Cask. The GA-9 fuel support structure divides the cavity into nine compartments instead of four as in the GA-4. The cask body shape closely follows the shape of the array of spent fuel assemblies. This uncommon shape of flat sides with rounded corners contributes to achieved capacity of four assemblies. The depleted uranium gamma shield also is shaped to fit the shape of the contents. The sides of the gamma shield are thicker than the corners since the flux is greater at the sides than at the corners. The depleted uranium shield's strength, which is not considered in the structural analysis, adds significantly to the structural capabilities of the cask. Similarly, the neutron shield is rounded at the corners, flat on the sides, with the sides thicker than the corners. At each end of the casks is an aluminum honeycomb impact limiter to absorb energy and limit forces during an impact. The impact limiters are identical for the GA-4 and GA-9 Casks.

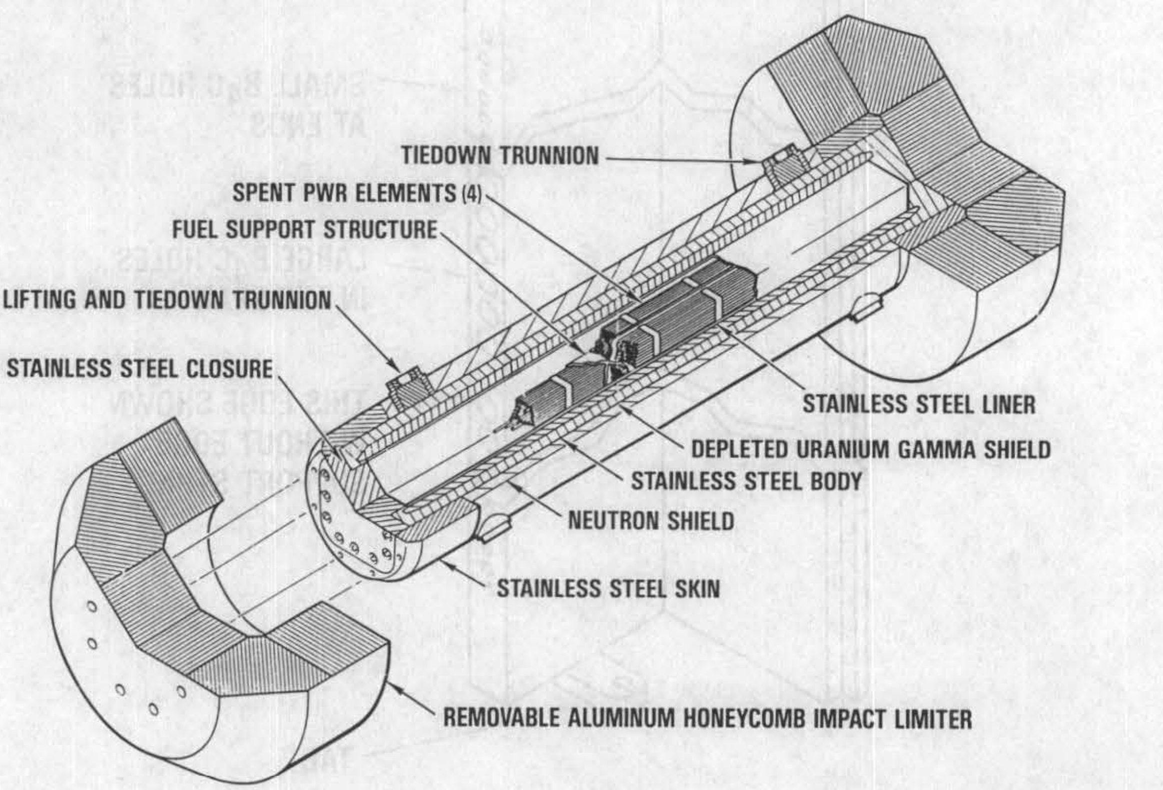

Fig. 1 GA-4 Cask Exploded View

The GA-4 and GA-9 Casks use a fuel support structure rather than a traditional basket to separate and support the fuel assemblies. Figure 2 shows the GA-4 Cask fuel support structure which consists of welded XM-19 stainless steel plates with drilled holes to accept solid B_4C rods. After the holes are filled with B_4C, they are covered with welded edge plates. The use of solid B_4C permits a more compact array than would be possible using a matrix of boron and aluminum. The fuel support structure is removable for repair or decontamination, but the cavity liners are integral with the casks.

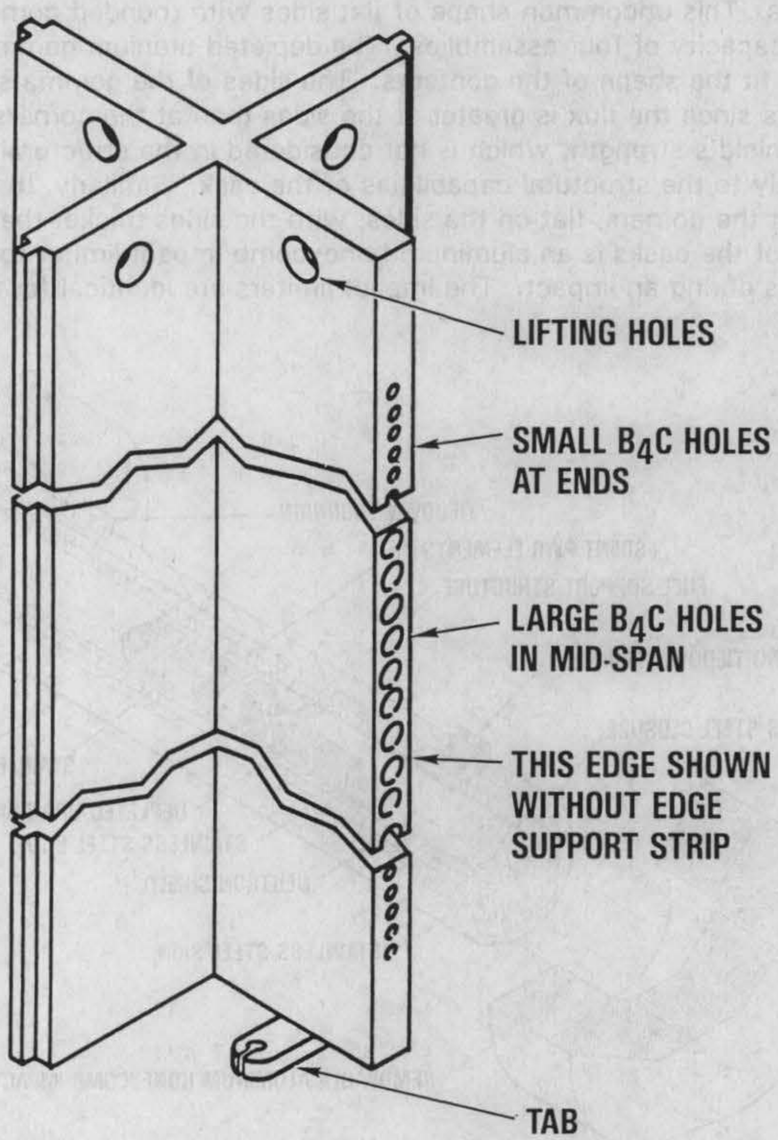

Fig. 2 GA-4 Fuel Support Structure Showing Holes for B_4C Pellets

GA-4 Burnup Credit

The GA-4 Cask relies on burnup credit to maintain criticality control for enrichments greater than 3 wt% U-235 (Boshoven, 1992). Relying on burnup credit means that the criticality control design considers the depletion of U-235 and the buildup of actinides and solid fission products. For PWR fuel with enrichments of 3% or less, and for all BWR fuel, the casks meet the requirements for criticality safety using an assumption of fresh fuel. Solid boron carbide pellets provide the needed degree of poison to assure subcriticality under optimum moderation for both the GA-4 and GA-9 Casks. Measurements of PWR fuel assemblies with enrichments greater than 3 wt% U-235 will be performed prior to loading to assure that the GA-4 Cask contains neither fresh nor under-burned fuel.

Neutron Shield Material Qualification

Earlier this year, GA completed qualification testing of two polymer materials for use in the neutron shield (Boonstra, 1992). The two materials are Reactor Experiments' (RE) high-melt index polypropylene with boron and Bisco Products' (BP) Modified NS-4 with boron.

GA's contract with the DOE requires the use of a solid material for the neutron shield. This requirement comes from the desire to avoid the problems of liquid materials, i.e., leaking and thermal expansion due to freezing or boiling. With solid materials, the challenge is finding a material with high hydrogen content and low density that is self-extinguishing after exposure to a fire environment.

In January 1992, we tested RE high-melt index polypropylene. This material self-extinguished within 15 minutes after removal from the 1475°F fire environment and thus passed the test. The temperature on the back side of the polypropylene stayed below 212°F. The other material, BP Modified NS-4 with boron, passed the test by self-extinguishing after a 30-minute exposure to the fire environment. The polypropylene material has a greater hydrogen concentration per unit weight than the Modified NS-4 with boron, which makes the neutron shield 700 lb lighter.

Impact Limiter Design

The configuration of the aluminum honeycomb impact limiters is identical for both casks. The design has been refined through three successive quarter-scale model test programs where the models were statically crushed in a compression testing machine to obtain force-versus-deflection data (Koploy, 1992). As a result of the development testing, we refined the design which now has honeycomb of three different crush strengths and three different cell orientations. We have also demonstrated that the impact limiters will absorb the required energy and that their attachments are sufficient to assure the impact limiters will remain with the cask during the regulatory accidents. We are in the process of fabricating a half-scale model that we plan to destructively test to verify the structural design under dynamic conditions.

An efficient system of radial ribs of XM-19 stainless steel transmits impact limiter loads to the sides of the cask body through the non-structural neutron shield. Figure 3 shows the ribbed support structure which extends to the top of the closure and protects the

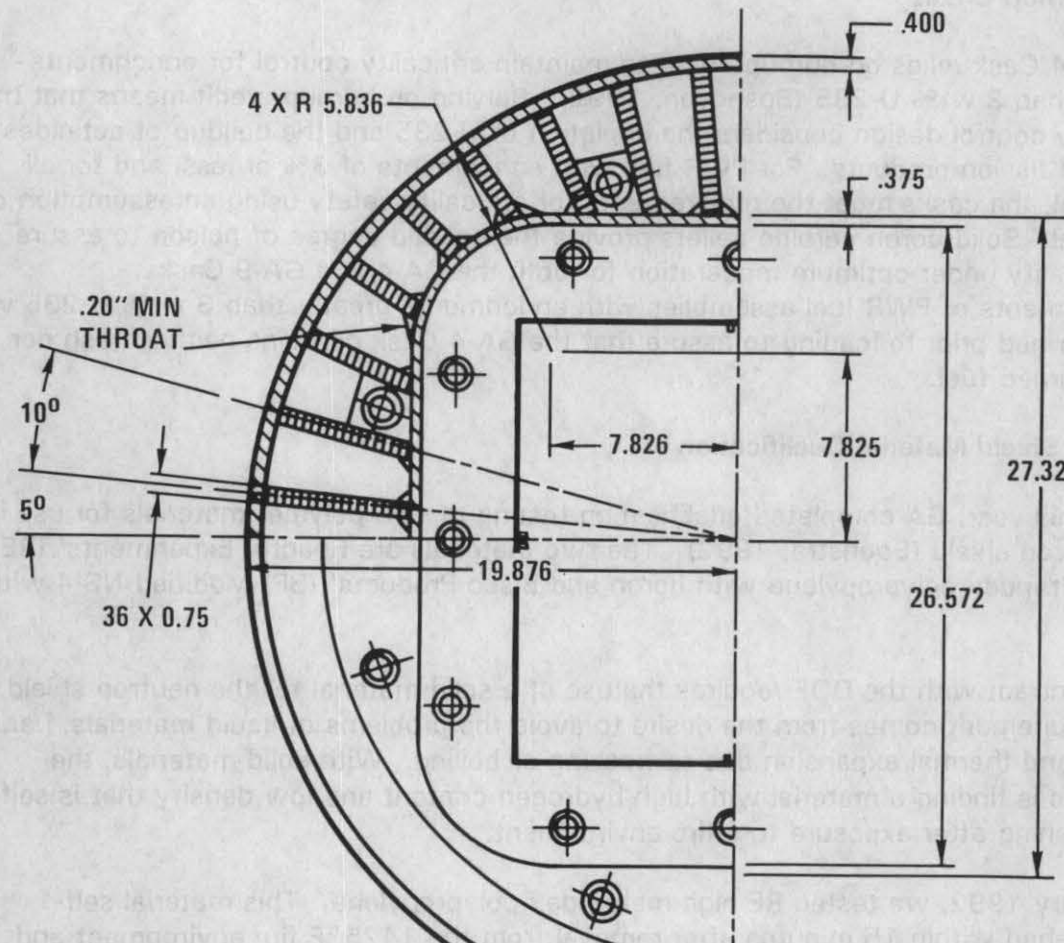

Fig. 3 Top View of GA-4 Closure-End Impact Limiter Support Structure

closure from direct loads from the impact limiter during a 30-foot drop event. The support structure protects the closure without incurring the weight penalty of extending the steel cask sidewalls up to the top of the closure. The ribs utilize lightening holes to further minimize the weight of the structure.

Thermal Design Limits

The GA-4 and GA-9 Casks meet all thermal design limits for both normal and hypothetical accident conditions of transport. GA used a design heat load of 617 W per PWR assembly and 205 W per BWR assembly with an axial power profile having a peaking factor of 1.22 to calculate the maximum temperatures. Table 1 shows the maximum temperatures of the GA-4 and GA-9 Cask components during normal

TABLE 1 MAXIMUM COMPONENT TEMPERATURES (°F) FOR NORMAL TRANSPORT CONDITIONS

	GA-4 Cask	GA-9 Cask	Design Limit
Fuel Cladding	348	299	716
Fuel Support Structure	343	283	700
Cavity Liner	273	234	700
Gamma Shield	232	204	>700
Cask Wall	221	197	700
Neutron Shield	221	197	250
Outer Skin	197	185	>250
Closure Seal	143	134	300
Impact Limiter	145	140	200
Personnel Barrier	136	134	180

conditions of transport and the corresponding design temperature limits. The table shows that all component temperatures have comfortable margins. For the hypothetical accident conditions, we imposed the regulatory radiation environment temperature of 1475°F with an emissivity of 0.9 for 30 minutes. For this condition, the package surface absorptivity is 0.8. As the neutron shield and outer skin are not designed to withstand the 30-foot drop and puncture sequence of accidents, the fire accident condition thermal model assumes the absence of these components. Other conditions assumed for the fire accident include crushing of the closure-end impact limiter and a 6-inch wide gash across its top which exposes the closure surface to the hot environment. Table 2 shows the maximum temperatures of critical components during the hypothetical fire accident and the corresponding temperature limits. The table shows that all critical components are within temperature limits.

Future Design Changes

The cask designs have undergone review by the DOE Transportation Review Group, the Edison Electric Institute's Utility Nuclear Waste and Transportation Program, and a DOE-sponsored Independent Review Group. As a result of these reviews, GA has or is performing feasibility studies to evaluate several design modifications. These include accommodating BWR water channels in the GA-9 Cask, increasing the clearance between the impact limiters and the support structure to facilitate removing and installing the impact limiters, and developing a four-element version of the GA-9 Cask which will accommodate CE 16x16 PWR fuel. CE 16x16 PWR fuel is about 10 in. longer and 0.3 in. narrower than most of the other PWR fuels and, thus, will fit in the GA-9 but not the GA-4 Cask.

The GA-9 Cask fuel support structure is being modified so that it will not extend to the top of the cask. With this modification, there is sufficient space in the upper region of the cavity to accommodate channel clips and spacer buttons that extend beyond the

TABLE 2 MAXIMUM COMPONENT TEMPERATURES (°F) FOR HYPOTHETICAL ACCIDENT CONDITION

	GA-4 Cask	GA-9 Cask	Temperature Limit
Closure	720	720	>1000
Closure Seal	365*	361*	> 500
Cask Body	1140	1140	1500

* Above 350°F for Less Than 1 Hour

envelope of the water channels. The existing cavity dimensions of 5.74 in. square are adequate to accommodate the water channels, considering the deformations that occur during reactor operation.

For increasing the operating clearance between the impact limiter and the cask, GA is developing a design using slightly tapered conical mating surfaces. With a 1.5 degree taper, the diametrical clearance increases to more than 1.25 in. when the impact limiter begins to engage with the cask.

Future Tests

GA plans to perform prototype endurance testing of the cask semitrailer, full-scale closure seal design verification tests, as well as half-scale structural model tests of the hypothetical accident condition 30-ft drop and puncture sequence.

We will subject a prototype GA-9 Cask trailer to 8,000 miles of fully-loaded operations on a test track to simulate approximately 250,000 actual miles. We will establish the test track parameters based on a road profile test of a representative mix of state highway and interstate miles. The trailer will be instrumented to record g-levels. We will inspect the trailer structure periodically to monitor for weld cracks and other signs of degradation.

GA also plans to verify the design of the closure seal system. The configuration of the seals and their grooves will be full-scale as there is no method to properly scale leakage tests. We will test the ethylene propylene seal material over its operational temperature range of -40°F to 365°F. The testing will include the effects of relaxation of seal compression that results from elastic deflections of the closure during the hypothetical thermal accident condition.

The structural adequacy of the cask design will be verified by a series of half-scale model tests of the GA-4 Cask. The half-scale cask will be subjected to three sequences of the hypothetical accident conditions of free drop and puncture specified in 10CFR71.73. We plan to do these drop sequences to ensure that the orientation with maximum damage is tested.

Sequence 1 is a 30-ft side drop of the cask onto an unyielding surface followed by a puncture drop against the side of the closure. Sequence 2 is a 15° from horizontal free drop (slapdown) followed by a puncture drop onto the center of the cask body. Sequence 3 is a free drop onto the top corner (center-of-gravity [c.g.] over corner) followed by a puncture attack on the top of the closure. All tests will be performed at ambient temperature with the cask pressurized to maximum normal operating pressure. Accelerations at key points on the cask body will be recorded to verify that maximum predicted stress levels are not exceeded during the drop events. In addition, gross dimensional checks will be made before and after each sequence. High speed cameras and video will be used for all tests. After each sequence a leakage test will be performed to verify that the containment boundary is intact.

REFERENCE

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