Early Tests of Drum Type Packagings – The Lewallen Report

Allen C. Smith
Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, South Carolina 29808
(803) 725 2943, allen.smith@srnl.doe.gov

Abstract
The need for robust packagings for radioactive materials (RAM) was recognized from the earliest days of the nuclear industry. The U.S. Department of Energy (DOE) Rocky Flats Plant developed a packaging for shipment of Pu in the early 1960's, which became the U.S. Department of Transportation (DOT) 6M specification package. The design concepts were employed in other early packagings. Extensive tests of these at Savannah River Laboratory (now Savannah River National Laboratory) were performed in 1969 and 1970. The results of these tests were reported in "Drum and Board-Type Insulation Overpacks of Shipping Packages for Radioactive Materials", by E. E. Lewallen. The Lewallen Report was foundational to design of subsequent drum type RAM packaging. This paper summarizes this important early study of drum type packagings.

Introduction
The DOE Rocky Flats Plant developed a simple, robust packaging configuration for shipping Plutonium in the early 1960's. The design was adopted by DOT as the 6M, and was widely used to ship Type B quantities of radioactive materials until it was decertified in October, 2008.

The 6M employed a containment vessel, designated the 2R, constructed of commercial pipe with cap or plug top closure and circumferentially welded disk for the bottom closure. The 2R containment vessel was enclosed in an overpack, consisting of a commercial drum and a thick annulus of "Celotex" cane fiberboard. The "Celotex" provided impact and thermal protection for the 2R and served to locate it in the center of the package. The lid of the drum was retained with a conventional clamp ring retainer. The 6M became the paradigm for drum-size radioactive materials packagings.

The development of the 6M packaging concept coincided with the development of the first regulations for RAM packagings. In 1961, the IAEA published Safety Series 6, Regulations for the Safe Transport of Radioactive Material.

The Lewallen Report
During 1969 and 1970, seven packaging designs were subjected to drop and fire tests at the Savannah River Site and reported in "Drum and Board-Type Insulation Overpacks of Shipping Packages for Radioactive Materials" (the Lewallen Report)[1]. The results

published in the Lewallen report were used as guidance on many subsequent packagings, a number of which are still in use.

Figure 1. Components of the 6M Specification Packaging.

The packages tested contained three major components: an inner shipping container assembly (in present terminology, containment vessels), an insulation assembly to provide thermal and impact protection for the inner container (i.e., an overpack), and an outer container or drum. The size and weight of the packages tested are shown below, in Table 1. The packages are shown in Figure 2.

Table 1. Package Characteristics.

Package Model	Total Weight, lb	Inner Container Weight, lb	External Dimensions hgt x dia, in.	Inner Container Dimensions, hgt x dia, in.
LP-12	130	35	28 5/8 x 19 1/4	18 x 10
JP-179	230	75	34 ¾ x 23 ½	23 ½ x 12 3/8
LP-50	260	90	40 x 23 1/2	30 x 14
JP-100	400	3 x 62	42 ¾ x 25	33 ½ x 8 5/8
JP-157	305	99	42 ¾ x 25	32 ¾ x 17 1/8
JP-157S	420	180	54 1/8 x 25	43 9/16 x 17 1/8
UO_2	880	595	38 1/8 x 27	24 ½ x 10

Inner shipping containers were not discussed in detail. Each inner container was analyzed and found adequate to prevent loss of the material being shipped under normal and accident conditions of transport. The UO_2 package incorporated a lead cask to provide radiation shielding.

Impact Absorbing and Thermal Insulating Materials
"Celotex" was used as the principal insulating material "because of its suitable mechanical properties and successful similar applications elsewhere." It was noted that venting of the drums was required to prevent rupture of the drum during a fire caused by gasses given off by the "Celotex" during a fire event. "Cerafelt" or "Cera Form" insulation were used at the vents to prevent smoldering of the "Celotex" following the fire.

Part of the study conducted by Lewallen addressed alternative materials for the overpack insulation. These are compared in Table 2, where A is satisfactory and D is unsatisfactory.

Table 2. Comparison of Characteristics of Insulation Materials

	"Celotex"	Plywood	"Cera Form"	Vermiculite	"Fesco"	"Firedike"
Resilience	A	C	D	D	C	B
Thermal Insulation	B	B	A	A	A	A
Material Cost	A	C	D	A	A	B
Fabrication Cost	B	B	C	B	A	C
Life Expectancy	A	A	D	A	C	B
Personnel Hazard	B	A	C	A	B	B

Resiliance is ability to absorb energy from severe impact without permanent deformation.
Thermal insulation is indicative of thermal conductivity and thermal stability at high temperature.
Material cost is only base material cost, not including fabrication.
Fabrication cost is labor and materials to render the insulation material serviceable.
Life expectancy is indicative of durability or potential for reuse.
Personnel hazard is indicative of any toxic or irritating properties.

The insulation materials tested were identified by their trade names, "Celotex", "Fesco", "Cera Foam", "Cerafelt", Vermiculite, and "Firedike." "Fesco" is a noncombustible roofing insulation. It is a weaker and more brittle material that "Celotex". "Cera Form" is an alumina-silica refractory insulating material, stable to 2300 ºF. Its thermal performance was judged to be excellent, but its strength is inadequate to assure a minimum thickness of insulation after a drop test impact. "Cerafelt" is a spun alumina-silica felt with fibers bonded by organic and inorganic binders, with a density of about 6 lb/ft^3. Its thermal performance was judged to be excellent. "Cera Form" and "Cerafelt" are registered trade names of Johns-Manville Co. "Firedike" is a mineral wool and slag composition used primarily as a, fire-resistant ceiling covering. Vermiculite is hydrous silicate, usually made by pulverizing mica. It is loose and requires separate support for the inner container.

Table 3. Properties, Commercially Available Forms, and Cost of Insulation Materials

	Thermal Conductivity (Btu/(hr ft ºF)		Thermal Stability in Air	Density Lb/ft^3	Available Forms	Approximate Cost Unmachined (August 1971), $/ft^3
	100 ºF	1000 ºF				
"Celotex" (industrial grade)	0.031		Mechanically degrades above 280 ºF Bursts into flame at 425 ºF in air	13 - 20	½ to 3 inch thick sheets	1.60
"Fesco"	0.03		Fuses at approximately 500 ºF but maintains thermal resistance	11	1 to 3 inch thick sheets	1.00
"Cera Form"	0.028	0.067	Stable up to 2300 ºF with 2.2% shrinkage. Incombustible	10 - 12	1/4 to 1 1/2 inch thick sheets and special ordered forms	22.00
"Cerafelt"	0.025 (6 lb/ft^3) 0.027 (16 lb/ft^3)	0.075 0.050	Stable up to 2300 ºF Incombustible	3 – 24 As specified	1/16 to 2 inch thick sheets and rolls	16.50
Plywood (Fire Retardant Grade CD-DFPA)	0.066		Burns at high temp. Self extinguishing	35	1/4 to 1 inch thick sheets	5.65
"Vermiculite" (expanded)	0.04		Incombustible	7	Bagged or loose	0.60
"Firedike" (plain)	0.031		Burns at approximately 1400 ºF. Self extinguishing	20 - 22	½, 5/8 and 3/4 inch sheets	4.00

Drum Tests

Because of their greater strength and closer dimensional tolerances, the outer drums were Military Standard drums. It was found that tightness of the closure rings was critical to performance under impact conditions, requiring special tightening (torquing) procedures. Locking rings with drop forged lugs, similar to DOT specification 17H, with high strength bolts, such as ASTM A-325, were recommended for all packagings.

The outer steel drums specified for each package design were tested for load resistance (as a beam), penetration and compression. No yielding was observed in any of the packagings.

Package Tests

The packages were tested following the regulations in place at the time. These consisted of a 30 ft drop, puncture by dropping the packages on a 6 in. (15 cm.) cylindrical post from 40 in.(1 m), and 30 minute, test in a furnace at 1475 ºF (800 ºC). Eight of the prototype packages were subjected to the thermal test. The furnace employed was a gas fired heat treatment oven. The packages were supported on a frame mounted a large carriage for entry to and exit from the oven. The time temperature curve for the furnace is shown in Figure 3. The furnace temperature was maintained at an average of 1475 ºF, determined by 12 thermocouples surrounding the packages.

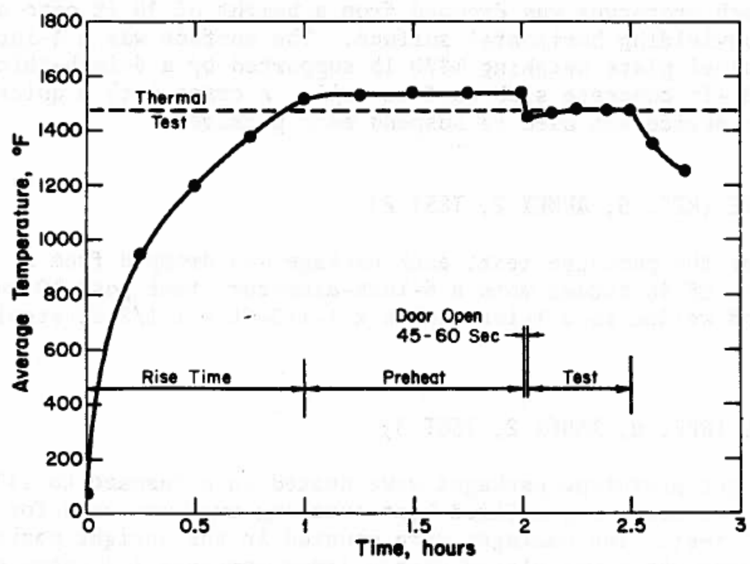

Figure 3. Furnace Thermal Response.

Package Designs

The package configurations tested are shown in Figure 2 and Table 3.

Prototypes 1, 2, and 3 (JP-100) were tested to determine the relative performance of "Fesco" board, a combination of "Cera Form" and "Cerafelt", and "Celotex". The packagings contained three JP-100 aluminum containment vessels, which were supported in a three-leaf clover arrangement.

Prototypes 4, 5, and 6 were tested as part of the development of the JP-100 packaging and to further investigate the performance of "Celotex". Prototype 6 was "similar to Prototype 5 except a 16 gage insert, approximately 12 x 3 in. was welded to the drum opposite the point of impact."

Prototypes 7 and 8 (JP-179) were tested to compare the thermal insulation properties of "Celotex" (combustible) with "Fesco"(non-combustible). With the exception of the insulation material, the packages were identical. Four 3/8 in. vent holes were located in the bottom of each package. Temperature sensing pellets were distributed in the insulation.

Prototypes 9 and 10 (LP-50) were preliminary tests to determine the impact properties of thinner "Celotex" in heavier packages, The insulation was 4 in. thick on sides, top and bottom, with local thin areas corresponding to recesses for the inner container valve and flange.

Prototypes 11 and 12 (LP-50) were dimensionally similar to Prototypes 9 and 10, except 16 gage elongated DOT Specification 6J drums were used.

Prototypes 11 (LP-50) and 13 (JP-100) had four 3/8 in. vent holes in the bottom and four 3/8 in. vent holes aligned vertically on the side. The side vent holes were adopted in an effort to avoid bulging, due to over pressurization, experienced in thermal tests of Prototypes 7 and 8. Prototypes 12 (LP-50) and 14 (JP-100) had six 3/8 in. vent holes located immediately under the clamp ring and disks of “Cerafelt” were placed on top of the “Celotex”.

Prototypes 13 and 14 (JP-100) were dimensionally similar to Prototypes 5 and 6, except 16 gage Military Standard MS63055-3 (80 gal.) drums were used.

Prototype 15 (JP-157S) was tested to demonstrate that 28 in. diameter, heavy drums were suitable for packaging. The package consisted of an elongated Military Standard MS 63057 drum, with a capacity of 140 gal. Vent holes were provided immediately below the drum curl.

Prototype 16 (JP-157S) was tested to investigate a smaller and lighter package than Prototype 15. The insulation thickness on the sides was 2 13/16 in. and 4 in. on the top and bottom. Vent holes were provided immediately below the drum curl.

Prototype 17 was an LP-12 container in a 30 gal Military Standard MS24029-2 drum with 4 in. insulation on top, bottom and sides and with tight fit between insulation and drum.

Prototype 18, 19 and 20 were UO_2 packagings consisting of 16 gage, 55 gallon, 17C drum, with “Celotex” insulation and 12 in diameter dummy containment vessels. Insulation thickness was 6 in. on the sides and 4 in., top and bottom. The containment vessel for Prototype 18 weighed 671 lb. Prototype 19 had a 4 in. tall shock absorbing structure attached to top, and a 631 lb containment vessel. Prototype 20 employed a 57 gal drum, a “Cera Form” ring at the top of the insulation, a shock absorbing structure on top of the package and a 677 lb containment vessel.

Test Results

The package test program included multiple examples of each of the seven designs except for the LP-12. A total of twenty prototype packagings were tested, as shown in Table 4. All designs were tested in top corner, horizontal and puncture drops. Several designs were subjected to multiple drops, including axial, bottom down drops. The resulting damage was typical of that seen in other tests of drum type packagings. In side drops, the side was flattened, in bottom drops, the package was shortened by buckling of the bottom rolled seam (chime) and lower rolling ring, and in top corner drops, the impact area was crushed. The puncture tests resulted in minor indentation, but not rupture of the drums. In several of the tests, the lids were opened, exposing the insulation in the corner or horizontal drops.

As a result of the tests for Prototypes 1, 2, and 3, "Cera Form", "Cerafelt" and "Fesco" were eliminated for further consideration, Figure 7. "Celotex" was found durable enough for a reusable package and effectively absorbed shock loads of the accident condition tests.

Tests of Prototypes 4, 5, and 6 all resulted in disengagement or opening of the lid, Figure 8. They confirmed the ability of "Celotex" to withstand the drop tests. That is, they protected the containment vessels from mechanical damage. It was concluded that the package provided adequate mechanical protection for the three JP-100 inner containers.

Table 4. Summary of Hypothetical Accident Tests of Prototypes

Prototype Number	Number of Inner Containers	Type Package	Nominal Size, gal	Weight, lb	Drum Gage Thickness	Insulation	Remarks	Test [a]		
								30-ft Drop	40-inch Puncture	1475 ºF Thermal
1	3	JP-100	60	325	18	"Fesco"	With top hat	F	F	-
2	3	JP-100	60	351	18	"Cera Form"	With top hat	F	F	-
3	3	JP-100	60	348	18	"Celotex"	With top hat	F	F	-
4	2	JP-100	60	294	18	"Celotex"	With top hat	P	P	-
5	3	JP-100	80	377	18	"Celotex"		F	P	-
6	3	JP-100	80	380	18	"Celotex"	16-gage insert welded into Prototype 5	P	P	-
7	1	JP-179	55	184	18	"Fesco"		P	P	P
8	1	JP-179	55	217	18	"Celotex"		P	P	P
9	1	LP-50	60	260	18	"Celotex"	With top hat	F	P	-
10	1	LP-50	60	260	18	"Celotex"	With top hat	P	P	-
11	1	LP-50	60	260	16	"Celotex"	Vents in side	P	P	F
12	1	LP-50	60	260	16	"Celotex"	Vents in top	P	P	P
13	3	JP-100	80	402	16	"Celotex"	Vents in side	P	P	F
14	3	JP-100	80	402	16	"Celotex"	Vents in top	P	P	P
15	1	JP-157S	140	496	16	"Celotex"		P	P	-
16	1	JP-157S	110	420	16	"Celotex"		P	P	P
17	1	LP-12	30	130	18	"Celotex"		P	P	P
18	1	UO_2	55	846	16	"Celotex"		F	-	-
19	1	UO_2	55	824	16	"Celotex"		F	P	-
20	1	UO_2	55	880	16	"Celotex"		P	P	-
a. F means failed; P means passed										

Prototypes 7 & 8 withstood the drop tests with acceptable deformation and were subjected to the thermal tests, performed in a furnace, Figure 9. The packages were oriented vertically, with their four, 3/8 vent holes at the bottom. The thermal tests resulted in excessive bulging of the tops due to pressurization of the drums by gaseous decomposition products during the thermal test. For subsequent thermal tests, the vent holes were relocated to the sides of the drum body to avoid their being plugged by insulation

The tests for Prototypes 9 and 10 resulted in acceptable damage and showed the adequacy of “Celotex” for the LP-50 Package for impact absorption.

Tests of Prototypes 11, 12, 13 and 14 investigated the performance of alternate drums and vent hole arrangements, Figure 10 and 11. The packagings withstood the drop tests with acceptable damage.

Prototypes 11 and 13 were subjected to a simultaneous furnace test. Each prototype had four 3/8 in. holes in the bottom and four 3/8 in. holes aligned vertically on the side. Three days after the furnace test, the prototypes were opened and the “Celotex” burst into flame. Insulation adjacent to the side vent holes was destroyed by combustion during the furnace test and smoldering after the prototypes were removed from the furnace. Natural convection through the vertically arranged vent holes sustained the smoldering. Minimum damage occurred to the bottom insulation disk in each prototype because the weight of the insulation and inner containers plugged the vent holes, retarding flow of gases. The temperature sensitive pellets adjacent to the smolder area indicated the smolder temperature was between 400 and 450 F.

Prototypes 12 and 14 had six 3/8 in. vent holes located immediately below the locking ring. Disks of “Cerafelt” were placed on top of the “Celotex”. Some combustion of the Celotex adjacent to the vents occurred, but smoldering was prevented. Temperatures were sufficiently lower in 12 and 14 to qualify the packages, but greater assurance of prevention of excessive burning and smoldering was required.

Prototypes 15, 16, and 17 were separate examples of various package designs, 15 and 16 being large packagings and 17 being a 30 gal packaging. All withstood the drop tests, protecting their containment vessels. Prototype 16 was subjected to thermal testing. The performance of all three was acceptable.

Prototypes 18, 19, and 20 were examples of a UO_2 cask, Figures 12 and 13. All were quite heavy. Various concepts for enhancing the top closure were evaluated as part of these tests. Some opening occurred at the closure seam in all three tests. 18 and 19 were disqualified for this reason. For Prototype 20, sufficient insulation remained for the thermal test to be performed. Based on these tests, a closure with a skirt that fit around the body (to strengthen the closure in impact) was recommended.

Celotex Thermal properties
The section of the report titled “Thermal Properties of “Celotex” has been very important for later packaging designs. The study of the thermal properties of Celotex showed that to avoid shrinkage and distortion, the maximum normal temperature of the celotex should be 250F, Figure 4. The rule of thumb that a minimum of 2 in. of “Celotex” is required to protect the containment vessels has its basis in the results presented here, Figures 5. Charring was found to be typically 1 ¾ in. deep in the thermal tests of the packages. The results of the charring investigation are shown in Figure 5.

A simplified thermal analysis to determine the internal surface temperature of a celotex overpack of a cylindrical drum with internal decay heat release and various celotex thicknesses was performed. The results are given in Figure 6.

The benefits of “Cerakote” fire retardant were evaluated and found to delay ignition of the “Celotex”, but not affect the ignition temperature.

Vent Holes
Venting of the packaging received a lot of attention in the study. Vent holes in the bottom of the package were obstructed by the insulation and were not satisfactory. A vertical row of holes along the side of the drum allowed air circulation and resulted in extensive smoldering. This was also unacceptable. A series of holes around the top of the package, adjacent to the curl, and backed by a ring of “Ceraform” was found to be effective.

Report Conclusions
Type B shipping packages insulated with “Celotex” require certain design features and handling techniques to meet regulations. The following items should be considered:

- Venting of outer drums is recommended, particularly for sizes above 30 gal.
- Smoldering of “Celotex” must be prevented.
- Outer drums must have adequately strong closures, which are primarily dependent on size of locking curl, type of locking lugs and thickness of metal. Military standard drums were found satisfactory.
- Insulation materials must fit tightly within the drum and around the inner container with no voids to cause disarrangement of insulation materials during impact.
- The decay heat or radioactive materials within the shipping package must be limited to limit the maximum temperature of “Celotex” insulation to less that 250 F during normal shipping conditions.
- Special procedures for torquing locking rings are required to relieve friction forces around the periphery of the closure as the locking bolt is torqued.
- Each configuration of a package has different impact and thermal capabilities.

Recommended specifications for shipping packages with drum and board-type insulation are given in the Appendix of the report. *These specifications are based on experience at the Savannah River Plant during the series of hypothetical accident condition tests as* *prescribed by the regulations. Although all packages in Table A-1 were not tested, adequate experience was gained to be reasonably sure that all packages would survive the drop test and thermal test specified in the regulations with a temperature rise of the contents not exceeding 230 F.*

Conclusions

The Lewallen Report demonstrated the ability packagings employing drum and insulation board overpacks and engineered containment vessels to meet the Type B package requirements.

Because of the results of the Lewallen Report, package designers showed high concern for thermal protection of "Celotex". Subsequent packages addressed this by following strategies like those recommended by Lewallen and by internal metal shields and supplemental, encapsulated insulation disks, as in 9975.

The guidance provide by the Lewallen Report was employed in design of a large number of drum size packagings over the following three decades. With the increased public concern over transportation of radioactive materials and recognition of the need for larger margins of safety, more sophisticated and complex packages have been developed and have replaced the simple packagings developed under the Lewallen Report paradigm.

Contract Number

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References

1. Regulations of the Safe Transport of Radioactive Marterials, Safety Series 6, IAEA Safety Standards, International Atomic Energy Agency, Vienna.1961.

2. Lewallen, E. E., "Drum and Board-Type Insulation Overpacks of Shipping Packages for Radioactive Materials", Du Pont Savannah River Laboratory Report DP-1292, July, 1972.

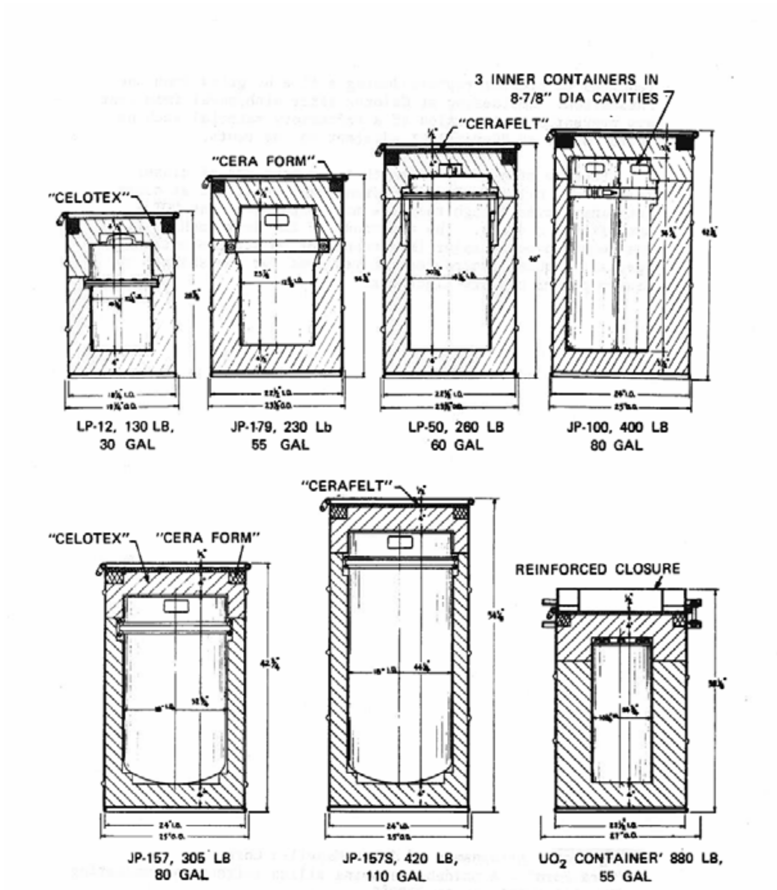


Figure 2. Packages Included in Test Program

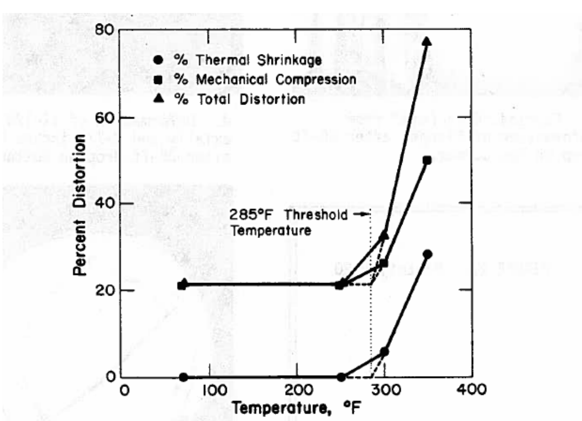


Figure 4. Thermal Response of Celotex.

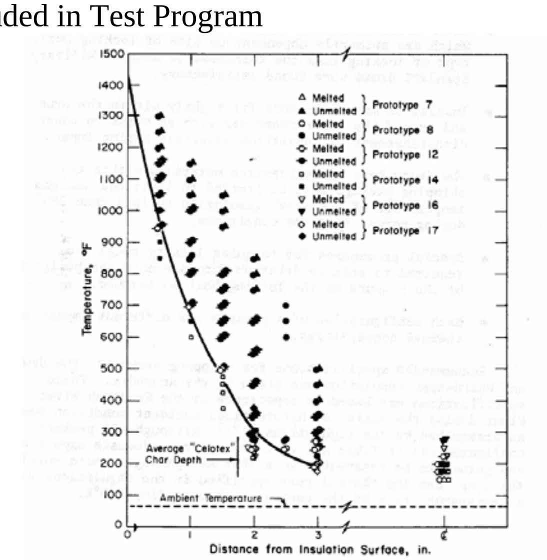


Figure 5. Degradation of Celotex in Thermal Tests.

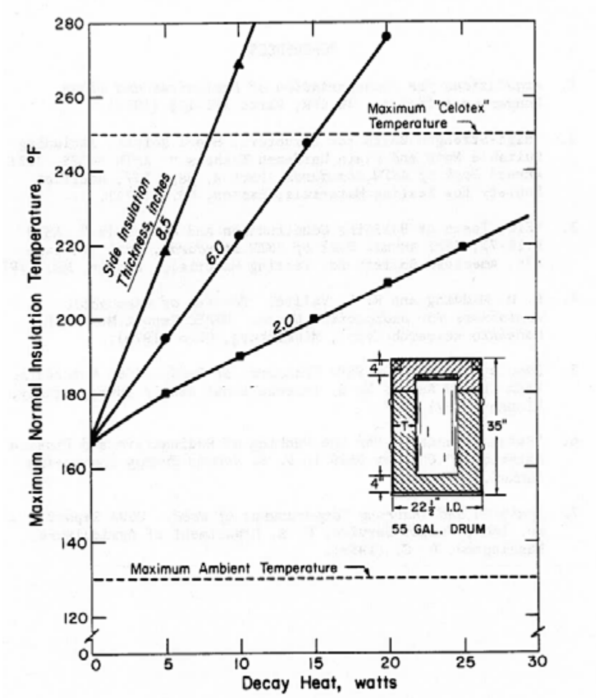
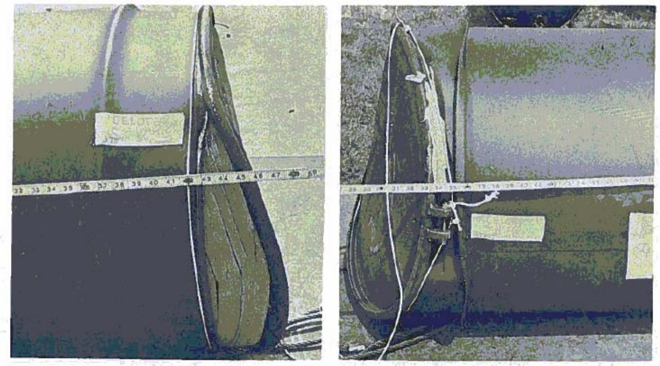


Figure 6. Celotex temperature for heat generating contents.

a. Results of 30-ft Drop on Top Corner, Side, and Bottom and Penetration Test on Bottom.

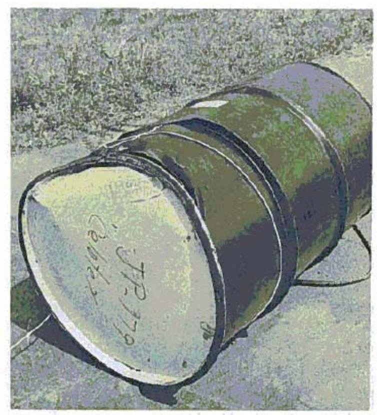
Figure 7. Prototype 1



a. After 30-ft Drop on Top Corner. Side of Impact.

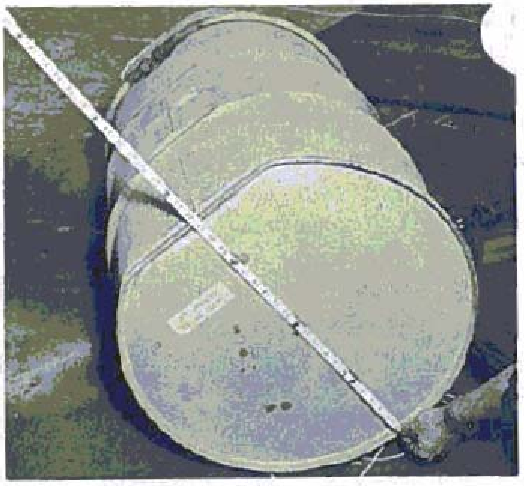
b. Height Reduced 4-3/8 inches at Impact Point After 30-ft Drop on Top Corner.

Figure 8. Prototype 5



a. After 30-ft Drop on Top Corner and Side.

Figure 9. Prototype 8



a. Diameter Reduced 3/16-inch after 30-ft Drop on Side.

Figure 10. Prototype 11.

a. "Celotex" Exposed ~8 inches and Radiant Heat Paths Between Discs after Thermal Test.

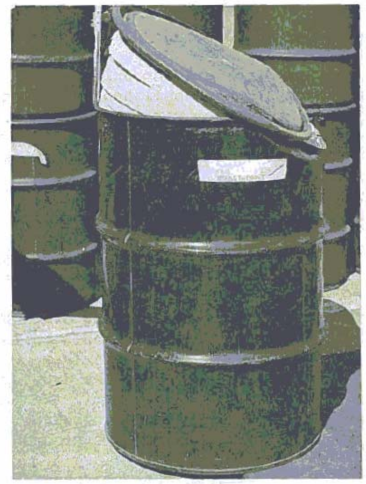


Figure 12. Prototype 18

a. 5-1/4-inch Deformation after 30-ft Drop on Corner.

Figure 11. Prototype 14

a. 1-1/8 inch Gap from Deformatio of Flanges after 30-ft Drop on Top Corner.

c. Exposed "Cera Form" from Deformation of Flanges after 30-ft Drop on Top Corner.

Figure 13. Prototype 20