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The General Purpose Fissile Package, A Replacement for the 6M Specification Package

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ABSTRACT

The General Purpose Fissile Package (GPFP) is a robust, single containment package, capable of transporting Plutonium and Uranium metals and oxides. The DOT 6M specification package is being withdrawn from service and the GPFP has been designed as a robust, cost-effective, user-friendly replacement. The design incorporates the proven Chalfont type containment vessel, employed by the widely used 9975 package. Based on the package size and proposed contents, its evaluation includes the 10CFR71.73 “Crush” test. To ensure this capability, the package overpack was constructed using urethane foam and load distribution features. Testing has confirmed the package’s ability to withstand the hypothetical accident condition tests, as specified in the Code of Federal Regulations. The features important to users are discussed and test results are described in this presentation.

INTRODUCTION

Department of Transportation (DOT) 6M Specification Packages have been used extensively for the transport of Type B quantities of fissile radioactive materials (uranium and plutonium metals and compounds) since the 1960’s. In recognition of the improved state of the art for radioactive materials packaging, DOT has instituted a phased elimination of the 6M in favor of packages certified to meet the performance requirements specified in the Code of Federal Regulations. Any replacement for the 6M must be economical, user friendly, able to accommodate the contents authorized for the 6M, and available at an early date.

GPFP DESIGN

Requirements

In response to the need for a Type B packaging to replace the 6M, the Savannah River Packaging Technology department has developed the General Purpose Fissile Package, or GPFP. In addition to the requirements listed above, the single containment GPFP design meets the latest revision of 10CFR71, which eliminated the requirement for double containment for plutonium contents. For the GPFP to meet a broad range of shipping needs of the Department of Energy, the GPFP is designed to accommodate materials which meet the DOE 3013 standard and most of the contents authorized for the widely used 9975 package. The GPFP is designed to allow efficient shipment by maximizing the number of packages which can be transported at one time. Designed to transport more than 1000 A2, the GPFP has successfully passed the regulatory Hypothetical Accident Condition test sequence, including the very challenging Crush test.

GPFP Design

The GPFP design incorporates the proven Chalfant containment vessel design (employed in the 9965, 9968 and 9975 packages). The Chalfant design is leak testable, space efficient and very robust. The drum and drum closure design has been developed from established practice and has been successfully tested.

Package size and weight are important factors in determining the maximum number of packages which can be transported in a single shipment. The overall package dimensions have been chosen to allow efficient packing for transport. The weight of the package has been kept low to maximize the payload per shipment. For this reason, the GPFP does not incorporate shielding. However, if a particular content should so require, the large containment vessel (compared to the 2R containment vessel employed by the 6M) can accommodate a shielded "basket" as part of the contents. The ability to accommodate various basket configurations enables provision of shielding appropriate to the contents being shipped.

The GPFP overpack incorporates feature to facilitate operations and minimize maintenance issues. The overpack has an easily cleaned liner, should decontamination be necessary. Protection against impact and fire is provided the annular urethane foam layer. The Crush test is a severe challenge for drum-type packages. Finite Element Analysis of the sequential HAC tests indicated that adopting urethane foam as the overpack impact absorbing material would enable the GPFP to withstand the Crush.

The package lid is a single piece, secured with only eight bolts and weighing less than 20 lbs. The lid consists of a cap filled with ceramic insulation, the bolting flange, and a thick insulated plug that fills the upper section of the liner, Figure 1.

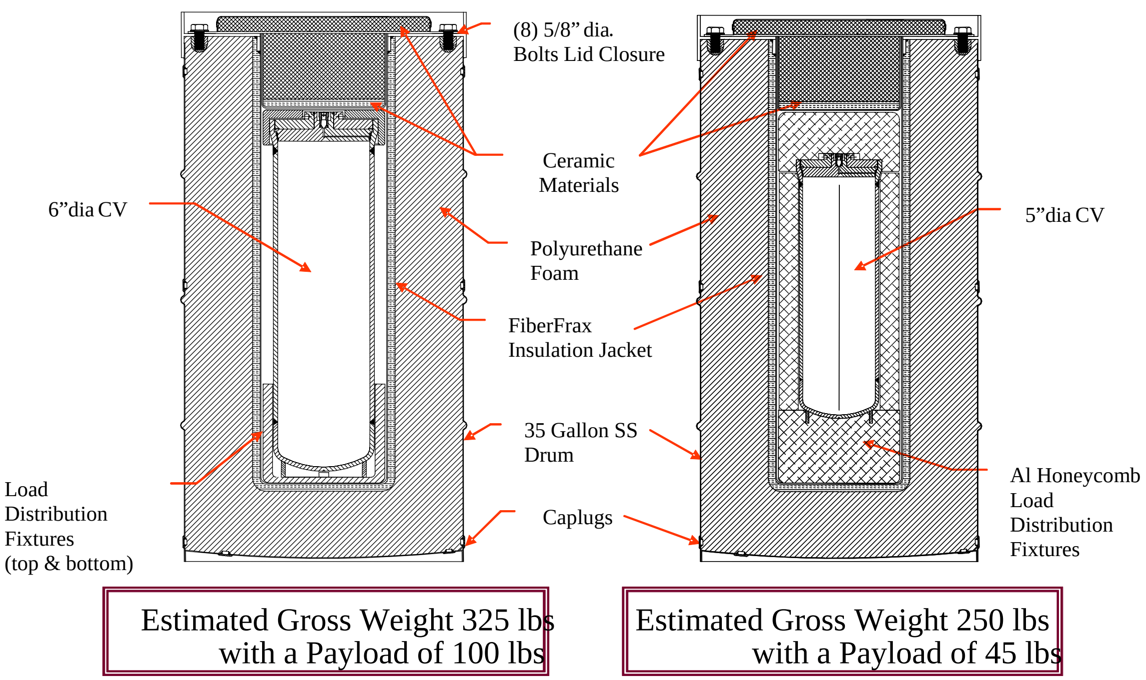

Figure 1. 9977 General Purpose Fissile Package.

Upper and lower load distribution fixtures center the containment vessel in the liner and protect the liner from sharp edges, such as the bottom skirt and the square boss on the top of containment vessel closure. They also stiffen the liner against radial loading during the horizontal Crush and help support the containment vessel during horizontal and shallow angle drops.

Although the reference design of the GPFP employs the secondary containment vessel design of the 9975 as its containment vessel, the GPFP overpack can also be used to transport a 9975 primary containment vessel. Using the primary containment vessel requires only the addition of aluminum honeycomb spacers to support the smaller containment vessel within the liner.

TESTING

Prototype GPFP packagings have been subjected to the regulatory sequential tests, as required by Title 10, Part 71 of the Unites States Code of Federal Regulations. The regulations require that, throughout the tests, the package maintain containment of the radioactive contents, shielding for radiological hazards, and subcriticality for any fissile contents. Particular interest was directed to confirmation of the analytical results which predicted the ability of the urethane foam, combined with other design features, to withstand the Crush test.

A GPFP package was subjected to the Normal Conditions of Transport (NCT) tests, in addition to the Hypothetical Accident Condition (HAC) tests. The NCT tests include vibration, water spray (Figure 2), a 4 ft drop, a corner drop, reduced internal pressure, compression and penetration (Figure 3). The HAC testing was conducted on packages primarily at ambient temperatures and on one cooled to -20°F.

Figure 2. Water Spray Test

Figure 3. Penetration Rod Rebound.

Pursuant to the regulatory requirement that the test be conducted in the orientations most challenging to the package, the test orientations were specified to provide maximum accelerations to the containment vessel and damage to the overpack. The axial and horizontal drops provide maximum acceleration to the containment vessel, in the axial and lateral directions. Preliminary investigations indicated that impact conditions would crush and fracture the foam, increasing its susceptibility to thermal degradation in the subsequent fire test. For this reason, the Center-of-Gravity over corner (CGOC) orientation, which results in significant crushing of the overpack structure, was specified to establish the most vulnerable pre-test condition for the overpack for the fire test. The test orientations are shown in Table 1.

The preliminary analyses indicated that the overpack would be most highly stressed by the horizontal crush test. In this test, the crush plate loads the annular cross section radially. Because the foam becomes more brittle and hence susceptible to greater damage at low temperatures, the horizontal Crush test package was chilled to -20°F.

The peak package temperatures occur when a package with the maximum decay heat rate content is subjected to the HAC Fire test. To simulate the effect of heat generating contents, all packages were held in an environmental chamber at 200°F for minimum of 48-hrs, prior to the thermal tests. The packages were wrapped in insulation for transport to the test facility. While on the test stand, the packages were wrapped in insulation and maintained at temperature by band heaters until the start of the test.

The Chalfant containment vessel design has been subjected to the HAC sequential testing for certification of the 9965, 9968, and 9975 packages, and is a well proved design. Credit is taken for the previous immersion tests of the Chalfant containment vessel, performed as part of the 9975 certification testing. Although this test program was focused on challenging the overpack, the test conditions extended the range of challenges to which the Chalfant design has been subjected.

Prior to the HAC Sequential Tests, and following each of the tests, the packages were digitally radiographed, to permit evaluation of the internal damage to the package at each stage of the testing. Following the completion of the HAC test sequence, the packages were cut apart and the internal conditions of the components evaluated. The containment vessels were removed and leak tested, to confirm that they had remained leak tight.

TEST RESULTS

NCT Tests

Many of the NCT tests are not a challenge for Type B packages, such as the GPFP. However, the maximum temperature attained in the interior of a package is typically during the NCT Solar conditions. The accelerations imposed on the interior components during the one meter drop are typically high. The vibration exposure may also prove challenging for some designs and materials. The GPFP was subjected to the full suite of NCT tests and found to perform well. The vibration test revealed some minor surface fretting of the aluminum load distribution fixtures. A thermal test was performed on a GPFP with an internal heater (to simulate heat generating contents) in an environmental chamber. The NCT tests are illustrated in the figures following the text.

Free Drop Test

Nine-meter free drop tests were performed for the bottom down, top down, horizontal and center of gravity over corner orientations. As noted above, these orientations challenge the containment vessel and overpack structure. Experience has shown that shallow angle drops, which are highly challenging to clamp ring closures on drum type packages, are not a severe challenge for drum packages with a bolted flange closure. In addition, the damage to the overpack from a shallow angle drop is similar to that from a horizontal drop. The overpacks are quite robust and protected the containment vessels in all cases. The packages respond more elastically than fiberboard (e.g., Celotex) packages, such as the 6M, so that the rebound height is typically greater. Figures 4 and 5.

Figure 4. TP-2 After 9 m CGOC Drop.

Figure 5. TP-3 After 9 m Horizontal Drop.

Crush Test

The crush test is a severe test for drum type packages. Demonstrating the ability of the urethane foam overpack design to protect the containment vessel in these tests was an important goal in the test program. The overpack met this requirement in all cases, with margin. Drum-type packages are the most vulnerable in the horizontal impact orientation. In this case, although Test Package 3's overpack protected the containment vessel against damage, a tear resulted along the chime where the buckling of the drum bottom unfolded the outer layer (i.e., the drum bottom layer) of the rolled seam of the chime. The bottom material in this region has been thoroughly work hardened. Although this tear did not prevent the overpack from protecting the containment vessel in the subsequent fire test (because of the thermal resistance of the urethane foam), a sanitary bottom configuration, which will be resistant to such an event, has been adopted for the production packages. A confirmatory test of the sanitary bottom configuration is scheduled.

Figure 6. TP-2 Following CGOC Crush Test.

Figure 7. TP-3 Following Horizontal Crush.

Puncture Tests

The Puncture test is not a significant challenge to drum type packages because the mass of the package is not great enough for the puncture pin to penetrate the drum shell. For the GPFP tests, the puncture pin was targeted to strike at the mid point of the package, maximizing the lateral bending of the overpack and exploiting any cracks in the urethane foam. Test Package 3 was subjected to a second Puncture test with the pin impacting at the location of the tear in an attempt to increase the damage to drum skin and the foam in the lower part of this package (Figure8).

Figure 8. Puncture Pin Damage to TP-5.

Thermal Tests

The packages were subjected to the regulatory fully engulfing fire test, conducted in accordance with ASTM Standard E 2230-02. The tests were performed at the South Carolina Fire Academy, where suitable facilities are available, Figures 9 and 10.. The tests were performed by Novatech,, who have performed numerous fire tests for certification of radioactive material packages. The packages were burned in the orientation expected to be most challenging. The tests confirmed the ability of the urethane foam and Fiberfrax insulation system to protect the containment vessels from the fire. A practice burn was performed using a mock-up of a GPFP without the urethane foam. The liner was attached to the upper deck-plate and insulated with the Fiberfrax layer, only. The maximum temperatures for the mock-up, practice package were 435°F, which is well within the limited duration service temperature for the o-ring seals in the containment vessel.

Figure 9. Fully Engulfing Fire Test of TP-2.

Figure 10. TP-5 During Post Fire Test Cooldown.

The urethane foam intumesces as it undergoes thermal degradation, producing a voluminous, very low density char-foam decomposition product. In preliminary furnace tests of urethane foam overpacks, the char-foam was found to flow out of the fill and vent holes in the package and accumulate in large clumps in the furnace, which was an oxygen starved environment. In the fire tests, material exiting the package was burned away immediately. Combustible gaseous decomposition products jetted from the vent holes in the packages during and immediately after the fire exposure. These jets burned with a bright flame, which could be detected occasionally in the midst of the fire. The expanding char-foam material pushing against the bottom or Test Package 3, opened the tear formed in the crush test (without increasing its length). This resulted in an increased loss in foam mass (ca. 20%), compared to the other packages.

Post Test Examination

Following each test in the sequence, the packages were digitally radiographed to document the cumulative effects of the tests on the packages. Following completion of all the tests and final radiographs, the packages were cut open and the interior components examined, Figures 11 and 12. As part of this process, the containment vessels were removed for leak testing. For Test Package 3 it was possible to remove the containment vessel by opening the lid in the normal manner. In the other 3 cases, the containment vessel removed by cutting the bottom off of the liner. In all cases the fire test resulted in degradation of much of the urethane foam, with a residual cocoon of un-degraded urethane foam remaining attached to the FiberFrax blanket. The residual, un-degraded foam in Test Package 3, the package subjected to horizontal drop and crush, was almost separated in two lobes, rather than completely enclosing the liner. This was the result of accelerated thermal degradation of the foam in the regions where crushing and breakage of the foam had occurred from the drop and crush tests, Figures 13 and 14.

Figure 11. Removal of Charfoam from TP-4.

Figure 12. Radiograph of TP-4 Following Fire Test

Figure 13. Residual Foam Following Removal of Charfoam from TP-3.

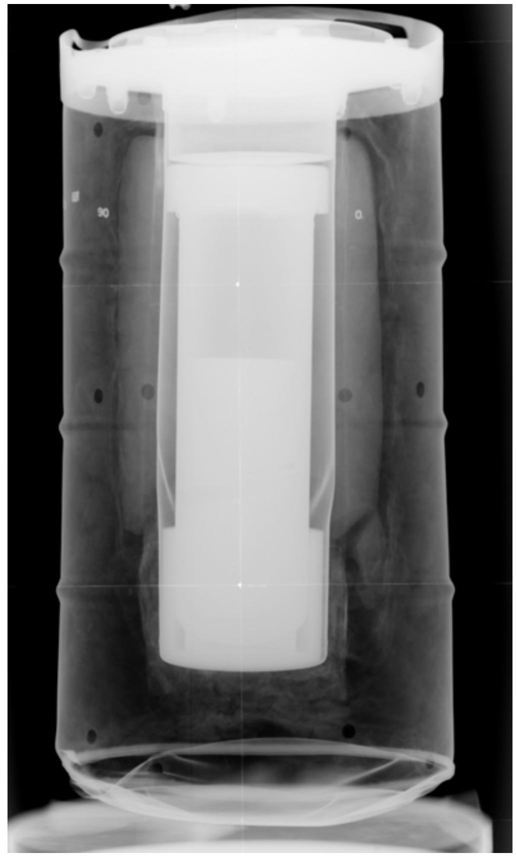

Figure 14. Radiograph of TP-3 Following Fire Test.

The examination of the residual, un-degraded urethane foam revealed cracks that were clearly present before the fire test. The radiographs showed indications that coincided with these features, indicating the stage in testing at which the cracking occurred. The buckling of the liner in Test Package 3, the horizontal test case, was seen in the radiographs to have occurred as a result of the 9-m drop.

The structure of the char-foam was similar in all cases. The degraded material varied from plastic rich material immediately adjacent to the undegraded foam, to frangible, carbonaceous or coked material on the outer surface, against the drum wall. When the outer shell was removed, the outer surface of the char-foam was convoluted with nodules of char-foam separated by deep channels or fissures.

The temperature labels installed on the inside of the liner and on the containment vessels confirmed that the interior temperatures were well within the acceptable range, in all cases. The maximum temperature recorded on a containment vessel was 280ºF on the vessel from Test Package TP-4. The peak containment vessel temperature on the practice package (which had no urethane foam insulation) was 435°F. This indicates that the FiberFrax layer alone is sufficient to provide the required thermal protection. The peak internal temperatures were found on the bottom of the top plug, being on the order of 270ºF. These results are summarized in Table 2.

Post Test Leak Test

The leak tests performed on the containment vessels after their removal from the test packages showed the vessels were leak tight, in all cases. The results are given in Table 3. It is worthy of particular note that the containment vessel from the practice package was found to be leak tight.

CONCLUSIONS

The sequential performance tests of the GPFP package demonstrated that the package meets the regulatory performance requirements of 10 CFR 71 with ample margin.

The tests confirmed that the urethane foam overpack material enables the GPFP to withstand the very challenging Crush test.

Although Test Package 3 withstood the subsequent thermal tests, the tear which occurred at the package in the crush test is undesirable. Accordingly, a revised drum bottom design will be employed for the production packages.

Table 1. GPFP Test Conditions for NCT and HAC Tests.

	Package	Practice	TP-2	TP-3	TP-4	TP-5	TP-6	TP-7	Prototype
Initial Conditions	Pressure (MNOP/Ambient)	Amb.	Amb.	Amb.	Amb.	Amb.			
	Temperature -20°F to 100°F	Amb.	75ºF.	-20°F	Amb.	Amb.			
Normal Conditions of Transport 10CFR71.71(c)	(1) - Heat (Solar, 100°F)						19 watts No Solar 11/4-11/05		
	(2) - Cold (-40°F, no solar)								
	(3&4) - Reduced/Increased External Pressure								
	(5) - Vibrations		BD 8/17/05						BD 8/17/05
	(6) - Water Spray		BD 10/10/05						
	(7) - 4-ft Free Drop		TD 10/10/05						
	(8) - Corner Drop	Note 1							
	(9) - Compression		BD 10/11/05						
	(10) - Penetration		BD 10/10/05						
Hypothetical Accident Conditions 10CFR71.73(c)	(1) - 30-ft Drop		CGT 10/17/05	H 10/18/05	TD 10/17/05	BD 10/18/05			
	(2) - Crush		CGT 10/26/05	H 10/26/05	BD 10/26/05	CGT 10/26/05			
	(3) - Puncture		H 10/26/05	H & CGB 11/07/05	H 11/07/05	H 11/07/05			
	(4) - Thermal	H 11/30/05	TD 12/02/05	H 12/14/05	BD 12/07/05	BD 12/13/05			
	(5) - 3-ft Immersion - fissile	Note 2							
	(6) - 50-ft Immersion - all	Comparison							

Table 2. Component Temperatures

Package	Practice	TP-2	TP-3	TP-4	TP-5
Bottom of Top Plug		290	380	435	435
CV Top	435	Inner 250	Inner 270	280	260
Liner Side	CV: 320	250	270	250	250
Liner Bottom	CV: 340	260	340	250	250

Table 3. GPFP Leak Test Results and Package Weights

	Package	Practice	TP-2	TP-3	TP-4	TP-5	
Leak Test (std cc he/sec)	CV SN		3084	3967	3999	3224	
	Pre-Testing		1e-9	2.0e-9	9.7e-10	1e-9	
	Post-Testing	2.2e-9 12/07/06	7.3e-10 1/03/06	1.8e-9 12/29/05	1.7e-9 1/04/06	7.3e-10 1/03/06	
Weight (lb)	Pre-Testing		341.1	340.6	339	341.6	
	Post-Testing		293.1	286.3	291.6	292.4	
	Change		48.0	54.3	47.4	49.2	BD/TD Ave. 48.2

DISCLAIMER

REFERENCES

1. *Packaging and Transportation of Radioactive Materials*, United States Code of Federal; Regulations, Title 10, Part 71 January 2005.
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