CERTIFICATION TESTING FOR THE ES-2 SHIPPING PACKAGE*

M. R. Feldman (1), L. B. Shappert (2), R. D. Bailey (2), G. A. Byington (1), K. D. Handy (1), *R. E. Oakes Jr. (1)*, and *E. Stumpfl* (1),

(1) Lockheed Martin Energy Systems, Inc., P.O. Box 2009, Oak Ridge, Tennessee 37831-8206
(2) Lockheed Martin Energy Research Corp., P.O. Box 2008, Oak Ridge, Tennessee 37831-6495

SUMMARY

The ES-2 is a multiconfiguration, Type B fissile material shipping package, designed by the Y-12 Nuclear Packaging Systems. It is unique in that a castable refractory material performs primary impact absorption and thermal insulation duties. This material, unlike the insulation often used in fissile material packages, such as Celotex™ and various foams, is fireproof at temperatures associated with Type B package testing (800°C). The ES-2 is designed to permit the use of three different containment vessels which can result in as many as six different configurations. Eight prototype units were manufactured and successfully tested to U.S. Federal Regulatory Requirements (10 CFR 71.73).

PACKAGE DESCRIPTION

Typical fissile material containers are relatively small, thin-shelled packages, and the ES-2 is no exception. The ES-2 confinement vessel is based on a 208-liter stainless steel drum. Angle iron is welded inside the upper rim of the drum. Studs, designed to secure the drum lid, are attached to the horizontal edge of the angle iron. A liner is attached to the vertical surface of the angle iron to form a cavity for the castable refractory material. This enclosed cavity, bounded by the liner, the angle iron and the drum, is filled through a hole cut in the bottom of the drum. Once the material has been fully cured, the hole is sealed. A top plug, which sits above the containment vessel(s) and below the lid of the drum, is made of thin-gage stainless steel and is also filled with the castable refractory material.

The castable refractory chosen for use in this packaging was Kaolite 1600™, primarily consisting of Portland cement and vermiculite. Typical material density is about 0.47 g/cc (29 lb/ft^3) in the pours of the prototype containers, although typical pours on a smaller laboratory scale for testing were about 15% less. The thermal conductivity of the material is such that it protects the inner container during a 30-min exposure to 800°C. However, it is not so low that it prohibits the use of the package for transporting contents which produce moderate quantities of heat (probably about a 40-W maximum).

The three inner containers of the ES-2 package are designated as small (S), medium (M) and large (L). The small containment vessel fits inside the medium containment vessel, which, in turn, fits inside the large containment vessel. This arrangement permits three

*Research performed by the Oak Ridge Y-12 Plant, managed by Lockheed Martin Energy Systems, Inc. for the U.S. Department of Energy under contract DE-AC05-84OR21400.

single-containment configurations (ES-2S, ES-2M, and ES-2L); two double-containment configurations (ES-2MS and ES-2LM); and one triple-containment configuration (ES-2LMS). The versatility of the design allows for the possible transport of many different contents. Currently, the ES-2M configuration is being certified for transporting highly enriched uranium (HEU) metal cylinders, and the ES-2LM is being certified for carrying HEU oxide (Fig. 1). Other possible contents currently being pursued include plutonium metal and plutonium oxide.

The three inner containers designed for the ES-2 package are fabricated from stainless steel and are of similar construction. The flange of each container has two grooves to provide for a double O-ring seal configuration. The inner O-ring is the containment boundary, and the outer O-ring is included to permit leak-testing. The lid is attached to the body by high-strength bolts, which are threaded into a Monel™ nut ring just below the lower flange.

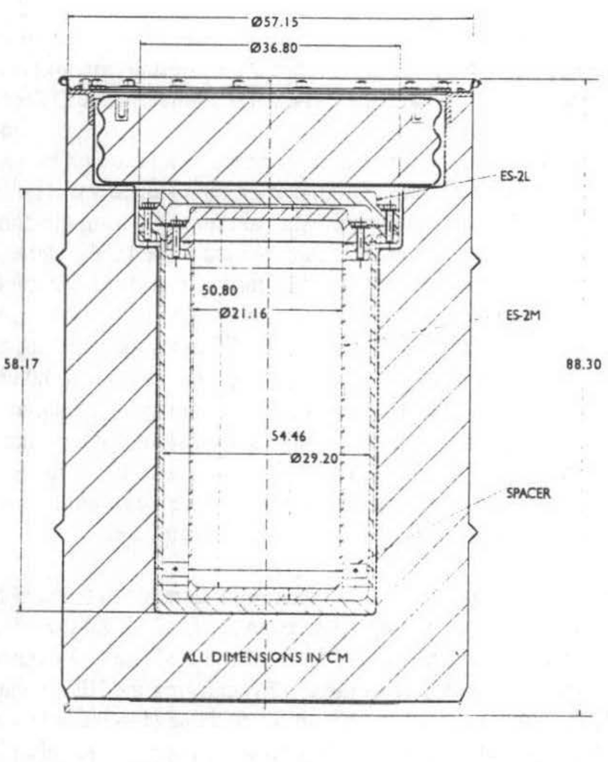

Fig. 1. A schematic view of the ES-2LM test package

PACKAGE TESTING

Eight prototype units were fully tested to both normal conditions of transport (NCT) as specified in 10 CFR 71.71 and hypothetical accident conditions (HACs) as specified in 10 CFR 71.73. Table 1 lists the eight prototype units and the testing each underwent. Both the ES-2LM and ES-2M configurations were tested for HACs, including drop testing, puncture testing, thermal testing, and leak testing. NCT testing included vibration testing, drop testing, static loading, immersion (under 15 m of water), and penetration testing. NCT thermal evaluation was performed by computer analyses. The ES-2M unit, subjected to vibration testing, was subsequently tested under HAC's conditions.

ES-2M and ES-2LM prototype units were assembled with mock contents for testing purposes. Temperature-indicating black-out labels were installed on the inner container(s) and the liner of each of the prototype units was subjected to HAC testing. These labels indicated the maximum temperature reached and were calibrated in 14°C increments from 52–260°C. Because of the uncertainty of the performance of the Kaolite material, radiography techniques were used to document its condition both before and after structural testing.

STRUCTURAL TESTING

Because of the limited number of prototype units available for physical testing, finite-element (FE) modeling was used to determine HAC drop-test orientations which would cause the ES-2 to receive the most damage. The computational code DYNA-3D (LS-DYNA3D 1995) was used to consider the following drop orientations for both the ES-2M and ES-2LM configurations: side drop, end drop on top , end drop on bottom, center of gravity (CG) over top corner, CG over bottom corner, and slapdown. The angles to be used for the slapdown testing were determined based on results from the computer code "Slapdown," a rigid body dynamics code (Sjaardeman and Wellman, March 1988) which determined maximum accelerations and velocities for various slapdown angles.

Structural data on the Kaolite material, for use in the FE analysis, were obtained through an experimental program performed by the Y-12 Development Division (Oakes 1997). These experiments determined stress-vs-strain curves for constrained samples that were compressed until nearly full compaction. These experiments also determined that density and temperature (both high and low) had little effect on strain rates. This research also determined that neutron-absorbing agents, such as boron carbide, could be added to the Kaolite 1600™ without significantly affecting material strain rates.

From the FE analyses, it was determined that maximum damage to the package occurred during either side-drop or slapdown drop tests. Both the ES-2M and the ES-2LM packages were tested in these orientations; the ES-2LM was also tested in a CG-over-top-corner orientation. Additionally, the analyses of the ES-2M carrying the HEU metal cylinders showed that the HEU cylinder would cause significant damage to the side wall of the containment vessel at drop-test impact. For this reason an open-ended aluminum sleeve, which fit between the HEU cylinder and the containment vessel, was added to the ES-2M configuration design. This sleeve acted to spread out the load from the impact of the HEU cylinder, thereby causing no discernable damage to the containment vessel.

Table 1. Test and Analysis Summary for the ES-2/ES-2LM Package [a]

Container Type	Normal Conditions	Vibration Testing	9-m Top Drop	9-m Bottom Drop	9-m CG Over Lid Corner	9-m CG Over Bot Corner	9-m Bot/Lid Slap Down	9-m Side Drop	1-m foot Punch Drop	Thermocouple PCV	Preheat to 43 °C	Thermal Test
Unit-1 M								1-YES	2-YES		3-YES	4-YES
Unit-2 M							12° angle 1-YES		2-YES		3-YES	4-YES
Unit-3 M										1-YES	2-YES	3-YES
Unit-4 M		1-YES						2-YES	3-YES		4-YES	5-YES
Unit-5 LM								1-YES	2-YES		3-YES	4-YES
Unit-6 LM							17° angle 1-YES		2-YES		3-YES	4-YES
Unit-7 LM					1-YES				2-YES		3-YES	4-YES
Unit-8 LM	1-YES Spray/Drop											
Drop Analysis M			YES	YES	YES	YES	YES					
Thermal Analysis M	YES										YES	YES
Drop Analysis LM			YES	YES	YES	YES	YES					
Thermal Analysis LM	YES										YES	YES

[a] Numbering Refers to Sequence of Activities

Results from the FE analyses showed excellent agreement with the results obtained during physical drop testing (Fig. 2). Not only did exterior damage to the package match the theoretical prediction, but post-drop test radiography verified that interior damage to the package was as predicted by FE analysis.

The greatest physical damage occurred in the tests of Units 5 through 8, having the LM configuration. These packages are heavier than those having the M configuration, approximately 295 kg vs 225 kg. Unit 6 (Table 1) was dropped from 9 m at an angle of 17° to the horizontal, impacting first on its bottom and then slapping down its top end. The impact resulted in a large, flattened trapezoidal area, approximately 36 cm across the bottom and 20 cm across the top. Only about 15 cm of the drum lid was bent out-of-round. None of the closure studs were sheared off. The puncture test indented the side wall of the drum to a depth of about 0.75 cm.

VIBRATION TESTING

Vibration testing of a single ES-2M prototype unit was performed at Wyle Laboratories in Huntsville, Alabama. Two different vibration tests were performed on the unit, during which accelerometers were attached to the vibration table, the lid of the test package, and the lid of the containment vessel. The first test was a 10–500-Hz scan, performed in 1- to 2-Hz increments, to determine resonant frequencies of both the total package and the containment vessel. The other test was a 42-h random 10–500-Hz colored-noise endurance test, which approximated conditions of 67,000 km of travel on a common carrier. Following the endurance test, radiography indicated that some deterioration of the cast refractory material had taken place, although no voids or gaps were detected. Because of the radiography findings, the unit was subsequently subjected to the HAC series of tests to determine the effect of the vibration testing on the performance of the package under accident conditions. The response of this package to HAC testing was quite comparable to that of units not vibration-tested. Structural damage from drop and puncture testing was similar to those units not vibration-tested. During thermal testing, peak temperatures at the inner container were found to be less than 15°C greater than similar locations on units not vibration-tested.

THERMAL TESTING

HAC thermal testing of the ES-2 package was performed at Lindberg Heat Treating Services in Solon, Ohio. The salon furnace that was used has been thoroughly characterized specifically for these tests. Package loading and unloading are performed by a large, manually operated loading mechanism. Typical loading times are about 40 s. The furnace burners were adjusted so excess air could flow into the furnace during testing to avoid an oxygen-deprived atmosphere. A total of seven ES-2 prototype units were thermally tested under HACs, including three ES-2LM units which had been drop tested, three ES-2M units which had been drop tested (one of which had also been vibration tested), and one ES-2M unit which was in an undamaged condition. This undamaged unit had been equipped with 20 internal thermocouples, 10 on the inner liner and 10 on the containment vessel. The thermocouples were used to both verify the reading of the temperature-indicating labels and to give temperature vs time history for the unit rather

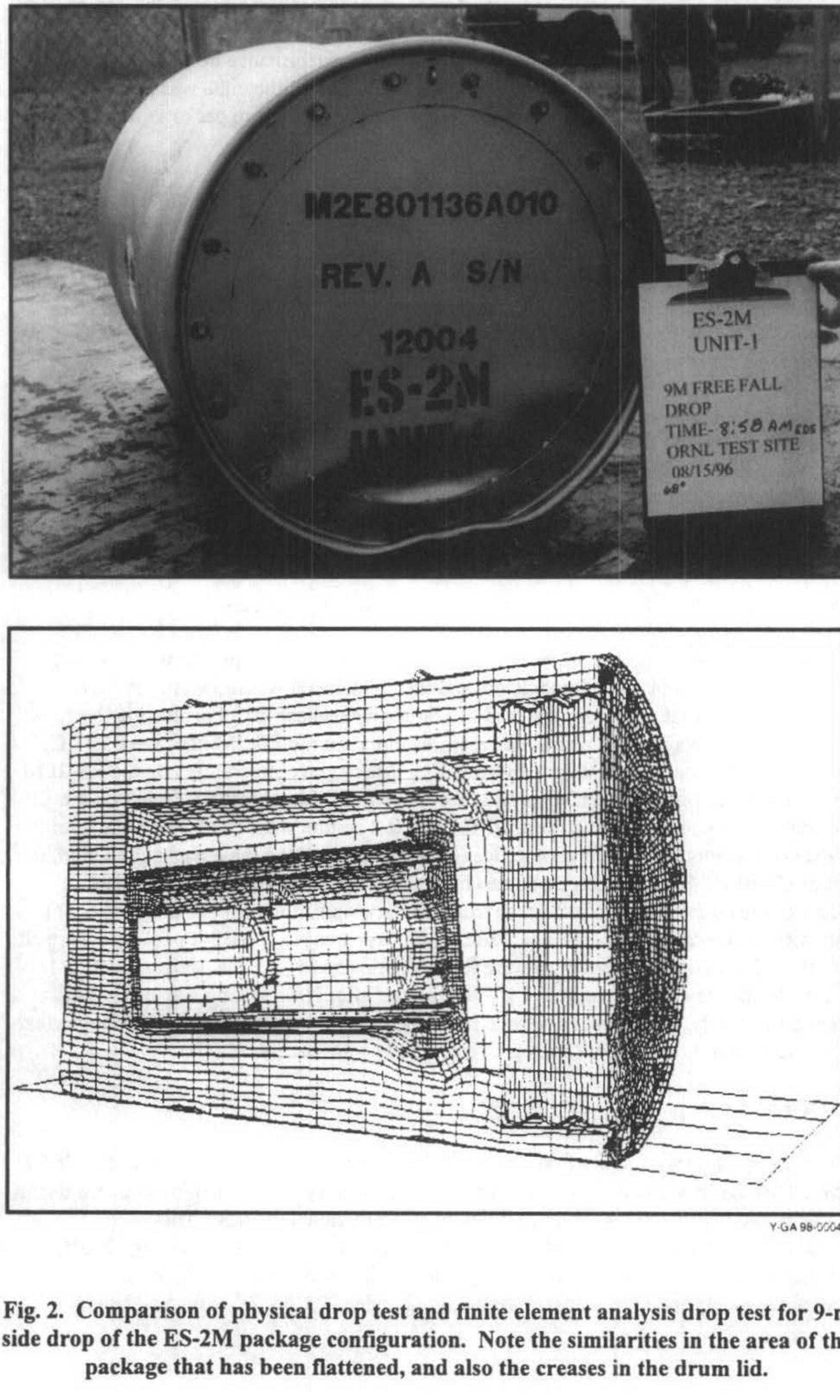

Fig. 2. Comparison of physical drop test and finite element analysis drop test for 9-m side drop of the ES-2M package configuration. Note the similarities in the area of the package that has been flattened, and also the creases in the drum lid.

than just the peak temperature given by the temperature-indicating labels. This unit had not been drop-tested in order (1) to ensure that damage to the internal thermocouples did not take place and (2) to permit a comparison in the thermal performance between a package that had been structurally tested and one that had not. Each of the units was heated in a special preheated chapter to ensure that the temperature of the entire package was at least 38°C prior to initiation of HAC thermal testing.

Six thermocouples were placed on the exterior of each package before thermal testing. A very conservative test procedure was used which did not begin the 30-min thermal test clock until at least 5 of the 6 external package thermocouples had reached 800°C. This typically took 10 to 12 min, meaning that the packages were actually exposed to the HAC thermal environment for 40 to 42 min. After loading, furnace surface temperatures rose above 800°C in less than 1 min. The furnace was typically controlled at about 840°C to ensure that all surfaces of the furnace were above 800°C.

When thermal testing was completed, the package was removed from the furnace. As each emerged, there was no flaming and no tar or char on the exterior of any of the packages. There was a slightly visible release of steam through the vent holes near the top of the drum for the first several minutes after testing. Further investigation showed that each of the containers lost between 3.9 and 4.3 kg of weight during the thermal test due to the evolution of steam from the cast refractory material.

POST THERMAL TEST DISASSEMBLY AND LEAK TESTING

Posttest disassembly of the packages revealed that all packages had performed very well. The temperatures found on the inner liners and the containment vessels were very low, indicating that the cast refractory material had done an excellent job of protecting the contents of the package. Maximum temperatures found on the ES-2M liner were 107°C, and on the ES-2M containment vessel were 93°C. Maximum temperatures on the ES-2LM liner were 150°C, on the ES-2LM secondary containment vessel were 93°C and on the ES-2LM primary containment vessel were 80°C. The test results were consistent both from one package to another and for geometrically similar areas on the same package. Often, for foam or Celotex™-based packages, somewhat unpredictable hot-spotting will occur because of the condensation of off-gases from the decomposition process, but it does not occur with the ES-2 package. Temperatures in the seal areas of the ES-2 packages were all well below the maximum use-temperature for the O-ring seals. All the packages were successfully leak tested to at least 1×10^{-4} std cc/s air after HAC testing was completed. During disassembly, the packages were found to be in such good condition it is thought that they could be put through HAC testing a second time without failure.

RESULTS

The ES-2 shipping package is a fissile material, Type B shipping package designed by Y-12 Nuclear Packaging Systems. This package is unique for a Type B packaging in that it uses a castable refractory material as an impact limiter and a thermal insulator. This material is fireproof at the temperatures associated with Type B package testing (800°C). Two different configurations of this package, the ES-2M and the ES-2LM, have successfully undergone regulatory testing required under 10 CFR 71. Minimal damage occurred during HAC structural testing, and peak internal temperatures were low during HAC thermal testing. The package is currently in the certification process where it is anticipated the ES-2M will be certified to transport HEU and its metal cylinders and the ES-2LM will be certified to transport HEU oxide.

Because of the uniqueness of the ES-2 package design, a U.S. patent has been applied for. The patent application specifically cites the use of a castable refractory material as an impact absorber and a thermal insulator and its ability to increase neutron absorption within the package by the addition of certain materials into the castable refractory material without sacrificing the structural integrity and thermal properties of the package.

The performance of the ES-2 package during HAC testing was superior to that of typical fissile material Type B packages because of the castable refractory material which does not decompose at temperatures associated with HAC thermal testing. The package is also highly versatile because of its unique three-containment vessel design. These characteristics make the ES-2 a strong candidate to become the U.S. Department of Energy Type B fissile material shipping package for the future.

REFERENCES

LS-DYNA3D software version 936.02, Livermore Software Technology Corp., Livermore, California, December 20, 1995.

Oakes, R. E. Jr., Mechanical Properties of a Low-Density Concrete for the New ES-2 Shipping/Storage Container Insulation, Impact Mitigation Media and Neutron Absorber, Y/DW-1661, Oak Ridge Y-12 Plant, Oak Ridge, Tenn., April 1997.

Sjaardema, G. D. and Wellman, G. W., Numerical and Analytical Methods for Approximating the Eccentric Impact Response (Slapdown) of Deformable Bodies, Sandia Report SAND88-06116 UC—71, Sandia national Laboratories, March 1988.

[illegible]

[illegible]

[illegible]

REFERENCES

[illegible]

[illegible]

[illegible]

SESSION 14.1

Radiation and Environmental Impact