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SAFETY ANALYSIS REPORT – PACKAGES
SRL 4.5-TON CALIFORNIUM SHIPPING CASK
(Packaging of Fissile and Other Radioactive Materials)

FINAL REPORT

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(Packaging of Radioactive and Fissile Materials)

Abstract

A shielded cask especially designed for shipping californium-252 neutron sources is basically a spherical steel shell filled with water-extended polyester as the shielding material. The cask complies with requirements for shipping "large quantities" of radioactive materials as described in AEC Manual, Chapter 0529, "Safety Standards for Packaging of Radioactive and Fissile Materials."[1] The cask also complies with IAEA "Regulations for the Safe Transport of Radioactive Materials," 1973 Revised Edition.

Description of Packaging

Californium (^{252}Cf) sources fabricated at the Savannah River Laboratory are shipped to recipients in a shipping cask made especially for this service. The five-foot diameter spherical cask, shown in figures 1 through 6, is filled with a cast-in matrix of water-extended polyester (WEP)[2] with boric acid incorporated in the aqueous phase for neutron absorption and ethylene glycol incorporated for freeze protection (to -40°C). WEP has a density of 1.07 g/cc and begins to decompose at ~200°C.

Table 1. WEP Formulation

Material	Weight, Parts
Ethylene glycol	130
Water	120
Boric acid	40
Sodium hydroxide	9 (pH 7.5)
"Lupersol DSW" (hardener)	1
	300

This solution is mixed into 200 parts by weight of Ashland Chemical's type 661-P polyester resin.

[1] A reproduction of AECM 0529 is included with this report.
[2] See Reference 5.

The ^{252}Cf sources are contained inside the cask cavity in capsules or shipping containers that are qualified as "special form" radioactive material, reference 1. Nuclear properties of ^{252}Cf are summarized below.

Table 2. Nuclear Properties of ^{252}Cf

Mode of decay	
Alpha emission	96.9%
Spontaneous fission	3.1%
Half-life	
Alpha decay	2.731 ±0.007 years
Spontaneous fission	85.5 ±0.5 years
Effective (α and SF)	2.646 ±0.004 years
Neutron emission rate	2.31×10^{12} neutrons per second per gram
Neutrons emitted per spontaneous fission	3.76
Average neutron energy	2.348 million electron volts
Average alpha particle energy	6.117 million electron volts
Gamma emission rate (exclusive of internal conversion X-rays)	1.3×10^{13} photons per second per gram
Dose rate at one meter in air	
Neutron	2.2×10^{3} rem per hour per gram
Gamma	1.6×10^{2} rads per hour per gram
Decay heat	
From alpha decay	18.8 watts per gram
From fission	19.7 watts per gram
Source volume (excluding void space for helium)	<1 cm^3 per gram

The shipping cask normally will be transported on a flatbed trailer; however, occasional intercontinental shipments may require that the cask be transported aboard ship. Four combination lifting and tiedown lugs are integral parts of the cask, which weighs approximately 9000 pounds. It is expected that up to 25 mg ^{252}Cf will be shipped in this cask via "Less Than Load" motor vehicle, and up to 85 mg ^{252}Cf via exclusive-use vehicle based on the radiation measurements shown in table 3*; the exact quantity limit is governed by actual radiation measurements for each shipment. Although the quantities shipped do not fall within the category of "large quantities" of nonfissile, Group I material (>5000 Ci of ^{252}Cf in "special form"), as defined in AECM 0529, the cask does comply with applicable regulations for large quantity shipments given in that chapter. Shipments also comply with applicable sections of the IAEA Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition.

* Radiation measurements were made, with an 18.7 mg ^{252}Cf source in the cask, to evaluate shielding integrity.

Table 3. Dose Rate Measurements

(Cask Loading: 18.7 mg ^{252}Cf; sources not centered)

1. At equator (girth) measured γ dose rates at 1-1/4 inch from surface vary gradually from 26 mR/hr to 13 mR/hr.

   Values at surface (calculated from measured values), from 28 to 14 mR/hr.
   Values at 36 in. (calculated from measured values), from 6 to 3 mR/hr.
   Values at 1 meter from center
   (calculated from measured values), from 16 to 8 mR/hr.

2. Bottom to top traverse.

   Through point of maximum intensity:

   23 to 26 to 18 mR/hr (measured at 1-1/4 inches from surface)
   25 to 28 to 20 mR/hr (calculated at surface)
   5 to 6 to 4 mR/hr (calculated at 36 inches from surface)
   14 to 16 to 11 mR/hr (calculated at 1 meter from center)

   Through point of minimum intensity:

   10 to 13 to ∿10 mR/hr (measured at 1-1/4 inches from surface)
   11 to 14 to 11 mR/hr (calculated at surface)
   2 to 3 to 2 mR/hr (calculated at 36 inches from surface)
   6 to 8 to 6 mR/hr (calculated at 1 meter from center)

3. At point of maximum intensity:

   At 5 inches from surface: γ, 19 mR/hr; n, 13 mrem/hr;
   Total 32 mrem/hr. (measured)

   At surface: γ, 22 mR/hr; n, 15 mrem/hr; Total 37. (calculated)
   (for 85 mg: Total ∿168 mrem/hr calculated)

   At 36 inches from surface: γ, ∿5 mR/hr; n, ∿3 mrem/hr;
   Total ∿8 mrem/hr. (measured)
   (for 25 mg: Total ∿10.6 mrem/hr calculated)

4. At minimum point on equator:

   At 5 inches n, ∿6 mrem/hr. (measured)
   At surface n, ∿7 mrem/hr. (calculated)
   At 36 inches n, ∿2 mrem/hr. (calculated)
   At 1 meter from center n, 5 mrem/hr. (calculated)

5. Through top plate: γ, 8 mR/hr at 1-1/4 inches from surface. (measured)
   9 mR/hr at surface. (calculated)
   ∿2 mR/hr at 36 inches. (calculated)
   5 mR/hr at 1 meter from center. (calculated)

   n, 8-9 mrem/hr at 5 inches from surface. (measured)
   12 mrem/hr at surface. (calculated)
   ∿3 mrem/hr at 36 inches. (calculated)
   7 mrem/hr at 1 meter from center. (calculated)

Compliance with AEC Regulations

The safety standards for packaging radioactive materials for shipment are contained in AEC Manual Appendix 0529. Compliance of this cask with pertinent sections is discussed by section number as follows:

I. DEFINITIONS AND EXEMPTIONS

A. Definitions

No comment required, except for the following items.

3. Containment vessel. The enclosed container well at the center of the shipping cask is considered the containment vessel. The capsules in the cask are primary containers for the ^{252}Cf.

8. Maximum normal operating pressure. The pressure inside the containment vessel.

11. Package. The cask and source capsules.

13. Primary coolant. Air in the containment vessel which transfers heat from the capsules to the cask inner surface whence it flows by conduction through the WEP shielding to the cask outer shell.

15. Special form.

    (b) The capsules in the cask are considered special form and conform to Annex 4 of AEC Appendix 0529.

B. Exemptions

Not applicable.

II. PACKAGE STANDARDS

A. General Standards for All Packaging

1. No reaction between package and contents. The inner surface of the cask shell is painted to prevent any potential corrosion by the WEP (no attack has been observed in reusable steel molds used to cast WEP slabs at SRL). Sections from the 1/4 scale model examined two and one-half years after fabrication show no corrosion or attack of the WEP on the steel. See Reference 6 .

^{252}Cf is compatible with materials used for its encapsulation (type 304L stainless steel, Zircaloy 2, Pt-10% Rh) and the capsule materials are compatible with the type 304L cask well. See References 7 and 8 .

2. Positive closure on packaging. The cask closure is bolted in place and cannot be inadvertently opened. A seal wire is used to indicate possible tampering with the cask closure.

3. Lifting devices. The cask tie-down devices comply with the requirements of this section as shown in Appendix A.

B. Structural Standards for Large Quantity Packages

The ability of the cask to meet these standards is shown in Appendix A.

C. Criticality Standards for Fissile Material Packages

Not applicable.

D. Evaluation of a Single Package

1. a. Effect of normal transport conditions on package. An analysis of the package under normal conditions is given in Appendix B.

b. Effect of accident conditions on package. An analysis of the effects of an accident is given in Appendix C. A quarter-scale model of the cask was used for drop tests. An inverted drop from 30 feet demonstrated the ability of the cask closure and plug to remain intact. A side drop from 30 feet demonstrated the ability of the spherical shell to resist damaging deformation. A side drop from 40 inches onto a vertical steel bar demonstrated the ability of the shell to resist puncture. Postdrop radiography of the cask model containing a ^{252}Cf source showed no detectable cracks in the WEP shielding matrix. Because minimal deformation occurs, the radiation level following a drop accident will be the same as before.

Thermal resistance of the WEP was demonstrated by a test in which one surface of a model of a segment of the 5-foot diameter cask was subjected to a temperature of

1475°F for a period of 30 minutes. The WEP adjacent to the heated surface was destroyed to a depth of approximately 0.6 cm. Since the WEP is fixed in place, this is the maximum damage that will result from the assumed thermal exposure. Details of WEP properties and of the thermal tests are included in reference 4.

This test demonstrated that the increase in radiation will be less than one percent as a result of damage sustained by exposure to the hypothetical thermal accident conditions. During and following such exposure, the maximum temperature in the source cavity will not exceed 260°F (includes conduction by cavity support structure). Since the materials to be transported in this container themselves qualify as "special form," they will not be damaged by such exposure.

2. Evaluation of package. The cask was evaluated separately from the vehicle. No credit was taken for restraints provided by tiedown to the vehicle.

3. Approval of different accident conditions. Not applicable.

E. Standards for Normal Conditions of Transport for a Single Package

Normal conditions of transport are discussed in Appendix B. The cask meets all the requirements stipulated in Annex 1 of AEC Appendix 0529.

1. a. No release of radioactive materials. The source capsule will be contained inside the cask during normal or accident conditions of transport. In addition, the capsule qualifies as "special form" and will contain the ^{252}Cf during transport (reference 1).

   b. Effectiveness of package not reduced. The containment and shielding effectiveness of the package is not reduced significantly during normal or accident conditions of transport.

c. <u>No mixture of gases or vapors in package which could significantly reduce the effectiveness of the package through increase of pressure or explosion.</u> Radiolysis of the water and ethylene glycol in the WEP matrix may occur because of neutron bombardment, although tests showed this to be negligible. The amount of hydrogen gas formed by radiolysis was calculated using the G values in reference 2. The void volume inside the WEP shielding space is approximately 1% of the WEP volume (1.13×10^3 in^3), and is caused by characteristic shrinkage of WEP during curing. The minimum hydrogen concentration for creating an explosive mixture is 4% of the air volume or 45.2 in^3 (740 cc).

<u>Volume of H_2 evolved by radiolysis of H_2O</u>

V_{H_2O} = volume of H_2 evolved by radiolysis of H_2O

$$V_{H_2O} = \frac{(G_{H_2})(\phi)(22.4 \times 10^3 \text{ cc/mole})(8.75 \times 10^3 \text{ hr/yr})}{(6 \times 10^{23} \text{ molecules/mole})}$$

$= 254$ cc/yr

where: $G_{H_2} \cong 0.4$ molecules/100 ev

ϕ = radiation intensity

$= 1.94 \times 10^{20}$ ev/hr (per 10 mg ^{252}Cf)

$$\text{time to reach 4\% concentration} = \frac{740 \text{ cc } H_2}{254 \text{ cc/yr}}$$

$= 2.9$ years

<u>Volume of H_2 evolved by radiolysis of $C_2H_6O_2$</u>

$V_{C_2H_6O_2}$ = volume of H_2 evolved by radiolysis of $C_2H_6O_2$

$$= \frac{(G_{C_2H_6O_2})(\phi)(22.4 \times 10^3 \text{ cc/mole})(8.75 \times 10^3 \text{ hr/yr})}{(6 \times 10^{23} \text{ molecules/mole})}$$

$\cong 6330$ cc/yr

where: $G_{C_2H_6O_2} \cong 10$ molecules/100 ev

ϕ = radiation intensity $= 1.94 \times 10^{20}$ ev/hr

$$\text{time to reach 4\% concentration} = \frac{740 \text{ cc } H_2}{6330 \text{ cc } H_2/\text{yr}}$$

$= 0.12$ year

The calculations are conservative because no credit was taken for the following factors:

- o Voids within WEP matrix that would increase the total air space.
- o Resistance to diffusion of H_2 through the WEP mass to the bulk air space.
- o Losses of H_2 to the ambient atmosphere.
- o Recombination of H_2 and O_2.

The measured H_2 concentration in the WEP space was less than 0.1% in a 68-day test in which the full size cask contained ^{252}Cf sources totaling 18.7 mg. There was no pressure buildup in the WEP space during the test. The cask will be vented after each use and during each annual inspection to ensure that a pressure buildup and/or hazardous H_2 concentration is not accumulated in service.

d. Radioactive contamination of the primary coolant.

Not Applicable.

e. No loss of coolant or mechanical cooling devices. The cask is passively cooled. Heating from the source capsule is less than 12 Btu/hr (1.4 Btu/hr per 10 mg ^{252}Cf). This heat is transferred by conduction, convection, and thermal radiation from the source capsule, through air, to the cask inner surface; and by conduction through the WEP mass to the cask outer surface. Even if all air were evacuated from the source cavity in the cask, the heat could easily be removed by conduction and/or radiation.

2. Package for shipment of fissile material. Not applicable.

3. Containment vessel not vented directly to atmosphere. There are no vents in the cask cavity during normal conditions of transport.

F. Standards for Hypothetical Accident Conditions for a Single Package

Discussed in item II,D,1,b of this section.

G. Evaluation of an Array of Packages of Fissile Material

Not applicable.

H. Specific Standards for a Fissile Class I Package

Not applicable.

I. Specific Standards for a Fissile Class II Package

Not applicable.

J. Specific Standards for a Fissile Class III Package

Not applicable.

III. QUALITY ASSURANCE PROCEDURES FOR FABRICATION, ASSEMBLY, AND TESTING

A. Establishment and Maintenance of Procedures

1. A quality assurance program, including documentation, tickler systems, and procedures, has been established to:

   a) Ensure that requisite standards of quality are met in fabrication, assembly, and testing of each cask.

   b) Ensure that the cask in use continues to meet the requisite standards of quality.

B. Elements of the Quality Assurance Program

1. The program consists of a formal system of procedural organizational arrangements as follows:

   a) Specified quality during constriction was ensured:

Item	Specified Quality	Designated Unit
Cask	Figures 1, 2,3,4,5, & 6	Savannah River Laboratory Laboratory Operations and Services Section, Mechanical Services Group

   b) Figures 1,2,3,4,5, and 6 designate codes, standards and specifications for materials, equipment, and methods of fabrication, testing, and performance.

   c) Quality control of materials, equipment, and services in instances where this has not already been established by existing standards and specifications is performed by Du Pont prior to acceptance.

   d) An annual audit of Du Pont's programs to assess their effectiveness is made by AEC-SR.

e) Quality Assurance Records are prepared by the Savannah River Laboratory and maintained in auditable files, by SRL in the Californium Facility Cask Information File and by the SRP Project Department in the PRD Quality Assurance Record File for this container.

f) This report, DPSPU 74-124-6, demonstrates that this shipping package is in compliance with AEC Manual Chapter 0529.

g) This shipping package passed acceptably the tests prescribed in Annexes 1, 2, and 4 of AEC Manual Chapter 0529. Also, standard written operating procedures ensure that preliminary determinations are made as prescribed in part IV,C of the manual.

h) The californium shipping cask is inspected by the custodian on each return to Savannah River Laboratory. The inspection includes a radioactive contamination check, inspection for damaged parts, visual examination of welds, and functional fit inspection of parts.

The californium shipping cask is inspected annually and biennially* to ensure that it continues to meet design standards. A comprehensive radiation survey is performed around the cask containing a large source to reaffirm shielding integrity. A form, DPSTP-R-131-QA6, (attached) is completed on which each of the items inspected is listed and the inspector initials each item as the inspection is performed. Any damage is repaired and recorded on the inspection form.

i) The training, testing, and certification of manufacturing and inspection personnel involved in special processes, such as welding and nondestructive testing, and the certification of equipment and procedures used in the performance of special processes, are described in SRP Specification SP-5999, "Preparation of Purchase Specifications for Radioactive Material Shipping Containers," SRL Maintenance Procedures DPSTOM 38, and applicable Pittsburg Testing Laboratory procedures.

WEP pouring is accomplished under the direction and close observation of a qualified SRL engineer.

* See Reference 11.

PERIODIC INSPECTION OF CASK USA -6642-BL(AEC-SR) (4.5 TON CALIFORNIUM SHIPPING CASK)

Approval Date
January 1974

PURPOSE:

To inspect the cask annually or biennially to insure that it continues to meet design standards and to permanently record the results of this inspection.

NOTE: (1) During prolonged periods of storage the cask is exempted from this inspection, but the inspection must be performed before the cask is returned to service.

(2) Items marked with (*) to be performed only during biennial inspections.

PREPARATION:

The cask should be located where an overhead crane is available for lifting. A "Work Request" should be written to secure the necessary inspecting services.

REFERENCES:

RDT Standard -
E 12-7, Insepction and Preventative Maintenance of Radioactive Materials Packaging.
Safety Analysis Report -
SRL 4.5 Ton Californium Shipping Cask, DPSPU-72-124-3.
Drawings:

ST5-15813, R-20 - 4.5-Ton Californium Shipping Cask-Assembly
ST5-15814, R-13 - " " " " " Pc (1)
ST5-15815, R-8 - " " " " " Pc (2)
ST5-15816, R-12 - " " " " " Pc's (3)(5) (6) & (9)
ST5-15817, R-6 - " " " " " Pc (4) & (7)
ST5-15818, R-3 - " " " " " Assembly View A-A

SK-2140-LS,R-3 - Alteration of Shipping Plug, Pc (4) - 1 Unit & 4 Unit Polyethylene Capsule Spacers.

DISTRIBUTION:

This procedure must be completed in duplicate. One copy will be retained in the Californium Facility Cask Information File. The second copy will be forwarded through the Project Department (currently W. R. Hitchman, 706-H) to the PRD Quality Assurance Record File for this container.

RECORD OF PERIODIC INSPECTION

ANNUAL ______

BIENNIAL ______

A. SURFACE CONDITION

Surface shall be free of corrosion, gouges, cracks or other deformations as determined by visual inspection. Painted surfaces must be free of major cracks, chips or blisters. Mating and sealing surfaces shall not be deformed to the extent that gaskets will not function or that excessive force is required for sealing.

☐ Acceptable

☐ Corrective Action Required ______________________

____

☐ Reinspected Acceptable

Inspected By ______________________ Date ______________

B. *WELDS

Annually welds shall be determined to be sound by visual inspection. Biennially dye penetrant shall be used an all welds at lifting and tie-down lugs after paint is removed to determine that they are free of cracks.

☐ Acceptable

☐ Corrective Action Required ______________________

____

☐ Reinspected Acceptable

Inspected By ______________________ Date ______________

C. CLOSURE DEVICES

Bolts and nuts shall not be bent or otherwise deformed. Threads shall be uniform and free of burrs. Provisions for installing seal wires shall be present.

☐ Acceptable

☐ Corrective Action Required ______________________

____

☐ Reinspected Acceptable

Inspected By ______________________ Date ______________

D. LIFTING AND TIE-DOWN LUGS

Visual inspection shall indicate no misalignment, wear or other deformation which would materially affect strength. Holes shall not be worn or burred.

☐ Acceptable

☐ Corrective Action Required ______________________________

____

☐ Reinspected Acceptable

Inspected By ______________________________ Date ____________________

E. REUSABLE GASKET

Parker "O"-Ring gasket, on the bottom face of the shield plug flange, shall be free of visible evidence of deterioration or damage. It shall fit snugly in the "O"-Ring groove provided. There shall be no sharp edges or burrs on the groove.

☐ Acceptable

☐ Corrective Action Required ______________________________

____

☐ Reinspected Acceptable

Inspected By ______________________________ Date ____________________

F. *RADIATION (SHIELDING INTEGRITY)

Biennially radiation surveys shall be performed on the cask containing a Californium-252 source of about 10 mg. (The shield plug must be in place during measurements.)

☐ No change in shielding integrity

☐ Corrective Action Required ______________________________

____

☐ Reinspected Acceptable

Inspected By ______________________________ Date ____________________

G. FUSIBLE PLUGS

Inspect fusible plugs (9) and verify they conform to SRL drawing ST5-15813.

☐ Acceptable

☐ Corrective Action Required ______________________

____

☐ Reinspected Acceptable

Inspected By ______________________ Date ______________

H. TAGGING AND CERTIFICATION

The supervisor with overall responsibility for the performance of the periodic inspection shall insure that each inspection is performed by qualified personnel. After the inspections are complete and all deficiencies corrected, he shall have a durable metal tag affixed to the cask bonnet.

QA Inspection Expires ______________*

*One year after date of inspection.

The supervisor also completes the following certification.

I certify that Cask L-________ was inspected on __________. All deficiencies have been corrected and the cask meets the specifications outlined in the preceding inspection instructions.

______________________ ______________

Supervisor's Signature Date

IV. OPERATING PROCEDURES

A. Establishment and Maintenance of Procedures

Operating procedures and annual inspections will ensure continued compliance with AECM 0529.

B. Assumptions as to Unknown Properties

Not applicable.

C. Preliminary Determinations

1. Inspection. The cask was inspected to ensure proper fabrication. All welding was performed by SRL welders qualified under SRP Welding Procedure Qualifications DPSOP 126. Welds were radiographically inspected by Pittsburgh Testing Laboratory and radiographs filed in PTL file No. 4024-14. There were no cracks or voids which could significantly reduce the effectiveness of the cask. Table 3 (page 3) shows measured radiation dose rates outside the cask with 18.7 mg of ^{252}Cf in the source cavity.

2. Pressure Tests. The air in the cask cavity is at atmospheric pressure at the loading temperature of approximately 80°F and will be at a pressure of 2.8 psig if the internal temperature reaches 185°F, the maximum temperature of the cask surface caused by solar heating during conditions of normal transport. Because the maximum normal operating pressure in the cask cavity is below 5 psig, no elevated pressure test is required.

3. Marking. The Certificate of Compliance identification number is engraved on a stainless steel plate attached, by welding, to the outer surface of the cask.

   The owner, model number, and weight are engraved on a stainless steel plate attached, by welding, to the outer surface of the cask.

D. Routine Determination

Procedures are established to ensure that each use of the cask is in compliance with AECM 0529. See References 9 and 10 .

E. Records

The Savannah River Laboratory prepares a record of the information requested in this section of AEC Appendix 0529 for each shipment, and retains the record for 2 years per AEC Manual 0230.

Compliance with IAEA Regulations

The safety standards for packaging radioactive materials for international shipment are contained in the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition. Compliance of the shielded cask with the pertinent sections is discussed by number.

SECTION II - PACKAGING AND PACKAGE DESIGN REQUIREMENTS

The package is designed in accordance with the principles given in Section I, (131); the package is adequate to prevent loss or dispersal of the radioactive contents and to retain the efficiency of its radiation shielding properties if it is subjected to the tests specified in Section VII, paras. 709-721 as appropriate.

GENERAL DESIGN REQUIREMENTS FOR ALL PACKAGINGS AND PACKAGES

201. The package is adequately equipped with handling and tiedown lugs.

202. Not applicable because package weight is more than 50 kg.

203. The cask is designed to enable safe handling by mechanical means. See Appendix A.

204. The cask lifting lugs are adequate for the intended purpose. See Appendix A; A,3.

205. There are no lifting attachments other than the normal lifting lugs and the cask base which is designed for handling with a forklift vehicle.

206. The outer surface of the cask is designed to avoid the collection and retention of rainwater.

207. The painted external surface of the cask may be easily decontaminated.

208. The shipper complies with the requirement that any features added to the package at the time of transport which are not part of the package must not reduce the safety of the package.

ADDITIONAL REQUIREMENTS FOR STRONG INDUSTRIAL PACKAGES

Not Applicable.

ADDITIONAL REQUIREMENTS FOR TYPE A PACKAGES

210. All external dimensions of the package exceed 10 cm.

211. The cask closure incorporates a security seal which is not readily breakable and which, while intact, is evidence that the package has not been illicitly opened.

212. The cask is designed so that the external surface is free from protruding features except for the eight fusible plugs threaded into the spherical surface.

213. The cask is designed so that all materials are satisfactory for use within the temperature range of -40°C to 70°C. See Appendix B, Sections 1 and 2.

214. All welded, brazed, or fusion joints were made by welders qualified under SRP Welding Procedure Qualifications DPSOP 126. All welds meet Class III requirements per Engr. Spec. SW 60 W.

215. Cask closure bolts will be adequately torqued to prevent loosening by normal vibration during transport. See Appendix A.

216. The cask closure is bolted in place and cannot be inadvertently opened.

217. The cask is used for Special Form Material.

218. The outer closure is bolted in place and cannot be inadvertently opened.

219. The ^{252}Cf is compatible with materials used for its encapsulation (type 304L stainless steel, Zircaloy 2, and Pt-10% Rh), and the capsule materials are compatible with the type 304L stainless steel cask well. There is no liquid primary heat transfer medium.

220. Not applicable — no liquids.

221. The cask is equipped with nine fusible plugs, filled with an alloy (52.5% Bi, 32.0% Pb, 15.5% Sn) which melts at 203°F, located in the shield material section. Calculations in Appendix A: B,2 show that the cask can withstand pressures greater than 25 psig. The internal pressure will not exceed 15.6 psig, the maximum vapor pressure of the WEP components and air pressure at this temperature.

222. A 1/4 inch needle valve is installed in the top of the WEP shielding space to enable sampling the atmosphere to measure H_2 buildup as discussed in section II,E-1.c under "Compliance With AEC Regulations" (page 7). This valve is not connected to the cask cavity and, therefore, radioactive material and/or primary coolant cannot escape.

223. The source capsule will be contained inside the cask during normal or accident conditions of transport. In addition, the capsule qualifies as "Special Form".

224. Stress in the lifting lugs does not exceed one-third of the minimum yield strength. See Appendix A: A,3.

The tiedown attachments are adequate for transport. See Appendix A: A,4.

225. The cask meets test specifications required in Section VII, paras. 709-714.

226. Not applicable — no liquids.

227. Not applicable — no gases.

BASIC ADDITIONAL REQUIREMENTS FOR TYPE B (U) PACKAGES

228. The cask meets all additional requirements specified for Type A packages.

229. The cask meets these requirements. See Appendixes B and C.

230. The cask meets these requirements. See Appendixes B and C.

231. The package is so designed and constructed that:

a) The heat generated within the package does not affect the efficiency of the package under the conditions encountered in transport. The heat from decay of ^{252}Cf is small in comparison to the heat absorbed from direct sunlight. The IAEA conditions of normal transport are still-air ambient temperature of 38°C and direct sunlight exposure of 400 cal/cm^2 for 12 hr/day (123 Btu/(hr)(ft^2). If the cask is subjected to direct sunlight at an ambient temperature of 38°C (100°F) in still air, the cask surface temperature will be 62°C (144°F) and the resulting internal air pressure in the cask cavity will be 1.8 psig. The pressure in the WEP shielding containment will be 5 psig (combined air and water vapor pressure). See Appendix B, 1 for a discussion of other conditions. The cask shell withstands pressures greater than 25 psi as shown in Appendix A: B,2. The temperature of the WEP increases to about 185°F (85°C) during curing; therefore, the 62°C cask temperature is within the tolerable range of WEP temperatures.

The solar heat input to the cask is given by the equation:

$$Q_{SR} = SA_{SR}\,\alpha_{SR}$$

where: S = maximum solar radiation for 24 hr avg

S = 123 Btu/(hr)(ft^2) (IAEA stipulation for curved surface)

A_{SR} = 0.5 × cask surface area = 39 ft^2

α_{SR} = 0.6 for steel surface

Q_{SR} = 123 Btu/(hr)(ft^2) × 39 ft^2 × 0.6 = 2880 Btu/hr

The decay heat input is calculated as follows per 10 mg ^{252}Cf:

Q_{CF} = 40 watts/gram × 10 × 10^{-3} gram × 3.413 Btu/(watt)(hr)

= 1.4 Btu/hr per 10 mg Cf (this is neglected in heat transfer calculations)

The total heat input to the cask is, therefore, 2880 Btu/hr. The heat rejected from the cask must equal the heat input at equilibrium. Heat rejection is by natural convection to the still air and by radiation to the surroundings. The equation for the heat rejection is as follows:

$$Q_T = (h_c + h_r)(A)(T_S - T_A)$$

where: Q_T = total heat rejected = 2880 Btu/hr

h_c = coefficient for natural convection heat transfer

h_r = coefficient for radiation heat transfer

A = surface area of cask = 39 ft^2 (only area of hemisphere assumed)

T_S = cask surface temperature, °C

T_A = ambient temperature = 38°C (100°F)

The final trial temperature, T_S, was 144°F (62°C).

h_c = 0.75 Btu/(hr)(ft^2)(°F)

h_r = 0.94 Btu/(hr)(ft^2)(°F)

Q_T = (0.75 + 0.94)(39 ft^2)(144°F - 100°F) = 2900 Btu/hr

The cask temperature is insufficient to alter the form of the contents or damage the radiation shielding.

b) The temperature of the accessible surfaces of the package will be at essentially the stipulated ambient air temperature of 38°C in shade because the heat from permissible quantities of ^{252}Cf is negligible.

232. Condition assumed as stated.

233. Not applicable.

SPECIFIC ADDITIONAL REQUIREMENTS FOR TYPE B (U) PACKAGES

234. Compliance does not depend upon filters, nor upon a mechanical cooling system.

235. The package is not capable of venting continuously during transport.

236. There is no pressure relief system for the source cavity in the cask.

237. The maximum normal operating pressure in the cask well does not exceed 0.35 kg/cm^2 (5 psig) so that no pressure test is required. However, the cask shell can withstand pressures greater than 25 psig. See Appendix A: B,2.

238. The air pressure within the cavity will increase to 38 psig at a temperature of 800°C. The corresponding stress in the cavity wall is 680 psi which is below the minimum yield strength of type 304L stainless steel at 800°C.

239. The primary heat transfer mechanism in the cavity is conduction and thermal radiation in an air medium. The normal operating pressure will not exceed the maximum allowable pressure of 7 kg/cm^2 (100 psig).

240. See para. 231.

241. Not applicable — no liquid.

SECTION IV - ACTIVITY LIMITS

Although the quantities shipped in this cask will be less than that designated as a "large quantity" of nonfissile, Group I materials (>5000 Ci of ^{252}Cf in "special form"), as defined in IAEA regulations, the cask does comply with applicable regulations for large quantity shipments.

SECTION V - CONTROLS FOR TRANSPORT AND STORAGE IN TRANSIT

MIXED PACKING

501. Not applicable.

NONFIXED RADIOACTIVE CONTAMINATION

502. The painted exterior surface of the package is designed to be easily decontaminated so the nonfixed radioactive contamination can be kept below the levels specified in Table XI, IAEA Section V.

503. The package is classified category III — Yellow.

504. Not applicable.

505. Not applicable.

506. Not applicable.

507. Not applicable.

508. Shipper will comply.

509. Shipper will comply.

LABELLING AND MARKING

510. Two labels which conform to the model given in para. 519, Figure 4 for Category III — Yellow, will be affixed to two opposite sides of the outside of the package to indicate dose rate category for each shipment made under IAEA regulations.

511. Shipper will comply.

512. Shipper will comply.

513. Shipper will comply.

514. The gross weight of the cask, approximately 9500 pounds, is plainly and durably marked on the name tag affixed to the outside of the package.

515. Not applicable for Type B package.

516. The package is plainly and durably marked on the outside with an identification mark allocated by the competent authority.

517. The outside of the package is stamped with the trefoil shown in IAEA Section V, Figure 1. The trefoil is stamped into the steel surface so that it is fire and water resistant.

518. Shipper will comply.

519. Shipper will comply.

SECTION VII – TEST AND INSPECTION PROCEDURES

DEMONSTRATION OF COMPLIANCE WITH THE TESTS

701. (c) Test were accomplished using a 1/4 scale model of the cask that was fabricated from the same type and grade of material as the fullsize cask.

(d) Calculations were used where applicable.

702. Test conditions comply. See Appendixes B and C.

TEST FOR PACKAGING

Number of Specimens to be Tested

703. One 1/4 scale model of the cask was used for testing. A model of a segment of the 5-foot-diameter cask was used for thermal testing.

Preparation of a Specimen for Testing

704. All specimens were examined prior to testing.

705. The containment system of the packaging is specified by drawings.

706. External surfaces of the specimen were photographed for easy identification.

Testing the Integrity of Containment and Shielding

707. Test with ^{252}Californium sources demonstrated that the integrity of the package was not affected. See para. 725, Appendixes B and C.

Target for the Drop Tests Specified in Paras. 712, 716, 719 and 732

708. Targets are indicated for each test. See Appendixes B and C.

Tests for Demonstrating Ability to Withstand Normal Conditions of Transport

709. See Appendixes B and C.

710. See Appendixes B and C.

711. Water spray test. Water spray will have no affect on the painted steel exterior surface of the cask.

712. Free drop test. The packaging is designed to withstand a 30-foot free fall with no impairment of radiation shielding and no loss or dispersal of radioactive material; therefore, it meets the requirements of the 1.2-meter (4-foot) free fall. See Appendix C,1 for results of 1/4 scale model drop tests.

713. Compression test. This was not conducted because it is less severe than the USAEC requirement of withstanding a uniform external loading of 25 psig. See Appendix A: B,2.

Additional Tests for Type A Packaging Designed for Liquids and Gases

715. Not applicable — no liquids or gases.

716. Not applicable — no liquids or gases.

717. Not applicable — no liquids or gases.

Tests for Demonstrating Ability to Withstand Accident Conditions in Transport

718, 719, 720. The hypothetical accidental conditions are similar to those required by the USAEC. The package will survive the tests as required. The tests were performed with different models (See Appendix C) because the mechanical tests did not produce damage that would influence the thermal tests. The immersion test is not required for nonfissile materials.

721. The package is designed to be leaktight at a depth of 15 meters in water. The pressure at a depth of 15 meters is 21.3 psig based on water at its greatest density (39.2°F) (22 psig for sea water) and is less severe than the USAEC requirement for withstanding an external pressure of 25 psig as discussed in Appendix A: B,2.

Water Inleakage Test for Fissile Material Packages

722. Not applicable.

723. Not applicable.

724. Not applicable.

Tests for Integrity of Containment and Shielding

725. The test for integrity of containment.

Following two 30-foot free drops and the 40-inch free drop onto the steel pin as discussed in Appendix C, the closure in the 1/4 scale model of the cask was undamaged and in place. The ^{252}Cf is contained in "special form" capsules which are contained in the cask after the drop.

The test for integrity of shielding.

The 1/4 scale model of the casks, containing a 65 μg source of ^{252}Cf, was examined by radiography with X-ray film on the entire surface before and after the drop tests in paras. 709 - 721. There was no difference in the measured radiation, indicating that shielding integrity was not affected by the drops.

The increase in radiation resulting from thermal damage of the WEP would be less than 1% as discussed in Appendix C,3.

TESTS FOR SPECIAL FORM RADIOACTIVE MATERIAL

Not applicable.

INSPECTION REQUIREMENTS TO BE FULFILLED BEFORE FIRST SHIPMENT AND BEFORE EACH SHIPMENT OF CERTAIN TYPES OF PACKAGE

Before first shipment.

738. Prior to the first use, the cask was given a radiation shielding integrity test as shown in table 3, page 3. Pressure tests and thermal dissipation tests are not applicable because the cask is not pressurized under normal conditions and the heat from decay of permissible quantities of ^{252}Cf is negligible.

Before each shipment.

739. Shipper will comply.

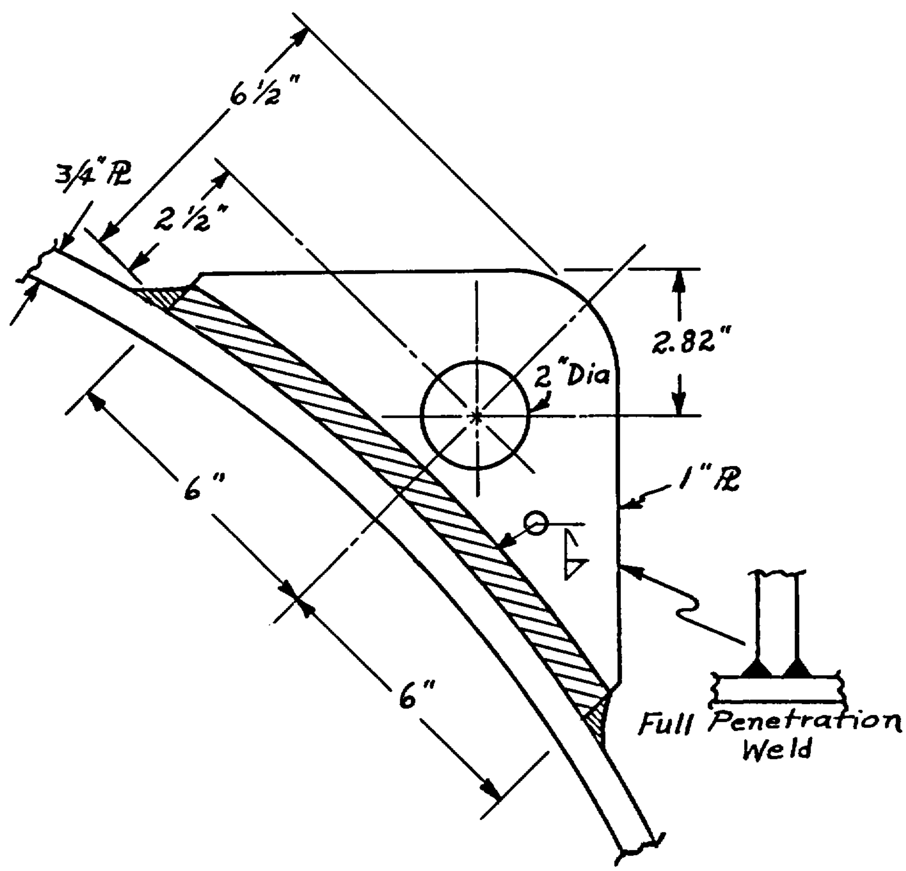
APPENDIX A

Compliance With Package Standards — Structural Integrity

A. General Standards for All Packaging

3. Lifting Devices

a. Lifting devices which are structural parts of the package. (No stress greater than yield at 3 times package weight.) Package weight is approx 9000 pounds. Four combination lifting and tiedown lugs are on the package. Only two lugs would normally be used for lifting; all four lugs would be used for tiedown.



LIFTING LUG DETAIL

Lug is 1" plate, ASTM A-516-Gr. 55

Ultimate strength = 55,000 psi

Yield strength = 30,000 psi

3 times package weight = 27,000 pounds

Minimum lift load capacity required per lug = 13,500 pounds

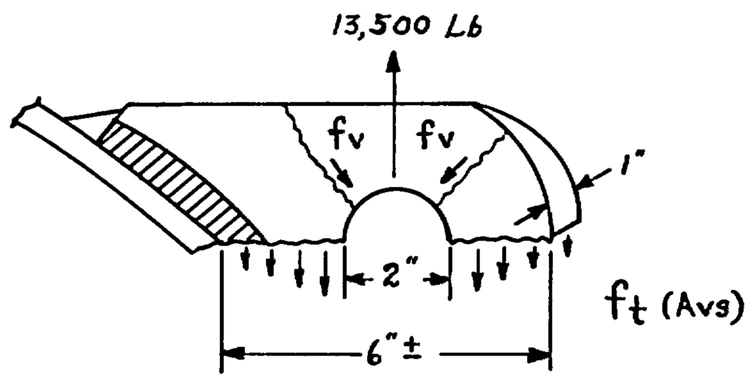


Plate Tension

$$f_t = \frac{13{,}500 \text{ lb}}{(6" - 2")(1")} = 3375 \text{ psi avg}$$

Lug Shear-Out

$$f_v = \frac{13{,}500 \text{ lb}}{2 \times 2.5} = 2700 \text{ psi avg}$$

Allowable shear stress ≈ 15,000 psi (50% of yield stress in tension)

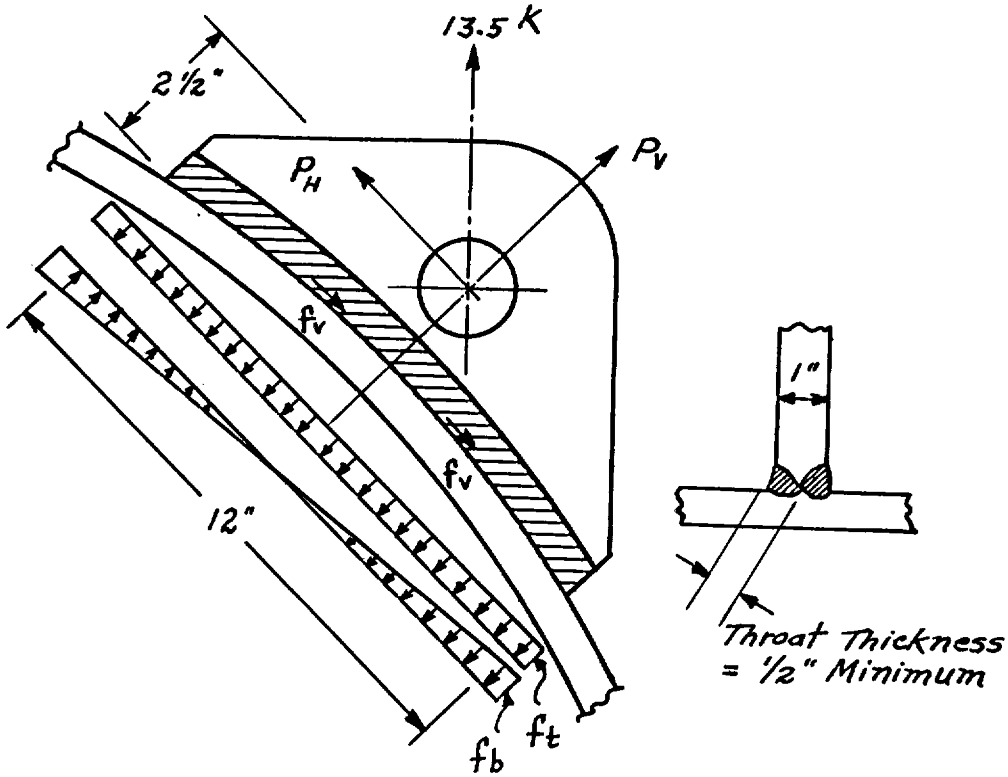
Welds

Allowable weld stress = 30,000 psi

Split 13,500 lb load into components

P_H = parallel to weld

P_V = perpendicular to weld



$P_H = P_V = 9550$ lb

$f_t = \dfrac{9550 \text{ lb}}{(26")(0.5")} = 730$ psi tensile weld stress

$f_b = \dfrac{(9550 \text{ lb})(2.5")}{\dfrac{1 \times (12)^2}{6}} = 990$ psi weld stress - moment from P_H

$f_v = \dfrac{9550}{26 \times 0.5} = 730$ psi weld stress (longitudinal shear)

$f_b + f_t = 1720$ psi

Weld is satisfactory since the maximum stress is less than the yield stress of 30,000 psi.

d. Lifting devices which are structural parts of the package. (Failure of the devices under excessive load would not impair the containment or shielding properties of the package.)

Removal of the lifting lugs would not impair the containment or shielding properties of the package.

4. Tiedown Devices

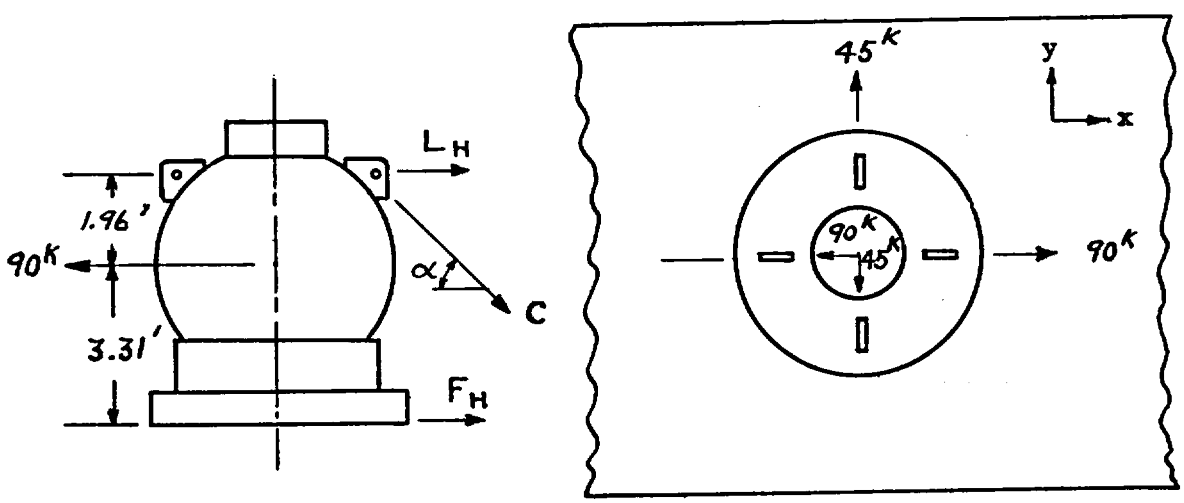
a. Tiedown devices which are structural parts of the package. (No stress greater than yield from a static force with longitudinal, transverse, and vertical components of 10 g, 5 g, and 2 g, respectively.)

$$10\ g = 10 \times 9000\ lb = 90{,}000\ lb$$
$$5\ g = 5 \times 9000\ lb = 45{,}000\ lb$$
$$2\ g = 2 \times 9000\ lb = 18{,}000\ lb$$

Cable Stresses

Investigation of typical angles (α) of tiedown cables will show whether lugs are satisfactory with normal tiedown angles.

Case I - lugs parallel to direction of travel.



$$L_{H_x} = \frac{3.31}{5.27} \times 90{,}000 = 56{,}000\ lb$$

$$F_{H_x} = \frac{1.96}{5.27} \times 90{,}000 = 33{,}470\ lb$$

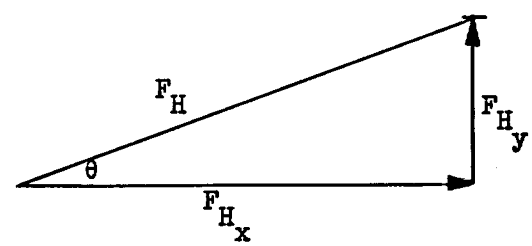
$$C_x = \frac{L_H}{\text{Cos}\ \alpha} = \frac{56{,}000}{\text{Cos}\ \alpha}$$

$$L_{H_y} = \frac{3.31}{5.27} \times 45{,}000 = 28{,}000 \text{ lb}$$

$$F_{H_y} = \frac{1.96}{5.27} \times 45{,}000 = 16{,}735 \text{ lb}$$

$$C_y = \frac{L_{H_y}}{\cos\alpha} = \frac{28{,}000}{\cos\alpha}$$

Resultant Force on Base

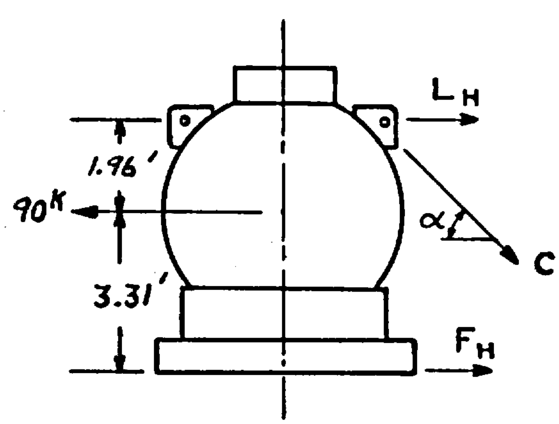


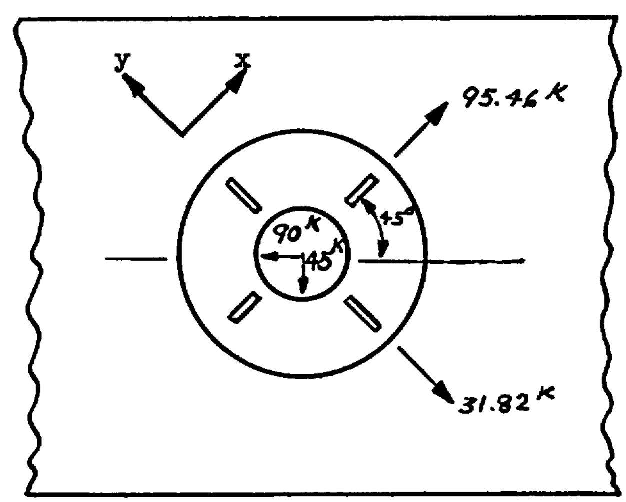
$$\tan\theta = \frac{16{,}735}{33{,}470} \qquad \theta = 26.6°$$

$$F_H = \sqrt{(16{,}735)^2 + (33{,}470)^2}$$

$$F_H = 37{,}420 \text{ lb}$$

Case II - lugs 45° to direction of travel





$$\frac{45{,}000}{\cos 45°} = 63{,}640$$

$$\frac{22{,}500}{\cos 45°} = \frac{31{,}820}{95{,}460 \text{ lb}}$$

$$L_{H_x} = \frac{3.31}{5.27} \times 95{,}460 = 59{,}890 \text{ lb}$$

$$F_{H_x} = \frac{1.96}{5.27} \times 95{,}460 = 35{,}500 \text{ lb}$$

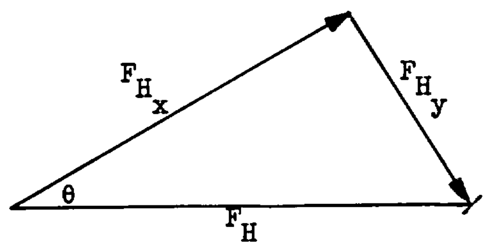
$$C_x = \frac{L_H}{\cos\alpha} = \frac{59{,}900}{\cos\alpha}$$

$$L_{H_y} = \frac{3.31}{5.27} \times 31,820 = 19,986 \text{ lb}$$

$$F_{H_y} = \frac{1.96}{5.27} \times 31,820 = 11,834 \text{ lb (-y direction)}$$

$$C_y = \frac{L_{H_y}}{\cos \alpha} = \frac{19,986}{\cos \alpha}$$

Resultant Force on Base



$$\tan \Theta = \frac{11,834}{35,500}$$

$$\Theta = 18.4°$$

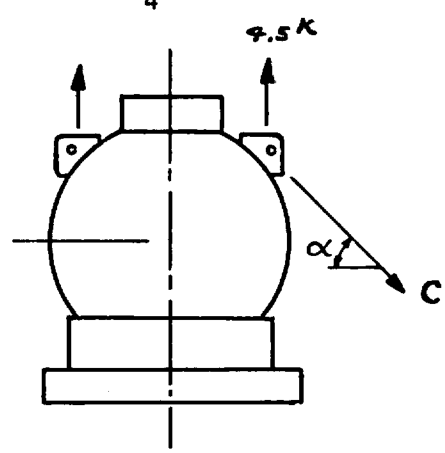
$$F_H = \sqrt{(11,834)^2 + (35,000)^2}$$

$$F_H = 37,420 \text{ lb}$$

The largest resultant of longitudinal and transverse forces is C_x of case II i.e., $\frac{59,900}{\cos \alpha}$.

In all cases the vertical force is 2 g = 18,000 lb, or

$$V_H = \frac{18,000}{4} = 4500 \text{ lb per lug}$$



$$C = \frac{4500}{\sin \alpha}$$

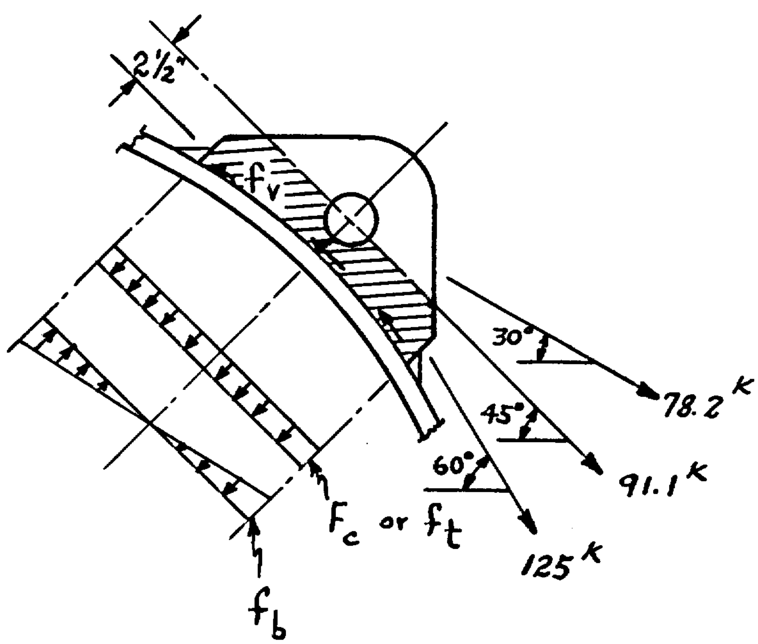
The maximum cable tension resulting from all forces is therefore $\frac{59,900}{\cos\alpha} + \frac{4500}{\sin\alpha}$. Values of tension as a function of α are shown in the following table.

Angle, α	$\frac{59,900}{\cos\alpha}$	$\frac{4500}{\sin\alpha}$	Cable Tension, lb	Cable Diameter, in.[a]
20°	63,740	13,160	76,900	1-1/2
30°	69,170	9,000	78,170	1-1/2
45°	84,710	6,360	91,070	1-5/8
60°	119,800	5,200	125,000	2
65°	141,730	4,970	146,700	Too steep
75°	231,430	4,660	236,100	Too steep

[a] Wire rope of improved plow steel, safety factor of 5 applied. Installation should be sufficiently taut to remove sag, but not preloaded.

The cables will not be attached at an angle steeper than 60° at the trailer floor.

Lug Stresses - for cable pulls of 30°, 45°, or 60°



$$\text{weld section mod} = \frac{1 \times 12^2}{6} = 24\ \text{in}^3$$

$$\text{weld throat area} = 26 \times 0.5 = 13\ \text{in}^2$$

For 45° Pull

$$f_v = \frac{91,100}{13} = 7000 \text{ psi (shear)}$$

$$f_b = \frac{(91,100)(2.5)}{24} = 9490 \text{ psi (bending)}$$

$$f_t = 0$$

For 30° Pull

moment arm = 2.5 cos 15° = 2.415 in.

$$f_b = \frac{(78,200)(2.415)}{24} = 7870 \text{ psi (bending)}$$

$$f_t = \frac{(78,200)(\sin 15°)}{13} = 1560 \text{ psi (tension)}$$

$$f_v = \frac{(78,200)(\cos 15°)}{13} = 5810 \text{ psi (shear)}$$

Maximum tensile stress = $f_t + f_b$ = 9430 psi

For 60° Pull

$$f_b = \frac{(125,000)(2.415)}{24} = 12,580 \text{ psi (bending)}$$

$$f_c = \frac{(125,000)(\sin 15°)}{13} = 2490 \text{ psi (compression)}$$

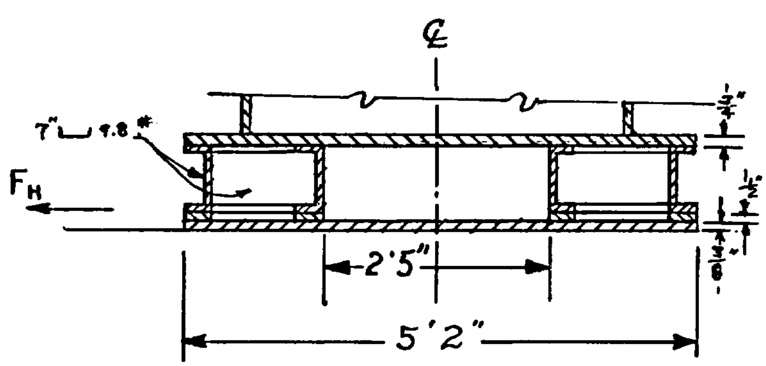
$$f_v = \frac{(125,000)(\cos 15°)}{13} = 9290 \text{ psi (shear)}$$

$$\text{maximum combined shear stress} = \sqrt{\frac{12,580 + 2,490}{2}^{2} + (9,290)^2}$$

$$= 12,000 \text{ psi}$$

Thus, the weld tensile yield stress of 30,000 psi and the shear yield stress of 15,000 psi are not exceeded for any of these configurations.

Stresses in Cask Base



[All Material Type A-36 Except 1/2" Thick BAR - SAE 1020]

Base orientation shown for Case II cask orientation. F_H, Case I = F_H, Case II = 37,420 lb.

a. Shear between Cask Base and Trailer Floor.

Use 1-1/4" bolts, A-307, 10,000 psi design shear stress. Allowable load, single shear = 9,690 lb/bolt. Min number bolts =

$$\frac{F_H}{9,690} = \frac{37,420}{9,690} = 3.86 \text{ i.e, 4 bolts}$$

Bearing area on baseplate = Dt = 1-1/4 × 3/8 = 0.469 in^2.
Area for 4 bolts = 4 × 0.469 = 1.88 in^2.

$$\text{Bearing stress} = \frac{F_H}{A} = \frac{37,420}{1.88} = 19,900 \text{ psi}$$

(Well below 36,000 yield stress)

b. Shear in Base Channels

(Bending in channels is prevented by short channels perpendicular to the main channel members. See figure 2.)

Shear stress in web, σ_v, $= \frac{F_H}{A}$

Where A = total length (234") × web thick. (0.210")

$$\sigma_v = \frac{37,420}{234 \times 0.210} = 761 \text{ psi (very low)}$$

c. Shear in assembly welds

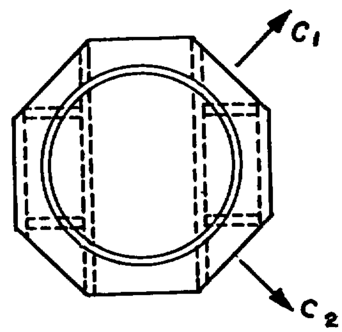
(Two 1/4" welds per channel, except single weld on short perpendicular members)

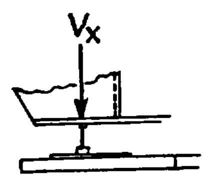
Shear stress in welds, $\sigma_v = \frac{F_H}{A}$

Where A = weld length (411") × weld size (1/4") × 0.707.

$$\sigma_v = \frac{37,420}{411 \times 1/4 \times 0.707} = 515 \text{ psi (very low)}$$

d. Vertical Loading of Channels





For a 60° cable angle:

C_1, = 125,000 lb (Case II, table)

$$C_2 = C_y + \frac{4500}{\sin\alpha} = \frac{19,986}{\cos\alpha} + \frac{4500}{\sin\alpha} = 45,170 \text{ lb}$$

Total vertical load = (125,000 + 45,170) sin 60°
= 147,400 lb

Distribute load over 4 channel crossover points:

$$V_x = \frac{147,400}{4} = 36,850 \text{ lb}$$

For interior load:

$$\frac{R}{t\ (N + 2k)} \leq 0.75\ F_y$$

where:
F_y = 36,000 psi yield stress
R = max allowable reaction
t = 1/4" web thickness
N = 1" bearing region, skirt
k = 7/8" (7-inch channel)

$$\frac{R}{(1/4)[1 + 2\ (13/16)]} \leq (0.75)(36,000)$$

$$R \leq 18,560 \text{ lb}$$

V_x = 36,850 lb > 18,560 lb (web stiffener required)

$$\text{Stiffener area} = \frac{36{,}850}{F_y} = \frac{36{,}850}{36{,}000} = 1.0^{+}\ \text{in}^2$$

[1-1/2" × 1" (1.5 in^2) stiffener added at each of 8 crossover points — reference figures 1 and 6.]

c. Tiedown devices which are structural parts of the package. (Failure of tiedown devices under excessive load shall not impair ability of package to meet other requirements of Package Standards.)

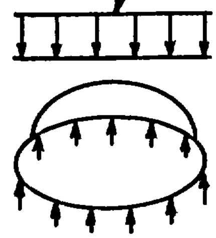
The shielding capacity of the sphere is not impaired, nor is the basic impact resistance of the sphere altered, if the lugs which are used for tiedown tear loose or if the bottom skirt is removed. The lugs and skirt do not contribute to the shielding capacity.

B. Structural Standards for Large Quantity Packaging

1. Load Resistance

(Package regarded as a simple beam — no stress greater than yield with 5 times loaded weight uniformly distributed.)

This specification is not directly applicable to a sphere. The sphere can be examined by supporting it on its midperimeter and placing a uniform load equal to 5 times the package weight atop the upper half.



$$\text{Perimeter} = \pi\ (60.75) = 190.85 \text{ in.}$$

$$\text{Load/in.} = \frac{45{,}000}{190.85} = 235.8 \text{ lb/in.}$$

$$f_V = \frac{235.8}{0.75} = 314 \text{ psi}$$

$$\text{Area of hemisphere} = \frac{\pi\ D^2}{2} = \frac{3.14\ (60.75)^2}{2}$$

$$= 5797 \text{ in}^2$$

$$\text{Avg pressure} = \frac{45{,}000}{5797} = 7.76 \text{ psi}$$

This condition is less severe than the following requirement that the sphere be subjected to 25 psi external pressure.

2. External Pressure

No loss of containment at 25 psig. (These analyses are also valid for internal pressure.)

Sphere

$$f = \frac{PR}{2t}$$

where: R = 30.375 in.

P = 25 psi

t = 0.75 in.

$$f = \frac{25 \times 30.375}{2 \times 0.75} = 506.3 \text{ psi membrane stress}$$

Top Plate

Plate = 22.5" dia × 0.75" thick

Perimeter fully welded — assumed fixed support

Load, q = 25 psi

$$M = \frac{-q\ a^2}{8}$$

a = 11.25" radius

M = -396 in. lb/in.

$$f_b = \frac{6M}{t^2}$$

f_b = 4220 psi bending stress at perimeter

In neither case is the yield stress exceeded.

APPENDIX B

Normal Conditions of Transport

1. Heat

If the cask is subjected to direct sunlight at an ambient temperature of 130°F in still air, the cask surface temperature will not exceed 183°F for the most severe case postulated; i.e., a horizontal unpainted steel surface (ϵ = 0.6) facing upward at noon on June 21 when the peak solar radiation is 310 Btu/(hr)(ft^2) for the horizontal surface (reference 3). Also, for this case, the area of the cask hemisphere facing away from the sunlight is assumed to be unavailable for heat rejection. The pressure of the air in the cask cavity cannot exceed 2.8 psig even if the cavity were uniformly heated to 183°F. The pressure in the WEP shielding containment cannot exceed 10.6 psig for combined air and water vapor pressure at a uniform temperature of 183°F. The temperature of the WEP increases to about 185°F during curing; therefore, the cask temperature is within the tolerable range of WEP temperature.

For normal conditions of transport, the cask will be painted with white zinc oxide paint which has a low absorptivity at solar wavelengths of only 0.18 but a high emissivity at 100°F of 0.95 (reference 3). The surface temperature of the painted cask at the same conservative conditions stated above is only 148°F. Pressures in the cavity and WEP shielding cannot exceed 2.0 psig and 5.5 psig, respectively.

The solar heat input to the cask is given by the equation:

$$Q_{SR} = SA_{SR}\,\alpha_{SR}$$

where: S = solar radiation [310 Btu/(hr)(ft^2) max for horizontal surface] [reference 3]

A_{SR} = projected area of cask = 19.6 ft^2

α_{SR} = 0.6 for steel surface

Q_{SR} = 310 Btu/(hr)(ft^2) × 19.6 ft^2 × 0.6 = 3640 Btu/hr

The decay heat input is calculated as follows per 10 mg ^{252}Cf:

Q_{CF} = 40 watts/gram × 10 × 10^{-3} grams × 3.413 Btu/(watt)(hr)

= 1.4 Btu/hr per 10 mg ^{252}Cf (this heat is neglected in calculations)

The heat rejected from the cask must equal the solar heat input at equilibrium. Heat rejection is by natural convection to the still air and by radiation to the surroundings. The equation for heat rejection is as follows:

$$Q_T = (h_c + h_r)(A)(T_S - T_A)$$

where:
- Q_T = total heat rejected = 3640 Btu/hr
- h_c = coefficient for natural convection heat transfer
- h_r = coefficient for radiation heat transfer
- A = surface area for heat transfer = 39 ft^2 (hemisphere)
- T_S = cask surface temperature, °F
- T_A = ambient temperature = 130°C

The final trial temperature, T_S, was 183°F (trial and error solution).

h_c = 0.82 Btu/(hr)(ft^2)(°F)

h_r = 0.96 Btu/(hr)(ft^2)(°F)

Q_T = (0.82 + 0.96)(39 ft^2)(183°F - 130°F) = 3640 Btu/hr

2. <u>Cold</u>

If the cask is subjected to an ambient temperature of -40°F in still air and shade, the cask temperature will approach -40°F because the decay heat from the ^{252}Cf source (1.4 Btu/hr per 10 mg ^{252}Cf) is negligible.

Freeze resistance of the WEP formulation was demonstrated by a test (reference 4) in which a cylindrical casting containing embedded thermocouples and weighing 11 kg was repeatedly cooled to temperatures below -40°C and then thawed. After six cycles of cooling and thawing the casting was sectioned and examined for physical damage such as cracking or crumbling. No damage was detectable.

The freeze resistance test, as performed, is more severe than specifications require. Cooling and thawing were done at high rates, so that a complete freeze-thaw cycle could be completed in approximately 24 hours. The cooler itself was at a temperature much lower than -40°C. Temperature gradients from the surface of the casting to the center were at times as high as 25°C. Such gradients undoubtedly caused stresses which would not have occurred at lower cooling rates. Also, since cooling was continued on each cycle until it was assured that every part of the casting was below -40°C, much of the casting survived temperatures much lower than that value.

3. Pressure

Atmospheric pressure of 0.5 times standard atmospheric pressure. (The cask can withstand pressures greater than 25 psig as shown in Appendix A: B,2.)

a. Tensile stress in sphere

$$F = \frac{PR}{2t}$$

where: F = tensile stress, psi

P = 0.5 × std atm. press. = 7.5 psi

R = radius of sphere = 30.375 in.

t = thickness of spherical shell = 0.75 in.

$$F = \frac{(7.5)(30.375)}{(2)(0.75)} = 152 \text{ psi}$$

b. Bending stress at edges of top plate

$$F = \frac{6\ PR^2}{8\ t^2}$$

where: F = bending stress at edges of plate

P = 0.5 × std atm. press. = 7.5 psia

R = radius of top plate = 11.25 in.

t = thickness of top plate = 0.75 in.

$$F = \frac{6 \times 7.5 \times 11.25^2}{8 \times 0.75^2} = 1265 \text{ psi}$$

In both cases the stresses calculated are less than the allowable tensile yield stress of 30,000 psi.

4. Vibration

Vibration normally incident to transport. The tiedown conditions on the cask are such that the only forces imposed on the package are those experienced through the wheel springs of the transport vehicle. Any normal truck or railroad car capable of carrying 9000 pounds would be suitable.

5. Water Spray — To keep entire surface wet for 30 minutes.

A water spray would not affect the painted steel cask if the outer cover is closed and the O-ring gasket is in place at the shield plug. The source capsules would not be affected if the cover and gasket were removed to allow water to enter the cask cavity.

6. Free Drop — A free drop through a distance of four feet for a package weighing less than 10,000 pounds onto a flat unyielding surface.

This drop is not as severe as the 30-foot drop for the hypothetical accident conditions discussed in Appendix C.

7. Corner Drop

Not applicable for packages of other than wood or fiberboard nor for package weight exceeding 110 pounds.

8. Penetration — Impact of the hemispherical end of a vertical steel cylinder 1-1/4 inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture.

This test is not as severe as the drop of the cask model onto the end of a 1-1/2 inch diameter vertical steel bar from a height of 40 inches, simulating dropping the full size cask onto a 6 inch diameter bar, for the hypothetical accident conditions discussed in Appendix C.

9. Compression

A compressive load equal to five times the package weight, applied for 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally he transported.

The 1/4 scale cask model, previously used for drop testing (Appendix C), was used for this test. It was placed on a concrete floor with a 3/4 × 24 × 24-inch steel plate placed on the top-hat. A 3000 lb load ($5 \times \frac{1}{16} \times$ wt of full size package) was then placed on this plate for 24 hours.

No evidence of damage to the cask was noted. Overall cask height remained unchanged — 18-3/4 in. Visual examination of the weld area, where the top-hat connects to the sphere, indicated no detectable damage.

APPENDIX C

Hypothetical Accident Conditions

1. Free Drop

A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected. A 1/4 scale model of the cask, figure 7, was dropped through a distance of 30 feet onto a one-inch-thick steel plate resting on an unyielding concrete slab. Maximum damage was expected from a top impact, the results of which were:

1) Pneumatic tests at 7.5 psig with model submerged in water for bubble detection before and after drop showed no evidence of leakage.

2) No evidence of damage to spherical shell. The maximum change in diameter of the cask model was 0.053 inch or about 0.3% of the original diameter of 15.35 inches.

3) The closure remained intact; however, the torque required to loosen the plug-retaining nuts was decreased from the predrop value of 27 inch-pounds to 0 to 15 inch-pounds, indicating an elongation of the studs.

4) The top cover remained tight, figure 8, but the retaining screw heads were damaged from direct contact with the impact surface. This damage is of no consequence from a safety point of view because the top cover acts as a weather cover and is not a structural component of the cask.

Following the top impact, the cask was dropped through 30 feet onto the spherical "side" to determine deformation caused by impact on the spherical surface. The results of this impact were:

1) The spherical surface was deformed inward 1/4 inch maximum over a flattened area 3-1/2 inches in diameter as shown in figure 9.

2) The shield plug remained intact.

3) The weather cover remained tight.

4) Cask diameter changes, other than at the impact area, were up to 0.070 inch or about 0.5% of the original diameter of 15.35 inches.

5) No other damage was observed. Neutron radiography before and after the drop tests verified the integrity of the shielding.

2. Puncture — 40-inch drop onto end of 1-1/2 inch diameter bar.

Following the two 30-foot drops, the cask model was dropped through 40 inches onto the upper end of a vertical steel bar. The bar was 1.5 inches in diameter, representing a 1/4 scale equivalent of a bar 6 inches in diameter, and was welded upright on the steel impact plate. The cask model did not "squarely" impact the bar. The test was considered more severe than a direct end-on impact because the force was concentrated over a smaller area. Deformation of the cask surface, figure 10, was about 0.080 inch maximum and was crescent shaped indicating that only about 1/4 of the end area of the bar contacted the cask surface.

3. Thermal — 30-minute exposure to radiant heat source of 1475°F.

Thermal resistance of the WEP formulation was demonstrated by a test (reference 4) in which one surface of an 11 kg steel-encased casting of WEP, figure 12, was subjected to a temperature of 1475°F for a period of 30 minutes in the arrangement shown in figure 13A. This test demonstrated that surface exposure to high temperatures penetrated the WEP to a very shallow depth, figure 13. Increased radiation resulting from thermal damage would be less than 1%. This test was

not run sequentially with the drop test model because the drop tests showed no damage that could affect the thermal tests.
The test arrangement was so designed that its configuration and size simulated a segment of the spherical five-foot-diameter steel shipping cask, figure 11. Approximately 0.69% of the surface of the cask was represented by the heated surface of the WEP.

As shown in figure 12, the 3/4-inch plate representing the cask wall was designed to extend one-inch radially beyond the WEP so that the heat input to this extra area would compensate for the heat loss to the shell surrounding the WEP. In addition the connection between the 3/4-inch plate and the 11 ga shell was arranged to provide only a small cross-sectional area and a circuitous route for heat conduction. During the test, essentially equal temperatures at the two thermocouple locations on the shell (figure 13) indicated little heat flow along the shell. The lack of a singificant temperature gradient in the 3/4-inch plate was later evident from the uniformity of WEP degradation adjacent to the plate. The cooling coil encircling the model shell was not used except for a brief period approximately 20 minutes after the start of the test. Introduction of approximately 150 ml of water at this time resulted in the sharp drop in shell temperature evident in figure 13.

Gases driven out of the plastic during the thermal exposure period were condensed and the liquid was collected for subsequent analysis. The first fraction to be collected, starting 8 minutes after the beginning of the exposure period, was colorless and transparent (water with some boron). About two minutes later, a flammable, dark-colored turbid liquid, lower in density and immiscible with the first, began to be collected concurrently. Temperature of the condenser effluent was 28°C. A total of approximately 300 ml of liquid was collected of which 100 ml was the less dense phase. The rate of evolution, 14 ml/min, was nearly constant. The total volume collected was found later to correspond approximately to the volume loss of the casting. Practically all material driven off from the casting was condensable. Only a small amount of whitish fumes was discharged from the condenser. Nine fusible plugs (m.p. 203°F) in the shipping cask allow venting during fire. The venting area of the nine fusible plugs is 1.8 in^2.

The test container and the casting were sectioned for examination. It was found that plastic adjacent to the heated container wall had been destroyed to a depth of approximately 0.6 cm. The exposed plastic surface was charred and friable and was characteristic of a partially coked organic. Flakes of solid material from the surface would burn when ignited but were self extinguishing when the source of heat was removed. Furthermore, continued burning in an accident situation is not likely because of the restricted access of air to the interior of the cask. Subsurface damage was detectable to approximately 0.8 cm; below this, the WEP was essentially unaffected. The increase in radiation resulting from thermal damage would be less than one percent.

4. Water Immersion — (Fissile material packages only.)

Not applicable.

ADDENDUM I

Safety for Users

A. Handling Procedure (Safety for Other Users)

1. General

The cask is rated for shipment of up to 25 mg ^{252}Cf via LTL motor vehicle and up to 85 mg via exclusive-use vehicle. The cask is filled with a cast-in matrix of water-extended polyester (WEP) with ethylene glycol added for freeze protection to -40°F. The cask is a five-foot diameter sphere mounted on a base and it weighs approx 9000 pounds.

2. Normal Handling

The cask is equipped with lifting eyes on the top for handling by overhead crane and is mounted on a base for handling with a forklift vehicle.

No unusual hazards are associated with handling the cask. Radiation measurements for each loading are included with the cask shipment papers.

3. Source Location

The source or sources are loaded in the polyethylene or lead insert normally used with the cask or in an approved source holder supplied by the user. Instructions and photographs regarding source loading arrangement and the best method of unloading are included with the cask shipment papers.

4. Typical Loading Instructions

a. Position cask in desired location.

b. Survey and smear cask.

c. If clean, loosen and remove twelve 3/8 in. hex head bolts from cover.

d. Remove top cover (weight approx 30 lb).

e. Loosen and remove eight 5/8 in. hex nuts securing plug flange.

f. Remove plug (weight approx 80 lb).

g. Smear plug for contamination.

h. Survey cask cavity to verify that it is empty and clean.

i. Place source(s) into cask cavity, being sure that source(s) are in holder at bottom of cavity.

j. Secure plug flange with eight 5/8 in. hex nuts removed in step f (max torque 350 in-lb).

k. Replace outside cover and secure with twelve 3/8 in. hex head bolts (max torque 230 in-lb).

l. Remove all attached labels.

m. Survey cask and install proper category radioactive labels on two sides of the cask 180° apart.

5. Typical Unloading Instructions

a. Survey and smear cask before opening.

b. If clean, break seal wire on cover bolts.

c. Loosen and remove twelve 3/8 in. hex head bolts from cover.

d. Remove top cover (weight approx 30 lb).

e. Locate string(s) attached to source(s) and unroll, laying out strings to keep from tangling.

f. Loosen and remove eight 5/8 in. hex nuts securing plug flange.

g. Radiation and Contamination Control personnel should be available to survey for radiation exposure during source(s) removal and to smear for contamination before plug is removed.

h. Remove plug (weight approx 80 lb), being careful that source(s) are not accidently removed during plug extraction.

i. Smear plug for contamination.

j. Remove source(s) from cask using waxed nylon string attached to source.

k. Survey cask cavity after all sources are removed.

l. Secure cask plug and top cover.

m. Remove all attached labels.

n. Install EMPTY labels on two sides of the cask 180° apart.

o. Return cask to:

E. I. DUPONT DENEMOURS AND COMPANY
SAVANNAH RIVER PLANT
DUNBARTON, SOUTH CAROLINA

6. <u>Specifications and Weights of Replacement Items</u>

Ref assembly dwg ST5-15813.

Top-hat cover - Pc 6 - dwg ST5-15816; weight - 25 pounds

Cover bolts - Pc 11 - dwg ST5-15813;
3/8" - 16 UNC × 1-1/2" long hex head SS bolts
with lockwashers

Plug assembly - Pc 4 - dwg ST5-15817; weight - 85 pounds

O-Ring Gasket - Pc 10 - 5 1/2 × 6" × 1/4" - Parker No. S2-433
(silicone)

Studs Pc 5C - dwg ST5-15816;
5/8" - 11 UNC-2A × 2-1/2" long steel

Nuts - Pc 14 - dwg ST5-15813; 5/8" - 11 UNC-2A hex nut

References

1. "Description of ^{252}Cf Sources," February 1971 (available from USAEC-SR as a complete document or in the following individual sections).

   Appendix B — Industrial Sources, SR-CF-100 Series
   Appendix C — Shipping Capsule Assembly, SR-CF-1000 Series
   Appendix D — Primary Capsule, SR-CF-XX Series
   Appendix E — Primary Capsule, SR-CF-1X Series

2. Kelsch, R. D., and C. A. Wilkins, E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, S. C., USAEC report DPSPU 68-124-2, "Safety Summary Report, Curium Shipping Cask," April 1968.

3. Shappert, L. B., Union Carbide Corporation, Oak Ridge National Laboratory, Oak Ridge, Tenn., USAEC report ORNL-NSIC-68, "Cask Designers Guide," February 1970.

4. McMillan, T. S., E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, S. C., USAEC report DP-1262, "Thermal Evaluation of Water-Extended Polyester," March 1972.

5. Stoddard, D. H., E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, S. C., USAEC report DP-1339, "^{252}Cf Shielding with Water-Extended Polyester," January 1974.

6. Ondrejcin, R. S., E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, S. C., SRL Report DPST-74-336, April 1974.

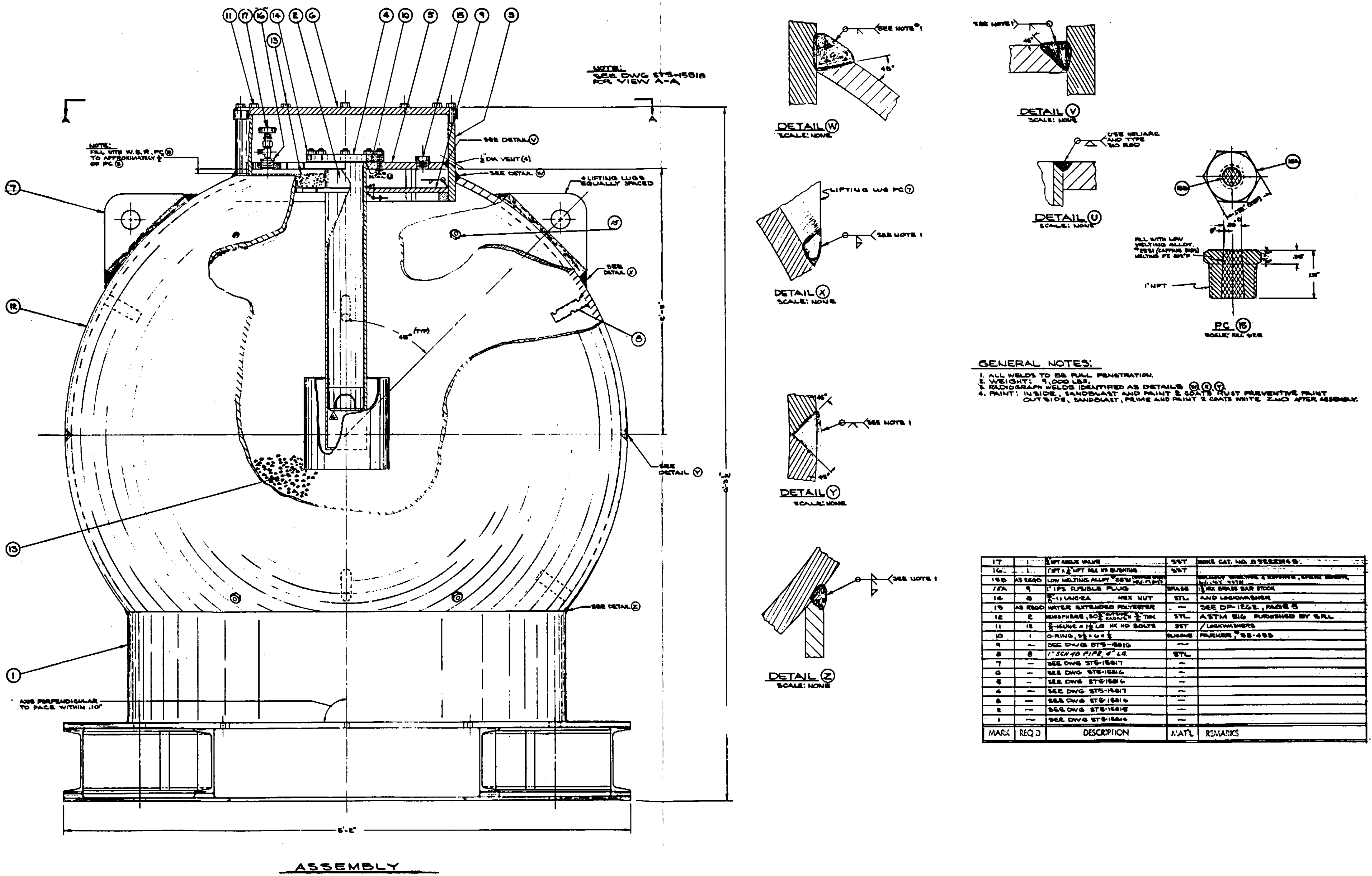
7. W. R. McDonell, et al, Proceedings of The American Nuclear Society-National Topical Meeting, XOND-710402 Vol II (TID 4500) "Preparation of Industrial ^{252}Cf Neutron Sources at Savannah River Laboratory," April 1971.

8. McDonell, W. R. and Mosley, W. C., E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, S. C., USAEC report DP-MS-72-35, "Long-Term Integrity of ^{252}Cf source Materials."

9. Procedure DPSTOL-57-31, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, S. C.

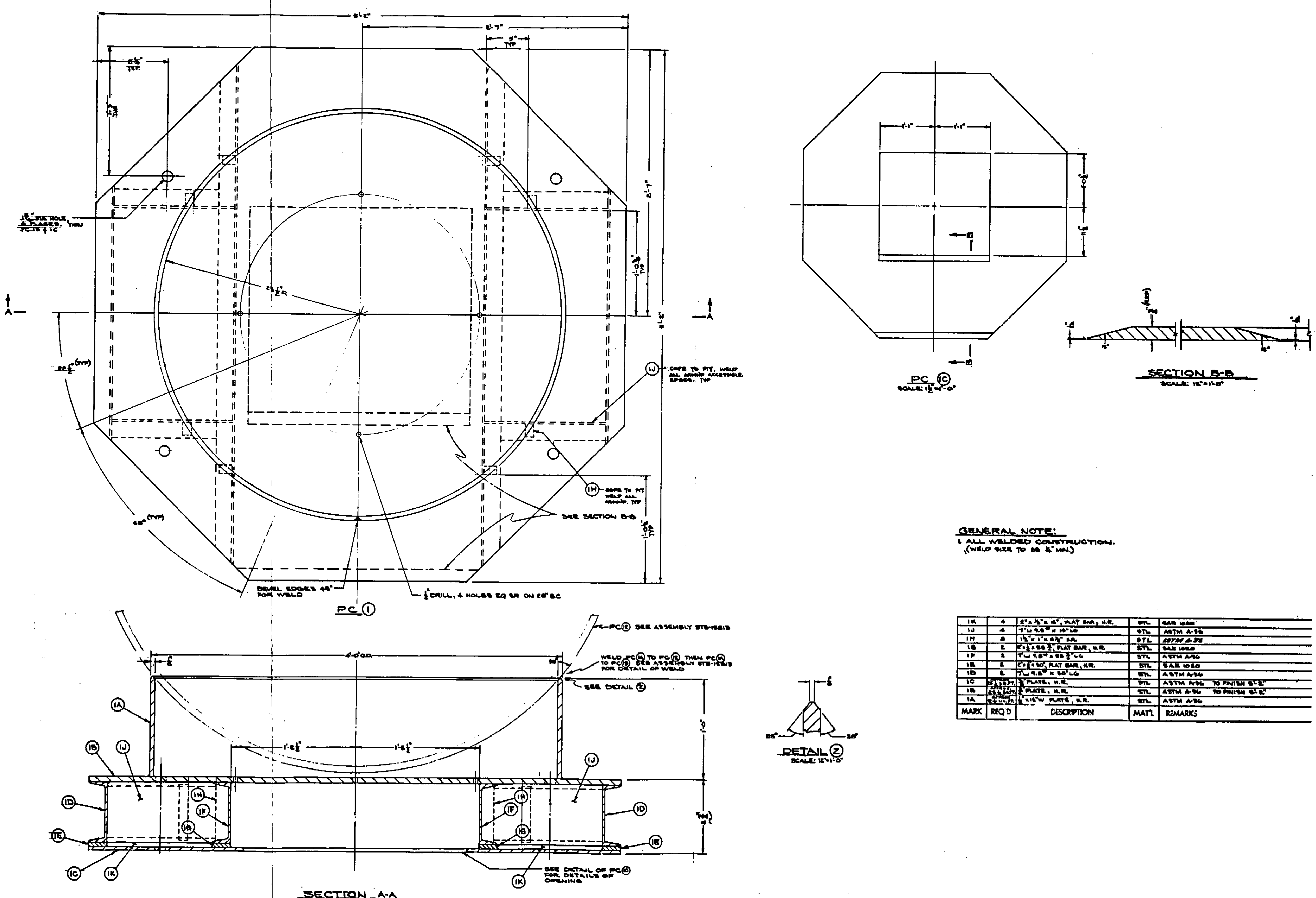
10. Procedure DPSTOL-57-30, Savannah River Laboratory, E. I. du Pont de Nemours and Comapny, Aiken, S. C.

11. RDTE 12-7, Inspection and Preventive Maintenance of Radioactive Materials Packaging. (Sept 1974 - Draft).



MARK	REQ'D	DESCRIPTION	MAT'L	REMARKS
17	1	¾ NPT ANGLE VALVE	SST	HOKE CAT. NO. [illegible]
16	1	1" NPT x ¾ NPT HEX HD BUSHING	SST	
15B	AS REQD	LOW MELTING ALLOY "2531"		[illegible]
15A	9	1" IPS FUSIBLE PLUG	BRASS	1¼ HEX BRASS BAR STOCK
14	8	⅝-11 UNC-2A HEX NUT	STL	AND LOCKWASHER
13	AS REQD	WATER EXTENDED POLYESTER	—	SEE DP-1262, PAGE 5
12	2	HEMISPHERE, 30½ OUTSIDE RADIUS x ½ THK	STL	ASTM 516 FURNISHED BY SRL
11	12	⅝-16UNC x 1½ LG HX HD BOLTS	SST	/LOCKWASHERS
10	1	O-RING, 5½ x 6 x ¼	SILICONE	PARKER #2-455
9	—	SEE DWG ST5-15816	—	
8	8	1" SCH 40 PIPE, 4" LG.	STL	
7	—	SEE DWG ST5-15817	—	
6	—	SEE DWG ST5-15816	—	
5	—	SEE DWG ST5-15816	—	
4	—	SEE DWG ST5-15817	—	
3	—	SEE DWG ST5-15816	—	
2	—	SEE DWG ST5-15815	—	
1	—	SEE DWG ST5-15814	—	

FIGURE 1. ²⁵²Cf SHIPPING CASK ASSEMBLY (DU PONT DWG ST5-15813, REV 33, FEBRUARY 1976)



GENERAL NOTE:
1. ALL WELDED CONSTRUCTION. (WELD SIZE TO BE 1/4" MIN.)

MARK	REQ'D	DESCRIPTION	MAT'L	REMARKS
1K	4	2" x 1/2" x 12", FLAT BAR, H.R.	STL	SAE 1020
1J	4	7" ⊔ 9.8# x 14" LG	STL	ASTM A-36
1H	8	1 1/2" x 1" x 6 1/2" H.R.	STL	ASTM A-36
1G	2	5" x 1/2" x 58 3/4", FLAT BAR, H.R.	STL	SAE 1020
1F	2	7" ⊔ 9.8# x 58 3/4" LG	STL	ASTM A-36
1E	2	5" x 1/2" x 50", FLAT BAR, H.R.	STL	SAE 1020
1D	2	7" ⊔ 9.8# x 50" LG	STL	ASTM A-36
1C	APPROX. 25 1/2 SQ.FT.	1/2" PLATE, H.R.	STL	ASTM A-36 TO FINISH 8'-2"
1B	APPROX. 25 1/2 SQ.FT.	1/2" PLATE, H.R.	STL	ASTM A-36 TO FINISH 8'-2"
1A	APPROX. 12 1/2 LIN.FT.	1/2" x 12" W PLATE, H.R.	STL	ASTM A-36

FIGURE 2. 252Cf SHIPPING CASK PC 1 (DU PONT DWG ST5-15814, REV 29, MARCH 1976)

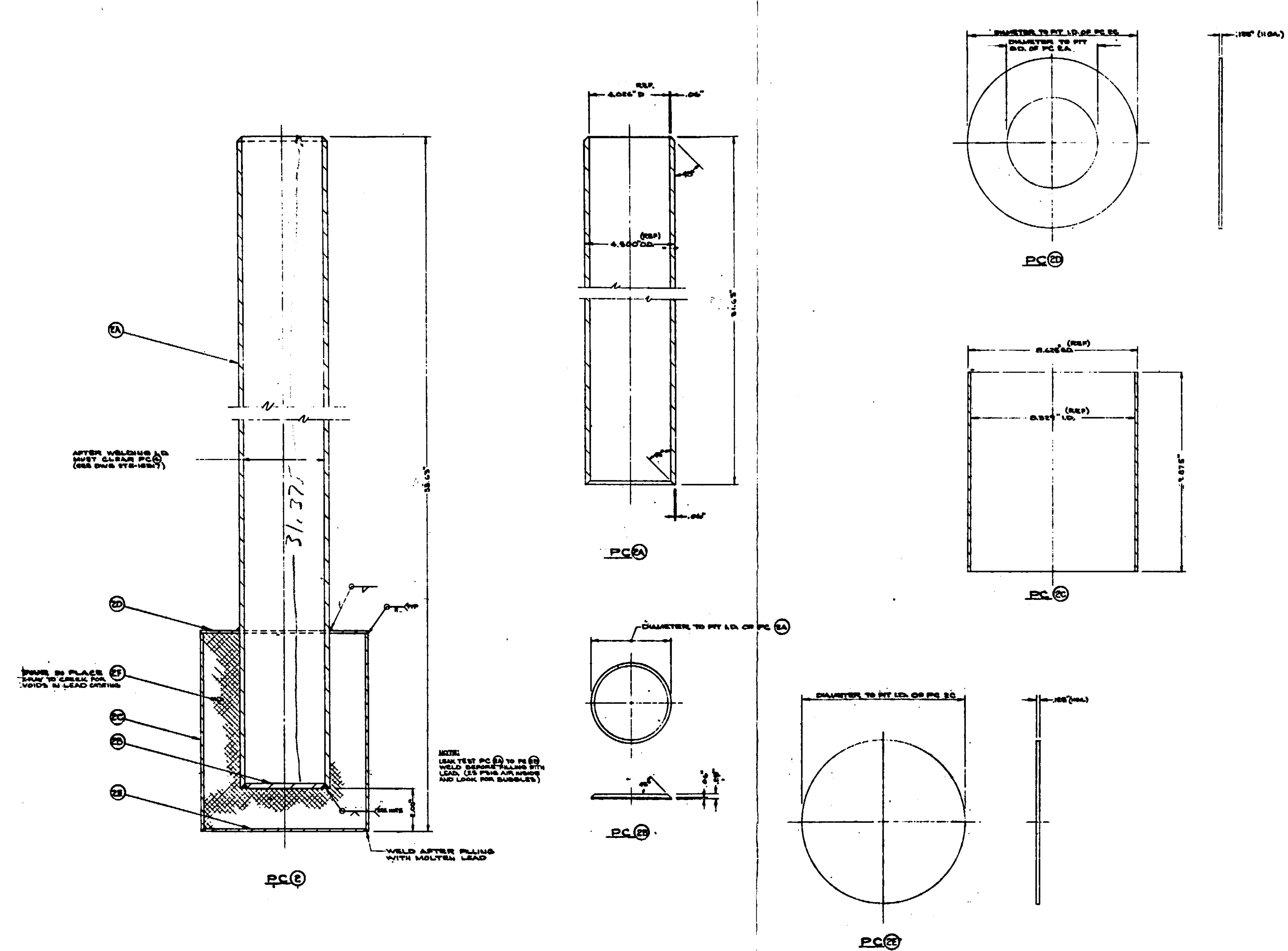


FIGURE 3. ^{252}Cf SHIPPING CASK PC 2 (Du Pont dwg ST5-15815)

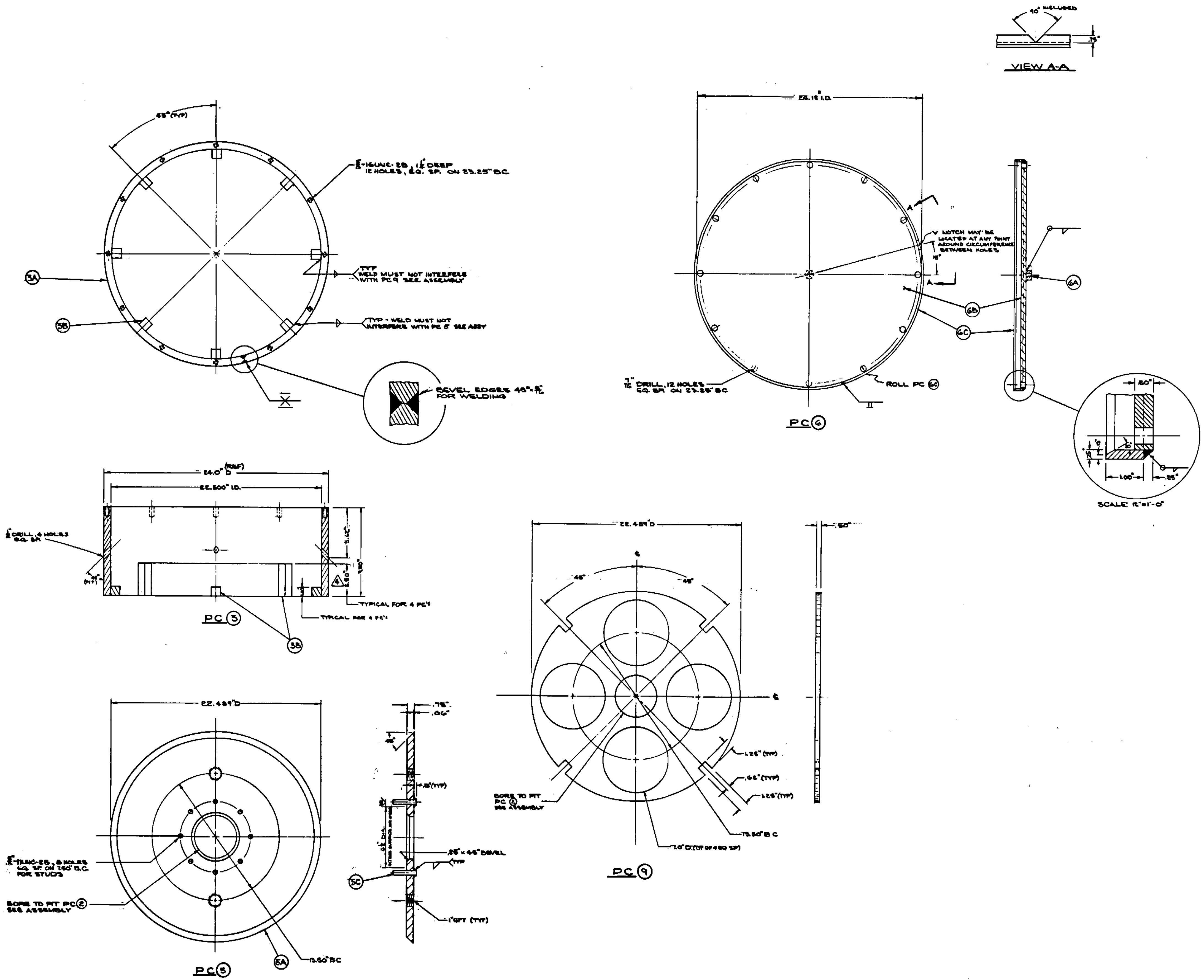


FIGURE 4. ^{252}Cf SHIPPING CASK PC's 3 , 5 , 6 , AND 9
(Du Pont dwg ST5-15816)

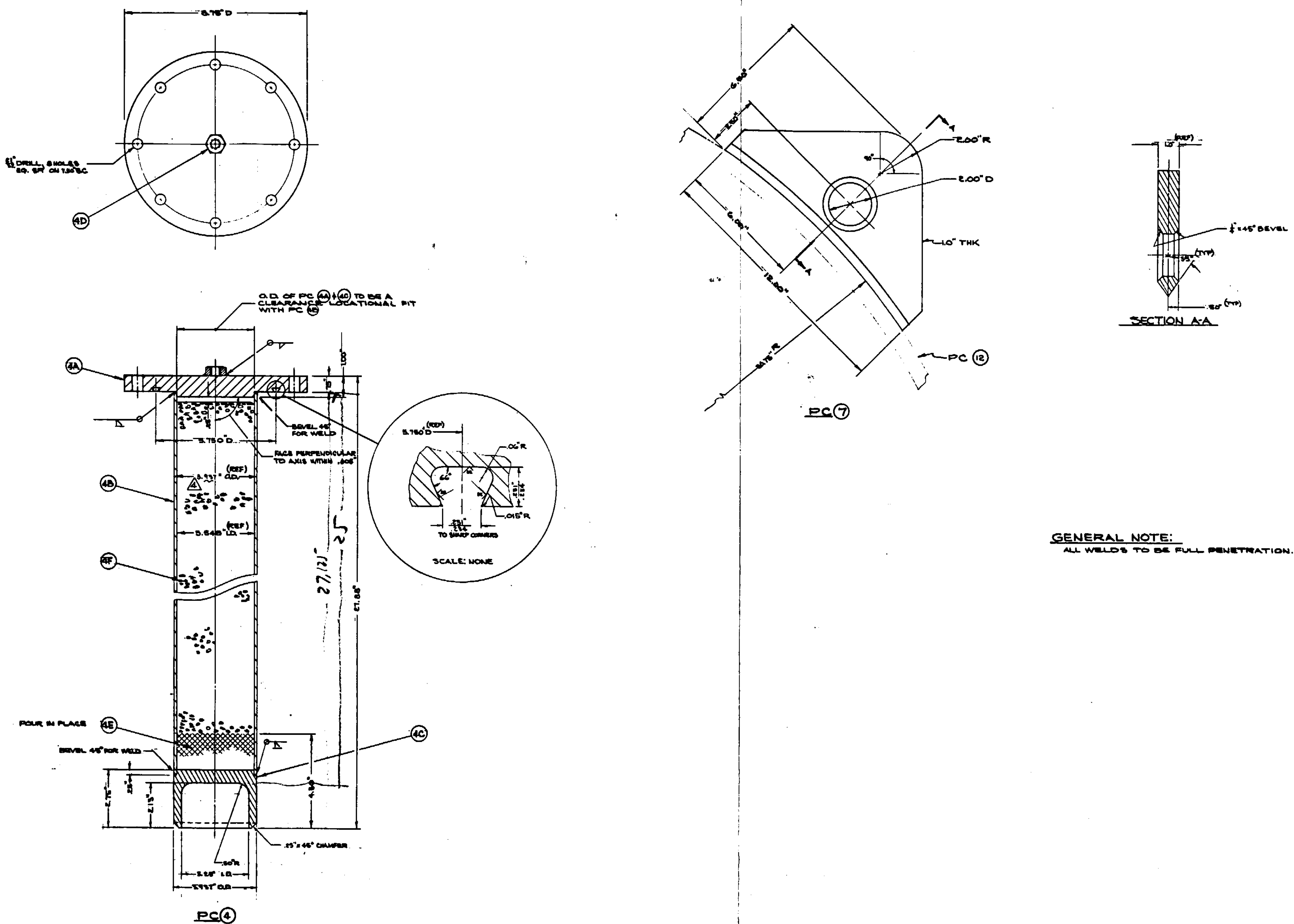


FIGURE 5. ^{252}Cf SHIPPING CASK PC's 4 AND 7
(Du Pont dwg ST5-15817)

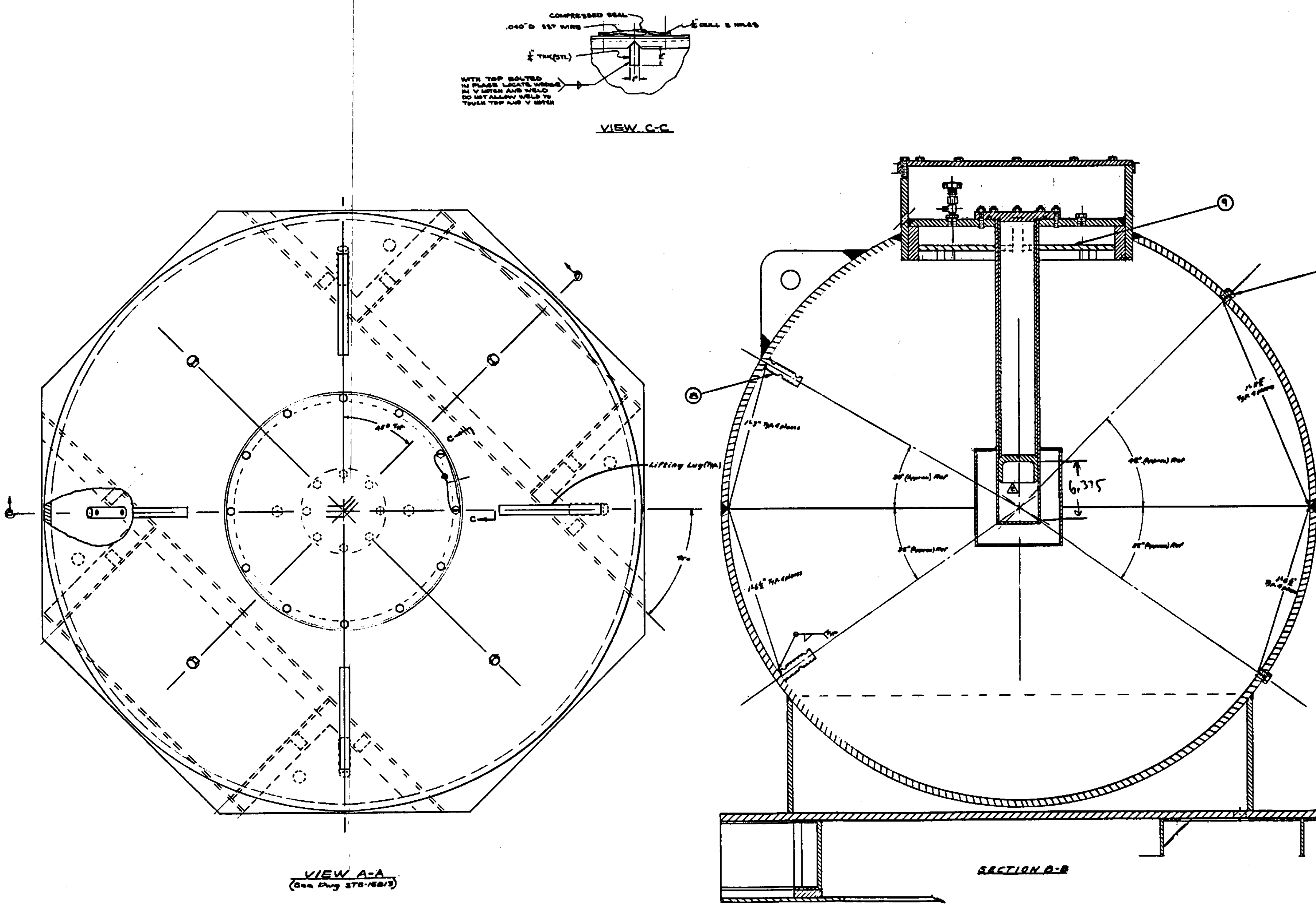


FIGURE 6. ^{252}Cf SHIPPING CASK ASSEMBLY, VIEW A-A
(DU PONT DWG ST5-15818, REV 5, FEBRUARY 1976)

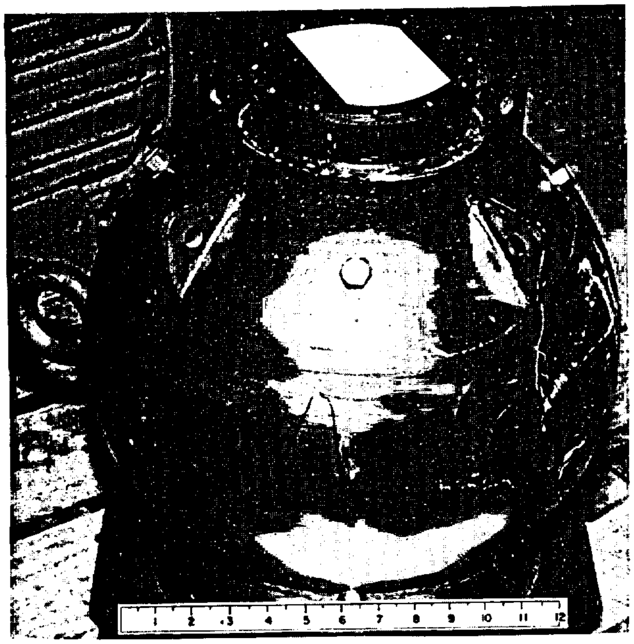


FIGURE 7. QUARTER-SCALE MODEL OF ^{252}Cf SHIPPING CASK. DPSPF 15366-1.

FIGURE 8. TOP OF QUARTER-SCALE MODEL AND IMPACT AREA AFTER 30-FOOT INVERTED DROP. DPSPF 15366-7.

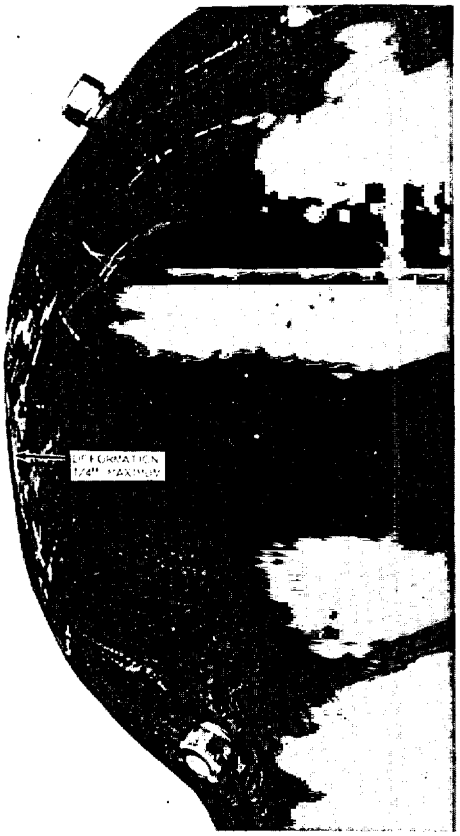


FIGURE 9. DEFORMED AREA OF QUARTER-SCALE MODEL AFTER 30-FOOT SIDE DROP. DPSPF 15366-12.

FIGURE 10. DEFORMATION AFTER 40-INCH DROP ONTO END OF 1-1/2" DIA VERTICAL STEEL PIN. DPSPF 15366-13.

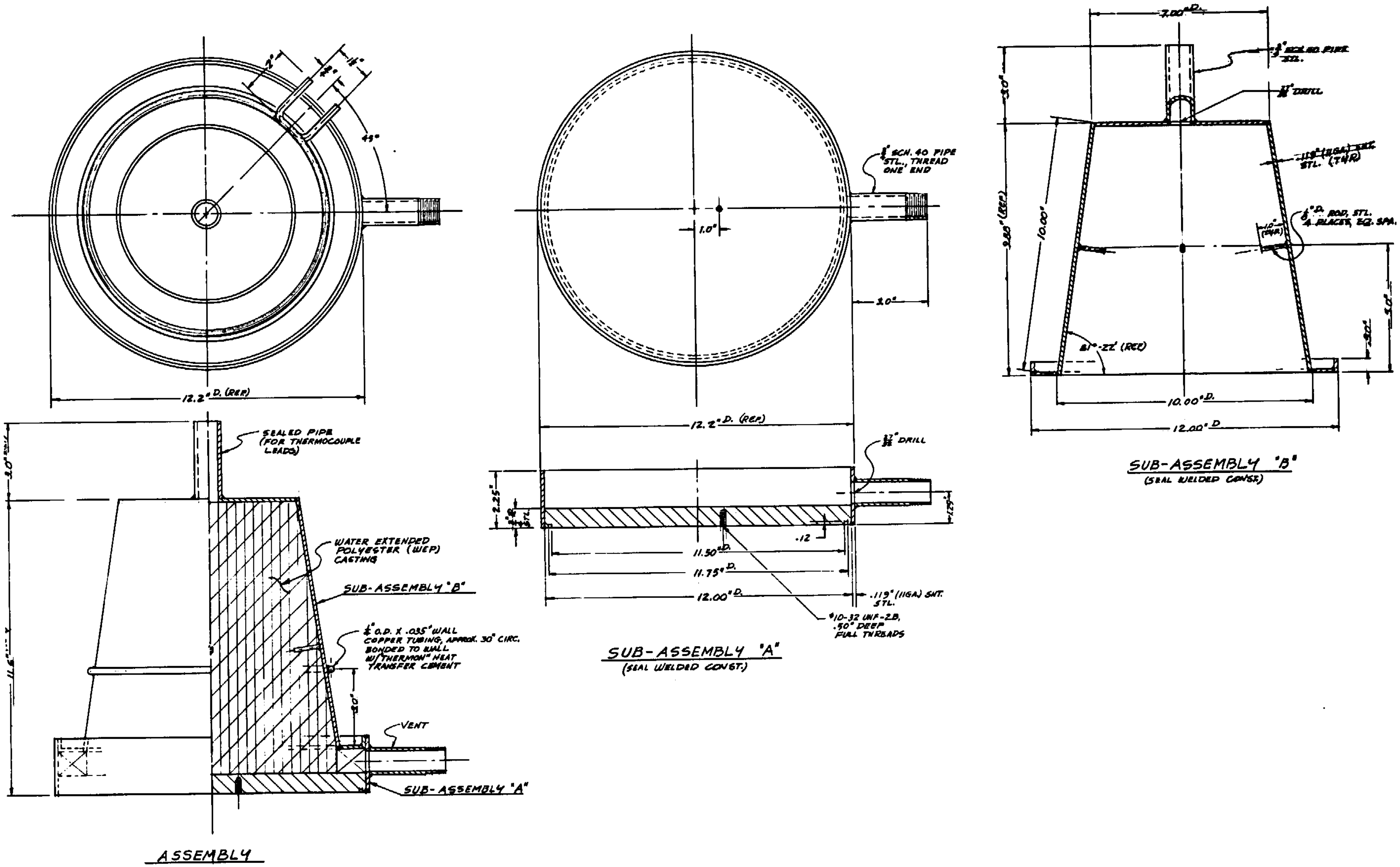


FIGURE 11. SHIPPING CASK THERMAL TEST MODEL (DU PONT DWG SK-2825-LS, REV 0, MARCH 1976)

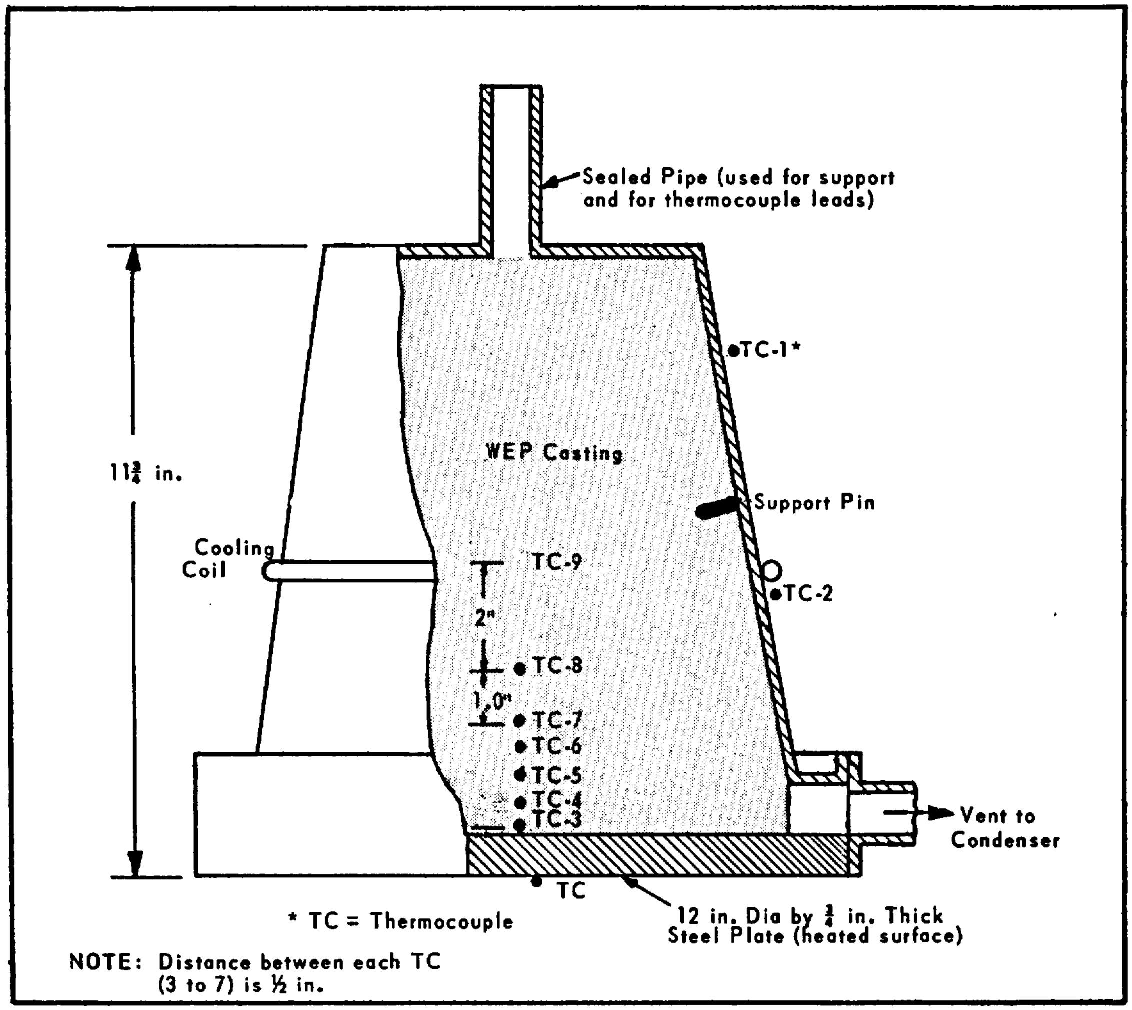


FIGURE 12. MODEL OF CASK SEGMENT FOR THERMAL TESTING

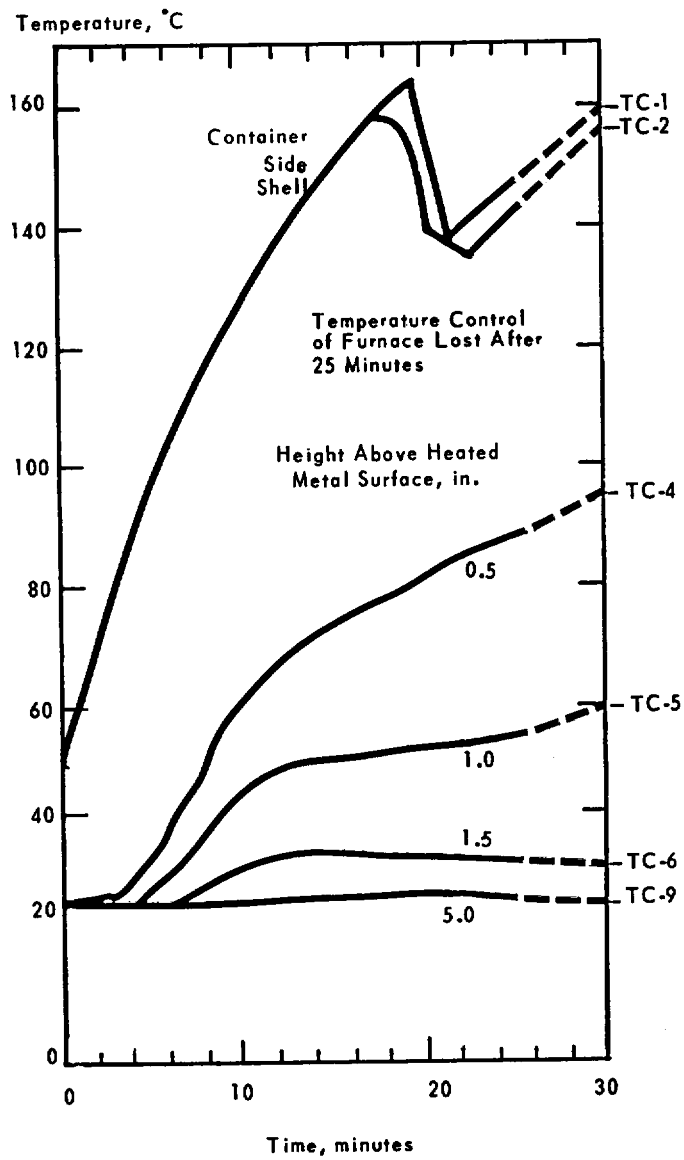


FIGURE 13. TEMPERATURES WITHIN THE WEP CASTING AND UNHEATED CONTAINER SURFACES DURING THE HIGH TEMPERATURE TEST

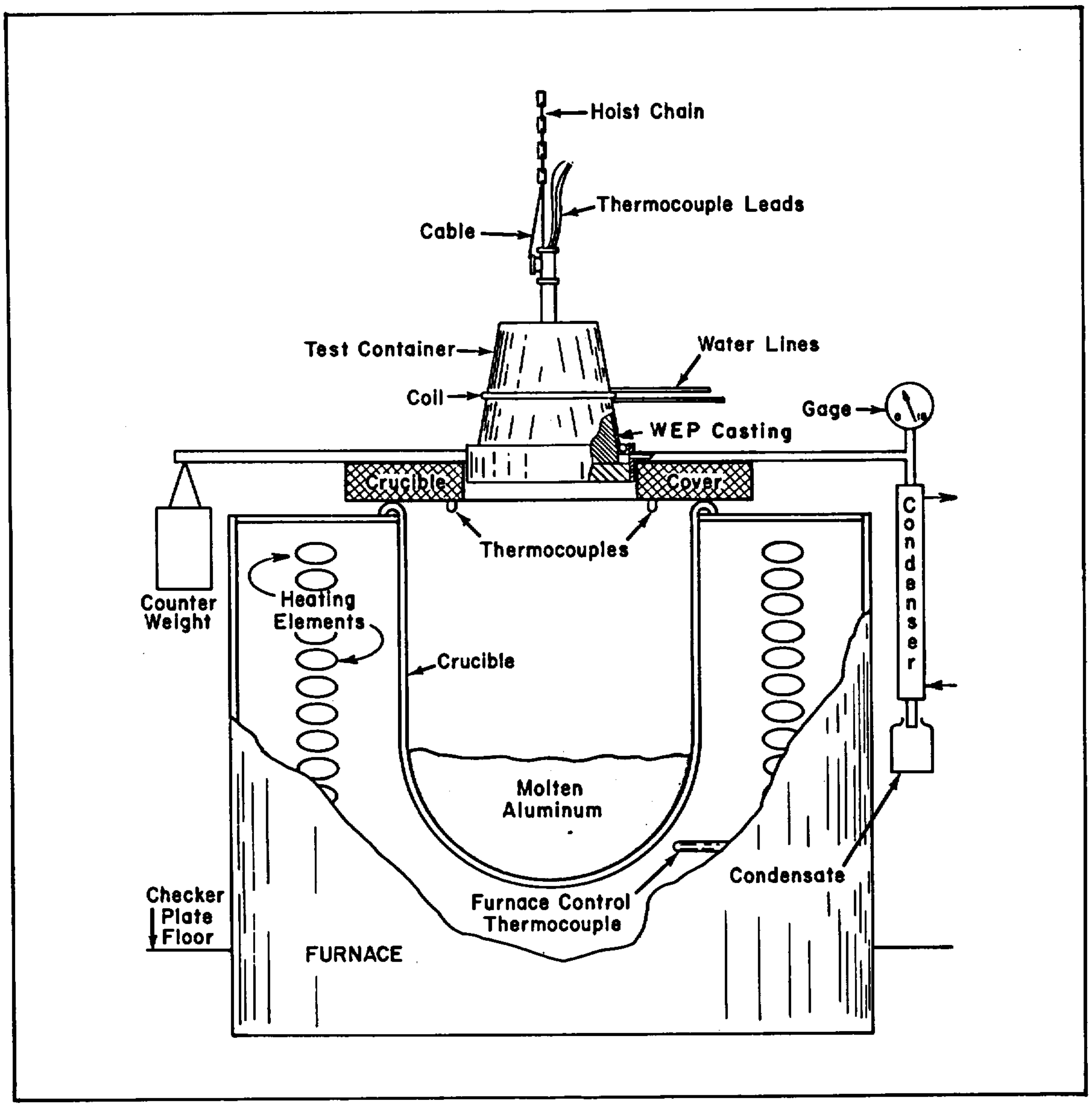


FIGURE 13A. THERMAL TESTING OF MODEL OF CASK SEGMENT WITH AVAILABLE FURNACE

U.S. ATOMIC ENERGY COMMISSION
AEC MANUAL

Volume: 0000 General Administration
Part : 0500 Health and Safety

AEC 0529-01
OS

Chapter 0529 SAFETY STANDARDS FOR THE PACKAGING OF FISSILE AND OTHER RADIOACTIVE MATERIALS

0529-01 POLICY

Fissile and other radioactive material shall be packaged and prepared for shipment in a manner that provides assurance of protection of the public health and safety during the transportation of such materials.

0529-02 OBJECTIVE

To establish safety standards for the packaging of fissile and other radioactive materials for shipment by AEC or by contractors not subject to 10 CFR 71.

0529-03 RESPONSIBILITIES AND AUTHORITIES

031 **The Director, Division of Operational Safety:**

a. determines the need for, and develops new and revised safety standards to be applied in the preparation of fissile and other radioactive materials for transportation.
b. provides a central point of coordination with the Director of Regulation for developing and revising health and safety codes pertaining to safety in the transportation of fissile and other radioactive materials which are intended for use in the AEC programs or by other federal agencies.
c. conducts periodic appraisals to determine the adequacy of the implementation of this chapter.
d. renders interpretations of this chapter.

032 **The Director, Division of Waste Management and Transportation,** in addition to the responsibilities and authorities assigned in 033, below:

a. administers the program for design review and issuance of AEC Certificates of Compliance as provided in 056, below, AECM 5201, and 49 CFR 172.39 -173.396.
b. assists field offices in expediting essential shipments consigned to or by AEC and in securing waivers or exemptions from Federal Transportation Regulations.
c. prepares guidance criteria and procedures for application of package testing and quality assurance standards.
d. coordinates the total input for the General Manager in the development and revision of transportation regulations.

033 **Heads of Divisions and Offices, Headquarters, excluding Regulatory,** provide guidance, instructions, standards, and criteria as described in Chapter 0101, consistent with this chapter, to assure the safe packaging of fissile and other radioactive materials, including:

a. directing cognizant managers of field offices to require modifications of equipment procedures or practices.
b. imposing additional requirements for packaging standards.
c. curtailing or suspending the use of specific packages when necessary.

034 **Managers of Field Offices, and the Director, Division of Naval Reactors,** consistent with guidance, instructions, standards, and criteria issued pursuant to 033, above:

a. grant AEC approval for packages which meet the standards contained in appendix 0529 and 10CFR 71.31--71.40, and which are to be used for the transportation of fissile or other radioactive materials in greater than Type A quantities.
b. grant AEC approval for shipments made under the National Security Exemption provided to the AEC and DOD under the Transportation of Explosives Act (18 U.S.C. 832c) and in accordance with the requirements of pertinent AEC manual chapters. Packages for such shipments must meet the policy stated in section 01.
c. grant such alternatives to the requirements set forth in appendix 0529 as will provide equivalent protection to life or property and to the common defense and security; and within 30 days after granting an alternative, provide the Director, Division of Operational Safety, a detailed report of the reasons for granting it. The granting of such alternatives is in no way to be construed as the granting of exemptions or exceptions from or to the Department of Transportation or other regulatory agency requirements.
d. conduct annual appraisals of contractor operations to assure compliance with the

requirements of this chapter.

e. require that their contractors carry out, as a minimum, quality assurance programs described in this chapter, and as provided for in appendix 5201.
(*NOTE:* Contractors shall not be permitted to exercise any of the above authorities.)

035 The Manager, Albuquerque Operations Office, in addition to the responsibilities and authorities assigned in 032, above, shall establish safety standards for packaging and transportation of nuclear weapons and their components in accordance with 055, below.

0529-04 DEFINITION

041 AEC Contractor for the purposes of this chapter, means a prime contractor or subcontractor of the Atomic Energy Commission who is exempt from the requirements of 10 CFR 71.

0529-05 BASIC REQUIREMENTS

051 Applicability. The provisions set forth in this chapter and its appendix apply to the Headquarters, field offices, and AEC contractors.

052 Coverage. This chapter and its appendix cover policies and procedures for the preparation of fissile and other radioactive materials for shipment outside the boundaries of AEC-controlled sites by for-hire or private carriers, or on public vehicles or aircraft.

053 Federal Regulations. When offered to the carrier, each shipment of radioactive materials shall be in compliance with the applicable safety regulations of the Department of Transportation (DOT) or the U.S. Postal Service, depending on the mode of transportation.

054 Other Regulations

a. **International Atomic Energy Agency (IAEA) Regulations.** Each shipment of fissile and other radioactive materials consigned to a foreign country must meet the requirements set forth in IAEA Safety Series No. 6, "Regulations for the Safe Transport of Radioactive Materials." Specifically, "Requirements for Packaging and for Delivery of Packages to Transport," must be met to be in compliance with this chapter.

b. **International Air Transport Association (IATA) Restricted Article Regulations.** Each shipment of fissile and other radioactive materials consigned to a foreign country must meet the requirements set forth in IATA Restricted Articles Regulations when shipped via commercial aircraft.

c. **U.S. Air Force AFM-71-4, Packaging and Handling of Dangerous Materials for Transport by Military Aircraft.** Each shipment of fissile and other radioactive materials must meet the requirements set forth in AFM-71-4 when shipped via USAF aircraft.

055 Package Standards for Radioactive Materials in Amounts Greater Than Type A Quantities

a. Packages of radioactive materials shall be prepared for shipment and transported in accordance with the provisions of this chapter. DOT specification containers for Type B and fissile materials are considered to meet the standards of this chapter, and no specific AEC Certificates of Compliance are required for their use.

b. Nuclear weapons and their components shall be packaged and transported in accordance with the standards in this chapter or with other standards which provide a degree of safety at least equivalent to that provided by the AEC and DOT regulations. Standards will be developed and documented under 035, above.

c. Packages shipped under the National Security Exemption of 18 U.S.C. 832.c must be in compliance with the standards in this chapter and must also comply with the provisions of other pertinent AEC manual chapters.

d. All other packages for fissile and other radioactive materials in amounts greater than Type A quantities shall be designed, constructed, and used in accordance with the standards contained in the attached appendix, and in 10 CFR 71.31–71.40. Materials described in 71.6 are exempt from this requirement.

e. A quality assurance program must be established and implemented to assure that packages for radioactive materials are fabricated, maintained, and used in accordance with the regulations and approved design features. The program must meet the requirements in appendix 5201.

056 AEC Certificates of Compliance for Packages of Radioactive Materials in Excess of Type A

Quantities. Upon determination that a package design does in fact meet the requirements of this chapter and and its appendix and the AEC Standards in 10 CFR 71.31–71.40, an AEC Certificate of Compliance will be issued by the AEC to the contractor. Procedures for obtaining and issuing these certificates are set forth in AECM 5201. No certificate is necessary for shipments meeting the requirements of 10 CFR 71.6 or 71.7.

057 **AEC as Consignor.** Where an AEC office serves as the actual consignor, rather than a contractor, appropriate internal procedures shall be established by the responsible field office manager to assure compliance with the standards contained in this chapter.

058 **Waivers and Exemptions.** Packages which do not meet the standards in the DOT Hazardous Materials Regulations, and which do not qualify for shipment under the National Security Exemption, may be shipped only under the provisions of a waiver or exemption issued by the DOT, or on public vehicles or aircraft if approved under the provisions of AEC 0529-034c. Applications for a DOT Special Permit for waiver or exemption shall be prepared in accordance with 49 CFR 170.13 and shall be forwarded to the DOT for issuance of a special permit.

059 **Existing Packagings.** Existing packagings for radioactive materials must meet the standards of this chapter. However, Type B packagings designed and constructed prior to February 15, 1969, which could be subject to loss of shielding resulting from subjecting the packaging to the puncture test followed by the thermal test (49 CFR 173.398(c)(2)), are also approved for continued use. The packaging design must be covered by a DOT Special Permit providing for administrative and operational controls as may be necessary to compensate for the deficiencies in package integrity and to provide equivalent safety in transportation.

0529-06 REFERENCES

a. **AEC Regulation.** Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport."

b. **DOT Regulations**
   1. Title 49, CFR Parts 170-189, and Title 14, CFR Part 103, "Hazardous Materials Regulations."
   2. Title 46, CFR Part 146, "Transportation or Storage of Explosives or other Dangerous Articles or Substances, and Combustible Liquids on Board Vessels."

c. **U.S. Postal Service Regulation.** Title 39, CFR Parts 124 and 125, "Nonmailable Matter" and "Matter Mailable Under Special Rules."

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

e. **AECM 2401,** "Physical Protection of Classified Matter and Information."

f. **AECM 2405,** "Physical Protection of Unclassified Special Nuclear Material."

g. **AECM 0230,** "Records Disposition."

h. **AECM 0530,** "Nuclear Criticality Safety."

i. **AECM 0560,** "Program to Prevent Accidental or Unauthorized Nuclear Explosive Detonations."

j. **AECM 5201,** "Transportation and Traffic Management" (to be reissued under the title "Transportation of Property").

k. AEC Directory of Radioactive and Fissile Materials Shipping Containers, 1969.

l. International Air Transport Association (IATA) Restricted Article Regulations.

m. U.S. Air Force AFM-4, "Packaging and Handling of Dangerous Materials for Transport by Military Aircraft."

n. Transportation of Explosives Act (18 U.S.C. 832.c).

0529-07 NATIONAL EMERGENCY APPLICATION

During a national emergency, as defined in AECM 0601-04, the provisions of this chapter and appendix will continue in effect.

PART I

DEFINITIONS AND EXEMPTIONS

A. **DEFINITIONS** (as used in this appendix)

1. **Carrier** means any person engaged in the transportation of passengers or property, as common, contract, or private carrier, or freight forwarder, as those terms are used in the Interstate Commerce Act, as amended, or the U.S. Postal Service.

2. **Close Reflection by Water** means immediate contact by water of sufficient thickness to reflect a maximum number of neutrons.

3. **Containment Vessel** means the receptacle on which principal reliance is placed to retain the radioactive material during transport.

4. **Fissile Classification** means classification of a package or shipment of fissile materials according to the controls needed to provide nuclear criticality safety during transportation as follows:

   a. **Fissile Class I.** Packages which may be transported in unlimited numbers and in any arrangement and which require no nuclear criticality safety controls during transportation. For purposes of nuclear criticality safety control, a transport index is not assigned to Fissile Class I packages. However, the external radiation levels may require a transport index number.

   b. **Fissile Class II.** Packages which may be transported together in any arrangement but in numbers which do not exceed a transport index of 50. For purposes of nuclear criticality safety control, individual packages may have a transport index of not less than 0.1 and not more than 10. However, the external radiation levels may require a higher transport index number but not to exceed 10. Such shipments require no nuclear criticality safety control by the shipper during transportation.

   c. **Fissile Class III.** Shipments of packages which do not meet the requirements of Fissile Classes I or II and which are controlled in transportation by special arrangements between the shipper and the carrier to provide nuclear criticality safety.

5. **Fissile Materials** means uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241.

6. **Large Quantity** means a quantity of radioactive material, the aggregate radioactivity of which exceeds that specified in the following table for a transport group as defined in 16., below:

Radionuclide Identification	I	II	III	IV	V	VI-VII	Special Form
Radioactivity	20 Curies	20 Curies	200 Curies	200 Curies	5,000 Curies	50,000 Cureis	5,000 Curies

7. **Low Specific Activity Material** means any of the following:
   a. Uranium or thorium ores and physical or chemical concentrates of those ores.
   b. Unirradiated natural or depleted uranium or unirradiated natural thorium.
   c. Tritium oxide in aqueous solutions, provided the concentration does not exceed 5.0 millicuries per milliliter.
   d. Material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed:
      (1) 0.0001 millicuries of Group I radionuclides; or
      (2) 0.005 millicuries of Group II radionuclides; or
      (3) 0.3 millicuries of Group III or IV radionuclides.

   NOTE: This may include, but is not

limited to, materials of low radioactivity concentration, such as building rubble, metal, wood, and fabric scrap, glassware, paper and cardboard, solid or liquid plant waste, sludge, and ashes.

e. Nonradioactive objects externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination, when averaged over an area of one square meter, does not exceed 0.0001 millicuries (220,000 disintegrations per minute), per square centimeter of Group I radionuclides or 0.001 millicuries (2,200,000 disintegrations per minute) per square centimeter of other radionuclides.

8. **Maximum Normal Operating Pressure** means the maximum gauge pressure which is expected to develop in the containment vessel under the normal conditions of transport specified in annex 1, below, considered individually.

9. **Moderator** means a material used to reduce by scattering collisions, and without appreciable capture, the kinetic energy of neutrons.

10. **Optimum Interspersed Hydrogenous Moderation** means the occurrence of hydrogenous material between containment vessels to such an extent that the maximum nuclear reactivity results.

11. **Package** means packaging and its radioactive contents.

12. **Packaging** means one or more receptacles and wrappers and their contents, excluding fissile material and other radioactive material, but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment.

13. **Primary Coolant** means a gas, liquid, or solid, or combination of them, in contact with the radioactive material, or if the material is in special form, in contact with its capsule, and used to remove decay heat.

14. **Sample Package** means a package which is fabricated, packed, and closed to fairly represent the proposed package as it would be presented for transport, simulating the material to be transported, as to weight and physical and chemical form.

15. **Special Form** means any of the following physical forms of radioactive material of any transport group:

a. The material is in solid form having no dimension less than 0.5 millimeter or at least one dimension greater than 5 millimeters; does not melt, sublime, or ignite in air at a temperature of 1000°F; will not shatter or crumble if subjected to the percussion test described in annex 4, below; and will not be dissolved or converted into a dispersible form in amounts greater than 0.005 percent by weight if immersed in water at 68°F or placed in air at 86°F for one week.

b. The material is securely contained in a capsule having no dimension less than 0.5 millimeter or at least one dimension greater than 5 millimeters which (1) will retain its contents if subjected to the tests prescribed in annex 4, (2) is constructed of materials which do not melt, sublime, or ignite in air at 1475°F, and (3) will not be dissolved or converted into a dispersible form in amounts greater than 0.005 percent by weight if immersed for one week in water at 68°F or in air at 86°F.

16. **Transport Group** means any one of the seven groups in which radionuclides in normal form are classified, according to their toxicity and their relative potential hazard in transport (see annex 3).

a. Any radionuclide not specifically listed in one of the groups in annex 3 shall be assigned to one of the groups in accordance with the following table:

	Radioactive Half-Life		
Radionuclide	0 to 1000 days	1000 days to 10^6 years	Over 10^6 Years
Atomic Number 1-81	Group III	Group II	Group III
Atomic number 82 and over	Group I	Group I	Group III

b. For mixtures of radionuclides the following shall apply:
   (1) If the identity and respective activity of each radionuclide are known, the permissible activity of each radionuclide shall be such that the sum of the ratios between the total activity for each group to the permissible activity for each group will not be greater than unity.
   (2) If the groups of the radionuclides are known, but the amount in each group cannot be reasonably determined, the mixture shall be assigned to the most restrictive group present.
   (3) If the identity of all or some of the radionuclides cannot be reasonably determined, each of those unidentified radionuclides shall be considered as belonging to the most restrictive group which cannot be positively excluded.
   (4) Mixtures consisting of a single radioactive decay chain where the radionuclides are in the naturally occurring proportions shall be considered as consisting of a single radionuclide. The group and activity shall be that of the first member present in the chain. Exception: If a radionuclide "x" has a half-life longer than that of the first member and an activity greater than that of any other member, including the first, at any time during transportation, the transport group of the nuclide "x" and the activity of the mixture shall be the maximum activity of that nuclide "x" during transportation.

17. **Transport Index** means the number placed on a package to designate the degree of control to be exercised by the carrier during transportation. The transport index to be assigned to a package of radioactive material shall be determined by either a. or b., below, whichever is larger. The number expressing the transport index shall be rounded up to the next highest tenth; e.g., 1.01 becomes 1.1.
   a. The highest radiation dose rate in millirem per hour at three feet from any accessible external surface of the package.
   b. The transport index for each Fissile Class II package is calculated by dividing the number 50 by the number of such Fissile Class II packages which may be transported together as determined under the limitations of part II,I.1. The calculated number shall be rounded up to the first decimal place.

18. **Type A Quantity and Type B Quantity** mean a quantity of radioactive material, the aggregate radioactivity of which does not exceed that specified in the following table:

Transport Groups (See I,A.16.)	Type A Quantity (in curies)	Type B Quantity (in curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI and VII	1,000	50,000
Special Forum	20	5,000

B. EXEMPTIONS

A shipper is exempt from all requirements of this appendix to the extent that he delivers to a carrier for transport packages each containing not more than a Type A quantity of radioactive material, as defined in A.18, above, which may include one of the following:

1. Not more than 15 grams of fissile material.
2. Thorium or uranium containing not more than 0.72 percent by weight of fissile material.
3. Uranium compounds, other than metal, (e.g., UF_4, UF_6, or uranium oxide in bulk form, not pelleted or fabricated into shapes) or aqueous solutions of uranium, in which the total amount of uranium-233 and plutonium present does not exceed 1.0 percent by weight of the uranium-235 content, and the total fissile content does not exceed 1.00 percent by weight of the total uranium content.
4. Homogeneous hydrogenous solutions or mixtures containing not more than:
   a. 500 grams of any fissile material, provided the atomic ratio of hydrogen to fissile material is greater than 7600.
   b. 800 grams of uranium-235, provided that the atomic ratio of hydrogen to fissile material greater than 5,200, and the content of other fissile material is

not more than 1 percent by weight of the total uranium-235 content.

c. 500 grams of uranium-233 and uranium-235, provided that the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content.

5. Less than 350 grams of fissile material, provided that there is not more than 5 grams of fissile material in any cubic foot within the package.

PART II

PACKAGE STANDARDS

A. GENERAL STANDARDS FOR ALL PACKAGING

1. Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components or between the packaging components and the package contents.
2. Packaging shall be equipped with a positive closure which will prevent inadvertent opening.
3. Lifting devices for packagings.
   a. If there is a system of lifting devices which is a structural part of the packaging, the system shall be capable of supporting three times the weight of the package without generating stress in any material of the packaging in excess of its yield strength.
   b. If there is a system of lifting devices which is a structural part only of the lid, the system shall be capable of supporting three times the weight of the lid and any attachments without generating stress in any material of the lid in excess of its yield strength.
   c. If there is a structural part of the packaging which could be employed to lift the package and which does not comply with a., above, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.
   d. Each lifting device which is a structural part of the packaging shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the packaging.
4. Tiedown devices for packagings
   a. If there is a system of tiedown devices which is a structural part of the packaging, the system shall be capable of withstanding, without generating stress in any material of the packaging in excess of its yield strength the following: (1) a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package, (2) a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package, and (3) a horizontal component in the traverse direction of five times the weight of the package.
   b. If there is a structural part of the packaging which could be employed to tie the package down and which does not comply with a., above, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.
   c. Each tiedown device which is a structural part of the packaging shall be so designed that failure of the device under excessive load would not impair the ability of the packaging to meet other requirements of this section A.
5. Determination of transport indexes for packagings see part I,A.17. of this appendix.

B. STRUCTURAL STANDARDS FOR TYPE B AND LARGE QUANTITY PACKAGING

Packaging used to ship a Type B or a large quantity of radioactive material, as defined in part I,A.6 and 18, above, shall be designed and constructed in compliance with the structural standards of this section. Standards different from those specified in this section may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

1. **Load Resistance.** Regarded as a simple beam supported at its end along any major axis, packaging shall be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to 5 times its fully loaded weight, without generating stress in any material of the packaging in excess of its yield strength.
2. **External Pressure.** Packaging shall be adequate to assure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 pounds per square-inch gauge.

C. CRITICALITY STANDARDS FOR FISSILE MATERIAL PACKAGES

1. A package used for the transport of fissile material shall be so designed and constructed

and its contents so limited that it would be subcritical if it is assumed that water leaks into the containment vessel; and

a. water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of its contents; and
b. the containment vessel is fully reflected on all sides by water.

2. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that any contents of the package which are liquid during normal transport leak out of the containment vessel, and that the fissile material is then:
   a. in the most reactive credible configuration consistent with the chemical and physical form of the material.
   b. moderated by water outside of the containment vessel to the most reactive credible extent.
   c. fully reflected on all sides by water.
3. The manager or other designated official may approve exceptions to the requirements of this section where the containment vessel incorporates special design features which would preclude leakage of liquids in spite of any single packaging error, and appropriate measures are taken before each shipment to verify the leak tightness of each containment vessel.

D. EVALUATION OF A SINGLE PACKAGE

1. The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:
   a. The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model by test or other assessment to the normal conditions of transport as specified in E., below.
   b. The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions, as specified in F., below.
2. Taking into account controls to be exercised by the shipper, the manager or other designated official may permit the shipment to be evaluated together with or without the transporting vehicle for the purpose of one or more tests.
3. Normal conditions of transport and hypothetical accident conditions different from those specified in E. and F., below, may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

E. STANDARDS FOR NORMAL CONDITIONS OF TRANSPORT FOR A SINGLE PACKAGE

1. A package used for the shipment of fissile material or more than Type A quantity of radioactive material as defined in part I, A.6 and 18, above, shall be so designed and constructed, and its contents so limited that under the normal conditions of transport specified in annex 1 below:
   a. there will be no release of radioactive materials from the containment vessel.
   b. the effectiveness of the packaging will not be substantially reduced.
   c. there will be no mixture of gases or vapors in the package which could, through any credible increases of pressure or an explosion, significantly reduce the effectiveness of the package.
   d. radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} curies of activity of Group I radionuclides per milliliter, 5×10^{-6} curies of activity of Group II radionuclides per milliliter; 3×10^{-4} curies of activity of Group III and Group IV radionuclides per milliliter.
   e. there will be no loss of coolant or loss of operation of any mechanical cooling device.
2. A package used for the shipment of fissile material shall be designed and constructed, and its contents so limited, that under normal conditions of transport specified in annex 1, considered individually:
   a. the package will be subcritical.
   b. the geometric form of the package contents would not be substantially altered.
   c. there will be no leakage of water into the containment vessel. This requirement need not be met if, in the evaluation of undamaged packages

under H.1, I.1.a., or J.1., below, it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material.

d. there will be no substantial reduction in the effectiveness of the packaging, including:
  (1) reduction by more than 5 percent in the total effective volume of the packaging of which nuclear safety is assessed.
  (2) reduction by more than 5 percent to the effective spacing on which nuclear safety is assessed between the center of the containment vessel and the outer surface of the packaging.
  (3) occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4-inch cube.

3. A package used for the shipment of more than Type A quantity of radioactive material as defined in part I,A.6. and 18., above, shall be so designed and constructed, and its contents so limited, that under the normal conditions of transport specified in annex 1, considered individually, the containment vessel would not be vented directly to the atmosphere.

F. STANDARDS FOR HYPOTHETICAL ACCIDENT CONDITIONS FOR A SINGLE PACKAGE

1. A package used for the shipment of more than Type A quantity of radioactive material (see part I,A.6. and 18., above) shall be so designed and constructed, and its contents so limited, that if subjected to the sequence of the hypothetical accident conditions specified in annex 2, it will meet the following conditions:
  a. The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1000 millirems per hour at three feet from the external surface of the package.
  b. No radioactive material would be released from the package except for gases and contaminated coolant containing total radioactivity exceeding neither:
    (1) 0.1 percent of the total radioactivity of the package contents; nor
    (2) 0.01 curie of Group I radionuclides, 0.5 curie of Group II radionuclides, 10 curies of Group III radionuclides, 10 curies of Group IV radionuclides, and 1000 curies of inert gases irrespective of transport group.

  A package need not satisfy the requirements of this paragraph if it contains only low specific activity materials, as defined in part I,A.7, above, and is transported on a motor vehicle, railroad car, aircraft, inland watercraft, or hold or deck of a seagoing vessel assigned for the sole use of the shipper.

2. A package, used for the shipment of fissile material shall be so designed and constructed, and its contents so limited, that if subjected to the sequence of the hypothetical accident conditions specified in annex 2, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:
  a. the fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents.
  b. water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.
  c. there is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

G. EVALUATION OF AN ARRAY OF PACKAGES OF FISSILE MATERIAL

1. The effect of the transport environment on the nuclear criticality safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in H., I., or J., below, for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In the case of a Fissile Class III shipment, the manager or other designated official may, taking into account controls to be exercised

by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.

2. In determining whether the standards of H.2., I.1.b., and J.2., below, are satisfied, it shall be assumed that:
   a. the fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together.
   b. water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

H. SPECIFIC STANDARDS FOR A FISSILE CLASS I PACKAGE

A Fissile Class I package shall be so designed and constructed and its contents so limited that:

1. any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered.
2. two hundred and fifty such packages would be subcritical in any arrangement, if each package were subjected to the sequence of the hypothetical accident conditions specified in annex 2, with close reflection by water on all sides of the array and with optimum interspersed moderation unless there is a greater amount of interspersed moderation in packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in G., above.

I. SPECIFIC STANDARDS FOR A FISSILE CLASS II PACKAGE

1. A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:
   a. five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water.
   b. twice that number of such packages would be subcritical in any arrangement if each package were subjected to the sequence of hypothetical accident conditions specified in annex 2, with close reflection by water on all sides of the array and the optimum interspersed hydrogenous moderation, unless there is a greater amount of interspersed moderation in the packaging in which case the greater amount may be considered. The condition of the package shall be assumed to be as described in G., above.
2. The transport index for each Fissile Class II package is calculated by dividing the number 50 by the number of such Fissile Class II packages which may be transported together as determined under the limitations in 1., above. The calculated number shall be rounded up to the first decimal place.

J. SPECIFIC STANDARDS FOR A FISSILE CLASS III SHIPMENT

A package for a Fissile Class III shipment shall be so designed and constructed and its contents and number of packages so limited, that:

1. the undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water.
2. the shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in the sequence specified in annex 2, with close reflection by water on all sides of the array and with the packages in most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to be exercised over the shipment. The condition of the package shall be assumed to be as described in G., above. Hypothetical accident conditions different from those specified in this subparagraph may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

PART III

QUALITY ASSURANCE PROCEDURES FOR THE FABRICATION, ASSEMBLY, AND TESTING OF OFFSITE SHIPPING CONTAINERS

A. ESTABLISHMENT AND MAINTENANCE OF PROCEDURES

1. Each field office shall require its contractors to establish and maintain a quality assurance program to:
   a. assure that the requisite standards of quality are met in the fabrication, assembly, and testing of each package.
   b. assure that packages in use continue to meet the requisite standards of quality.

B. ELEMENTS OF A QUALITY ASSURANCE PROGRAM

1. The program shall consist of a formal system of procedural and organizational arrangement which:
   a. require that specific responsibilities be assigned to designated units (including those of the vendor, the fabricator, and the contractor) for assuring specified quality at all stages of construction.
   b. designate codes, standards, and specifications for materials, equipment, methods of fabrication, testing, and performance.
   c. provide for quality control of materials, equipment, and services in instances where these have not already been established by existing standards and specifications.
   d. provide, as required by AECM 0504, for at least an annual audit of the AEC contractors' programs to assess their effectiveness.
   e. provide that quality assurance records are maintained in an auditable file during the service life of the container.
   f. provide for a method of determining that packagings procured for use from other sources, including AEC contractors and subcontractors or from licensees meet the requirements of AECM 0529.
   g. establish acceptance criteria in terms of measurable characteristics and the effects of appropriate tests prescribed in annexes 1, 2, and 4 and as required in part III,C.
   h. provide for a program of routine maintenance inspection and, where necessary, retesting to assure that reusable containers continue to meet the applicable design standards.
   i. provide for required training, testing, and certification of manufacturing and inspection personnel involved in special processes, such as welding and nondestructive examination, and for the required certification of equipment and procedures used in the performance of special processes.

PART IV

OPERATING PROCEDURES

A. ESTABLISHMENT AND MAINTENANCE OF PROCEDURES

1. The shipper shall establish and maintain:
   a. operating procedures adequate to assure that the determinations and controls required by this appendix are accomplished.
   b. regular and periodic inspection procedures adequate to assure that the shipper follows the procedures required by a., above.

B. ASSUMPTIONS AS TO UNKNOWN PROPERTIES

When the isotopic abundance, mass, concentration, degree of irradiation, degree of moderation, or other pertinent property of fissile material in any package is not known, the shipper shall package the fissile material as if the unknown properties have such credible values as will cause the maximum nuclear reactivity.

C. PRELIMINARY DETERMINATIONS

1. Prior to the first use of any packaging for the shipment of more than a Type A quantity of radioactive material or fissile materials, such packaging shall be inspected to ascertain that there are no cracks, pinholes, uncontrolled voids, or other defects which could significantly reduce its effectiveness.
2. Prior to the first use of any packaging for the shipment of more than a Type A quantity of radioactive or fissile materials, where the maximum normal operating pressure will exceed 5 pounds per square-inch gauge, the containment vessel shall be tested to assure that it will not leak at an internal pressure 50 percent higher than the maximum normal operating pressure.
3. Packaging shall be conspicuously and durably marked with its model number. Prior to applying the model number, an inspection shall be made to determine that the packaging has been fabricated in accordance with the approved design.

D. ROUTINE DETERMINATIONS

Prior to each use of a package for shipment of radioactive or fissile material, the shipper shall ascertain that the package with its contents satisfies the applicable requirements of part II including determinations that:

1. the packaging has not been significantly damaged.
2. any moderators and nonfissile neutron absorbers, if required, are as authorized.
3. the closure of the package and any sealing gaskets are present and are free from defects.
4. any valve through which primary coolant can flow is protected against tampering.
5. the internal gauge pressure of the package will not exceed, during the anticipated period of transport, the maximum normal operating pressure.
6. contamination of the primary coolant will not exceed, during the anticipated period of transport, the limits in part II,E.1.d.

E. RECORDS

This shipper shall maintain for a period prescribed in appendix 0230, "Records Disposition," a record of each shipment of fissile material and each shipment of amounts of radioactive material greater than Type A quantities as defined in part I,A.6. and 18., in single packages, showing where applicable:

1. identification of the packaging by model number.
2. details of any significant defects in the packaging, with the means employed to repair the defects and prevent their recurrence.
3. volume and identification of coolant.
4. type and quantity of material in each package, and the total quantity in each shipment.
5. for each item of irradiated fissile material:
   a. identification by model number.
   b. irradiation and decay history to the extent appropriate to demonstrate that its nuclear and thermal characteristics comply with approved conditions.
   c. any abnormal or unusual condition relevant to radiation safety.
6. date of the shipment.
7. for Fissile Class III, any special controls exercised.
8. name and address of the transferee.

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9. address to which the shipment was made.
10. results of the determinations required by C. and D., above.

F. DOCUMENTATION OF TECHNICAL BACKUP SUPPORT FOR SPECIFICATION, CERTIFIED, AND SPECIAL PERMIT PACKAGINGS

Packagings that have been certified by the AEC as meeting DOT regulations and packagings for which specifications have been published by the DOT or a special permit has been issued by the DOT may be used by any shipper having authority to ship radioactive or fissile materials. Therefore, it is essential that technical information and limits pertinent to the construction and use of these packagings be available to all potential users. Accordingly, steps will be taken to implement the following requirements:

1. Field office managers shall require contractors under their jurisdiction to prepare a bound distributable document for each new specification, certified, or special permit, packaging designed, developed, and fabrication by him for offsite shipment of fissile and other radioactive materials. Such a document shall also be required for existing packagings for which the DOT has issued special permits except in those instances of packagings of a highly specialized design and used solely by the originator. Should these specialized packagings be adopted for more general utilization, an appropriate technical document must then be prepared. It shall be the responsibility of the originator or first user to prepare the document for an existing packaging if it is to be used by other AEC field offices and contractors. Obsolete packagings no longer in use and containers used for onsite movement of materials are not subject to these documentation requirements unless they are reactivated, altered, or requested for use in offsite shipments. In such instances the party or parties requiring reactivation and/or alterations shall prepare or have prepared the appropriate document.
2. Each document shall provide, as a minimum, the following information:
   a. a complete physical and technical description of the package.
   b. a safety analysis report including considerations for meeting the requirements for packaging and transport safety, nuclear criticality safety, and radiological safety. Pertinent documents in existence as of the date of this revision are acceptable.
   c. design and development information including pertinent data, analytical methods, and the results of the prescribed tests.
   d. tables, graphs, drawings, pictures, and technical references as required to give a clear treatment of the subject.
3. Each document shall be prepared and submitted to the Technical Information Center in accordance with appendix 3201, part III,B.2. for reproduction and distribution based upon need.

ANNEX 1

NORMAL CONDITIONS OF TRANSPORT

1. **Heat**–Direct sunlight at an ambient temperature of 130°F in still air.

2. **Cold**–An ambient temperature of -40°F in still air and shade.

3. **Pressure**–Atmospheric pressure of 0.5 times standard atmospheric pressure.

4. **Vibration**–Vibration normally incident to transport.

5. **Water Spray**–A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of 30 minutes.

6. **Free Drop**–Between 1½ and 2½ 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.

Free Fall Distance

Package Weight (pounds)	Distance (feet)
Less than 10,000	4
10,000 to 20,000	3
20,000 to 30,000	2
More than 30,000	1

7. **Corner Drop**–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 1 foot onto a flat essentially unyielding horizontal surface. This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight, and to all Fissile Class II packagings.

8. **Penetration**–Impact of the hemispherical end of a vertical steel cylinder 1¼ inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture.

9. **Compression**–For packages not exceeding 10,000 pounds in weight, a compressive load equal to either 5 times the weight of the package or 2 pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

ANNEX 2

HYPOTHETICAL ACCIDENT CONDITIONS

1. **Free Drop**–A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

2. **Puncture**–A free drop through a distance of 40 inches striking, in a position maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.

3. **Thermal**–Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1475°F for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.

4. **Water Immersion (fissile material packages only)**–Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

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ANNEX 3

TRANSPORT GROUPING OF RADIONUCLIDES

Element[1]	Radionuclides[2]	Group
Actinium (89)	Ac 227	I
	Ac 228	I
Americium (95)	Am 241	I
	Am 243	I
Antimony (51)	Sb 122	IV
	Sb 124	III
	Sb 125	III
Argon (18)	Ar 37	VI
	Ar 41	II
	Ar 41[3] (uncompressed)	V
Arsenic (33)	As 73	IV
	As 74	IV
	As 76	IV
	As 77	IV
Astatine (85)	At 211	III
Barium (56)	Ba 131	IV
	Ba 133	II
	Ba 140	III
Berkelium (97)	Bk 249	I
Beryllium (4)	Be 7	IV
Bismuth (83)	Bi 206	IV
	Bi 207	III
	Bi 210	II
	Bi 212	III
Bromine (35)	Br 82	IV
Cadmium (48)	Cd 109	IV
	Cd 115 m	III
	Cd 115	IV
Calcium (20)	Ca 45	IV
	Ca 47	IV
Californium (98)	Cf 249	I
	Cf 250	I
	Cf 252	I
Carbon (6)	C 14	IV
Cerium (58)	Ce 141	IV
	Ce 143	IV
	Ce 144	III
Cesium (55)	Cs 131	IV
	Cs 134 m	III
	Cs 134	III
	Cs 135	IV
	Cs 136	IV
	Cs 137	III
Chlorine (17)	Cl 36	III
	Cl 38	IV
Chormium (24)	Cr 51	IV
Cobalt (27)	Co 56	III
	Co 57	IV
	Co 58 m	IV
	Co 58	IV
	Co 60	III
Copper (29)	Cu 64	IV
Curium (96)	Cm 242	I
	Cm 243	I
	Cm 244	I
	Cm 245	I
	Cm 246	I
Dysprosium (66)	Dy 154	III
	Dy 165	IV
	Dy 166	IV
Erbium (68)	Er 169	IV
	Er 171	IV
Europium (63)	Eu 150	III
	Eu 152 m	IV
	Eu 152	III
	Eu 154	II
	Eu 155	IV
Fluorine (9)	F 18	IV
Gadolinium (64)	Gd 153	IV
	Gd 159	IV
Gallium (31)	Ga 67	III
	Ga 72	IV
Germanium (32)	Ge 71	IV
Gold (79)	Au 193	III
	Au 194	III
	Au 195	III
	Au 196	IV
	Au 198	IV
	Au 199	IV
Hafnium (72)	Hf 181	IV
Holmium (67)	Ho 166	IV
Hydrogen (1)	H 3 (see tritium)	
Indium (49)	In 113 m	IV
	In 114 m	III
	In 115 m	IV
	In 115	IV
Iodine (53)	I 124	III
	I 125	III
	I 126	III
	I 129	III
	I 131	III
	I 132	IV
	I 133	III
	I 134	IV
	I 135	IV
Iridium (77)	Ir 190	IV
	Ir 192	III
	Ir 194	IV
Iron (26)	Fe 55	IV
	Fe 59	IV
Krypton (36)	Kr 85 m	III
	Kr 85[3] (uncompressed)	V

Element[1]	Radionuclides[2]	Group
	Kr 85	III
	Kr 85[3] (uncompressed)	VI
	Kr 87	II
	Kr 87[3] (uncompressed)	V
Lanthanum (57)	La 140	IV
Lead (82)	Pb 203	IV
	Pb 210	II
	Pb 212	II
Lutetium (71)	Lu 172	III
	Lu 177	IV
Magnesium (12)	Mg 28	III
Manganese (25)	Mn 52	IV
	Mn 54	IV
	Mn 56	IV
Mercury (80)	Hg 197 m	IV
	Hg 197	IV
	Hg 203	IV
Mixed Fission Products	MFP	II
Molybdenum (42)	Mo 99	IV
Neodymium (60)	Nd 147	IV
	Nd 149	IV
Neptunium (93)	Np 237	I
	Np 239	I
Nickel (28)	Ni 56	III
	Ni 59	IV
	Ni 63	IV
	Ni 65	IV
Niobium (41)	Nb 93 m	IV
	Nb 95	IV
	Nb 97	IV
Osmium (76)	Os 185	IV
	Os 191 m	IV
	Os 191	IV
	Os 193	IV
Palladium (46)	Pd 103	IV
	Pd 109	IV
Phosphorus (15)	P 32	IV
Platinum (78)	Pt 191	IV
	Pt 193	IV
	Pt 193 m	IV
	Pt 197 m	IV
	Pt 197	IV
Plutonium (94)	Pu 238 (F)	I
	Pu 239 (F)	I
	Pu 240	I
	Pu 241 (F)	I
	Pu 242	I
Polonium (84)	Po 210	I
Potassium (19)	K 42	IV
	K 43	III
Praseodymium (59)	Pr 142	IV
	Pr 143	IV
Promethium (61)	Pm 147	IV
	Pm 149	IV
Protactinium (91)	Pa 230	I
	Pa 231	I
	Pa 233	II
Radium (88)	Ra 223	II
	Ra 224	II
	Ra 226	I
	Ra 228	I
Radon (86)	Rn 220	IV
	Rn 222	II
Rhenium (75)	Re 183	IV
	Re 186	IV
	Re 187	IV
	Re 188	IV
	Re Natural	IV
Rhodium (45)	Rh 103 m	IV
	Rh 105	IV
Rubidium (37)	Rb 86	IV
	Rb 87	IV
	Rb Natural	IV
Ruthenium (44)	Ru 97	IV
	Ru 103	IV
	Ru 105	IV
	Ru 106	III
Samarium (62)	Sm 145	III
	Sm 147	III
	Sm 151	IV
	Sm 153	IV
Scandium (21)	Sc 46	III
	Sc 47	IV
	Sc 48	IV
Selenium (34)	Se 75	IV
Silicon (14)	Si 31	IV
Silver (47)	Ag 105	IV
	Ag 110 m	III
	Ag 111	IV
Sodium (11)	Na 22	III
	Na 24	IV
Strontium (38)	Sr 85 m	IV
	Sr 85	IV
	Sr 89	III
	Sr 90	II
	Sr 91	III
	Sr 92	IV
Sulphur (16)	S 35	IV
Tantalum (73)	Ta 182	III
Technetium (43)	Tc 96 m	IV
	Tc 96	IV
	Tc 97 m	IV
	Tc 97	IV
	Tc 99 m	IV
	Tc 99	IV
Tellurium (52)	Te 125 m	IV
	Te 127 m	IV
	Te 127	IV

Element[1]	Radionuclides[2]	Group
	Te 129 m	III
	Te 129	IV
	Te 131 m	III
	Te 132	IV
Terbium (65)	Tb 160	III
Thallium (81)	Tl 200	IV
	Tl 201	IV
	Tl 202	IV
	Tl 204	III
Thorium (90)	Th 227	II
	Th 228	I
	Th 230	I
	Th 231	I
	Th 232	III
	Th 234	II
	Th Natural	III
Thulium (69)	Tm 168	III
	Tm 170	III
	Tm 171	IV
Tin (50)	Sn 113	IV
	Sn 117	III
	Sn 121	III
	Sn 125	IV
Tritium (1)	H 3	IV
	H 3 (as gas, as luminous paint or absorbed on solid material)	VII
Tungsten (74)	W 181	IV
	W 185	IV
	W 187	IV

Element[1]	Radionuclides[2]	Group
Uranium (92)	U 230	II
	U 232	I
	U 233 (F)	II
	U 234	II
	U 235 (F)	III
	U 236	II
	U 238	III
	U Natural	III
	U Enriched (F)	III
	U Depleted	III
Vandium (23)	V 48	IV
	V 49	III
Xenon (54)	Xe 125	III
	Xe 131 m	III
	Xe 131[3] m (uncompressed)	V
	Xe 133	III
	Xe 133[3] (uncompressed)	VI
	Xe 135	II
	Xe 135[3] (uncompressed)	V
Ytterbium (70)	Yb 175	IV
Yttrium (39)	Y 88	III
	Y 90	IV
	Y 91 m	III
	Y 91	III
	Y 92	IV
	Y 93	IV
Zinc (30)	Zn 65	IV
	Zn 69 m	IV
	Zn 69	IV
Zirconium (40)	Zr 93	IV
	Zr 95	III
	Zr 97	IV

[1] Atomic Number shown in parentheses.
[2] Atomic weight shown after the radionuclide symbol.
[3] Uncompressed means at a pressure not exceeding one atmosphere.
m Metastable state.
(F) Fissile Material.

ANNEX 4

TESTS FOR SPECIAL FORM MATERIAL

1. **Free Drop**—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.

2. **Percussion**—Impact of the flat circular end of a 1-inch diameter steel rod weighing 3 pounds, dropped through a distance of 40 inches. The capsule or material shall be placed on a sheet of lead, of hardness number 3.5 to 4.5 on the Vickers scale, and not more than 1-inch thick, supported by a smooth essentially unyielding surface.

3. **Heating**—Heating in air to a temperature of 1475°F and remaining at that temperature for a period of 10 minutes.

4. **Immersion**—Immersion for 24 hours in water at room temperature. The water shall be at pH 6—pH 8, with a maximum conductivity of 10 micromhos per centimeter.