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Alternate Materials in Design of Radioactive Material Packages

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ABSTRACT
This paper presents a summary of design and testing of material and composites for use in radioactive material packages. These materials provide thermal protection and provide structural integrity and energy absorption to the package during normal and hypothetical accident condition events as required by Title 10 Part 71 of the Code of Federal Regulations. Testing of packages comprising these materials is summarized.

INTRODUCTION
This paper summarizes the design, fabrication and testing of current packaging materials and new material composites in five prototypical Type AF Packaging designs. The structural requirements of Title 10 Part 71 of the Code of Federal Regulations (CFR) were the basis used to evaluate packaging designs incorporating the materials. Thermal performance was evaluated by analysis and test but are not reported in this paper.

The five Type AF designs were evaluated by Savannah River National laboratory (SRNL) for use by the Department of Energy (DOE) as a replacement for the Department of Transportation (DOT) Specification Packaging UN1A2 that was phased out of the DOT regulations October 1, 2008. The tested package designs all had a 55-gallon style drum overpacks with a nested 30-gallon internal drum. The materials tested filled the thin annulus between the 30-gallon and 55-gallon drum. Each design evaluated the performance of the different materials against the structural 30-foot drop test and the crush test of 10 CFR 71.73.

Separate testing to compare two materials for use in a Type B Bulk Tritium Shipping Packaging (BTSP) was also performed. The Type B tritium packaging is under development by the SRNL for the National Nuclear Safety Administration (NNSA) to replace the DOE UC609 Packaging in service since the mid 1970s. For this evaluation, ceramic-fiber insulation material, similar to that discussed in this paper, was substituted for the polyurethane foam that is the insulation material designed for this package. The test packages for the two insulation materials were compared and evaluated against the thermal and structural tests of 10 CFR 71.73. Results of this evaluation can be found in Reference 1.

The orientations of the packages were chosen to maximize damage and standard orientations were used so that a direct performance comparison of the materials under investigation could be made. All structural tests were performed under ambient conditions.

TEST FACILITIES

All HAC drop and crush (impact) tests for the Type AF packaging materials investigations were performed at the SRS at the Savannah River Packaging Technology (SRPT) drop-pad outside Building 705-N in Central Shops. The impact and thermal performance testing on the Type B package design was performed by NovaTech located in Lynchburg, Virginia and at the Columbia, South Carolina Fire Academy.

PACKAGING TEST SPECIMENS

The materials and composite materials being evaluated for use in the new Type AF packaging were located between the 55-gallon outer drum and 30-gallon inner drum of the test packages.[2] The typical configuration of the five prototypical tested package designs is illustrated in Figure 1.

The 55-gallon drum is fabricated from 16-gauge carbon steel and is nominally 24 inches in diameter by 34-9/16 inches high when closed. The drum closure was a 12-gauge split-ring closure instead of the standard C-ring closure. The split-ring closure is similar to standard commercial C-ring closure used on most open-head drums but is halved and incorporates two 1 inch flange extensions, one extending horizontally and the other vertically from the C-ring. Each split-ring is identical and include 1½-inch diameter lugs welded at each end of the two split-rings. One lug is threaded with ⅝ 11UNC-2B thread; the other lug is drilled with a ¾-inch diameter through hole. The closure device secures the closure lid to the drum via two 3½ inch long, ⅝ carbon steel hex head bolts. Jam nuts were sometimes used to secure the closure bolt to the unthreaded lug. An ethylene propylene diene M-class (EPDM) gasket seals the overpack closure.

The 30-gallon drum and lid are fabricated from 18-gauge and 16-gauge carbon steel, respectively, and is nominally 18.3 inches in diameter by 29-1/8 inches high when closed. The drum lids included one or two standard commercially stamped and threaded bung hole flanges, ¾-inch diameter or 2-inch diameter. Standard ethylene propylene diene M-class (EPDM) gasket seals the 30-gallon drum closure. The 30 gallon drum split-ring closure cross section and gauge is identical to the 55-gallon overpack closure device, however, to optimize liner insulation thickness the 30-gallon drum closure in some configurations used low profile lugs with ½-13UNC-2B thread in lieu of the larger 55-gallon drum closure lugs. The low profile lugs are welded at each end of the two split-rings. Each split-ring is identical, with one lug threaded and the other with a through hole. The split-ring secures the closure lid to the drum via two carbon steel socket head screws. The 30-gallon drum is positioned both radially and axially within the 55 gallon overpack liner.

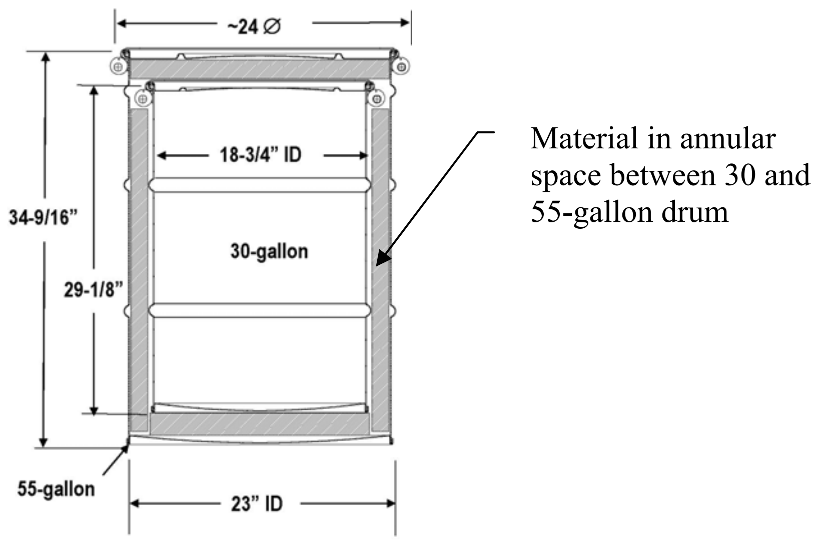

Figure 1 - General Type AF Shipping Package Configuration

The material configurations for the tested packaging prototypes are summarized in Table 1. Table 2 is a compilation of the package test configurations, the simulated payload dunnage and packaging weights.

Table 1 - Type AF Package Design Descriptions

Overpack Structural/ Thermal Material	General Description of Annular Material filling the annular space between the 30 and 55-gallon drums
Celotex	Formed Celotex rings and disks dropped in to the annular space
Ceramic Fiber	I-2300M Ceramic fiber formed into cylinder and disks
Beta Foam	DOW polyurethane automotive foam. Foam fills an annulus made by structural liner welded to the 55-gallon drum
GP Foam	General Plastics FR-3700 series foam. Used in multiple package designs. Foam integrally formed with 55-gallon drum; and foam cylinders and disk inserts dropped into the annular space
Honeycomb Composite	Rolled Honeycomb laminate reinforced with fiberglass.

Table 2 - Package Tested Configuration

Pkg ID	Package Description	Package Orientation		Package Weight (lbs)		Simulated Contents		Ambient Temperature (°F)	Test Date
		30-Ft Drop	Crush	Gross	Empty	Weight (lbs)	Dunnage	Drop/Crush	
PT1	Celotex-plain	CGOT	Horiz	341	152.4	188.6	Sand	84	9/29/08
PT3	Celotex w/pieced (glued) plywood	CGOT	Horiz	343	159	184.0	Sand	84	9/29/08
PT4	Celotex w/plywood	CGOT	Horiz					49	10/30/08
PT6	Celotex w/ whole plywood	CGOT	Horiz	330	148.5	181.5	Sand	78	10/1/08
PT9	Celotex w/strongback	CGOT	Horiz	323.8	150.8	173	Sand	72	10/8/08
PT10	Celotex w/ steel strongback top and bottom	CGOT	CGOT/Top	-	-	-	-	44	11/17/08
PH1	Al Honeycomb composite	CGOT	Horiz	294.2	144.2	150	Brass	73	10/2/08
PH2	Al Honeycomb composite w/strongback	CGOT	CGOT	326.4	155	171.4	Brass	61	11/4/08
PX0	I2300 Plain	Slap-Down	Horizontal	316	-	~200	Eco-mass	-	5/15/08
PX1	I2300 Resin coated w/strongback	Topdown	Vert	300.8	166.2	134.6	Brass/ p-gravel	61	11/17/08
PX2	I2300 resin coated w/strongback	CGOT	CGOT	292.6	153.8	138.8	p-gravel	41	11/18/08
R201	Dowfoam/lined	CGOT	Horiz	341.4	191.2	150.2	Rock	61	10/2/08
R202	Dowfoam/lined	CGOT	CGOT	348.4	196.2	152.2	Rock	55	10/30/08
PT5	GP foam insert low density	CGOT	Horiz	331.4	143	188.4	Sand	83	9/30/08
PT7	GP foam insert high density	CGOT	Horiz	344.4	162.2	182.2	Sand	71	10/1/08
PT8	GP foam pour high density	CGOT	Horiz	331.4	138.4	193	Sand	70	10/2/08

Package Descriptions

This section provides a description of the five tested configurations. A summary of the test results of each configuration and a comparison of the damaged packages is in the next section.

Celotex Construction

Celotex is a low cost material which has historically been used as thermal and structural insulation and support material in radioactive material packages, e.g., the DOT 6M Specification Packaging. This material was investigated as a baseline and its possible continued use in the Type AF package that was under development. At least four Celotex configured package designs were investigated. The design differences are highlighted in Table 2. One design consisted of only Celotex; two other Celotex configurations incorporated solid or pieced together sheets of plywood reinforcement. Plywood disk reinforcement has been used successfully in past 6M designs that were subject to 30-ft drops and was added for investigation of reinforcement against a horizontal crush test. The fourth design included a rolled steel angle, referred to as a “strong-back”, to reinforce the 55-gallon drum ends. For all the Celotex designs, Celotex was glued, using common wood glue, into cylinders and dropped into the 55-gallon drums. Each Celotex assembly consisted of a set of three stacked cylinders and two disks. Figure 2 illustrates a typical Celotex assembly, its insertion into the 55-gallon drum and an example of the rolled steel angle used to reinforce the drum closure.

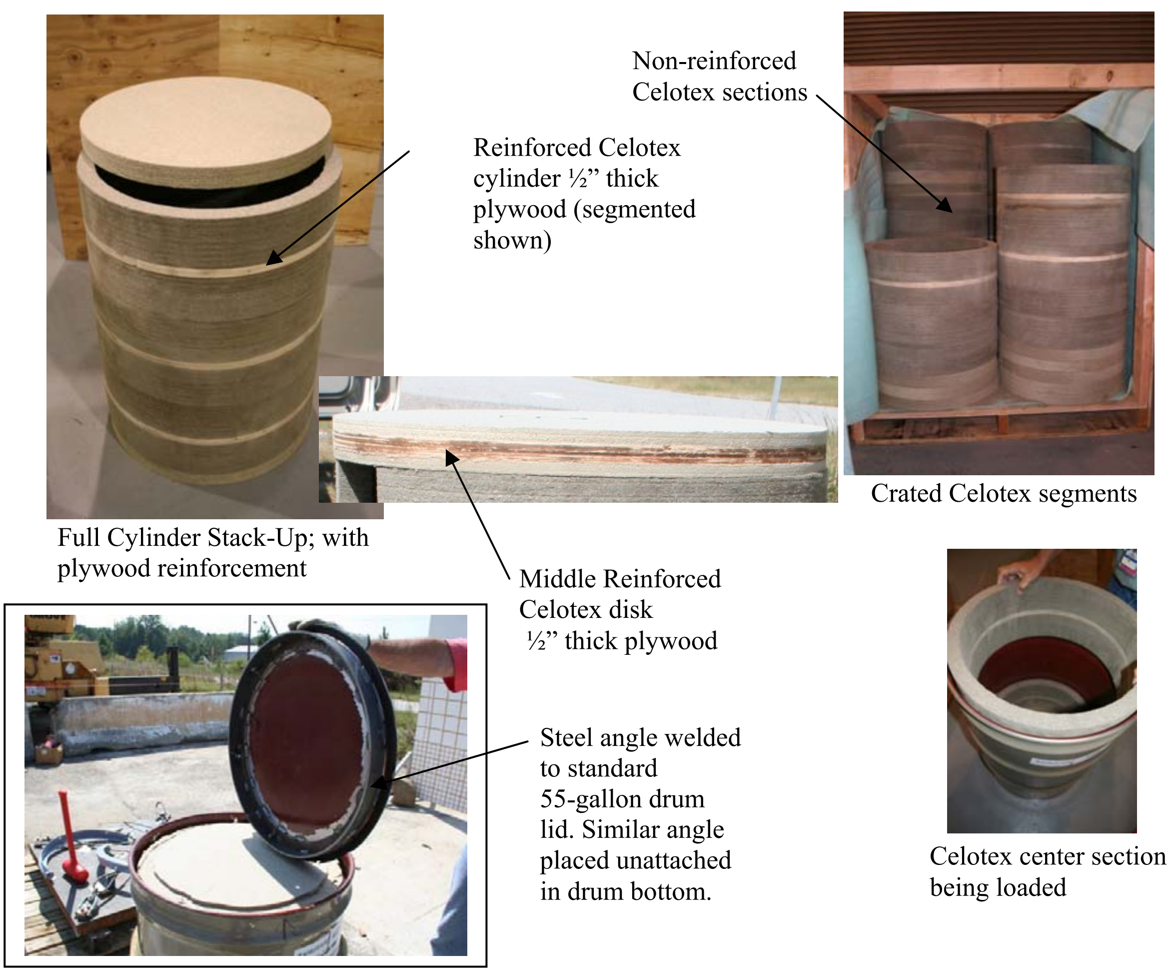

Figure 2 Celotex Assemblies and Reinforcements

Aluminum Honeycomb Construction

Aluminum honeycomb composite structures are widely used in the aircraft industry to achieve light-weight structural components; these characteristics make them viable alternatives to Celotex. In addition to the evaluating the structural performance of honeycomb composites for Type AF packages, fire retardant additives were investigated for the different honeycomb composite structures. Aluminum honetcomb material is currently used in certified Type B shipping packages as energy absorbing material, and the Bulk Tritium Shipping Package under development by SRNL uses an aluminum honeycomb composite structure similar to that investigated. [3] The two aluminum honeycomb composite designs listed in Table 2 were fabricated as follows.

- Three ¼-inch thick by ¼ inch cell size honeycomb sheets rolled and bonded together with honeycomb supported adhesive; and the completed composite covered with fiberglass cloth. (PH1)
- Two layer honeycomb structure (¼-inch thick by ½"-inch thick) rolled and bonded with honeycomb supported adhesive. The outer layer was wrapped with a single layer of Aero Foam and the composite was covered with fiberglass cloth. (PH2)

Figure 6 illustrates a cross section of two example cylinder laminate constructions and the general configuration of the final PH1 and PH2 assemblies designated in Table 2 shown with an enclosed 30-gallon drum. The aluminum honeycomb material used in the tested assemblies were manufactured with fire resistant additives.

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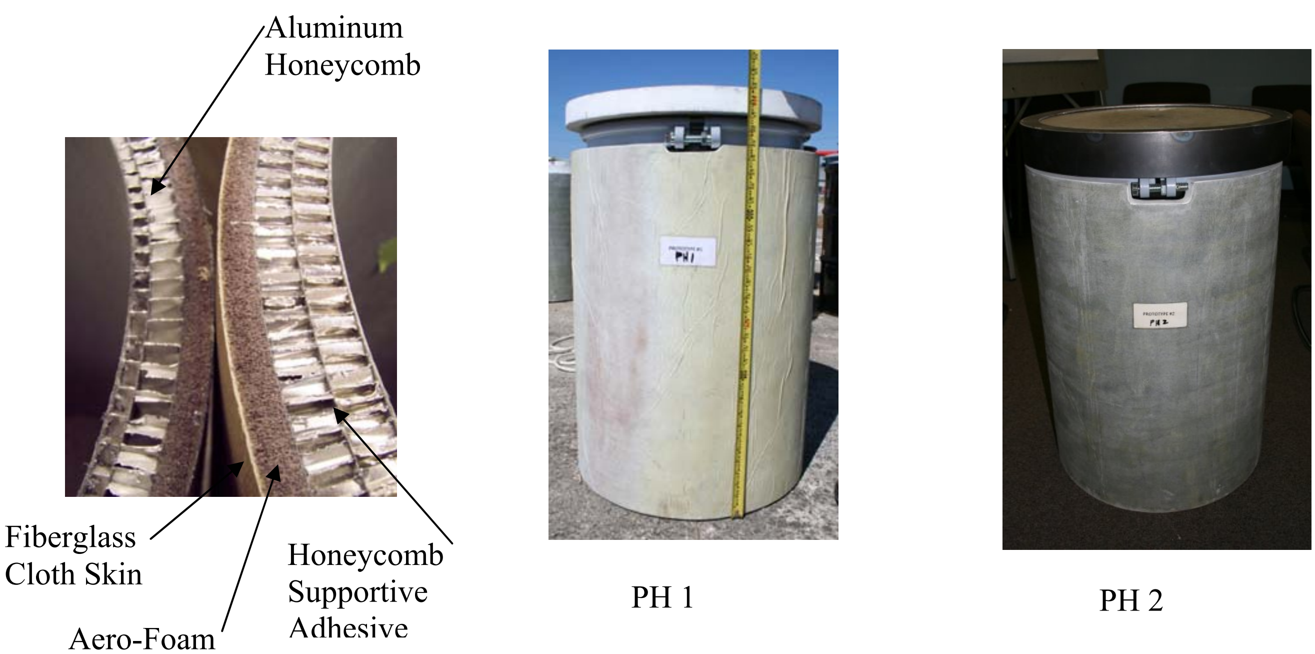

Figure 3 Aluminum Honeycomb Composite Structures

I-2300M Ceramic Construction

I-2300M is a ceramic fibrous material. Advantages of the ceramic material is its extremely low cost, it is inert to water, it's fire resistant to a continuous temperature of 2300ºF and is moldable and machinable. A few disadvantages are it has relatively low strength and is somewhat friable. However, by sealing and reinforcing the material its low strength and friable features can be mitigated. When substituted into the BTSP Type B package prototype, there was sufficient radial thickness (approximately 5-inches) to compensate for the low strength and the material was contained between the outer drum shell and the drum liner . The material was successfully used in a prototype BTSP and tested through complete HAC testing, i.e., drop, crush, and fire. The inherent low strength of the material in the Type AF design (a maximum radial cross section of 1.4 inches) was addressesd by the addition of fiberglass coating and by bonding the fabricated cylinder into the 55-gallon drum with polyurethane foam. The fiberglass coating eliminates friability of the material. Additionally, the fabricated I-2300M inserts (cylinder and top disk) included angle stiffening rings.

The three tested I-2300M configurations designs are summarized in this report. The first is similar to the plain Celotex insert configuration with the exception the material is I-2300M Ceramic fiber (PX0). For the second configuration, I-2300M inserts were sealed in fiberglass resin (PX1). The third configuration was the same as the second with the exception that a steel stiffening ring was added to the top disk. Not reported in this paper is the final I-2300M configuration. The sealed units were covered in only fiberglass resin (no cloth). This trapped the material but the resin is brittle with minimal strength. The final configuration was wrapped in fiberglass cloth and was secured in the 55-gallon drum with resin. Additionally, the tops and bottom of the 55-gallon drum was strengthened with steel stiffening rings. Also not discussed in this paper is the combining of the I-2300M with Aluminum honeycomb to improve strength and eliminate material friability issues. Figure 4 illustrates the design configurations.

PX0

PX1

PX2

Figure 4 I-2300M Composite Structures

General Plastics Polyurethane Foam Construction

Based on the successful use of General Plastics FR-3700 polyurethane foam in other package designs developed by SRNL (i.e., 9977, 9978 and BTSP), a similar construction for the Type

AF was investigated. Though the type foam was the same as the aforementioned packages a different foam density and method of construction was used for the Type AF in an attempt to keep package fabrication costs low. The steel liner used in the 9977, 9978 and BTSP package designs was not used for the GP foamed packagings. Two distinct designs were developed for the Type AF prototypes. In the first, the General Plastics foam for the AF was cast in six separate drop-in pieces: two disks and four cylinders. The pieces were assembled inside the 55-gallon drum similar to the Celotex design. For the second design the main body of the foam was monolithic cast directly into the 55-gallon drum utilizing a removable form. A top foam disk was used to close the foam structure. Figure 5 shows the different construction methods.

PT5

PT8

High Density
Foam Poured in
Place

Three Stacked
Cylinders

PT5

Figure 5 General Plastics Foam Construction

Dow Automotive Polyurethane Foam Construction

Based on the successful use of polyurethane foam in other package designs (i.e., 9977, 9978 and BTSP), a similar polyurethane foam formulation supplied by DOW Automotive was investigated. The DOW formula is used by the Auto Industry as a structural reinforcement for hollow car beams. The DOW polyurethane foam investigated was injected between the drum liner and drum wall in a similar manner as the 9977/9978 and BTSP packages. The foam is inserted as a two part liquid and when combined the mixture quickly rises and sets to a rigid state. A formed liner is welded into the 55-gallon drum forming a cavity in which the DOW foam is injected. In addition to the change in foam formulation, techniques for stiffening the package closure was also investigated. Figure 6 shows the typical construction method used for the DOW Autmotive Foam. In this package configuration, the drum lid is also reinforced with polyurethane foam. A shallow pan is welded to the bottom of the standard 55-gallon drum lid forming cavity in which the foam is injected.

Figure 6 Drum Construction for DOW Automotive Foam

PACKAGING DROP TEST COMPARISON

The 30-ft Center-of-gravity-over-top (CGOT) drop tests resulted in the greatest damage to the 55-gallon drum closure being pushed down towards the top rolling hoop of the drum. However, the packages tested generally showed minimal damage when subjected to the 30-ft drop as compared to the damage from the crush tests. Results of the 30-ft drop tests are illustrated in Figure 7.

PT1

PT3

PT6

PT9

PH1

PH2

PX0

PX1

PX2

R201

R202

Figure 7 Center of Gravity over Top 30-ft Drop Damage Observed for Packagings

PACKAGING CRUSH TEST COMPARISON

The crush test proved much more challenging for the test packages. For comparison, similar test orientations are shown together. Figure 8 shows packages that were crushed in a horizontal orientation. Figure 9 illustrates packages crushed in the CGOT orientation and Figure 10 shows package PX1 crushed vertically.

PT1 (top) PT1 (bottom) PT3

PT6 PT9 PT5

PT7 PT8

Figure 8 Horizontal Package Crush Damage

PT4 PH2 PX2

R202

Figure 9 CGOT Package Crush Damage

PX1

Figure 10 Vertical Package Crush Damage

CONCLUSIONS

The effect of the 30-ft drop on any of the packages tested did not result in significant damage to the drums. This leads to the conclusion that regardless of the materials used they would all satisfy the structural demands resulting from the 10CFR71 Hypothetical Accident Condition tests. Prototype package PT8 incorporating the poured in place General Plastics Foam is the lightest design. For the subsequent thermal test, the I-2300M ceramic material would provide the greatest protection to the packaging.

The effect of the crush test best differentiates the materials and construction techniques when the package must meet the performance requirements imposed by the 10CFR71 crush test.

The unreinforced Celotex packages performed poorly, and even when reinforced with plywood they did not perform as well as had been expected. The steel reinforced angles located at the drum opening significantly increased the closure performance of the package but not necessarily the bulk deformation incurred by the 10CFR71.73 crush test.

NRC Regulatory tests were performed on BTSP prototype packages incorporating two different types of thermal and structural materials. Based on the post-test examination and testing, it is concluded that I-2300M insulation can be substituted for polyurethane foam and provide adequate structural and thermal protection to the CV. The I-2300M has the advantage that it can withstand temperatures significantly greater than polyurethane foam permitting higher heat load contents. Furthermore, the I-2300M material reduces the g-loading transferred to the CV because it allows more energy to be absorbed in the overpack during HAC structural tests.

Of the five different designs fabricated and evaluated for the Type AF design, three were down selected for further evaluation. The designs were modified to better withstand the Hypothetical Accident Conditions (HAC) impact tests based on tests. Based on these tests, the three designs provide adequate structural protection to prevent any loss of contents during shipping as a Type AF package. Out of the three designs the foam lined package was chosen as the SRNL Type AF package of choice. [4]

Further, testing showed that some of the reinforced drum designs would be suitable as Type B package overpacks.

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