E66-M-91402

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DE92 017854

DEVELOPMENT STATUS OF THE GA-4 AND GA-9 CASKS*

Robert M. Grenier
General Atomics
P.O. Box 85608
San Diego, California 92186-9784
619-455-2583

ABSTRACT

General Atomics (GA) has developed two legal-weight truck spent fuel shipping casks for transporting commercial reactor spent fuel. The GA-4 Cask carries four pressurized-water reactor (PWR) assemblies, and the GA-9 Cask carries nine boiling-water reactor (BWR) assemblies. Depleted uranium and a borated polymer are the gamma and neutron shielding materials. Type XM-19 stainless steel is the structural material used for the cask body, closure and the structure which supports the fuel assemblies. The impact limiters are made of aluminum honeycomb. Solid boron carbide, contained in the removable fuel support structure, provides poison for criticality control. The GA-4 Cask uses burnup credit to maintain criticality safety with spent fuel assemblies having enrichments greater than 3 wt% U-235. GA has conducted an extensive test program for the neutron shield material and the aluminum honeycomb impact limiters. Additional planned testing includes verification testing of a half-scale model to confirm the structural design, full-scale high and low temperature leak testing of the closure seal design, and endurance testing of the semitrailer design.

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. 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 the final design of the GA-4 and GA-9 Casks and describes the developmental and design verification testing programs.

CASK DESIGN

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. 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.

The GA-4 Cask relies on burnup credit to maintain criticality control for enrichments greater than 3 wt% U-235. This 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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED 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.

Figures 1 and 2 show the GA-4 Cask arrangement and a cross section though the middle of the cask. Figure 3 shows the GA-9 Cask arrangement which is very similar to that of the GA-4 Cask. 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.

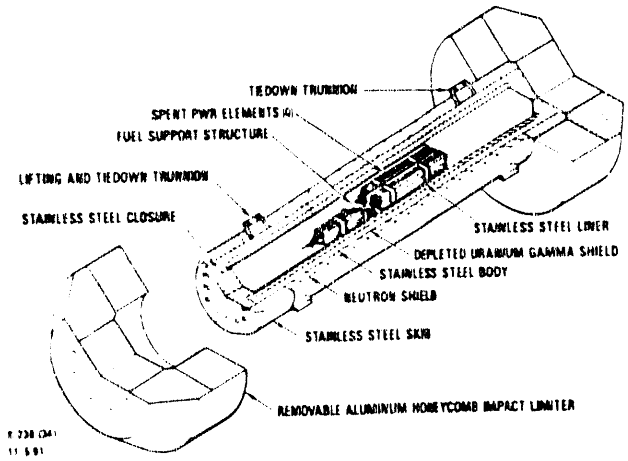

Fig. 1. GA-4 Cask Exploded View

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. GA is in the process of completing the qualification testing of several polymer materials under consideration for the neutron shield. The four materials under consideration are Reactor Experiments' (RE) high-melt index polypropylene with boron, Envirotech's (EN) high-density polyethylene with boron, EN high-melt index polypropylene with boron and Bisco Products' (BP) Modified NS-4 with boron.

The GA-4 and GA-9 Casks use a fuel support structure rather than a traditional basket to

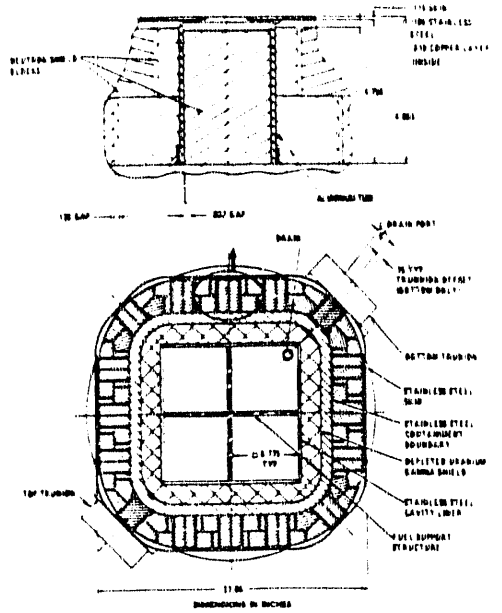

Fig. 2. GA-4 Cask Cross Section

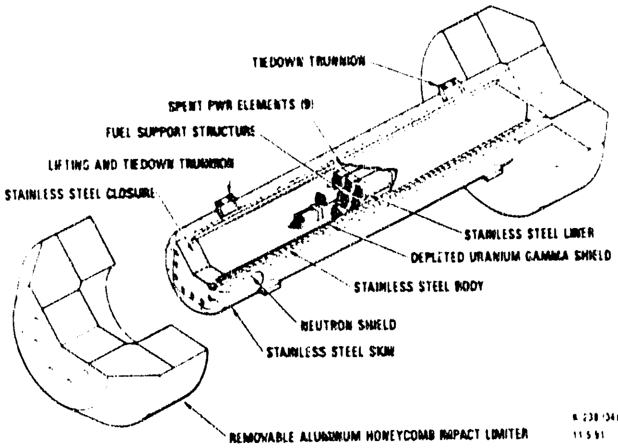

Fig. 3. GA-9 Cask Exploded View

separate and support the fuel assemblies. Figure 4 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 structures are removable for repair or decontamination, but the cavity liners are integral with the casks.

Figure 5 shows the configuration of the aluminum honeycomb impact limiters that are 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. Through the development testing program, we refined the design and have

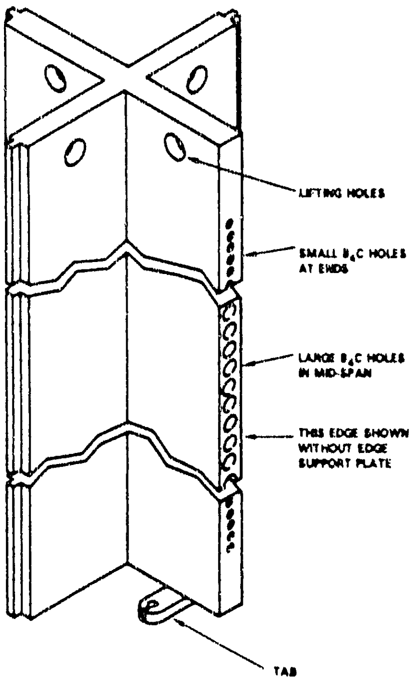

Fig. 4. GA-4 Fuel Support Structure Showing Holes for B_4C Rods

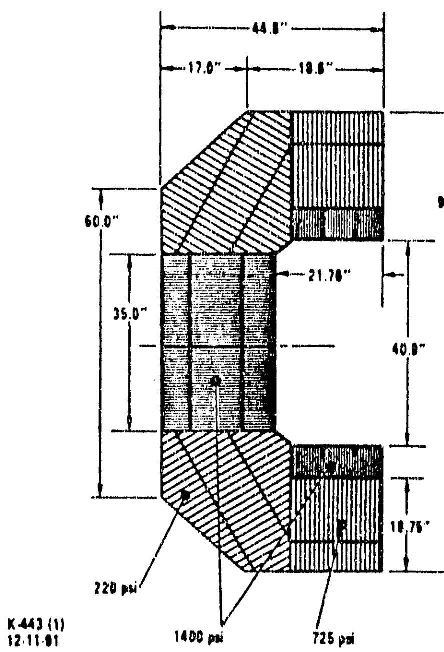

Fig. 5. Impact Limiter Design, Cross Sectional View Showing Different Honeycomb Parts

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. As a result of the development testing, refinements were made to the design which now has honeycomb of three different crush strengths and three different cell orientations.

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. Figures 6 and 7 show the ribbed support structure which extends to the top of the closure and protects the closure from direct loads from the impact limiter during a 30-foot drop event.

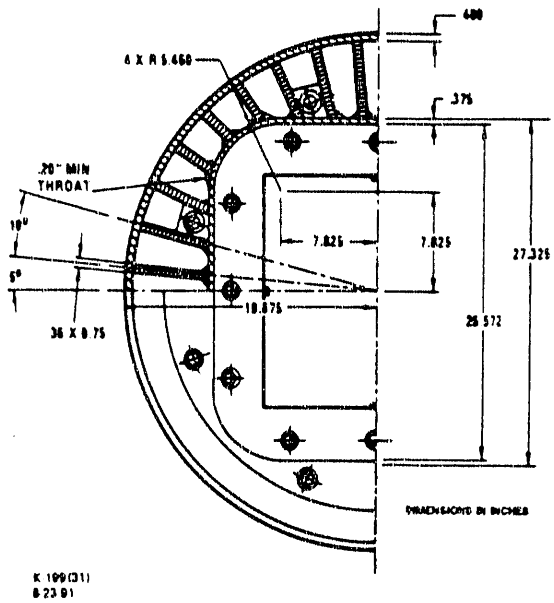

Fig. 6. Top View of GA-4 Closure-End Impact Limiter Support Structure

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.

The GA-4 and GA-9 Casks meet all their 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

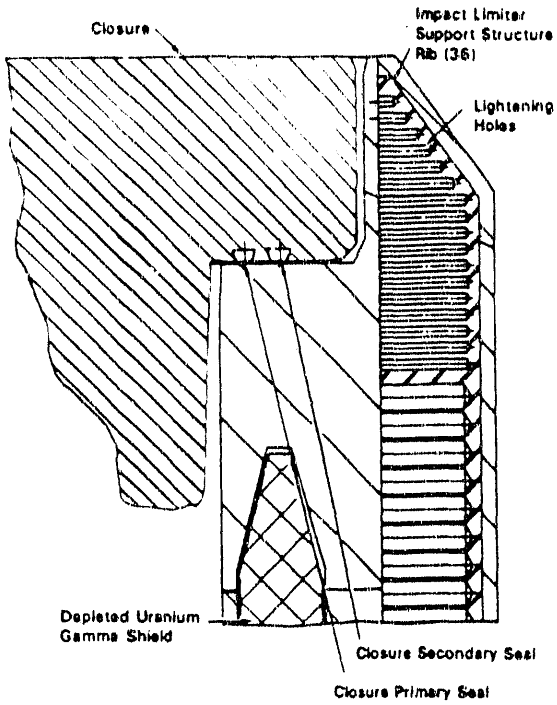

Fig. 7. Impact Limiter Support Structure Ribs and Closure Seal Configurations

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

shows the maximum temperatures of the GA-4 and GA-9 Cask components during normal conditions of transport and their 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 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

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

shows the maximum temperatures of critical components during the hypothetical fire accident and their corresponding temperature limits. The table shows that all critical components are within their temperature limits.

TESTING

Impact Limiter Development

GA performed a series of engineering tests to obtain data on the behavior of honeycomb impact limiters. The development program included testing of small samples to obtain basic information, as well as testing of complete quarter-scale impact limiters to obtain load-versus-deflection curves for different crush orientations. We used the test results to aid in the development of a computer code to predict the impact limiter loads. The results also helped us optimize the design of the impact limiters for the GA-4 and GA-9 Casks.

The test program had three phases. The first two phases consisted of honeycomb material tests and impact limiter component tests that provided information on the behavior of honeycomb and honeycomb impact limiters. The second and third phases consisted of tests of two successively optimized impact limiter designs. The results of the first two phases have been documented earlier.[1]

During the third phase, we tested four quarter-scale replicas of the impact limiter designs at seven different crush angles to provide load-versus-deflection data for the impact limiter. Three impact limiters were tested twice, on opposite sides. We tested the impact limiters in 15 degree increments ranging from side impact (90°) to end impact (0°).

Figure 8 shows the deformed shape of the impact limiter after a side crush (90°). Figure 9 shows the test setup and the compression testing machine used to crush the impact limiter. Figure 10 shows the test results and compares these with the range of analytical predictions resulting from possible variations in crush strengths of the honeycomb materials. At most of the other crush angles, our predictions were conservative and the models tended to absorb more than the predicted amount of energy. Table 3 shows that the energy

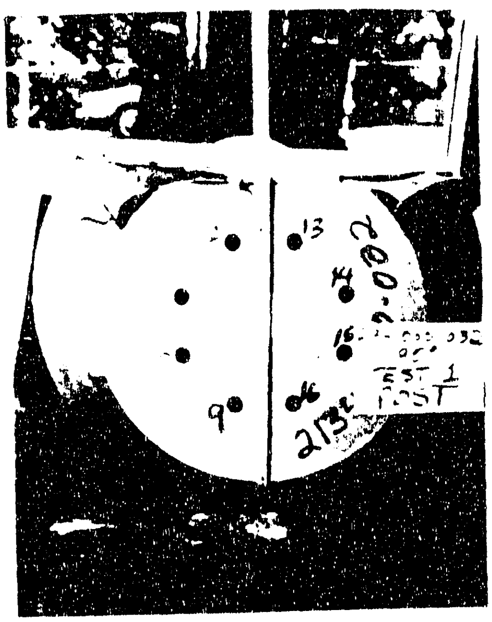

Fig. 8. Quarter-Scale Impact Limiter After a 0° Side Crush

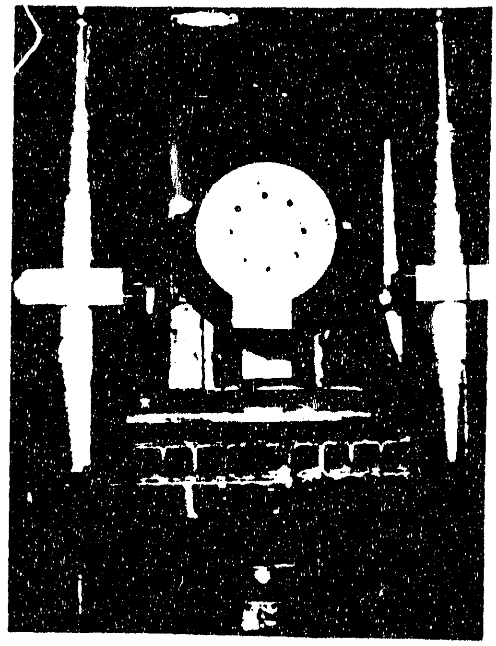

Fig. 9. Quarter-Scale Impact Limiter Test Set-Up

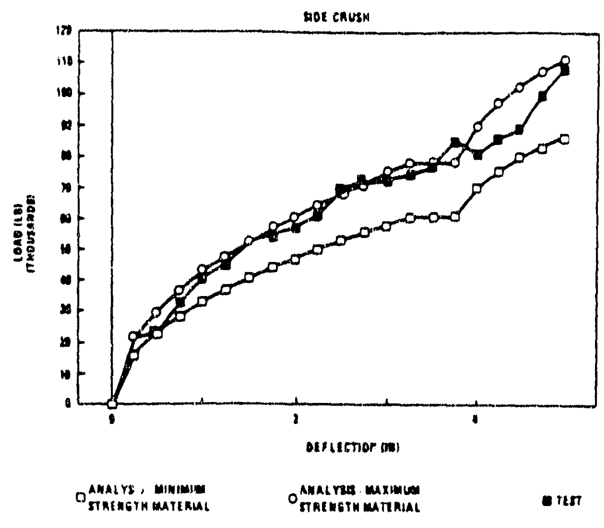

Fig. 10. Impact Limiter Test and Analysis Results Comparison for Side Drop

TABLE 3 COMPARISON OF QUARTER-SCALE IMPACT LIMITER CRUSH TEST RESULTS WITH DESIGN REQUIREMENTS

Crush Orientation	Quarter-Scale Model Energy Absorbed (in.-lbs)	Scaled Design Requirement (in.-lbs)*
0 (End)	717,000	293,000
15	698,000	293,000
30	626,000	242,000
45	464,000	213,000
60	218,000	213,000
75	480,000	213,000
90 (Side)	324,000	213,000

*Full-Scale Requirement Divided by 64

absorbed at each drop orientation is greater than necessary to meet the design requirement.

Neutron Shield Material Tests

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.

GA performed screening tests on thirteen materials and selected the best three of these for additional full-scale fire tests. These materials were the BP NS-4-FR and RE 201-1 and RE 207 neutron shields. Figure 11 shows the test configuration we used to expose full-scale cask wall segments to a 1475°F fire environment for 30 minutes. All three of these materials passed the

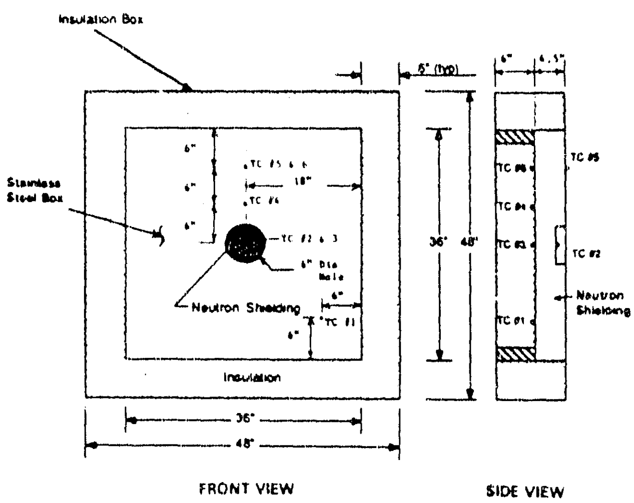

Fig. 11. Neutron Shield Fire Test Configuration with Thermocouple Locations

test as they self-extinguished within 30 minutes after removal of the heat source. The most weight-efficient material of these three is RE 201-1 which is borated polyethylene with a maximum recommended temperature limit of 180°F.

After these tests were performed, we made changes to the design which increased the GA-4 Cask neutron shield's maximum normal condition temperature from 167°F to 221°F. This increase resulted from eliminating paint on the cask's exterior surface and from increasing the heat load in the center region of the cask. Neither the RE 201-1 nor RE 207 material was acceptable at this temperature. Furthermore, using the BP NS-4-FR material would increase the weight of the neutron shield from 2500 lbs to 4000 lbs, which was not acceptable.

Therefore, GA initiated a new effort to find a more weight-efficient neutron shield material with an operating temperature of 250°F or greater. In July, 1991, we tested a boron polypropylene material manufactured by Kobe Steel. For this test we used 6-inch square blocks of material to more accurately simulate the design configuration. We also increased the size of the hole to 6-inches x 12-inches in response to a design review comment that the damage could be greater than the 6-inch diameter hole which we used in the earlier tests. This test was terminated after 15 minutes because of excessive smoke in the test facility. Since the test article continued to combust after the heat source was removed, we decided to look for another material with better self-extinguishing properties.

In November, 1991, we tested two more materials using the same test configuration as the previous test. One material, EN high-density polyethylene with one percent boron, behaved similarly to the boron polypropylene. The other material, BP Modified NS-4 with boron, passed the test by self-extinguishing after a 30-minute exposure to the fire environment. This material gives us a weight saving of 800 lbs in comparison with BP NS-4-FR. We will soon test boron polypropylene materials made by RE and EN. If one of these tests is successful, we will achieve an additional savings of 700 lbs.

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-foot 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 shown in Figure 7. 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-foot 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.

ACKNOWLEDGMENTS

*Work supported by the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, under DOE Field Office, Idaho, Contract DE-AC07-88ID12698.

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