Proceedings of the 19th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2019
August 4-9, 2019, New Orleans, LA, USA

NCT/HAC Testing of 9981 Type AF Shipping Container

Fletcher Davis, Joshua Flach, Christopher Cable, Paul Blanton
Savannah River National Laboratory
Aiken, SC

Abstract

The 9981 Type AF Shipping container is an adaptation of the 9979 Type AF shipping container. It was designed to carry a heavier payload to meet customer needs. Changes in the design necessary to contain the heavier payload required additional testing for both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). Due to the need to use multiple facilities and work between several groups, completion of the testing required significant planning and coordination. This paper describes the planning, execution and results of the 9981 testing.

I. Background

The Portsmouth Gaseous Diffusion Plant identified the need for a new packaging container after evaluating methods to ship large quantities of uranium metals. Portsmouth had received uranium metal from Fernald when the 10 CFR 70.22 fissile gram limits were less restrictive. The material could not be shipped in its original packaging using the current limits. The DOE Office of Packaging and Transportation suggested that the 9979 package, a Type AF packaging developed and tested by the Savannah River Site (SRS), may be a viable option. The 9979 packaging worked well for much of the material; however, as the evaluation progressed it was determined that there were several containers that exceeded the payload weight restrictions for the 9979. Many of these heavy containers contained a single piece of uranium metal making it difficult to divide into multiple containers. Size reduction of the material involved creating numerous unnecessary hazards. Therefore, an agreement was reached to develop a container similar to the 9979, which allowed for the transport of the weight and fissile content required. During initial discussions, the container was referred to at the 9979 Heavy. Once design and testing were officially started, the new container was designated as the 9981.

The 9981 incorporated several deviations from the 9979 to withstand a higher content weight payload. For example, the internal 30-gallon drum assembly was modified to include an internal steel liner and a polyurethane foam layer between the steel surfaces. An aluminum honeycomb cylinder with a silicon lining was also located between the top of the steel liner and the inside of the 30-gallon drum lid for energy absorption. Last, 1/4" stiffening rods were added to the bottom of the 55-gallon drum to provide additional structural support. Both the top curl and bottom chime were welded as well. These changes created a more robust container capable of withstanding accident conditions with heavier/denser payloads.

To qualify this new container, three methods were used to substantiate the performance of the package under NCT and HAC conditions. First, the similarities between the 9979 and 9981 package designs were noted and credited where applicable. Where comparisons could not be made, conditions/tests were addressed analytically by modeling and calculation or physically tested through performance tests. This paper describes the primary challenges that were encountered during testing and the outcome of the tests.

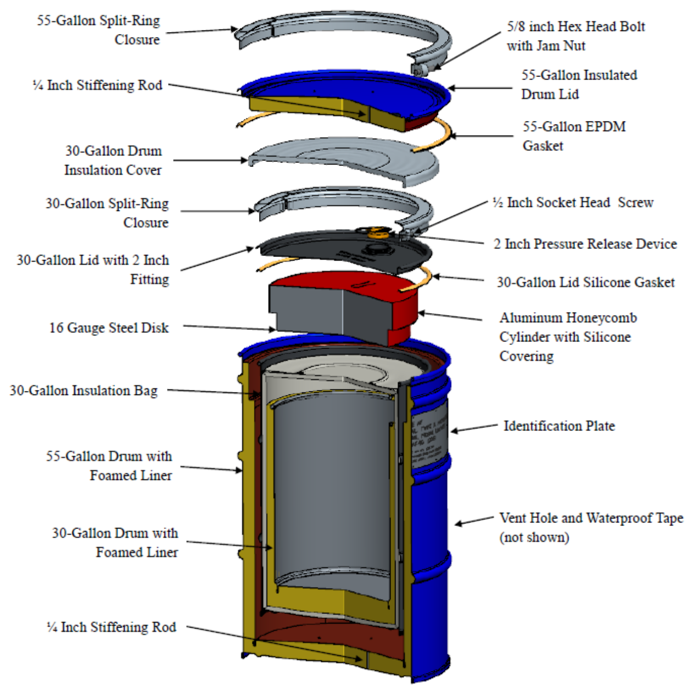


Figure 1 – 9981 Type AF Packaging Configuration

II. Planning

A. Identification of Required Tests

In the development phase of the container design and SARP preparation, the various regulatory tests required for NCT and HAC were evaluated to determine which tests could be physically completed and which tests could be completed through analysis and calculation. Due to the heavier payload of the 9981 package, it was determined that each structural test was critical and should be evaluated through testing. These structural tests included NCT tests (10 CFR 71.71) for free drop (4 ft), compression and penetration. Although evaluated through comparison to the 9979 package, the water spray test is a pre-requisite to the free drop; therefore, it was also included in physical testing. For HAC testing (10 CFR 71.73), the tests included the free drop (30 ft), crush and puncture tests. Packages SN-001X and SN-002X were preconditioned with the cold and heat temperature conditions specified in 10 CFR 71.71(b) respectively. Each of the remaining tests were addressed by analysis, calculation, and comparison to the original 9979 package.

Since the 9981 package was constructed of nearly identical materials to the 9979 package, the NCT cold condition was evaluated through comparison. Vibration loads and pressure variations caused by fluctuations in ambient conditions [10 CFR 71.71(c)(2), (3), (4), and (5)] were evaluated through analysis in calculation (M-CLC-G-00474). Based on the weight of the container (276.5 lbs), the 1 foot corner drop tests [10 CFR 71.71(c)(8)] were not required by regulation. For HAC thermal conditions, the thermal analysis [10 CFR 71.73(c)(4)] demonstrated that the fire event would not cause a breach in the containment of the 30-gallon drum (M-CLC-A-00621). This was supported by prior thermal testing of polyurethane foam packages. The immersion tests [10 CFR 71.73(c)(5) and (6)] were not required since the criticality analysis assumes water flooding of the package and water reflection on all sides (N-NCS-G-00173).

A Test Plan (M-TPR-A-00016) was created to address the structural tests and is summarized in Table 1. Orientations for the various drop tests were specified to challenge the container lids and container closure mechanisms as potential weak points.

Table 1 Test Matrix

Pkg ID		**Initial Conditions**		**Normal Conditions of Transport**									**Hypothetical Conditions**							
55-Gal Drum Serial #	*30-Gal Drum Serial #*	*Package Pressure*	*Package Temp. (^0F)*	*Heat (Soar, 100 ^0F)*	*Cold (-40 ^0F, no solar)*	*Pressure Variations (EXT)*	*Vibrations*	*Water Spray*	*4-ft Free Drop*	*Cprmer Drp[(1-ft)*	*Compression*	*Penetration*	*30-ft Drop*	*Crush*	*Puncture*	*Thermal*	*3-ft Immersion – Fissile*	*50-ft Immersion – all*	*290 psi*	*Leak Test*
SN-001X	SN-001X	A	-20	--	--	na	--	--	--	na	--	--	H	H	VTU	na	na	na	na	na
SN-002X	SN-002X	A	100	--	--	na	--	--	CGOT	na	--	H	CGOT	CGOB	H	na	na	na	na	na
SN-003X	SN-003X	A	A	--	--	na	--	--	VTD	na	--	VTD	CGOT	H	--	na	na	na	na	na
SN-004X	SN-004X	A	A	--	--	na	--	X	CGOT	na	X	H	VTD	VTU	VTD	na	na	na	na	na

A = Ambient	X = Required	na = not applicable
CGOT = Center of gravity over top corner	VTD = Vertical top down	H = Horizontal
CGOB = Center of gravity over bottom corner	VTU = Vertical top up	

B. Test Preparations

Once the Test Plan had been determined, the SRNL Packaging Technology & Transportation Engineering (PT&TE) group organized the testing. It was clear that all the performance tests required to demonstrate regulatory compliance could be conducted at the Savannah River Site (SRS) in N-Area using the concrete foundation of Building 8343 and a steel plate. This “drop pad” met the requirements of 10 CFR 71.71(c)(7) and 71.73(c)(1) and was already located on the pad from previous package testing. The drop pad consists of an 8 ft x 12 ft x 6.5 inch unyielding steel plate which floats on approximately 1-1/4 inch of grout on the concrete foundation of the building. The weight of the base plate is approximately 25,500 lbs which is approximately 39 times the maximum weight of the package (650 lbs). This location could be readily used to conduct all the drop tests, penetration tests, crush tests, puncture tests, and compression test.

There were a few test activities that could not be completed at the drop pad. For example, the thermal chamber was approximately 12 miles from the test pad, andthere was not a water supply available at the N-Area drop pad. Therefore, the water spray test was conducted at 711-5N, which was approximately half a mile from the drop pad. Originally, the loading and closing of all the test containers was going to take place at the drop pad. Due to the limited availability of rigging personnel and time constraints, it was advantageous to have the test packages loaded prior to the first official day of testing. As a result, the test containers were loaded using the hoist in the A-Area machine shop (Bldg. 749-A). This location is where the test containers were opened after testing was complete.

As the locations were being identified, PT&TE worked on developing the necessary procedures, data sheets, work instructions, and hazards analyses. This effort required seven procedures, each with their own data sheet(s), work instructions for the Rigging personnel, and two hazards analyses (one for PT&TE activities and one for rigging activities). It was also necessary to ensure all the necessary supplies, equipment, and personnel would be available to meet the schedule. This included a multitude of items such as the crane, crush plate, thermal chamber, torque wrenches, fluorescent powder for leak detection, etc. It also addressed the availability of rigging personnel, quality assurance, and scheduling the customer's visit to observe the testing.

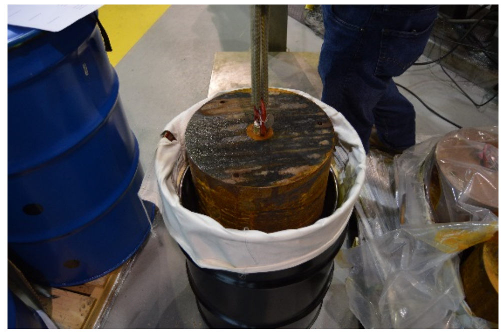
During the preparation, it became apparent that multiple knowledgeable personnel would be required to prepare and execute the required tests. Historically, there had always been a single person in charge of the overall testing; however, it took multiple members from the group to complete all the preparations, and to be prepared to control the activities at the various points around the Site.

The final challenge that was encountered during the test preparations was regarding the structural capacity of the available thermal chamber in 781-A. The thermal chamber was not structurally designed to handle the weight of the 9981 package and it was undetermined whether the support structure would be strong enough to support the package weight without modification. Furthermore, the chamber was lofted approximately 3 feet from the floor and was only marginally larger than the longest dimension of the package, which raised concerns regarding rigging operations. A thermal chamber with a larger payload capacity was not available.

The initial plan was to reinforce the support structure for the thermal chamber; however, this plan did not address the issues with loading and unloading the package. It was unclear whether the temporary structural support would adequately reinforce the chamber. The structural engineer supporting the project suggested constructing an insulated extension to the thermal chamber that could be mated to the thermal chamber for additional volume. This chamber modification is similar to the construction of modular walk-in environmental chambers and allows for significantly greater cooling volume. Additionally, rigging operations were made significantly easier due to the floor level elevation of the package. The insulation was sufficient to limit the loss of efficiency for the thermal chamber even with the increased volume.

III. Execution of Tests

Four prototype 9981 packagings were used to conduct the required regulatory testing depicted in the test plan over the course of two days. Prior to conducting the regulatory performance tests, simulated contents were loaded. The simulated container content was created to simulate a worst-case content, which was a single object at the maximum content weight for the container. The SRS machine shop fabricated steel weights (362 lbs ± 3 lbs) and installed a swivel hook on each weight to allow for loading. Each container had a combination of flour and fluorescent powder added to the top and bottom of the 30-gallon drum to provide a clear indication if the drum's containment boundary was compromised during the testing.



A. Water Spray (NCT)

The water spray test was conducted on a single container (SN-004X) using a simple spray set up. A frame was built out of PVC pipe with four shower heads and an attachment for a standard garden hose. The container was weighed prior to the test and subjected to a water spray that was substantially higher than the 2 inches/hour required by 10 CFR 71.71(c)(6). Actual simulated rainfall (based on a rain gauge on top of the container) exceeded 25 inches/hour. After the water spray test water was removed from the outside of the container and the container was weighed again to determine if it had increased in weight due to in-leakage of water. There was no change in the weight of the drum which met expectations for this type of container. Typically, the free drop test (4 foot drop) is to be conducted from 1.5 to 2.5 hours after the water spray test. However, for this package the Responsible Engineer deemed it more likely that if the package had water in-leakage, it would have a greater effect on the compression test than on the drop test. Therefore, the compression test was started within the 1.5 to 2.5 hour time frame rather than the drop test.

B. Compression (NCT)

The compression test was conducted on container SN-004X shortly after the water spray test. The container gross weight was recorded as 635 lbs based on measurement with a calibrated scale. In order to meet the regulatory requirements of 10 CFR 71.71(c)(9), the container was required to be subjected to a compressive load of 5 times the weight of the package (3,175 lbs) for 24 hours. For this test, SRS rigging personnel had identified a concrete weight that weighed 3,310 lbs. This weight was placed on the package for 24 hours with no visible damage to the container.

C. 4 Ft Drop Test (NCT)

The 4-foot free drop test [10 CFR 71.71 (c)(7)] was conducted on three of the four prototype containers. SN-001X, the container that was placed in the environmental chamber and cooled below -20^{0}C, was not subjected to this test. The Responsible Engineer indicated that the container should undergo the 30-foot free drop test followed by the crush test as soon as possible after coming out of the environmental chamber to maximize the potential for damage. Containers SN-002X, SN-003X, and SN-004X were all subjected to the 4-foot free drop test. SN-002X and SN-004X were dropped in a center-of-gravity-over-top-corner (CGOT) orientation on the bolted closure device. SN-003X was dropped vertical-top-down (VTD) in order to test the new aluminum honeycomb component.

Both SN-002X and SN-004X struck the drop pad on the closure lug and rebounded to experience a second impact where the bottom of the drum struck the pad. Both impacts resulted in scuffing of the paint on the closure lugs, slight compression of the closure lugs, very minor deformation of the clamshell closure, and minor flattening of the bottom chime of the container.

Container SN-003X impacted the pad almost completely vertically, rebounded, and landed top down. There was no noticeable damage or deformation of the package.

D. Penetration (NCT)

The penetration test [10 CFR 71.71(c)(10)] was conducted on containers SN-002X, SN-003X, and SN-004X. Container SN-001X was excluded from this test for the same reasons it was excluded from the 4-foot drop test. For containers SN-002X and SN-004X, the 13.2 lb steel cylindrical bar was dropped onto the drum side with several attempts made to impact at or near the vent holes. For SN-003X the cylindrical bar was dropped onto the bottom of the container between the stiffening rods. In all cases, the bar only caused a small dent or dimple in the containers. Based on the steel structure and liner with the polyurethane foam fill, this was the expected result.

E. 30 Ft Drop Test (HAC)

All four prototype packages underwent the 30-ft free drop test [10 CFR 71.73(c)(1)]. SN-001X 30-ft drop was performed with the packaging oriented so that its axis was approximately horizontal at release and so that the closure device lugs would be impacted. The impact resulted in scraping and scuffing of the paint on the lug. The lug was pushed in towards the drum, and the closure ring was slightly deformed. The bottom chime was somewhat flattened so that it was out of round.

The 30-ft drop test of SN-002X was performed with the package oriented with the center-of-gravity-over-top-edge (CGOT) such that the package would impact on the closure lugs. The impact resulted in compressing the closure lugs into the side of the drum and deforming the clamshell closure device. There was a small amount of bowing in the lid, and the bottom chime had a slight flat spot from the secondary impact.

The drop test for SN-003X was also performed with the package oriented in a CGOT configuration such that the package would impact on the closure lugs. The damage to the container was similar to SN-002X. The impact resulted in the closure lug being compressed into the side of the drum. The clamshell closure was deformed near the impact site, and the lid was bowed upward. The bottom chime was slightly flattened by the secondary impact.

SN-004X was oriented vertically-top-down for the 30-ft drop test. The impact resulted in half of the clamshell closure being depressed, slight damage to the closure lugs, and a single stiffening pin was externally depressed.

All of four tests were intended to stress the closure mechanism in one way or another. For the 9981 prototypes, there was no evidence of any potential package failure after the 30-ft drop tests were performed. It should be noted that oblique drops, otherwise known as “slap-down” impacts, are often the most severe for drum-type packages with open head closures secured by industry standard bolt/nut/ring closure devices. However, the clamshell closure device is significantly more robust as has been demonstrated in “shallow-angle” impact testing of 640-lb 6M packages (M-TRT-A-00002). Therefore, the 9981 package testing did not include oblique-orientation impacts.

F. Crush Test (HAC)

All four prototype packages underwent the 30-ft crush test [10 CFR 71.73(c)(2)]. The crush test was performed immediately after the 30-ft drop test in each instance. For the crush test, SN-001X was placed horizontally on the drop pad. The package was oriented such that one set of closure lugs rested on the plate, and the other set would be impacted by the crush plate. The crush plate struck the package nearly horizontally, rebounded, and struck the bottom of the drum. The impact resulted in localized buckling of the clamshell closure because of the drop/crush tests. After the crush test, further damage to the clamshell could be observed. Both closure lugs were pressed inward and the bottom of the drum was flattened. The bottom chime was flattened but remained intact. Both the top and bottom of the drum were creased due to the crushing effect. In addition, the secondary impact left a dent near the bottom of the drum where the corner of the plate impacted the drum.

The crush test for package SN-002X was conducted with the container oriented with center of gravity over bottom edge. The package was placed such that the crush plate would impact the closure lugs damaged in the 30-foot drop test. This orientation was achieved by using polystyrene insulation to support the package prior to the test. The crush plate impacted the package on the closure lug. The impact resulted in crushing of the lugs and drum. The closure lugs were compressed into the side of the drum. The clamshell closure device was distorted, and the lid of the drum was bowed up. The opposite closure lug was slightly damaged as well. The bottom chime of the drum was flattened and deformed.

For the crush test on package SN-003X, the package was placed horizontally on the drop pad with the closure lug damaged by the drop test facing up to be impacted by the crush plate. The crush plate hit the package nearly horizontally and rebounded to the side. The impact resulted in additional crushing and damage to the closure lug previously damaged. The opposite closure lug was also slightly compressed. The package was slightly crushed down the entire length. The bottom chime was flattened on both sides and the bottom of the drum also displayed some bowing.

The crush test for package SN-004X was performed with the package sitting vertically on the pad with the top up. The crush plate landed squarely on the top of the drum and rebounded. The impact resulted in a height reduction from collapse of the rolling hoops. The bottom hoop symmetrically bottomed out on the chime and the clamshell closure devices vertical flange compressed to the top rolling hoop.

The crush tests were performed to stress the areas impacted by the drop test to ensure the packages would not fail under the strain of multiple impacts. There was no evidence of any package failure from the crush tests.

G. Puncture Test (HAC)

The 40-inch puncture test [10 CFR 71.73(c)(3)] was conducted on packages SN-001X, SN-002X, and SN-004X. The three different tests were oriented such that one container would be tested by bottom impact (vertical-top-up), side impact (horizontal), and top impact (vertical top down) as shown in the test matrix. In all cases, the impact resulted in very little damage to the containers including only small depressions from the impact, scuffing, and chipping of paint. As with the penetration tests, this was the expected result for this container design.

IV. Results of Testing

A. Post-Test Inspection of Containers

At the end of all testing, each container was visually examined using a black light to determine if there was any evidence that the flour/fluorescent powder combination had escaped the 30-gallon drum. Initial inspection found no evidence that the 30-gallon drums had been compromised. After testing, the containers were transferred to the machine shop in A-Area for additional inspection. Each container had the 55-gallon drum top removed by cutting the damaged closure bolts, which could not be removed by any other method. The insulation cover was removed from the drum and the accessible surfaces of the 30-gallon drum were inspected for damage and the presence of the flour/fluorescent powder mixture. Each of the 30-gallon drums showed some deformation of the lid, but the clamshell closure mechanisms were all in good condition. When inspected using a black light, there was no evidence that the flour/fluorescent powder had escaped the container. This was a clear indication that none of the container contents had been released.

B. Summary of Damage

The major damage to the packaging resulted from the HAC 30-foot drop and the crush tests. The NCT tests and the HAC puncture tests had only a superficial impact on the containers. Thermal analysis shows the expected drum and payload temperatures before, during, and after the HAC fire event and indicates complete consumption of the overpack foam. The internal pressure in the 30-gallon drum and overpack drum resulting from the elevated temperature and evolution of gases from material degradation during the HAC fire are released by design through the relief valve. Therefore, the fire event does not alter the geometric configuration of the 55-gallon overpack or the 30-gallon drum.

Based on the observed and calculated conditions of the drums following the HAC events, the 9981 package design assures containment of the content, maintains shielding, and remains subcritical under all NCT and HAC packaging performance requirements.

C. Current Status

The performance of the 9981 package is documented in the Safety Analysis Report for Packaging (S-SARP-G-00020) that was prepared and submitted to DOE-HQ for review and approval. The SARP was formally review by Lawrence Livermore National Lab (LLNL) for the DOE-HQ Packaging Certification Program (PCP). All comments were addressed by SRNL and the Certificate of Compliance was issued on 5/20/2019.

V. Conclusion

The testing and analysis performed for qualifying the 9981 packaging demonstrated that the design of the container was sufficient to handle the higher content weight under all normal and hypothetical accident conditions. With the completion of the SARP review and approval, this provides a more robust container option for use by the DOE Complex. The 9979 packaging has served a valuable function within the DOE Complex since the elimination of DOT UN1A2 Specification Packages. The 9981 packaging has built on this process to provide a more robust packaging that meets all the same requirements but allows for a significantly increased weight of material. Currently, the container has been approved for a Low Enriched Uranium content, but it could readily be evaluated for other contents as customers identify a need for this packaging.

VI. References

Packaging and Transportation of Radioactive Materials, Code of Federal Regulations, Energy, Title 10 Part 71 (January 2009).

9981 Safety Analysis Report for Packaging Model 9981, Type AF-96 Shipping Package, S-SARP-G-00020, Revision 0, Savannah River Nuclear Solutions, Aiken, SC (Draft, February 2019)

Flach, J.P., *9981 Type AF Package: Weight and Load Evaluation*, M-CLC-G-00474, Revision 0, Savannah River Nuclear Solutions, Aiken, SC (January 2018)

Laurinat, J.E., *NCT and HAC Thermal Analysis of a 9981 Package*, M-CLC-A-00621, Revision 0, Savannah River Nuclear Solutions, Aiken, SC (January 2018).

L. Gelder, *Drop Tests for the 6M Specification Package Closure Investigation* (U), M-TRT-A-00002, Revision 0, Savannah River Nuclear Solutions, Aiken, SC (August 2003).

Harris, M.D., *NCSE: PORTS LEU Metal Waste in a 9981 Type AF Shipping Package* (U), N-NCS-G-00173, Revision 0, Savannah River Nuclear Solutions, Aiken, SC (January 2018)

Flach, J.P., *9981 Type AF Shipping Package – Test Plan* (U), M-TPR-A-00016, Revision 1, Savannah River Nuclear Solutions, Aiken, SC (January 2018).