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RECENT RADIOACTIVE MATERIAL PACKAGE TESTING EXPERIENCES AT OAK RIDGE NATIONAL LABORATORY

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ABSTRACT

Oak Ridge National Laboratory (ORNL) was a pioneer in the testing of radioactive material shipping packages and has been performing such tests for over 50 years. Currently, with the exception of thermal tests, testing is performed at the purpose-built Packaging Research Facility that is located at the National Transportation Research Center—a US Department of Energy user facility. Since PATRAM 2010, ORNL has performed several sets of tests including testing of the Y-12 National Security Complex (Y-12) ES-4100 shipping package, the Bull Run Metal, LLC TRU-Shield TS-141 waste container, the HS-99 Type AF shipping package, and several special form capsules. This paper provides an overview of the testing performed as well as a summary of advancements made to the ORNL package testing process during that time.

INTRODUCTION

Shipments of radioactive materials have been made from Oak Ridge National Laboratory (ORNL) since 1946. This early involvement in the shipment of radioisotopes led to ORNL being at the forefront of the development of regulations pertaining to the transport of radioactive material and its involvement in early testing of transport packages. ORNL has continuously maintained a radioactive material package testing capability since 1960. Early tests at ORNL were primarily focused on developing information that would support the development of transport regulations for both the United States and the International Atomic Energy Agency (IAEA) and to generate information and data that would assist designers in their quest to meet these regulations.[1] Subsequently, testing of prototype packages for certification purposes became a regular task at ORNL. Early tests were performed at the Tower Shielding Reactor site. Next, a drop pad was constructed near the ORNL Steam Plant. For the past decade, ORNL package testing has been conducted at the Packaging Research Facility (PRF) located at the National Transportation Research Center (NTRC). The NTRC is a US Department of Energy (DOE) user facility at which a wide array of transportation-related research and development is conducted. The PRF is a purpose-built facility designed specifically for testing of radioactive material transportation packages. This facility contains both an indoor drop pad and an outdoor drop pad, as well as other equipment necessary for packaging testing including a vibration table, a compression machine, and pressure drop, pressure rise, and helium leak detectors.

Over the past 3 years, ORNL has undertaken several different radioactive material package testing activities. These include testing of the ES-4100 shipping package, which is a prototype Type B fissile material package developed at the Y-12 National Security Complex (Y-12); the Tru Shield TS 141 lead-lined drum tested for Pacific Nuclear Systems; the 9980 (aka HS99) shipping package, which is a Type AF package developed by Savannah River National Laboratory (SRNL); and also several special form capsules. This paper briefly describes the testing processes undertaken for all of these units.

ES-4100

The ES-4100 presented a unique challenge for the ORNL testing staff. ORNL offers turnkey testing to 10 CFR 71 [2] requirements and was hired by Y-12 to perform this full suite of tests. In general, the PRF and the rest of ORNL's package testing infrastructure had been developed for fissile drum-type packages weighing up to 0.5 tonne. The ES-4100 test units each have a maximum loaded weight of just under 1 tonne and are just under 2 m tall (Figure 1). This meant that much of the infrastructure used for testing had to either be altered or completely redeveloped. Additionally, each ES-4100 unit houses four individual containment vessels (CVs), all of which had to undergo assembly and leak testing prior to being tested and then also had to undergo disassembly and two different leak tests after the package testing process was complete. Because six ES-4100 prototype units were being tested, this meant that 24 CVs had to be assembled, leak tested (three times each), and disassembled. The infrastructure that was built for the project included a new thermal test lifting/loading fixture and testing and cooling stands for the thermal tests, a vise to hold the CVs during assembly and disassembly, a stand to hold all 24 CVs during leak testing operations, and lifting fixtures for the drop tests. Additionally, a new methodology for preheating the test units prior to thermal testing also had to be developed. In the past, ORNL had used a steel-shelled preheat oven; however, the ES-4100 test units were much too large to fit inside this oven.

Figure 1. ES-4100 Test units as delivered for testing

ORNL assembled the six test units prior to testing. One unit used a lightweight payload in which only one of the four CVs contained a payload. The other five units were full-weight units in which all four CVs contained test-weight payloads. These five test units each weighed between 1953 and 2002 lb, and the lightweight unit weighed 1603 lb. Five of the six test units were to undergo hypothetical accident conditions (HAC) testing including the thermal test, so 176 temperature-indicating labels were affixed to each of these units such that the maximum temperature reached at that position in the test unit would be recorded. The sixth test unit was only to undergo normal conditions of transport (NCT) testing, so no temperature-indicating labels were included on this unit. All 24 CVs were leak tested to a pre-shipment standard prior to being inserted into the quad-body (drum) using a pressure-rise leak test method.

All six test units underwent the NCT drop test (1-m free drop). The orientations for these tests included center-of-gravity over corner (CGOC) with impact on the lid (two units), shallow-angle impact (slap-down) with initial impact on the base (two units), vertical with impact on the lid, and horizontal. For five of the six units, this test was followed immediately by the HAC drop test (9 m) in the same orientations. The test unit that did not undergo the HAC tests was subjected to only NCT tests (vibration and water spray prior to the drop test and compression and penetration after the drop test). The five units that underwent the HAC drop test were then subjected to the puncture test. The orientations for this test were chosen to exacerbate damage from the previous HAC and NCT drop tests. Damage measurements were taken between each test for four of the five units that underwent HAC testing. Table 1 provides a summary of the tests performed on each unit. The fifth unit was chilled to -40°C prior to testing (Figure 2). To ensure that the sequence of tests was performed on a test unit that was still as cold as possible, no measurements were taken between tests. Figure 3 shows the damage to Test Unit 2 after the 9-m drop test.

Table 1. Matrix of tests performed on ES-4100 test units

Test	**Test unit**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
NCT							
Vibration	X	X					
Water Spray	X	X					
1.2-m Drop	X	X	X	X	X	X	
Compression	X	X					
Penetration	X	X					
HAC							
9-m Drop		X	X	X	X	X	
Puncture		X	X	X	X	X	
Thermal		X	X	X	X	X	
1-m Immersion		X	X	X	X	X	
15-m Immersion							X

The five test units that were subjected to the structural HAC test were then subjected to the HAC thermal test. ORNL does not have a thermal test facility on-site, so a furnace at Latrobe Specialty Steel in Latrobe, Pennsylvania, was used for these tests. This facility has been used by ORNL on several previous occasions to perform HAC thermal tests that meet the requirements outlined in 10 CFR 71. Preheating is necessary prior to the thermal test, and the preheat oven used previously by ORNL for this purpose was too small for the ES-4100. The new preheat method used a temporary structure rather than a permanent one like the existing preheat oven. The structure of the preheat area was provided by aluminum "U" channels (often referred to as uni-strut). After the structure was built, ducting was placed inside the structure that would allow for even heating of the entire preheat volume. The uni-strut was subsequently covered by a thin foil-based insulation layer and then was covered by a tarp. Torpedo-type kerosene heaters were then connected to the two ends of the ductwork that emerged from the covered area. During construction, several thermocouples were placed inside the preheat area and were then attached to a control system that ensured that the minimum temperature inside the preheat area was greater than 43°C. All five test units were allowed to preheat for over 48 hours prior to thermal testing, thus ensuring that the temperature throughout each tests unit was at least 38°C. Figure 4 shows the pre-heat area being constructed and in use.

Figure 2. ES-4100 Test Unit 6 being removed from the environmental chamber after chilling

Figure 3. Damage to ES-4100 Test Unit 2 after 9-m drop test

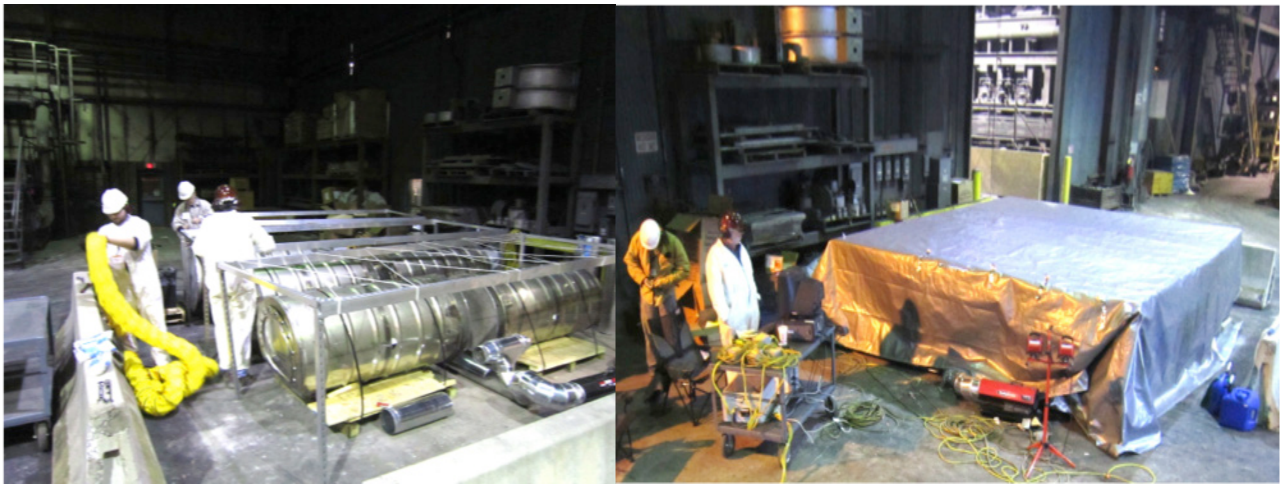

Figure 4. Pre-heat chamber during construction and in use

The thermal tests were all performed according to ASTM Standard E2230, *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material*.[3] In particular, the steady-state method of furnace testing, as described in Section 7.3.4.3 of ASTM E2230-08, was used for the ES-4100 test units. This method requires that the external skin of the package reach the regulatory temperature (800°C) before the 30-minute clock is started. Each test unit was instrumented with six thermocouples on its skin to allow for surface temperature determination. The test is performed by inserting the test unit onto a preheated cradle that sits within a preheated furnace. Every effort is made to reduce the loading time to ensure that the temperature within the furnace can recover quickly once the package is loaded and the furnace door is shut. All surfaces within the furnace (walls, ceiling, door, and floor) are also instrumented with thermocouples. These are the radiating surfaces from which most heat is transferred to the package, and therefore it is important to make sure they remain above 800°C throughout the duration of the test.

The five HAC test units were subjected to the thermal test successfully. Each test unit was individually loaded into the furnace in 50 to 55 seconds (furnace door beginning to open to furnace door fully shut). The total time in the furnace for the test units ranged from 42 to 45 minutes. That is, it took between 12 and 15 minutes for the skin of each test unit to reach 800°C and then the 30-minute test timer was started. The furnace temperature set point during each test was 870°C. At the end of each test, the test unit was removed from the furnace (Figure 5) and placed on a stand to cool. The stands were located in a protected alcove to ensure that no artificial cooling occurred as required by the regulations. When the thermal tests were completed and the test units had fully cooled, the test units were packaged for transport and returned to ORNL for disassembly, inspection, and leak testing.

Figure 5. ES-4100 test unit being removed from furnace after furnace test

The six test units were sequentially disassembled after testing was complete. Initially the lids were removed from the quad-bodies, which allowed removal of the intact CVs. The lid of test unit that was subjected to the CGOC 9-m drop test proved challenging to remove. All other quad-bodies were easily disassembled, and all 24 CVs were easily removed. At this point, the temperature-indicating labels on the interior of the quad bodies that were exposed to HAC tests were read, as were the temperature-indicating labels on the exterior of all of the CVs. Subsequently, each of the 24 CVs was subjected to two separate leak tests; first, a pre-shipment, pressure-rise leak test and second, a helium leak test. In order to perform the helium leak test, each CV had to be penetrated such that a vacuum could be pulled on the interior of the unit. Once a vacuum was established, a bag surrounding the CV was filled with helium. The pressure differential between the outside of the CV (at ~1 atm) and the inside of the CV (~0 atm) provided the driving force for the leak test. Any leakage pathways would result in helium entering the CV and then would be detected by a helium spectrometer attached to the CV. Once the CV leak testing was complete, the CVs were disassembled and the temperature-indicating labels on the interior of the CV and on the mock payloads were read.

A separate seventh test unit consisted solely of a single CV. This CV was subjected to the 15-m immersion test specified in 10 CFR 71.73(c)(6). This test unit was loaded with enough ballast to ensure it would not float and then assembled, and a pre-shipment pressure-rise leak test was performed. Subsequently, the unit was placed in a water chamber that was then pressurized to greater than 150 kPa for more than 24 hours. The unit was then removed from the water chamber and disassembled.

The results of the testing process are documented in ORNL/NTRC-043.[4]

TRU-SHIELD TS-141

Testing of TRU-Shield TS-141 lead-lined drum-type shipping packages was performed by ORNL. The package was being qualified for use in a burial ground as well as for transportation purposes, so the tests requested by the package owner were not based solely on transportation regulations. That is, a drop test from a height of 15 m was requested rather than the standard 9-m HAC drop test. The other test performed was a 1.2-m NCT drop test. It should be noted that the drop tests were the only tests performed for the customer.

Four test units were provided for testing. The test units were pre-assembled by the customer and included fluorescein, which is a fluorescing substance that can be used for leak detection. The assembled test units provided to ORNL each weighed approximately 3 tonnes. Three test units were subjected to the 15-m drop test, and the fourth test unit was subjected to the 1.2-m NCT drop test. The orientations for the 15-m tests were CGOC on lid, CGOC on bottom (Figure 6), and horizontal. The orientation for the 1.2-m drop test was CGOC on lid. Immediately after each test the test unit was covered with a black tarp, and ORNL personnel crawled under the tarp and used a black light to look for the presence of fluorescein. This process was also undertaken prior to testing to ensure that no material was present that could provide a false positive result.

The results of the testing process are documented in ORNL/NTRC-050.[5]

Figure 6. TRU-Shield TS-141 after CGOC on bottom drop test

HS99

The HS99 is a Type A fissile (Type AF) drum-type package being developed for the US Department of Homeland Security (DHS). DHS tasked ORNL with developing the package, and ORNL contracted SRNL to act as the design authority for the development of this package. SRNL provided ORNL with the test unit components, including mock contents, and ORNL assembled, tested, and disassembled the packages. Because the package is intended to be a Type AF package, it was necessary to meet the HAC requirements in 10 CFR 71. However, because it will only carry a Type A quantity of material, containment criteria do not apply and no leak testing was performed. No thermal tests were performed because the thermal qualification was performed by analysis.

A total of six test units were assembled for testing, as summarized in Table 2. One unit was subjected to the 1.2-m NCT drop test and the structural HAC tests (9-m drop, 9-m crush, and puncture tests); two units were subjected to the 1.2-m NCT drop test, the 0.3-m NCT corner drop tests (eight times), the NCT penetration test, and the structural HAC tests (9-m drop, 9-m crush, and puncture tests); one unit was subjected to the NCT water spray test, the 1.2-m NCT drop test, the 0.3-m NCT corner drop tests (eight times), the NCT penetration test, and the structural HAC tests (9-m drop, 9-m crush, and puncture tests); one unit was subjected to the NCT water spray test, the 1.2-m NCT drop test, the NCT compression test, the NCT penetration test, and the structural HAC tests (9-m drop, 9-m crush, and puncture tests); and one unit was only subjected to the vibration test. The unit that was subjected to the 1.2-m NCT drop test and the structural tests was chilled to -28.9°C prior to testing. With the exception of this chilled unit, all test units were dimensionally inspected between each test. The chilled unit was not dimensionally inspected between the tests to speed testing to ensure the package was as cold as possible while being tested. Figure 7 shows the damage to HS99 Test Units 1 through 5.

Table 2. Matrix of tests performed on HS99 Test Units

Test	Test Unit					
	1	**2**	**3**	**4**	**5**	**6**
NCT						
Vibration						X
Water Spray			X		X	
1.2-m Drop	X	X	X	X	X	
Corner Drop		X	X	X		
Compression					X	
Penetration		X	X	X	X	
HAC						
9-m Drop	X	X	X	X	X	
9-m Crush	X	X	X	X	X	
1-m Puncture	X	X	X	X	X	

After testing was completed, the test units were disassembled. Some were difficult to disassemble because of the deformation of the test unit caused by testing, so they were sectioned using a large band saw.

The results of the testing process are documented in ORNL/NTRC-054.[6]

TU-6 TU-4 TU-3 TU-2 TU-5

Figure 7. Damage to the HS99 Test Units 1-5 after testing

SPECIAL FORM TESTS

Tests have been performed on several different capsule designs in order to earn these designs Special Form Certification. These include the Los Alamos National Laboratory (LANL) FSO Capsule, the ORNL 2.5 kg Highly Enriched Uranium (HEU) Equivalent Radiation Signature Testing Device (RSTD), the ORNL 10 kg HEU Equivalent RSTD, and the ORNL Low Enriched Uranium (LEU) Annular Casting Capsule. Each of these test protocols consisted of a 9-m drop test, a percussion test, and a 10-minute 800°C thermal test. For each design, a single unit was used for the drop test and the percussion test, and a separate unit was used for the thermal test. For all designs, a helium leak test was performed after each test to meet regulatory requirements.

The results of the testing process for the LANL FSO are documented in ORNL/NTRC-039.[7] The results of the testing process for the ORNL 2.5 kg RSTD are documented in ORNL/NTRC-037,[8] and the results of the testing process for the ORNL 10 kg RSTD are documented in ORNL/NTRC-052.[9] Documentation of the results of the ORNL LEU Annular Casting Capsule are currently in progress.

SUMMARY

ORNL has performed radioactive material package tests for over 50 years. Recently, ORNL has tested of several different radioactive material packages including Type B packages (ES-4100), Type AF packages (HS99), special form capsules (LANL FSO, ORNL 2.5 kg RSTD, ORNL 10 kg RSTD, ORNL LEU Annular Casting Capsule), and storage packages (TRU-Shield TS-141). The testing process includes test plan and test report writing as well as performance of all required and/or requested tests.

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