

SANDIA REPORT

SAND88-3005 • TIC-0879 UC-71

Unlimited Release

Printed December 1988

A Review of the Safety Features of 6M Packagings for DOE Programs

US Department of Energy

Prepared by

Sandia National Laboratories

Albuquerque, New Mexico 87165 and Livermore, California 94550

for the United States Department of Energy

under Contract DE-AC04-76DP00789

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield VA 22161

N, FIS # codes
Printed copy: A05
Microfilm copy: A04

Distribution
Category UC-71

SAND88-3005

TTC-0879

A REVIEW OF THE SAFETY FEATURES OF 6M PACKAGINGS
FOR DOE PROGRAMS*

Prepared by

US DEPARTMENT OF ENERGY
Specification-6M Safety Task Force

September 26, 1988

ABSTRACT

This report compiles and summarizes
the extant documentation on Department of Transportation
Specification-6M packagings used to support
Department of Energy programs.

*This work performed at Sandia National Laboratories, Albuquerque, New
Mexico, supported by the U.S. Department of Energy under Contract **DE-AC04-**
76DP00789

ACKNOWLEDGMENTS

The authors of this report would like to express their gratitude to the members of the DOE Specification 6M Safety Task Force for their help in gathering the available information on DOT Specification 6M packagings and supplying other valuable information on the use of these **packagings** in support of Department of Energy programs.

A REVIEW OF THE SAFETY FEATURES OF 6M PACKAGINGS FOR DOE PROGRAMS

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Preface

FORMAT, SOURCE, AND PURPOSE OF THIS DOCUMENT

This report, prepared by a U.S. Department of Energy (DOE) Task Force and organized for **clarity** into two-page modules, argues that the U.S. Department of Transportation (DOT) Specification-6M packagings (hereafter referred to as 6M packaging, or simply 6M) merit continued DOE use and, if necessary, DOE certification.

This report is designed to address the specific requirements of a Safety Analysis Report for Packaging (SARP). While not a **SARP**, this report constitutes a compilation of all available documentation on 6M packagings. The authors individually, and the Task Force collectively, believe their investigation provides **justification** for the continued use of 6M packagings because they meet criteria for quality assurance and for safety under normal and accident conditions as defined by the U.S. Nuclear Regulatory Commission (NRC) regulations. This report may be used by DOE managers to assist in deliberations on future requirements for 6M packagings as they are required to support DOE programs.

For the purpose of ready evaluation, **th's** report includes categorical topics found in Nuclear Regulatory Guide 7.9, the topical guideline for SARI's. The format, however, will (it is hoped!) pleasantly surprise customary reader **expectations**. For, **while maintaining categorical** headings and subheadings found in **SARPs** as a skeleton, the Task Force chose to **adopt** the document design principles developed by Hughes Aircraft in the **1960s**, "Sequential Thematic Organization of Publications" (STOP). The STOP format divides **the** document into one or two-page modules or themes. Turning the page means changing the topic or seeing a new self-contained facet of the same topic. Each thematic module begins, after stating a categorical section heading, with a capitalized topic heading followed by an underlined sentence stating the main point or contention of the module. Figures, if any, occur on the right-hand page and relate specifically to the text. Production of this report according to STOP principles is a DOE pilot project; the authors will appreciate comments on its readability.

DOT Specification-6M packagings for the shipment of radioactive materials (RAM) are built according to the rules set forth in DOT regulations in Title 49, Code of Federal Regulations (**CFR**), Part 178.104. The 6M ranges in size from 10 to 110 gallons (the size of the outer metal drum). These **6Ms** have been safely, reliably, and economically used **for** more than 20 years to transport RAM among DOE laboratories and elements of the DOE production complex. Predictably, 6M packages have suffered accidents of varying severity; however, they have no record of ever having leaked.

The DOE chose to begin compiling all available information to **substantiate** the adequacy of **6Ms** when it was learned in 1983 the **DOT** might replace 49 CFR 178.104 with **regulations** eliminating specification packages for shipping Type B quantities of RAM. The new regulations might require instead that each packaging be separately certified either by the NRC for its licensees or by the DOE for use in its shipments.

The process of documentation of the 6M case began in the Fall of 1983 with the formation of the DOE Specification-6M Safety Task Force (see Figure P-1) which met periodically through 1984 and 1985 under the leadership of Richard Hahn, **DOE/HQ/OMA**. This report, coordinated by Sandia National Laboratories' Transportation Systems Development Department for the U.S. Department of Energy under Contract **DE-AC04-76DP00789**, is the result of the Task Force's efforts.

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Figure P-1 The original DOE Specification-6M Safety Task Force included 29 members from 16 organizations. Asterisks indicate the six principal authors of this report.

1.0 General Information

1.1 DESCRIPTION OF 6M PACKAGINGS

DOT Specification 6M packagings are used extensively for shipping Type B quantities of fissile and radioactive materials both within the DOE production complex and by other contractors and licensees.

The original 6M packaging was Dow Chemical Corporation's Model 1518 (Figure 1.1.1) a **10-gallon-size** container approved by the U.S. Atomic Energy Commission (now DOE) in March 1966 and issued DOT Special Permit 5000 the **following** month. DOT Specification 6M was issued in December 1968 to cover a variety of similar **containers** ranging in capacity from 10 to 110 gallons. While the DOT 6M specification authorizes the **110-gallon-size** packaging, the 110-gallon version of the 6M is used infrequently in support of DOE programs.

The 6M is a license-exempt, lightweight, economical, Type **B** package that is commercially available for a few hundred **dollars** and can be easily fabricated from common materials. This container has seen extensive service since 1967, and DOE contractors have a current inventory of 1,977 6M packagings.

Based upon many years of actual **transportation** history, the 6M has been shown to be a safe and reliable package. Although they have been exposed to incidents of varying severity, there has never been a release of radioactive contents from a 6M package.

Title 49 CFR Part 173.416 for Type **B** packages, and Part 173.417 for fissile materials describe the authorized contents of 6M packages (see Table 1.1.1). Part 173.416 specifies the **6M packaging is only for solid or gaseous radioactive materials that do not undergo pressure-generating decomposition at temperatures up to 250°F (121°C) and that do not generate more than 10 watts of radioactive decay heat.** The specified limits in the regulatory paragraphs cited above have been calculated on the basis of criticality and the 10-watt decay heat restriction. Some DOE **Certificates of Compliance** have been issued to provide for other radioactive contents or slight variations in construction of the 6M packagings. These containers are referred to in this report as "**6M-like**" packages.

For purposes of historical record, a file of "as-built" drawings for 6M packagings is included as Appendix A of this report.

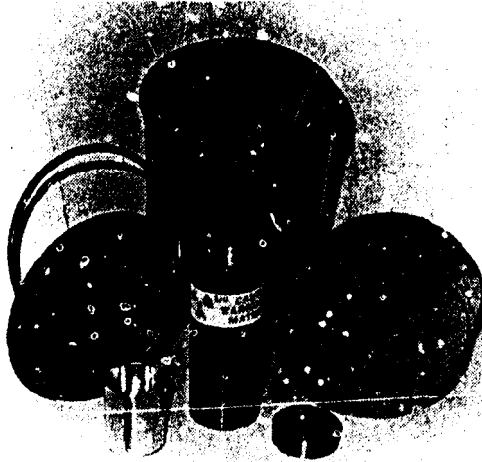


Figure 1.1.1 Components of the 6M packaging are a steel drum with lid and locking ring, a steel 2R containment vessel, and Celotex rings and disks. Food pack cans are typically used to package the radioactive material within the containment vessel.

Table 1.1.1 Up to 4.5 Kg of plutonium metal and corresponding amounts of uranium and oxides may be shipped in the 6M packaging.

APPROVED LIMITS • FISSILE MATERIALS*

Material Class II Transport Index (TI)	Package Contents (Kg)**	Fissile Cl. II Transport Index (TI)	Fissile Cl.111 Packages/ Vehicle
Pu-239 metal	4.5	1.0	125
Pu-239 compounds	4.5	0.2	625
U-235 metal	13.5	1.0	125
U-235 compounds	16	1.0	125

* Type B quantities of other radioactive materials are limited to 10 watts thermal energy by 49 CFR 173.441 (penetrating radiation).

** Assuming H/x = 0, see 49 CFR 173.417 for additional contents and restrictions.

1.0 General Information

1.2 CHARACTERISTICS OF OUTER DRUM

The outer steel structure of the **6M** packaging is a DOT-Specification drum of varying sizes that provides impact and thermal protection.

General construction requirements for a 6M packaging (49 CFR 178.104-3) call for a DOT-6C or -17C open-head steel drum or an equivalent, with rated capacity of 10 to 110 gallons. Because **it** is convenient to use commercial drums, existing **6Ms** have been constructed from 10, 15, 30, and 55-gallon sizes, or portions of such drums welded together (see the 60-gallon 6M in Figure 1.2.1.).

To comply with the letter and the intent of 49 CFR 178.104 and to be within the envelope of any **designs** tested, any **"equivalent"** drum must have the characteristics given in Table 1.2.1.

Drum and closure construction as well as proper torquing methods for the locking ring bolt (see Module 7.5) are critical to the function of the package during the 30-foot drop test.

To prevent rupture during the thermal test, the drum must be vented. Two **common** venting methods are a single 1-inch hole centered in the lid, (Figure 1.2.2) or four 0.5-inch holes located no further than 1.5 inches below the top of the drum. For weather protection these holes must be closed with a plastic plug or other fusible material.

A refractory material must be placed between the vent hole(s) and the insulating rings for the best performance during the thermal test. A **0.5-inch** Cerafelt blanket is ideal for this application because it provides high temperature protection while allowing the package to vent through the porous structure of the blanket.

It should be noted that the **outer** drum is not the containment boundary for the 6M packaging; such containment is **provided** by the DOT-2R inner containment vessel. **Thus**, from a regulatory viewpoint it **is** permissible to have vent holes in the outer drum without compromising the containment boundary of **the** 6M packaging.

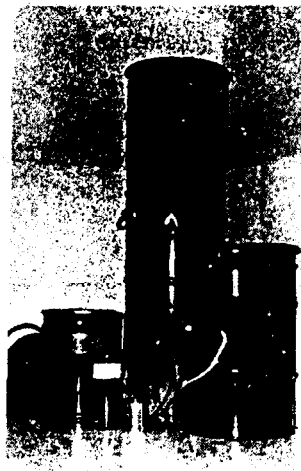


Figure 1.2.1 6M packagings may be constructed in many sizes varying from 10- to 110-gallon capacity. The drums shown are 10-, 30-, and 60-gallon sizes.

Table 1.2.1 Drums "equivalent" to the DOT-specification 6C or 17C may be used provided they have equal or better construction and metal thickness.

CHARACTERISTICS REQUIRED FOR "EQUIVALENT" DRUMS

Capacity (Gallons)	Metal Thickness. Body & Lid	Rolling Hoops	Closure
15 max	20 Ga	None	16 Ga bolted ring, drop forg. d lugs. 5/16" steel bolt
30 max.	18 Ga	2. rolled. in	12 Ga bolted ring, drop forged lugs. 5/8" steel bolt
Over 30	16 Ga	3* roller-in	12 Ga bolted ring, 5/8" steel bolt

*One within 3 inches of Cop curl



Figure 1.2.2 A 1-inch hole centered in the drum lid provides venting during an accidental fire. The refractory fiber pad used to prevent gaps in the Celotex while allowing gases to escape is visible just below the lid.

1.0 General Information

1.3 CHARACTERISTICS OF INSULATING DISKS AND RINGS

The insulating disks and rings provide heat and impact protection for the containment vessel.

Most 6M packagings use Celotex industrial board for thermal and impact protection; however, similar containers using plywood or laminated white oak or redwood have been successfully tested (Ref. 1.3.1). Title 49 CFR 178.104-3 allows the use of any of these materials; however, all 6M packagings used by DOE contractors have Celotex* as the insulating rings.

Celotex industrial board absorbs the shock of impact by compression and flow of the Celotex with little tendency to gap, shatter, or disintegrate (Figure 1.3.1). Also, in the reduced oxygen atmosphere inside the drum during the thermal test, Celotex only chars, with 1.5 inches of char depth being typical.

If Celotex is the chosen material, particular care must be taken to use only Celotex industrial board, because other types of building insulation and related products **are not** suitable.

It is important to control the fit of the insulation and containment vessel within the drum to prevent any gap from occurring during normal or accident conditions (Figure 1.3.2). The necessary inspection steps are given in the Operating Procedures, Section 7.0.

References • Module 1.3

- 1.3.1 Adcock, F. E., Plutonium Oxide Shipping Packages, RFP-501, Dow Chemical Co., Rocky Flats Div., Golden, Colorado, April 28, 1965.

*Celotex is a Trade Name for industrial cane fiberboard of the Celotex Corp., a subsidiary of the Jim Walter Corp.



Figure 1.3.1 This 55-gallon drum, weighing 535 pounds, was dropped from a height of 30 feet. Note how the Celotex insulation flows with no tendency to gap or shatter.

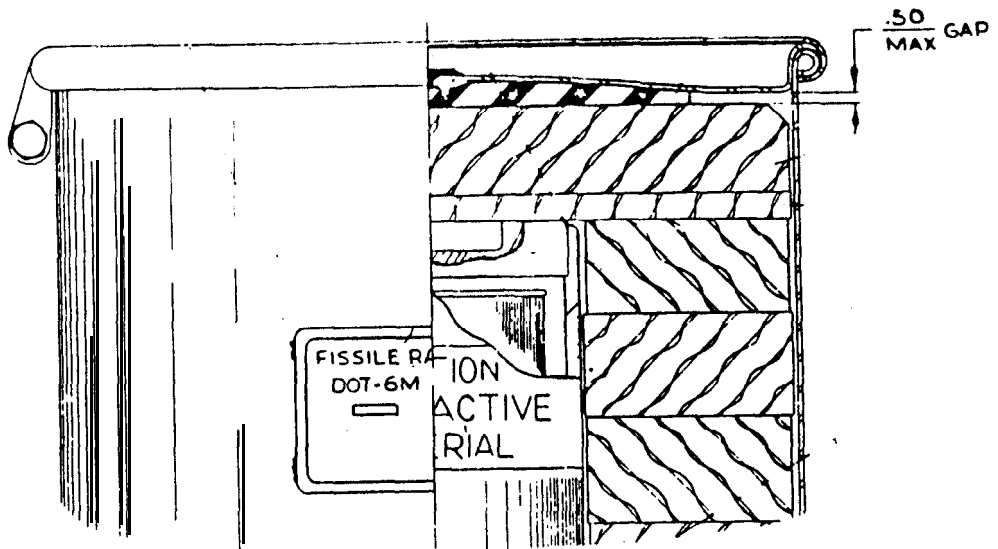


Figure 1.3.2 The 0.5-inch maximum gap between the drum and Celotex is filled with refractory fiber, thereby preventing gaps between the insulation rings.

1.0 General Information

1.4 CHARACTERISTICS OF DOT-2R CONTAINMENT VESSEL

Containment is provided by a DOT Specification-2R steel containment vessel closed with a threaded cap or pipe plug or by welding the closure.

Most 2R containment vessels in use consist of a steel-tube body with a welded end plate and closed on the other end by a pipe cap or a pipe plug luted (sealed) with room temperature vulcanizing **silastic** material. The inside diameter is restricted **to** a maximum of 5.25 inches by criticality considerations. Some design variations are provided in 49 CFR 178.34.

The type of sealing compound used in the threads and proper torquing procedures are critical to the successful leak integrity of the 2R containment vessel. (See Operating Procedures, Module 7.4 for details.) Use of common sealants such as Teflon tape or anaerobic compounds is unacceptable.

Radioactive material may be packaged within the containment vessel using one or more plastic bags, metal food pack cans, or polyethylene bottles. The exact configuration of the inner packaging depends on the material being shipped. While not a regulatory requirement, it is common practice, for purposes of handling ease, to place granular materials such as plutonium oxide within two concentric food pack cans. (See Figure 1.4.1; refer to Module 4.2 for details of sealing the food pack cans.)



Figure 1.4.1 This 2R containment vessel for a 10-gallon 6M package holds two No. 2 1/2-size food pack cans.

1.0 General Information

1.5 SUMMARY OF 6M PACKAGING REGULATORY TESTS AND ANALYSIS

The 6M packaging comes in a number of drum sizes and must be shown to sustain, by test or analysis, the normal conditions of transport as well as hypothetical accident conditions.

The 6M packaging comes in a variety of drum sizes ranging from 10 gallons to 110 gallons. These configurations may be examined from a regulatory viewpoint to ascertain that the packagings can sustain the normal and accident conditions of transport. Since this certification may be done by *test or* by analysis, in accordance with the regulations, there are a number of combinations that can be examined. Table 1.5.1 **si**ows the various 6M packaging sizes, certification methods (test or analysis) by regulatory environment category, and provides a reference to the appropriate module of this rrpvrt for further discussion.

Table 1.5.1 The safety evaluation for 6M packaging has addressed a number of packaging sizes and has been accomplished by a combination of tests and analysis.

SUMMARY OF 6M PACKAGING REGULATORY CONSIDERATIONS

Conditions of Transport	Addressed by Test/Analysis	Report Module	6M Packaging Size (gallons)
<u>Normal Conditions</u>			
Heat	Test/Analysis	2.2	10, 55
Cold	Analysis	2.3	10, 30, 55
Vibration	Analysis	2.3	10, 30, 55
Water Spray	Analysis	2.3	10, 30, 55
Free Drop(4 feet)	Test/Analysis	2.4	10, 30
Corner Drop	Analysis	2.5	10, 30, 55
Penetration	Test	2.5	10, 30
Compression	Test	2.5	10, 30, 55, 110
<u>Accident Conditions</u>			
Free Drop(30 feet)	Test	2.7	10, 30, 55
Puncture	Test	2.8	10, 30, 55
Thermal	Test/Analysis	2.9, 2.10 2.11	10, 30, 55
Load Resistance	Analysis	2.12	10, 110
Immersion	Test/Analysis	2.13	10, 30, 55

2.0 Structural Evaluation

2.1 GENERAL STANDARDS FOR ALL PACKAGES

The 6M packaging meets the general standards for all Type A and Type B packages.

Chemical and Galvanic Reactions

Requirement: A package must be of materials and construction that assure there will be no significant chemical, galvanic, or other reaction among the packaging components or between the components and the package contents, including possible reaction resulting from in-Leakage of water to the maximum credible extent.

Analysis: The steel, Celotex (or wood), and inner packaging materials have been selected to meet the above requirements. Adequacy has been demonstrated by 19 years of service.

Security Seal

Requirement: The outside of a package must incorporate a feature, such as a seal, that is not readily breakable. This feature, while intact, provides evidence that the package has not been opened by unauthorized persons.

Analysis: The drum is closed using a bolted ring with a lock nut to secure the Lid to the drum body. In addition, a Lead-wire security seal provides a tamper-indicating device that would indicate any attempt to gain unauthorized entry into the packaging.

Lifting Device

Requirement: Any lifting attachment that is a structural part of the package must be designed with a minimum safety factor of 3 against yielding when used to Lift the package in the intended manner. It also must be designed so failure of any Lifting device under excessive Load will not impair the ability of the package to meet other requirements. Any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for Lifting attachments.

Analysis : No lifting devices are provided, nor are they required. For most sizes in the 6M family, the packages are light enough to be handled manually or they are palletized. The largest size 6M, the 110-gallon, is used infrequently.

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2.0 Structural Evaluation

2.1 GENERAL STANDARDS FOR ALL PACKAGES (CONTINUED)

The DOT-6M container meets the general standards for all Type A and Type B packages.

Tie-down Devices

Requirement: (1) If a system of tie-down devices is a structural part of the package, the system must be capable of withstanding (without generating stress in any material in excess of its yield strength) a static force applied to the center of gravity of the package. The static force must have a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the package with its contents, and a horizontal component in the transverse direction of five times the weight of the package with its contents. (2) Any other structural part of the package that could be used to tie down the package must be capable of being rendered inoperable for tying down the package during transport, or must be designed with strength equivalent to that required for tie-down devices. (3) Each tie-down device which is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this part.

Analysis: No tie-down devices are provided. In some cases the 6M packages may be placed on pallets for ease in handling.

Positive Closure:

Requirement: Each package must incorporate a containment system securely closed by a positive fastening device which cannot be opened unintentionally.

Analysis: The containment is closed with a threaded pipe cap or plug which is luted (sealed) and torqued in place. The DOT-2R containment vessel also allows a bolted flange closure. Both designs cannot be opened unintentionally since tools and considerable effort must be used to open the containment vessel.

Valve or Pressure Relief Device

Requirement: A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage.

Analysis: Valves and/or pressure relief devices have not been provided on the DOT-2R containment vessel, nor are they required.

Excessive Surface Temperature

Requirement: A package must be designed, constructed, and prepared for transport so that in still air at 38°C (100°F) and in the shade, no accessible surface of a package would have a ~~temperature exceeding~~ 50°C (122°F) in a nonexclusive use shipment or 82°C (180°F) in an exclusive use shipment.

Analysis: Calculations (see module 3.3) show that under the conditions stated above the 10-gallon 6M packaging design with a maximum permissible loading of 10 watts will have a surface temperature less than 114°F. Larger packages will be at lower temperatures.

Load Resistance

Requirement: Regarded as a simple beam supported at its ends along any major axis, the packaging shall be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to five times its fully loaded weight, without generating stress in any material of the package in excess of its yield strength.

Analysis: Module 2.9 shows the results of such an analysis for the worst case, the geometry of a 110-gallon size 6M. The results of the analysis show that the 110-gallon 6M will have bending stresses significantly below the yield stress of the outer metal drum.

2.0 Structural Evaluation

2.2 GENERAL REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT • I

The 6M packaging complies with all requirements for normal conditions of transport as demonstrated by analysis and actual **tests**.

Evaluation of each package design under normal conditions of transport must include determining of the effect of certain conditions and tests on that design. A separate specimen may be used for each test as long as it is first subjected to the water spray test.

Compliance with requirements must be based on the ambient temperature preceding and following the tests. This temperature must remain constant at this value between -29°C (-20°F) and $+38^{\circ}\text{C}$ (100°F) that is most unfavorable for the feature under consideration. The internal pressure within the containment system must be considered to be the maximum normal operating pressure, unless a lower internal pressure consistent with the ambient temperature that precedes and follows the tests is more unfavorable.

Heat

Requirement: An ambient temperature of 30°C (100°F) in still air, with insolation temperatures according to the following table.

Form and Location of Surface	Temperature in Total Insolation* (g cal/cm)**
Flat surface, transported horizontally	
Base	None
Other surfaces	800
Flat surface, not transported horizontally	200
Curved surface	400

*Position must be maintained for 12 hours.

**Gram-calories per centimeter.

Analysis: The steady-state analysis involved thermal loading due to the 10-watt internal heat-generating capacity and solar insolation specified

by the regulations. The results of the steady-state analysis are given in Module 3.3, and are summarized as maximum temperatures at the surface of the inner containment vessel of **117°C (243°F)** for the 10-gallon-size 6M and maximum surface temperatures of **103°C (217°F)** for the **55-gallon-size** 6M.

References • Module 2.2

- 2.2.1 Sanchez, L.C., Longenbaugh, R.S., Moss, M., Haseman, G.M., Fowler W.E., Roth, E. P., Thermal Analysis of the **10-Gallon** and the **55-Gallon 6M** Containers With Thermal Boundary Conditions Corresponding to **10CFR71** Normal and Accident Conditions, **SAND87-1896**, TTC-0748, Sandia National Laboratories, Albuquerque, New Mexico, March 1988.

2.0 Structural Evaluation

2.3 GENERAL REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT • II

The DOT-6M container complies with all requirements for normal conditions of transport as demonstrated by analysis and actual tests.

Cold

Requirement: An ambient temperature of -40°C (-40°F) in still air and shade.

Analysis: The only materials affected by cold temperatures are the plastic vent plugs in the metal outer drum. They function **satisfactorily** at -54°C (-65°F); thus, the performance capability exceeds the regulatory requirement. The carbon steel in the DOT-6C or -17C drums may be subject to brittle fracture at -40°F , but a broad base of field experience with 6M packages has not uncovered any drum failures due to low-temperature drum properties.

Many cases are on record wherein failures have occurred for presumably adequately designed components, such as the metal drum of the 6M when fabricated from a ductile material like mild steel. No clear line of distinction exists between the ductile and the brittle response of normally ductile materials. When notch-impact tests are conducted on ductile materials, a "transition temperature" occurs below which they can behave in a brittle fashion, especially if the loads are applied very rapidly to the component (Ref. 2.3.1). While brittle behavior of the 6M metal drums is theoretically possible, no such behavior has been observed in approximately 20 years of actual field use of the 6M packaging.

Vibration

Requirement: Vibration normally incident to transport.

Analysis: The 6M packaging has no component that can be damaged by vibration encountered during normal transport. Thousands of shipments have been made without any evidence of damage or loss of contents due to normal vibration. A locking nut is applied to the lid closure ring bolt which, in addition, is secured with a lead seal. This seal acts as a safety wire to prevent loss of the lid-closure locking nut due to vibration.

Water Spray

Requirement: A water spray that simulates exposure to rainfall of approximately 5 centimeters (2 inches) per hour for at least 1 hour.

Analysis: The steel drum and vent plug are not susceptible to damage from this test.

References Module 2.3

- 2.3.1 Faupel, J. H., Engineering Design, Chapter 1, Materials and Properties, John Wiley and Sons, Inc., 1964.

2.C Structural Evaluation

2.4 GENERAL REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT • III

The DOT-6M container complies with all requirements for normal conditions of transport as demonstrated by analysis and actual tests.

Free Drop

Requirement: Between 1.5 and 2.5 hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. For Fissile Class II packages, this free drop must be preceded by a free drop from a height of 0.3 meter (1 foot) on each corner, or, in the case of a cylindrical Fissile Class II package, onto each of the quarters of each rim.

CRITERIA FOR FREE DROP TEST

<u>Package Weight</u>		<u>Free-Drop Distance</u>	
Kilograms	Pounds	Meters	Feet
5000 or less	11000	1.2	4
5000 to 10000	11000 to 22000	0.9	3
10000 to 15000	22000 to 33000	0.6	2
>15000	>33000	0.3	1

Analysis: A number of free drop **tests** have been performed on the 6M, resulting in little or no damage to the outer drum (see Refs. 2.4.1 and 2.4.2). Because little or no damage occurred, no physical damage detrimental to the 6M would be sustained in accident-condition transport tests,

References • Module 2.4

- 2.4.1 **Adcock**, F. E., **McCarthy**, J. D., **Wackler** W. F., Rocky Flats Model 203-1 Container (AEC-AL USA/5332/BLF), Safety Analysis Report for Packaging (SARP), RFP-1867, Rev. 1, Feb 27, 1974.
- 2.4.2 **Adcock**, F. E., **Wackler** W. F., RFP Container, Model 1518 for Fissile Class II and Class III Shipments, RFP-1042, 1968.

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2.0 Structural Evaluation

2.5 GENERAL REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT • IV

The 6M packaging complies with all requirements for normal conditions of transport as demonstrated by analysis and actual tests.

Corner Drop

Requirement : A free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 0.3 meter (1 foot) onto a flat, essentially unyielding, horizontal surface. This test applies only to fiberboard or wood rectangular packages not exceeding 50 kilograms (110 pounds) and fiberboard or wood cylindrical packages not exceeding 100 kilograms (220 pounds).

Analysis : The corner drop test is not applicable to the 6M because the 6M is not a fiberboard or wood box configuration.

Penetration

Requirement: Impact of the hemispherical end of a vertical steel cylinder of 3.2 centimeters (1.25 inches) diameter and 6 kilograms (13 pounds) mass, dropped from a height of 1 meter (40 inches) onto the exposed surface of the package that is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the package surface.

Analysis : Several penetration tests have been performed on the 6M (Refs. 2.2.1 and 2.3.1), resulting in only minor damage to the metal drum and no rupture of its metal surface (see Figure 2.5.1).

Compression

Requirement: For packages with a mass up to 5000 kilograms, the package must be subjected for a period of 24 hours to a compressive load applied uniformly to its top and bottom. The package must be in the position in which it would normally be transported. The compressive load must be the greater of the following:

1. The equivalent of five times the weight of the package, or;
2. The equivalent of 12.75 kilopascals (1.85 pounds per square inch) multiplied by the vertically projected area of the package.

Analysis: Compression tests of various sizes of steel drums have been conducted at loadings in excess of five times the package weight with no measurable deformation. A summary of the test loads is given in Table 2.5. 1.

References , Module 2.5

- 2.5.1 Edling, D. A., Hopkins D. R., Wilson, S. C., DOT 7A , Type A Certification Document, Mound Laboratory, Monsanto Research Corp., June 1985.
- 2.5.2 Harbolshaimer J. A., Safety Analysis Report for Packaging, Type L-10 Class II Shipping Container, ARH-3050, May 1974. (Note: The L-10 is a "6M-like" packaging.)

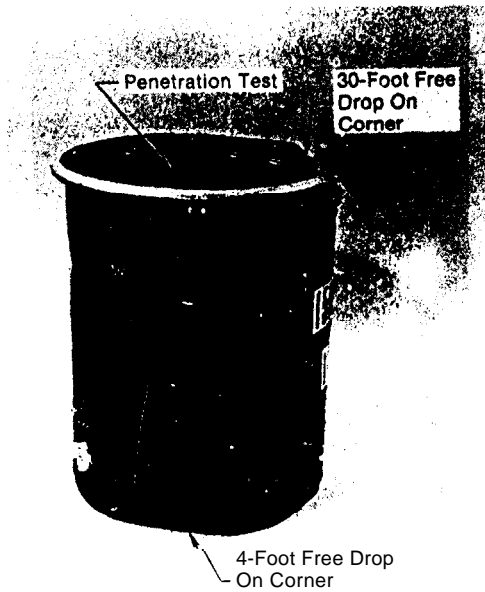


Figure 2.5.1 The results of the penetration test for normal conditions of transport show only minor damage to the 6M drum.

Table 2.5.1 STATISTICAL LOADS ON 6M PACKAGINGS YIELD NO MEASURABLE DEFORMATION.

Drum Size (gallons)	Type/Capacity	Maximum Gross wt. (pounds)	Gross Wt. x5 (pounds)	Test Wt. (pounds)	Reference
10	6C 20 Ga	160	800	800	2.5.1
30	17H 18 Ga	460	2300	2600	2.5.1
55	17H 16 Ga	640	3200	6400	2.5.1
110	17H 16 Ga	640	2300	3000	2.5.2

2.0 Structural Evaluation

2.6 REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The 6M meets all hypothetical accident condition tests.

Review of the published and unpublished literature shows the 6M has been tested to current regulations (with the exception of the 50-foot immersion test) and other criteria more than any other radioactive waste packaging in use. The original tests of a 10-gallon-size package were performed by Dow Chemical Company in 1967 to qualify for Special Permit 5000 (Ref. 2.6.1). Various additional tests were performed later in 1967 to confirm the higher gross weights proposed for the DOT Specification 6M (Refs. 2.6.2, 2.6.3).

Sandia National Laboratories tested the 6M and two other containers to flight recorder standards, which include 1000-g shock, 5000-pound static crush, and a half-hour thermal test at 1100°C (2000°F) (Ref. 2.6.4). These packagings were loaded with uranium oxide, so leakage, should any occur during the accident tests, could be readily determined. Although the 6M suffered considerable damage, no uranium oxide leakage was found. It is important to note that proper drum closing, venting procedures, and improved thread sealants contributed to the success of this test.

Other tests performed on 6M packages demonstrate they exceed regulatory test standards. A 300-foot drop and a 983°C (1800°F) fire for 1 hour showed the partial loss of the drum lid during both thermal and drop tests; lack of a venting system and improper locking-ring closing techniques caused the lid loss (Ref. 2.6.5). Dye solution leaked from the containment vessels during several tests when an improper thread sealant was used. These tests have contributed greatly to the knowledge of container performance during severe over-tests and resulted in improved operating procedures. (Details of the accident condition tests are given in Modules 2.7 through 2.10.)

References - Module 2.6

- 2.6.1 **Adcock, F. E., Wackler W, F.**, RFP Container-Model 1518 for Fissile Class II and Class III Shipments, RFP-1042, Dow Chemical Co., 1968.
- 2.6.2 **Adcock, F. E., McCarthy J. D., Wackler W. F.**, Rocky Flats Model 203-1 Container (AEC-AL **USA/5332/BLF**) Safety Analysis Report for Packaging (**SARP**), RFP-1867, Rev. 1, Feb. 27, 1974,
- 2.6.3 **Adcock, F.E., Wackler W. F.**, Preliminary Report, Drop-Test of Lead-filled DOT6-M Containers, Dow Chemical Co. June 6, 1968.
- 2.6.4 **McWhirter, M., et al.**, Final Report on Special Tests of Plutonium Oxide Shipping Containers to FAA Flight Recorder Survivability Standards, **SAND75-0446**, Sandia National Laboratories, Albuquerque, New Mexico, September 1975.
- 2.6.5 **Bonzon, L. L.**, Final Report on Special Impact Tests of Plutonium Shipping Containers, Description of Test Results, **SAND76-0437**, Sandia National Laboratories, February, 1977.

2.0 Structural Evaluation

2.7 RESULTS OF ACCIDENT CONDITION TESTS • FREE DROP

Since 1967, many 30-foot free drop tests have been conducted on 6M and 6M-like packagings of 10- to 55-gallon size, resulting in little or no damage to the packagings.

Free Drop

Requirement: A free drop of the package through a distance of 30 feet onto a flat, essentially unyielding, horizontal surface, striking the surface in a position in which maximum damage to the package is expected.

Analysis: The results of free drop tests are reported in Refs. 2.7.1 and 2.7.2 for 30-gallon and 10-gallon 6M packages. These tests involved dropping 6Ms in an orientation such that the point of impact was on the drum corner near the locking-ring bolt. Minor deformation occurred at the point of impact, but the locking-ring and cover remained intact, with no Celotex exposed.

Overall damage was expected to be maximum with a corner drop: however, additional drops were made to maximize specific types of damage. The 10-gallon 6M (Ref. 2.7.2) and 30-gallon "6M-like" containers were dropped on their sides to maximize flattening or loss of spacing. Results were a 0.20- and a 0.25-inch decrease in effective radius. Two 10-gallon 6Ms (Ref. 2.7.3) were dropped 30 feet end-on to maximize crushing of the Celotex by the containment vessel. No permanent Celotex deformation was noted for a typical containment vessel weighing 20 pounds. A lead-filled containment vessel weighing 71 pounds resulted in a Celotex compression of approximately 0.7 inch. Even with the deformations in the Celotex noted, both packages remained functional and passed subsequent thermal tests.

References • Module 2.7

- 2.7.1 **Adcock**, F. E., **McCarthy**, J. D., **Wackler**, W. F., Rocky Flats Model 2030-1 Container (AEC-AL **USA/5332/BLF**), Safety Analysis Report for Packaging (SARP), RFP-1867, Rev, 1, Feb. 27, 1974.
- 2.7.2 **Adcock**, F. E., **Wackler**, W. F., RFP Container, Model 1518 for Fissile **Class** II and Class III Shipments, RFP-1042, 1968.
- 2.7.3 **Adcock**, F. E., **Wackler**, W. F., Preliminary Report, Drop-Test of **Lead**-filled DOT-6M Containers, **Dow Chemical** Co., June 6, 1968.

2.0 Structural Evaluation

2.8 RESULTS OF ACCIDENT CONDITION TESTS • PUNCTURE

The **40-inch** (1 meter) free drop onto a **6-inch** (15 centimeter) probe has been performed on **10-** and **55-gallon** 6M packages with virtually no damage to them.

Puncture

Requirement: A free drop of the package through a distance of 40 inches (1 meter) in a position in which maximum damage is expected, onto the **upper** end of a solid, vertical, cylindrical, mild steel bar mounted onto an essentially unyielding, horizontal surface. The bar must be 6 inches (15 centimeters) in diameter, with the top **horizontal** and its edge **rounded** to a radius of not more than 0.25 inch (6 millimeters). The bar's length must be sufficient to cause maximum damage to the package, but not less than 8 inches (20 centimeters). The long **axis** of the bar must be vertical.

Analysis: Results of puncture tests performed on 6M packages are given in Refs. 2.8.1 and 2.8.2. These tests were performed on **10-** and **30-gallon** drums, respectively. Both sets of reported puncture tests resulted in minor damage to the outer drums. The tests were performed on the drum ends and sides in an effort to develop maximum damage. The 10-gallon drum sustained a minor dent of approximately 0.3 inch in depth. The 55-gallon drum was dropped onto the puncture probe, impacting the slightly convex drum cover. No **rupture** or tearing of the drum cover **occurred**, and the plastic vent plug **remained** in place in the center of the **cover**. The containment vessel was undamaged in the puncture tests, and remained centrally located in the Celotex insulating rings.

References • Module 2.8

- 2.8.1 **Adcock**, F. E., **Wackler**, W. F., RFD Container, Model 1518 for Fissile Class II and Class III Shipments, RFP-1042, 1968.
- 2.8.2 **Adcock**, F. E., McCarthy, J. D., **Wackler**, W. F., Rocky Flats Model 2030-1 Container (AEC-AL **USA/5332/BLF**), Safety Analysis Report for Packaging (SARP), RFP-1867, Rev. 1, Feb. 27, 1974.

2.0 Structural Evaluation

2.9 RESULTS OF ACCIDENT CONDITION TESTS - THERMAL

Roth by analysis and by testing, the 6M package has been shown to satisfy the requirements of the thermal testing under the hypothetical accident conditions of transport.

Thermal

Requirements: Exposure of the whole specimen for not less than 30 minutes to a heat flux not less than that of a radiation environment of 800°C (1475°F), with an emissivity coefficient of at least 0.9. For purposes of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to a fire, or 0.8, whichever is greater. In addition, when significant, convective heat input must be included on the basis of still ambient air at 800°C (1475°F). Artificial cooling must not be applied after cessation of external heat input, and any combustion of construction materials must be allowed to proceed until it terminates naturally. The effects of solar radiation may be neglected before, during, and after the test.

Analysis: Thermal tests were conducted in a 275-kilowatt induction furnace (Ref. 2.9.1) preheated to 830°C (1525°F) before the 30-minute test runs at 800°C (1675°F). The test specimen was a "6M-like" 30-gallon drum configuration instrumented with thermocouples to continuously record interior temperatures during the test. The test results are shown in Figure 2.9.1. The outer surface of the containment vessel reached a peak temperature of 95°C (205°F). This temperature occurred approximately 2 hours after the start of the test and represents a rise of about 57°C (135°F) above that of the package components at the start of the test.

Ref. 2.9.2 reports an additional set of thermal tests on a 10-gallon 6M, (see Figure 2.9.1). The package was placed in a preheated induction furnace and exposed to the thermal environment for 30 minutes. The thermocouples shorted out during the first 5 minutes of exposure, so the internal temperatures could not be monitored directly. Temperature-sensitive pellets were placed on the cans inside the containment vessel and on the exterior of the containment vessel. The 93°C (200°F) pellets on the side and bottom of the containment vessel showed that 93°C (200°F) had just been reached. The pellets on the cans in the containment vessel indicated 65°C (150°F) had been exceeded, but 79°C (175°F) had not been reached (Figure 2.9.2). No scorching of paint on the radiation label occurred, nor did the metal cans in the containment vessel swell.

The magnitude of the temperatures inside and near the containment vessel were less than the 149°C (300°F) required for gasket material compatibility (Specification 2R for the containment vessel).

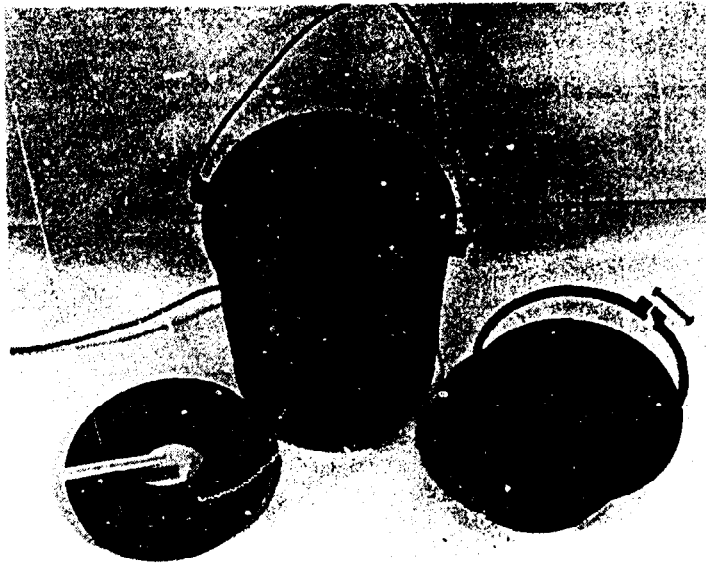


Figure 2.9.1 Typical depth of char after the thermal test is 1.5 inches radially. Note pristine condition of containment vessel.

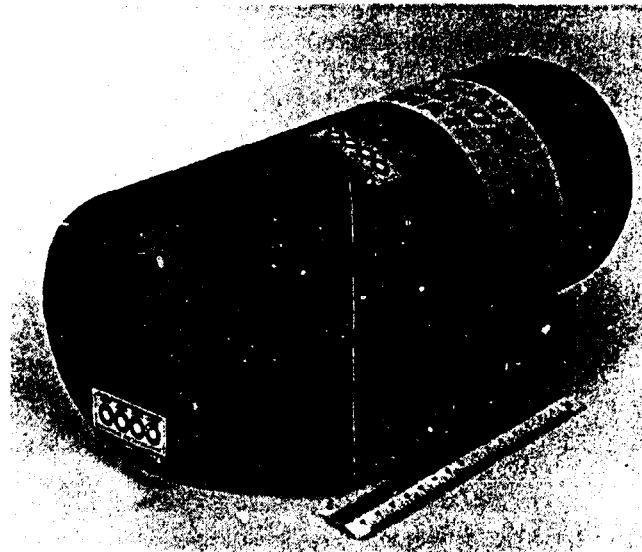


Figure 2.9.2 Temperature labels on the 2R containment vessel show that 93°C (200°F) was exceeded, but 107°C (225°F) was not reached.

References - Module 2.9

- 2.9.1 Adcock, F. E., McCarthy, J. D., Wackler, W. F., Rocky Flats Model 2030-1 Container (AEC-AL USA/5332/BLF), Safety Analysis Report for Packaging (SARP), RFP-1867, Rev. 1, Feb. 27, 1974.
- 2.9.2 Adcock, F. E., Wackler, W. F., RFP Container, Model 1518 for Fissile Class II and Class III Shipments, RFP-1042, The Dm Chemical Co., Rocky Flats Div., Golden, Colorado, 1968.

2.0 Structural Evaluation

2.10 RESULTS OF ACCIDENT CONDITION TESTS • TRANSIENT THERMAL ANALYSIS

Both by analysis and by testing, the 6M has been shown to pass the requirements of the transient thermal conditions under hypothetical accident conditions of transport.

Transient Thermal Analysis

A transient thermal analysis was performed for the accident conditions of transport for the 10-gallon and 55-gallon sizes of the DOT-6M. The analysis used the Q/TRAN thermal systems analysis code, Ref. 2.10.1, which uses the traditional thermal network approach. Q/TRAN has been used in thermal benchmark problems for spent fuel casks, Refs. 2.10.2 to 2.10.5. The geometry of the thermal model is shown in Figure 2.10.1. The model uses three methods of energy transfer, (1) conduction heat transfer within the solid regions of the DOT-6M; (2) natural convection from the surfaces of the 6M container to a still air environment; and (3) thermal radiation between the surfaces of the 6M container and the environment.

The results for a transient thermal analysis were obtained from a two-dimensional model. Selective thermal results were obtained for the region of the 2R inner containment vessel, the mid-thickness location of the Celotex thermal insulation material and the outer surface of the DOT-6M. These results are given in Module 3.6. The variation of temperature with respect to time for the transient analysis is presented in Table 3.6.1 for the 10-gallon configuration of the DOT-6M since it has the least amount of thermal insulation.

References • Module 2.10

- 2.10.1 Rockenbach, F. A., Q/TRAN, Version 1.2 User's Manual, PD Engineering Inc., Santa Ana, CA, May 1986.
- 2.10.2 Sanchez, L. C., Performance Testing of Thermal Analysis Codes for Nuclear Fuel Casks, SAND84-1854, TTC-0509, Sandia National Laboratories, Albuquerque, New Mexico, January 1987.
- 2.10.3 Sanchez, L. C., Solutions Obtained To International Benchmarking Problems for Nuclear Fuel Casks Using Q/TRAN, SAND85-2621, TTC-0631, Sandia National Laboratories, Albuquerque, New Mexico, February 1987.
- 2.10.4 Mantuefel, R. D., Klein, D. E., and Yoshimura, H. R., Benchmarking the Q/TRAN Thermal Analysis Code, IAEA-SM-286/95P, Proceedings of PATRAM-86, Davos, Switzerland, June 16-20, 1986, pp 465-474.
- 2.10.5 Glass, R. E., Thermal Benchmarking: A Status Report, IAEA-SM-286/100P, Proceedings of PATRAM-86, Davos, Switzerland, June 16-20, pp 497-499.

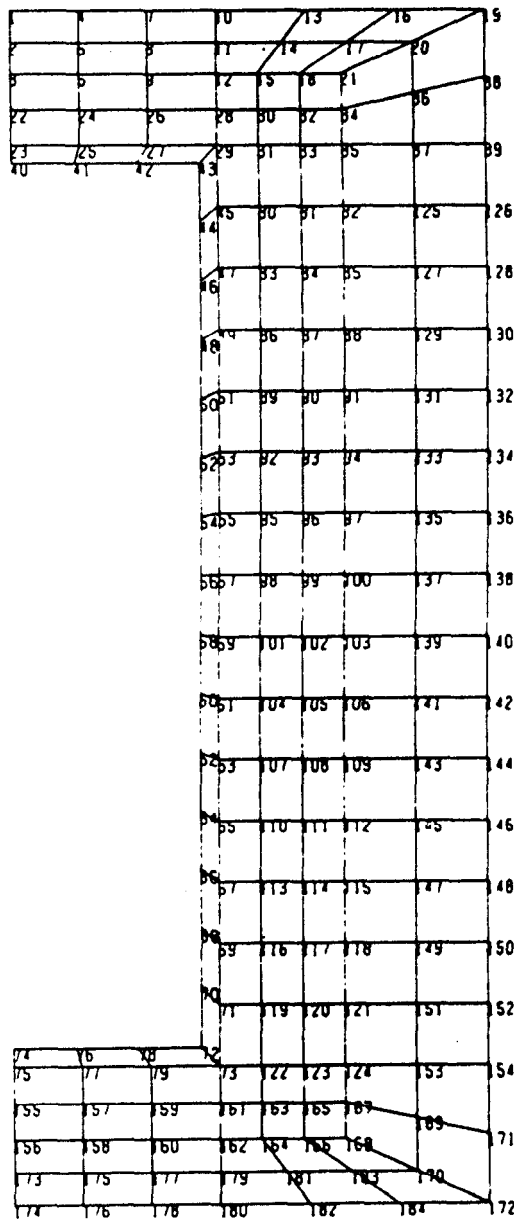


Figure 2.10.1 Two-dimensional mesh used for thermal analysis of the 10-gallon and 55-gallon DOT-6M containers

2.0 Structural Evaluation

2.11 RESULTS OF ACCIDENT CONDITION TESTS • THERMAL STRESSES

The thermal gradients in the region of the containment vessel were so small they produced negligible thermal stresses in the body of the containment vessel.

Thermal Stresses

The heat generation region in the transient thermal analysis model consists of the radioactive material within the containment vessel and the containment vessel itself. The maximum thermal **gradient** across the thickness of the 2R containment vessel is small, less than 1°C (2°F). Under these conditions, for such small thermal gradients, no significant thermal stress occurs in the walls of the containment vessel. (See Module 3.6 for details of the transient thermal analysis.)

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2.0 Structural Evaluation

2.12 LOAD RESISTANCE OF THE 6M PACKAGING

The load resistance of the 6M packaging, as measured by its bending resistance, produces stresses significantly below the yield stress of the outer metal drum.

Load Resistance

Requirement: Regarded as a simple beam supported at its ends along any major axis, the 6M packaging should be capable of withstanding a static load equal to five times its fully loaded weight. The load should be normal to and uniformly distributed along the 6M's length, and should not generate stress in any material of the packaging in excess of its yield strength.

Analysis: Assuming a 110-gallon 6M package (as a limiting case) to be loaded as specified above, the stress on the drum may be calculated as follows:

Maximum gross weight = 640 pounds

Total static load: $W = 5 \times 640 = 3200$ pounds

Beam length: $L = 69.6$ inches

Drum outside diameter: $D_o = 22.6$ inches

Drum inside diameter: $D_i = 22.5$ inches

Maximum bending moment: $M_{max} = WL/8 = 27840$ pound-inches

Moment of inertia: $I = (\pi/64) ((D_o)^4 - (D_i)^4) = 270.5$ inches⁴

Distance from neutral axis: $c = D_o/2 = 11.3$ inches

Maximum bending stress: $= (M_{max})c/I = 1163$ pounds per square inch (psi).

The yield stress for carbon steel is 35000 psi. Thus, the 6M's 1163 psi bending stress (the effective measure of the bending resistance of the 6M packaging) is significantly below the yield stress for carbon steel, with a safety factor of approximately 30. A similar analysis for a 10-gallon-size 6M gave an even smaller bending stress.

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2.0 Structural Evaluation

2.13 RESULTS OR ACCIDENT CONDITION TESTS • IMMERSION

The **6M** packaging meets the conditions of the water immersion test

Water Immersion

Requirement: For Fissile Material, in those cases where water inleakage has not been assumed for criticality analysis, the specimen must be immersed under a head of water at least 0.9 meters (3 feet) for a period of not less than 8 hours and in the attitude at which maximum leakage is expected.

Analysis: Immersion **tests** were performed on **6M** packagings of the 10- and 30-gallon size (see Refs. 2.13.1 and 2.13.2). The containment vessels were determined to be watertight.

References • Module 2.13

- 2.i3.1 Adcock, F. E., McCarthy, J. D., **Wackler**, W. F., Rocky Flats Model 2030-1 Container (AEC-AL USA/5332/BLF), Safety Analysis Report for Packaging (SARP), RFP-1867, Rev. 1, Feb. 27, 1974.
- 2.13.2 Adcock, F. E., **Wackler**, W. F., RFP Container, Model 1518 for Fissile Class II and Class III Shipments, RFP-1042, The Dow Chemical Co., Rocky Flats Div., Golden, Colorado, 1968.

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3.0 Thermal Evaluation

3.1 THERMAL PROPERTIES OF 6M PACKAGING MATERIALS

The thermal properties of materials typically used in 6M packaging fabrication must be known to perform thermal analyses.

The two-dimensional heat transfer analysis of the DOT-6M package required the thermal properties for Celotex, mild steel, and air. Properties for mild steel and air were available from the open literature, but the thermal properties for Celotex at elevated temperatures had to be obtained experimentally and are reported in Ref. 3.1.1. The thermal conductivity of Celotex was measured in an Argon atmosphere with the use of a Synatech thermal comparator, Refs. 3.1.2 and 3.1.3. Density values were calculated from measured weight and volume values. The specific heat of Celotex was determined using differential scanning calorimetry (DSC), Ref. 3.1.4. Values for the thermal properties of Celotex are shown in Table 3.1.1 and Figures 3.1.1 through 3.1.3.

Table 3.1.1 THERMOPHYSICAL PROPERTIES OF CELOTEX

T (°C)		Thermal Conductivity (W/m·°C)	Density (kg/m ³)	Specific Heat (J/kg·°C)
25.	(298°K)	0.053	270.	1280.
86.	(359°K)	0.059	..	1506.
146.	(419°K)	0.063	286.	1745.
226.	(493°K)	0.065	297.	2046.
278.	(551°K)	0.051	313.	2063.

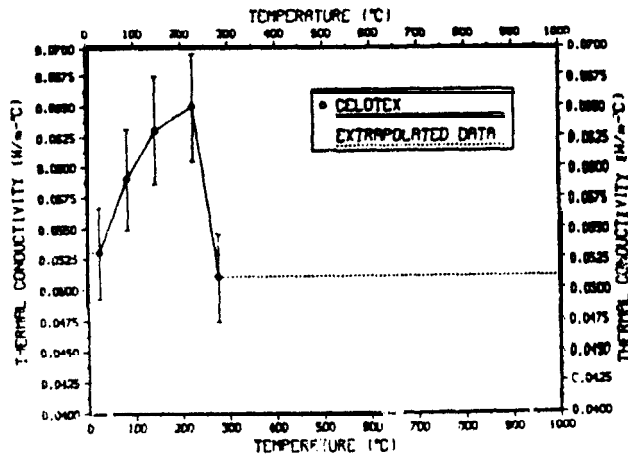


Figure 3.1 Thermal conductivity versus temperature

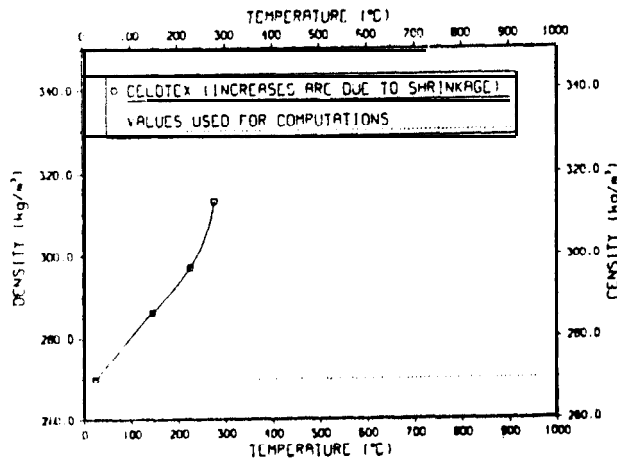


Figure 3.1.2 Density versus temperature

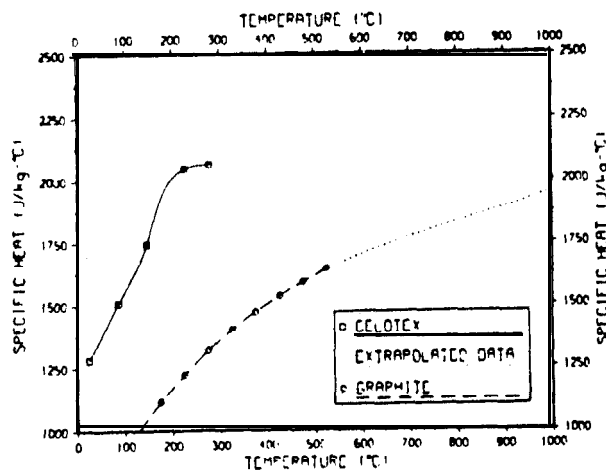


Figure 3.1.3 Specific heat versus temperature

3.0 Thermal Evaluation

3.1.1 REFERENCES FOR MODULE 3.1

The references for **Module 3.1** are included in this module.

References - Module 3.1

- 3.1.1 Sanchez, L. C., Longenbaugh, R. S., Moss, M., Haseman, G. M., Fowler, W. E., Roth, E. P., Thermal Analysis of the **10-Gallon** and the **55-Gallon 6M Containers** With Thermal Boundary Conditions Corresponding to **10CFR71** Normal Transport and Accident Conditions, **SAND87-1896**, TTC-0748, Sandia National Laboratories, Albuquerque, New Mexico, March 1988.
- 3.1.2 Moss, M., Koski, J. A., Haseman, G. M., Measurements of Thermal Conductivity by the Comparative Method, **SAND82-0109**, Sandia National Laboratories, Albuquerque, NM, March 1982.
- 3.1.3 Sweet, J. N., et al., Comparative Thermal Conductivity Measurements at Sandia National Laboratories, **SAND86-0840**, Sandia National Laboratories, Albuquerque, NM, June 1986.
- 3.1.4 Callanan, J.E., Sullivan, S. A., Development of Standard Operating Procedures for Differential Scanning Calorimeters, Review of Scientific Instruments, Vol. 57, No. 10, October, 1986, pgs 2585-2592.

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3.0 Thermal Evaluation

3.1 THERMAL ANALYSIS METHODOLOGY

The thermal model used to analyze the DOT-6M package for the normal environment and transport accident conditions has boundary conditions that are in accordance with the regulations of MC's 10 CFR 71.

Three modes of energy transfer were used in this analysis:

- 1 Conduction heat transfer with the solid regions of the 6M package,
2. natural convection from the surfaces of the 6M containers to still air in the environment, and
- 3 thermal radiation between the surfaces of the 6M packages and the environment

Thermal phases and boundary conditions are in accordance with the NRC's regulations, 10 CFR 71, Kef 3.2.1, and can be observed in Tables 3.2.1 and 7.2.2 in module 3.2.1, for the normal conditions of transport and for hypothetical accident scenarios, respectively. These values were applied to the mesh models for the 10-gallon and the 55-gallon 6M containers as shown in Figure 2.10.1. Thermophysical properties for the materials used in the 6M packages are given in Module 3.1, and more discussion of the steps used to model the packages can be found in Ref. 3.2.2.

References - Module 3.2.1

- 3.2.1 Packaging and Transportation of Radioactive Material, U. S. Nuclear Regulatory Commission, Title 10, Code of Federal Regulations, Part 71, 1987.
- 3.2.2 Sanchez, L. C., Longenbaugh, R. S., Moss, M., Haseman, G. M., Fowler, W. E., Roth, E. P., Thermal Analysis of the 10-Gallon and the 55-Gallon 6M Containers With Thermal Boundary Conditions Corresponding to 10 CFR 71 Normal Transport and Accident Conditions, SAND87-1896, TTC-0748, Sandia National Laboratories, Albuquerque, New Mexico, March 1988.
- 3.2.3 Shippers--General Requirements for Shipments and Packagings, US Department of Transportation, Title 49, Code of Federal Regulations, Part 173.415.

Table 3.2.1 DESCRIPTION OF PARAMETERS FOR **NORMAL** TRANSPORT CONDITIONS*

Thermal Phases (periodic, every 24 hours)

(I) Twelve-hour heat up period where solar insolation impinges upon the package in an environment of ambient temperature of 38°C (100°F) in still air with insolation according to the following:

<u>Form and location of surface</u>	<u>Total insolation for a 12-hour period</u>
Flat surfaces transported horizontally	
--Base	None
• -Other surfaces	800 (g cal/cm ²)
Flat surfaces not transported horizontally	200 (g cal/cm ²)
Curved surfaces	400 (g cal/cm ²)

(II) Twelve hour cool down period where heat is dissipated to external air at an ambient temperature of 38°C (100°F).

Materials

Insulation region • Celotex industrial board
 Structural regions • mild steel

Boundary Conditions

(I) Periodic Conditions (12-hour heat up and 12-hour cool down)

External: Ambient temperature $T_a = 38^\circ\text{C}$
 Heat Transfer coefficient $\alpha_a \theta_s^{1/4}$ (W/m² · K)
 $\theta_s = T_s - T_a$ (K)
 $T_s =$ local surface temperature (°C)

Internal: Heat generation rate $Q = 10\text{W}^\dagger$

*Required thermal phases and boundary conditions are those of 10 CFR 71, Ref. 3.2.1. Environment emissivity and surface absorptivity values were chosen to coincide with required values for the hypothetical accident scenario (see Table 3.2.2). Incident solar insolation is assumed to be totally absorbed.

** Convection heat transfer is modeled within the heat transfer code Q/TRAN in a manner similar to this expression but incorporates a varying boundary layer thickness for the natural convection phenomena.

†Value required in Ref. 3.2.3.

3.0 Thermal Evaluation

3.2.1 THERMAL ANALYSIS METHODOLOGY (Continued)

Table 3.2.2, Description of Parameters for Hypothetical Accident Scenario, is contained in this module.

Table 3.2.2 DESCRIPTION OF PARAMETERS FOR HYPOTHETICAL ACCIDENT SCENARIO*

Thermal Phases

- (I) The steady-state initial conditions where heat is dissipated to external air at an ambient temperature of 38°C (100°F) (no insolation),
- (II) the engulfing fire transient where radiation and convection from an 800°C (1472°F) fire environment provide an external heat input, and
- (III) the cool down period with external boundary conditions identical to the initial steady-state phase,

Materials

Insulation region • Celotex industrial board
 Structural regions • mild steel

Boundary Conditions

- (I) Initial Steady-State Conditions

External: Ambient temperature $T_a = 38^\circ\text{C}$
 Heat transfer coefficient $h_a \propto \theta_s^{1/4} (\text{W/m}^2 \text{ K})$
 $e = T_s \cdot T_a (\text{K})$
 $T_s = \text{local surface temperature}$
 Environment emissivity $\epsilon_a = 0.9$
 Surface absorptivity $a_s = 0.8$
 All reflections are diffuse

Internal: Heat generation rate $Q = 10 \text{ W}^\dagger$

- (II) Fire Test Transient Conditions--Duration 30 Minutes

Initial temperatures from (I) above

External: Ambient temperature $T_a = 800^\circ\text{C}$
 Heat transfer Coefficient $h_a \propto \theta_s^{1/4} (\text{W/m}^2 \text{ K})$
 $e = T_s \cdot T_a (\text{K})$
 $T_s = \text{local surface temperature}$
 Environmental emissivity $\epsilon_a = 0.9$
 Surface absorptivity $a_s = 0.8$
 All reflections are diffuse

Internal: As shown (I) above

- (III) Cool Down Transient Conditions --Duration: Until peak payload temperatures are reached.

Initial temperature from end of transient (II) above

External and internal boundary conditions as from (I) above

* Required thermal phases and boundary conditions are those of 10 CFR 71.

** Convection heat transfer is modeled within the heat transfer code Q/TRAN in a manner similar to this expression but incorporates a varying boundary layer thickness for the natural convection phenomena. Natural convection phenomena for hypothetical accident scenario is specified in 10 CFR 71 to be added when deemed significant.

† Value required in Ref. 3.2.3.

3.0 Thermal Evaluation

3.3 THERMAL ANALYSIS FOR NORMAL CONDITIONS • PACKAGE TEMPERATURES

Maximum temperatures were calculated for 10-gallon and 55-gallon 6M packages for normal conditions of transport and hypothetical accident conditions of transport, and these temperatures were found to be at acceptable levels.

Temperature response for the 6M package (with a thermal payload of 10 W) for the normal conditions of transport (see Table 3.2.1) can be observed in Figures 3.3.1 and 3.3.2. The oscillatory temperature shown in these figures is due to the solar insolation applied to the 6M containers. The temperature values for key locations are shown in Table 3.3.1 and indicate that the maximum temperature of the payload region (inner liner of container) does not exceed 117°C (243°F) for the 10-gallon 6M configuration and 103°C (217°F) for the 55-gallon 6M package.

References • blodule 3.3

- 3.3.1 Shippers--General Requirements for Shipments and Packagings. US Department of Transportation, Title 49, Code of Federal Regulations, Part 173.415.

Table 3.3.1 TABULATED RESULTS FOR THE THERMAL RESPONSE OF 6M PACKAGES TO NORMAL TRANSPORT CONDITIONS AFTER 5 DAYS' EXPOSURE TO INSOLATION CYCLE*

	Periodic Peak Temperature:** (°C)		Average Temperature (°C)	
	Package Size 10-Gallon	Package Size 55-Gallon	Package Size 10-Gallon	Package Size 55-Gallon
Outer diameter of 6M Package	77	77	59	58
Inner liner of GM Package	117	103	109	102

* Calculated temperatures correspond to a thermal payload of 10 watts, Ref 3.3.1.

** Temperature varies within a 12-hour period.

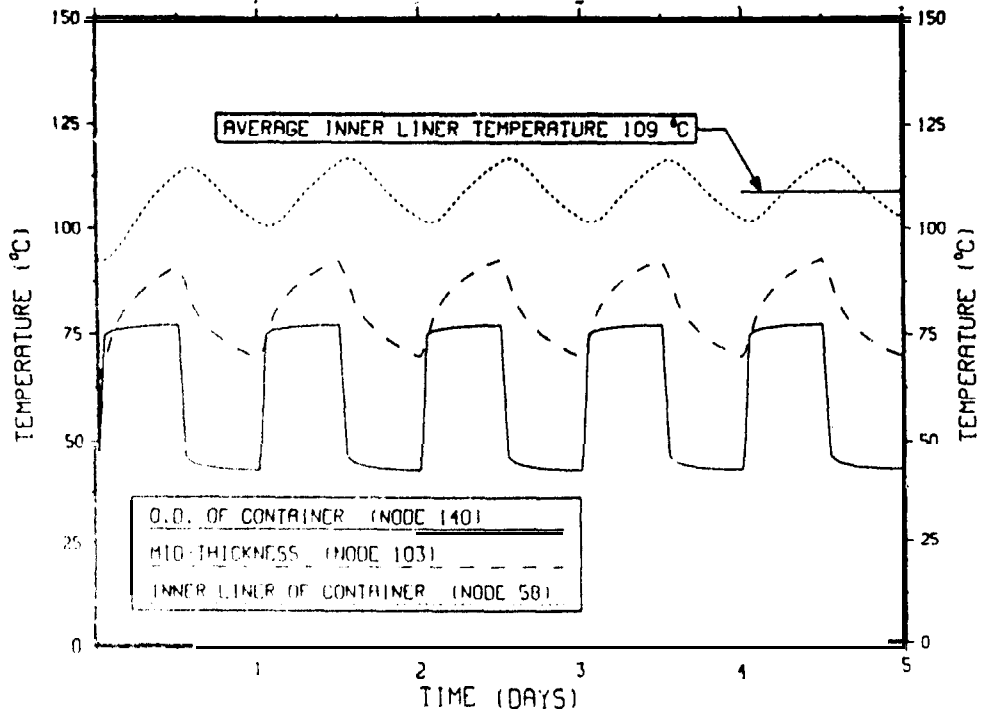


Figure 3.3.1 Temperature-time profile of the 10-gallon 6M package subjected to normal transport conditions (initial temperatures correspond to a steady-state solution without solar insolation).

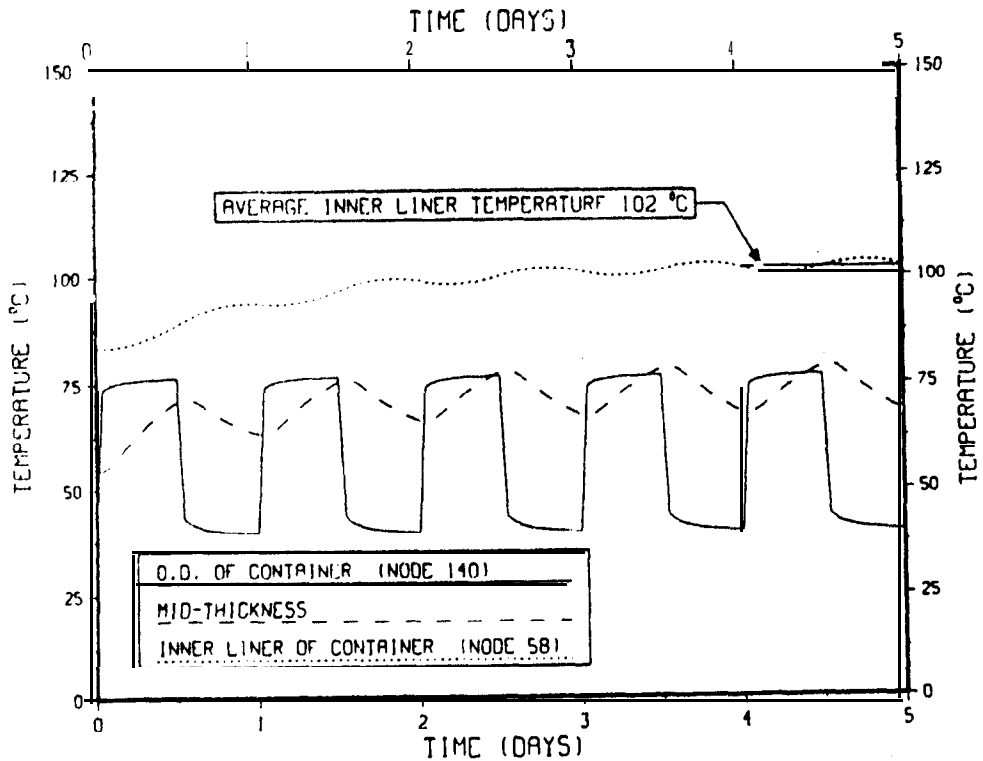


Figure 3.3.2 Temperature-Time Profile of the 55-Gallon 6M Package subjected to Normal Transport Conditions (initial temperatures correspond to a steady-state solution without solar insolation).

3.0 Thermal Evaluation

3.4 THERMAL ANALYSIS FOR NORMAL CONDITIONS • PACKAGE INTERNAL PRESSURES

Maximum internal pressures for normal conditions of transport are a function of maximum package internal temperatures.

The sealed 2R containment vessel of the 6M package may become pressurized due to the heating of the containment vessel under normal conditions of transport. This thermal environment was evaluated in Module 3.3. For normal transport, the maximum internal temperature inside the containment vessel is 117°C (243°F) due to the lo-watt internal heat source and solar insolation acting upon a lo-gallon 6M. The total pressure within the containment vessel will be the sum of the partial pressures of the heated entrapped air, the vapor pressure of any water in the system or the radioactive material form, and the **decompositicn** gases of any of the organic packaging materials. The material form must be dry and packaged in a dry air environment. Further, this analysis assumes negligible decomposition of organic materials.

Therefore, the pressure generated by heating the entrapped air in the 2R containment vessel is given by

$$P_{\text{air}} = 14.7 \times \frac{(243 + 460)}{(70 + 460)} = 19.4 \text{ psia (4.8 psig)}$$

The pressure of the entrapped air is assumed to be the major component of the maximum normal operating pressure (MNOP) of the containment in normal transport.

It should be noted that the imposition of the **assumption** that the material form is dry and that there is no organic decomposition of the organic materials in the packaging is, in **effect**, placing a restriction on the material form and the packaging materials in the 6M. Procedural steps should be implemented that reinforce these requirements. (See modules in Section 7.0).

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3.0 Thermal Evaluation

3.5 THERMAL ANALYSIS FOR NORMAL CONDITIONS • THERMAL STRESSES

Maximum thermal stresses due to normal conditions of transport lie well within the allowable thermal stresses of the containment vessel.

The thermal stresses in the 2R containment vessel are a function of the temperature gradient through the wall of the vessel. An analysis of the temperatures on the inside and the outside of the containment vessel wall was made for the 10-gallon and the 55-gallon 6M geometry. There was essentially a negligible (less than 0.1°C) temperature gradient through the **0.25-inch** wall thickness of the containment vessel, which in turn indicates there is essentially no thermal stress in the containment vessel wall under the thermal environment imposed by the normal conditions of transport.

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3.0 Thermal Evaluation

3.6 THERMAL ANALYSIS FOR ACCIDENT CONDITIONS • PACKAGE TEMPERATURES

Maximum temperatures have been determined for the 10-gallon and 55-gallon 6M packages for hypothetical accident conditions, and these temperature magnitudes indicate that the thermal response of the packages to accident conditions is acceptable.

The temperature **response** for 6M packages exposed to hypothetical accident conditions is presented in Table 3.6.1. These results indicate the following:

1. The maximum inner liner temperature for the 10-gallon 6M package (at Node 58) resulting from the simulation of accident thermal conditions is 120°C (248°F).
2. The Celotex material region will have a 2- to 3-cm thickness that will char [that is, the temperature in this region will exceed the char temperature of 250°C (482°F) to 300°C (572°F), see Ref. 3.6.1].
3. The maximum inner liner temperature for the 55-gallon 6M package (at Node 58) resulting from the simulation of accident conditions is 95°C (203°F).
4. The Celotex material region will have a 2- to 3-cm thickness that will char (see Ref. 3.6.1).

References for Module 3.6

- 3.6.1 Sanchez, L. C., Longenbaugh, R. S., Moss, M., Haseman, G. M., Fowler, W. E., Roth, E. P., Thermal Analysis of the 10-Gallon and the 55-Gallon 6M Containers With Thermal Boundary Conditions Corresponding to 10 CFR 71 Normal Transport and Accident Conditions, SAND87-1896, TTC-0748, Sandia National Laboratories, Albuquerque, New Mexico, March 1988.
- 3.6.2 Shippers-General Requirements for Shipments and Packagings, US Department of Transportation, Title 49, Code of Federal Regulations, Part 173.415.

Table 3.6.1 TABULATED RESULTS FOR THE THERMAL RESPONSE OF 6M PACKAGES
SUBJECTED TO HYPOTHETICAL ACCIDENT CONDITIONS*

Time (Min)	Temperature at Inner Liner of GM Container (°C)	
	Container Capacity 10-Gallon	55-Gallon
0.0**	92.0	83.8
10.0	92.0	83.8
20.0	92.1	83.8
30.0	92.4	83.8
40.0	93.3	83.8
50.0	94.7	83.8
60.0	96.6	83.8
70.0	98.8	83.9
80.0	101.0	83.9
90.0	103.3	84.0
280.0 Peak temperature for 10-gallon 6M	120.3	
1000.0 Peak temperature for 55-gallon 6M		95.0

*Calculated temperatures (from Ref. 3.6.1) correspond to a payload of 10 watts, Ref. 3.6.2.

**Steady-state normal transport condition, without insulation, in accordance with Table 3.2.2.

3.0 Thermal Evaluation

3.7 THERMAL TESTING FOR ACCIDENT CONDITIONS

Maximum and minimum temperatures have been recorded in the thermal testing of 6M packages, and these temperatures lie well within the operating range of the 2R containment vessel.

The thermal tests which represent the thermal environment of the accident conditions of transport were conducted in a 275-kilowatt induction furnace (Ref. 3.7.1) preheated to 830°C (1525°F) before to the 30-minute test runs at 800°C (1475°F).

The test specimen was a 30-gallon 6M, instrumented with thermocouples to continuously record interior temperatures during the test. The test results are shown in Figure 3.7.1. The outer surface of the containment vessel reached a peak temperature of 95°C (205°F). The peak temperature occurred about 2 hours after the start of the test and represents a rise of about 57°C (135°F) above that at the start of the test. Ref. 3.7.2 reports an **additional** set of thermal tests on a 10-gallon 6-M. The package was placed in a pre-heated induction furnace and exposed to the thermal environment for 30 minutes. The thermocouples shorted out during the **first** 5 minutes of exposure and the internal temperatures could not be monitored directly. Temperature-sensitive pellets were placed in **cans in** the containment vessel and on the exterior of the containment vessel. The 93°C (200°F) pellets on the side and bottom of the containment vessel showed 93°C (200°F) had just been recorded. The pellets on the cans in the containment indicated that 65°C (150°F) had been exceeded but 79°C (175°F) had not been reached. There was no scorching of **paint on the radiation label** and no swelling of the tin cans in the containment vessel.

The magnitudes of these observed temperatures on the 2R containment vessel are less than the 149°C (300°F) which is required for maintaining the gasket seal capability in the containment vessel.

References • Module 3.7

- 3.7.1 **Adcock**, F. E., McCarthy, J. D., **Wackler**, W. F., Rocky Flats Model 2030-1 Container, (AEC-AL USA/5332/BLF), (SARP), RFP.1867, Rev. 1, February 27, 1974.
- 3.7.2 **Adcock**, F. E., **Wackler**, W. F., RFD Container, Model 1518 for **Fissile** Class II and Class III Shipments, RFP-1042, The Dow Chemical Co., Rocky Flats Div. Golden, Colorado, 1968.

Time-Temperature Data Recorded from Thermocouple Stations During Thermal Test Runs

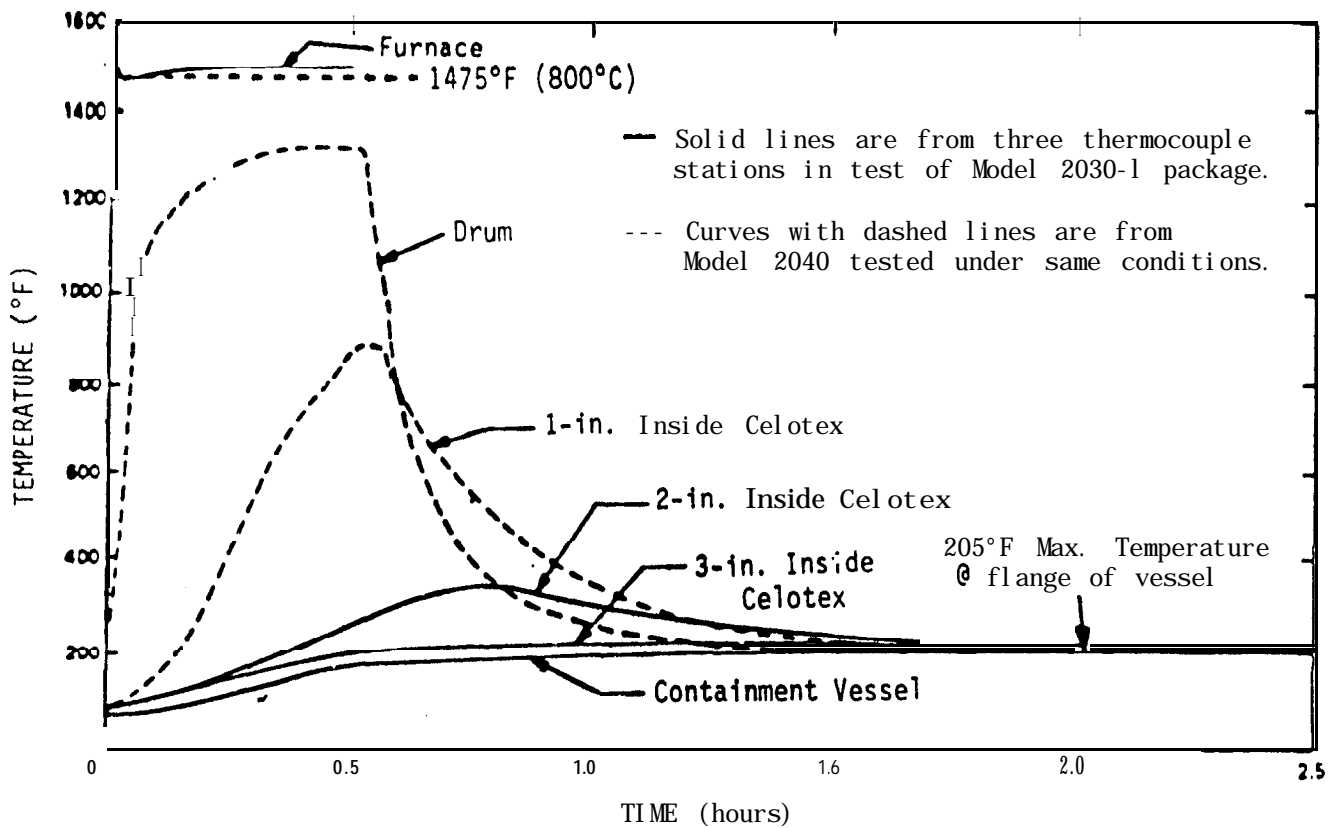


Figure 3.7.1 Time-temperature data recorded from thermocouple stations during thermal test runs (Ref. 3.7.2) on a 30-gallon 6M show the 2R containment vessel is not over-heated.

3.0 Thermal Evaluation

3.8 THERMAL ANALYSIS FOR TRANSPORT ACCIDENT CONDITIONS • PACKAGE INTERNAL PRESSURES

Maximum and minimum internal pressures for accident conditions occur at maximum and minimum internal temperatures for accident conditions, respectively, and lie within the design pressure limits of the 2R containment vessel.

The internal heat generation region in the **transient** analysis model consisted of the radioactive material within the containment vessel itself. The maximum temperatures reached at the inner liner of the 6M package was 120.3°C (248°F) for the 10-gallon 6M. The maximum temperature reached at the inner liner for the 55-gallon 6M was 95°C (203°F). The maximum pressure of the air entrapped in the 2R containment vessel can be calculated as follows.

$$P_{\text{air}} = 14.7 \times \frac{(248 + 460)}{(70 + 460)} = 19.6 \text{ psia (4.9 psig)}$$

The pressure of the air entrapped in the containment vessel (4.9 psig) is well within the structural capabilities of the vessel,

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4.0 Containment

4.1 TYPES OF RADIOACTIVE MATERIALS **AUTHORIZED** FOR 6M PACKAGINGS

The 6M packaging is authorized to contain Type B quantities of fissile and other radioactive materials in solid form.

The solid materials placed in the 6M are normal or special form*, and range from metal or ceramic shapes (e.g., buttons, castings, fuel elements) to powders. The radioactive **de .ay** heat from these materials cannot exceed 10 watts.

Only stable materials that do not decompose, **outgas**, or react chemically with the packaging material up to temperatures of 177°C (350°F) should be packaged in 6M containers. The authorized amount of fissile materials allowed in the 6M container is discussed in appropriate sections of 49 CFR, the DOT regulations.

Dispersible powders require special packaging to provide proper containment. A procedure for packaging dispersible powders is included in Modules 7.2, 7.3, and 7.4. This procedure provides for double **containment** of plutonium oxide powders under hypothetical accident conditions.

*For definition of special form, see 49 CFR Part **173.403(z)**.

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4.0 Containment

4.2 DESIGN AND PERFORMANCE OF PRIMARY AND SECONDARY CONTAINMENT SYSTEM

The containment system (2R containment vessel and sealed metal food pack cans) of the 6M packaging provides containment for authorized radioactive materials in compliance with regulatory requirements,

Containment Boundary

The principal containment boundary for the 6M packaging is the 2R containment vessel, Figure 4.2.1 (see Module 4.2.1). Secondary containment is provided in most cases by sealed food pack cans. All radioactive materials other than special form materials or clad fuel elements must be packaged in one or more secondary containers. When properly sealed 2R containment vessels and metal cans are used, double containment is achieved, even for materials in powder form.

Containment Vessel

The 2R containment vessel, which is considered the primary containment, has been subjected to temperatures of 160°C (320°F) and pressures of 100 psig without leaking greater than 10^{-5} atm-cm³/s. The food pack cans, when properly sealed, can be heated to 177°C (350°F) and pressurized to 15 psig and not leak greater than 10^{-5} atm-cm³/s (Refs. 4.2.1, 4.2.2). The seal on a properly sealed food pack can has also been tested using a helium leak detection technique and found to leak less than 5×10^{-8} atm-cm³/s of helium gas at 24°C (75°F). The leak rates for the 2R vessel and the food pack cans are sufficiently low to prevent releases of radioactive materials in excess of the allowable A_1 , $\times 10^{-6}$ curies per hour under normal conditions and A_2 curies per week under accident conditions (Ref. 4.2.2).

Containment Penetrations

No penetrations such as valves or plugs exist in the 2R containment vessel or the food pack cans.

Seals and Welds

The 2R vessel is sealed by applying a silicone rubber compound (G.E. Silicone Hi-Temp Gasket Material, GEC56002). The silicone rubber has a temperature range of -62°C (-80°F) to 260°C (500°F).

The food pack cans are mechanically sealed using a sealing machine. The sealing operation squeezes a butyl rubber material applied to the can lid into the space between the metal folds.

The 2R vessel has a butt-welded plate on one end. The welds are made in accordance with the A.W.S. D1.1 welding code, and are examined using a dye penetrant procedure and/or radiography.

The side seam of the food pack can is crimped and soldered, or welded after crimping. The welding or soldering operation conforms to the Federal Specification PPP-C-96D.

Closure

The closure of the 2R containment vessel is a pipe cap or plug. After silicone rubber compound is applied to the threads, the cap or plug is tightened using a torque of at least 100 foot-pounds.

The closure for the food pack cans is accomplished with can lids, which are specially designed to fold around a flange on the can body and produce a double seam. This double seam consists of five thicknesses of plate interlocked or folded and pressed firmly together (see Figure 4.2.2). To obtain an air hermetic seal, the lid must be crimp-sealed to the can body using a properly adjusted sealing machine. Instructions for properly adjusting two commonly used sealing machines are given in Ref. 4.2.1.

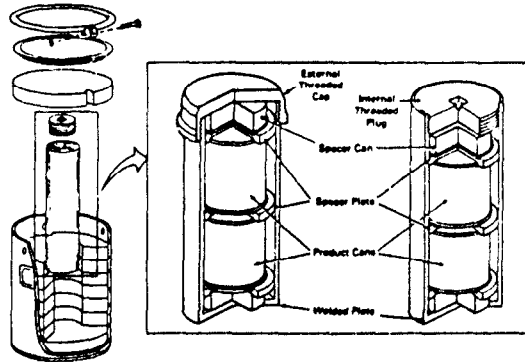


Figure 4.2.1 Both of the typical 2R containment configurations provide for positive sealing during normal and accident conditions of transport.

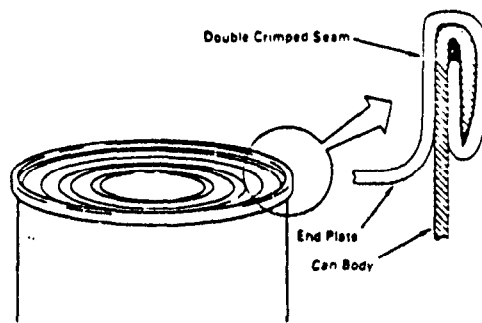


Figure 4.2.2 Section view of completed seam after second seaming roll operation.

References - Section 4.2

- 4.2.1 Taylor, J. M. Gas Leak Characteristics of Inner Packaging Components Used in the DOT-Spec 6M Container, PNL-5591, Pacific Northwest Laboratory, Richland, WA, 1985.
- 4.2.2 Taylor, J. M. Radioactive Particulate Release Associated with the DOT-Spec 6M Container Under Hypothetical Accident Conditions. PNL-5747, Battelle Pacific Northwest Laboratory, Richland, WA, 1986.

4.0 Containment

4.3 PERFORMANCE UNDER NORMAL CONDITIONS OF TRANSPORT

The 2R vessel and inner metal cans of the 6M container provide adequate containment of radioactive materials to meet regulatory requirements under the normal conditions of transport.

The effects of normal conditions of transport are as follows.

Heat: Temperature response for 6M containers (with a thermal payload of 1 watts) for normal transport conditions produce gas temperatures in the region of the 2R vessel of 117°C (243°F). At this temperature, the air pressure inside the 2R is approximately 8 psig. When solar heating is ignored, the temperature reaches 114°C (237°F), which creates an air pressure of approximately 5 psig. These temperatures and pressures are within the service allowance of the 2R vessel and metal food pack cans inside it.

Cold: Minus 40°C (-40°F) ambient temperature does not affect the seals of the 2R vessel and metal food pack cans. The silicone rubber compound used for sealing the threads of the pipe plug or cap of the 2R vessel stays pliable and maintains seals to -62°C (-80°F) (manufacturer's data). The mechanical crimp seal on each metal can is not affected by temperature because the expansion and contraction characteristics are uniform throughout the seal. The mechanical properties of the steel 2R vessel at -40°C (-40°F) are not a problem under normal conditions of transport, because the vessel is protected from impact and vibration forces by the Celotex insulation rings and disks.

Reduced External Pressure: A reduced external pressure of 3.5 psia creates a pressure differential between the inside and the outside of the 2R vessel. This differential (11.2 psia) does not cause leakage; 2R vessels have been tested to 100 psig (114.7 psia) and still remained sealed.

Increased External Pressure: An external pressure of 20 psia does not compromise the seal of a 2R vessel. These vessels have been hydro-tested to 21.7 psia pressure without inleakage of liquid. If the 2R vessel has been properly sealed, the metal cans inside experience no significant pressure differentials.

Vibration: Vibration forces generated during transport have had no effect on the quality of the seals of the 2R vessel and the metal food pack cans. This information is based on shipping records for 6M packages over 17 years of use.

The remaining tests prescribed for normal conditions of transport such as water spray, free drop (1.2 meters), compression, and penetration do not cause any significant damage to the 6M package such that radioactive material is released from the metal cans and the 2R vessel.

Release of Radioactive Material: The **maximum** leakage of helium from a sealed metal can has been measured at 4.8×10^{-8} atmosphere. cubic centimeters per second ($\text{atm-cm}^3/\text{s}$) at 21°C (70°F). The **air leak** rate from a sealed metal can under normal conditions of transport with **no solar heating** [117°C (243°F), approximately 5 psig] is approximately 3×10^{-8} $\text{atm-cm}^3/\text{s}$. **When solar heating** is considered, the air leak rate is approximately 4×10^{-8} $\text{atm-cm}^3/\text{s}$.

A gas leak rate of 10^{-7} $\text{atm-cm}^3/\text{s}$ (dry air at 25°C) (5×10^{-8} cm^3/s leak test sensitivity) is considered to be leaktight (ANSI Standard N14.5). Double containment of plutonium powders can be made by using more than one sealed metal can to **accomodate** each quantity of plutonium and placing the cans in a 2R containment vessel which is then sealed.

Tests have shown that a leak rate test with a sensitivity of 5×10^{-8} cm^3/s is not necessary to determine particle leaktightness under normal conditions of transport. The maximum permissible mass release **rate** under normal conditions for plutonium dioxide (PuO_2) powder is 4×10^{-9} grams per hour.

A test was conducted with depleted uranium dioxide (UO_2) powder (Ref. 4.3.1) placed in food pack cans inside a 2R vessel in a 6M. ²The **outer-most** food pack can (the first sealed barrier) was bubble tested and showed no leakage. The bubble test was done **under field** conditions and had a gas leak rate sensitivity of no more than 10^{-3} cm^3/s . After the 6M drum was dropped 30 feet on an unyielding target and 40 inches onto a **6-inch** steel cylinder (puncture probe), the 2R vessel was removed from the 6M drum and placed in a tube furnace. The tube furnace was heated above 190°C (375°F) for 2 hours, then rotated (at 2 rpm) and vibrated (120 hertz, 0.6 to 0.8 g) for 6 hours, heat-up-and-soak time (6 hours).

The 2R vessel was then removed from the furnace and allowed to air cool. Using a procedure outlined in Ref. 4.3.1, the vessel was sampled 4 days later to determine if any UO_2 powder had leaked from the No. 3 can. No UO_2 powder was detected. The detection level of the analytical method was less than 2×10^{-9} g uranium. The test showed that under conditions more severe than what would be expected during normal **conditions** of transport, the release rate for the powder was less than 2×10^{-9} g/hr.

Consequently, a leakage test that has the sensitivity of 10^{-3} cm^3/s is adequate to determine particle leaktightness for the metal cans used to contain radioactive material.

References • Section 4.3

- 4.3.1 Taylor, J. M. Radioactive Particulate Release Associated with the DOT-Spec. 6M Container Under Hypothetical Accident Conditions, PNL-5747, Battelle Pacific Northwest Laboratory, Richland, Washington, 1986.

4.0 Containment

4.4 PRESSURIZATION OF THE CONTAINMENT VESSEL UNDER NORMAL CONDITIONS OF TRANSPORT

The pressurization of the 2R vessel and metal food pack cans under normal conditions of transport does **not cause leakage in excess** of regulatory requirements.

The pressure buildup inside the 2R containment vessel and the metal food pack cans results from the expansion of the gas atmosphere confined within these containers. Packaging materials such as treated vermiculite, silicone rubber, and plastics do not **outgas** significantly at temperatures up to 177°C (350°F) to contribute to package pressure,

Tests were conducted to determine the degradation and outgassing of polyethylene plastics, polyvinyl chloride plastics, and Celotex up to temperatures of 177°C (350°F). The materials were placed in a container that could be sealed, and the pressure was monitored during heating. [The container was first heated empty to 177°C (350°F), then it was loaded with the plastics or Celotex.]

The amount of plastic loaded into the container was about 100 grams, a typical amount used to "bag out" material from a glove box into a metal can. When the materials were heated to 177°C (350°F), the pressure did not increase above that observed when the container was heated empty to the same temperature.

Eighty-five grams of silicone rubber also were heated to 177°C (350°F) in the container: a small pressure increase of between 2 and 3 psi above the pressure from the **expansion** of the air was observed. This total **amount** of pressure **would not degrade** the seals of the metal cans.

Radioactive materials loaded into the 6M packaging must be stable up to 177°C (350°F), so they do not cause pressurization if they have been properly prepared.

A possible source of pressure buildup could be **vaporization** of the water absorbed by **hygroscopic** powders. Pressurization due to steam generation from absorbed water during the heating of the 2R vessel is considered in Module 4.5. For the present discussion, **it** is assumed the powders are dry when packaged.

The expansion of the gas (usually air) inside **the** 2R vessel and metal cans **is** caused by the decay heat of the radioactive material inside **the** insulated 6M package. Under normal conditions (with **no** solar heating effect **considered**), with 21°C (70°F) ambient temperature and maximum internal heat generation from the radioactive material, the peak temperature within the 2R is 114°C (237°F). The pressure of the gas is:

$$P = 14.7 \times \frac{(237 + 460)}{(70 + 460)} = 19.3 \text{ psia (4.6 psig)}$$

When the solar heat load is considered, the peak temperature would be 175°C (347°F). This would generate a pressure of:

$$P = 14.7 \times \frac{(347 + 460)}{(70 + 460)} = 22.4 \text{ psia (7.7 psig)}$$

Neither pressure would degrade the seals of the metal food pack cans or the 2R containment vessel.

Coolant Contamination: **The air inside the 2R vessel and food pack cans would be considered a coolant because it acts as a heat-transfer medium.** The air itself does not become contaminated, and no radioactive gases are generated by the **types of materials packaged in the 6M container.** Consequently, coolant contamination would not occur.

Coolant Loss: The 2R vessel and **metal cans are** closed containers that do not have vents **or** pressure-relief devices. Venting could only occur through the sealed **threaded** surfaces of the 2R and through the crimped layers of the metal cans. The sealed 2R vessels are bubble tested before first use and on a periodic **basis after** first use. This test has shown that the gas leak rate is less than 10^{-5} cm³/s. The sealed metal cans have been tested for leakage by using a **helium mass** spectrometer. After the metal cans were sprayed **with helium**, the gas in-leakage was compared with a **calibrated** leak of 10^{-8} cm³/s. The leak rates for the 2R vessel and metal cans are low enough to prevent loss of any air containing aerosols (powders).

4.0 Containment

4.5 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The primary and secondary packaging components of the 6M container are assembled to protect the radioactive material from being released in quantities greater than A_2 Ci per week when the 6M container is subjected to hypothetical accident conditions.

The packaging configuration shown in Figure 7.2.1 has protected the metal cans from damage during 30-foot drop tests and 40-inch drops onto a 6-inch diameter cylinder (Ref. 4.5.1). During heating to a temperature of 802°C (1475°F) for 30 minutes, the temperature inside the 2R vessel reached a maximum of 175°C (347°F). The pressure due to the expansion of the gas (usually air) inside the vessel at this temperature is:

$$P = 14.7 \times \frac{(347 + 460)}{(70 + 460)} = 22.4 \text{ psia (7.7 psig)}$$

Another source of pressure is from adsorbed water. Plutonium dioxide (PuO_2) powders are hygroscopic (Ref. 4.5.2). Unless they are treated to remove the water and then stored in dry atmospheres, they will adsorb water in quantities of approximately 3 milligrams water per gram of PuO_2 . If the maximum allowable amount of PuO_2 were loaded into the 6M packaging, there would be enough water to develop an equilibrium condition inside the sealed metal food pack cans. Thus, at 117°C (243°F), the saturated steam pressure inside the cans would be about 120 psig, which would cause the cans to fail. To protect the inner packaging from the high steam pressure, only dry powders must be packaged (Loss of Ignition less than 1 percent).

Fission Gas Products: No materials packaged in the 6M packaging produce fission gas products.

Release of Radioactive Material: Materials that are encapsulated, non-powder materials, and fuel elements will not be released from the 6M container during normal or accident conditions. These materials are considered to be nondispersible. Powders, however, are dispersible; appropriate leak tests must be administered to determine if the package will contain powders under accident conditions. The allowable mass release of reactor-grade plutonium (the more restrictive form of plutonium) is 3.15×10^{-5} g/hr (A_2 Ci/week) under accident conditions. An experimental study, Ref. 4.5.1, demonstrated that when depleted uranium oxide (DUO) powders were packaged as shown in Figure 4.5.1, the 6M container could be subjected to hypothetical accident conditions (the 30-foot drop test, puncture test, and the 30-minute fire test), and the loss of DUO would be less than 3.15×10^{-5} g/hr of powder. The study assumed that the DUO powder would leak in a manner similar to PuO_2 powders. This assumption appears valid. Comparing PuO_2 powder leakage and DUO powder leakage from corresponding sizes of orifices under similar conditions showed the DUO powder has greater leakage (Ref. 4.5.4). One study (Ref. 4.5.1) showed that the DUO powder released was less than the detectable limits (less than 2×10^{-5} g uranium) for the method used to detect uranium (laser fluorimetry). Another study (Ref. 4.5.1) also determined that metal food pack cans having air leak rates not exceeding 96 cubic centimeters per minute do not release powders in excess of the allowable 3.15×10^{-5} grain per hour.

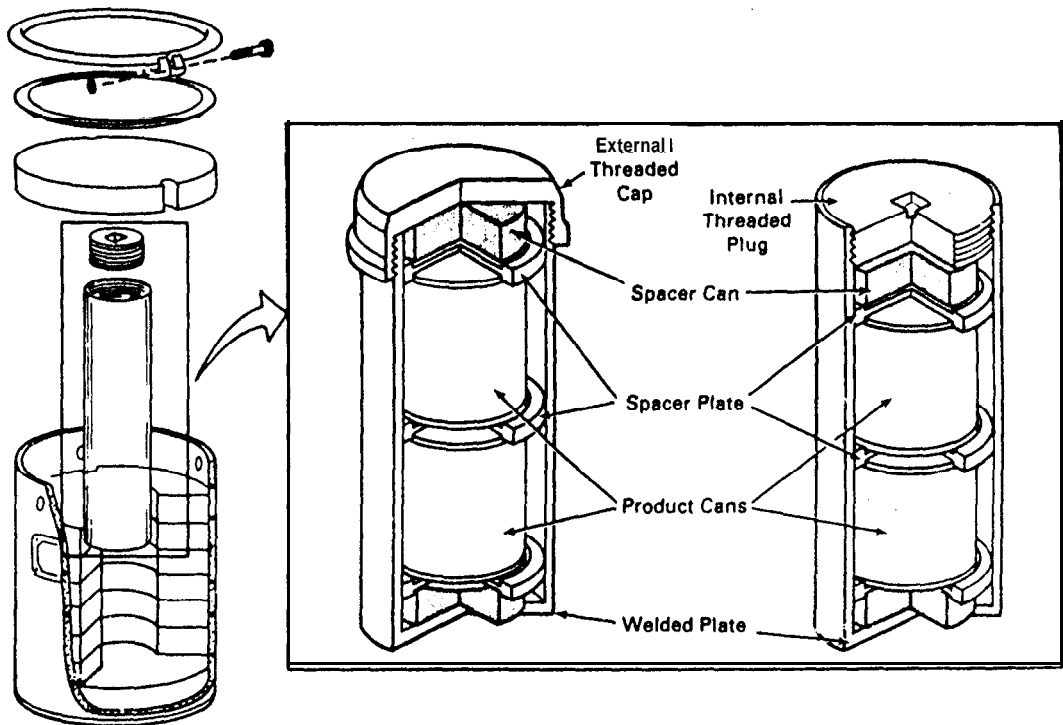


Figure 4.5.1 Packaging arrangement to protect metal food pack cans containing plutonium dioxide inside the 2R containment vessel.

References • Module 4.5

- 4.5.1 Taylor, J. M. Radioactive Particulate Release Associated with the DOT-Spec 6M Container Under Hypothetical Accident Conditions. PNL-5747, Battelle Pacific Northwest Laboratory, Richland, Washington, 1986.
- 4.5.2 Stakebako, J. L., and Dringman, M. R. Hygroscopicity of Plutonium Dioxide, RFP-1056, Dow Chemical Co., Rocky Flats Division, Golden, Colorado. 1968.
- 4.5.3 Sutter, S. L. et al., Depleted Uranium Dioxide Powder Flow Through Very Small Openings, NUREG/CR-1099, PNL-3177, Battelle Pacific Northwest Laboratory, Richland, Washington, 1980.
- 4.5.4 Yesso, J. D., et al., Study of Plutonium Oxide Powder Emissions from Simulated Shipping Container Leaks, NUREG/CR-1302, PNL-3278, Battelle Pacific Northwest Laboratory, Richland, Washington, 1980.

5.0 Shielding

5.1 SHIELDING REGULATIONS

When necessary, shielding may be provided within the 2R containment vessel to reduce penetrating radiation in accordance with federal regulatory requirements,

The level of nonfixed (removable) radioactive contamination on the external surfaces of each package offered for shipment must be kept as low as practicable. This level is specified in 49 CFR 173.443 and 10 CFR 71.78. These regulations also describe the method for assessing the amount of external surface contamination.

Because packages containing radioactive materials (RAM) may be carried on the same vehicle as passengers, a simple system was developed to determine how many passengers could be loaded and how to segregate the packages from passengers and film. This system is the radiation transport index (TI), which yields the highest dose rate at 1 meter (3.3 feet) from any accessible external-surface of the RAM package measured in millirems per hour, rounded to the next highest tenth. The radiation level at any point on the external surface of the package must not exceed 200 millirems per hour, and the TI may not exceed 10 except for packages shipped by exclusive-use vehicles.

When more than one package is loaded onto a transport vehicle, a total transport index is obtained by adding the TIs for each individual package. The total TI for a single vehicle or storage location generally may not exceed 50.

All packages must retain their shielding effectiveness during normal transportation. The TI must not increase during transport as the result of faulty shielding, from shifting of the packages, or from the movement of the shielding in the packages.

Packages shipped by rail, highway, or water in exclusive-use closed transport vehicles may not exceed the following radiation levels as provided in 49 CFR 173.441(b) and similar requirements in 10 CFR 71.47:

- One thousand millirem/hour on the external package surface.
- Two hundred millirem/hour at a point 2 meters (6.6 feet) from the vertical planes projected by the outer lateral surfaces of the car or vehicle; or, in the case of an open vehicle, at any point 2 meters from the vertical planes projected from the outer edges of the vehicle.
- Two millirem/hour in any normally occupied position in the car or vehicle.

(This provision does not apply to private motor carriers when the personnel are operating under radiation protection and wear radiation-exposure monitoring devices.)

Any package containing more than limited quantities of RAM must be labeled on two opposite sides with one of the three warning labels: "RADIOACTIVE WHITE I," "RADIOACTIVE YELLOW II," or "RADIOACTIVE YELLOW III" (49 CFR 173.421). Table 5.1.1 gives a summary of the RAM package label criteria.

Table 5.1.1 RAM **PACKAGE** LABELING REQUIREMENTS ARE SPECIFIED BY DOT REGULATIONS.

Transport Index (TI)	Radiation Level at Package Surface (RL)	Fissile Criteria	Label Category*
N/A	0.5 millirem/hour	Fissile Class I only, No Fissile Class II or III	White I
1.0	0.5 millirem/hour	Fissile Class I, Fissile Class II with TI 1.0, No Fissile Class III	Yellow II
1.0	50 millirem/hour	Fissile Class II with TI 1.0, Fissile Class III	Yellow III

* Any package containing a "Highway Route Controlled Quantity" (49 CFR 173.403) must be labeled as Radioactive Yellow III, (DOT, 1983).

5.0 Shielding

5.2 NON-SHIELDED 6M CONFIGURATIONS

Some AM designs are configured such that the packaging components provide sufficient shielding material to meet the regulatory requirements for surface radiation.

In order to prepare a general and conservative shielding analysis for the 6M packaging, a single point source of Cobalt-60 with an activity equal to 1 curie was assumed to be located at the interior wall surface of the 2R containment vessel. The point source is meant to be a generalized approach to evaluating the shielding properties of typical 6M packagings in the limited sizes (limited in the sense of radial dimension) 10- and 55-gallon drums. In volume, the 110-gallon drum is the largest size of the 6M packagings, but its diameter is the same as that of a 55-gallon drum. Actual surface dose rates can be determined by linearly extrapolating the results from a 1-Ci source, as shown in Table 5.2.1, to the specified activity. The location of the source and the geometry of the shielding design are shown in Figure 5.2.1.

The variables for the 10- and 55-gallon geometries are given in Table 5.2.2. The energy-dependent variables are shown in Table 5.2.1, and the shielding analysis results for a 1-Ci source for the non-shielded version of the 6M are presented in Table 5.2.2.

For a single shield design the surface dose rate is given in the equation below:

$$\text{Surface Dose Rate} = \text{DR} = \frac{[(O)(M)(E)(Ss)(Bs)]e^{-Ust}}{4\pi r^2} \quad (5.2)$$

where

- ss = source strength (photons/second)
- r = radius centimeters
- Bs = build-up factor shield
- us = shield attenuation coefficient (centimeters)
- t = shield thickness (centimeters)
- E = gamma energy (million electron volts • MeV)
- M = mass energy absorption coefficient
(centimeter² per gram • cm/g)
- Q = 1.6 x 10⁻⁸ rad per MeV/g

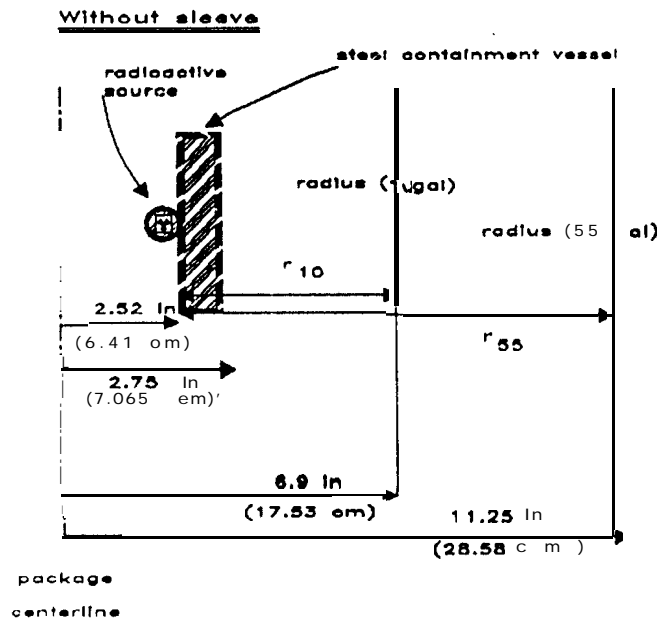


Figure 5.2.1 6M non-shielded design configuration shows the radioactive source and shielding design geometry.

Table 5.2.1 GAMMA-SPECIFIC DATA FOR 6M NON-SLEEVED DESIGN ARE USED TO CALCULATE DOSE RATES.

Gamma	E (MeV)	μ_s (cm^{-1})	B_s (unitless)	M (cm^2/g)
1	1.17	0.45	1.4	0.03
2	1.33	0.45	1.4	0.03

Table 5.2.2 THE SHIELDING ANALYSIS SUMMARY FOR THE LIMITING RADIAL SIZES OF 6M PACKAGES SHOWS BASIC DOSE RATE DATA.

6M Drum Size (non-sleeved design)	Surface Dose Rate (millirads per hour)
10 gallons	7.8×10^1
55 gallons	2.1×10^1

5.0 Shielding

5.3 SHIELDED 6M CONFIGURATIONS

Some radioactive materials transported in 6M packages have sufficient source term magnitude that it is necessary to install additional shielding material in the package in order to meet the regulatory requirements for surface radiation.

Some 6M configurations may require additional shielding because of the magnitude of the activity of the material being transported in the package. When this is the case, an additional amount of shielding may be installed into the interior of the 2R containment vessel. Based upon material in Ref. 5.3.1, the shielding for this type of geometry can be approximated by

$$DR = \text{Surface Dose Rate} = \frac{(S)(Bs1)(Bs2)e^{-[(us1)(t1) + (us2)(t2)]}}{4\pi r^2}$$

where Bs1 and us1 are the gamma-specific data for the first or inner shield (depleted uranium) and Bs2 and us2 are the gamma-specific data for the second or outer shield (steel, the wall of the 2R containment vessel).

The geometric variables for the sleeved design are shown in Figure 5.3.1, the energy-dependent variables in Table 5.3.1, and the surface radiation dose from a 1-Ci source from the sleeved design in Table 5.3.2. As with the non-sleeved design, the results for the surface dose rate from the 1-Ci source can be linearly extrapolated to obtain the surface dose for the magnitude of RAM being transported in a sleeved 6M package.

Table 5.3.1 THE DATA SHOWN ARE USED IN THE GENERIC SHIELDING CALCULATIONS

Gamma	E (MeV)	us1 (cm ⁻¹)	us2 (cm ⁻¹)	Bs1 (unitless)	Es2 (unitloss)	M (cm ² /g)
1	1.17	1.31	0.45	2.5	1.5	0.03
2	1.33	1.31	0.45	2.5	1.5	0.03

Table 5.3.2 THE GENERIC SHIELDING ANALYSIS CALCULATIONS ARE SHOWN FOR A 1-Ci Co-60 SOURCE.

Drum Size	Surface Dose Rate (mrad/hr)
10 gallons	1.5 x 10 ⁴
55 gallons	4.1 x 10 ³

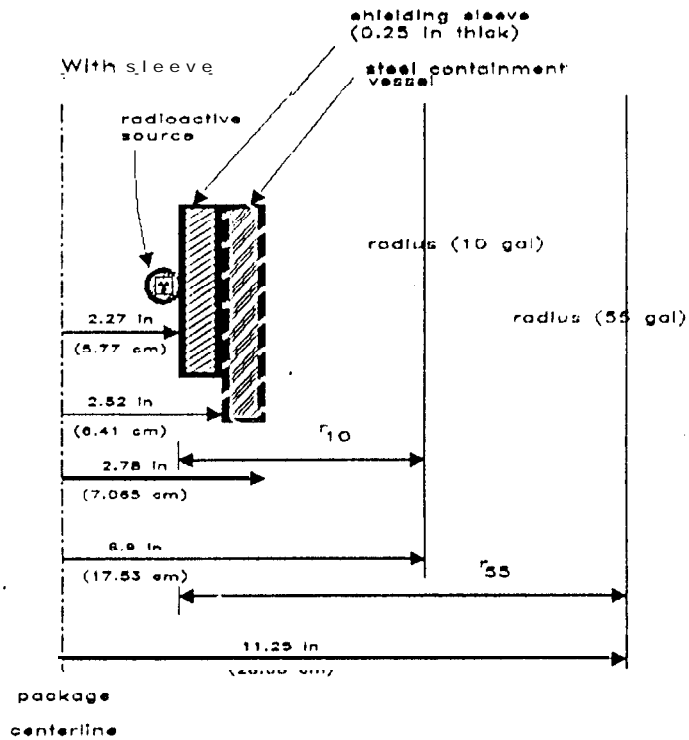


Figure 5.3.1. The 6M shielded-design configuration.

References • Module 5.3

- 5.3.1 Morgan, K. Z., Turner, J. E., Principles of Radiation Protection, R. E. Krieger, Publishing Co., 1973.
- 5.3.2 Jaeger, R. G., ed., Engineering Compendium on Radiation Shielding, Vol. I, Springer-Verlag, New York, 1968.

6.0 Criticality

6.1 USE OF 6M FOR SHIPMENT OF FISSILE MATERIAL

The 6M packaging provides a satisfactory method of transporting several fissile materials.

A 6M container of appropriate size may be selected for many fissile material transport applications. Detailed evaluations have been provided for Uranium-235, Plutonium 239, and Uranium-233. Resulting allowable loadings and transport indexes (TIs) provide more economical transport than previously authorized.

The tabulated mass values for Uranium-235 may be applied to any enrichment. The 10-watt thermal heat load restriction on the 6M results in maximum loadings of approximately 20 grams of Plutonium-238 and approximately 96 grams of Americium-241. Tabulated plutonium mass values may be applied to Neptunium-237 in the absence of validated calculations for this material.

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6.0 Criticality

6.2 TABULATED VALUES OF FISSILE CLASS I AND CLASS II LIMITS

The derived fissile material mass limits meet a wide variety of packaging and transportation needs.

The fissile materials of greatest interest to the DOE and its contractors for shipment are enriched uranium and plutonium. An occasional need arises to transport Uranium-233. Fissile Class I package limits are provided for these materials loaded in 10-, 15-, 30-, 55-, and 110-gallon sizes of 6Ms (Table 6.2.1). Fissile Class II package limits provided for the 30-gallon 6M are also applicable to the 55- and 110-gallon sizes (Table 6.2.1).

The influence of fissile material density on allowable loadings is a complex function of container size, array size, and material density. Increased moisture content reduces the quantity of fissile material that may be loaded in a container for a specified transport index. These influences have been accommodated in a detailed criticality evaluation (Ref. 6.2.1).

The evaluations performed on the 6M package covered a broad range of fissile materials and forms for various packaging sizes. The analyses were performed to satisfy fissile material mass limit requirements for:

1. The single package safety analysis of 10-, 15-, 30-, 55-, and 110-gallon 6M packagings.
2. Fissile Class I packages (minimum Transport Index = 0.0) of the 10-, 15-, 30-, 55-, and 110-gallon 6M packages as subcritical infinite arrays of undamaged and damaged packages.
3. Fissile Class II packages (minimum Transport Index = 0.1, 0.5, 1.0, 5.0, and 10.0) of 30-gallon 6Ms; this information may be then applied to the 55-gallon and 110-gallon 6M sizes.

The criticality evaluation given in Ref. 6.2.1 provides an adequate basis for the subcritical nature of 6M packagings. Additional margins of subcriticality have been introduced into the safety analysis by considering 100 percent fissile isotopes. These circumstances plus other real considerations (such as less than theoretical material densities and less reactive material compositions) provide substantial margins of safety for the single package configuration, and to a lesser extent, for the array evaluations. It is concluded in Ref. 6.2.1 that the material mass limits and conditions outlined in Table 6.2.1 for the use of 6M packagings meet specific federal criticality safety regulations found in 10 CFR and 49 CFR.

References - Module 6.2

- 6.2.1 Thomas J. T., and Hopper, C. M. Nuclear Criticality Safety Analysis for the 6M Specification Package, (Draft Report), ORNL-6176, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 1986.

FISSILE CLASS I MASS LIMITS (KILOGRAMS) FOR URANIUM AND PLUTONIUM

Material	Form	H/x Density of Uranium or Plutonium (g/cm ³)	Package Size (gallons)					
			10	15	30	55	110	
135 ^u	metal or alloys	0	>4.7	0.91	1.69	15.08	20.75	23.5
	compounds	<1	1.1 to 7.1	0.65	1.21	1.50	23.12	34.5
		<3	1.1 to 4.6	0.48	0.91	7.00	17.11	30.38
		<10	0.5 to 2.1	0.27	0.51	4.25	10.51	19.25
213 ^u	metal or alloys	0	>4.6	0.49	0.84	6.62	7.39	7.39
	compounds	<1	1.7 to 1.0	0.42	0.76	5.99	12.54	16.50
		<3	1.1 to 1.5	0.31	0.60	6.19	10.72	15.63
		<10	0.5 to 2.0	0.18	0.34	2.33	5.94	9.96
Pu	metal or alloy	0	>4.9	0.47	0.74	4.99	5.76	5.25
	compounds	<1	1.8 to 1.4	0.46	0.81	7.84	10.41	10.41
		<3	1.2 to 4.7	0.36	0.68	5.62	10.1	10.41
		<10	0.5 to 2.1	0.2	0.44	3.42	7.65	10.41

Fissile Class II Uranium Mass Limits for 30-gallon 6M

Material	Form	H/x Density of Uranium (g/cm ³)	Transport Index					
			0.1	0.5	1.0	5.0	10.0	
235 _U	metal or alloys	0	>4.7	18.0	20.2	21.6		
	compounds	<1	1.8 to 7.1	11.0	22.2	25.3	34.0	41.0
		<3	1.1 to 4.6	14.0	18.0	20.7	27.6	31.5
		<10	0.5 to 2.1	6.5	8.8	10.0	14.0	15.8
233 _U	compounds	<1	1.7 to 7.0	8.6	11.0	12.0	15.0	16.5
		<3	1.1 to 4.5	7.0	9.3	10.3	13.6	17.2
		<10	0.5 to 2.0	1.6	1.6	6.3	8.3	9.1

Notes for Tables 6.2.1

1. Uranium containing more than 1 percent of U-233 shall be treated as U-233.
2. Uranium containing more than 1 percent of plutonium (Pu) shall be treated as plutonium.
3. When both the U-233 and the Pu content exceed 1 percent, the most restrictive limit shall apply.
4. The plutonium limits apply to any plutonium isotopic composition so long as the Pu-240 content exceeds the Pu-241 content.
5. The maximum internal heat load for any 6M package is 10 watts,
6. The maximum useable internal diameter of the 2R containment vessel used for U-233 shall be 4 inches.
7. Allowable loadings shall comply with all features of Table 6.2.1. For (example, a shipment of UO₂-235 at a density of 0.95 shall use the Fissile Class I limit appropriate to an H/x of 10, even though the actual H/x is less than one.
8. Plutonium values in excess of 4.5 kg are provided for use with mixtures of uranium and plutonium not exceeding the 10-watt limitation,
9. The tabulated mass values are for total uranium and plutonium without regard to isotopic content.

6.0 Criticality

6.3 BASIS FOR TABULATED LOADING VALUES

The method of deriving the allowable loadings for the 6M has resulted in compliance with the criteria presented in the regulations of the United States and the International Atomic Energy Agency.

While puncture and drop tests result in some distortion of the outer drum of the 6M, this small magnitude of deformation of the packaging has no influence on the allowable loadings. Array calculations have been based on the closest possible stacking of the containers.

Exposure of the 6M to the thermal test representing hypothetical accident transport conditions results in charring of the outer portion of the Celotex insulating disks and rings. In the array calculations, the hydrogen and oxygen were removed from the outer 2-inch region of the Celotex. This is consistent with the results of actual thermal tests.

Single-package evaluations assumed full water reflection and water inleakage to the 2R containment vessel, with the fissile material distributed in the most reactive concentration achievable, as determined by validated computational techniques.

The evaluation of single-package configurations and arrays of 6M packagings used broadly accepted calculation techniques. The specific codes used are common discrete coordinate and Monte Carlo computer programs. All the input parameters and processing techniques are part of the SCALE program (Ref 6.3.1), which is the preferred analytical approach of the NRC.

References • Module 6.3

6.3.1 SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200, published 1982, revised June 1983. December 1984.

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7.0 Operating Procedures

7.1 OPERATING PROCEDURES FOR 6M PACKAGINGS

The safety of 6M packagings used in support of DOE programs is assured by strict observance of detailed operating procedures and inspections.

For 20 years the 6M container has served as one of the nation's primary "Type B" packagings. During this period there has never been a serious accident or release of radioactive contents from a 6M package to the environment. This record is due partly to the design and partly to the careful adherence to the operating procedures and inspections developed by the users of these packagings.

Procedures for the following operations are included in Section 7, Operating Procedures:

<u>Module</u>	<u>Operation</u>
7.2	General specifications and requirements for plutonium packagings
7.3	Packaging of plutonium material in food pack cans
7.4	Loading of the 2R containment vessel
7.5	Final assembly of the 6M package
7.6	Unpacking procedures for the 6M package

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7.0 Operating Procedures

7.2 GENERAL SPECIFICATIONS AND REQUIREMENTS FOR PLUTONIUM PACKAGINGS

The following generic specifications are intended to apply to all plutonium packaging for shipment. More detailed requirements are given for dispersible materials in the following section. This set of specifications is intended to call attention to the principal factors that need to be controlled in the transport of plutonium material.

The inner packaging shall not degrade and shall remain intact when subjected to the maximum temperature expected during normal shipment. Determination of the maximum shall include: (1) heat from radioactive decay, chemical reactions within the package, and external heat sources, (2) evaluation of insulation or barriers to heat flow, and (3) evaluation of the package configuration inside the insulated drum for the maximum credible time.

Pressure within the food pack cans and 2R vessel shall not exceed the pressure that these components are subjected to during leak testing, (e.g., bubble testing at approximately 15 psig). Considerations relating to the maximum pressure shall include: (1) gas formation due to thermal decomposition of the contents, (2) thermal expansion of the gases, (3) radiolytic gas generation, and (4) gas formation by chemical reactions within the package.

The outer surface of the sealed metal containment system shall be free of radioactive contamination.

Each containment system (metal food pack can) shall be clearly and uniquely labeled. The label shall be legible after being subjected to maximum normally expected temperature and radiation dose for the maximum credible time.

Each package or shipment shall include a complete listing of the contents. The listing shall describe the material within each containment system. If needed, special handling instructions for unpacking shall be included with the packing list.

Solid plutonium compounds that are dispersible, such as powders, and are stable in air at the credible shipping temperature shall be placed in a metal container (such as a taped slip-lid can), which is then placed in a sealed polyethylene bag. This bag is placed inside a mechanically sealed food pack can. Finally, the food pack can is placed inside another mechanically sealed food pack can.

*The temperature expected to be achieved as a result of exposure to the hypothetical accident conditions, approximately 149°C (300°F).

The compound must have a loss of ignition (LOI)* of less than 1 percent when heated in an inert atmosphere at **450°C** (842°F) for 2 hours. Compounds that react with air, such as **carbides or hydrides**, must be packaged in an inert atmosphere. Prior to shipment, the powders must be stored in a dry atmosphere (dew point, 21°C (70°F)) to prevent adsorption of water.

* LOI is usually a measure of volatile components. Some chemical reactions could result in weight gain on ignition, and if this is possible, a method other than weight change must be used to determine volatile components.

7.0 Operating Procedures

7.3 PACKAGING OF PLUTONIUM MATERIAL IN **FOOD PACK** CANS

The packaging of plutonium materials in food pack cans according to the following procedure will contain dispersible plutonium powders within the regulatory limit.

This procedure pertains to the operation of placing the plutonium material in food pack cans before placing the cans in the 2R containment vessel. At this stage of the operation, the plutonium has been placed in a metal container such as a taped, slip-lid can inside a glove box. The metal container has been "bagged out", that is, placed in a polyethylene bag inside the glove box and made ready for placement in the food pack can.

The food pack cans used to contain the plutonium material must conform to Federal Specification PPP-C-96D. The cans are classified as Type I, Class 3, packer's cans. Only ribbed reinforced lids (concentric rings) shall be used. The flat profile (no rings) lids will permanently deform when pressurized to 15 psig during bubble testing.

Packaging Procedures

- 1 Inspect can body and make certain it is not dented or damaged.
- 2 Inspect the flange on the can body. If the flange has been severely bent or creased, do not use it. Small creases can usually be straightened by using long-nose pliers. Run your finger around the flange to make certain it is smooth and no **discontinuities** are **present**. Generally, there is a small ridge in the flange where the side seam intersects it, If the ridge is quite abrupt, smooth it off carefully with a fine-toothed jewelers file or discard the can.
- 3 Inspect the lid and make sure the rim where the rubber compound has been applied is smooth and uniform. There should be no exposure of metal showing through the rubber compound. If there are scratches or shiny spots (metal showing through), discard the lid. Also, make sure the curl or roll-over at the rim of the lid is uniform and not dented.
- 4 Place the bagged container (polyethylene bag) in the food pack can (No. 2 1/2 size) as shown in Figure 7.3.1. The silicone rubber spacers shown are about **0.5-inch** thick. Do not force or stuff the bag into the food pack cans.
- 5 Place the lid on the can and check to see that the lid is seated properly. The curl on the rim of the lid should be below the flange on the can. Do not rotate the lid on the flange, or the rubber compound may be scratched or damaged.
- 6 Center the cans on a properly adjusted can sealer (see Appendix B of Ref. 7.3.1). Rotate the base **plate to** make certain the can is centered.

7. Raise the can or lower the chuck depending on the sealer, making sure the lid to be sealed is properly engaged in the chuck. Position the can so that the part of the lid directly over the side seam on the can does not contact the seaming roller first.
8. Before cranking the handle of the sealer (motorized can sealers return to correct starting position automatically), make certain that the seaming rollers are in the proper starting position (see Ref. 7.3.1 Appendix B, for discussion on properly setting up the sealer). Crank the handle in the clockwise direction. Try to maintain a uniform rotation through the sealing operation. If a motorized can sealer is being used, only use one complete cycle to seal the cans. Repeating the the cycle will not provide better seals, but may degrade the first sealing operation.
9. Lower the turntable or raise the chuck, and remove the can. If the can is stuck on the chuck, the second seaming roller is set too tight.
10. Visually examine the can for obvious defects as illustrated in Appendix B of Ref. 7.3.1. If defects are present, the can sealer is out of adjustment and must be repaired.

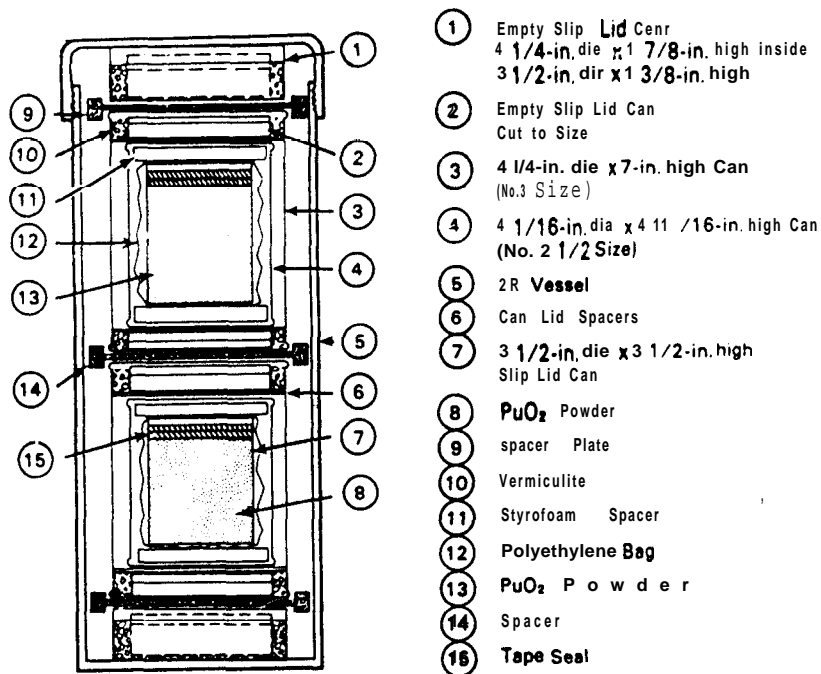


Figure 7.3.1 Packaging arrangement to protect metal cans containing PuO₂ inside 2R containment vessel.

References - Module 7.3

- 7.3.1 Taylor, J. M. Gas Leak Characteristics of Inner Packaging Components Used in the DOT-Spec 6M Container, PNL-5591, Battelle Pacific Northwest Laboratory, Richland, Washington, 1985.

7.0 Operating Procedures

7.4 LOADING OF THE 2R CONTAINMENT VESSEL

Leak tightness of the DOT-2R containment vessel is assured by proper **luting** (sealing) and torquing of the vessel's cap or plug closure.

A visual inspection of the threads on the 2R containment vessel body and pipe cap or plug should be conducted prior to use. If the threads are damaged continuously from the bottom of the thread to the top, then the part must be rejected. The fit between **the** mating parts determines how well a pipe assembly seals. Steps that should be taken in order to obtain a proper seal are listed below.

1. Visually inspect the threads on the 2R containment vessel pipe body and pipe cap or plug. If the threads are damaged continuously from the bottom of the thread to the top, reject the part. Repair minor damage using a thread dressing tool.
2. Stack the cans inside the containment vessel as shown in Figure 7.4.1. The impact-absorbing cans shown between the No. 3 cans are made by cutting a 4 1/4-inch-diameter x 5 9/16-inch-high slip-lid can. The inner can shown can be made up from a 3 1/2-inch-diameter x 3 1/2-inch-high slip-lid can. The inner can is centered inside the outer can with vermiculite. Spacer plates are required between the No. 3 cans and the impact-absorbing cans so that the impact load will be transmitted to the sidewalls of the No. 3 cans. This will prevent the No. 3 cans from deforming during impact. The details of the spacer plates are shown in Figure 7.4.2. To prevent the can lids from becoming concave during impact, fill the space between the can lid and the spacer plate. This can be done by forming a plug of a low-melting alloy such as **bismuth-cadmium** (60 percent Bi, 40 percent Cd), Melt the alloy and pour it onto the lid of a sealed No. 3 can. Level the plug by drawing a straight edge across the top of the can. After the plug has solidified, remove it and file off enough material around the circumference so it fits easily onto the lid of the can. The plug will conform to the shape of the can lid as shown in Figure 7.4.3. The plugs are easy to fabricate and are reusable.
3. Coat the threads on the containment vessel body and cap or plug with a liberal amount of G.E. Silicone Hi-Temp Gasket Material, or equivalent material approved by DOE, and screw the plug or cap into or onto the containment vessel body until hand-tight.
4. Place the containment vessel in a vise or other holding device and secure it so it will not slip.
5. Using a torque wrench with a pipe clamp or plug fixture, tarque the cap or plug to **100** foot-pounds.
6. Wipe off the excess pipe compound.
7. Bubble test* (see ANSI Standard N.14.5, Appendix A, A3.6, for bubble test procedure). If no streaming bubbles are observed, the seal is adequate.

*If G.E. Silicone Hi-Temp Gasket Material is used on the threads, **allow 12** to 14 hours for curing of the material before bubble testing the seal.

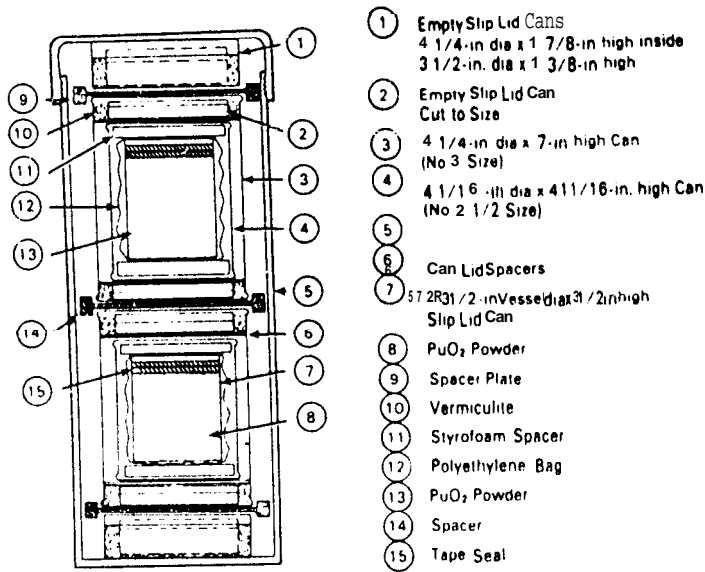


Figure 7.4.1 The packaging arrangement for the metal cans in the 2R containment vessel is shown.

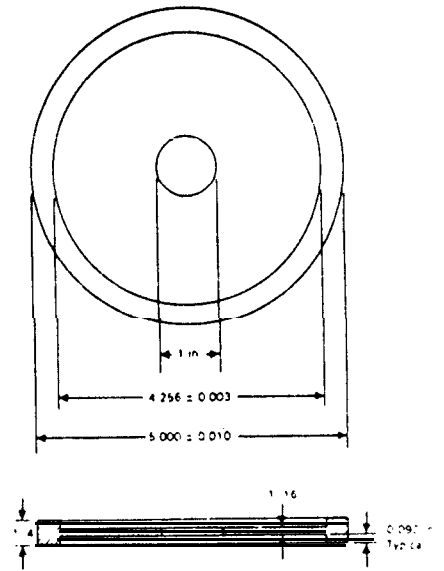


Figure 7.4.2 Metal spacer plates are used to separate the food product cans from the spacer cans.

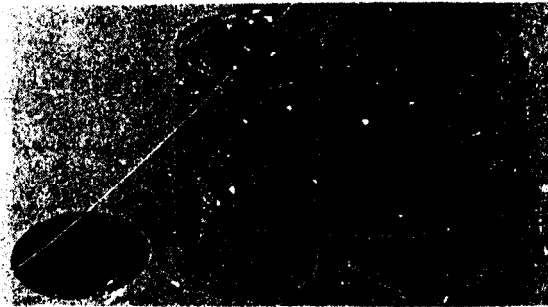


Figure 7.4.3 Metal plugs are used to protect the can lids from impact forces.

8. If less than one kilogram of powder is packaged, the plugs do not have to be used.

References - Module 7.4

7.4.1 Taylor, J. M. Radioactive Particulate Release Associated with the DOT-6M Container Under Hypothetical Accident Conditions, PNL-5747, Pacific Northwest Laboratory, Richland, Washington, 1986.

7.0 Operating Procedures

7.5 FINAL ASSEMBLY OF THE 6M PACKAGE

Package integrity is assured during final assembly according to **verifiable** procedures.

The final assembly of the 6M package consists of a number of verification steps to ensure total compliance with the DOT regulations in 49 CFR. Shown below is a checklist that will assist in complying with the DOT regulations.

1. Verify that the radioactive material to be shipped complies with DOT regulations.
2. Ensure that packaging of radioactive material is in a metal can or a polyethylene bottle, if the material is not special form.
3. Inspect the 2R containment vessel for damaged threads or other defects before placing the metal cans or polyethylene bottles into the vessel.
4. Verify that the threads on the vessel body and the cap or plug have been coated with a liberal amount of G.E. **Silicone** Hi-Temp Gasket Material.
5. Allow approximately 10 to 12 hours for the silicone sealing compound to cure before performing the leak testing. Ensure that the containment vessel cap or plug has been torqued (see Table 7.5.1) and leak tested.
6. Visually check the drum, drum lid, **lid** gasket, and locking ring (including lug welds) for defects.
7. Verify that the vent holes are functional.
8. Visually check the Celotex rings and disks for defects
9. Place the 2R containment vessel into the cavity formed by the Celotex rings and disks, and assemble the remaining rings and disk(s). Packages over 480 pounds require steel or wood bearing plates.
10. Verify that the 2R containment vessel is flush below the surface of the top Celotex ring to prevent gapping.
11. Verify a 0.5-inch gap (maximum) between the drum lid and the Celotex disk. Fill the gap with non-combustible packing material.
12. Secure the locking ring with the proper bolt and locking nut. Torque the locking ring bolt to the appropriate foot-pound level while tapping the locking ring with a soft-head hammer. Verify that the ends of the locking ring have not closed (come into contact with each other). (See Table 7.5.1 for bolt sizes and torque values.)

13. Check that the closure-ring bolt has been secured with a lock nut or equivalent device.
14. Apply the **lead wire** security seal to the **locking** ring and locking ring bolt.
15. Verify that the metal nameplate has been attached (welded) to the drum and that the markings on the 6M are legiile.
16. Attach the radioactive material label in two places as required by the DOT regulations. Check that the Transport Index **(TI) is** marked, where applicable.

Table 7.5.1 BOLT TORQUE SPECIFICATIONS FOR 6M PACKAGING
CLOSURE RING BOLTS.

Drum Capacity (gallons)	Minimum Bolt Diameter (inches)	Required Torque (foot-pounds)
Maximum	5/16	35 + 5
Over 15	5/8	45 + 5

7.0 Operating Procedures

7.6 UNPACKING PROCEDURES FOR THE 6M PACKAGE

Special attention must be given when unpacking dispersible, fissile, and other radioactive materials with respect to type of room filtration, protective clothing, health physics monitoring, and radioactive material packaging. Outlined below are steps that will assure that appropriate safety measures are taken to reduce the level of risk to as low as reasonably achievable.

1. Verify packaging contents using shipping papers and package serial number.
2. Conduct a radiation survey of the package surface to ascertain level of contamination (if any) and radiation dose rate.
3. Verify the presence of lead security seal on the drum locking ring and that the security seal is intact.
4. Put on protective clothing such as lab coat, rubber gloves, booties, and respirator.
5. Break the security seal and loosen locking ring bolt. Remove locking ring.
6. Remove drum lid while performing health physics survey for surface contamination on the inside of the package lid.
7. Remove Celotex end disk(s) and enough of the Celotex rings to provide a hand-hold on the 2R containment vessel. Check for contamination during this operation.
8. Remove the 2R containment vessel from the interior of the package, check for external contamination, and measure the radiation dose rate.
9. Open the containment vessel (lid torque is 100 foot-pounds) and remove metal cans or polyethylene bottles. Check for surface contamination.
10. Provided the internal contamination limits found in 49 CFR, Part 173.443 are met, reassemble empty shipping container, remove old labels, and affix an "Empty" label to the **outer drum**.

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8.0 Acceptance Tests and Maintenance Program

8.1 INSPECTION PRIOR TO FIRST USE OF THE PACKAGING

Acceptance tests ensure that the packaging will comply with the design intent and the federal regulations.

The acceptance testing program must include a visual and dimensional inspection of the 6M packaging and its components. This inspection will include a visual and dimensional inspection of the outer drum, Celotex rings and disks, 2R containment vessel, and other components. In addition, the welds on the outer drum and the containment vessel must be inspected by radiographic means, or an equivalent penetration inspection method.

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9.0 Quality Assurance

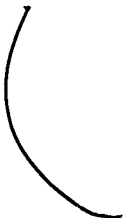
9.1 STRUCTURE AND FUNCTION OF THE QUALITY ASSURANCE PROGRAM

A formal organizational structure has been established and documented at the DOE Field Offices to provide adequate control over activities important to the safety of the 6M shipping package.

The DOE Quality Assurance (QA) program establishes controls over and ensures uniformity of procedure for activities such as packaging inspection, cleaning of exterior surfaces and components, purchase of additional packagings, and preparation of the packaging for delivery.

QA procedures involve multiple functions, including inspections. These inspections must be performed by personnel independent from the individuals performing the functional activity being inspected. A **similar** degree of independence must be maintained for other functional aspects of the QA program.

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9.0 Quality Assurance

9.2 QUALITY ASSURANCE PROGRAM FOR 6M PACKAGINGS

The generic **18-point** DOE QA Program is further addressed, with emphasis on safety-related features.

DOE's QA Program is implemented through five DOE field offices and their respective QA Orders. This program contains **18 elements** as identified in ANSI/ASME, NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities" (Ref. 9.2.1).

9.2.1 Program Objectives

The stated objective of the QA Program for 6M packagings is to monitor the various aspects of design, fabrication, procurement, and maintenance procedures to meet the transportation objectives that support DOE defense programs and waste management program activities. Program objectives include:

1. Identifying all safety-related features of 6M packagings.
2. Assuring that all safety-related features function as intended by design definition.
3. Ensuring that the 6M packaging does not deteriorate with use over its lifetime.
4. Providing that inspections are performed to determine that the packaging has been fabricated according to design definition drawings.

References - Module 9.2

- 9.2.1 Quality Assurance Program Requirements for Nuclear Facilities, ANSI/ASME, NQA-1, 1986 Edition.

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9.0 Quality Assurance

9.3 QUALITY ASSURANCE ASSESSMENT

The following items are related to the safety of the 6M packaging during both normal conditions of transport and the hypothetical accident conditions of transport.

Safety Feature	Safety Requirement	Certification Method
Outer drum	Confinement of contents	Verify that outer drum is DOT-17C or -6C and meets requirements of DOT specs
Locking ring and drop-forged lugs	Confinement of contents	Physical measurement and visual check of welds
Drum hole vents	Pressure relief	Visual check of size and location
Celotex components	Temperature and impact resistance	Material certification and physical measurement
2R Containment	Containment of product vessel	Material certification, physical measurement, verification of structural and leakage requirements; radiographic inspection of welds
Luting compound	Containment	Verify approved type
Food product cans*	Containment	Visual check (see Module 7.3)
Internal impact absorber**	Structural integrity of food product cans	Visual check (see Module 7.3)

*Note: Regarding QA procedures and in subjects discussed in this report, the DOE is exercising its authority to routinely examine its programs and procedures to improve operational quality and assure the safety of its program elements (in this case, the 6M packaging). DOE managers require improved procedures for the use of the 6M packaging as given in this document (see Ref. 9.3.1).

**Required only when double containment of contents is required.

References . Module 9.3

- 9.3.1 Roybal, E. M., Summary Report: Quality Assurance Effort on the DOT-6M Specification Packagings, U.S. Department of Energy, Albuquerque Operations Office, Albuquerque, New Mexico, September 1984.

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9.0 Quality Assurance

9.4 DESIGN CONTROL

Measures are to be established to ensure that the 6M packaging design meets the primary requirement of 49 CFR 178.104 with additional requirements of leaktightness, secondary containment boundaries, and energy absorption as required.

The basic design requirements for the packaging are given in 49 CFR 178.104, Specification 6M (metal packaging); hence the packaging name, "6M." A companion specification for the inner containment vessel is given in 49 CFR 178.134, Specification 2R.

If changes to the basic design of the 6M packaging are ever contemplated, they shall be reviewed to ensure that no significant changes have been made that would reduce the margin of safety of the packaging as described by design definition drawings.

The shipper shall verify the packaging is labeled and conforms to the 6M specifications, indicated above, before first use of the packaging.

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9.0 Quality Assurance

9.5 PROCURSMENT DOCUMENT CONTROL

The shipper shall-establish measures **to assure** adequate quality is provided in documents for procurement of safety-related materials and services.

The pertinent **safecy** features of the 6M packaging have been identified (see Section 5.3) and **all** purchase orders or contracts pertaining to the acquisition or **maintenance** of these features shall be controlled. This control is to ensure incorporation of design safety and reliability in these components and to guard against any loss of function of these safety features.

Procurement documents shall require all suppliers of these safety components to have a QA program for these safety-related items.

Suppliers of containment vessels may be required to have and/or domonstratc ASME Code **welding**, depending upon the procurement specification.

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9.0 Quality Assurance

9.6 INSTRUCTIONS, PROCEDURES, AND DRAWINGS

Procedures are established for initial inspection, use, and repair of the 6M packaging to **ensure** that its design intent continues to be met **over** the lifetime of the packaging.

Each DOE Field Office, or contractor within the jurisdiction of the respective Field Office, that is involved in the use or acquisition of 6M packagings to support DOE programs shall maintain a record of the appropriate QA specifications that are required to meet the intent of this section. The particular requirements of QA are as follows:

1. Acceptance procedures have been established for the inspection and tests to be performed before the first use of the 6M packaging.
2. Measures have been established to ensure that plans for necessary repairs, rework, and retrofit of the packaging do not significantly alter the packaging design or compromise the design safety features of the packaging.
3. Measures have been established to ensure that the loading and unloading of the package contents occur under controlled conditions.
4. Measures have been established to ensure that the package is in a good and serviceable condition, adequately secured, properly security sealed and labeled in accordance with DOT regulations.
5. Design definition drawings for the packaging will designate **all** safety features and indicate the methods used to verify design safety features.
6. Design definition drawings, and revisions to these drawings, will be controlled so that the margins of safety provided by the design safety features will not be altered without DOE approval.

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9.0 Quality Assurance

9.7 DOCUMENT CONTROL

Each of the documents under the control of the DOE QA Program is identified and controlled so recent revisions are available to persons responsible for using the documents. Revisions require review and approval by the same organization that performed the original review and approval.

At a minimum, the DOE QA Program exercises control over the following classes of documents with respect to 6M packaging:

- Site QA and Quality Control Manuals
- Operating Procedures
- Maintenance Procedures
- Inspection and Test Procedures
- Loading and Unloading Procedures
- Packaging and Transport Procedures
- Repair Procedures.

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9.0 Quality Assurance

9.8 CONTROL OF PURCHASED MATERIALS, EQUIPMENT, AND SERVICE

Measures are taken to ensure the design and fabrication of the 6M packaging has been performed under the control of the DOE QA Program.

In order to ensure the establishment of a series of QA control records during the acquisition of new packagings in the DOE system, appropriate documentation, as identified in the purchase order, will accompany the new packagings from the supplier to the using organization.

All certification on the external drums and containment vessels for 6M packagings will be as specified by the DOT.

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9.0 Quality Assurance

9.9 IDENTIFICATION AND CONTROL OF MATERIALS, PARTS, AND COMPONENTS

Measures have been established to adequately identify and control all parts used for repair and rework of 6M packagings.

The measures established by the DOE QA Program to provide control over materials, parts, and components **are** as follows:

1. All replaceable spare parts and components are identified by the manufacturer.
2. Limited-life items, such as O-rings and luting (sealing) compounds, have their "use date" and "shelf life" stated.
3. Items whose shelf life has expired will not be used in support of 6M packaging maintenance procedures.
4. Items that have been exposed to detrimental **environmental** conditions such as freezing of RTV **silastic** luting compounds, or any environmental excursion beyond the bounds stated by the manufacturer or the QA Program, will not be used.

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9.0 Quality Assurance

9.10 CONTROL OF SPECIAL PROCESSES

During the manufacturing and/or repair of the containment vessel for the 6M packaging, special processes such as welding, nondestructive testing, and leakage testing are performed with applicable codes.

Control of special processes for the 6M packaging involves the following:

1. Procedures, equipment, and personnel are qualified in accordance with applicable codes.
2. Manufacturing and repair functions are performed by qualified personnel, and accomplished in accordance with written process sheets with recorded evidence of verification.
3. Qualification records of procedures, equipment, and personnel are established, filed, and kept current.

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9.0 Quality Assurance

9.11 INSPECTION CONTROL

Inspections are performed on 6M packagings upon receipt and during useful life to ensure **they** continue to **meet** the design intent.

The following inspections occur during 6M useful life in accordance with the provisions of the DOE QA Program:

1. Visual inspections upon receipt of the packaging to ensure compliance with procurement documents.
2. Inspection to ensure adequate maintenance of the packaging.
3. Procedures and procedural checklists to ensure inspections are performed to verify compliance with the following:
 - a. Packages are properly assembled;
 - b. Shipping papers are properly completed; and
 - c. Package marking and labeling are in accordance with DOT regulations.

The QA inspections described above are to be performed by personnel independent of the individuals performing the functional activity being inspected.

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9.0 Quality Assurance

9.12 REQUIRED TEST CONTROL .

Measures have been established to ensure that acceptance tests and maintenance tests have been performed before the package is delivered to a carrier (transporter).

The acceptance tests to be performed before first use of the 6M packaging are specified in Module 8.1 of this report. Operating procedures for 6M packagings are contained in Modules 7.1 through 7.6.

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9.0 Quality Assurance

9.13 CONTROL OF MEASURING AND TEST EQUIPMENT

Test equipment is routinely calibrated against known standards

Dimensional-measuring equipment and leakage-determination instruments are labeled or tagged to indicate the planned date of the next calibration required, and these calibration records are identified and traceable to the appropriate standards. Measures have been established to ensure that in-house references or transfer standards have been calibrated against nationally registered standards.

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9.0 Quality Assurance

9.14 HANDLING, STORAGE, AND SHIPPING

Measures are established to ensure that the design intent of the 6M packaging is met during handling, storage, and shipping.

The Celotex insulation material is stored in a dry environment to prevent any degradation in its insulating properties and its density, which are important in mitigating the effects of impact during package drops. Damage to the external painted surfaces of the outer steel drum is routinely repaired. Inspections are conducted to verify that the handler complies with all DOT requirements before delivering the package to the carrier (transporter).

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9.0 Quality Assurance

9.15 INSPECTION, TEST, AND OPERATING STATUS

The status of the inspection and test activities will be identified either on the 6M packagings or in documents traceable to the packagings.

Measures are established to indicate that individual items of the package that are procedurally controlled by the QA Program have not been inadvertently bypassed during required inspections and tests. Status of inspections, tests, and operating conditions, including maintenance, will be reviewed and kept current by the organizations responsible for quality assurance.

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9.0 Quality Assurance

3.16 CONTROL OF NONCONFORMING MATERIALS, PARTS, OR COMPONENTS

Nonconforming items will be reviewed, and recommended dispositions will be proposed and approved in accordance with documented procedures.

Safety-related items that are nonconforming shall not be accepted for service if, by their use, the package safety margin is reduced. Such items are quarantined until proper disposition is completed. Measures are established to identify nonconformances **and** the individuals responsible for approval of their disposition.

Nonconformance reports are analyzed by QA personnel to determine quality trends for appropriate management review and assessment.

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9.0 Quality Assurance

9.17 QUALITY ASSURANCE CORRECTIVE ACTIONS

Measures have been established to ensure that the cause of conditions detrimental to safety are promptly identified, reported to appropriate levels of management, and corrective actions implemented.

Responsibility for corrective actions will be assigned. Measures should be established to ensure that corrective actions have been implemented to preclude recurrence,

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9.0 Quality Assurance

9.18 QUALITY ASSURANCE RECORDS

Records to provide information on packaging design, fabrication, maintenance, tests and inspection, and general evidence supporting the performance of the packaging are maintained for the lifetime of the packaging.

Records showing evidence that all NRC and DOT requirements have been satisfied are retained, and their retention time is identified. Measures have been established to ensure that records maintained in-house or at other locations are identifiable and retrievable, and are not disposed of until prescribed conditions are satisfied. Entry of unauthorized personnel into record storage areas is precluded, and a record that is lost or damaged is promptly replaced.

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9.0 Quality Assurance

9.19 QUALITY ASSURANCE AUDITS

Audits are performed in accordance with written procedures, and are conducted by qualified personnel not having direct responsibility in the areas being audited.

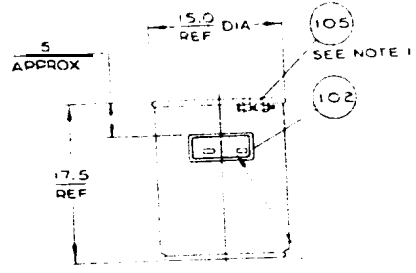
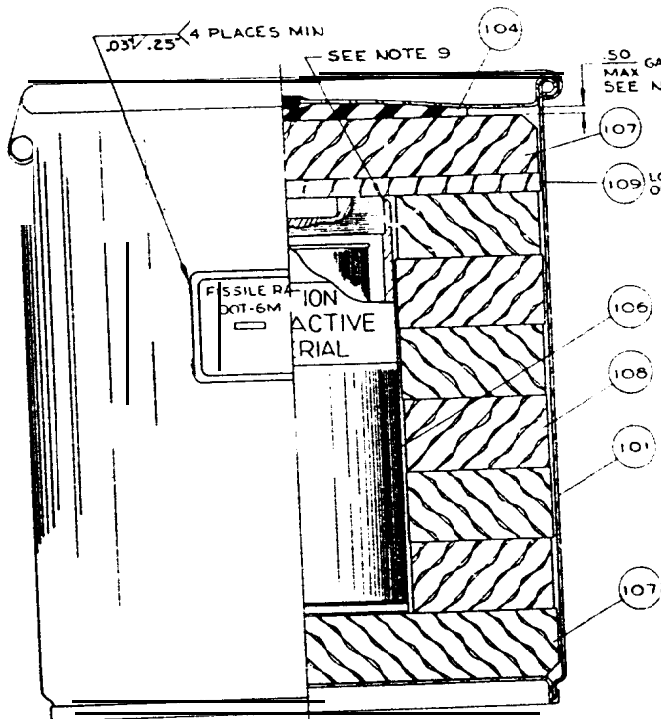
A list of activities important to the safe use of 6M packaging is identified, and the frequency with which each activity is audited is established and maintained. The frequency of audits should be based on the importance of the activity to the safety function. Audits are made of the manufacturers of the packaging to determine the extent of compliance with the purchase order, and to verify that the work is being controlled by a QA program. Deficient areas should be reaudited on a timely basis to verify implementation of **ccorrective** action.

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Appendix A

"AS BUILT" DRAWING FILE

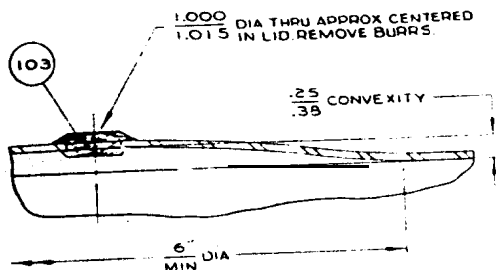
This appendix contains a file of "as built" drawings for several types and sizes of 6M packagings.



STAMP IDENTIFICATION NUMBERS --
OVERALL CONFIGURATION
 SCALE: NONE
 EMPTY WEIGHT: 51 LBS

NOTES:

1. SECURE THE LOCKING RING BY TAPPING WITH A SOFT-HEAD HAMMER WHILE TIGHTENING BOLT TO 30 - 40 FOOT-POUNDS. INSTALL LOCK NUT ON END OF BOLT PROTRUDING FROM THREADED LUG. INSTALL TAMPER-PROOF SECURITY SEAL.
2. CONVEX DRUM LID WITH CENTER VENT REQUIRED. SEE DETAIL. ADD CELOTEX PACKING (PART 109) IF REQUIRED TO OBTAIN SPECIFIED GAP. ADD SUFFICIENT CERAFELT TO ASSURE DRUM LID EXERTS A PRESSURE ON THE CELOTEX PACKING.
3. USABLE INSIDE DIMENSIONS FOR INNER CONTAINER ARE 4.180 DIAMETER BY 10.000 HGR. 4-1/16" DIAMETER CANS (#40) ARE SUGGESTED FOR USE WITH THIS PACKAGE.
4. APPROVALS:
 APPROVED BY ALO, IDENTIFICATION NUMBER AL-R2 ASSIGNED 3-3-67.
 APPROVED BY DEPARTMENT OF TRANSPORTATION, DOT SPECIAL PERMIT NUMBER 5000 ASSIGNED TO THE DOW CHEMICAL COMPANY, ROCKY FLATS DIVISION, 4-19-67.
 DESIGNATED SPECIFICATION 6M PACKAGE, SPECIAL PERMIT 5000 TERMINATED EFFECTIVE 12-31-68.
5. SEE DOT REGULATIONS FOR AUTHORIZED GROSS WEIGHT AND MATERIAL LIMITS.
6. CAUTION: ANY MATERIAL (INCLUDING PACKING) WITHIN THE INNER CONTAINER MUST NOT DECOMPOSE OR CAUSE A BUILDUP OF PRESSURE BELOW 250 PSI.
7. ANY RADIATION SHIELDING USED MUST BE PLACED WITHIN THE INNER CONTAINER.
8. SEE DRAWING SERIES P120#5 FOR ROCKY FLATS INSPECTION FORMS.
9. SEAL CONTAINMENT VESSEL WITH DOW-CORNING 732 RTV ADHESIVE/SEALANT.



LID REWORK DETAIL
 SCALE: NONE

LIST OF MATERIAL

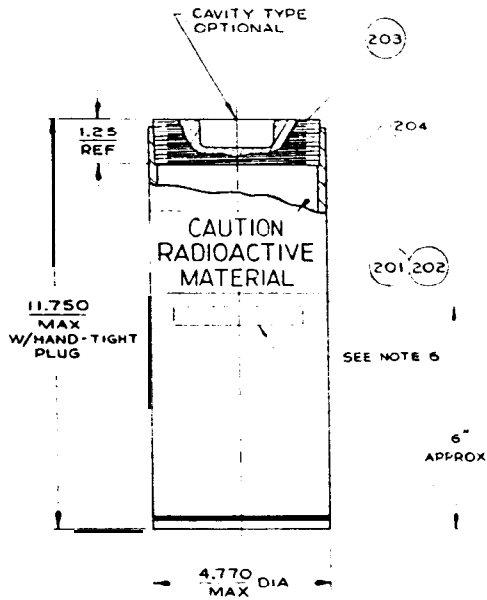
PART NO	QTY	DESCRIPTION	MATERIAL
100		ASSEMBLY	
101	1	DRUM - DOT-6C160, 10 GALLON, PER P14000	STEEL
102	1	DOT NAMEPLATE, P12322-1	SST
103	1	BUTTON PLUG - CAPLUG "BPF-1"	PLASTIC
104	1	INSULATION - JOHNS-MANSVILLE TYPE CFR, DENSITY 8 LBS, 8" MIN SQUARE + 1/2" MIN THICK	CERAFELT
105	1	SECURITY SEAL	
106	1	CONTAINMENT VESSEL SUBASSY, P11993-2	STEEL
107	2	DISK - PART 301, P11993-3	CELOTEX
108	4	RING - PART 302, P11993-3	CELOTEX
109	4 R	DISK - PART 305, P11993-3	CELOTEX

G TOTAL SHEETS WAS 4
 F GENERAL REVISIONS, ADDED VENTING SYSTEM # NOTES B, C

DATE	BY	REVISION
10-7-75	FEA	1
3-2-77	FT	2

RF CONTAINER MODEL 1518 PACKAGE CONFIGURATION (DOT-6M)

5 C P11993 1 6



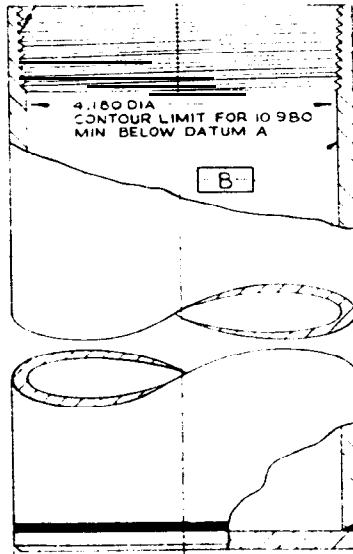
200 ASSEMBLY
SCALE: HALF

WEIGHT: 17 LBS
USABLE INSIDE HEIGHT: 10.000 MIN
INSIDE DIAMETER: 4.750 MIN

NOTES:

- SEE LEAST STANDARD Y14.5-1964 FOR EXPLANATION OF SYMBOLS AND FOR INTERPRETATION OF DIMENSIONS AND TOLERANCES.
- FINISH: 63 MICRONDICES, ALL MACHINED SURFACES.
- PARTS SHALL BE FREE OF BURRS, EDGES MAY BE BROKEN .060 MAXIMUM RADIUS OR CHAMFER.
- WELDERS AND WELDING PROCESSES SHALL BE QUALIFIED IN ACCORDANCE WITH SECTION IX OF THE ASME BOILER AND PRESSURE VESSEL CODE. WELDS SHALL BE FULL PENETRATION AND SHALL BE FREE OF Voids, Slips AND CRACKS AS DETERMINED BY VISUAL EXAMINATION. FUSED AREA SHALL HAVE AN ACCUMULATED DEPTH OF .200 MINIMUM FOR AT LEAST 95% OF THE CIRCUMFERENCE AND .100 MINIMUM FOR THE REMAINDER AS DETERMINED BY RADIOGRAPHIC INSPECTION. ANY WELD BEAD ON THE INSIDE SURFACES SHALL BE WITHIN THE SPECIFIED CONTOUR LIMIT.
- PREPARE SURFACES AS REQUIRED AND WITH LID IN PLACE, PAINT EXTERIOR WITH TWO COATS OF EPOXY FINISH, TENACO GREEN #355, OR APPROVED EQUIVALENT.
- EMBOSS OR DIE STAMP "RADIOACTIVE MATERIAL" AND "DOT-2R-XXXX", WHERE "XXXX" IS THE SERIAL NUMBER. CHARACTERS SHALL BE .250 MINIMUM HEIGHT. BLOCK OF SERIAL NUMBERS TO BE ASSIGNED BY PURCHASER.
- SEE P12085-2 FOR ROCKY FLATS INSPECTION FORM.

4" NPT
B.M. 020 TIRM



4.770 DIA OVER PART 202
4.720 AND WELD

201 202 TUBE SUBASSY
SCALE: FULL

LIST OF MATERIAL			
ITEM NO.	DESCRIPTION	QUANTITY	MATERIAL
201	TUBING - 4.750 - 4.750 O.D. x .275 - .225 WALL		STL
202	PLATE - 250 x 4.750 O.T.A.		STL
203	PIPE PLUG - 4" DWG P11993-5		STL
204	RADIATION LABEL - BRADY "RAD 2-C OR APPROVED EQUAL		

11.100
11.000

.250 REF

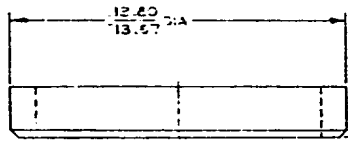
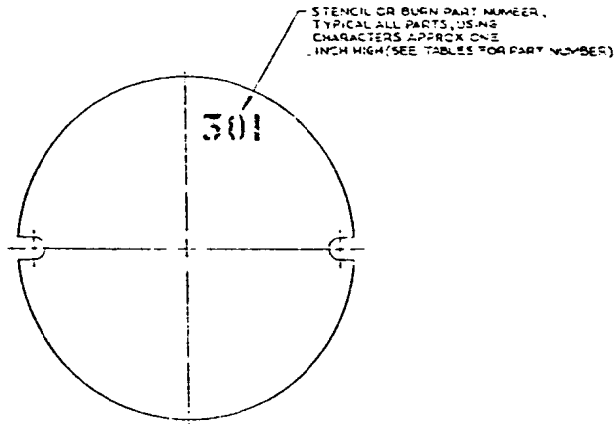
REV	DESCRIPTION	DATE	BY	CHKD
F	ITEM 203 WAS CAST IRON	10/27/66	FEA	FJT
E	REVISED NOTE 4	12/6/67	FEA	FJT
D	REVISED NOTES 1, 4 & 5 ADDED NOTE 7	2/26/68	FEA	FJT
C	REVISED NOTE 6, #CALLOUT	1/22/68	FEA	FJT
B	REVISED NOTE 6, AND TITLE	6/5/68	FEA	FJT
A	APPROVED FOR PRODUCTION	4/30/68	FEA	FJT

RF CONTAINER MODEL 1518 INNER CONTAINER

UNCLASSIFIED

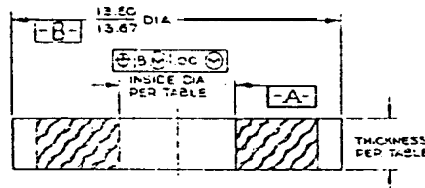
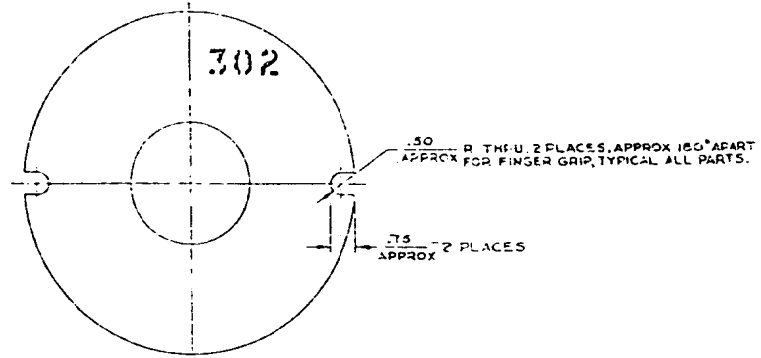
IC P11993 2 F

RF-PE CONTROLLED DWG.



.12 x .12 CHAMFER ALL AROUND
PART 301 ONLY

DISKS	
PART NO	THICKNESS
301	1.90-1.97
305	.50 APPROX



RINGS		
PART NO	IN. O.D. DIAMETER	THICKNESS
302	4.00 - 4.25	1.99-1.96
303	5.69 - 5.75	1.99-1.96
304	6.20 - 6.26	1.99-1.96
305	4.60 - 4.67	.50 APPROX

W FINGER NOTCHES NOT REQD

NOTES:

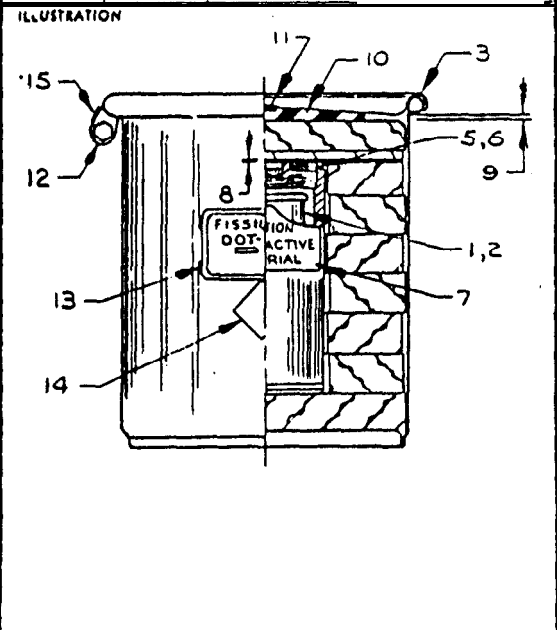
1. MATERIAL: CELOTEX INDUSTRIAL BOARD, CANE FIBER (BAGASSE), 3-PLY FACTORY-LAMINATED STOCK, NO SUBSTITUTE AUTHORIZED.
2. DRAWING INTERPRETATION PER ANSI Y14.5-1973 ALL DIMENSIONS ARE IN INCHES.

F ADDED PART 305, DELETED RECORD OF REVISIONS		4475	FEA
REVISIONS		DATE	BY
RFD CONTAINER MODEL 1518 PACKING		C P1199331F	

ITEM NO.	SPECIFICATION	INSPECTION ENTRY
1	Contents at containment vessel limited per DOT regulations. Record transport index where applicable.	
2	Contents packed per user's written procedure	
3	Drum, lid, gasket, and locking ring visually checked for harmful defects	
4	Celotex rings and disks visually checked for defects	
5	Male and female threads free of defects, steel pipe plug req'd.	
6	Threads sealed using #732 RTV sealant	
7	Radioactive caution label attached	
8	Containment vessel flush or below top celotex ring	
9	Celotex components in place per P11993-1 with .50 maximum gap	
10	Cerafelt insulation in place per PI 1993-1. Pressure required to seat drum lid	
11	Plastic vent plug installed	
12	Lid in place, locking ring secured with 1/2" diameter bolt and locknut. Bolt torqued to 30-40 foot pounds per user's written procedure	
13	Nameplate welded to drum, marking legible	
14	Radioactive material label, 2 places, Transport index marked (where applicable)	
15	Security seal applied	

DRAWING NUMBER P11993-1	SERIAL NUMBER RF #
OTHER IDENTIFYING NUMBERS, IF ANY Containment Vessel: DOT-2R-	

DIMENSIONAL INSPECTION			
INSPECTED BY	DATE INSPECTED	SHIFT	
ACCEPTED	REJECTED	BY Not Req'd.	DATE
RADIOGRAPHIC INSPECTION			
ACCEPTED	REJECTED	RADIOGRAPHIC REPT. NO. Not Req'd.	DATE
MATERIAL CERTIFICATION			
ACCEPTED	REJECTED	BY Not Req'd.	DATE
OVERALL ACCEPTANCE			
ACCEPTED	REJECTED	BY	DATE



REVISED ITEM 5	10-21-75	FEA
GENERAL REVISIONS	3-21-75	FJT
REV.	DESCRIPTION	DATE
APPROVALS FEA 3-20-75 FJT 3-21-75	TITLE RF CONTAINER MODEL 1518 PACKING CHECK LIST*	

*This form lists the minimum requirements for "ROUTINE DETERMINATION PRIOR TO EACH USE" as specified by AEC Manual, Chapter 0.529

4-4. RF Container Model 1518 Packing Check List

USE ABOVE SPACE FOR REMARKS

DATE	TOTAL SHEETS	SIZE	DRAWING NUMBER		
			NUMBER	SHEET	ISSUE
3/20/75		A	P11993	4	F

RF-PE CONTROLLED DWG.

INSPECTION TEMPERATURE. <i>66</i> F		DRAWING NUMBER P11993-1, 3 P14000	SERIAL NUMBER See Item 2
ITEM NO.	SPECIFICATION	INSPECTION ENTRY	OTHER IDENTIFYING NUMBERS, IF ANY
1	Quantity In lot		
2	Record serial numbers thru RF-		
3	Drum meets the requirements of P14000, Inspection form on file		
4	.25-.38 convexity x 6" min diameter		
5	Vent plug Installed		
6	Identification tag welded to drum, model no. and serial no. stamped		
7	Celotex rings and disks, no dimensional inspection required If components pass the following functional tests:		
a.	Visually checked for marking; defects, glue joints, and workmanship		
b.	6 rings, 2 disks, and containment vessel assembled per P11993-1, containment vessel flush or below top ring		
8.	Lid seats with .50 maximum gap		
		DIMENSIONAL INSPECTION	
		INSPECTED BY	DATE INSPECTED SHIFT
		ACCEPTED REJECTED BY	DATE
		See Item 7	
		RADIOGRAPHIC INSPECTION	
		ACCEPTED REJECTED RADIOGRAPHIC REPT. NO. Not Reqd.	DATE
		MATERIAL CERTIFICATION	
		ACCEPTED REJECTED BY	DATE
		Not Reqd.	
		OVERALL ACCEPTANCE	
		ACCEPTED REJECTED BY	DATE
		ILLUSTRATION	
		D REVISED & RETYPED 3-21-75 <i>FLY</i>	
REV.	DESCRIPTION	DATE	
APPROVALS EA 3-20-75 JT 3-21-75	TITLE RF INSPECTION FORM MODEL 1518 CONTAINER DRUM & PACKING		
DATE	TOTAL SHEETS	SIZE	DRAWING NUMBER NUMBER SHEET ISSUE
3/20/75		A	P12085 1 D

*This form lists the "PRELIMINARY DETERMINATION" required prior to first use of any package as specified by AEC Manual, Chapter 0529.

A-6. RF Inspection Form Model 1518 Container Drum and Packing

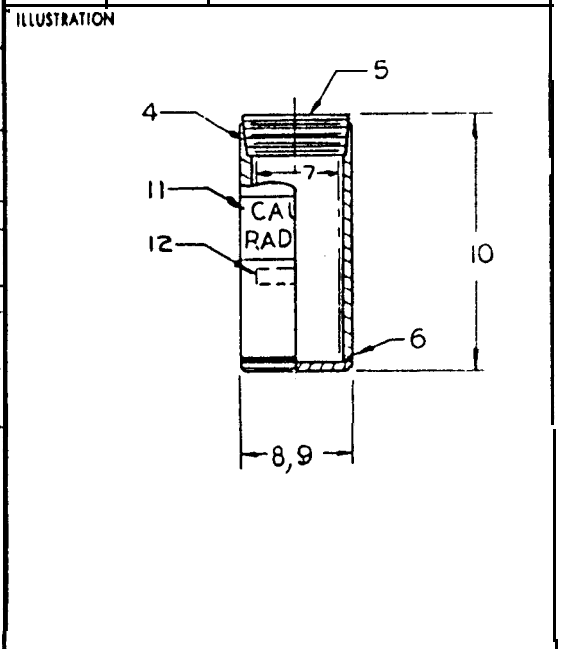
USE ABOVE SPACE FOR REMARKS

RF-PE CONTROLLED DWG.

ITEM NO.	SPECIFICATION	INSPECTION ENTRY
1	Quantity in lot	
2	Record serial numbers of containers in lot	
3	At least two assemblies from each lot shall have 100% dimensional and radiographic inspection. If these assemblies are satisfactory, remainder of lot may be given a functional inspection starting with item 4 below	70%
4	Threads free of burrs	
5	Pipe plug meets the requirements of P11993-5	
6	Weld full penetration and free of voids and defects (visual)	
7	4.180 dia. x 10.980 contour limit per gage P12087-1 or equivalent	
8	Weld and end plate machined approximately flush with tube O.D.	
9	4.770 max. dia.	
10	11.750 max. with pipe plug engaged hand-tight	
11	Caution label in place	
12	Identification marked per P11993-2	
13	Machining and painting exhibit good workmanship	

DRAWING NUMBER P11993-2, -5	SERIAL NUMBER See Item 2
OTHER IDENTIFYING NUMBERS, IF ANY Lot Number:	
DOCUMENT NO.	
COPY - OF _____ SERIES _____ NO. PAGES _____	

DIMENSIONAL INSPECTION			
INSPECTED BY	DATE INSPECTED	SHIFT	
ACCEPTED	REJECTED	BY	DATE
RADIOGRAPHIC INSPECTION			
ACCEPTED	REJECTED	RADIOGRAPHIC REPT. NO	DATE
MATERIAL CERTIFICATION			
ACCEPTED	REJECTED	BY Not reqd.	DATE
OVERALL ACCEPTANCE			
ACCEPTED	REJECTED	BY	DATE



*These forms list the "PRELIMINARY DETERMINATION" required prior to first use of any package as specified by AEC Manual, Chapter 0529.

*Radiography must be performed by certified Dow personnel. Record operator(s) man number.

C	REVISED ITEMS 5	10-21-71
B	REVISED ITEMS 2,3,7 & 12	2-26-74
A	APPROVED FOR PRODUCTION	3-25-68
REV.	DESCRIPTION	DATE

APPROVALS FEA 5-15-67	TITLE RF INSPECTION FORM * MODEL 1518 CONTAINER. INNER CONTAINER
FJT 5-15-67	

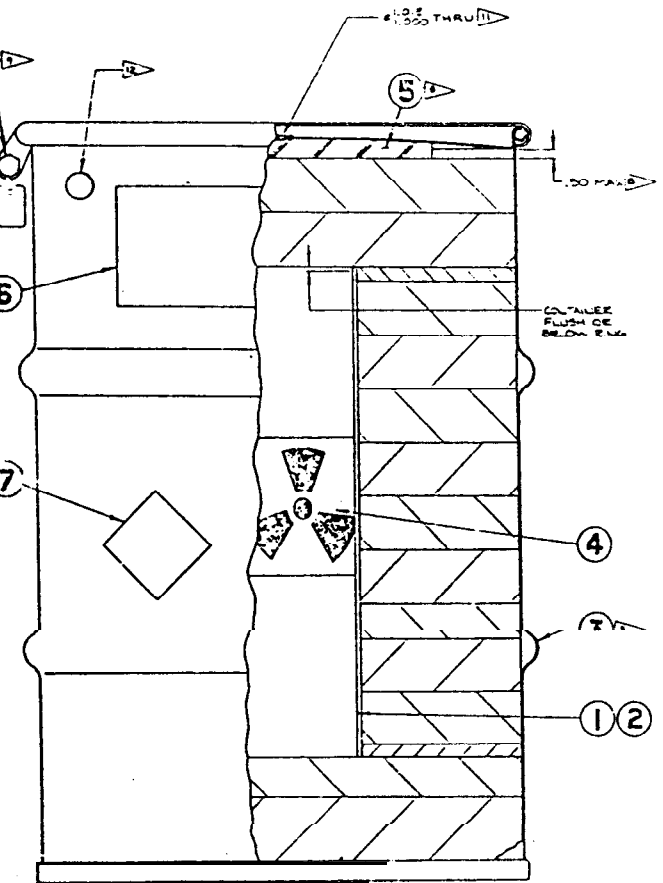
A-7. RF Inspection Form Model 1528 Container Inner Container

ABOVE SPACE FOR REMARKS.

DATE	TOTAL SHEETS	SIZE	DRAWING NUMBER		
			NUMBER	SHEET	ISSUE
4-27-67		A	P12085	2	C

RF-PE CONTROLLED DWG.

A-8. RF Container Model 2030-2 (30 Gallon 6M) Package Configuration



NOTES:

1. AUTHORIZED CONTENTS: (USE EITHER CONFIGURATION A OR CONFIGURATION B)
 - A. SEE DOT REGULATIONS FOR AUTHORIZED GROSS WEIGHT AND MATERIAL LIMITS. CONFIGURATION A (ITEM 1): ALUMINUM/PLUTONIUM/AMERICIUM BUTTONS 0.5 TO 3.0 INCHES HIGH CONTAINING VARYING PERCENTAGES OF ALUMINUM, PLUTONIUM, AND AMERICIUM. BUTTONS WILL BE SELECTIVELY MATCHED SUCH THAT TOTAL HEIGHT OF THE BUTTONS WILL NOT EXCEED 4.5 INCHES PER PAPER CAN.
 - B. CONFIGURATION B (ITEM 2): PLUTONIUM DIOXIDE, OR SALTS, SLAG, CRUMBLES, OR ASH CONTAINING SMALL RECOVERABLE QUANTITIES OF PLUTONIUM.

2. APPROVALS:

3. DRUM INSULATION AND DOT-2R CONTAINER SUPPLIED, AND CERTIFIED TO HAVE BEEN CONSTRUCTED IN ACCORDANCE WITH THE APPLICABLE DOT SPECIFICATIONS, BY PAF, INCORPORATED. REFERENCE ROCKWELL PURCHASE ORDER NO. 94388 DC DATED 09/21/83.
4. USABLE INSIDE DIMENSIONS (REF) FOR CONTAINMENT VESSEL:
 - CONFIGURATION A (ITEM 1): 5.125 DIA. X 17.75" HIGH
 - CONFIGURATION B (ITEM 2): 5" DIA. X 17" HIGH
5. ANY LEAD SHIELDING USED MUST BE PLACED WITHIN THE PAPER CONTAINER. LEAD SHIELDING SHALL BE SUFFICIENT TO REDUCE HEATING RADIATION TO LESS THAN 200 mR/HR AT THE EXTERNAL SURFACE OF THE CONTAINER.
6. CAUTION: ANY MATERIAL (INCLUDING PACKING) WITHIN THE PAPER CONTAINER MUST NOT DECOMPOSE OR CAUSE A BUILDUP OF PRESSURE BELOW 250°F.
7. SEAL CONTAINMENT VESSEL WITH DOW-CORNING #732 ADHESIVE SEALANT IN ACCORDANCE WITH PE777-08. PRODUCTION CONTROL PACKING PROCEDURES FOR BUILDING 707 AND 777.
8. CONVEX DRUM LID REQUIRED. ADD CELOTEX PACKING, IF REQUIRED TO OBTAIN SPECIFIED GAP. ADD SUFFICIENT REFRACTORY MATERIAL (CELOTEX) TO ASSURE DRUM LID EXERTS A PRESSURE ON THE CELOTEX PACKING.
9. SECURE THE LOCKING RING BY TAPPING WITH A SOFT-HEAD HAMMER WHILE TORQUING BOLT TO 40-50 FOOT POUNDS. INSTALL LOCKWASHER ON END OF BOLT PROTRUDING FROM THREADED LUG. INSTALL TAMPER-PROOF SECURITY SEAL.
10. SEE DRAWING P1498-3 FOR PACKING CHECKLIST.
11. VENT HOLE SHALL BE APPROXIMATELY CENTERED IN DRUM LID. SEAL WEATHER TIGHT WITH PLASTIC BUTTON PLUG.
12. ALTERNATE VENT HOLE WITH PLASTIC BUTTON PLUG. 14 AT 90° INTERVALS.

REV	DESCRIPTION	REV. DATE	BY	CHK
1	DELETED SIZE	01/28/83		
2	ADDED VENT HOLE IN DRUM LID. MADE EXISTING VENT HOLES ALTERNATE. REVISED FLAGNOTE 9. ADDED FLAGNOTE 11. P. 12. REVISED TITLE. MODEL 2030-2 (30GAL6M) WAS "MODEL 2030-2"	09/21/83	RC	JCL

2	SMALL PAPER CAN - 404			14
2	4" X 2" X 5" TALL (MUNDO)			
2	PLASTIC BAG			15
2	LARGE PAPER CAN			12
2	4" X 2" X 5" TALL (MUNDO)			
2	CELOTEX ALUMINUM FOIL			11
2	NO. 1000 BOLT			10
2	NO. 1000 NUT			
2	CELOTEX REFRACTORY PAPER CAN			8
2	CELOTEX REFRACTORY PAPER CAN			7
2	LABEL - RADIOACTIVE YELLOW III			6
2	NAMEPLATE			5
2	REFRACTORY INSULATION 1/2" DIA X 1/2"			4
2	RADIOACTIVE LABEL READY TO BE APPLIED			3
1	DOT-11C			2
1	DOT-2R			1
1	CONTAINMENT VESSEL (CONFIGURATION B)			
1	CONTAINMENT VESSEL (CONFIGURATION A)			

RF CONTAINER MODEL 2030-2(30GAL6M) PACKAGE CONFIGURATION

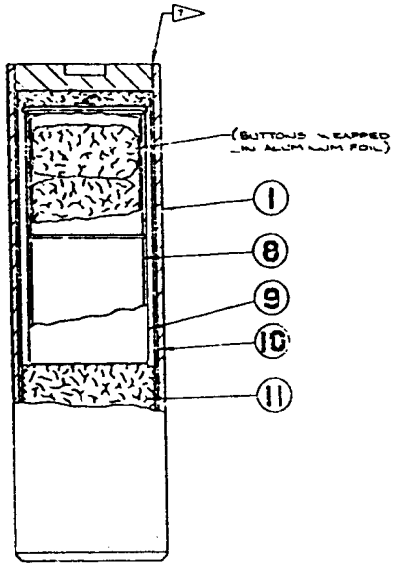
UNCLASSIFIED

UNCLASSIFIED

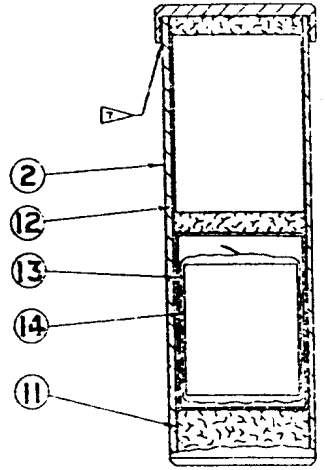
01406Z 014996

RF-PE CONTROLLED DWG.

A-9. 2-R Containment Vessel



CONFIGURATION A



CONFIGURATION B

RF-PE CONTROLLED DWG.

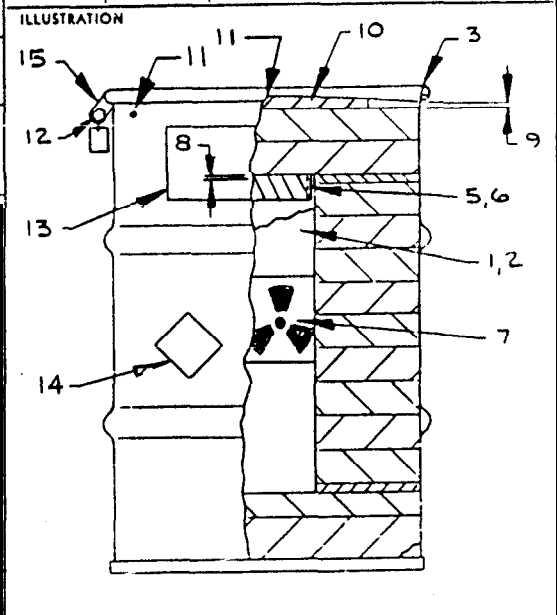
REVISED FOR CLASSIFICATION	DATE	BY	CHKD
UNCLASSIFIED	01/14/02	PLA996	
SHEET 2 OF 2			

142

UNCLASSIFIED

ITEM NO.	SPECIFICATION	INSPECTION ENTRY
1	Contents of containment vessel limited per P14996-1. Record transport index where applicable.	
2	Contents packed per user's written procedure.	
3	Drum, lid, gasket, and locking ring visually checked for harmful defects.	
4	Celotex rings and disks visually checked for defects.	
5	Threads free of defects, steel pipe plug or malleable iron pipe cap.	
6	Threads sealed using #732 RTV sealant.	
7	Radioactive caution label attached.	
8	Containment vessel flush or below top Celotex ring.	
9	Celotex components in place per P14996-1 with .50 max gap.	
10	Refractory insulation in place per P14996-1. Pressure req'd to seat drum lid.	
11	Plastic vent plug(s) installed.	
12	Lid in place, locking ring secured with 5/8" Dia. bolt and locknut. Bolt torqued to 40-50 foot pounds per user's written procedure.	
13	Nameplate welded to drum, marking legible.	
14	Radioactive material label, 2 places, Transport Index marked (where applicable).	
15	Security seal applied.	

DRAWING NUMBER P14996-1		SERIAL NUMBER	
OTHER IDENTIFYING NUMBERS, IF ANY Containment Vessel: DOT-2R			
DIMENSIONAL INSPECTION			
INSPECTED BY		DATE INSPECTED	SHIFT
ACCEPTED	REJECTED	BY Not Req'd	DATE
RADIOGRAPHIC INSPECTION			
ACCEPTED	REJECTED	RADIOGRAPHIC REPT. NO. Not Req'd	DATE
MATERIAL CERTIFICATION			
ACCEPTED	REJECTED	BY Not Req'd	DATE
OVERALL ACCEPTANCE			
ACCEPTED	REJECTED	BY	DATE



*This form lists the minimum requirements for "ROUTINE DETERMINATION PRIOR TO EACH USE" as specified by DOE order AL5480.1 CHAPTER III.

10. PF Container Model 2030-2 (30.Gallon 6M)
Packing Check List

USE ABOVE SPACE FOR REMARKS

REV.	2 REVISED ITEM	DATE	RCO
	1 ORIGINAL ISS	7-18-87	RCO
APPROVAL			
RF CONTAINER MODEL 2030-2 (30GAL6M) PACKING CHECK LIST*			
DATE	TOTAL SHEETS	SIZE	DRAWING NUMBER
5-3-84		A	P14996 3 2

REVIEWED FOR CLASSIFICATION:

By WAF 5-3-84

RF-PE CONTROLLED DWG.

UNCLASSIFIED

INSPECTION TEMPERATURE, °F			DRAWING NUMBER	SERIAL NUMBER																																																
			P14996 -1	See Item 2																																																
ITEM NO.	SPECIFICATION	INSPECTION ENTRY	OTHER IDENTIFYING NUMBERS, IF ANY																																																	
1	Quantity in lot																																																			
2	Record serial numbers thru RF-																																																			
3	Identification numbers embossed in lower head per DOT specification. Record Identification: Manufacturer's Symbol Gauge/Capacity/Year DOT Specification Other																																																			
4	Drum meets the requirements of DOT 17H: A. .0428 min thickness, body and heads. B. .0946 min closure ring w/drop forged lugs and 5/8 bolt, and nut (visual). C. .375 min convexity, both heads.		<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="4">DIMENSIONAL INSPECTION</th> </tr> <tr> <td>INSPECTED BY</td> <td>DATE INSPECTED</td> <td colspan="2">SHIFT</td> </tr> <tr> <td>ACCEPTED</td> <td>REJECTED</td> <td>BY</td> <td>DATE</td> </tr> <tr> <td></td> <td></td> <td>See Item 7</td> <td></td> </tr> <tr> <th colspan="4">RADIOGRAPHIC INSPECTION</th> </tr> <tr> <td>ACCEPTED</td> <td>REJECTED</td> <td>RADIOGRAPHIC REPT. NO.</td> <td>DATE</td> </tr> <tr> <td></td> <td></td> <td>Not Req'd</td> <td></td> </tr> <tr> <th colspan="4">MATERIAL CERTIFICATION</th> </tr> <tr> <td>ACCEPTED</td> <td>REJECTED</td> <td>BY</td> <td>DATE</td> </tr> <tr> <td></td> <td></td> <td>Not Req'd</td> <td></td> </tr> <tr> <th colspan="4">OVERALL ACCEPTANCE</th> </tr> <tr> <td>ACCEPTED</td> <td>REJECTED</td> <td>BY</td> <td>DATE</td> </tr> </table>		DIMENSIONAL INSPECTION				INSPECTED BY	DATE INSPECTED	SHIFT		ACCEPTED	REJECTED	BY	DATE			See Item 7		RADIOGRAPHIC INSPECTION				ACCEPTED	REJECTED	RADIOGRAPHIC REPT. NO.	DATE			Not Req'd		MATERIAL CERTIFICATION				ACCEPTED	REJECTED	BY	DATE			Not Req'd		OVERALL ACCEPTANCE				ACCEPTED	REJECTED	BY	DATE
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ACCEPTED	REJECTED	BY	DATE																																																	
5	Plastic vent plug(s) installed																																																			
a	Identification tag welded to drum, Model no. and serial no. stamped.		<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="4">ILLUSTRATION</th> </tr> <tr> <td colspan="4" style="text-align: center;"> </td> </tr> </table>		ILLUSTRATION																																															
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7	Celotex rings and disks, no dimensional inspection req'd if components pass the following functional tests: A. Visually checked for marking, defects, glue joints, and workmanship. B. Rings, disks, and containment vessel assembled per P14996-1. Containment vessel flush or below top ring. C. Lid seats with .50 max gap																																																			
8	Lug weld satisfactory (visual)																																																			
9	Gasket satisfactory, record type and material.																																																			
10	.187 min gap in locking ring per Section 2 of P12346.																																																			
11	Overall workmanship and painting satisfactory.																																																			
Notes:			<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td>2</td> <td>REVISED ITEM 5 AND DWG TITLE</td> <td>10-19-84</td> <td>RCB</td> </tr> <tr> <td>1</td> <td>ORIGINAL ISSUE</td> <td>7-18-87</td> <td>RCO</td> </tr> <tr> <th>REV.</th> <th>DESCRIPTION</th> <th>DATE</th> <th></th> </tr> </table>		2	REVISED ITEM 5 AND DWG TITLE	10-19-84	RCB	1	ORIGINAL ISSUE	7-18-87	RCO	REV.	DESCRIPTION	DATE																																					
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<p>1. A minimum of 5% of the drums in each lot shall be inspected for the items listed above.</p> <p>2. This form gives the minimum requirements for "PRELIMINARY DETERMINATION" before first use as specified in DOE Order AL5480, Chapter III.</p>			<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th>APPROVALS</th> <th>TITLE</th> </tr> <tr> <td></td> <td>RF INSPECTION FORM MODEL 2030-2 (30GAL 6M) CONTNR DRUM & PACKING</td> </tr> <tr> <th colspan="2">DRAWING NUMBER</th> </tr> <tr> <td>NO.</td> <td>SIZE</td> </tr> <tr> <td>NUM:</td> <td>SHEET ISSUE</td> </tr> <tr> <td>14-R-84</td> <td>A P14996 4 2</td> </tr> </table>		APPROVALS	TITLE		RF INSPECTION FORM MODEL 2030-2 (30GAL 6M) CONTNR DRUM & PACKING	DRAWING NUMBER		NO.	SIZE	NUM:	SHEET ISSUE	14-R-84	A P14996 4 2																																				
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A-11. RF Inspection Form Model 2030-2 (30 Gallon 6M) Container Drum and Packing

REVIEWED FOR CLASSIFICATION:

By WTA/EFEL 5/8 84

RF-PE CONTROLLED DWG.

Appendix B

DETERMINATION OF LEAK-SITE DIAMETER FOR METAL CANS UNDER NORMAL CONDITIONS
OF TRANSPORT

The leak-site diameter can be determined by using equations derived from Poiseuille's (Ref B.1), and Knudsen's laws (Ref. B.2).

The maximum helium gas leak rate measured for a mechanically crimp-sealed can was 4.8×10^{-8} atm-cm³/s at 24°C (75°F). To be conservative, the following assumptions were made:

1. Leakage is from one leak site.
2. The leakage path is considered to be a straight circular tube.

To calculate the diameter of the leak site the following equations were used:

$$L = (F_c + F_m) (P_u - P_d), \text{ where} \quad (1)$$

$$F_c = (2.49 \times 10^6) D^4 / (a)(u) \quad (2)$$

$$F_m = (3.81 \times 10^3) D^3 \sqrt{T/M} / (a)(u) \quad (3)$$

In the above equations,

L = Volumetric leakage rate (cm³/s)

F_c = Coefficient of continuum flow conductance per unit pressure (cm/atm-s)

F_m = Coefficient of free molecular flow conductance per unit pressure (cm/atm-s)

P_u = fluid upstream pressure (atm. abs)

P_d = fluid downstream pressure (atm. abs)

D = leakage hole diameter (cm)

a = leakage hole length (cm)

u = fluid viscosity (cP) (centipoise)

T = fluid absolute temperature (degrees Kelvin)

M = molecular weight (grams per mole)

P_a = average stream pressure = (P_u + P_d)/2 (atm. abs).

These equations represent **unchoked** flow. One condition that **must** prevail for **unchoked** flow is:

$$P_d/P_u > r_c,$$

where r_c is the critical pressure for the leaking gas. If P_d/P_u is less than r_c then the flow would be choked. A second condition that prevails for **choked** flow is:

$$r_f > 1,$$

$$\text{where } r_f = F_m/F_c.$$

The helium gas leakage for the metal cans was calculated using the following conditions:

$$P_u = 1 \text{ atm}$$

$$P_d = 0.01 \text{ atm}$$

$$T = 24^\circ\text{C}, (297^\circ\text{K})$$

$$a = 0.65 \text{ cm (leak path length for can crimp seal)}$$

$$u = 0.0189 \text{ cP}$$

$$m = 4$$

$$P_a = (0.01 + 1)/2 = 0.51 \text{ atm.}$$

When $P_d/P_u = 0.01$, which is less than the critical pressure ratio, and $r_c = 0.487$ for helium, the flow would be choked. The second condition **must** be that r_f is equal to or greater than 1. Putting the above values into Equations (2) and (3) we have:

$$F_c = 2.027 \times 10^8 D^4.$$

$$F_m = 9.920 \times 10^4 D^3.$$

Using a leak rate of $4.8 \times 10^8 \text{ cm}^3/\text{s}$ and Equation (1) we have:

$$4.8 \times 10^{-8} = (F_m + F_c) (P_u + P_d).$$

Solving the above equation by iteration yields the following values

$$D = 7.46 \times 10^{-5} \text{ cm}$$

$$F_c = 6.289 \times 10^{-9} \text{ cm}^3 / \text{atm-s}$$

$$F_m = 4.124 \times 10^{-8} \text{ cm}^3 / \text{atm-s}.$$

Since $F_c/F_m = r_f$, from the values for F_c and F_m , $r_f = 0.15$.

Since r_f is less than 1, free molecular flow dominates and the flow is **unchoked**. Consequently, Equation (1) is valid.

References • Appendix B

- B.1 Shapiro, A. H., The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, New York, The Ronald Press Company, 1953.
- B.2 Slattery, J. C., Momentum, Energy, and Mass Transfer in Continua, New York, Robert E. Kreiger Publishing Co., 1981.

APPENDIX C

DETERMINATION OF AIR LEAK RATE UNDER NORMAL CONDITIONS OF TRANSPORT

The air leak rate under normal conditions of transport can be determined using the leak site diameter calculated and the equations presented in Appendix B.

Using the diameter of the leak site calculated in Appendix B, the leak rate of air under the normal conditions of transport can be determined. The following conditions apply:

$$P_u = 1.3 \text{ atm (the pressure inside the 2R containment vessel at } 237^\circ\text{F)}$$

$$P_d = 1.0 \text{ atm}$$

$$D = 7.46 \times 10^{-5} \text{ cm}$$

$$a = 0.65 \text{ cm}$$

$$u = 0.0185 \text{ cP}$$

$$T = 387^\circ\text{K}$$

$$P_a = (1.31 + 1.0)/2 = 1.16 \text{ atm}$$

$$m = 29$$

Since $P_d/P_u = 1.0/1.3 = 0.77$, which is greater than the critical pressure ratio of $r_c = 0.528$ for air, then the flow is **unchoked**. Substituting for the above values into Equations (1) and (2) of Appendix B, we obtain:

$$F_c = (2.49 \times 10^6) \frac{(7.46 \times 10^{-5})^4}{(0.65 + 0.0185)} = 6.41 \times 10^{-10} \text{ cm}^3/\text{atm-sec}$$

$$F_m = (3.81 \times 10^3)(7.46 \times 10^{-5})^3 \frac{\sqrt{(387/29)}}{(0.65 + 1.16)} = 7.66 \times 10^{-9} \text{ cm}^3/\text{atm-sec}$$

$$L = (7.66 \times 10^{-9} + 6.41 \times 10^{-10})(1.31 + 1.0) = 2.57 \times 10^{-9} \text{ cm}^3/\text{sec}$$

When solar heating is taken into consideration, then the following conditions apply:

$$P_u = 1.54 \text{ atm (pressure in 2R vessel at } 347^\circ\text{F) using highest temperature from Table 3.3.2.}$$

$$P_d = 1.0 \text{ atm}$$

$$D = 7.46 \times 10^{-5} \text{ cm}$$

$$a = 0.65 \text{ cm}$$

$$u = 0.0185 \text{ cP}$$

$$T = 448^{\circ}\text{K}$$

$$P_a = (1.54 + 1.0)/2 = 1.27 \text{ atm}$$

$$m = 29$$

Since $P_d/P_u = 1.0/1.54 = 0.65$, which is greater than the critical pressure ratio of $r_c = 0.528$ for air, then the flow is unchoked. Substituting for the above values into Equations (1), (2), and (3) from Appendix B, we obtain:

$$F_c = (2.49 \times 10^6) \frac{(7.46 \times 10^{-5})^4}{(0.65 + 0.0185)} = 6.41 \times 10^{-10} \text{ cm}^3/\text{atm-sec}$$

$$F_m = (3.81 \times 10^3)(7.46 \times 10^{-5})^3 \frac{\sqrt{(448/29)}}{(0.65 + 1.27)} = 7.53 \times 10^{-9} \text{ cm}^3/\text{atm-sec}$$

$$L = (7.53 \times 10^{-9} + 6.41 \times 10^{-10})(1.54 \cdot 1.0) = 4.41 \times 10^{-9} \text{ cm}^3/\text{sec.}$$

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