Proceedings of the 21st International Symposium on the Packaging and Transportation of Radioactive Materials

PATRAM 25
JULY 27 – AUGUST 1, 2025
SAN ANTONIO, TX / SAN ANTONIO MARRIOTT RIVERCENTER

ORNL Package Testing Program Overview

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ABSTRACT

Radioactive materials are widespread in our everyday activities which are used in many different types of industries: Consumer products, Medicine, Industry, Energy, and Defense. In the United States there is about 3 million shipments of radioactive materials per year. With radioactive material being very widespread the number of new applications to ship these quantities increases daily. As such, ensuring the safe and secure transport of these materials is paramount, necessitating stringent packaging, transportation, and certification requirements.

Shipments of radioactive materials have been made from Oak Ridge National Laboratory (ORNL) for the past 65 years. Since the 1940s ORNL has been at the forefront of the early development of regulations pertaining to the transport of radioactive shipments and associated regulatory testing. The early involvement resulted in ORNL being one of the leaders in the development of regulations and testing standards pertaining to the testing and design of packages. Today all package testing activities are conducted under the Package Testing Program (PTP) at ORNL at the Package Evaluation Facility (PEF). The PTP develops and evaluates testing solutions – ensuring that they are safe, efficient, and meet regulatory requirements

ORNL PTP has extensive experience in the regulatory testing of radioactive material packages, supporting certification of Type A, Type, B, Type AF, and special form packages. The PEF serves as a one-stop-shop for design, testing, and certification of a wide variety of packages needed for shipment of radioactive materials. The facility provides the space, expertise, and equipment necessary to conduct rigorous performance testing under both normal and accident conditions or transport environments including free drop, dynamic crush, puncture, penetration, compression, vibration, water spray, water immersion, and thermal test.

The PTP remains a key contributor to the safety and compliance of radioactive material transportation. This presentation will provide an overview of the program's history, capabilities, and its ongoing role in advancing regulatory standards and transportation safety.

INTRODUCTION

When transporting radioactive or hazardous materials, safety and security are top priorities. Packaging and transportation regulations require reliable evidence that containers have passed rigorous performance tests to ensure that the public and the environment are protected from the hazardous nature of the cargo. Because of its long history in energy and security research, Oak Ridge National Laboratory (ORNL) has needed to ship hazardous packages for the past 65 years. Since the 1940s, ORNL has made significant contributions to transportation regulations and has been at the forefront of regulatory testing development [1]. Today, ORNL is a leader in standards development and testing of designs of radioactive material packages. ORNL plays a critical role in ensuring the safe transportation of radioactive materials across the United States by executing rigorous testing campaigns of packages that contain radioactive materials. Early testing activities focused on supporting the development of transportation regulations established by both the International Atomic Energy Agency (IAEA) and the United States. Currently, all package testing activities are performed under the Package Testing Program (PTP) at the Package Evaluation Facility (PEF) located at the National Transportation Research Center (NTRC), which is about 10 miles from the main ORNL campus.

The PTP develops and evaluates testing solutions, ensuring that they are safe efficient, and in compliance with regulatory requirements. The vision for the PTP is to be a world-class leader in the evaluation and testing of radioactive and hazardous material packages. The key elements necessary to fulfill this mission are an experienced and professional staff; state-of-the-art facilities, equipment, and instrumentation; and completion of challenging programs and projects important to package transportation. Collaborations with other internal and external organizations play a significant role in building stronger teams and achieving this vision. By adhering to and advancing regulatory standards, ORNL's PTP supports development of safe and compliant packaging, safeguarding the transportation process from potential risks associated with radioactive material logistics.

QUALITY ASSURANCE

The Package Testing Quality Assurance Program describes the PTP's approach to integration and implementation of quality principles, methods, procedures, and requirements as identified in 10 CFR 71 Subpart H, *Quality Assurance*, as applicable to Type A(F) and Type B packages tested by PTP staff. Effective implementation of the elements described in the PTP Quality Assurance Program Plan (QAPP) [2] ensures that expectations and requirements are properly addressed.

The Package Testing QA Program is composed of a QA program plan (QAPP) that defines the organizational roles, identifies source requirements, and includes the 18 quality elements defined in NQA-1 and 10 CFR 71 Subpart H. Each QA element is supported by an associated PTP QA implementation process and a data form which serves as the official quality record. The QA program includes a system for controlling documents and records. Similarly, the testing procedures and processes are controlled by package testing operations procedures that are part of the QA program. The operational procedures ensure that all testing activities are conducted in a quality, systematic manner, and they ensure that all records are captured and controlled. The following situations require written procedures to ensure quality results:

- When the consequences of errors could cause significant adverse impact
- When an activity involves qualitative and/or quantitative acceptance criteria
- When the operators are not intimately familiar with the procedure, when the procedure is complex, or when performance of work is infrequent
- When an activity is documented for quality control purposes

PACKAGE TESTING PROGRAM

The ORNL PTP has extensive experience in regulation, management, planning, assessment, and coordination of activities associated with the packaging and transportation of hazardous and radioactive materials. Package design and testing has been a key part ORNL operations for over 65 years. As a result, the PTP, which manages the PEF at the NTRC, is a one-stop shop for testing the wide variety of packages needed for the shipment of radioactive materials. The PEF builds upon ORNL's extensive design, evaluation, and testing experience. It provides the space and equipment needed to conduct the performance testing required for all types of nonhazardous and hazardous material packages. This includes testing under normal and accident conditions of the transport environments for radioactive packages (Type A[F] and Type B), special form, industrial packages, and other hazardous material performance-oriented packages.

Type A and Type B packages are two primary package classifications used when shipping radioactive materials. Each package type is designed to meet different levels of hazard containment. On the one hand, Type A packages are used for transporting low-level radioactive materials such as medical isotopes that present a relatively low risk to public safety. These packages are designed to withstand normal transportation conditions such as minor impacts or vibration, and they undergo specific testing to confirm their durability under routine scenarios. Type B packages, on the other hand, are used for shipping more hazardous radioactive materials like spent nuclear fuel. Type B packages are required to withstand not only normal transport conditions but also severe accident scenarios. To be certified, Type B packages must pass rigorous tests, including impact, puncture, fire, and water immersion tests, simulating extreme conditions to ensure that the package will not release its contents under any circumstances.

The US Department of Transportation (DOT) provides regulations pertaining to the classification of specific package contents identified as *special form*. These contents are encapsulated in a special form capsule (SFC). Such designation indicates that the contents are so encapsulated such that the likelihood of their dispersion is greatly reduced, even when subjected to significant insult such as a 9 m impact or a fire lasting 10 min. All SFC designs have been certified by DOT as being special form materials. In typical cases, this designation would have a significant impact when determining the types of packages that can be used. For purposes of receipt and storage at various facilities, the special form designation can greatly simplify the acceptance and receipt processes. Because SFCs are shipped to various facilities for use throughout their lifetime, it has been found to be highly advantageous for some contents to be certified as *special form*. To this end, DOT Certificates of Competent Authority (CoCAs) must be sought for SFC. This process consists of testing the SFCs according to the regulations found in 49 CFR 173.469. The SFCs must subjected to 9 m impact, 1 m percussion, and 10 min thermal tests, followed by helium leak tests. The SFC designs must meet the special form criteria and then must be certified by DOT to meet these requirements for international transport (should the need arise).

Packaging used for the transportation of radioactive and other hazardous materials must be capable of meeting normal conditions of transport (NCTs) requirements and hypothetical accident conditions (HACs). Evaluations of performance of these criteria typically involve a combination of analysis and testing. Required tests may include free drop, dynamic crush, puncture, penetration, compression, vibration, water spray, water immersion, and thermal [3] tests.

All testing campaigns in the package testing program are completed in three phases. Phase 1 is the test planning, operations planning, and scheduling phase. In Phase 1, it is essential to ensure that the test plan is complete, that all operating and QA procedures are in place, that all lab equipment has been calibrated per NQA-1 requirements, and that all staff members are up to date on their required training as mandated by NQA-1 requirements. Phase 2 is initiated upon completion and verification of all required documentation from Phase 1. Phase 2 is the regulatory testing phase, and it includes all testing activities. Testing activities include but are not limited to prototype package assembly, instrumentation, preparation, NCT testing, HAC testing, and post-test inspection. Phase 2 concludes when the last testing step has been completed. Phase 3 is the report writing and project closeout phase. PTP staff members write an extensive, detailed test report describing all testing activities and including all post-process testing data. The approved test report is sent to the testing campaign sponsor, and the packages are dispositioned.

TESTING CAPABILITIES

The PEF is a purpose-built facility for package testing with an approximate floor space of 2,400 ft^2 and a 15 ft high bay with a 5-ton overhead trolley crane. The PEF is the main site for all package testing operations. The package testing operations are divided into three phases. Phase 1 consists of package preparation and assembly; Phase 2 consists of regulatory package testing; and Phase 3 consists of posttest package measurements, disassembly, and data post-processing. The facility can perform the following tests: Free drop test, crush test, puncture test, penetration test, vibration test, and water immersion test. ORNL has a long history of radioactive material testing, giving the lab the unique advantage of having an experienced, fully vetted testing program. The testing facility, equipment, layout, and tools were specifically built for the regulatory testing of radioactive material packages. To qualify a radioactive material package, the design authority (DA) must conduct performance tests to demonstrate that the package meets the NCT and HAC requirements.

FREE DROP

Free drop tests require that the package be dropped onto a "flat, essentially unyielding horizontal surface" [4]. Drop height requirements vary from 0.3 m to 9 m (1 ft to 30 ft). A reinforced concrete pad with a thick, hardened steel impact surface with a total mass at least ten times that of the test object is generally considered to be an unyielding surface. This type of evaluation can be performed on the outdoor drop pad and the indoor drop pad (Figure 1, Table 1) at the PEF. Standard rigging equipment is available at the PEF, and current inspection stickers are available for all tests.

Drop testing capabilities include Type A free drop tests (49 CFR 173.465[c] and 49 CFR 173.466[a][1]), Type B free drop tests (10 CFR 71.71[c][7], 10 CFR 71.73[c][1]), Type B corner drop tests (10 CFR 71.71[c][8]), special form impact tests (49 CFR 173.469[b][1] and 10 CFR 71.75[b][1]), and performance-oriented packaging drop tests (49 CFR 178.603).

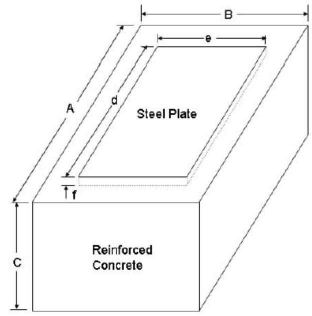

Figure 1. Drop pad general dimensions.

Table 1. Drop pad dimensions

Pad dimension	Drop pad	
	Outdoor (in.)	Indoor (in.)
A—length of concrete	300	99.5
B—width of concrete	159	72.5
C—depth of concrete	66	50
D—length of steel plate	242	75.5
E—width of steel plate	100.5	48.25
F—thickness of steel plate	4	2

Essentially Unyielding Drop Pads

The PEF has two drop pads that were built to be the "essentially unyielding horizontal surface". The indoor drop pad [4] (Figure 2) weighs 14.28 metric tons (15.75 tons) and measures 1.91 m (75.5 in.) × 1.22 m (48.25 in.), and it consists of a 5.08 cm (2 in.) thick steel plate and a reinforced concrete base. Packages can be lifted with and released from a 4.5 metric ton (5 ton) capacity bridge crane. The maximum lift height is approximately 4.7 m (15 ft) above the pad surface. The release mechanism is manually operated by a quick-release hook. The pad was designed for packages weighing less than 1,430 kg (3,150 lb). The impact pad serves as the primary pad for free drops of smaller packages, as well as other small packages subject to NCT tests.

The outdoor drop [4] pad weighs 127.84 metric tons (140.92 tons) and measures 6.14 m (242 in.) × 2.55 m (100.5 in.), and it consists of a 10.16 cm (4 in.) thick steel plate and a reinforced concrete base. This pad was for large packages with a maximum weight of 12,784 kg (28,184 lb). Large packages are lifted and released from a mobile crane that is brought to the NTRC for that purpose. This impact pad serves as the primary test pad for 15 m (50 ft) free drops and crushes required to demonstrate compliance of Type B radioactive material packages when subjected to the HAC tests. It is also used for demonstrating compliance of very large Type A package designs when subjected to NCT tests.

Figure 2. Indoor drop pad at the NTRC PEF[13].

<u>DYNAMIC CRUSH</u>

Smaller Type A(F) and Type B packages must be capable of withstanding a dynamic crush test per the regulations. Regulations state that the test unit must be “subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg (1,100 lb) mass from 9 m (30 ft) onto the specimen.” Crush tests are conducted on the outdoor drop pad by dropping a 1 m square mild steel plate (Figure 3) weighing 500 kg (1,100 lb) onto a test unit. The outdoor drop pad serves as the essentially unyielding surface. The crush test is recorded using two high-speed video cameras.

Figure 3. Dynamic crush plate at the PEF.

<u>PUNCTURE TEST CAPABILITIES</u>

Puncture testing is a required Type B package test (10 CFR 71.73[c][3]). This test requires the package be dropped 1 m (40 in.) onto a 15 cm (6 in.) diameter round steel punch mounted on an essentially unyielding surface. This evaluation can be performed at the PEF using a removable punch which can be securely attached to an appropriate drop test pad. The puncture bars used in the HAC puncture test are attached to the inside drop pad or the outside drop pad using four 1 in. grade 8 steel bolts.

Figure 4. HAC puncture test bar.

PENETRATION, PERCUSSION, AND BENDING TEST CAPABILITIES

The penetration, percussion, and bending tests include the Type A penetration tests (49 CFR 173.465[e] and 49 CFR 173.466[a][2]), the Type B penetration test (10 CFR 71.71[c][10]), the special form percussion tests (49 CFR 173.469[b][2] and 10 CFR 71.75[b][2]), and the special form bending tests (49 CFR 173.469[b][3] and 10 CFR 71.75[b][3]).

The penetration tests for Type A and Type B packages require a round steel bar with a 32 mm (1.25 in.) diameter and a weight of 6 kg (13 lb) to be dropped 1 m (40 in.) onto the package resting on a rigid, flat, horizontal surface and remaining immobile while the test is being performed.

Figure 5. NCT penetration test bar.

The special form percussion tests and bending tests are essentially variations of the penetration tests for Type A and Type B packages. The variations include the use of a smaller bar (25 mm [1 in.] diameter and 1.4 kg [3 lb]). For the percussion tests, the test item must rest on a 25 mm (1 in.) thick lead surface. For the bending tests, the specimen is securely clamped in a horizontal position so that one half of its length protrudes from the face of the clamp.

All of the variations of the penetration, percussion, and bending evaluations can be performed at the PEF by means of actual physical testing. A steel bar 3.2 cm (1.25 in.) in diameter with a hemispherical end and a mass of 6 kg (13.2 lb) is used for the penetration test, and a 12 in. square lead sheet with a thickness of 1 in. and a hardness number of 3.5 to 4.5 is used for the special form percussion test (Figure 6).

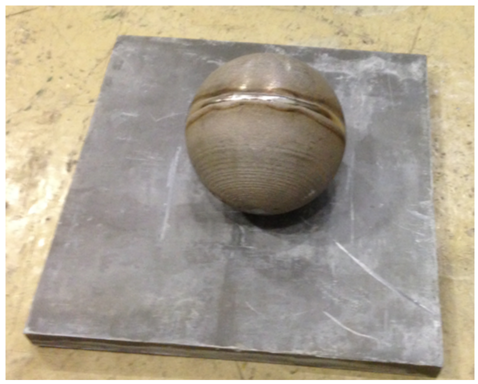

Figure 6. Special form percussion test set up.

COMPRESSION/STACKING TEST CAPABILITIES

The compression/stacking tests include the Type A compression test (49 CFR 173.465[d]), the Type B compression test (10 CFR 71.71[c][9]), and the performance-oriented packaging stacking test (49 CFR 178.606). The Type A and Type B compression tests require uniform loading of the entire top surface of the package using a load that is the greater than either five times the package weight or 1,300 kg/m^2 (265 lb/ft^2). The performance-oriented packaging stacking test requires stacking packages of an equivalent weight to a minimum height of 3.0 m (10 ft), [5].

Each of these evaluations can be performed at the PEF by means of actual testing. A compression tester is available to meet the testing requirement for Type A and Type B packages. The compression tester is a Lansmont model 152-30K capable of up to 30,000 lb of compressive force (Figure 7). The compression tester has a force accuracy of ±0.1% of force set point. The test unit is placed at the center of the compression tester, and a force of five times the maximum gross weight of the package is applied for 24 h. Pretest dimensional measurements are compared with the posttest dimensional measurements and recorded. Additionally, data from the compression tester linear variable differential transformer (LVDT) are included in the test report.

Figure 7. NCT Lansmont compression tester.

<u>VIBRATION TEST CAPABILITIES</u>

Vibration assessments include the Type A vibration test (49 CFR 173.410[f]), the Type B vibration test (10 CFR 71.71[c][5]), and the performance-oriented packaging vibration test (49 CFR 178.608). The Type A vibration evaluation requires that the package meet the performance-oriented package criteria for nonradioactive materials. The Type B vibration test requires exposure of the package to vibration normally incident to transportation. The performance-oriented packaging vibration test involves placing the samples on a vibrating platform that has a vertical or rotary double amplitude (peak-to-peak displacement) of 25 mm (1 in.). The test must be performed for 1 h at a frequency that causes the package to be raised from the platform by approximately 0.063 in. per 49 CFR 178.608.

This type of evaluation can be performed at the PEF using a Lansmont model 10000-10 vibration table (Figure 8) capable of random vibration of 3,200 lb from 10–500 Hz flat spectrum and sinusoidal vibration of up to 7,800 lb with a maximum stroke of 2.5 in. The large table is 60 in. × 60 in., and the small table is 34 in. × 34 in.

Figure 8. Lansmont vibration table.

WATER SPRAY TEST CAPABILITIES

Type A and Type B packages must be capable of withstanding water spray as specified in 49 CFR 173.465(b) and 10 CFR 71.71(c)(6). These tests call for exposing the package to a water spray of 5 cm (2 in.) per hour for a period of 1 h. This type of evaluation can be performed at the PEF by means of actual testing. The PEF water spray test system is a four-nozzle system constructed of polyvinyl chloride (PVC) pipe. The nozzles are arranged to spray the top and all vertical surfaces of a package simultaneously. The system simulates a rainfall of greater than 5 cm (2 in.)/h. An off-the-shelf, noncalibrated rain gauge is used to measure the simulated rainfall amount.

IMMERSION TEST CAPABILITIES

The immersion test is a required Type B test (10 CFR 71.73[c][6]). This test requires submerging a package in 0.9–15 m (3–50 ft) of water. This type of evaluation can be performed at the PEF using various immersion tubs (Figure 9) to submerge the package in 3 ft of water.

An additional 15 m test must be performed for all packages in accordance with a pre-approved operating lab operating procedure. The package containment vessel is lowered into a water-filled stainless-steel pressure vessel. The lid to the pressure vessel includes three threaded ports on the top surface. One port included a ¼ in. national pipe thread (NPT) to accept the installation of the digital pressure gauge, the second was fitted with a ½ in. ball valve to serve as a vent, and the third was fitted with a tube topped with ¾ in. NPT tee fitting. One side of the T fitting accepted a certified pressure released valve set to 30 psi, and the other side accepted a hose from a pneumatically actuated pump attached through a ¾ in. ball valve. A small amount of pressure was induced by compressive force while tightening the lid bolts of the pressure vessel lid. The pneumatic pump was then used to apply 25 psig and held there for 8 h (Figure 10).

Figure 9. NCT immersion tub.

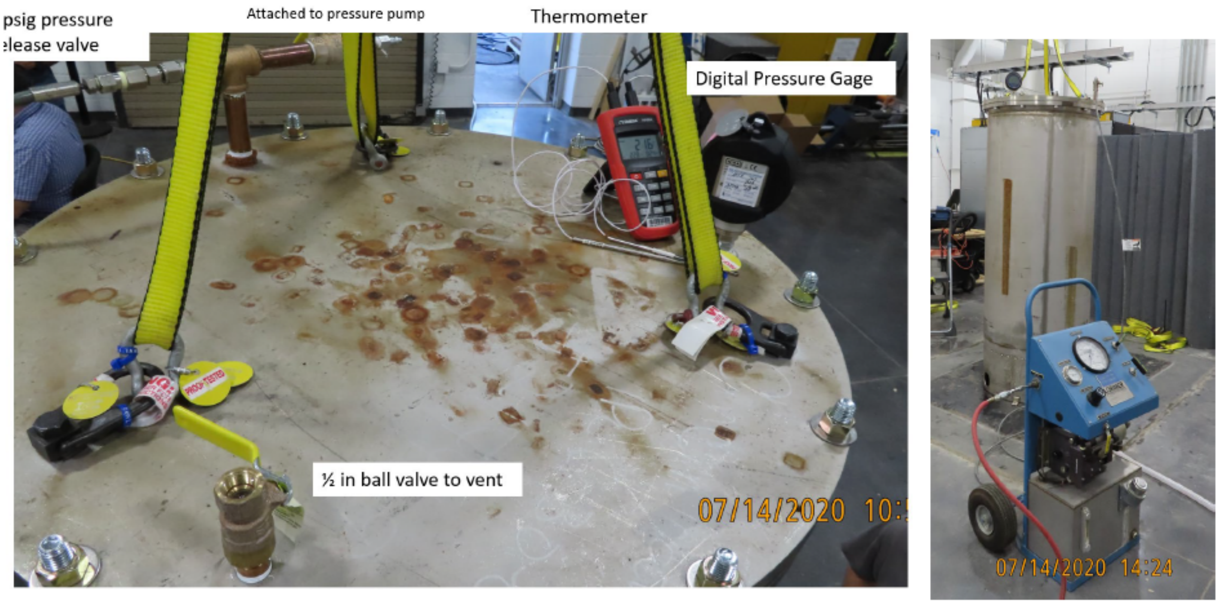

Figure 10. 15 m immersion test.

<u>THERMAL CAPABILITIES</u>

Type B packages must be capable of withstanding the NCT heat test specified in 10 CFR 71.71(c)(1). This test requires a package to be held at an ambient temperature of 38°C (100°F), followed by a 12 h period of insolation heat load ranging up to 800 g cal/cm^2. This type of evaluation can be performed at the PEF using an environmental testing chamber, but packages are typically analyzed in lieu of actual thermal testing. The Technical Testing and Analysis Center (TTAC) at ORNL [6] can simulate a broad range of environmental conditions. The TTAC facility has two temperature and humidity chambers with internal volumes of 27 ft^3 and 425 ft^3, respectively, and both chambers have a temperature range of −60°C to +160°C. Additionally, humidity can be set within a range of 5% to 98%. The cold test is a required Type B test (10 CFR 71.71[c][2]) in which a package is exposed to a temperature of −40°C (−40°F) in still air while in the shade. To meet the 10 CFR 71.71(c)(2) requirement, packages are chilled to a nominal temperature of −40^{o}F by placing them into an environmental chamber at the TTAC facility and initially setting the chamber control to −50°F for 48 h. After this initial period, the environment chamber is set to −40°F for at least 48 h. The largest environmental chambers measure 9 ft × 6 ft (Figure 11).

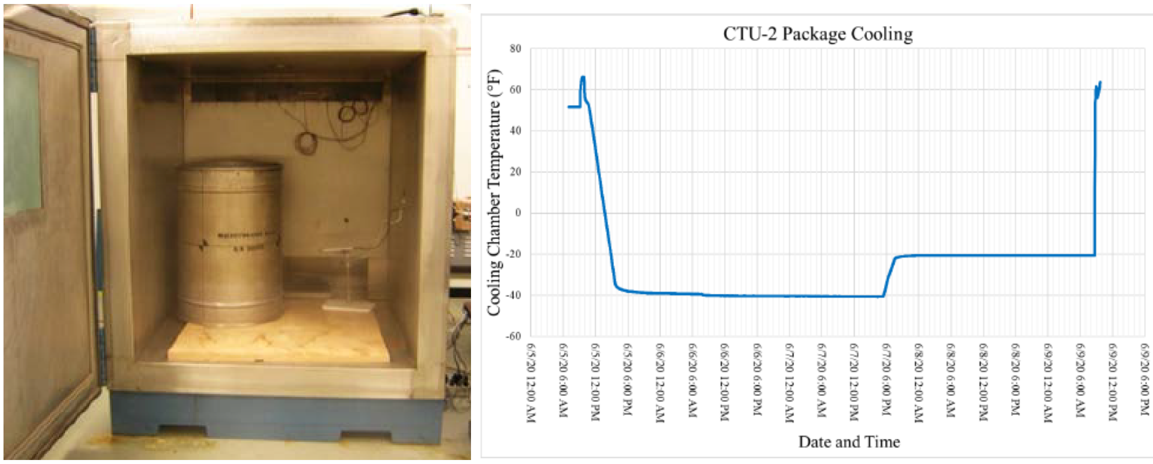

Figure 11. TTAC environmental temperature chamber.

Type B and fissile material packages must be capable of withstanding the HAC thermal test conditions as described in 10 CFR 71.73(c)(4). The Type B thermal test requires that the test unit be exposed to an 800°C (1,475°F) environment. This can be accomplished using a hydrocarbon fuel fire, or it can be performed in a furnace/autoclave. The PTP performs the HAC thermal test in a gas-fired furnace at a non-ORNL, off-site facility (Figure 12). The furnace is an open-fired natural-gas–fueled box furnace with a 20 × 12 × 8 ft work zone. The estimated heating design load is 10 tons with an operating temperature range ranging from 1,400 to 2,100°F. The thermal test is executed at the PEF in accordance with 10 CFR 71.73 (c)(4) using methods described in American Society for Testing and Materials (ASTM) E2230-08 *Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material,* Section 7.3.4.3, which specifies a steady-state furnace testing methodology [7].

Figure 12. Thermal test at Southwest Research Institute.

Requirements for the special form heat tests are specified in 49 CFR 173.469(b)(4) and 10 CFR 71.75(b)(4). The special form heat tests require that the test unit be heated in air to a temperature of 800°C (1,475°F), held at that temperature for 30 min, and allowed to cool naturally. This test would typically be accomplished in a furnace at ORNL (Figure 13). ORNL has small bench-top industrial furnaces that are located inside a fume hood or glovebox that are capable of supporting the special form heat testing activities for the PEF (Figure 13) [8][9][10].

Figure 13. Special form heat test in a fume hood furnace, glove box furnace, and standard gas furnace.

DATA ACQUISITION

Data from tests are acquired in several ways. Generally, a package will sustain damage in a test, and that damage is measured and recorded. Customers often wish to determine what occurred internally and/or externally after a test has been completed; in some cases, they wish to determine specific information during the test, such as the extent of damage or the shock loads that occur at specific points in the package. These requests are noted in the test plan that is developed for each test series. The PTP QA plan ensures that all data acquisition (DAQ) activities are controlled according to written procedures, checklists, and data sheets. The quality of the data is controlled by ensuring that all data collection instruments, and testing equipment are calibrated to an established standard.

Photographs and Videography

Digital photographs are taken during all testing activities to track and document the prototype test units and the cumulative damage to the package as it is subjected to the regulatory tests. The digital photographs are made in compliance with the NQA-1 QA requirements in accordance with the approved test plan.

For NCT and HAC tests, the PEF has two high-speed cameras that can be used to capture the dynamic impact of the packages onto the drop pad. The high-speed cameras have a filming rate of up to 4,000 fps. The maximum shutter speed is affected by the ambient lighting conditions. Consequently, higher frame rates and greater video resolutions can be achieved with the addition of high-wattage lights. The cameras are oriented at 90 degrees of one another facing the drop pad. The impact is captured through the high-speed camera software, and the video file is post-processed and exported as a media file. All media files are post-processed, reviewed for sensitivity and made available to the customer after the test.

Digital Image Correlation

Digital image correlation (DIC) and tracking is an optical method that employs image registration techniques for accurate 2D and 3D measurements of changes in images. This technique was used during free-drop testing of prototype packages to acquire data on position, velocity, and acceleration. The impact data were acquired using Mega Speed object tracking software and were used to perform calculations to find data on acceleration and maximum G-loads [11].

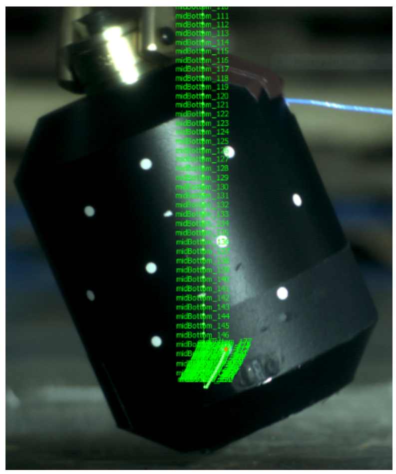

Figure 14. Digital image correlation object tracking.

Accelerometers

Accelerometers can be used to measure the acceleration and deceleration responses of various items. Accelerometers are one of the most used dynamic inertial sensors and offer a vast range of sensing. They are typically used in one of three modes: inertial measurement of velocity and position, attitude measurement, and vibration and shock measurement. Strategically affixing accelerometers to test units provides real-time position, velocity, and impact data during testing. The data obtained can be used to determine the overall behavior and response of a package when subjected to a test, and the data can also be used to assist in validating modeling and simulation results from finite-element analysis. ORNL has staff members experienced in accelerometer DAQ, installation, and instrumentation (Figure 15). The DAQ can be tailored to contain as many channels as needed to collect the data from a three-axis accelerometer. A laptop with M+P Vibplot 8 channel software is used to monitor and gather the data from all the accelerometers [12][13].

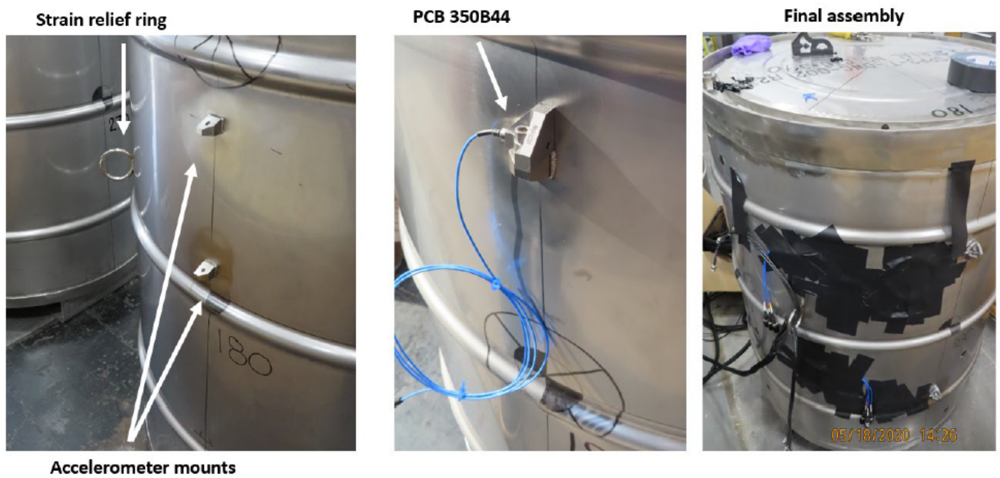

Figure 15. Package accelerometer placement.

<u>Thermocouple Data Acquisition System</u>

The thermal DAQ system consists of a personal computer, a bank of analog-to-digital converters for thermocouples, calibrated thermocouples, and controller software. This system has been assembled, programmed, and calibrated by ORNL Instrumentation and Controls Division personnel according to standards traceable to the National Institute of Standards and Technology (NIST). Before the system is used, calibration is checked and adjusted as necessary using a thermocouple calibrator. If necessary, the equipment will undergo additional calibrations to ensure that the system is qualified and working properly at the time of use. An ORNL-developed computer-based thermal monitoring system [14] is used to monitor the furnace environment and the test units during the HAC thermal tests. This system provides 72 data channels, the results of which are continuously logged to a data file. During setup, the system is set to log data every 15 s from each data channel. The preferred thermocouples for this application are 0.063 in. diameter type K thermocouples. These lightweight thermocouples respond rapidly to changes in temperature, thus providing a very accurate thermal profile of the furnace and test unit. Figure 16 illustrates the typical instrumentation setup for a Type B package thermal test.

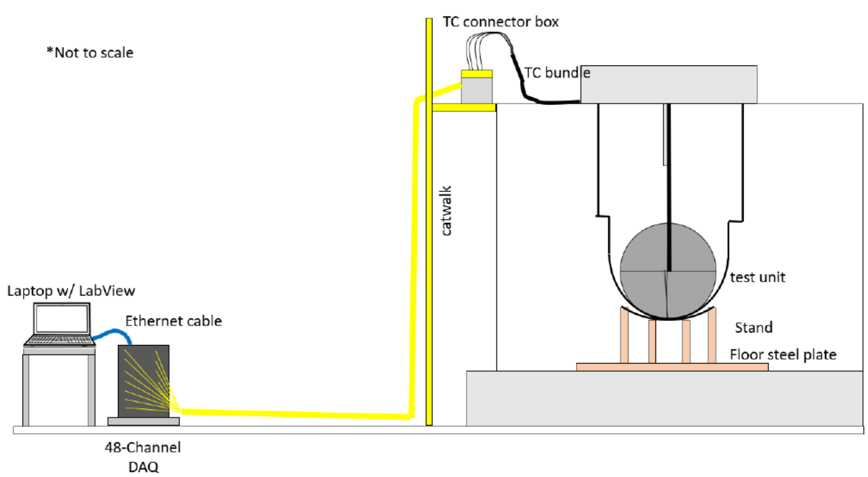

Figure 16. Typical thermal test wiring set-up.

Additionally, temperature labels ranging from 70°F to 400°F are placed at various locations inside the test units to determine the maximum temperatures at specific locations during the thermal test. The temperature label data are recorded during the disassembly process in Phase 3 and inputted to a data table which is used to create a heat map of the internal parts of the package, as shown in Table 2. The heat maps illustrate the temperature profile of various specific areas in the package. By grouping and sorting the temperature labels from the inner most radius to the outermost radius one can see the rise in temperature as you move out radially from the center of the package.

Table 2. Temperature label heat map.

Test content assembly [TL-10-105 and TL-10-190]	**0°**	**90°**	**180°**	**270°**
Top end cap center	200	200	200	200
Top end cap under flange	200	200	200	200
Tube upper	200	200	200	200
Tube middle	200	200	200	200
Tube lower	190	190	190	190
Bottom end cap under flange	190	190	190	190
Bottom end cap center	180	190	180	190
Weight upper	190	190	190	190
Weight lower	190	190	190	190
CV (inside) [TL-10-105 and TL-10-190]	**0°**	**90°**	**180°**	**270°**
Lid center	210	210	210	210
Body flange	200	210	210	210
Wall upper	200	210	210	210
Wall middle	200	200	210	200
Wall lower	200	200	200	200
Base neck	190	190	200	190
Base center	190	190	190	190
CV (outside) [TL-10-105 and TL-10-190]	**0°**	**90°**	**180°**	**270°**
Lid center	210	210	210	210
Lid flange	210	210	220	210
Body flange	210	210	220	210
Base neck	200	200	200	200
Base toe	190	190	200	190
Drum assembly (inside) [TL-10-190 and TL-10-290]	**0°**	**90°**	**180°**	**270°**
Drum lid bottom	230	230	230	230
Cavity wall upper	230	230	240	240
Cavity wall middle	230	230	240	240
Cavity wall lower	240	230	240	240
Cavity wall lowest	230	220	230	220
Cavity bottom	210	210	200	200

3D Metrology Scanning

The HandyScan Black Elite and the MetraScan scanner provides the most effective, reliable way to acquire accurate 3D measurements of physical objects. The 3D scanners features dynamic referencing, which means that both the scanner and the part can move during measurement and still can provide an accurate, high-quality scan. The accuracy of the scanner is 0.025 mm (0.0009 in.) with a 310 × 350 mm (12.2 × 13.8 in.) scan area. The rate of measurement is 1,300,000 measurements/s (Figure 17). Once the 3D scanning is complete, the generated 3D scan computer-aided design (CAD) data are post-processed and used for more precise dimensioning and measuring, as seen in Figure 18. 3D metrology enables precise, detailed measurements of any deformations, cracks, or structural changes. This technology provides the high-resolution, accurate data that are essential when verifying whether a prototype test unit meets regulatory testing standards. Because 3D metrology can be used to scan the smallest flaw in the test unit's structure, it can indicate whether the package can withstand real-world conditions. As such, this information will safeguard the public and ensure environmental safety during transport of radioactive materials. Finally, a post test 3D scan of a deformed package can provide additional evaluations of a damaged test unit. The damaged test unit 3D model can be revaluated for thermal, shielding, criticality to assess performance metrics of a damaged test unit [15].

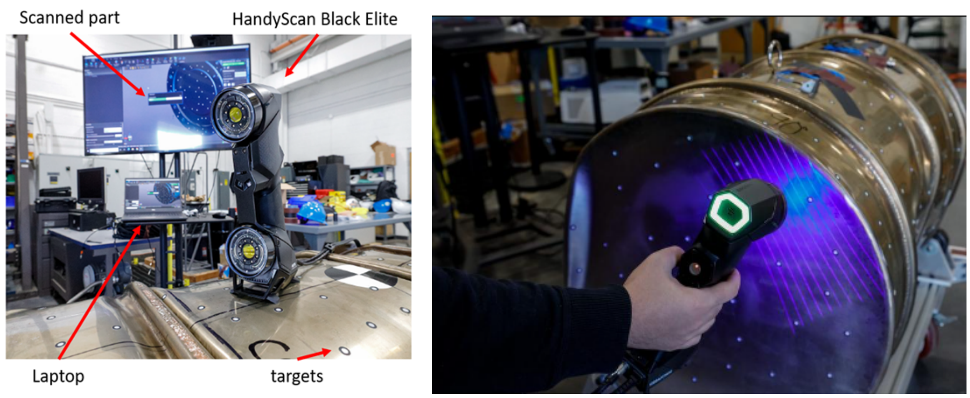

Figure 17. HandyScan Black Elite.

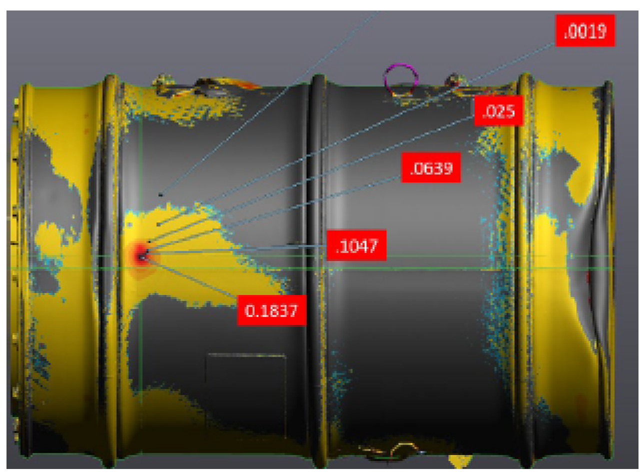

Figure 18. Post-process 3D scan.

<u>Leak Testing</u>

The PTP manages and oversees the execution of the operational and helium leak tests per ANSI N14.5 standards. PTP staff members use an onsite level III leak tester to execute the leak test. The operational leak test objective is to ensure the proper assembly of the package lid. The area between the O-rings is pressure tested using a pressure decay or pressure rise test. The change in pressure is recorded over a set time, and a leak rate is calculated. If the leak rate is below 1E-4 ref-cm^3/s, then the test is considered as passed. The helium leak test objective is to ensure that the containment vessel is leak-tight, meaning that the leak rate is less than 1E-7 ref-cm^3/s. Helium gas is introduced into the package, and a helium leak detector is used to monitor for any helium. Using this process, even the smallest flaw in the containment vessel can be detected, thus ensuring that the vessel maintains a robust seal under regulatory safety standards. Together, these tests provide a comprehensive assessment of the containment system's reliability, ensuring that radioactive materials remain securely enclosed, thus protecting handlers, the public, and the environment.

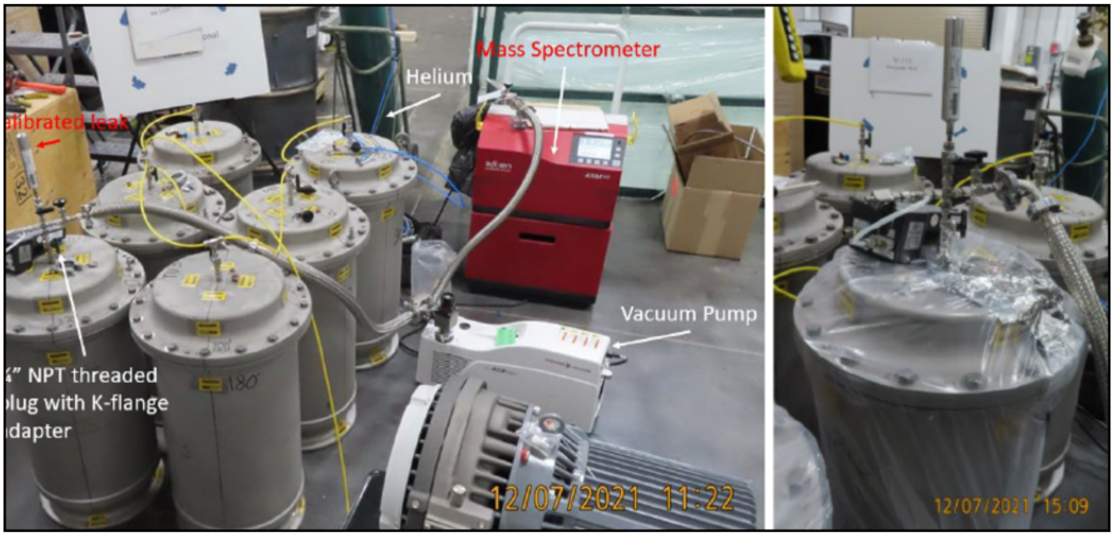

Figure 19. Helium leak test [16].

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