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Regulatory Testing of a Type B Shipping Container for NCT and HAC

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ABSTRACT

The safe transportation of radioactive material using appropriately designed and certified transportation packages is important to protect the public, contents, and environment. In the United States, all commercial transportation of radioactive material (Class 7 hazardous material) is regulated by the US Department of Transportation and US Nuclear Regulatory Commission. There are four basic types of packaging for Class 7 materials: Industrial, Type A, Type B, and Type C. Each packaging type must meet performance-based regulations to be certified for use in the transport of radioactive materials.

Packages used for the transportation of Type B quantities of radioactive materials must be capable of meeting normal conditions of transportation (NCT) requirements and hypothetical accident condition (HAC) requirements as defined in Title 10 Code of Federal Regulations Part 71 (10 CFR 71). Evaluation of package designs against these criteria typically involves a combination of analysis and physical testing. Required tests include free drop, crush, puncture, penetration, compression, vibration, water spray, water immersion, and thermal. The Oak Ridge National Laboratory Packaging Evaluation Facility at the National Transportation Research Center (NTRC) provides an inclusive testing capability for a wide variety of packages needed for shipment of radioactive materials.

This paper describes the preparation, regulatory testing, and posttest evaluation of a Type B shipping package tested to the 10 CFR 71.71 and 10 CFR 71.73 requirements. The package's response when subjected to the HAC sequence of free drop, crush, puncture, and thermal tests according to 10 CFR 71.73(c)(1), (c)(2), (c)(3) and (c)(4) was of interest in certifying the package for use in transporting radioactive material. The free drop, crush, and puncture tests were performed at the NTRC in Knoxville, Tennessee, and the thermal tests were performed at Latrobe Specialty Steel in Latrobe, Pennsylvania. The test units were subjected to pre-operational leak testing before the NCT and HAC tests were implemented, as well as a post-operational leak testing and helium leak testing once regulatory testing was complete.

INTRODUCTION

Radioactive materials are widespread in many different types of industries: consumer products, medicine, industry, energy, and defense. Globally, there are about 20 million shipments of radioactive materials transported each year via public roads, railways, and waterways [1]. When transporting radioactive or hazardous materials, safety and security are top priorities for all involved. A comprehensive system of rigorous packaging, transportation, and package-certification requirements is enforced through federal regulations to ensure that the public and environment are protected from the hazardous nature of the cargo.

Since the 1940s, ORNL has been at the forefront of the development of regulations pertaining to the transport of radioactive shipments and associated regulatory testing [2]. Currently the ORNL Package Testing Program (PTP) performs package testing activities at the Package Evaluation Facility (PEF) located at the National Transportation Research Center (NTRC) in Knoxville, Tennessee, USA. The ORNL PTP develops and evaluates testing solutions, ensuring that they are safe and efficient and meet regulatory requirements and customer needs.

Between June 2018 and January 2019, the ORNL PTP tested two MD-2 prototype units using the Type B performance tests prescribed in Part 71 of Title 10 Code of Federal Regulations (CFR). This paper describes test unit preparation, pretest condition, and conditioning of each test unit, normal-conditions-of-transportation (NCT) and hypothetical-accident-condition (HAC) testing, and posttest measurements and observations made of the damage resulting from these tests.

DESCRIPTION OF TEST UNITS

Each test unit (Figure 1) consisted of a containment vessel (CV) assembly, with the CV housed inside a confinement boundary assembly. The confinement boundary included a stainless steel outer drum containing a stainless steel inner liner. A lightweight refractory material, Packcrete, was cast into the annulus formed between the stainless steel inner liner and the outer drum. This boundary also contained a drum lid/top plug weldment, rubber inserts, and fastening hardware. The CV consisted of a stainless steel body, fastening hardware, and two O-rings. Internal to the CV was a sealed insert (SI) with a surrogate test weight.

Figure 1. Test unit prototype

TYPE B TESTS

As a Type B package, the MD-2 must meet the performance-based criteria of 10 CFR 71.71 and 10 CFR 71.73 [3]. The ORNL PTP performed all the tests required for preparation of an acceptable application for package certification. The following 10 CFR 71.71 NCT-mandated tests were performed: vibration, 10 CFR 71.71 (c)(5); water spray, 10 CFR 71.71 (c)(6); 4 ft (1.2 m) drop, 10 CFR 71.71 (c)(7); compression, 10 CFR 71.71 (c)(9); and penetration, 10 CFR 71.71 (c)(10).

After completion of the NCT tests, the following mandated 10 CFR 71.73 HAC tests were performed: free drop, 10 CFR 71.73 (c)(1); crush 10 CFR 71.73 (c)(2); puncture, 10 CFR 71.73 (c)(3); and thermal, 10 CFR 71.73 (c)(4).

TEST MATRIX

Table 1 provides the sequence of tests and processes performed on each test unit. Each test unit was designated with a unique identification number, TU-11 and TU-12. TU-12 was subjected to the full sequence of NCT and HAC tests. TU-11 was subjected to the 1.2 m (4 ft) NCT free drop test, followed by the full sequence of HAC tests. The 1.2 m (4 ft) free drop, 9 m (30 ft) free drop, 9 m (30 ft) crush test, and 1 m (3.3 ft) puncture tests for TU-11 were executed with the package preconditioned to a temperature of -40°C.

Table 1. MD-2 test matrix

	TU-11	TU-12
Regulatory test	1.2 m (4 ft) drop/HAC	HAC
Temperature	Cold	Ambient
Pretesting Activities		
Leak test CV (operational)	X	X
Chill test unit to -40°C (-40°F)	X	
NCT TEST		
Vibration, 10 CFR 71.71 (c)(5)		X
Water spray, 10 CFR 71.71 (c)(6)		X
1.2 m (4 ft) drop, 10 CFR 71.71 (c)(7)	X	X
Compression, 10 CFR 71.71 (c)(9)		X
Penetration, 10 CFR 71.71 (c)(10)		X
HAC TEST		
9 m (30 ft) drop, 10 CFR 71.73 (c)(1)	X	X
Crush, 10 CFR 71.73 (c)(2)	X	X
Puncture, 10 CFR 71.73 (c)(3)	X	X
Thermal, 10 CFR 71.73 (c)(4)	X	X
Posttesting Inspection		
Disassembly and posttest inspection	X	X
Leak test CVs, ANSI N14.5 (operational)	X	X
Leak test CV ANSI N14.5 (He)	X	X
0.9 m (3 ft) CV immersion, 10 CFR 71.73 (c)(5)	X	X

PRETESTING ACTIVITIES

Several activities were required to prepare the units for testing as shown in Table 1. These activities focused on documenting the initial condition of each test unit, installing data acquisition devices (temperature-indicating labels) in various locations on the test units, and assembling each test unit per operational procedures and the Package Testing Program Quality Assurance Program Plan. Upon arrival of the test units at the Packaging Evaluation Facility, the prototype units were disassembled, visually inspected, and identified with a unique ID. After a complete disassembly, the test units were reassembled per the approved assembly procedures in the test plan. During assembly, the units were marked and affixed with temperature-indicating labels (Figure 2). The markings on the test units consisted of test unit ID number on all parts and components, four axial lines on each quad section of the drum body and containment vessel, circumferential lines on the drum body to indicate the center of gravity (CG) of the test unit, the location of the CV flange, and the location of the SI flange (Figure 2). Additionally, “FL” and “CG” target symbols were marked on the outer drum to identify the location of the CG of the SI and CV flange, respectively, for impact testing.

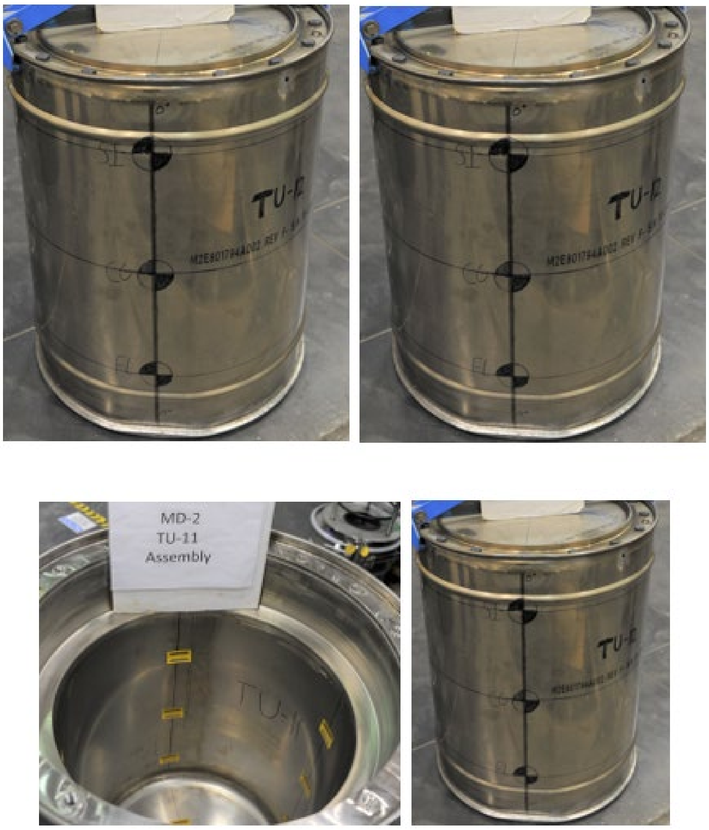

Figure 2. Test unit markings and temperature labels

Pretest Operational Leak Test

Prior to the final assembly of the CV into the outer drum, the O-ring seals of the CV assembly of TU-11 and TU-12 were leak tested. These leakage rate tests were conducted in accordance with Section 7.6 of ANSI N14.5-1997 [4] and followed the manufacturer's pre-shipment leakage rate testing procedure. Successfully passing a pre-shipment test (1×10^{-4} ref-cc/sec) indicates that the O-rings were installed and functioning properly [4]. The vacuum module of the leakage test unit evacuates the volume between the O-rings and then uses a very precise pressure transducer to measure the pressure rise over the test period. The instrument was set to a test sensitivity of $\leq 5 \times 10^{-5}$ ref-cc/sec. The recorded minimum test sensitivity for TU-11 was 1.78×10^{-5} ref-cc/sec and 8.15×10^{-6} ref-cc/sec for TU-12.

Chilling of TU-11

TU-11 was chilled before the structural tests were conducted. TU-11 was placed in an environmental chamber at ORNL and chilled to -56.6°C (-70°F) for 24 hours and then -43°C (-45°F) for at least 70 hours (Figure 3). The test unit was cooled in an environmental chamber manufactured by Russells (serial number 03941553). The chamber is 1.5 × 1.5 × 1.5 m (5 × 5 × 5 ft) and had a temperature range from -57 to 77°C (-70 to +170°F).

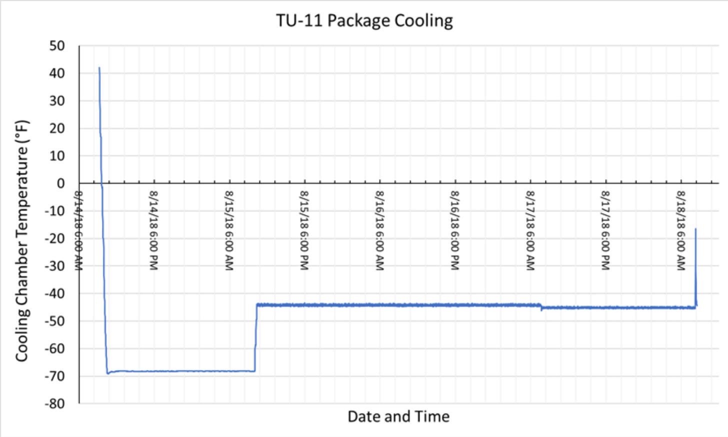

Figure 3. TU-11 cooling temperature profile

NCT TESTS

The applicable NCT tests specified in 10 CFR 71.71 includes a water spray test, a compression test, a vibration test, a penetration test, and a 1.2 m (4 ft) free drop test. Table 1 lists the NCT tests that were performed on the test units and the sequence in which they were conducted.

The vibration test for the test unit is designed to simulate the environmental effects of the vibration regime that the test unit will experience during highway transport. A vibration spectrum simulating the Safe Secure Trailer/Safeguards Transporter (SST/SGT) [6] was used. The test duration was based on the longest trip that the package is likely to endure, namely 1 h per 1,000 trip miles. Hence, the 4 h test duration used was conservative and should encompass any conceivable trip that a MD-2 package might undergo within the continental United States. The water spray test was conducted on the package within 2.5 h prior to the NCT 4 ft drop test and is noted on the test forms for the subsequent tests. With a rain gauge positioned near the bottom of the test unit, the flow rate was measured to be > 5 cm/h (2 in/h) [3].

The NCT drop tests were carried out on the NTRC indoor and outdoor drop pad. These drop pads provided essentially unyielding surfaces for the NCT free drop tests [5]. Both test units were subjected to the 1.2 m (4 ft) drop in a horizontal orientation. The free drops resulted in minimal deformation of the package dimensions with a maximum change in diameter of about 14.28 mm (9/16 in).

The compression and penetration test were the final NCT tests. The package was subjected to a 3,500 lb compression load for 24 h. After the compression test, the test unit was subjected to a penetration test. A 6 kg (13.2 lb) bar was dropped on the “FL” target symbol from 1 m. The bar struck the drum body and formed a 6.3 mm (1/4 in) dent on the side of the package. Figure 4 shows the TU-12 NCT tests performed.

Figure 4. Test unit NCT tests

HAC TESTS

The 10 CFR 71.73 HAC compliance testing sequence was performed on the test units. One test unit was chilled to below -40°C (-40°F) before the HAC structural tests. For the 9 m (30 ft) dynamic crush test, the portion of the package damaged in the previous tests was placed in contact with the drop pad, and the 1 m × 1 m (3.3 × 3.3 ft) 500 kg (1,100 lb) crush plate was dropped to impact on the opposite (i.e., the undamaged) side. Next, all test units were subjected to the HAC puncture test, which was followed by the thermal test and finally the immersion test. Following each of the structural tests on TU-12, dimensional measurements were made to document the damage. Dimensional measurements were not taken between the tests on the chilled test unit (TU-11) so that it would remain as cold as possible for all the tests.

After structural testing, the test units were 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 to perform this test. Preheating of the test units is necessary prior to thermal testing [3]. The test units were preheated in a 1.8 × 1.8 × 2.7 m (6 × 6 × 9 ft) environmental chamber. The test units were preheated for more than 48 h prior to thermal testing, thus ensuring that the temperature throughout each test unit was at least 43°C (110°F). Figure 5 shows the preheat chamber set up with the kerosene heaters used as the heat source. A mechanical bulb thermostat was used to control the temperature in the chamber to ensure a steady temperature was kept throughout the preheating time.

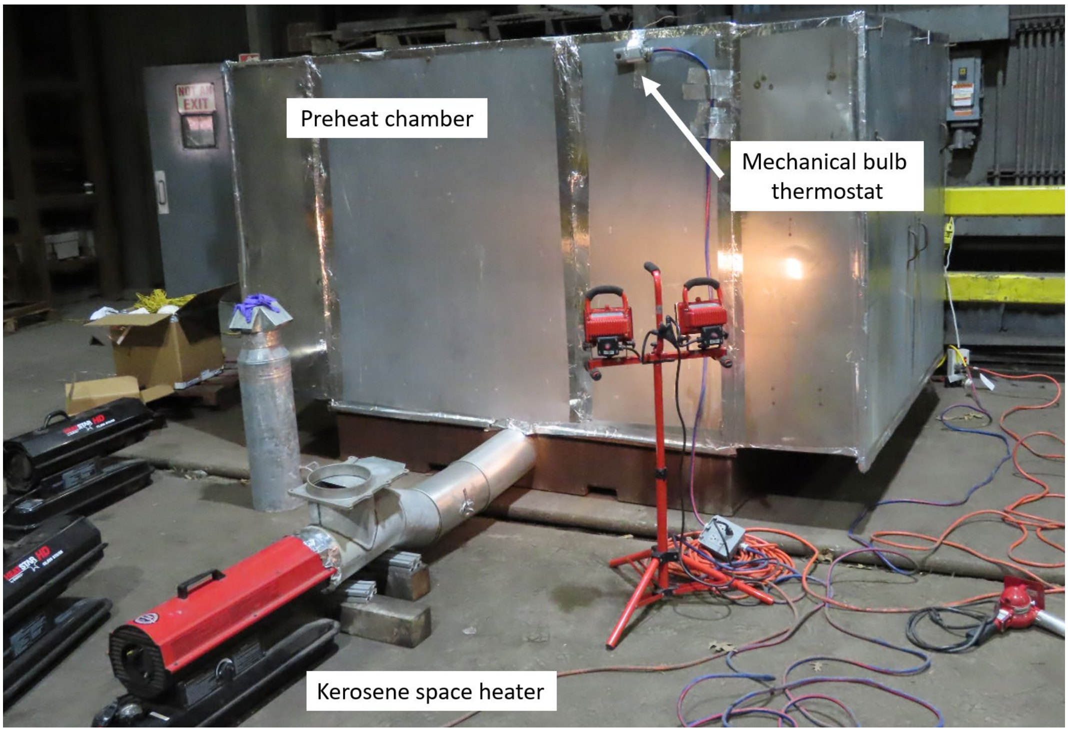

Figure 5. Test unit NCT tests

The thermal tests were all performed according to the ASTM Standard E2230, *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Materials* [7]. Specifically, the steady-state method of furnace testing, Section 7.3.4.3 of ASTM E2230-13, was used. This thermal test method requires that the external surface of the package reach the regulatory temperature of 1,472 °F (800°C) before the 30 min test is started. To measure the surface temperature, six thermocouples (TCs) were affixed to the exterior side surfaces of the test unit. Additionally, the furnace surfaces were instrumented with 15 TCs and the test stand was instrumented with 3 TCs. These are the radiating surfaces from which most of the heat is transferred to the test unit; therefore, it was important to ensure that the furnace surfaces remained above 800°C (1,472°F) throughout the 30 min test. Once furnace preparations were completed, several practice loadings were performed on the cold furnace to ensure that the test units could be rapidly loaded onto the test stand and rapidly unloaded from the furnace to minimize the cooling of the furnace that would occur while the door was open. After the cold load/unload practice was completed, the furnace was fired. Once fired, the furnace was allowed to heat soak for more than at 24 h before testing was initiated. A computer-based thermal data acquisition system developed by ORNL was used to monitor and record the furnace surface temperatures and test unit surface temperatures during the tests. The package and furnace TCs were bundled with a steel wire. The TC bundle length was then connected to a portable TC connector box. The TC connector box was then connected to the data acquisition, which transferred data to the laptop via an ethernet cable. The data acquisition system was set to log data every 15 s from each data channel. A calibrated 1.57 mm (0.062 in) diameter Type K TC that was 15.24 m (50 ft) in length was used for the thermal test. These relatively lightweight TCs provide a very rapid response to changes in temperature, which in turn provides a very accurate picture of the furnace and test unit thermal behavior. Figure 6 illustrates the instrumentation setup of the thermal test.

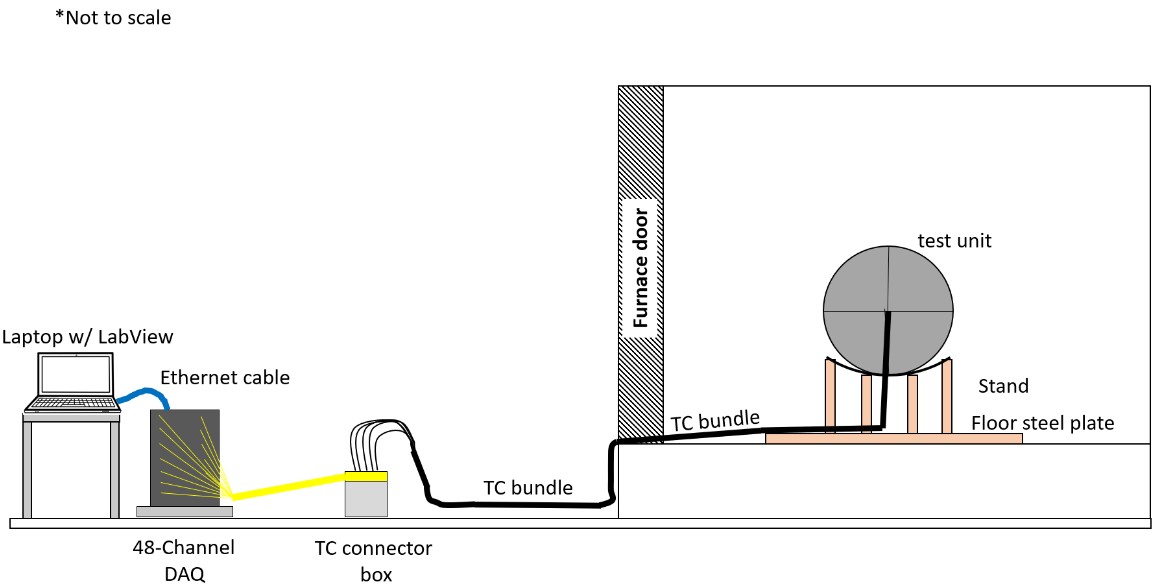

Figure 6. Thermal test instrumentation setup

Each test unit was loaded into the furnace in about 40 to 50 s. After the furnace doors were closed, the 30 min test period did not start until the following criteria were met: (1) 5 external TCs on the test unit surface were reading >802°C (1,475°F), and (2) 15 TCs on the furnace surfaces were reading >802°C (1,475°F), and (3) at least 2 TCs on the test stand were reading > 802°C (1,475°F). It took about 8 to 12 min to reach these criteria, which meant that the test units were in the furnace environment for a total of 38 to 42 min. Upon completion of the 30 min test, each package was removed from the furnace and placed on a cooling stand where it was permitted to cool naturally. When the temperatures of the package surface were below 30°C (86°F), the test units were packaged for transport and returned to ORNL for disassembly, inspection, and leak testing.

Figure 7. Test unit furnace removal and cooling

POSTTEST OBSERVATIONS

The test units were disassembled after the thermal test was complete. The unique design of the test unit created a situation in which the CVs of the test units could not be removed from the drum portions in the normal manner because the external damage to the drum body indicated that the deformation of the drum inner liner would prevent the CV base from sliding out. Instead, the sidewalls of the drum exterior surface were cut circumferentially to reveal the drum's inner liner. The drum's inner liner was cut as well to reveal the CV and remove it. The temperature-indicating labels data in the test unit were recorded on the appropriate test form, and the CVs were subjected to two separate leak tests: first, a preshipment, pressure-rise leak test and second, a helium leak test. To perform the helium leak test, a hole was drilled on the CV, and the vessel was tapped with a 6.35 mm (0.25 in.) National Pipe Thread tapered pipe thread to create a vacuum in the interior of the CV. Once a vacuum was established, a bar surrounding the CV was filled with helium. The pressure differential between the outside of the CV and the inside of the CV provided the driving force for the leak test. Any leakage pathways would result in helium entering the CV, which would be detected by a helium spectrometer attached to the CV. Upon successful completion of the leak tests, the CVs were subjected to the 24 h water immersion test, and then the CVs were fully disassembled, and the data from the temperature-indicating labels on the CVs were recorded. A contour plot of the temperature-indicating labels was created to visually illustrate the hot and cold spots on the package from the thermal test (Figure 8). The full results for this testing process are documented in ORNL/TM-2019/1108 *Test Report for MD-2 Limited Scope Compliance Testing with Packcrete, Volume 1 – Main Report* [8].

Temperature indicator number location chart				
Test weight and fixture (TL-10-105, TL-10-190)				
Location (outside)	**0°**	**90°**	**180°**	**270°**
Top fixture	190	190	200	190
Weight upper	180	180	180	180
Weight lower	180	180	180	180
On the ALR8 SI (TL-10-105, TL-10-190)				
Location (outside)	**0°**	**90°**	**180°**	**270°**
Lid top center	200	NA	NA	NA
Under flange	190	190	200	200
Body mid height	190	200	200	200
Body bottom	200	200	210	200
Lid bottom center	210	NA	NA	NA
On the CV (TL-10-105, TL-10-190)				
Location (inside)	**0°**	**90°**	**180°**	**270°**
Body top	220	230	240	230
Body side upper	180	200	230	220
Body mid height	200	200	210	210
Body flange	200	210	210	210
Base flange	200	210	210	210
Base bottom	200	210	220	210
On the inner liner and drum lid weldment (TL-10-190, TL-10-290)				
Location (inside)	**0°**	**90°**	**180°**	**270°**
Drum lid bottom	230	240	250	240
Cavity top	310	310	320	320
Cavity center	320	330	320	310
Cavity lower	230	230	240	300
Cavity bottom	220	210	230	230

Figure 8. Temperature indicating labels for test unit 11 (°F).

CONCLUSIONS

ORNL has performed radioactive material package tests for more than 50 years. Recently, ORNL has tested several different radioactive material packages including the Type B packages discussed here (MD-2 with Packcrete). The packages were exposed to the 10 CFR 71.71 and 10 CFR 71.73 Type B tests at the NTRC Package Evaluation Facility or ORNL. The packages were subjected to a posttest helium leak test to ensure that the containment boundary in the package was maintained throughout tests performed on each unit. The testing process includes the test plan and test report writing as well as performance of all required and/or requested tests. The final findings were compiled in a three-part test report and delivered to the design authority.

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