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THERMAL TESTING OF PROTOTYPE GENERAL PURPOSE FISSILE PACKAGES USING A FURNACE

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ABSTRACT

The 9977 / 9978 General Purpose Fissile Package (GPFP) was designed by SRNL to replace the DOT 6M Specification Package and ship Plutonium and Uranium metals and oxides. Urethane foam was used for the overpack to ensure the package would withstand the 10CFR71.73(c)(2) crush test, which is a severe test for drum-type packages. In addition, it was necessary to confirm that the urethane foam configuration provided adequate thermal protection for the containment vessel during the subsequent 10CFR71.73(c)(4) thermal test. Development tests were performed on early prototype test specimens of different diameter overpacks and a range of urethane foam densities. The thermal test was performed using an industrial furnace. Test results were used to optimize the selection of package diameter and foam density, and provided the basis for design enhancements incorporated into the final package design

INTRODUCTION

The General Purpose Fissile Package (which has subsequently been designated the 9977 and 9978) was developed as a replacement for DOT 6M Specification Packaging. As such, it must be able to ship Plutonium and Uranium metals and oxides, meet the Type B performance requirements, and be economical to build and use.

In order to enable the GPFP to withstand the Hypothetical Accident Condition (HAC) Crush Test, urethane foam was

Figure 1 -- GPFP 16-in and 18 1/2-in Diameter Overpacks.

chosen for the impact absorbing overpack material. Finite element modeling (FEM) indicated that a urethane foam-filled overpack would provide sufficient rigidity to withstand the10CFR71.73(c)(2) crush test.

The ability of the urethane foam overpack to withstand the 10CFR71.73(c)(4) thermal test was less amenable to computer modeling and simulation than the structural performance tests, due to the complexity of modeling the thermal degradation process for the foam. Consequently, thermal tests were performed with development prototypes to investigate the behavior of the urethane foam in a fire event. Based on the results of the development tests, detailed design enhancements were incorporated into the final design.

GPFP DESIGN

The GPFP is conceptually similar to other drum-type packages, with a robust containment vessel enveloped within an insulated overpack for protection against impact and fire. The GPFP incorporates the proven Chalfant containment vessel (CV) design. The Chalfant design is space efficient and very robust. The overpack has a full liner insert for the CV. Urethane foam is injected between the overpack and full liner to protection for the CV from impact and fire. The outer shell of the overpack is a stainless steel drum with a bolted, insulated closure.

Upper and lower load aluminum 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 a horizontal crush test and help support the containment vessel during horizontal and shallow angle drop tests.

TEST PROGRAM

The 9977 GPFP development prototypes were assembled from surplus 16-in and 18-½ in diameter x 36-in tall drums,, modified to conform to the initial GPFP design, and surplus containment vessels. The internal components, such as the CV liner and aluminum load distribution plates, were fabricated at the Savannah River Site (SRS). The drum overpack and lid foam installation operations were coordinated for SRS by the Kansas City Plant (KCP) and performed by General Plastics. Three 18 ½ overpack were filled with foam of densities 16, 20 and 24 lb/ft^3 respectively. Two 16-in overpacks were filled with 20 and 24 lb/ft^3 foam respectively. The prototype GPFP packages are illustrated in Figure 1.

Temperature indicating labels (TIL) were installed on the developmental prototype packages prior to the 10CFR71 tests. The TIL were installed on the exterior and interior of the CV, and at key locations surrounding the CV in the interior of the overpack. The CV were loaded with surrogate contents, a 100 lb stainless steel cylinder, and leak tested before assembling them into the overpacks. Each packaging was radiographed prior to testing to establish a baseline for internal damage assessments.

Prior to the thermal tests, the packages were subjected to the 10CFR71.73 drop, crush and puncture test sequence. These tests were conducted at the Savannah River Site.

A general purpose industrial heat treatment furnace, previously employed for preliminary thermal tests on the 5320 packaging, was used to test the GPFP prototypes. A test stand to support and center the packaging in the furnace was constructed from structural steel angles. The test stand held the packaging horizontally and as near the center of the furnace as adequate clearance for the handling boom allowed. The test stand also functioned as a calorimeter by attaching thermocouples to it to confirm the thermal radiation field in the furnace met the CFR thermal test requirement. Upon opening the door to insert the packagings, it was noted that the color temperature of the stand closely matched the furnace refractory wall, in every case. This observation, combined with the furnace thermocouple readings, confirmed that the radiation environment in the furnace was consistent with the CFR test requirements.

The test plan scheduled the prototype packages for the 10CFR71.73 tests, except for immersion. The free-drop and crush test orientations are shown in Table 1. The crush tests orientations were selected to exploit the damage to the package from the free-drop test. All thermal testing was conducted with the package loaded and oriented horizontally because of space limitations on the furnace.

Table 1 – GPFP Development Prototype Test Orientations

Packaging Identification	Drum Diameter (in.)	Foam Density (lb/ft3)	Drop Orientation	Crush Orientation
DP-1	18 1/2	16	CGOC top down	CGOC bottom down (impact on top)
DP-2	18 1/2	24	Axial top down	Axial bottom down (impact on top)
DP-3	18 1/2	20	Horizontal	Horizontal
DP-5	16	24	Axial top down	Axial bottom down (impact on top)
DP-6	16	20	Horizontal	Horizontal

TESTING

The thermal tests for the development prototypes were conducted with a field procedure developed from the guidance for furnace testing packages in the ASTM Thermal Test Standard E2230-02. The initial tests were performed using the “steady state” method, in which the 30 minute test exposure begins when the drum (package) surface temperature attains 800C. This procedure was very effective for Celotex® insulated packages, where a gap between the Celotex® and the shell was present, allowing the drum to quickly attain the required temperature. However, the initial obersevations with the GPFP prototypes showed that this method resulted in an overly severe test, because the urethane foam in contact with the surface absorbed heat and significantly delayed (or prevented) the overpack surface temperture reaching 800C. Consequently, the later thermal tests were conducted using the test stand structure as a calorimeter. The thermocouples mounted on the test stand indicated that the radiation environment in the furnace satisfied the thermal test for the start of the tests, Table 2 (Because of its size, Table 2 follows the text.).

For each test, the furnace was heated to 927C and held at that temperature for three hours to attain steady state conditions in the furnace walls and thereby minimize the heat loss from opening the door to insert the package. The package was inserted into the furnace using a handling boom, Figure 2. The door was closed immediately after the handling boom was withdrawn. The 30-minute test started when the temperature at the top of the drum reached 800C. During the testing, combustible gaseous decomposition products escaped around the furnace door, burning as they mixed with the ambient air. After 30 minutes, the furnace door was slowly opened to allow combustion of combustible gasses. The packages were removed and allowed to cool naturally.

Following the completion of each thermal test, the package was Digital Radiographic (DR) to evaluate the effects of the test on the internal structure of the packaging.

RESULTS AND DISCUSSION

The data from the thermocouples and temperature labels are given in Table 3. When placed in the furnace, the package and the charfoam which evolved from the package partially shielded the test stand thermocouples and the thermocouple at the bottom of the package from the radiation environment. Consequently they remained a few degrees below the temperature at the top of the package. After the package was removed, the test stand temperature rapidly rose to its pre-test value, confirming that the furnace had maintained the thermal radiation field during the test. Figure 3 shows the temperature profile for package DP-2.

The Decomposition of urethane foam produced a large volume of combustible gases and pressurized the interior surface of the overpack

Table 3. Maximum Indicated Temperatures for Development Prototype Containment Vessels In Furnace Test

Temperature Label Location	Maximum Temperature Indicated by Label				
	DP-1	DP-2	DP-3	DP-5	DP-6
Vessel Cone Seal Plug (outside)	340	400	480	500	330
Vessel Outside Wall (Near Closure)	340	340	340	340	330
Vessel Outside Wall (180 from above)	340	340	340	340	330
Vessel Cone Seal Plug (inside)	320	320	320	320	330
Vessel Inside Wall (Near Closure)	260	320	320	290	320

Urethane foam intumesces as it undergoes thermal degradation, which produces voluminous, very low density char-foam decomposition product. In preliminary furnace tests of urethane foam overpacks, the char-foam was observed to flow out of the overpack fill and vent holes and accumulate in large clumps in the furnace, which was an oxygen starved environment during the test. The vent and fill holes in DP-2 were sealed to observe the consequences of impeding the foam’s egress. The expanding char-foam material in DP-2 pressurized the interior of the drum and caused the rolled chime to fail, opening along an arc of 100º. Similarly, because of the restricted venting of some of the other packages, their bottoms were bulged by the intumescence of the degrading urethane foam.

Table 4. Weight Loss During Thermal Tests

Package	DP-1	DP-2	DP-3	DP-5	DP-6
Pre Test Weight, lb	338	355	350	329	315
Post Test Weight, lb	288	303	301	279	271

After the tests, the residual decomposition products left in the furnace burn or smolder until they are completely consumed.

All packages self extinguished within about 20 minutes after the test.

POST TEST EXAMINATION

The temperature of o-ring seals in radioactive material package containment is usually the limiting temperature, since seals failure is likely to result in the loss of containment. The post-test examination of the CV showed that the seals remained within the acceptable temperature in every test case. Post test leak testing confirmed that containment was maintained.

The temperature labels installed on the inside of the CV liner and on the containment vessels confirmed that the interior temperatures were well within the acceptable range for the O-rings, in all cases. The maximum temperature recorded on a containment vessel was 500 F on the vessel from Test Package DP-5. These results are summarized in Table 3.

The post test examination showed that sufficient heat was conducted into the package along the CV liner and top plug enclosure, or by convection through the lid/liner gap to cause significant degradation of the foam within the top plug.

The thermal tests showed that insufficient venting of the overpack, for foam insulated packages, can burst the overpack seams from the thermal decomposition of the foam.

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 taken apart and destructively examined. Black, sooty deposits of decomposition products were typically found on the upper portions of the liner interior and on the containment vessels. The containment vessels were carefully removed and leak tested. In all cases the thermal test resulted in degradation of much urethane foam, with a layer of un-degraded foam remaining surrounding some or all of the CV liner. The residual, un-degraded foam in DP-3 and DP-6, the packages subjected to horizontal drop and crush, was separated in two lobes, as the result of accelerated thermal degradation in the crack propagation regions.

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 conditions, indicating the stage of sequential testing at which the cracking occurred. The buckling of the liner in DP-3 and DP-6, the horizontal test cases, was clearly seen in the radiographs and occurred as a result of the 9 meter 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 overpack interior. When the overpack was cut away and removed, the outer surface of the char-foam was convoluted with nodules of char-foam separated by deep channels or fissures.

CONCLUSIONS

The furnace test in this case was very challenging to the packaging design. The furnace tests subjected the packages to a longer period of exposure to a high temperature environment than the subsequent pool fire tests, performed for the certification tests.

The overpack of urethane foam insulted packages must allow sufficient venting during thermal testing to prevent over pressurization.

The performance testing of the GPFP prototpye demonstrated that the package design meets the regulatory performance requirements of 10 CFR 71.

DISCLAIMER

REFERENCES

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Table 2. Thermal Test Summary

Package (in order of testing)	Time to start of Test, min.	Test Method	Top TC 30 Min Avg (C°)	Bottom TC 30 Min Avg	Test Stand TC 30 Min Avg	Test Stand Rear TC 30 Min Avg	Time to self extinguish, min	% wt loss
DP-1	16	Steady State	850	810	729		22	60
DP-6	15	Steady State	802	781	790	756	14	64
DP-5	21	Steady State	822	778	864	863	9	60
DP-3	9	Calorimeter	812	757	765	776	21	52
DP-2	8	Calorimeter	823	792	788	812		48


Figure 2. Insertion of Package DP-6 in furnace and removal at end of test.

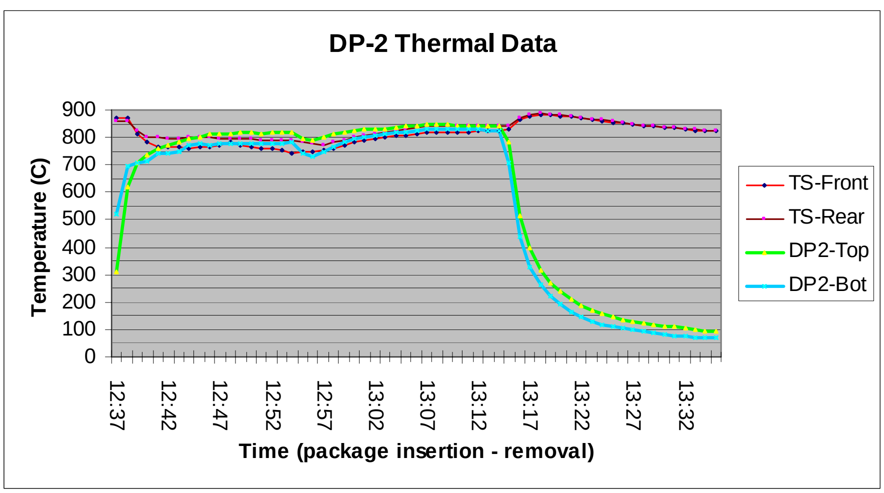

Figure 3. Thermal response of DP-2 during furnace test.