Contract No:

This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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Building the SRNL Radioactive Material Packaging Testing Centre of Excellence: Approaching the Full Suite

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ABSTRACT

The Savannah River National Laboratory (SRNL) Packaging Technology (PT) group is a regulatory testing and packaging design organization that houses close to two dozen engineers, with seven of those considered well qualified/internationally recognized experts with a combined radioactive materials packaging experience of more than 200 years.

The PT group actively supports various federal agencies, with the Department of Energy (DOE), National Nuclear Security Administration (NNSA), the Nuclear Regulatory Commission (NRC) and the Department of Homeland Security being primary customers. Currently, it manages a fleet of over ten package designs, with a combined fleet size of over 5,000 individual Type-A liquids, -AF, and -B packages. Additionally, it is also currently developing three new radioactive material packages.

To ensure that SRNL PT package testing and design capabilities will continue to align with its changing missions, in 2021 the SRNL Radioactive Packaging Test Centre of Excellence was established. As part of this effort, package testing capabilities and strengths continue to be expanded, and improved upon, to match current and future mission needs, ensuring SRNL remains a recognized leader in performing the required regulatory testing of radioactive material packages specified in the U.S. Code of Federal Regulations.

This paper summarizes the approach and results of the latest performed internal assessment of SRNL's radioactive material package testing, strengths, and capabilities. The capabilities are approaching "near full-suite inhouse", with an exception for Hypothetical Accident Condition Fire Testing with packages having an outside volume of greater than 0.16 m^3 (35 gallons). In such, cases the performance of the test must be performed at a vendor facility.

INTRODUCTION

The Savannah River National Laboratory (SRNL) is located near Aiken, South Carolina at the Department of Energy (DOE) Savannah River Site (SRS). Much of the site was originally constructed in the 1950s to support the U.S. weapons stockpile program, which originally had five operating nuclear reactors. The last operating SRS nuclear reactor was officially shut down in the early 1990s, with operations and facilities changing their mission across the site. PT's mission was changed to bettering national and global security while developing innovative technologies to support nuclear material packaging.

Since the end of the cold war radioactive material packaging test capabilities have continued to technologically evolve at SRNL. High speed videos have largely replaced standard "before and after test photographs." Although a few decades ago most analog technology became part of the digital conversional, only recently as part of developing the SRNL Radioactive Packaging Test Centre of Excellence, has SRNL PT replaced/updated significant test equipment allowing for increased digitalization, resulting in improved testing accuracy, more data and better analyses.

A cutaway picture of a representative SRNL designed Type B radioactive material package is shown in Figure 1.

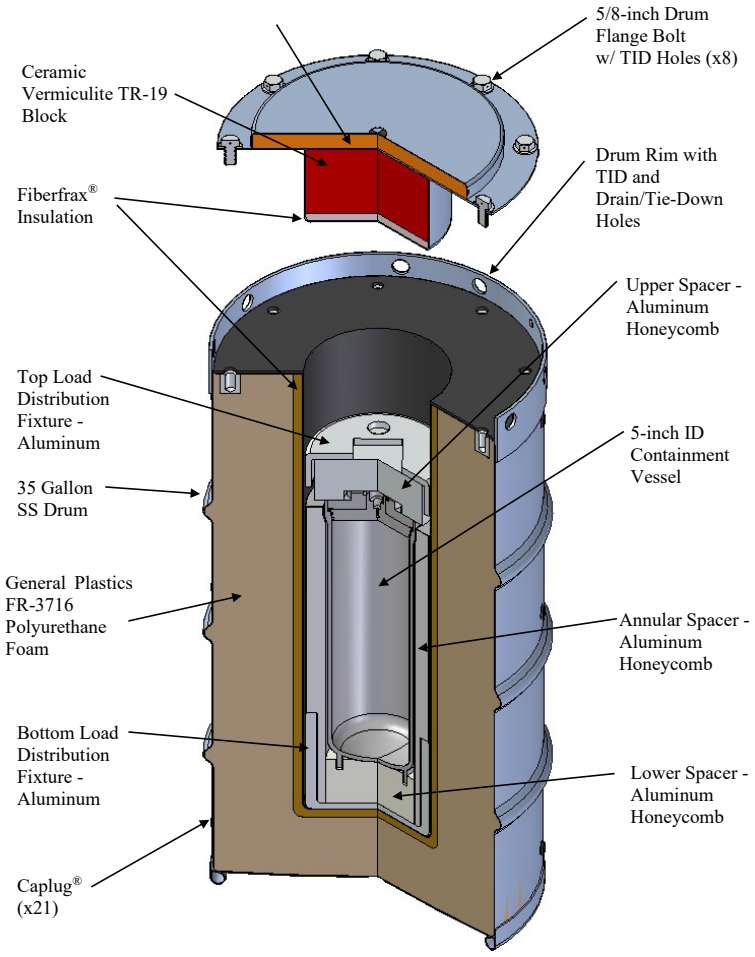

Figure 1. Cut-Away of a Representative SRNL Designed Type B Package

The minimum required regulatory testing for a Type-B package is found in the U.S. Code of Federal Regulations, 10 CFR 71. Specifically, the tests for the Normal Conditions Transport (NCT) are found in 10 CFR 71.71[2], while the tests for the Hypothetical Accident Conditions (HAC) are found in 10 CFR 71.73[3]. There is a minimum of thirteen tests (or analyses) required. Eight for the Normal NCT and five for the HAC. The commonly used names for these NCT and HAC tests, as well as their associated CRF location are shown in Figure 2 and Figure 3, respectively.

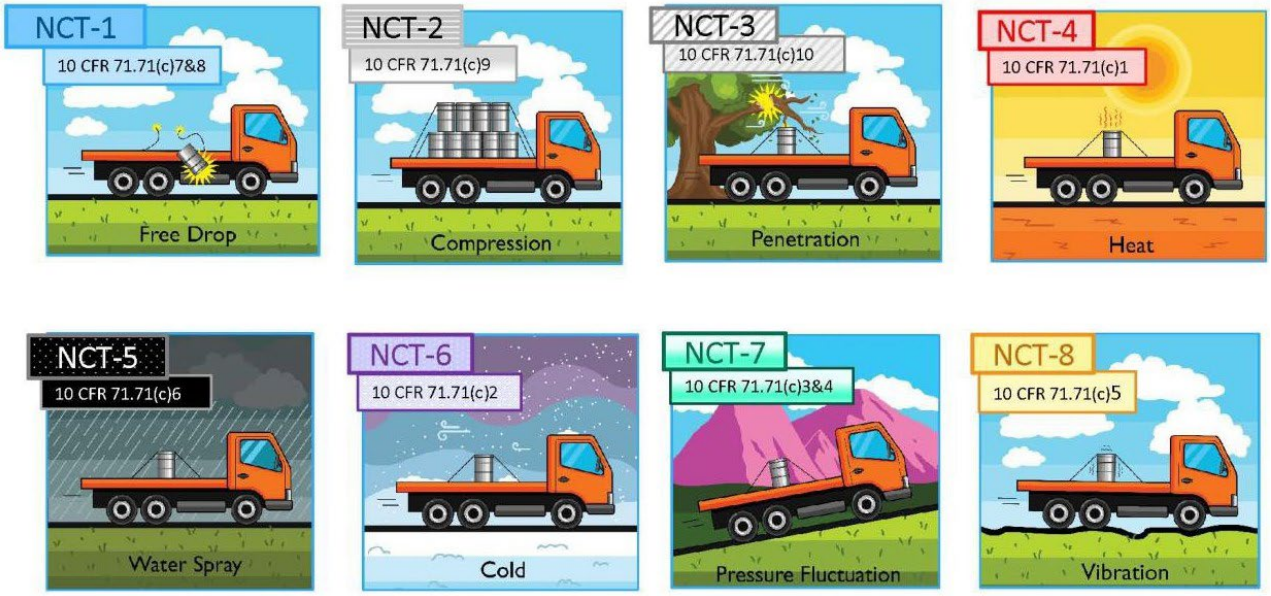

Figure 2. Minimum Required Tests for Normal Conditions of Transportation

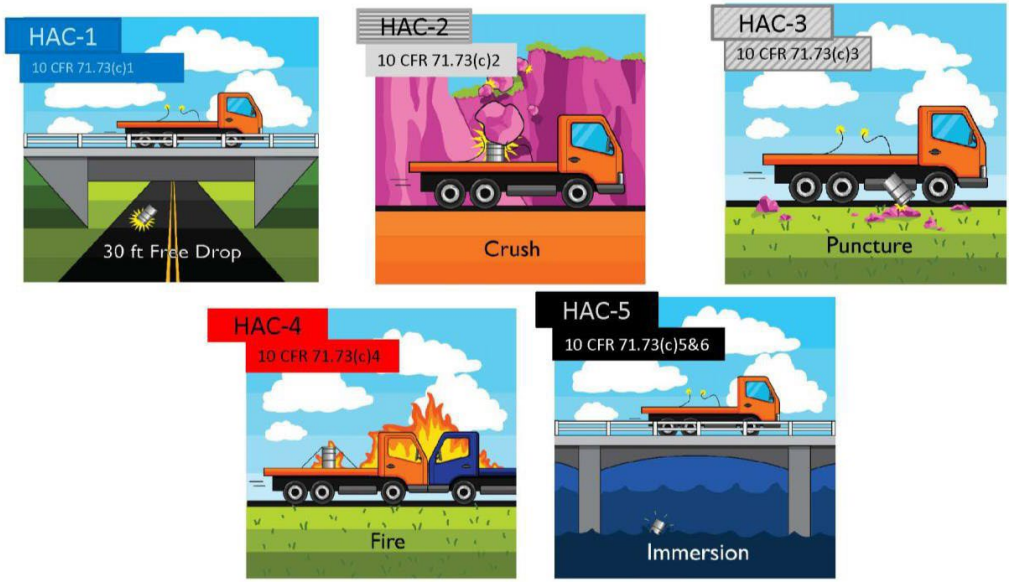

Figure 3. Minimum Required Tests for Hypothetical Accident Condition

As part of ensuring that SRNL PT remains a leader in performing radioactive material packaging testing, a detailed yearlong critical review of the SRNL testing capabilities versus the regulatory specified requirements (with the regulatory requirements specified by Figures 2 and 3 was performed in 2021. The approach used and the results of the assessment follow.

APPROACH

The thirteen tests were grouped, combining those which make use of the same primary equipment/facilities, such as the tests that require the use of a drop test pad.

A brief summary of the of test requirements and associated facilities are then provided. To aid in understanding the pedigree/capabilities of newly installed equipment, the manufacturer and model numbers, are provided, as applicable. Limitations and disadvantages associated with the equipment/facility are also discussed. Identified, improvements associated with data quality and collection as the result of the "new equipment" are also discussed.

Note: As a safety measure, the plan is that any future equipment/facilities/improvements potentially costing over $100,000 (U.S.), will first require a detailed cost benefit analysis that effectively considers both the upkeep and maintenance costs and potential advantage/ disadvantages associated with leveraging, subcontracting, and renting the equipment or service will be developed prior to initiating future procurement actions.

ASSESSMENTS

The following assessments were performed of each of the testing groups

Drop, Compression/Compaction, and Puncture/Puncture Testing (NCT/HAC 1-3)

During free drop tests, the package must be dropped onto a flat, unyielding, horizontal surface to obtain maximum expected damage. The NCT required drop distance based on package weight for solids is shown in Table 1.

Table 1. NCT Criteria for Drop Test

Package Weight	Free Drop Distance
Less than 5,000 kg (less than 11,000 lbs)	1.2 m (4 ft)
5,000 to 10,000 kg (11,000 to 22,000 lbs)	0.9 m (3 ft)
10,000 to 15,000 kg (22,000 lbs to 33,100 lbs)	0.6 m (2 ft)
More than 15,000 kg	0.3 m (1 ft)

For HAC liquids and solids , the requirement is 9 m (30 ft). The HAC drop will normally bound the NCT drop so the NCT drop test may not be needed.

For a typical 0.25 m^3 (55 gallon) drum size Type-B package, full size free drop testing has traditionally been performed by using the Building 723-A's High Bay drop testing pad. This is available for packages weighing less than 454 kg (1000 lbs). When factoring in the weight of the internal components of a package and its content, a loaded typical 0.25 m^3 (55 gallon) drum style package, such as the SRS 9975 package, can easily exceed this limit.

Figure 4 displays several elements of the drop test performed in the 723-A High Bay. The drop plate is made from battleship steel, commonly used in armored vehicles. The drop plate is 0.5 m^2 (5 ft^2) and 16.5 cm (6.5 inch) thick, anchored to a 0.56 m^2 (6 ft^2) by 0.9 m (36 inch) thick reinforced concrete slab insulated from the surrounding concrete floor. The plate and concrete combined weighs approximately 7076 kg (15,000 lbs) thus providing the regulatory required unyielding surface.

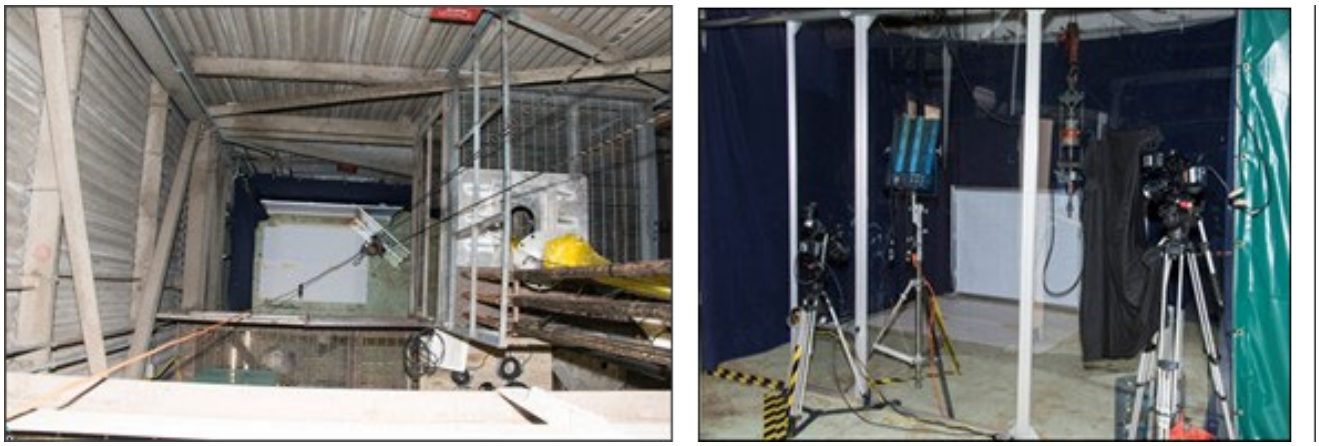

Figure 4. Preparation of Building 723-A High Bay Area of Facility for Drop Testing

Disadvantages of using the 723-A High Bay for package testing include:

- PT must compete with the rest of SRNL to use the facility.
- The high bay cannot be used during lightning or thunderstorms.
- The maximum allowable weight is 454 kg (1000 lbs), based on weight of the pad size and hoist capabilities (Note: A fully loaded 0.25 m^3 (55 gallon) drum loaded with bags of concrete will easily exceed this limit. A loaded SRNL 9975, as previously noted, will also exceed this package limit.

The N-Area outside drop pad supports the drop testing of larger packages, but it is an outside facility subject to weather conditions and requires the renting of a crane. The outside drop pad is a 2.4 m × 3.7 m × 15.9 cm (8 ft × 12 ft × 6.25 inch) block of thick battleship steel, weighing approximately 11,340 kg (25,500 lbs). The plate is bonded onto a concrete foundation. The steel is floated on an approximately 3.7 m × 4.6 m × 3.8 cm (12 ft × 15 ft × 1.5 inch) thick grout base. Use of the outside drop pad in N-Area with a rented crane is shown in Figure 5.

Figure 5. SRNL N-Area Outside Drop Test Pad

A drop test tower is currently under development. It will offer an improvement in testing capabilities (size, weight, and drop accuracy), while removing the necessity of renting a crane.

The drop test pads are also used to perform the HAC Crush Test and the NCT Compression tests identified in Figure 2 and Figure 3 as NCT-2 and HAC-2, respectively. For HAC, a dynamic crush plate of 499 kg (1,000 lbs) is dropped 9 m (30 ft) onto the package. However, if the overall density of the package exceeds 1000 kg/m^3 (62.4 lbs/ft^3), the crush test is not required by the regulations.

For NCT, a compression load that is 5 times the weight of the package or 13 kPa (1.89 psi) is applied to the top and bottom of the package for 24 hours. Although this has been traditionally conducted by placing masses on top of the package to equal the load, the DFM 150 kN Floor Model UTM has been acquired. This quasi-static compression system simulates compression testing, removing the necessity for using a drop pad for compression testing. Machine capabilities include accurate measurement of applied force and package compression, and a built-in data data acquisition that allows all data to be transferred easily to a database [4]. This allows for accurate data collection over a 24-hour period, while being easily accessible for data analysis. The quasi-static compression system is shown in Figure 6.

Figure 6. Installed DFM 150 kN Floor Model UTM

The drop test pads are used to perform the HAC Penetration and the NCT Puncture tests. For HAC-3, the package is dropped 1 meter (3ft) from the position onto a steel bar mounted perpendicular to the package on an unyielding surface, while for NCT-3 the steel bar impacts the most vulnerable exposed surface from 1 m (40 inch).

High-speed video camera, capable of recording at 1,000 frames/second, are regularly used for both drop and impact testing. Compared to traditional cameras, which are only able to capture footage at 60 frames/second, the high-speed camera shows exactly how a package had deformed under impact. This footage may also supplement finite element analyses (FEA) simulations of impacts of the package, verifying simulation accuracy.

Fire and Temperature Testing (HAC-4/NCT-4)

The NCT high temperature test requires a temperature of at least 38°C (100°F) to test if the package can withstand insolation. There is also an advantage with the data logging system in the environmental chamber have the capability of being to measure and record the rate of insolation in the atmosphere and at different surfaces of the package. The HAC fire test requires the average flame temperature to be at least 800°C (1475°F) in a period of 30 minutes with a fuel source extending horizontally beyond the package by 1 m (40 inch) or more. These HAC tests are usually performed in a furnace or using a pool fire. To test small packages which are at most 0.16 m^3 (35 gallon), an electric furnace is available at SRNL. For larger packages exceeding 0.16 m^3 (35 gallon), the package must be tested by pool fire. Currently testing must be contracted to the South Carolina Fire Academy in Columbia, South Carolina. To improve testing in the future, a gas fired furnace which could test larger packages with an outside volume of up to 0.7 m^3 (150 gallon) and satisfy HAC-4 testing is being developed.

Water Immersion and Precipitation Testing (HAC-4/ NCT-4)

Both tests are designed to prove the water tightness of the package. The HAC tests simulate scenarios such as a package falling into deep waters. For HAC-5, the package must face a water pressure that is equivalent to an immersion of 15 m (50 ft). NCT tests simulate precipitant weather conditions such as rain with the spray testing occurs approximately at 5 cm/hr. (2 in/hr.) for a period greater than 1 hr. There are advantages that come with the data logging capabilities in the NCT-5 tests. Adding a flowmeter attached to a datalogger with flow recorded every thirty seconds other than a written on a piece of paper before and after the test.

Cold and External Pressure Testing (NCT-6 and NCT-7)

Packages subject to extreme cold, specified by NCT-6, must be able to withstand a cold temperature of -40°C/-40°F in still air and shade. NCT-7 requires that the package must withstand both a reduced ambient pressure of 25 kPa (4 psi) and an increased pressure of 140 kPa (20 psi) without any buckling.

NCT-6, along with NCT-4, may both be fulfilled by utilizing the environmental chamber (Refer to Figure 7). The temperature within the chamber can be reduced to -40°C/-40°F. In addition, the environmental chamber's temperature may be increased to 100°F to fulfill NCT-4. Without access to the environmental chamber, instead the package would have to withstand a temperature of 4.4°C/40°F, then proven that all individual components of the package can withstand 40°C/-40°F. The environmental chamber allows for testing at this temperature, so this analysis would not have to be conducted.

Figure 7. Exterior of Environmental Chamber

To check that a package could withstand pressure changes, as specified by NCT-7, a structural analysis of the package at 140 kPa (20 psi) would be conducted. Some concerns to focus on includes buckling of the package, and components failing. In most cases, the highest pressure will bound the maximum damage, so analysis at the lower pressure is optional.

Vibration Testing (NCT-8)

Vibration testing, specified by NCT-8, is used to verify that packages' structure integrity will remain unchanged after shipping. Before acquiring the vibration table, the testing was contracted to other testing facilities who had vibrations tables. With our recently acquired, SRNL has recently acquired and installed a high frequency vibration table shown in Figure 8. This table can produce random vibrations of up to 296 kN (66,500 lbf) and from 0 to 3,000 Hz while operating for hours on end. Data collection is also conducted by the table's controller, allowing users at SRNL to conduct vibration testing, automatically digitally have the data collected, then analyze the data making use of the instrument's data acquisition system [5].

Figure 8. SRNL PT Vibration Table

CONCLUSION

Test equipment is constantly being evaluated and updated to expand SRNL's testing capabilities. Currently, SRNL has the onsite capability of testing packages with an outside volume of up to 0.16 m^3 (35 gallon), including performance of the thirteen Type B tests normally attributable to 10 CFR 71 and 10 CFR 73. However, testing slightly larger packages would bring some complications. For example, Free Drop Testing of packages weighing more than 454 kg (1000 lbs) generally has to be conducted outside. HAC Pool Fire Testing for packages with an outside volume exceeding 0.16 m^3 (35 gallon) must be also contracted. The addition of the environmental chamber and the vibration table has allowed for High and Low Temperature Testing, as well as greatly simplified Vibration Testing. Verification of package integrity at Varying Pressures, to check for buckling or component failure is performed by modeling.

SRNL plans to continue to further expand and improve upon its testing capabilities. This includes a drop test frame for facilitating outdoor HAC Free Drop Testing, and possibly a larger furnace to expand the HAC Fire Test testing to larger packages with an outside volume of up to 0.7 m^3 (150 gallon). With integration of this test equipment, SRNL will not only be approaching the full suite, but have the full inhouse minimum regulatory NCT and HAC Testing capability.

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