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DRUM AND BOARD-TYPE INSULATION OVERPACKS OF SHIPPING PACKAGES FOR RADIOACTIVE MATERIALS

E. E. LEWALLEN

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Savannah River Laboratory

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by

E. E. Lewallen

Works Technical Department
Savannah River Plant

Approved by

L. W. Fox, Superintendent
Reactor Technology Section

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E. I. DU PONT DE NEMOURS & COMPANY
SAVANNAH RIVER LABORATORY
AIKEN, S. C. 29801

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ABSTRACT

Seven different shipping packages for radioactive materials were developed at the Savannah River Plant. The packages have "Celotex" overpacks for heat and impact protection and Military Standard drums for outer containers. In development tests, twenty prototype packages were dropped 30 ft, and eight packages were heated to 1475°F in a furnace. Military Standard drums were specified for outer containers of all packages because of the strength and close tolerances of these drums. Special torquing procedures were required and cover gaskets were omitted to assure strong closures. Clearances between the insulation, drum, and inner container were minimized to constrain the insulation during impact. Because "Celotex" is combustible and evolves gases when heated, drums were vented to avoid rupture. "Cera Form," a refractory insulation material was placed adjacent to the vents to retard air flow into the drum and prevent smoldering of "Celotex." "Cerafelt," a more-flexible refractory material, was placed between the drum cover and "Celotex" to serve as a spacer and to prevent combustion if the cover is ruptured.

Because "Celotex" degrades mechanically during long exposure to high temperature (above 250°F), the internal temperature from decay heat must be limited. Alternative materials for "Celotex" were studied. "Fesco" and "Firedike" were found suitable substitutes for "Celotex." Specifications for drum-type insulation overpacks are presented as an Appendix.

CONTENTS

INTRODUCTION

During 1969 and 1970, seven different kinds of packages with "Celotex"* for heat and impact protection were developed at the Savannah River Plant to ship radioactive materials. To avoid process modifications, previously constructed containers were modified and used as inner container assemblies in six packages. Overpacks consisting of modified steel drums and insulation assemblies were developed from tests. A seventh package was developed in entirety to ship recovered uranium oxide from Italy to Oak Ridge.

In the development program, twenty prototype packages were tested. All prototypes were dropped 30 ft at least once. Eight of the prototypes were heated to 1475°F for 30 minutes. From these tests, much was learned about the capabilities of insulated, Type B[1] shipping packages. General conclusions from the development program are given on page 50. Recommended specifications for this type of package are given in the Appendix. Use of the specifications presented in the Appendix should result in packages that survive the regulatory accident tests in the prescribed sequence.[1] The tests and results are described in detail in this report.

At the request of the Atomic Energy Commission, this report was prepared to document experience gained at the Savannah River Plant for use at other facilities and for possible guidance in formulating new specifications by the Atomic Energy Commission and the Department of Transportation (DOT).

*Registered tradename of Celotex Corp.

SHIPPING PACKAGE COMPONENTS

The seven shipping packages designed and tested at the Savannah River Plant contain three major components:

- An inner shipping container assembly provides single or multiple envelopes to prevent loss of radioactive material.
- An insulation assembly provides thermal and impact protection for the inner container.
- An outer container or drum, which is vented, protects and constrains the insulation during normal and accident conditions of transport.

Figure 1 shows the three components of each shipping package.

The packages shown in Figure 1 were developed for minimum total volume to accommodate the weight and volume of the inner container. Some of the characteristics of each package are given below:

Package Model	Total Weight, lb	Inner Container(s) 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 3/4 x 23 1/2	23 1/2 x 12 3/8
LP-50	260	90	40 x 23 1/2	30 x 14
JP-100	400	3 x 62	42 3/4 x 25	33 1/2 x 8 5/8
JP-157	305	99	42 3/4 x 25	32 3/4 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 1/2 x 10

The inner shipping containers will not be discussed in detail. These containers provide primary and/or secondary containment of radioactive materials, and in the case of the UO_2 Package, the lead cask provides radiation shielding. Each inner container was analyzed and found adequate to prevent loss of the material being shipped under normal and accident conditions of transport.

"Celotex" was used as the insulating material because of its suitable mechanical properties and successful similar application elsewhere. Although "Celotex" is not stable at high temperatures, it can be used as insulation for shipping radioactive materials of low decay heat. Venting of the drums was

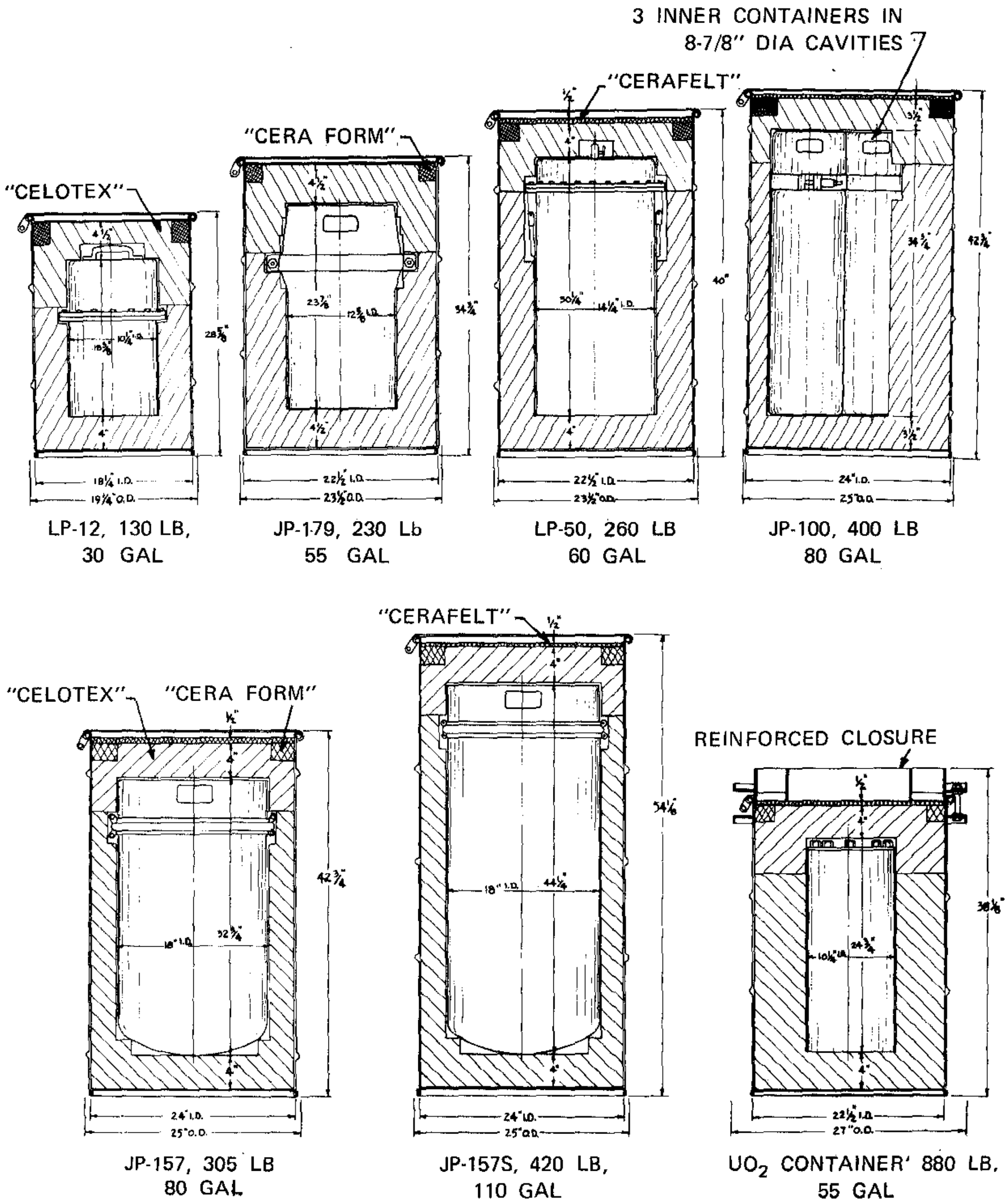

FIGURE 1. Shipping Packages Developed at Savannah River Plant

required to prevent rupture during a fire by gases from the insulation. Smoldering of Celotex after withdrawal from heat was prevented by insertion of a refractory material such as "Cera Form"* or "Cerafelt"* adjacent to the vents.

Because of greater strength and dimensions of closer tolerances, Military Standard drums were specified as outer containers even though they are more expensive than DOT Specification drums. The tightness of the drum locking rings was found to be of major importance for impact protection. Special torquing procedures are required for the shipper to assure proper closure tightness.

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* Registered tradenames of Johns-Manville Corp.
"Cera Form" - A moldable alumina-silica refractory insulating material stable up to 2300°F.
"Cerafelt" - A loosely spun alumina-silica refractory material with a density of $\sim$6 lb/ft^3.

COMPARISON OF MATERIALS FOR SHIPPING PACKAGES

Materials for constructing reusable Type B packages for shipping radioactive material of low decay heat were chosen on the basis of safety, ease of package assembly and disassembly, minimum cost of fabrication and maintenance, and maximum life expectancy. Military Standard drums were specified for the outer container of all packages because of strength and close tolerances. Of the various insulating materials considered, only "Celotex," "Fesco,"* and "Firedike"* appeared adequate. "Fesco" and "Firedike" are more thermally stable than "Celotex," but are less impact-resistant. "Celotex" loses strength when maintained at >285°F for extended periods, but it can be used for radioactive material with low decay heat (recommended insulation temperature <250°F). "Fesco" and "Firedike" can be used where internal insulation temperatures might exceed 250°F in normal transport.

OUTER CONTAINERS

Military Standard drums (Figure A-1 in the Appendix) were the strongest of the tested containers. Impact strength is greatly affected by the size of the drum locking curl. The curl of the Military Standard drum was the largest and strongest observed (0.450 in.). Although drums meeting DOT Specifications 6C, 6J, and 17C[1] have been used successfully as outer containers, several of these drums were observed with curls that were obviously too small.

Results of 30-ft drop tests indicate that a very close fit between the insulation and drum improves impact resistance. Dimensions vary widely for DOT drums because DOT specifications define only performance criteria and tolerances of volume. Small dimensional tolerances of Military Standard drums are specified to assure interchangeability of components. Therefore, to avoid select fitting of drums and insulation assemblies, Military Standard drums are preferred.

Several locking rings with sheet-formed, spot-welded lugs (Style 1 in Figure A-1 in the Appendix) were not strong enough. Drop-forged lugs 5/8 in. thick (similar to DOT Specification 17H[1]) are recommended for all packages. Mild steel locking bolts, normally provided with drums, formed unsafe, sharp edges

* Registered tradename of Johns-Manville Corp.

particularly when used several times with impact wrenches. Bolts of high strength material (ASTM A-325[2] or equal 23-35 R_c hardness) are reusable and safe.

The cost of Military Standard drums is approximately twice the cost of other drums. The average costs from three vendors (as of August 1971) for Military Standard drums with drop forged lugs on locking rings in lots of 50-100 are given below:

Military Standard	Capacity, gallons	Inside Diameter, inches	Inside Height, inches	Material Gage	Average Cost, $
MS27683-7	30	18.25	26.99	18	15.90
MS27683-14	57	22.50	33.33	16	26.30
MS27683-19	61	22.50	35.77	16	28.20
MS27683-22	80	28.00	29.98	16	42.00
MS27683-22[a]	140	28.00	52.00	16	75.00
MS27683-23	80	24.00	41.12	16	44.00
MS27683-23[a]	100	24.00	52.00	16	67.00

a. Elongated.

INSULATION

Both impact and thermal protection are required from the insulation material. Low fabrication costs and long life expectancy are important secondary requirements. Table I shows a comparison of properties of several insulation materials on a graded scale (A, satisfactory; D, unsatisfactory). *Resilience* is the capability of the material for absorbing energy from severe impact by crushing without permanent deformation. *Thermal insulation* is related to thermal conductivity at normal and elevated temperatures and thermal stability at elevated temperatures. *Material cost* is only the insulation material costs. *Fabrication cost* is the labor and extraordinary materials to render the insulation material serviceable. *Life expectancy* is related to the material's durability and its potential for reuse. *Personnel hazard* relates to toxic and irritating properties experienced while working with the material. Properties of some insulation materials are further described in Table II.

TABLE I

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

TABLE II

Properties, Commercially Available Forms, and Cost of Insulation Materials

	Thermal Conductivity, BTU/(hr-ft-°F)		Thermal Stability in Air	Density, lb/ft^3	Available Forms	Approximate Cost Unmachined (August 1971), $\$/ft^3$
	100°F	1000°F				
"Celotex" (industrial grade)	0.031		Mechanically degrades above 280°F Bursts into flame at 425°F in air	13-20	1/2- to 3-inch-thick sheets	1.60
"Fesco"	0.03		Fuses at approximately 500°F but maintains thermal resistance	11	1- to 3-inch-thick sheets	1.00
"Cera Form"	0.028	0.067	Stable up to 2300°F 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°F 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°F Self extinguishing	20-22	1/2-, 5/8-, and 3/4-inch sheets	4.00

"Celotex"

"Celotex" is a fiberboard made from sugar cane fibers bonded together with an organic glue. Only industrial-grade "Celotex" as described by Mil F-26862A (except para 3.7) is acceptable.* Its shear strength is 31 to 33 psi. Its durability and cost make it the most desirable material tested provided measures are taken to improve its thermal properties as described beginning on page 46. The material may be machined similarly to wood. Complex shapes may be punched using specially shaped blades.

"Fesco"

"Fesco" board is a dark brown, noncombustible roofing insulation composed of perlite granules bound with a mineral binder and fibers. Shear strength is 7.0 psi. The material absorbs approximately the same amount of energy as "Celotex" upon impact when tightly constrained, but practically all deformation is permanent, and the material tends to fracture randomly throughout, leaving effectively no tensile strength. Its brittleness requires care in package assembly. A durable envelope is needed to prevent damage during normal conditions if prolonged and repeated use is required. For severe impact conditions, "Fesco" must be closely constrained by the inner and outer containers to prevent fracture and disarrangement.

"Fesco" evolves gases and chars when heated to 1475°F. The charred area fuses (approximately 2 inches deep) and becomes crystalline, closing small cracks formed in impact.

"Fesco" appears to be adequate insulation material when tightly constrained in the package. Repeated use is possible if care is taken in assembly and disassembly after each trip and if broken components are replaced.

"Cera Form"

"Cera Form" is an insulation material molded from a wet slurry of alumina-silica refractory fiber and bonded by organic and inorganic binders. Its thermal stability is excellent. The material is brittle, and damage from handling must be avoided. "Cera Form" tends to tear unless cut very carefully. Cutting tools dull rapidly. The surface can be made harder and more abrasion resistant, but less resilient, by applying the inorganic impregnant "Cera Preg."** The strength of "Cera Form" is inadequate to assure a minimum thickness of insulation after a

* Samples of residential-grade "Celotex" were evaluated and found to have considerably less strength and to burn faster.

** Registered tradename of Johns-Manville Corp.

30 ft impact unless some additional mechanical protection is provided. The mineral fibers form a dust that is extermelv irritating to personnel if inhaled. The thermal stability and porosity of "Cera Form" make it an excellent material to prevent smoldering of "Celotex" (see page 46).

"Cerafelt"

"Cera Felt" is a spun alumina-silica felt with fibers bonded with organic and inorganic binders. It is stable up to 2300°F and adequately durable for a blanket-spacer under the drum cover to prevent smoldering and to constrain the "Celotex" within the drum (page 48).

Vermiculite

Vermiculite is hydrous silicate, which is usually made by pulverizing mica. It tends to pack when vibrated as in transport. Since the material is loose, supplemental means of support of the inner container is required to avoid displacement in normal and impact conditions. Also, unless some pre-positioned receptacle is provided, the vermiculite must be removed for each packing.

"Firedike"

"Firedike" consists of mineral wool and slag closely bonded together. It is used primarily as an acoustical, fire-resistant ceiling covering for time-temperature-rated construction required by most building codes. For example, a maximum temperature rise of 250°F is allowed for a wood ceiling shielded with 5/8-inch-thick "Firedike" and exposed to a 1-hour fire increasing to 1700°F at the end.[3] Plain "Firedike" board units commonly used for light fixture enclosures have been used in shipping containers by other nuclear facilities.[4] Some irritating mineral dust is produced by handling "Firedike." "Firedike" can be used for higher decay heat loads than "Celotex."

DRUM TESTS

Outer steel drums for the shipping packages were tested for load resistance, penetration, and compression.[1,5,6]

LOAD RESISTANCE (REF. 6, PARA. 3, B.1)

A drum similar to the drum of each of the six shipping packages shown in Figure 1 was tested for load resistance. A drum from the UO_2 package was not tested, but was qualified by analogy to DOT Specification 6M.[1] The end rolling chimes of each drum were simply supported, and lead shot weighing 5 times the fully loaded package was uniformly distributed along the length of the axis. No detectable yielding occurred in any drum.

PENETRATION (REF. 6, ANNEX 1, PARA. 8)

A 13-lb vertical steel cylinder 1-1/4 inches in diameter was dropped from a height of 4 ft onto the most vulnerable surface of each drum. The test was performed with the insulation in place in the drum.

Maximum deflection of 16-gage and 18-gage drums was 1/4 inch. No rupture of the sheeting or damage to insulation occurred.

COMPRESSION (REF. 6, ANNEX 1, PARA. 9)

Each drum received a compressive load of five times the weight of the fully loaded package. The load was applied uniformly against the top and bottom of each drum during a 24-hr period.

Maximum force was in the JP-157S outer container. The JP-1575 drum with insulation in place was loaded on top with 2400 lb of lead. No yielding occurred after 24 hr.

PACKAGE TESTS

To evaluate the performance of possible package designs, twenty different prototype packages were subjected to free drop, puncture, and thermal tests.[1,5,6]

FREE DROP (REF. 6, ANNEX 2, TEST 1)

Each prototype was dropped from a height of 30 ft onto a flat, unyielding horizontal surface. The surface was a 1-inch-thick steel plate weighing ∿870 lb supported by a 6-inch-thick, 20- x 30-ft concrete slab on firm soil. A crane with a quick release device was used to suspend each package.

PUNCTURE (REF. 6, ANNEX 2, TEST 2)

For the puncture test, each package was dropped from a distance of 40 inches onto a 6-inch-diameter steel post 10 inches high and welded to a 1-inch-thick x 1-1/2-ft x 1-1/2-ft steel plate.

THERMAL (REF. 6, ANNEX 2, TEST 3)

Eight prototype packages were heated in a furnace to 1475°F for 30 minutes. A gas-fired heat-treating oven was used for the thermal test. The packages were mounted in the upright position in a frame which was placed upon a large carriage for entry and exit from the oven. Figure 2 shows a typical time-temperature curve for the oven used for thermal tests in this report. The average temperature was maintained at 1475 ±10°F and was determined by 12 thermocouples surrounding the container.

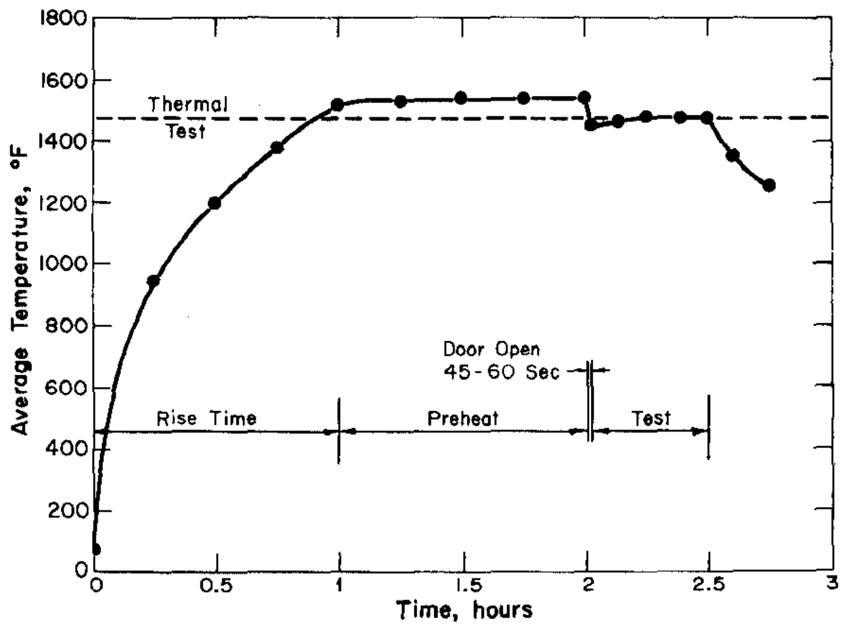


FIGURE 2. Average Furnace Temperature during Thermal Test from 12 Thermocouples Surrounding the Container

RESULTS OF PROTOTYPE TESTS

The results of free drop, puncture, and thermal tests for the twenty prototype packages are summarized in Table III.

TABLE III

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°F 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 1, 2, and 3

Prototypes 1, 2, and 3 were tested to determine the relative capabilities of "Fesco" board, a combination of "Cera Form" and "Cerafelt," and "Celotex." Each drum was made from two separate 55-gal, 18-gage, DOT Specification 17C[1] drums. The body of one drum was used with a 4-5/8-inch-high "top hat" assembled from another drum. The "top hat" assembly consisted of a locking ring curl cut from a drum cover and welded to a cylinder cut from the lower body of a drum. Three JP-100 aluminum inner shipping containers weighing approximately 62 lb each were supported in a three-leaf clover configuration within each drum. Insulation thickness at the top and bottom of each prototype was 4 inches. Minimum insulation thickness at the side of each prototype was

1-1/2 inches. Each drum was clamped with a 12-gage locking ring with 5/8-inch-thick forged lugs. Each 3/8-inch locking bolt was torqued to approximately 20 ft-lb while a soft hammer was used to tap around the ring.

In Prototype 1, the insulation consisted of 1-inch-nominal "Fesco" board glued to form discs approximately 2-1/8 inches thick. Each disc was sawed to fit around the inner shipping containers with 1/4 ±1/16-inch diametral clearance. The diameter of each "Fesco" disc was 5/16 ±1/16 inch less than the inside diameter of the drum. A 16-gage steel sheet was placed between the "Fesco" and top of the inner shipping containers to prevent punching through the insulation during impact of the top.

A 30-ft drop on the top corner of Prototype 1 resulted in metal-to-metal contact between the inner shipping container and the drum creating an unacceptable thermal link. Cumulative compression from a 30-ft drop and a 40-inch puncture test on the side reduced insulation thickness to 1 inch. Results from thermal tests of Prototype 7 (JP-179) showed a probable maximum temperature of 700°F (630°F rise) at 1-inch depth. The maximum allowable internal temperature is 250°F. Crumbling of the "Fesco" during assembly and from tests showed short life expectancy of insulation from normal usage (Figure 3).

In Prototype 2, 1-inch "Cerafelt" sheeting was wrapped around a 16-gage steel inner liner. One "Cera Form" disc, 2-1/2 inches thick, was placed in the bottom of the drum to support the metal liner. Three 5/8-inch-thick discs of "Cera Form" were fitted around the bottom of the liner. Scraps of "Cerafelt" were packed tightly in all cavities. One "Cera Form" disc, 1-1/8 inch thick, was fitted around the liner at the top as shown in Figure 4c. One disc, 2-1/2 inches thick, was placed in the "top hat" of the drum. A 12-gage steel sheet was placed on top of the inner containers to prevent punching a hole in the top insulation disc.

Prototype 2 was dropped 30 ft with the top surface approximately 30° from the horizontal. The impact point deflected approximately 4 inches along the axis of the package (Figure 4a). Buckling of the "top hat" of the drum approximately 30° away from the impact point exposed approximately 3 in.^{2} of insulation. Due to the noncombustible property of the insulation, exposure does not disqualify the package. A 30-ft drop on the side flattened the drum 15/16 inch. A 30-ft drop, flat on the bottom, reduced the drum height 1-1/4 inch. The crimped edge around the bottom of the drum was forced up, and the side of the drum was buckled. A puncture test on the bottom of the prototype gave a 1-1/4-inch indentation, but no rupture of the drum (Figure 4b).

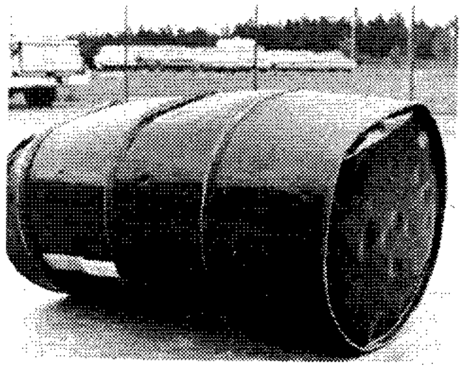
Disassembly of Prototype 2 after the 30-ft drop test showed "Cera Form" broken and out of place and considerable damage to the metal liner and one inner container (Figures 4c and d). Fragility of "Cerafelt" results in unreliable shock and thermal protection. "Cera Form" discs have short life expectancy, even with careful handling.

Prototype 3 (Figure 5) consisted of 2-inch-thick "Celotex" discs sawed to fit around the inner containers with 1/4 ±1/16-inch diametral clearance. The diametral clearance between the discs and inside surface of the drum was 5/16 ±1/16 inch. Solid insulation discs, 2 inches thick, were placed in the top and bottom of the drum.

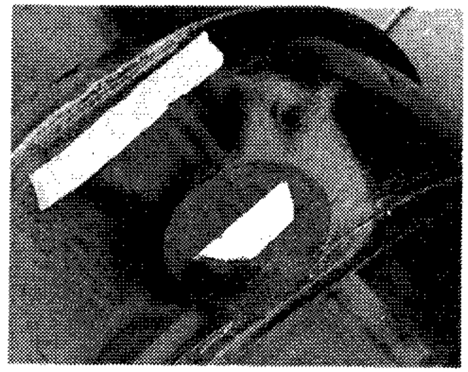
Prototype 3 was dropped 30 ft on its top corner, side, and bottom (Figure 5a and b). The drop on the top corner deflected the drum approximately 3-1/2 inches axially. The side impact flattened the drum 3/4 inch. The bottom impact reduced the height of the drum 1 inch by crushing the bottom crimped edge and buckling the lower chime of the drum. No openings in the drum occurred. Puncture tests were made on the side and bottom with no rupture of the drum.

Inspection of the inner components of Prototype 3 showed 1-inch-thick insulation at the area of impact at the top corner. Slight bending of the inner container adjacent to the impact area occurred. Minimum insulation thickness after side impact was 1-1/4 inch. Indentation from the puncture tests superimposed on the impact area of the 30-ft side drop reduced insulation to one inch thickness (Figure 5d). Jagged cracks approximately 1/4 inch wide occurred at the thinnest insulation. Radiant heat transfer would be excessive through these cracks. The bottom insulation disc was crushed 3/8 inch by the inner containers from impact of the 30-ft drop on the bottom. Arrangement of the insulation discs was orderly, and strength of the material was undiminished, except at the cracks where rupture had occurred.

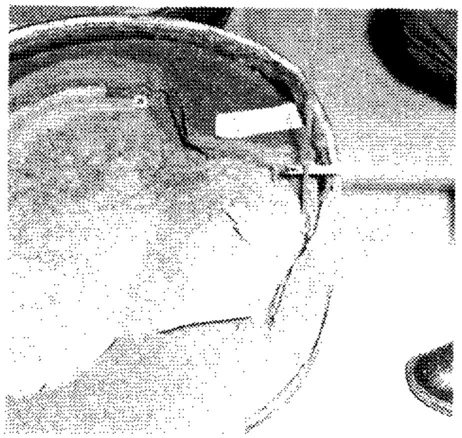
Tests of Prototypes 1, 2, and 3 eliminated a combination of "Cera Form" and "Cerafelt" as insulation. "Fesco" withstood impact but required special containment and a protective liner for a reusable packaging system. "Celotex" was durable enough for reuse and more effectively absorbed shock loads of accident conditions.



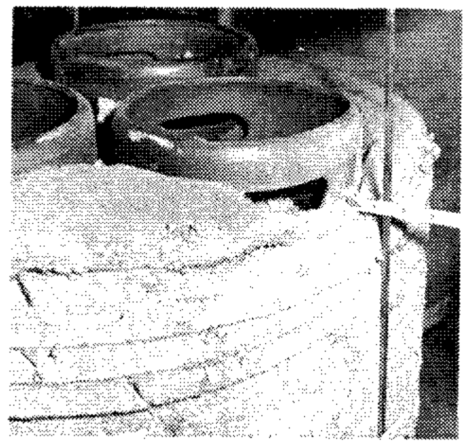
a. Results of 30-ft Drop on Top Corner, Side, and Bottom and Penetration Test on Bottom.



b. Diameter Decreased 2-1/2 inches at Indentation after Puncture Test.



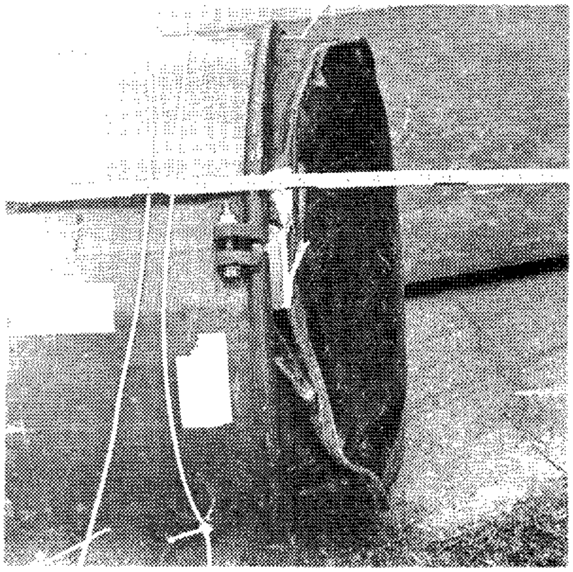
c. Metal-to-Metal Contact between Inner Shipping Container and Steel Drum after Drop and Puncture Tests.



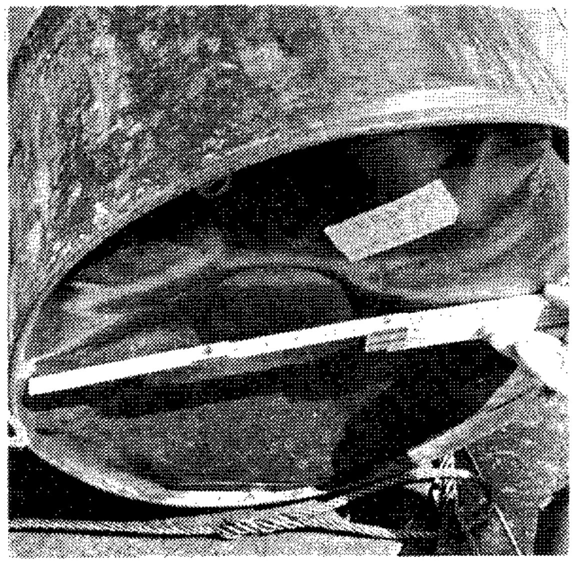
d. Bent Inner Shipping Container and Excessively Thinned Insulation after Drop and Puncture Tests.

FIGURE 3. Prototype 1

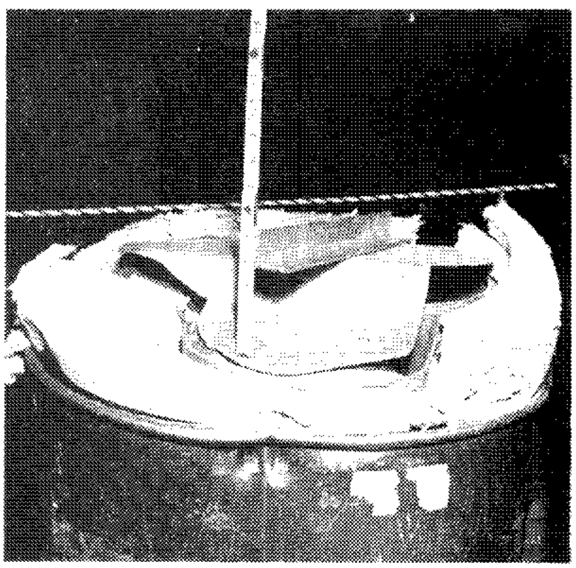
e. Crushed "Fesco" from 30-ft Drop and Puncture Tests on Side. Insulation Thickness Decreased 1-inch at Indentation.



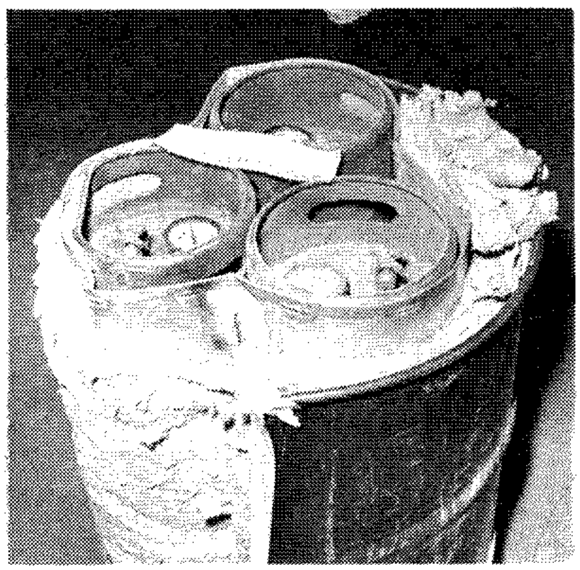
a. After 30-ft Drop on Top Corner.



b. Indentation of 1-1/4 inches after 40-inch Drop on Post.

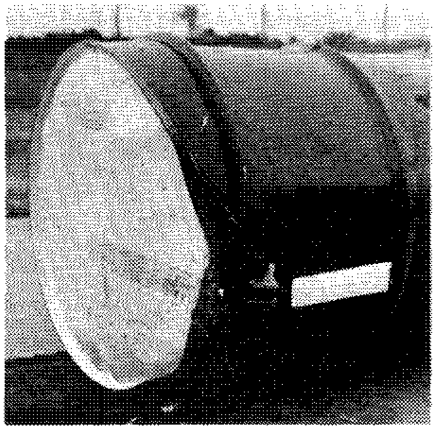


c. "Cera Form" Disk Broken and Disarranged from 30-ft Drop.

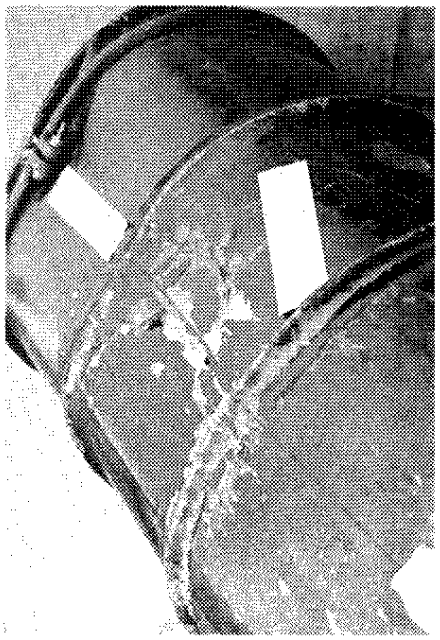


d. Damage to "Cerafelt" and Inner Containers from 30-ft Drops on Side and Top Corner.

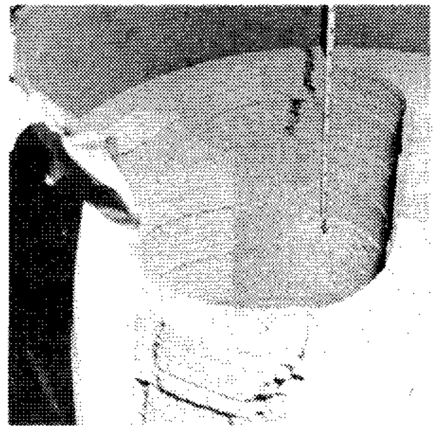
FIGURE 4. Prototype 2



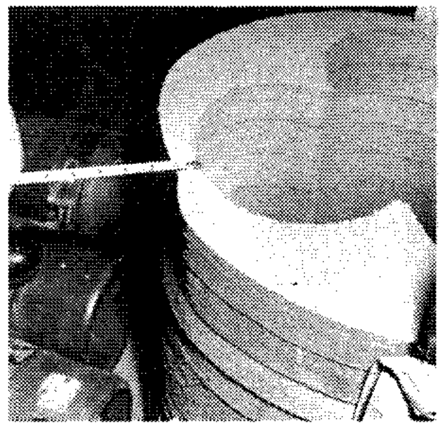
a. Deflection ∿3-1/2 inches after 30-ft Drop on Top Corner.



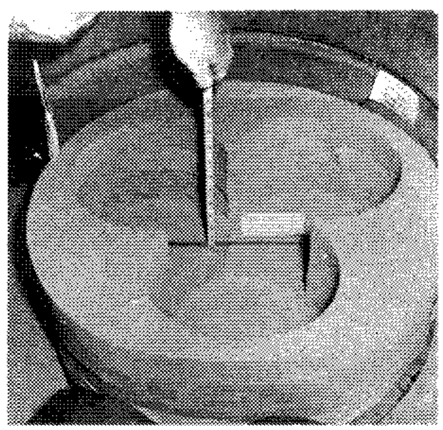
b. After 30-ft Drop and 40-inch Puncture Test on Side.



c. Cracks in "Celotex" Large Enough to Cause Thermal Link from Drop and Puncture Tests.



d. Thinned "Celotex" at Puncture Test Indentation.



e. "Celotex" indented 3/8 in. from 30 foot drop on bottom.

FIGURE 5. Prototype 3

Prototypes 4, 5 and 6

Prototypes 4, 5 and 6 were specifically tested to develop a JP-100 shipping package and to learn more of the structural capabilities of "Celotex."

Prototype 4 comprised an 18-gage DOT Specification 37A[1] drum with an 18-gage, 4-5/8-inch-high "top hat" similar to Prototypes 1-3, and "Celotex" discs surrounding two JP-100 inner shipping containers. DOT Specification 37A[1] requires a curl at the top of the drum with a nominal diameter of 3/8 inch. The drum tested had a curl of 0.34 inch diameter and irregular shape.

Prototype 4 was dropped 30 ft on its top corner with a deformation of approximately 2-1/2 inches axially at the impact point (Figure 6a). At impact the drum cylinder flattened allowing the more rigid "top hat" and locking ring to slip over the curl opposite to the point of impact. Increase of the size of the curl and use of 16-gage metal were proposed to improve performance.

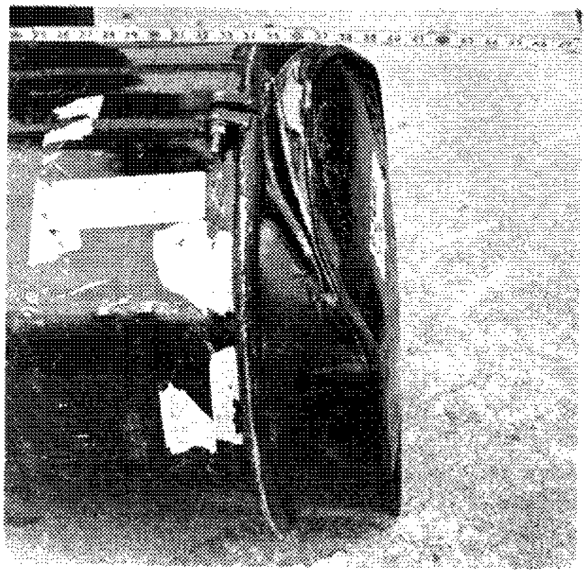
The Prototype was reassembled and dropped 30 ft on its side. The outside diameter was reduced 5/16 inch.

A 30-ft drop on the bottom reduced the overall height 1-1/4 inch on one side and 1/4 inch on the opposite side (Figure 6b). Most deflection occurred in buckling of the lower rolling chime.

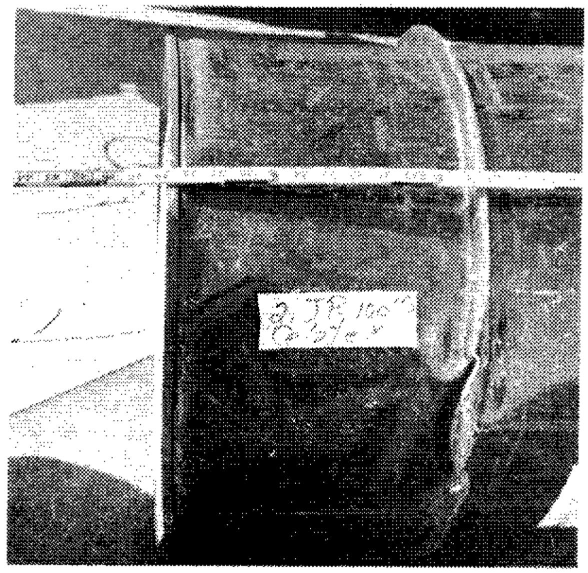
A 40-inch puncture test on the same area as the 30-ft drop on the side depressed the outer container 5/8 inch. The "Celotex" was depressed 3/8 inch, leaving a minimum insulation thickness of 3-3/16 inches (Figure 6d). The inner containers were not damaged. The insulation in the top of the package was indented to depth of approximately 1/2 inch by the inner containers at impact on the top corner.

Prototype 5 was assembled from an 18-gage, 80-gal Military Standard MS63055 drum with "Celotex" discs surrounding three JP-100 inner containers. The 3/8-inch locking bolt was torqued to approximately 20 ft-lb while the locking ring was tapped with a soft hammer.

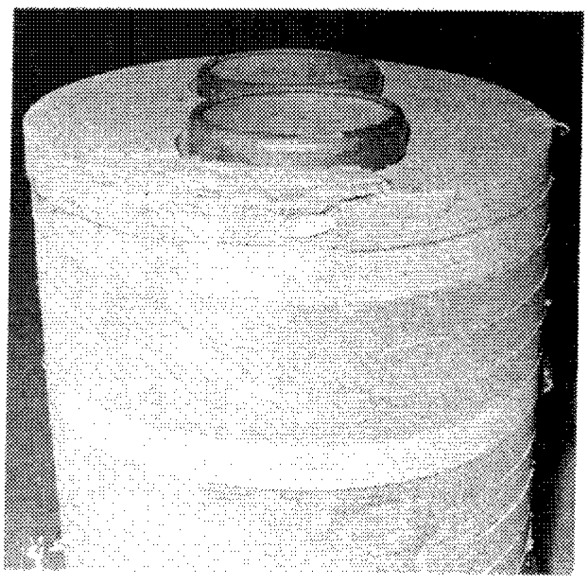
Impact from a 30-ft drop on the top corner exposed insulation opposite the point of impact (Figure 7). As with Prototype 4, flattening of the shell during impact allowed the cover and locking ring to slip over the curl. The curl was straightened at both ends of the opening. The neoprene gasket contributed to the failure by reducing metal-to-metal contact between the cover and body and by acting as a spring that bounced the cover off the body during impact.



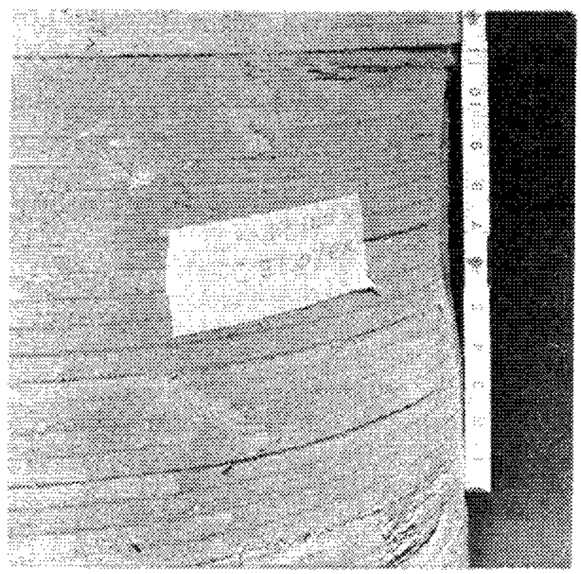
a. After 30-ft Drop on Top Corner.



b. Height Reduced 1-1/4 and 1/4 inches on Opposite Sides After 30-ft Drop on Bottom.

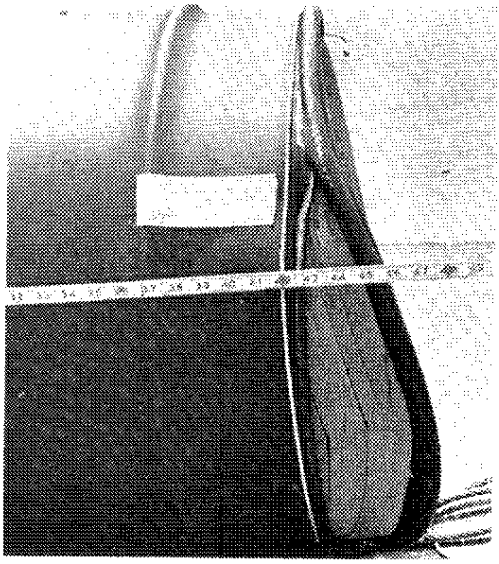


c. No Damage to Inner Containers after 30-ft Drop on Top Corner, Side, and Bottom.

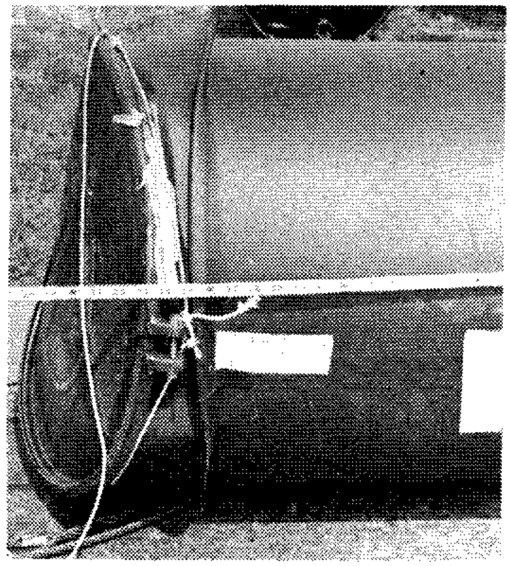


d. Insulation Decreased 3/8-inch from Puncture Test. Cracks are from Side Impact.

FIGURE 6. Prototype 4



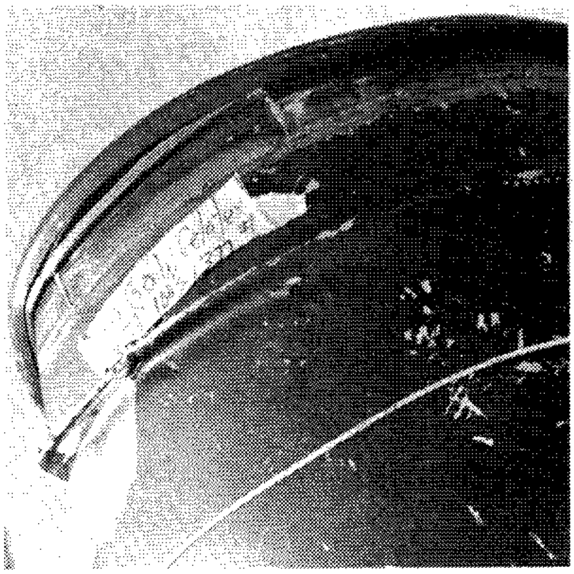
a. After 30-ft Drop on Top Corner. Side of Impact.



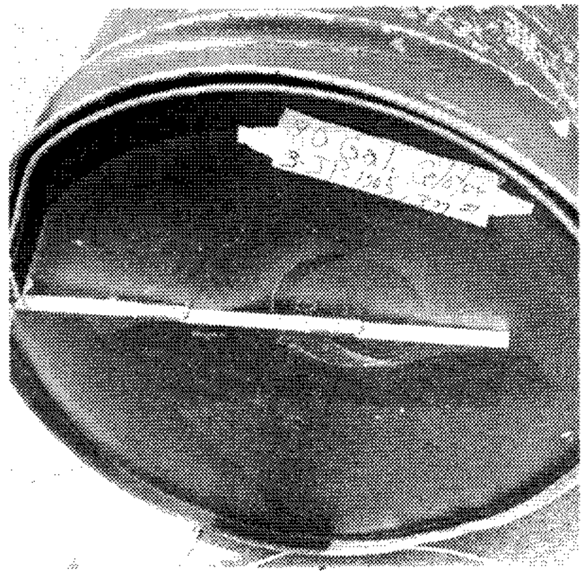
b. Height Reduced 4-3/8 inches at Impact Point After 30-ft Drop on Top Corner.

FIGURE 7. Prototype 5

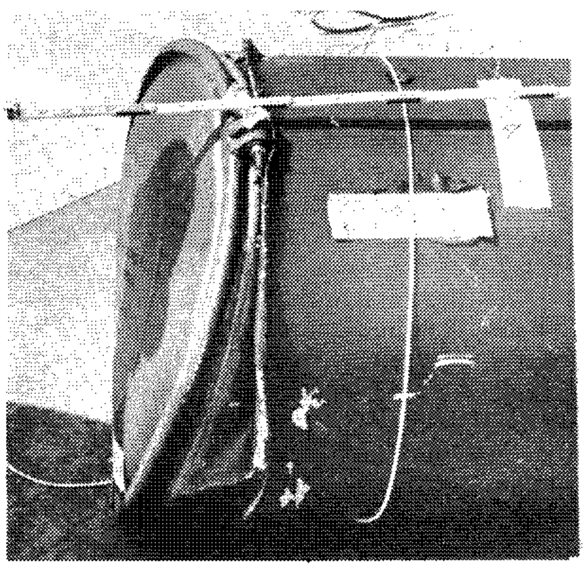
Prototype 6 was assembled from an 18-gage, 80-gal drum similar to Prototype 5 except a 16-gage insert approximately 12 inches x 3 inches was welded into the drum opposite the point of impact. The gasket was removed. A 30-ft drop on the side forced the cover and locking ring off the curl, but no insulation was exposed (Figure 8). The cover was reclosed, and the prototype was dropped on the bottom. Puncture tests were made on the side and bottom. The prototype was dropped on the top corner depressing the corner axially 4-3/4 inches. Inspection of the inside of the prototype revealed slight bending of the inner container top and no cracks in the insulation. It was concluded that a thicker metal (16-gage), 80-gal Military Standard drum with a minimum tightness of 20 ft-lb of the locking ring bolt, no gasket, and closely constrained insulation provides adequate mechanical protection for three JP-100 inner containers.



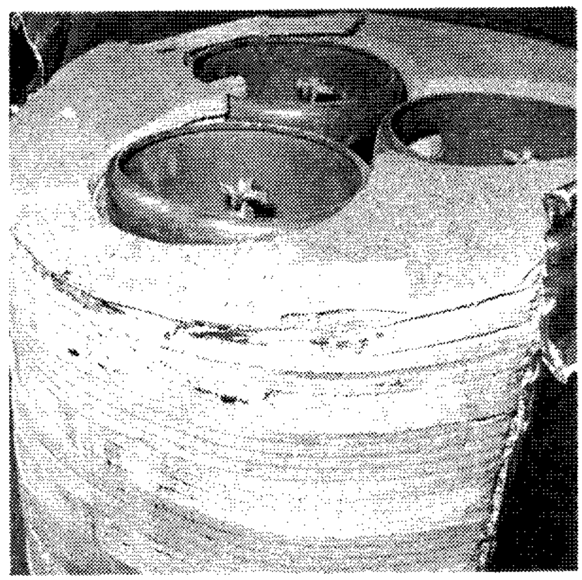
a. After 30-ft Drop on Side. 16-Gage Insert is Welded in Curl and Gasket was Removed.



b. After 30-ft Drop on Bottom and Puncture Test.



c. Height Reduced 4-3/4 inches After 30-ft Drop on Top Corner.



d. Slightly Bent Inner Container Nearest Impact Point after Drop Tests.

FIGURE 8. Prototype 6

Prototypes 7 and 8

Prototypes 7 and 8 were tested to compare the thermal insulation properties of combustible "Celotex" and noncombustible "Fesco." Two 18-gage, 55-gal, DOT Specification 6J[1] drums were tested. Locking rings of 12-gage sheet with 5/8-inch-thick drop-forged locking lugs were used.

Prototype 7 was assembled with 2-inch-thick "Fesco" insulation discs. The JP-179 inner container was surrounded by 4-3/4-inch-thick insulation on the sides and 4-1/2-inch-thick insulation on the ends. Two areas approximately 2 x 3 inches at the closure lugs of the inner container had 1-5/16-inch insulation thickness. Temperature sensing pellets were distributed in the insulation. The gasket was removed. The locking ring was torqued to approximately 20 ft-lb while the ring was tapped with a soft hammer. Prototype 7 weighed 184 lb. Results of tests of Prototype 7 are shown in Figure 9.

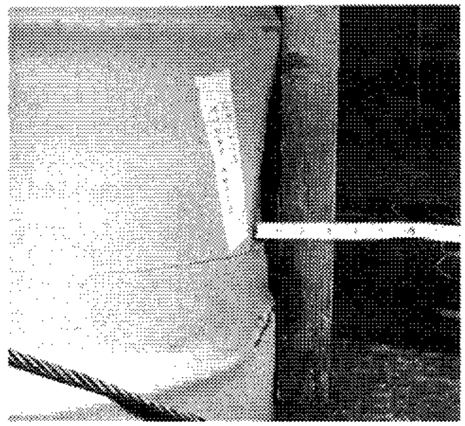
Prototype 8 had the same dimensions as Prototype 7, but "Celotex" was substituted for insulation. Prototype 8 weighed 217 lb. Results of tests of Prototype 8 are shown in Figure 10.

Prototype 7 was dropped 30 ft on its side at the seam in the drum cylinder. The drum was flattened 9/16 inch. The locking ring diameter was reduced 1 inch (Figure 9a). No openings occurred. A puncture test on the same impact area as the 30-ft drop indented the metal drum 5/8 inch (Figure 9b). No rupture of the metal occurred.

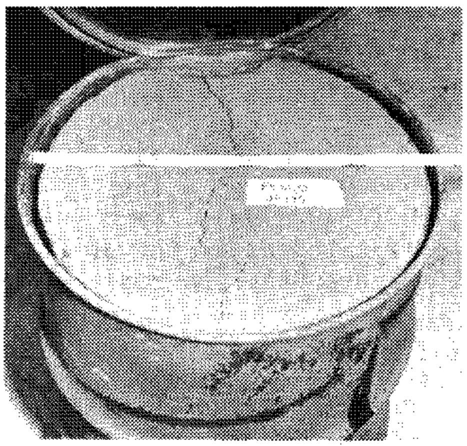
Prototype 8 was dropped 30 ft on its top corner with the seam in the drum cylinder and locking lugs at the impact point. The corner at the point of impact was deformed 2-3/8 inches axially with the drum. The top curl of the drum was straightened on both sides approximately 30° from the point of impact, showing a near release of the cover. Use of 16-gage drums and spot welding the underside of the curl to the drum body are proposed to strengthen the curl. A 30-ft drop on the side crushed the rolling chimes and flattened the body 9/16 inch. A 30-ft drop on the bottom crushed the crimped edge at the bottom and buckled the rolling chimes, as shown in Figure 10a. No openings occurred. The puncture test (Figure 10b) reduced the diameter 1 inch in the area of impact.

Prototype 7 and 8 were heated in a furnace in an upright position at 1475°F for 30 minutes. Four 3/8-inch-diameter vent holes were located in the bottom of each drum. The drums in the furnace showed excessive bulging of the cover due to pressurization of combustible gases. Vent holes were relocated to the cylindrical body to avoid pluggage by the insulation.

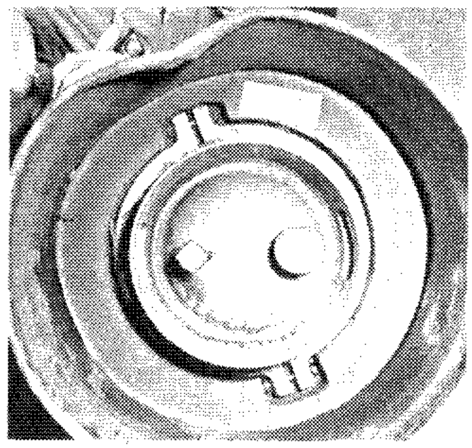
a. Locking Ring Diameter Reduced 1 inch from 30-ft Drop on Side.



b. Diameter Reduced 5/8-inch after Puncture Test.

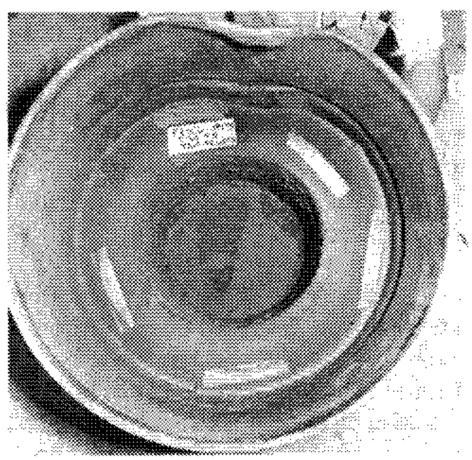


c. Thermal Shrinkage of "Fesco" of 1/4-inch Radially after Thermal Test.



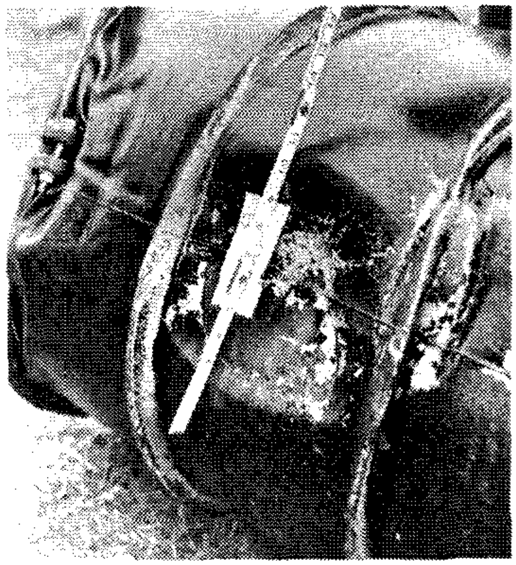
d. "Fesco" Crystallized ~2 inches Deep after Thermal Test.

Figure 9. Prototype 7

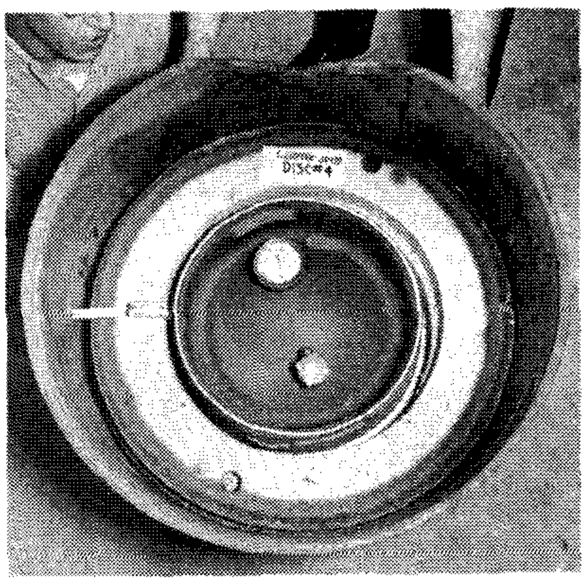


e. Location of Temperature-Sensitive Pellets during Thermal Test.

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



b. Diameter Reduced 1-inch after Puncture Test.



c. ∿5/16-inch of "Celotex" Burned Away from Surface after Thermal Test. Char Depth of 1-3/4 inches from Original Surface.

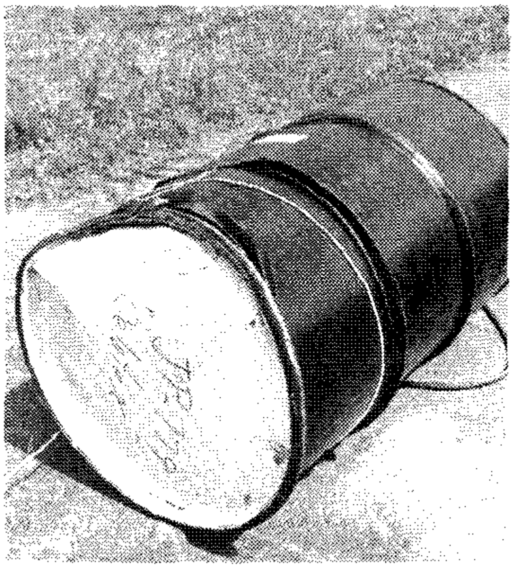
FIGURE 10. Prototype 8

Prototypes 9 and 10

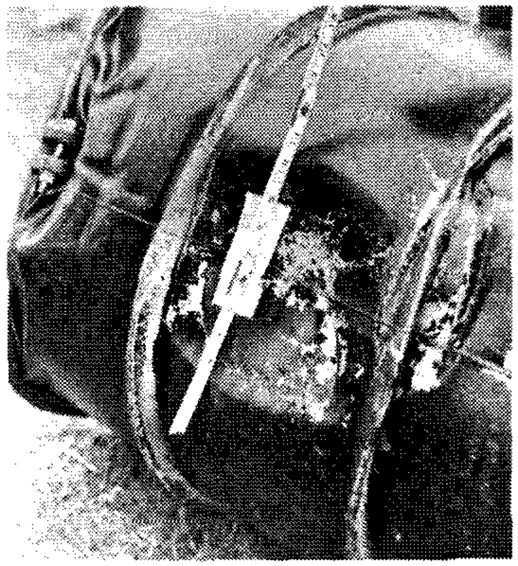
Tests of Prototypes 9 and 10 were preliminary tests to determine the impact properties of thinner "Celotex" insulation in heavier packages, but not to assess the performance of a drum closure. Prototypes 9 and 10 were similar. The LP-50 inner container was excessively long for a 55-gallon drum; therefore, "top hats" were fabricated by welding formed closure rings, cut from drum covers, to lower drum sections. Insulation was 4 inches thick on side, top, and bottom with a small 2-inch-thick area for recess of the inner container valve and a 3-inch-thick area for recess of the inner container flange.

Prototype 9 was dropped 30 ft on its top corner (Figure 11). The closure opened approximately 1/2 inch opposite the point of impact. The welded joint between the "top hat" and the 18-gage closure ring yielded. "Celotex" within the cover was depressed approximately 3/8 inch from impact of the 86-lb inner container. No damage was observed in the lower insulation assembly.

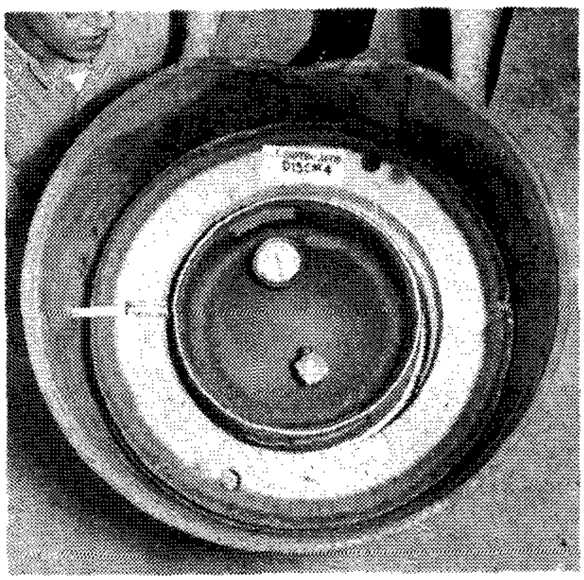
Prototype 10 was dropped 30 ft on its top corner (Figure 12a). The height was reduced 3-1/2 inches at the impact point. A 30-ft drop on the side reduced the outside diameter 1/8 inch. A 30-ft drop on the bottom reduced the height 2-1/2 inches. Most deformation from the bottom drop occurred in the rolling chimes, as shown by Figure 12b. Puncture tests on the side and bottom gave 1/4-inch maximum indentation and no rupture of the drum (Figure 12c and d). The tests of Prototypes 9 and 10 showed adequacy of "Celotex" for the LP-50 package for impact protection. Stronger 16-gage drums elongated without the "top hat" were then evaluated for overall performance as described below.



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



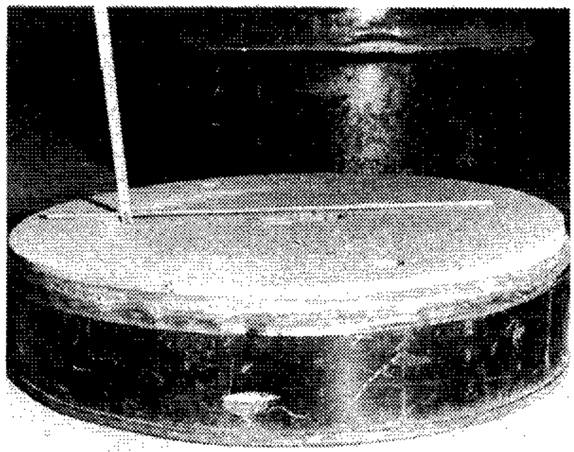
b. Diameter Reduced 1-inch after Puncture Test.



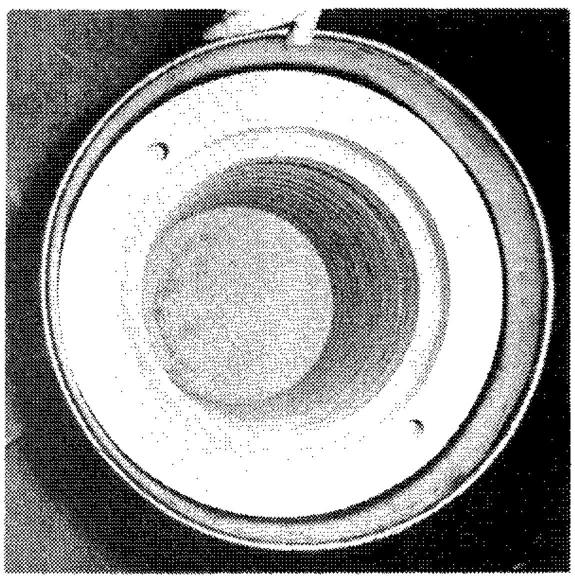
c. ~5/16-inch of "Celotex" Burned Away from Surface after Thermal Test. Char Depth of 1-3/4 inches from Original Surface.

FIGURE 10. Prototype 8

a. Closure Opened 1/2-inch Opposite Impact Point after 30-ft Drop on Top Corner.

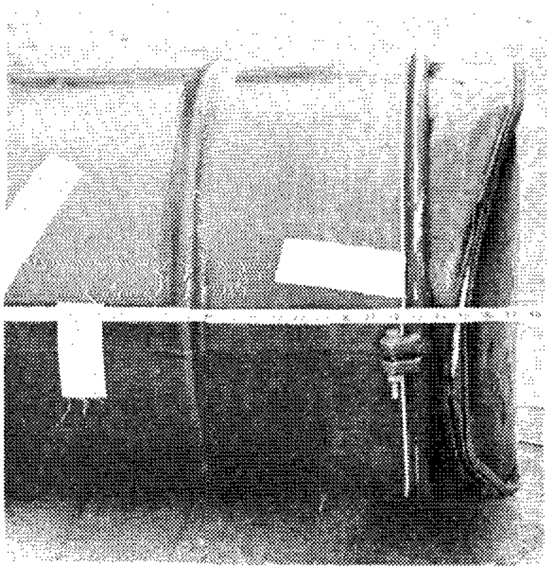


b. "Celotex" Depressed ~3/8-inch by Inner Container at Impact. Closure Ring Yielded.

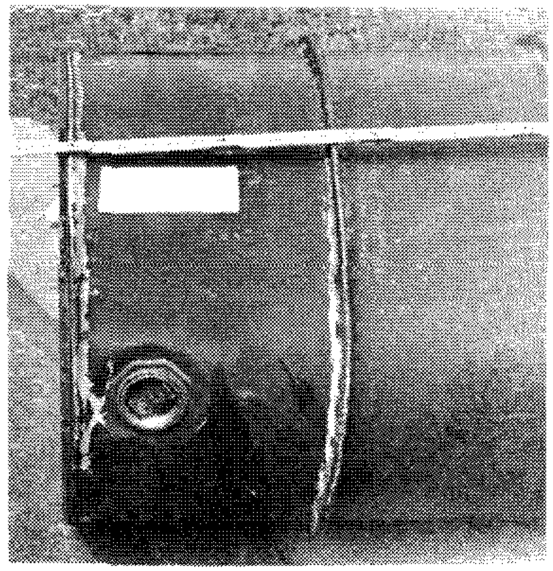


c. Undamaged Lower Insulation Assembly after Drop on Top Corner

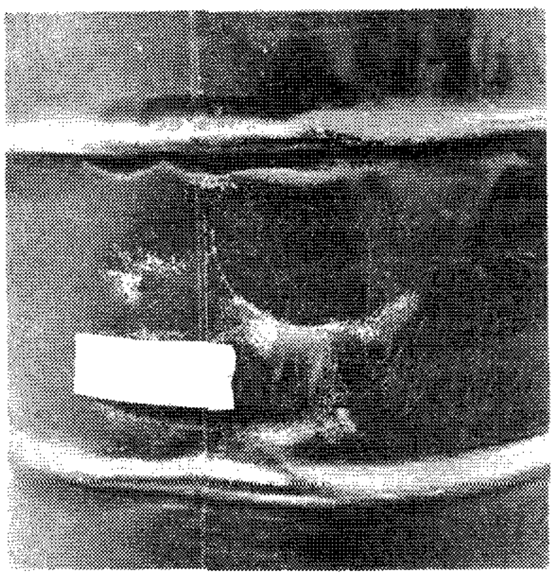
FIGURE 11. Prototype 9



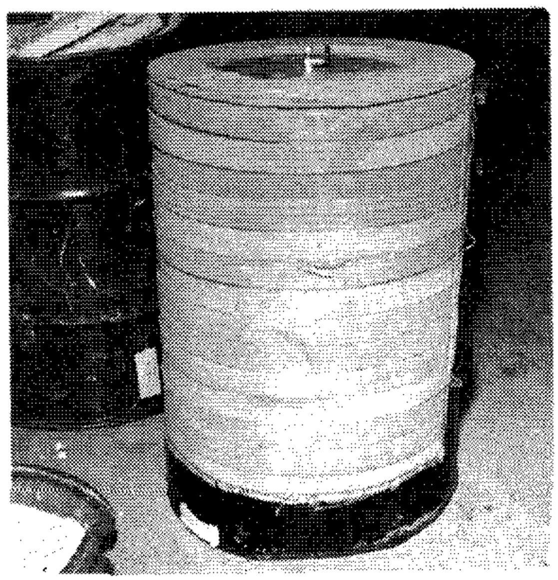
a. Deformed 3-1/2 inches after 30-ft Drop on Top Corner.



b. Height Reduced 2-1/2 inches after 30-ft Drops on Top Corner, Sides, and Bottom.



c. Indented 1/4-inch after Puncture Test. No Metal Rupture.



d. Minor Damage to Insulation after Drop and Puncture Tests.

FIGURE 12. Prototype 10

Prototypes 11, 12, 13, and 14

Prototypes 11 through 14 were tested (Figures 13-16) to demonstrate the adequacy of 16-gage drums and thermal protection by "Celotex." Prototypes 11 and 12 were dimensionally similar to Prototypes 9 and 10 except 16-gage elongated DOT Specification 6J[1] drums were used. Prototypes 13 and 14 were similar to Prototypes 5 and 6 except 16-gage, Military Standard MS63055-3 (80 gal) drums were used. To assure tightness of the closure, the locking ring of each drum was torqued to approximately 20 ft-lb while a soft hammer was used to tap around the circumference. Impact tests of Prototypes 11 through 14 created no detrimental openings in the drums.

Prototype 11 was dropped 30 ft on its side, and then puncture tested on the same impact area with negligible damage (Figure 13a). The diameter was reduced 3/16 inch by the 30-ft impact and indented 1/16 inch by the puncture test.

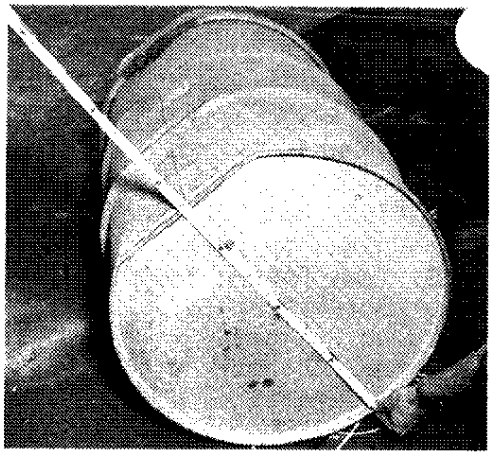
Prototype 12 was dropped 30 ft on its top corner with an approximately 3-inch deformation of the corner, as shown by Figure 14a. A puncture test indented the side 1/16 inch.

Prototype 13 was dropped 30 ft on its side adjacent to one of the three JP-100 inner containers. Rotation during descent allowed most damage to occur in the closure area. A puncture test indented the drum side approximately 5/8 inch.

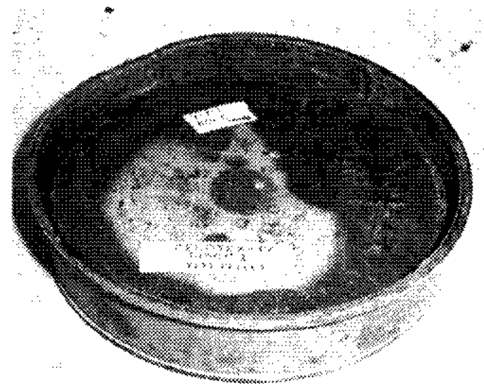
Prototype 14 was dropped 30 ft on its top corner causing approximately 5-1/4 inch deformation of the corner, as shown by Figure 16. A puncture test indented the side 5/8 inch.

Prototypes 11 and 13 were furnace tested at the same time. Each prototype had four 3/8-inch-diameter vent holes in the bottom and four 3/8-inch holes aligned vertically on the side. Three days after the furnace tests, the prototypes were opened and the "Celotex" burst into flame. Figures 13b-e show damage to insulation of Prototype 11; Figure 15 shows the damage to Prototype 13.

Insulation adjacent to the side vent holes was destroyed by combustion of the "Celotex" during the furnace test and by smoldering after the prototypes were removed from the heat. Natural convection through the vertically arranged vent holes sustained the smoldering. Minimum damage occurred to the bottom insulation disc in each prototype because the weight of the insulation and inner containers plugged the vent holes, retarding flow of gases. Temperature-sensitive pellets adjacent to the smolder area indicated the smolder temperature was between 400 to 450°F.

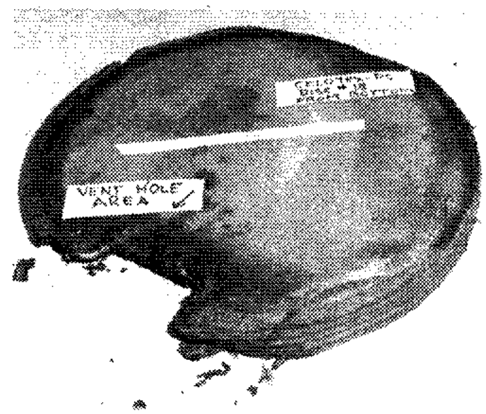


a. Diameter Reduced 3/16-inch after 30-ft Drop on Side.

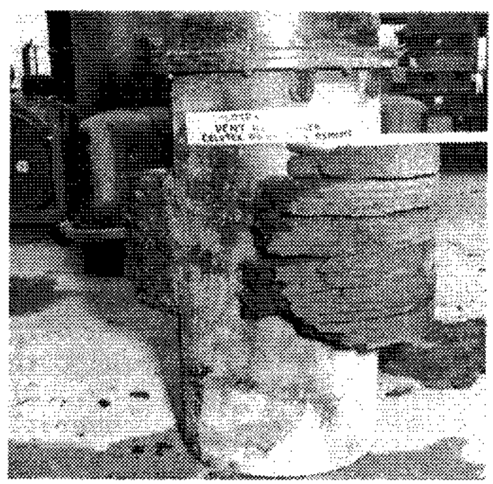


b. Smolder Damage to Upper Insulation Disc after Thermal Test.

c. Insulation Disc Adjacent to Bottom Vent Holes Reduced 1-inch in Thickness after Thermal Test.

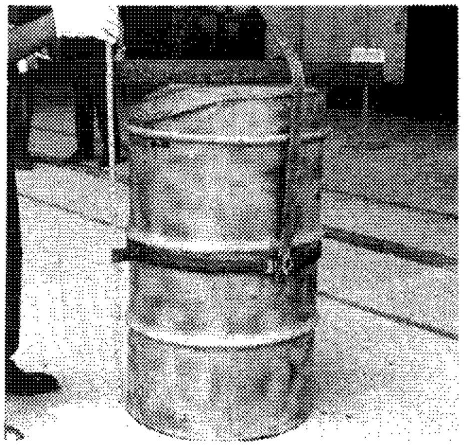


d. Smolder Damage to Second Insulation Disc from Bottom after Thermal Test.

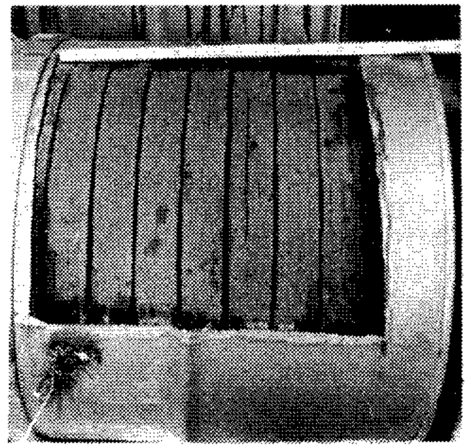


e. Smolder Damage at Midsection after Thermal Test.

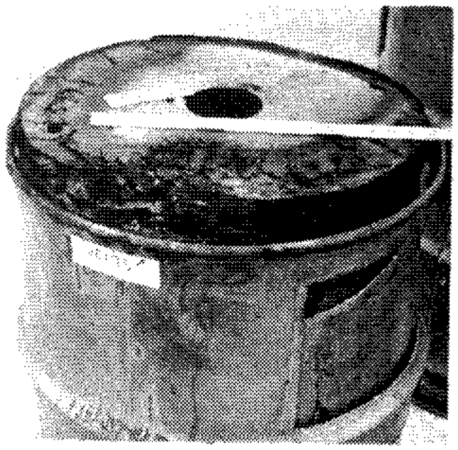
FIGURE 13. Prototype 11



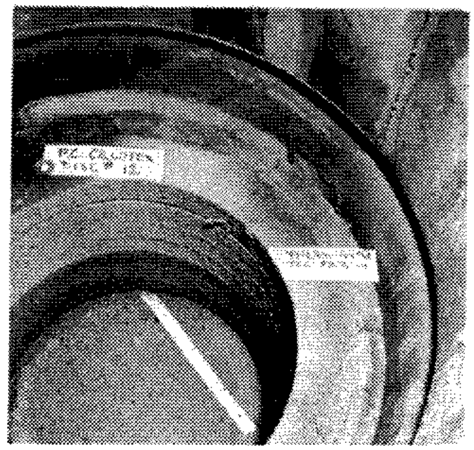
a. 3-inch Deformation after 30-ft Drop on Corner.



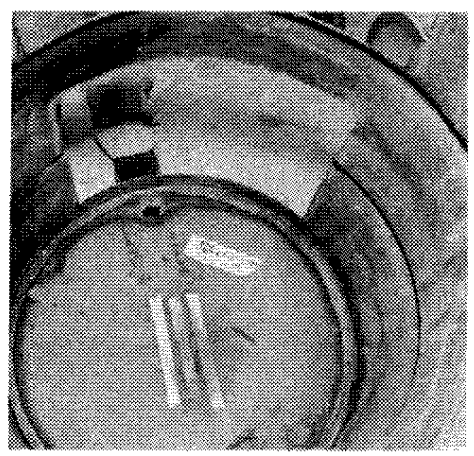
b. Charring at Interfaces of "Celotex" discs after Thermal Test.



c. Burned "Celotex" Adjacent to Vents and Closure Joints after Thermal Test.



d. "Celotex" near Midsection after Thermal Test.

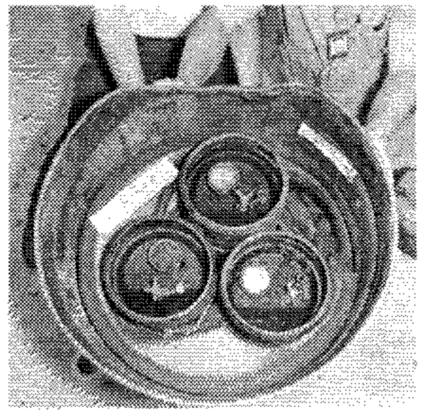


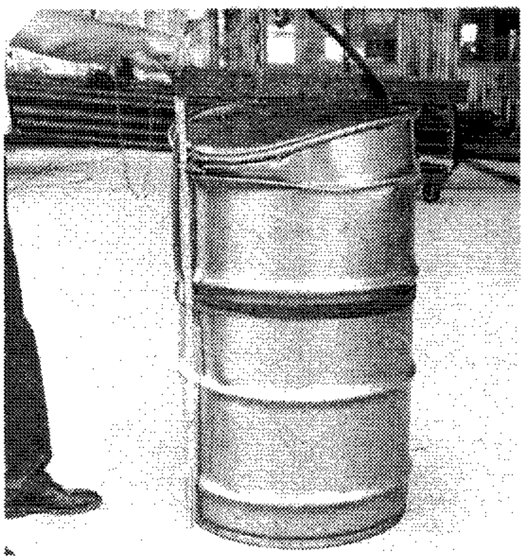
e. Location of Temperature-Sensitive Pellets in Bottom Insulation Disc during Thermal Test.

FIGURE 14. Prototype 12

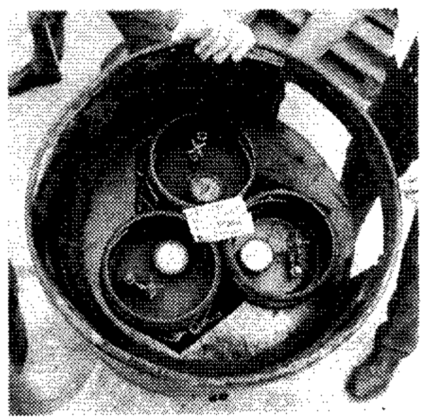
FIGURE 15. Prototype 13

Damage to Insulation Adjacent to Vents from Smolder during Thermal Test





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



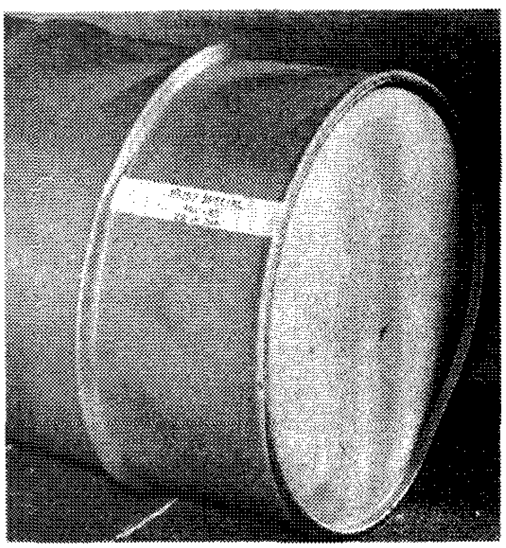
b. Interface Between Top and Bottom Insulation Assemblies after Thermal Test.

FIGURE 16. Prototype 14

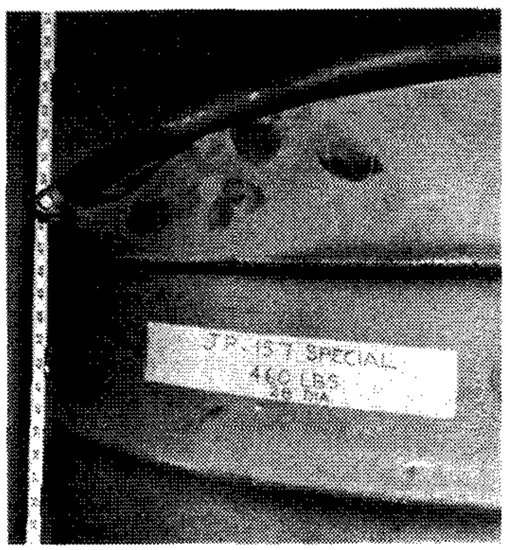
In Prototype 12 and 14, six 3/8-inch-diameter vent holes were located immediately under the locking ring, and discs of "Cerafelt" were placed on top of the "Celotex." Some combustion of "Celotex" adjacent to the vents occurred, but smoldering was prevented. In Prototype 12 where the "Cerafelt" was adjacent to the vent holes, only minor damage to the "Celotex" occurred (Figure 14). Temperatures of inner containers were kept sufficiently lower in Prototypes 12 and 14 to qualify the packages, but greater assurance of prevention of excessive burning and smoldering was required.

Prototype 15

Prototype 15 was tested to demonstrate that heavy, 28-inch-diameter drums are adequate. The package consisted of an enlongated 16-gage Military Standard MS63057 drum with a 140-gal capacity. The cavity for the inner container was 18 inches in diameter giving an insulation thickness of 4-13/16 inch on the side and a thickness of 4 inches on top and bottom. A 30-ft drop on the top corner deformed the corner approximately 5-1/2 inches (Figure 17). A 30-ft drop on the bottom shortened the drum ~2 inches. The deformation occurred in the crimped edge at the bottom and the first rolling chime.



a. 2-inch Deformation after 30-ft Drop on Bottom.



b. 5-1/2-inch Deformation after 30-ft Drop on Corner.

FIGURE 17. Prototype 15

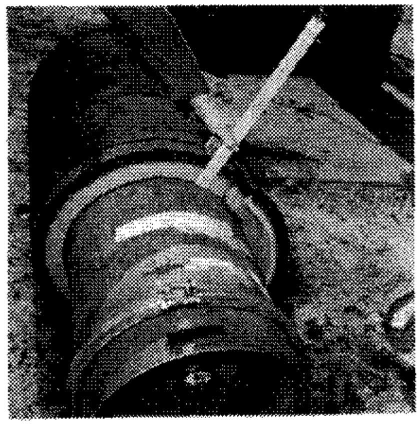
Prototype 16

Size and weight of the JP-157S package, as tested with Prototype 15, were reduced by modifying the V-band of the aluminum inner container to reduce its effective diameter. A 24-inch diameter, 16-gage Military Standard MS63055-3 drum with a 110-gal capacity was used giving a 2-13/16-inch insulation thickness on the side and 4-inch thickness on the top and bottom.

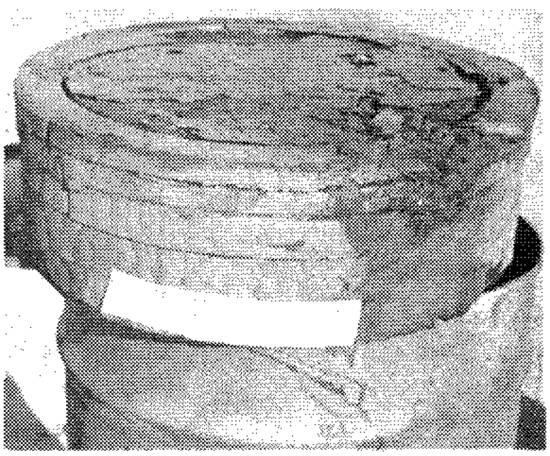
Drops on the side, top corner, and bottom of the JP-157S prototype resulted in negligible damage. A puncture test indented the side approximately 1/4 inch. Four different hold-downs for a 62-lb component, mounted on an aluminum tray within the inner container, were tested in 30-ft drops on the top, bottom, and side of the prototype. Three weaker holddowns failed, and the fourth, and strongest, retained the component in place. Strength analysis showed the holddown would begin to yield from a static force 450 times the component's weight axially or 275 times the component's weight laterally. The calculated static forces required to cause failure are not direct measures of the deceleration of the package because of the dynamic nature of the impact; however, the static force calculation enabled specification of holddowns for other components by analogy, without very complex analysis.

Furnace tests of Prototype 16 shown in Figure 18 resulted in negligible damage. Details of the furnace test are given in the section on thermal properties of "Celotex." A shorter, lighter JP-157 package in an 80-gal drum was designed by analogy to the JP-157S, and no tests were required.

a. "Cerafelt" Blanket in place on left, "Cera Form" Ring, and "Cerakote"-Protected "Celotex" with Blanket Removed on Right.



c. Insulation and Inner Container Removed from Drum.

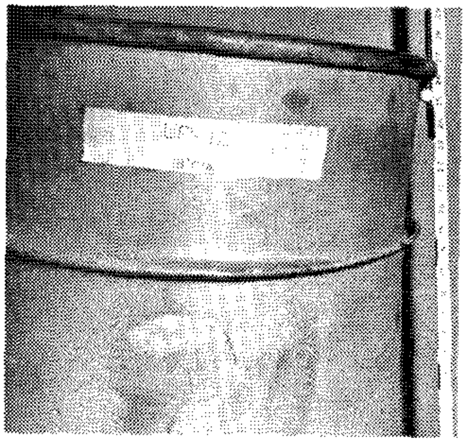


b. Top Insulation Assembly Coated with "Cerakote." Compare with Figure 14.

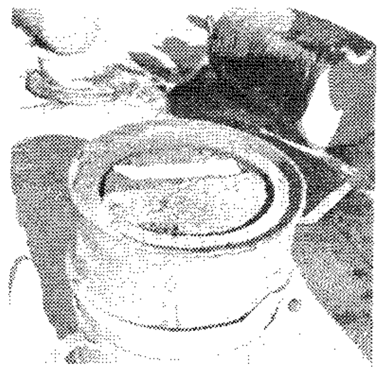
FIGURE 18. Prototype 16

Prototype 17

An LP-12 inner container was placed in a 18-gage, 30-gal Military Standard MS24029-2 drum (Figure 19). Insulation was 4 inches thick on top, bottom, and side. The insulation diameter was approximately 1/16 inch less than the inside diameter of the drum. Approximately 25 lb of force was required to push the bolted insulation assembly into the drum. A 30-ft drop on the top corner reduced the height approximately 1-1/2 inches (Figure 19a). Negligible damage resulted. See page 46 for details of the thermal test.



a. Height Reduced 1-1/2 inches from 30-ft Drop on Corner.



b. After 30-ft Drop and Thermal Tests.

c. After Thermal Test. Top Insulation Assembly Removed.

d. Discs from lower Insulation Assembly After Thermal Test.

FIGURE 19. Prototype 17

Prototypes 18, 19, and 20

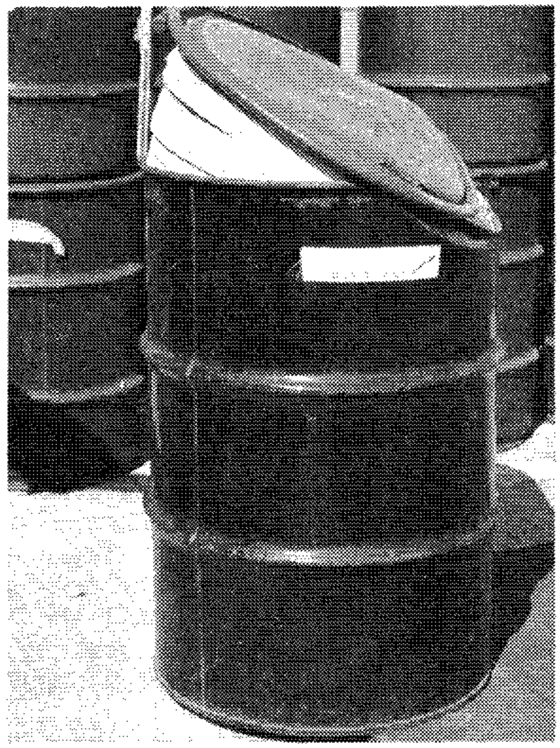
Shipment of uranium oxide requires double containment and lead-shielding, accomplished by inserting a DOT Specification 2R[1] inner container within a 595-lb lead cask 10 inches in diameter and 24-1/2 inches long. Thermal- and impact-protection was provided by an overpack of "Celotex" and a 55 gallon drum. Prototypes 18, 19, and 20 were tested to assure that impact damage would not expose combustible "Celotex" or create a direct heat path to the lead cask.

Prototype 18 consisted of a 16-gage, 55-gal DOT Specification 17C[1] drum, "Celotex" insulation, and a 12-inch-diameter, 671-lb dummy cask. The total weight was 846 lb. Diametral clearance between the insulation and the drum was 5/16 inch giving a nominal insulation thickness of 6 inches on the side. The top and bottom had 4-inch-thick insulation. There was no vertical clearance between the insulation and the drum or the cask. The locking ring was tightened (∿15 ft-lb) until the locking lugs touched. The radial clearance between the locking ring and the drum body was no greater than 1/16 inch all around.

A 30-ft drop on the top corner caused the cover to spring open ∿8 inches opposite the point of impact (Figure 20). This exposed the "Celotex" and created radiant heat paths from the drum between the insulation discs to the cask. The area of impact was crushed ∿2 inches axially with the container and 6 inches radially. The package was disqualified because exposure of the combustible "Celotex" and the radiant heat paths to the cask would cause failure of the thermal test. The estimated maximum weight for which this package would have satisfactorily passed the test is 600 lb.

Prototype 19 was assembled using similar materials to Prototype 18 except a 4-inch-high, shock-absorbing structure of 14-gage steel was welded to the cover. The dummy cask weighed 631 lb. The curl at the top of the drum body was spot welded to the drum body at 2-inch intervals. The locking ring was tightened ∿15 ft-lb until no more threads were available on the locking bolt. This gave approximately 3/32-inch radial clearance between the locking ring and drum body all around.

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



b. After 30-ft Drop on Corner

FIGURE 20. Prototype 18

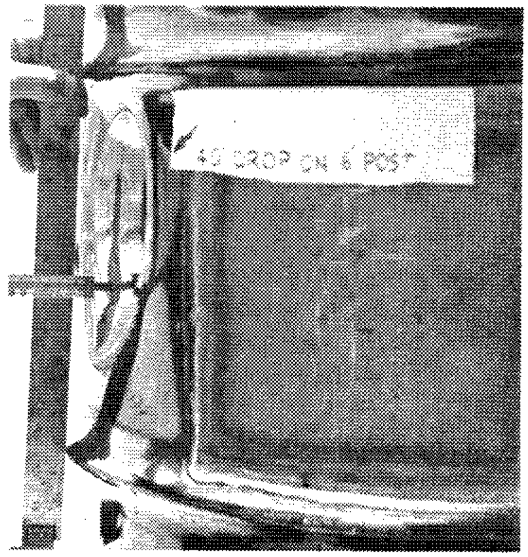
A 30-ft drop on the side flattened the lower body 1/2 inch and did not breach the drum (Figure 21). An impact on the top corner forced the cover away from the drum body ~2 inches opposite the point of impact. A 2-inch opening between top and bottom insulation assemblies allowed a direct heat path to the cask. At impact, flattening of the drum body allowed the more rigid cover to slip off the locking curl of the body. A tight fit between the insulation discs and the drum is needed so that the insulation supports the drum during impact. Recommended maximum allowable diametral clearance between insulation and the drum is 1/4 inch, with a slight interference fit preferred. A puncture test indented the 16-gage drum 5/8 inch with no rupture. Prototype 19 was disqualified.

Prototype 20 was assembled from a 57-gal Military Standard MS63054-5 drum reinforced with 12-gage bolted flanges and a 4-inch-high, shock-absorbing structure welded to the cover. The 677-lb dummy cask was 12-3/8 inches in diameter and 23 inches high. The total weight was 880 lb. Diametral clearances between the cask and insulation and between the insulation and drum were 5/16 inch and 1/4 inch, respectively. Vertical clearance between the cask and insulation was ~1/2 inch. A slight interference existed between the insulation and cover. Maximum radial clearance between the locking ring and drum body was ~3/32 inch. The locking ring bolt was torqued to ~15 ft-lb. Flange bolts were torqued to 8 ft-lb.

A 30-ft drop on the top corner gave a gap approximately 1-1/8 inches high opposite the impact point (Figure 22a, b, and c). Only the incombustible "Cera Form" ring was exposed. Consequently, the result was acceptable. Impact of the bottom corner crushed the corner ~11-1/4 inches axially and 8-7/8 inches radially with no breach of the drum (Figure 22d). Adequate insulation thickness remained at the corner to provide thermal protection.

Figure 1 shows the uranium oxide shipping package developed as a result of tests of Prototypes 18, 19, and 20. The flange diameter was reduced slightly below that of Prototype 20 to increase rigidity, and bolt spacers were specified to tie the flanges together rigidly. Although this package is considered acceptable, the cost could be reduced, and the handling operations would be simplified by using a closure with a skirt that fits down around the body to strengthen the closure in impact.

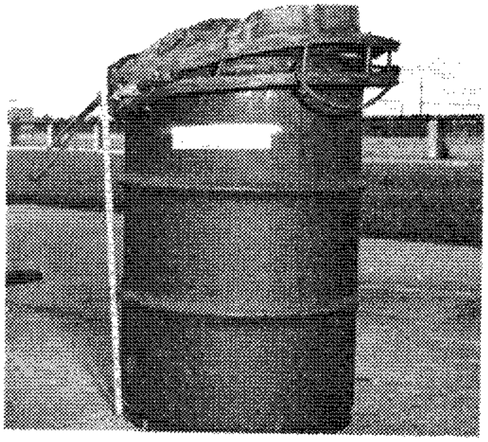
a. After 30-ft Drops on Top Corner and Side and Puncture Test.



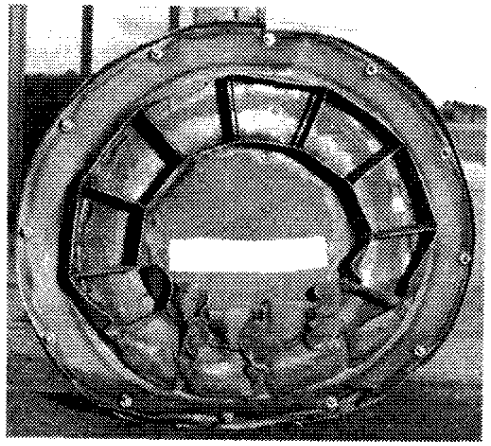
b. 5/8-inch Indentation after Puncture Test.

c. Displacement of Insulation Assembly after 30-ft Drop on Corner. Gap Between Top and Bottom Insulation Assemblies not Shown.

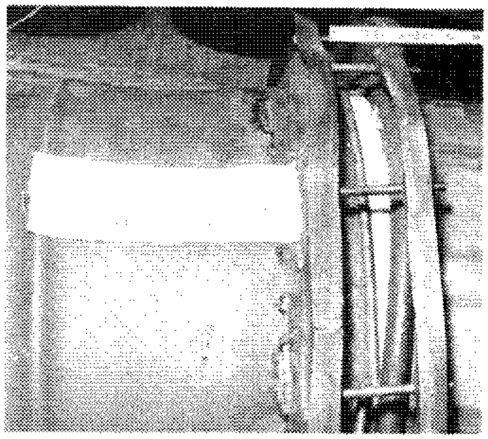
FIGURE 21. Prototype 19



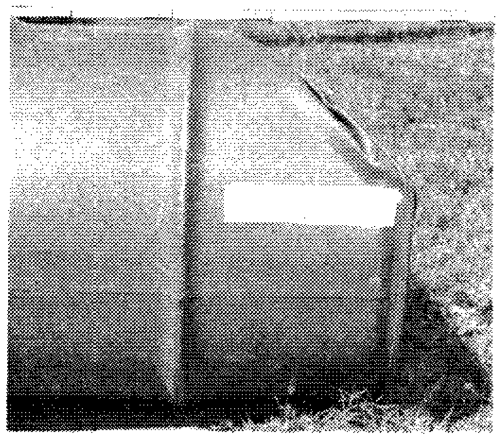
a. 1-1/8 inch Gap from Deformation of Flanges after 30-ft Drop on Top Corner.



b. Damage to Shock Absorbing Structure after 30-ft Drop on Top Corner.

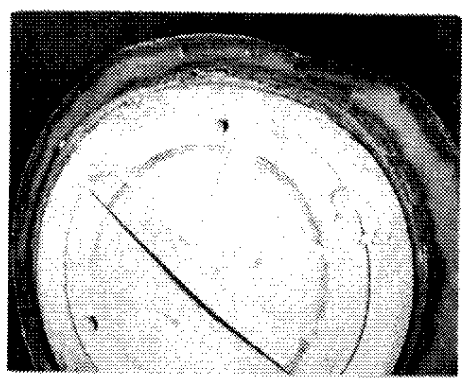


c. Exposed "Cera Form" from Deformation of Flanges after 30-ft Drop on Top Corner.



d. Deformation of 11-1/4 inches axially and 8-7/8 inches Radially after 30-ft Drop on Bottom Corner.

FIGURE 22. Prototype 20



e. Damage to "Cera Form" Ring and Flange after 30-ft Drop on Top Corner.

THERMAL PROPERTIES OF "CELOTEX"

MAXIMUM NORMAL TEMPERATURE

The quantity of radioactive materials that generates decay heat must be limited with "Celotex." Elevated temperatures for prolonged periods of time degrade "Celotex" structurally. Consequently, effectiveness of the insulation during impact and fire conditions would be reduced.

Samples of "Celotex" were exposed to 200, 250, and 350°F for 14 days. Thermal shrinkage and distortion from compressive loads were determined for each sample. The compressive stresses varied from 0 to 86 $lb/in.^2$ The range of stress was chosen based upon 86$lb/in.^2$ static stress supporting the heaviest inner container and an estimated factor of 10 for inertial forces, which probably would be experienced in a short drop on a loading dock. The stress-strain relation for each sample is almost linear for the stress range studied. The thermal effects are shown in Figure 23. A threshold exists at ∿285°F, above which significant breakdown of "Celotex" occurs. An analogous threshold effect exists for wood.[7] For a safety margin, the maximum normal temperature limit for "Celotex" and wood is 250°F.

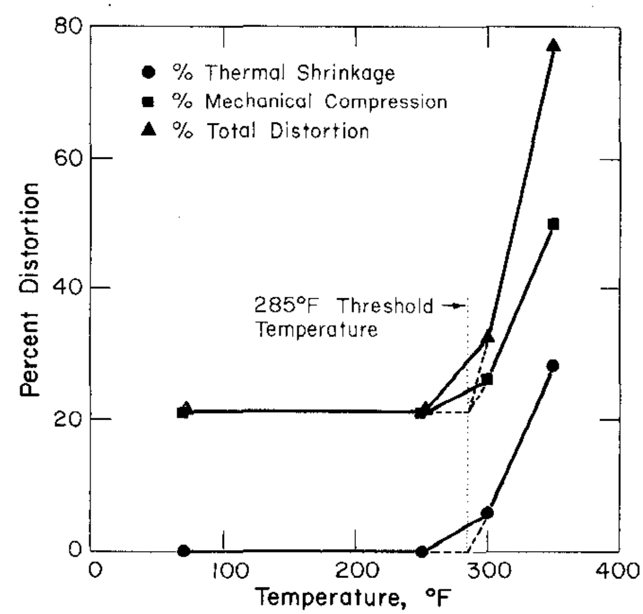


FIGURE 23. Distortion of "Celotex" Exposed to Elevated Temperature and Compressed to 86 psi

Figure A-2 in the Appendix shows calculated inner container surface temperature (inner surface temperature of the "Celotex") for a 55-gal package with varying decay heat dissipation. Ambient conditions are still air at 130°F in the sun. Maximum insulation temperatures for insulation thicknesses of 2, 6, and 8-1/2 inches in the side and 4 inches in the top and bottom are given as functions of radioactive decay heat in Figure A-2. The quantity of radioactive material in the package should be limited to maintain the insulation temperature below 250°F in normal transport.

The data shown in Figure A-2 is calculated using an insolation factor of 309 Btu/hr-ft^2 on a projected area through the diagonal of the drum. The insolation factor is derived using a solar constant of 442 Btu/hr-ft^2, a relative air mass of 1 and a transmissivity of 0.7. No diurnal variation is assumed; thus, the results are conservative. A surface absorptivity of 0.94 is assumed. A five-node mathematical model is used. The nodes consist of 1) the sunny side including the drum, air gaps, and insulation; 2) the sunny top; 3) the shaded side; 4) the shaded bottom; and 5) the inner container.

EFFECT OF "CERAKOTE"

Samples of "Celotex" exposed to 400°F began to smolder very slowly beginning at the corners and rough surfaces. At 425°F samples burst into flame and burned rapidly. All samples were exposed to 50-75% humidity for four days before the tests. Increasing the air supply by leaving the oven door open decreased ignition time but had no effect on ignition temperature. Ignition time was greater for larger samples. A coating of "Cerakote" delayed ignition but did not affect ignition temperature. Figure 19b shows protection from "Cerakote" on half of the top insulation assembly of the LP-12 package after a furnace test. Approximately 1/4 inch of "Celotex" burned away on the surface not protected by "Cerakote." "Cerakote" seems to prevent smoldering if the drum is breached. "Cerakote" also stabilizes irritating dust and larger particles of cane fiber gradually released from the "Celotex" surface. Based on the above advantages, "Cerakote" was used as a coating for the insulation assemblies of all shipping packages.

EFFECT OF VENTING

"Celotex" is mostly cellulose. Consequently, when the material is heated to high temperatures, combustible gases evolve, and the outer surface burns if oxygen is present. Figure 24 shows the violent evolution of burning gases from two containers during a thermal test. Abnormal bulging of drums of Prototypes 7 and 8 warned of impending rupture when four 3/8-inch-diameter vent holes in the bottom of the drums were plugged with insulation.

FIGURE 24. Violent Evolution of Combustible Gases from Vent Areas of "Celotex" - and "Fesco" - Insulated Packages

In other tests,* drums burst and "Celotex" burned as a consequence of overpressurization. All drums after tests of Prototypes 7 and 8 were vented in the cylindrical body of the drum, and no gaskets were used. (Gaskets are deleted primarily for impact protection). Vertical alignment of vent holes on the drum body caused smoldering after removal from heat as discussed in the following section. Equally spaced vent holes located immediately under the locking ring prevented smoldering and assured at least one unplugged hole regardless of orientation in the fire.

A vent area of 0.005-in.^{2} per linear inch of closure joint was assumed. Approximately 0.005-in.^{2} vent area per lb of "Celotex" (0.08 in.^{2}/ft^3 of "Celotex") was successful. To reduce entry of moisture into the drum, each vent hole was covered with 0.010-inch-thick lead tape on both sides.

SMOLDERING

"Celotex" smoldered when vent holes were aligned vertically on the sides of Prototypes 11 and 13 (see Figures 13 and 15). Natural convection through the vent holes sustained smoldering in the adjacent "Celotex" after the package was removed from heat. To prevent convection in Prototypes 12 and 14, vents were located immediately under the locking ring. These prototypes passed the thermal test, but damage (Figure 14) shows that better assurance for preventing smoldering is needed. A 2-inch-square ring of "Cera Form" was inserted in the "Celotex" adjacent to the vents of Prototypes 16 and 17. The two prototypes subsequently passed thermal tests in considerably better condition. Figure 19b shows the LP-12 prototype with the "Cera Form" in place after a furnace test.

As an added improvement for heavier packages, a blanket of "Cerafelt" is specified under the drum cover on top of the "Celotex." "Cerafelt" is stable up to 2300°F and may prevent burning or smoldering of the "Celotex" even if the closure is breached, assuming no "Celotex" is exposed. Equally important, the blanket serves as a spacer to assure that the insulation is tightly constrained to avoid breaching the closure. Several 1/2-inch thicknesses may be used if required. The right side of Figure 18a

* R. D. Madding and R. E. Vallee, Monsanto Research Corp., Miamisburg, Ohio, unpublished results (1969).

shows the improved condition of the "Celotex" after a furnace test with the "Cerafelt" blanket and "Cerakote". The blanket is shown in place on the left side of the figure. Comparison of Figures 18a and b and 14c shows the improved condition of the "Celotex" due to the "Cerafelt" blanket.

CHARRING

"Celotex" chars an average of 1-3/4 inches deep during the 1475°F, 30-min furnace test (Figures 18c and 19d). Areas unprotected by refractory insulation and adjacent to vents may char to a greater depth, as shown by Figure 14. Figure 25 shows the maximum temperature distribution within the insulation.

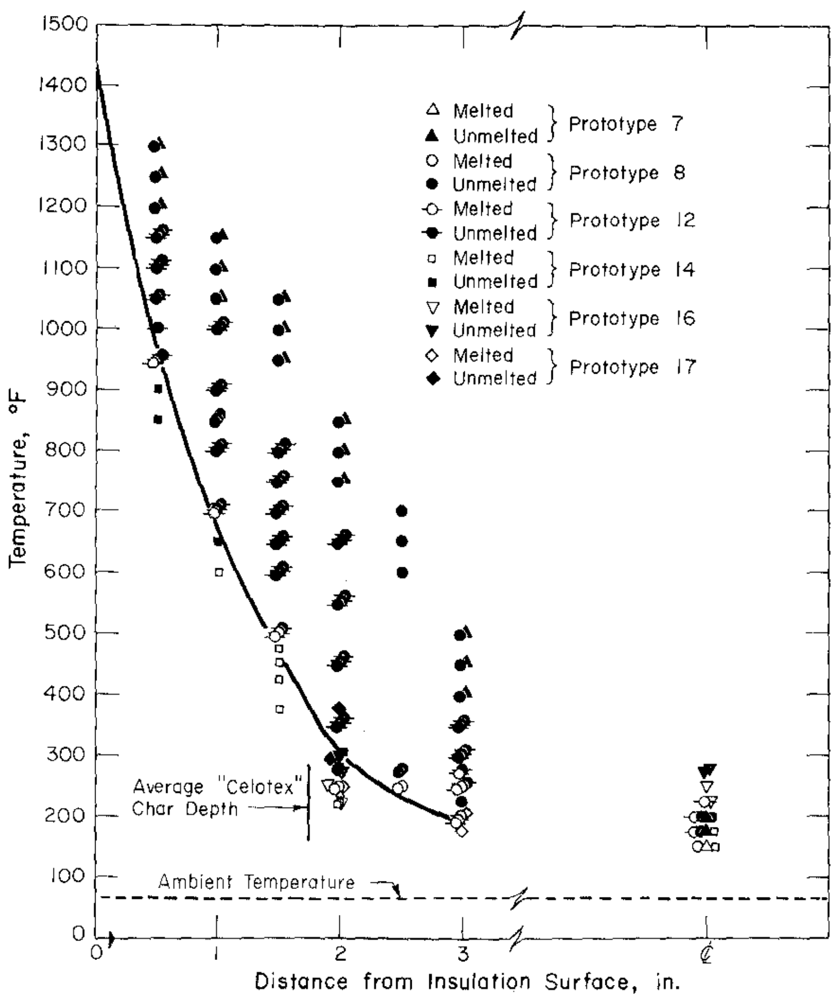


FIGURE 25. Maximum Temperature in Container During Thermal Test Determined by Temperature-Sensitive Pellets

CONCLUSIONS

Type B shipping packages insulated with "Celotex" require certain design features and handling techniques to meet regulations.[1,5,6] 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 of radioactive materials within the shipping package must be limited to limit the maximum temperature of "Celotex" insulation to less than 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. These specifications are based on experience at the Savannah River Plant during the series of hypothetical accident condition tests as prescribed by the regulations.[1,5,6] Although all package configurations 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.

APPENDIX

GENERAL SPECIFICATIONS FOR DRUM AND BOARD-TYPE INSULATION OVERPACKS OF TYPE B SHIPPING PACKAGES

Rated Capacity. Rated capacity should be not less than 12 gal nor more than 140 gal for the outer container.

General Construction Requirements. General construction requirements are:

a) Outside drum should conform to Military Standard MS27683 or equivalent with a locking curl 0.450 inch or greater diameter (Figure A-1). Drum wall may be either a single sheet of steel or may be produced by welding together two appropriate lengths of drums. Welding must be continuous seam welding. Packages must comply with the dimensions given in Table A-1.

b) Vents should be arranged either as

   1) Three 5/16-inch-diameter holes drilled 1 inch below top of body approximately 120° apart, or

   2) Three 5/16-inch-diameter holes drilled in the cover and three in the bottom of the drum equally spaced and 2 inches from the circumference.

c) Each vent hole should be covered on both sides with lead tape of minimum thickness of 0.010 inch. Bonding must be resistant to sun and water. Plastic plugs with a water sealant may be substituted for lead tape.

d) No gasket should be used on the drum closure.

e) Locking rings should be 12-gage minimum thickness with forged steel locking lugs, similar to DOT Specification 17C,[1] drilled with good alignment for 3/8-inch locking bolt. Lugs should be drilled 1/8-inch diameter for seal wire parallel to and 3/8 inch above bolt holes. Length of locking ring should allow 1/2-inch-minimum to 3/4-inch-maximum end separation when torqued to 20 ft-lb on drum without gasket.

f) Locking bolt and nut should be 3/8-16 UNC hex zinc or cadmium plated. Bolts should be 4 inches long with threads a minimum of 2-3/4 inches long. ASTM A325[2] material or equal with hardness 23-35 RC must be used. A washer 7/16 inch i.d. x 1 inch o.d. should be used on each end of the bolt. Self-locking nuts or jam nuts are recommended.

g) Shipper should assure that locking bolt is torqued to 20 ft-lb, while a soft hammer is used to vibrate the locking ring to release circumferential friction forces between the locking ring and curl.

h) Shipper should provide a tamperproof lockwire and seal.

i) A package heavier than the maximum given in the Table A-1, but not more than 900 lb, is acceptable provided it is equipped with a reinforced closure as used with Prototype 20 or other test-proven modification, and provided the insulation thickness is not less than 6 inches on the side and 4 inches on ends for "Celotex," or 7 and 5 inches, respectively, for "Fesco" or "Firedike."

j) Diametral clearance between the insulation and drum and between the insulation and the inner containment vessel should not exceed 1/4 inch. There should be no voids that would allow disarrangement of insulation discs at impact.

k) The discs of insulating materials should be at least 1/2 inch thick and as follows:

   1) "Celotex" or equivalent industrial cane fiberboard, as described in Military Specification Mil-F-26862A except Para 3.7.

   2) "Fesco" or equivalent perlite granules bound with a mineral binder and fibers (10.5 lb/ft^3 density minimum).

   3) "Firedike" or equivalent mineral wool and slag in sheet form as used for lighting recesses in time-temperature rated ceilings as tested in Reference 3.

l) Venting of the outer container is accomplished as follows:

   1) If either "Fesco" or "Firedike" is used, any vent arrangement described in Para.(b) is permitted. Adequate thickness of a felted refractory insulation blanket is required under the cover to assure a tight fit.

2) If "Celotex" is used, vents in the side as in Para. (b)(1) require a ring of noncombustible porous refractory material having a cross section not less than 2 inches in either dimension, positioned under the drum cover with 1/4-inch maximum diametral clearance to the drum. A blanket of at least 1/2-inch thickness of felted refractory insulation must be placed under the cover to give a tight fit and provide added thermal protection. Vents in the top and bottom as in Para. (b)(2) require at least 1/2-inch-thick blanket on top and bottom for tightness and added thermal protection.

m) When "Celotex" is used, the quantity of material being shipped must be limited in decay heat to allow a maximum normal insulation temperature not exceeding 250°F. Figure A-2 may be used to determine the maximum decay heat for a 55-gal container.

TABLE A-1

Dimensions for Type B, Insulated Shipping Packages

Capacity, gal	Inside Diameter, inches	Inside Height, inches	Maximum Gross Weight, lb[c]	Minimum Thickness of Uncoated Metal, gage[c]	Minimum Thickness[b,c] of Insulation, inches: Side	Ends
12[a]	13.81	19.69	100	20	2.5	2.5
19[a]	15.38	23.88	150	18	2.5	2.5
30[a]	18.25	26.99	200	18	2.0	2.5
57[a]	22.50	33.33	600	16	6.0	4.0
61	22.50	35.77	275	16	4.0	4.0
61	22.50	35.77	600	16	6.0	4.0
60	24.00	30.74	350	16	3.0	4.0
80[a]	24.00	41.12	400	16	3.0	4.0
80	24.00	41.12	500	16	5.0	4.0
110	24.00	52.50	425	16	3.0	4.0
110	24.00	52.50	550	16	5.0	4.0
79[a]	26.00	34.43	425	16	3.0	4.0
79[a]	26.00	34.43	500	16	5.0	4.0
95	26.00	41.12	425	16	3.0	4.0
95	26.00	41.12	500	16	5.0	4.0
80[a]	28.00	29.98	400	16	3.0	4.0
80[a]	28.00	29.98	500	16	5.0	4.0
140	28.00	52.50	400	16	3.0	4.0
140	28.00	52.50	500	16	5.0	4.0

a. Most commonly used and economical sizes.

b. Insulation thickness is based upon "Celotex." 1-inch greater thickness is required for "Fesco" or "Firedike."

c. Criteria for choice of maximum gross weight, minimum thickness of metal, and minimum thickness of insulation are based on results of drop tests. A minimum of 2 inches of insulation is required to prevent >230°F temperature rise in regulatory hypothetical thermal accident conditions.

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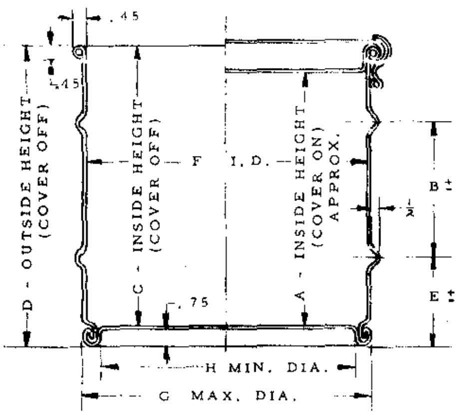


BODY

DRUM ASSY NO.	CAPACITY GALLONS	BODY	COVER STYLE 1	COVER STYLE 2	BODY AND BOTTOM DIMENSIONS								WT
					A	B	C	D	E	F	G	H	
MS-27683-1	16	MS-27683-30	MS-27683-60	MS-27683-90	19.88	12.38	20.44	21.24	4.0	15.38	15.13	14.58	24.5
MS-27683-2	19	MS-27683-31	MS-27683-60	MS-27683-90	23.88	16.36	24.44	25.24	4.0	15.38	15.13	14.58	27.
MS-27683-3	20	MS-27683-32	MS-27683-61	MS-27683-91	18.11	11.00	18.58	19.48	4.25	18.25	18.00	17.45	25.
MS-27683-4	22	MS-27683-33	MS-27683-62		12.89	N.A.	13.46	14.26	N.A.	22.50	22.25	21.70	
MS-27683-5	27	MS-27683-34	MS-27683-62		16.11	11.00	16.68	17.48	3.28	22.50	22.25	21.70	
MS-27683-6	29	MS-27683-35	MS-27683-66		9.46	3.50	10.04	10.84	3.50	30.0	29.75	29.20	
MS-27683-7	30	MS-27683-36	MS-27683-61	MS-27683-91	26.99	11.00	27.56	28.36	8.68	18.25	18.00	17.45	33.
MS-27683-8	30	MS-27683-37	MS-27683-63		15.49	6.44	16.06	16.86	4.88	24.0	23.75	23.20	
MS-27683-9	30	MS-27683-38	MS-27683-65		11.18	4.50	11.75	12.55	3.50	28.0	27.75	27.20	
MS-27683-10	34	MS-27683-39	MS-27683-64		14.73	6.50	15.30	16.10	4.88	26.0	25.75	25.20	
MS-27683-11	38	MS-27683-40	MS-27683-62		22.24	11.00	22.81	23.61	6.34	22.50	22.25	21.70	
MS-27683-12	39	MS-27683-41	MS-27683-66		12.68	4.50	13.25	14.05	4.88	30.00	29.75	29.20	
MS-27683-13	45	MS-27683-42	MS-27683-62		26.11	11.00	26.68	27.48	8.28	22.50	22.25	21.70	
MS-27683-14	57	MS-27683-43	MS-27683-62		33.33	11.00	33.90	34.70	11.87	22.50	22.25	21.70	
MS-27683-15	58	MS-27683-44	MS-27683-66		19.03	11.00	19.60	20.40	4.88	30.00	29.75	29.20	
MS-27683-16	59	MS-27683-45	MS-27683-64		25.68	17.00	26.25	27.05	4.88	26.00	25.75	25.20	
MS-27683-17	60	MS-27683-46	MS-27683-63		30.74	21.68	31.31	32.11	4.88	24.00	23.75	23.20	
MS-27683-18	60	MS-27683-47	MS-27683-65		22.43	15.50	23.00	23.80	4.88	28.00	27.75	27.20	
MS-27683-19	61	MS-27683-48	MS-27683-62		35.77	11.00	36.34	37.14	13.28	22.50	22.25	21.70	
MS-27683-20	77	MS-27683-49	MS-27683-66		25.33	17.00	25.90	26.70	4.88	30.00	29.75	29.20	
MS-27683-21	79	MS-27683-50	MS-27683-64		34.43	24.00	35.00	35.80	4.88	26.00	25.75	25.20	
MS-27683-22	80	MS-27683-51	MS-27683-65		29.98	19.00	30.55	31.35	4.88	28.00	27.75	27.20	
MS-27683-23	80	MS-27683-52	MS-27683-63		41.12	32.00	41.69	42.49	4.88	24.00	23.75	23.20	

MATERIAL: Steel; Specification QQ-S-698 Body and Bottom 18 Gage (Min.)

FINISH AND MARKING: In accordance with Procurement Specification

DIMENSIONS IN INCHES: Unless otherwise specified, tolerance on heights plus or minus .12 other dimensions plus or minus .03, angles plus or minus 2°.

NOTE: When humidity indicators and handles are specified, the drum assembly numbers will reflect this addition by a suffix dash and letter as follows:

Examples: MS-27683-4-I = Assy's with Indicator
MS-27683-4-H = Assy's with Handles
MS-27683-4-IH = Assy's with Indicator & Handles

For indicator and handle location see procurement specification

Review: 69, WC, WP Project No. 8110-0153
User: MO, MU, 11, GL, CG, SH, MC

This standard has been approved by the Department of the ... and is mandatory for use by that activity. All other military activities are required to employ this standard where suitable.

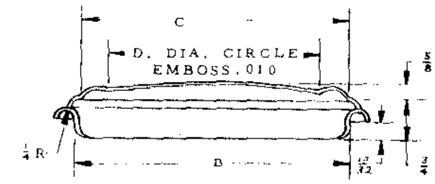
APPROVED, 14 MAR 69 REVISED

P.A. Air Force - 69 Other Cust Navy - AS Army - GL Air Force - 69	TITLE DRUMS, METAL-SHIPPING AND STORAGE 16 to 80 GALLONS	MILITARY STANDARD MS27683
PROCUREMENT SPECIFICATION MIL-D-6054	SUPERSEDES: MS 24209, MS 63053 thru MS 63058	SHEET 1 OF 3

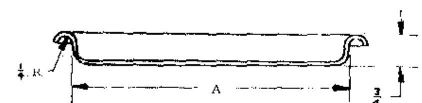
DD FORM 1 SEP 61 672-1 EDITION OF 1 SEP 57 MAY BE USED.

FIGURE A-1. Specifications for Military Standard Drums

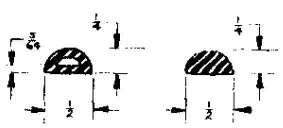
FED. SUP CLASS



ALT. COVER (STYLE 2)



COVER (STYLE 1)



GASKET
MS 27683
-90 THRU -96

ALT. GASKET
MS 27683
-100 THRU -106

COVER STYLE I	CAPACITY GALLONS	A	COVER STYLE 2	CAPACITY GALLONS	B	C	D	GASKET	ALT. GASKET
MS27683-60	16 and 19	15.33	MS27683-90	16 and 19	15.32	14.46	12.00	MS27683-90	MS27683-100
MS27683-61	20 and 30	18.20	MS27683-91	20 and 30	18.19	17.33	15.00	MS27683-91	MS27683-101
MS27683-62	22, 27, 38, 45, 57 and 61	22.45	N.A.					MS27683-92	MS27683-102
MS27683-63	30, 60 and 80	23.95	N.A.					MS27683-93	MS27683-103
MS27683-64	34, 59 and 79	25.95	N.A.					MS27683-94	MS27683-104
MS27683-65	30, 60 and 80	27.95	N.A.					MS27683-95	MS27683-105
MS27683-66	29, 39, 58 and 77	29.95	N.A.					MS27683-96	MS27683-106

MATERIAL: Steel; Specification QQ-S-698 COVER: #18 Gage (min.)

FINISH AND MARKING: In accordance with Procurement Specification

DIMENSIONS IN INCHES: Unless otherwise specified, tolerance on heights plus or minus .12, other dimensions plus or minus .03, angles plus or minus 2°.

APPROVED 14 MAR 69 REVISED

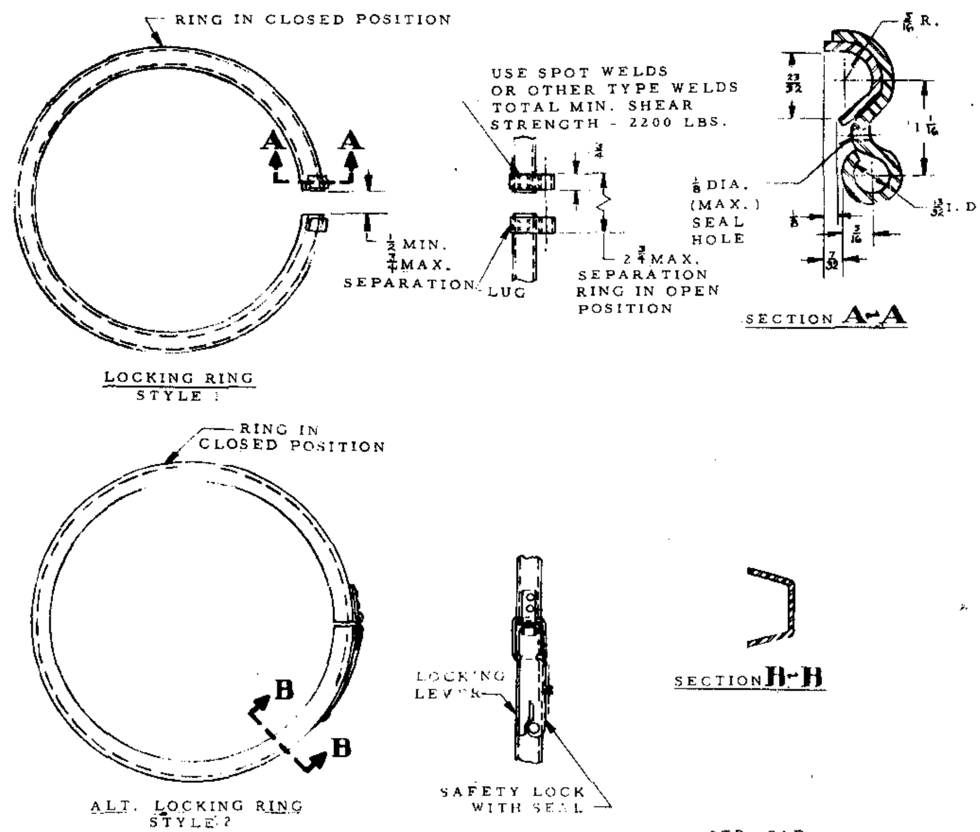
P.A. Other Cust	TITLE DRUMS, METAL-SHIPPING AND STORAGE 16 to 80 GALLONS	MILITARY STANDARD MS27683
PROCUREMENT SPECIFICATION MIL-D-6054	SUPERSEDES: MS 24209, MS 63053 thru MS 63058	SHEET 2 OF 3

DD FORM 1 SEP 63 672-1

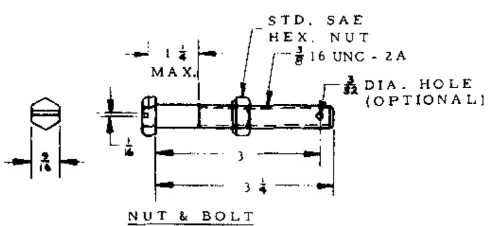
EDITION OF 1 SEP 57 MAY BE USED.

Figure A-1 (Continued)

FED. SUP CLASS



CAPACITY GAL.	STYLE 1 LOCKING RING	STYLE 2 LOCKING RING
16 and 19	MS-27683-80	MS-27683-70
20 and 30	MS-27683-81	MS-27683-71
22, 27, 58, 45 57 and 61	MS-27683-82	MS-27683-72
30, 60 and 80	MS-27683-83	MS-27683-73
34, 59 and 79	MS-27683-84	MS-27683-74
30, 60 and 80	MS-27683-85	MS-27683-75
29, 39, 58 and 77	MS-27683-86	MS-27683-76



MATERIAL: Steel; Specification QQ-S-698

LUG AND LOCKING RING: #12 Gage

FINISH AND MARKING: In accordance with Procurement Specification

APPROVED 14 MAR 69

REVISED

This standard has been approved by the Department of the and is mandatory for use by that activity. All other military activities are requested to employ this standard where suitable.

P.A. Other Cust	TITLE DRUMS, METAL-SHIPPING AND STORAGE 16 to 80 GALLONS	MILITARY STANDARD MS27683
PROCUREMENT SPECIFICATION MIL-D-6054	SUPERSEDES: MS 24209, MS 63053 thru MS 63058	SHEET 3 OF 3

DD FORM 1 SEP 63 672-1

EDITION OF 1 SEP 57 MAY BE USED.

U. S. GOVERNMENT PRINTING OFFICE

Figure A-1 (Continued)

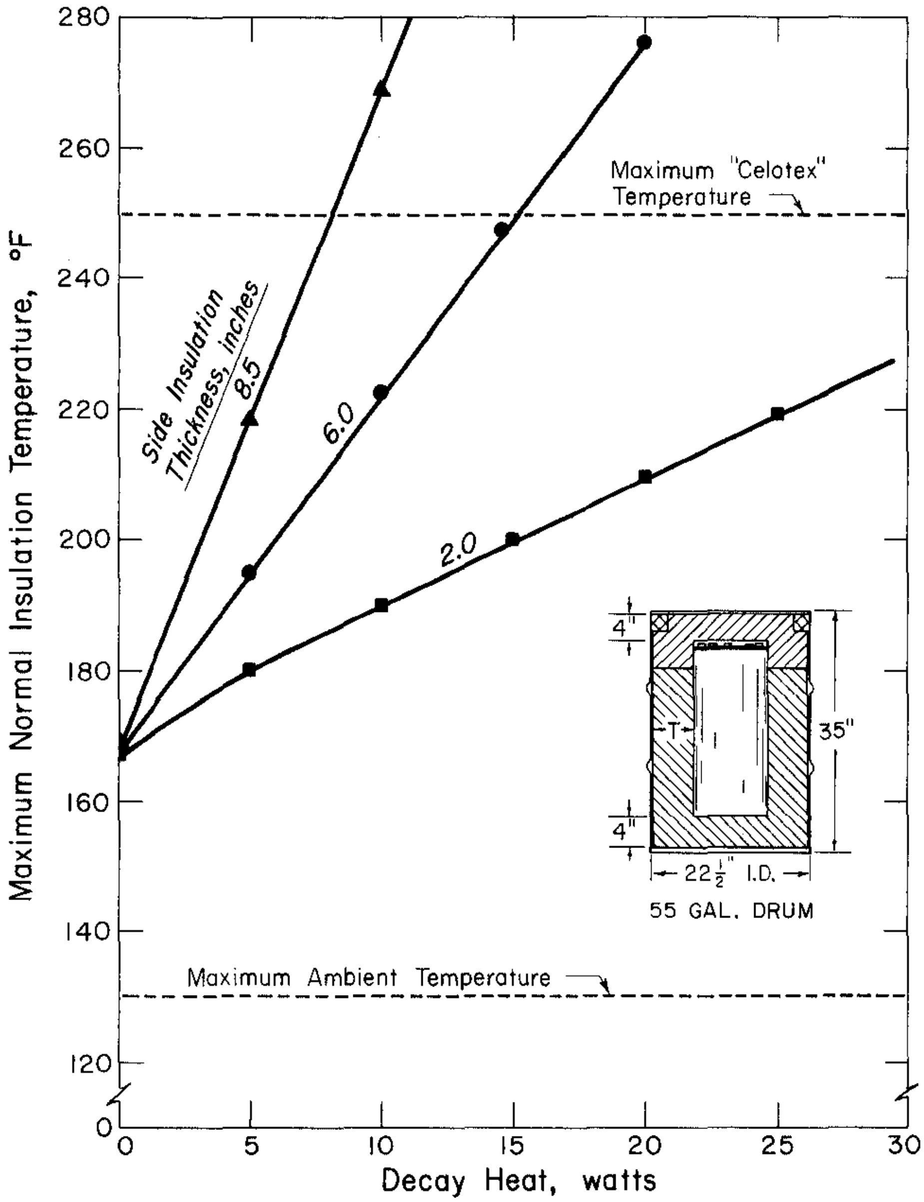


Figure A-2. Maximum Normal Insulation Temperature as a Function of Radioactive Decay Heat Dissipation for a 55-gal Drum in the Sun with Different Side Insulation Thicknesses.

REFERENCES

1. *Regulations for Transportation of Explosives and Other Dangerous Articles.* 49 CFR, Parts 171-178 (1972).

2. "High-Strength Bolts for Structural Steel Joints, Including Suitable Nuts and Plain Hardened Washers." ASTM A-325, *1971 Annual Book of ASTM Standards*, Part 4, page 337, American Society for Testing Materials, Easton, MD. (1971).

3. "Fire Tests of Building Construction and Materials." ASTM E119-71, *1971 Annual Book of ASTM Standards*, Part 14, page 436, American Society for Testing Materials, Easton, MD. (1971).

4. R. D. Madding and R. E. Vallee. *Testing of Disposable Containers for Radioactive Waste.* USAEC Report MLM-1660, Monsanto Research Corp., Miamisburg, Ohio (1970).

5. *Regulations for the Safe Transport of Radioactive Materials.* IAEA Safety Series No 6, International Atomic Energy Agency, Vienna (1967).

6. "Safety Standards for the Packing of Radioactive and Fissile Materials," Chapter 0529 in *U. S. Atomic Energy Commission Manual.* (1969).

7. *Ignition and Charring Temperatures of Wood.* USDA Report No. 1464, Forest Service, U. S. Department of Agriculture, Washington, D. C. (1958).

TL:jc