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SAFETY SUMMARY REPORT – LP-50 TRITIUM CONTAINER
(Packaging of Radioactive and Fissile Materials)

FINAL REPORT

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MASTER

E. I. du Pont de Nemours and Company
Savannah River Plant
Aiken, South Carolina 29801

Compiled by

R. F. Rogers
R. A. Scaggs

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AEC Manual Chapter 0529

SAFETY SUMMARY REPORT — LP-50 TRITIUM CONTAINER
(Packaging of Radioactive and Fissile Materials)

Abstract

Elemental tritium is shipped at low pressure in an insulated container in compliance with AEC Manual Chapter 0529 (AECM 0529)^a, Safety Standards for the Packaging of Radioactive and Fissile Materials. The package is not a radiological hazard under normal or hypothetical accident conditions.

Description of Shipment

Elemental tritium is shipped from the Savannah River Plant in a stainless steel vessel (primary container) sealed within an aluminum vessel (secondary container) and carried in a steel drum with a least 4 inches of "Celotex"^b insulation. Two secondary container designs (figure 1) exist: one with a flat cover and the other with a dome. The packaging components are shown in figures 1 through 7.

Tritium gas may be pure or may contain varying amounts of protium (hydrogen-1), deuterium, or helium. The following restrictions apply to the use of this container:

Maximum tritium content	75,300 cc-STP (953,500 curies)
Maximum total pressure in primary container as loaded	24.2 psia (1250 torrs) at 25°C

Each package contains a large quantity of nonfissile, Group VII material, as defined in AECM 0529, and complies with appropriate sections of that chapter. No exemptions are claimed.

^a A reproduction of AECM 0529 is included with this report.

^b The Celotex Corporation's trademark for structural building and insulation board, Mil-F-26862-A-Type II.

Comparison With Regulations

The packaging standards required of AEC contractors are contained in AECM 0529. All pertinent sections will be discussed, in sequence.

I. DEFINITIONS AND EXEMPTIONS

- A. **Definitions** - No comment is required.
- B. **Exemptions** - Not applicable.

II. PACKAGE STANDARDS

A. General standards for all packaging

1. No reaction between package and contents. There will be no significant reaction between the contents and packaging. (Permeation of tritium through the container wall is discussed later.)
2. Positive closure on packaging. The outer drum is equipped with a bolted closure ring which cannot be inadvertently opened.
3. Lifting devices. Not applicable; no lifting devices are included.
4. Tie-down devices. Not applicable; no tie-down devices are included.

B. Structural standards for large quantity packaging

The outer drum was uniformly loaded to 1760 pounds, more than five times the assembled package weight of 257 pounds, without indication of yield. The test was performed in the manner prescribed in this section. The ability of the package to withstand 25 psig external pressure is shown in Addendum 1.

C. Criticality standards for fissile material packages

1. Nuclear safety with water inleakage. Not applicable.
2. Nuclear safety with leakage from container. Not applicable.

D. Evaluation of a single package

- 1(a) Effect of normal conditions on package. An analysis of the package under normal conditions is given in Addendum 2.

1(b) Effect of accident conditions on package. An analysis of effects of an accident is given in Addendum 3.

2. Evaluation of package and vehicle together. Not applicable.

3. Approval of different accident conditions. Not applicable.

E. Standards for normal conditions of transport for a single package

Discussed with item II,D,1(a).

F. Standards for hypothetical accident conditions for a single package

Discussed with item II,D,1(b).

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. OPERATING PROCEDURES

A. Establishment and maintenance of procedures

Operating and inspection procedures will be established to ensure continued compliance with AECM 0529. Pertinent operating procedures (DPSOLs) are:

- 232-H-113, Certification of Pressure Test
- 114, LP-50 Loading/Shipping Verification
- 804, Loading
- 814, Preparing and Shipping Product Container LP-50
- 1414, Pressure and Leak Testing Product Containers

B. Assumptions as to unknown properties

Not applicable.

C. Preliminary determinations

1. Packaging was inspected to ensure freedom from defects.
2. Each primary container has been leak-tested and shown not to leak more than 7×10^{-8} atm cc/sec at 1-1/2 times its maximum normal operating pressure of 14.3 psig at 85°C.
3. Packaging will be marked with a steel tag after ascertaining that it was properly fabricated.

D. Routine determinations

Savannah River Plant uses operating procedures to ensure compliance with this requirement.

E. Reports

Savannah River Plant records the information required for each shipment and maintains the records for at least two years.

ADDENDUM 1

Package StandardsSTRUCTURAL STANDARDS - EXTERNAL PRESSURE

(No loss of contents at 25 psig)

External pressure will affect only the aluminum outer containment vessel.

I. FLAT-TYPE SECONDARY CONTAINER

Material: Aluminum alloy 356 (T-51 temper conservatively assumed) [1]

Tensile strength = 23,000 psi

Yield strength = 16,000 psi

Elongation = 1% in 2 in. or less

Shear ultimate = 17,000 psi

Endurance limit = 7,500

Procedure described by ASME Pressure Vessel Code, Section VIII, is used to evaluate ability to withstand external pressure.

$$\text{Shell: } \frac{L}{D_o} = \frac{26.75}{14} = 1.91 \quad \frac{D_o}{t} = \frac{14}{.234} = 60$$

$$B = 7400 \text{ (fig. UNF 28.5)}$$

$$P_a = \frac{B}{D_o/t} = \frac{7400}{60} = 123 \text{ psig} > 25$$

OK

Bottom Head: Use allowable stress = 16,000 psi (yield)

$$P = \frac{S}{C} \left(\frac{t}{d} \right)^2 = \frac{16,000}{0.3} \left(\frac{.312}{13.25} \right)^2 = 29.5 \text{ psig} > 25$$

OKTop Head: (356 - T6 Aluminum) $S_u = 30,000$ psi, $S_y = 20,000$ psi

$$P = \frac{S}{C} \left(\frac{t}{d} \right)^2 = \frac{20,000}{0.2} \left(\frac{.25}{13.375} \right)^2 = 35 \text{ psig} > 25$$

OK

Flange & Bolting:

Gasket: Linear Inc. O-ring, cat no. 1820-84

$$W_{mg} = \pi b G y = \pi (.137)(14.22)(200) = 1220 \text{ lb}$$

$$A_{mg} = \frac{1220}{20,000} = .061 \text{ in.}^2$$

$$A_B = 8(.0317) = .253 \text{ in.}^2$$

$$W = \frac{1}{2} (A_{mg} + A_B) S_a = \frac{1}{2} (.061 + .253)(20,000) = 3140$$

$$M_O = W h_G = 3140 (.638) = 2000 \text{ in-lb gasket seating} \leftarrow$$

Governs

$$M_O = H_d(h_d - h_G) + H_t(h_t - h_G)$$

$$= .785 (13.5)^2 (25) (.883 - .638) + [.785 (14.22)^2 (25) - .785 (13.5)^2 (25)] (.82 - .638)$$

$$= 875 + 71 = 946 \text{ in-lb operating}$$

$$\text{Bolt stress} = \frac{3140}{.253} = 12,400 \text{ psi}$$

OK

Flange Constants:

$$\begin{aligned}
 K &= A/B = 16.25/13.5 = 1.20 & F &= .875 \\
 T &= 1.84 & V &= .35 \\
 Z &= 5.55 & f &= 3.6 \\
 Y &= 10.75 & e &= F/h_b = .875/1.78 = .491 \\
 U &= 11.81 & d &= U/V h_b (g_o)^2 = \frac{11.81}{.35} (1.78)(.234)^2 = 3.3 \\
 g_a/g_o &= .526/.234 = 2.25 \\
 h_b &= \sqrt{B_g} = \sqrt{3.16} = 1.78 & \text{Use allowable stress} &= 6250 \text{ psi} \\
 h/h_b &= .292/1.78 = .164 \\
 L &= \frac{te + 1}{T} + \frac{t^3}{d} = \frac{.5(.491) + 1}{1.84} + \frac{(.5)^3}{3.3} = .676 + .038 = .714
 \end{aligned}$$

Flange Stresses:

$$\begin{aligned}
 S_H &= \frac{fM_b}{L(g_a)^2 B} = \frac{3.6(2000)}{.714(.526)^2 (13.5)} = 2700 \text{ psi} < 1.5(6250) & \text{OK} \\
 S_R &= \frac{(1.33te + 1)M_b}{Lt^2 B} = \frac{[(1.33)(.5)(.491) + 1]2000}{.714(.5)^2 (13.5)} = 1100 \text{ psi} < 6250 & \text{OK} \\
 S_T &= \frac{YM_b}{t^2 B} - ZS_r = \frac{10.75(2000)}{(.5)^2 (13.5)} - 5.55(1100) = 280 \text{ psi} < 6250 & \text{OK}
 \end{aligned}$$

Conclusion: The flat-type secondary container will withstand 25 psig external pressure; therefore, the inner product container should be unaffected.

II. DOMED-TYPE SECONDARY CONTAINERA. Materials

- 1) Domed cover is fabricated of aluminum alloy 6061-T6.

Tensile strength	= 24,000 psi	[2]
Yield strength	= 12,000 psi	[3]
Elongation	= 18% in 2 in. or less	[3]
Shear ultimate	= 12,000 psi	[3]
Endurance limit	= 9,000 psi	[3]
Allowable tensile stress, S_f	= 8,000 psi (yield at 250°F)	[4]

- 2) Bolts are ASME SA-193B8 (ASTM 193 type 304 GR B8)

Tensile strength	= 75,000 psi
Allowable tensile stress, S_f	= 13,650 psi

B. Yield Pressure (P) of Cover Weldment (figure 6, E)

- 1) Hemispherical head [para U6-33(c)]

Allowable compressive stress, S_c = Smaller of B or S_f

Inside spherical radius, L_1 = 8.25 in.

Head thickness, t = 0.25 in.

$$L_1/t = 8.25/0.25 = 33$$

$$L_1/100t = \frac{8.25}{100 \times 0.25} = 0.33$$

Using figure UNF-28.3 -

$$B = 5500$$

$$\text{Since } B = 5500 < S_f = 8000$$

$$\begin{aligned} \text{Allowable external pressure} = P &= \frac{B}{L_1/t} = \frac{5500}{33} \\ &= 167 \text{ psid} \end{aligned}$$

Since this is greater than the specified differential pressure of 25 psid, the thickness of 0.25" is adequate.

- 2) Hemispherical head [para U6-35(a), UA-6(c)] - allowable differential pressure of dome.

$$P_a = \frac{6 S_f t}{5 L_1} = \frac{6 \times 8000 \times 0.25}{5 \times 8.25} = 29.2 \text{ psid}$$

This is less than the 167 psi differential by para U6-33(c) but is greater than design pressure of 25 psi differential; therefore, the design is satisfactory.

C. Thickness of Cover Flange (Design thickness = 0.25")

$$t_f = Q \left[1 + \sqrt{1 + \frac{7.5 M_o}{P Q B L}} \right]$$

where:

$$Q = \frac{P}{S} \frac{L_1}{4} \left[\frac{1}{1 + 6 \left(\frac{C - B}{C + B} \right)} \right]$$

t_f = flange thickness, in.

M_o = total moment acting upon the flange, in-lb

P = differential pressure across spherical head = 25 psid

B = inside diameter of flange = 13.5 in.

$$L = \text{factor} = \frac{t_c + 1}{T} + \frac{t^3}{d} = 8.5$$

L_1 = inside spherical radius = 8.25 in.

S = minimum tensile yield strength = 6000 psi

C = bolt circle diameter = 15.5 in.

$$\text{then: } Q = \frac{25 \times 8.25}{6000 \times 4} \left[\frac{1}{1 + 6 \left(\frac{15.5 - 13.5}{15.5 + 13.5} \right)} \right]$$

$$Q = \frac{206}{24,000} \left[\frac{1}{1.414} \right]$$

$$Q = 0.00605$$

Solving for Mo -

$$W_{m2} = \pi b Gy$$

where: W_{m2} = min bolt load for gasket seating, lb

y = min design seating stress = 200 psi

b = effective gasket seating width = 0.137"

G = gasket diameter = 14.375"

$$\therefore W_{m2} = \pi \times 0.137 \times 14.375 \times 200 = 1240 \text{ lb}$$

$$A_{m2} = \frac{W_{m2}}{S_a} = \text{total required cross-sectional area of bolts, sq in.}$$

where: S_a = allowable bolt stress at atmospheric temp = 20,000 psi

$$\text{then: } A_{m2} = \frac{1240}{20,000} = 0.062 \text{ sq in.}$$

A_B = actual cross-sectional area of bolts

$$= 8 \times 0.0317 \text{ in}^2 = 0.254 \text{ in}^2$$

$A_B > A_{m2}$ ($0.254 > 0.062$) $\therefore$ bolts are OK

$$W = 1/2 (A_m + A_B) S_a$$

$$\therefore W = 1/2 (0.062 + 0.254) 20,000$$

$$W = \frac{0.316}{2} \times 20,000 = 3160 \text{ lb}$$

$$M_o = W_{hy} = W \frac{(C-G)}{2}$$

$$\therefore M_o = 3160 \left(\frac{15.5 - 14.375}{2} \right) = 3160 \times \frac{1.125}{2} = 3160 \times 0.563$$

$$= 1780 \text{ in.-lb}$$

$$\begin{aligned}
\text{where: } t &= Q \left[1 + \sqrt{\frac{7.5 Mo}{PQBL}} \right] \\
&= 0.00605 \left[1 + \sqrt{\frac{7.5 \times 1890}{25 (0.00605)(13.5)(8.5)}} \right] \\
&= 0.00605 \left[1 + \sqrt{\frac{14,200}{17.35}} \right] = 0.00605 \left[1 + \sqrt{820} \right] \\
&= 0.00605 \times 29.6 = 0.179 \text{ in.}
\end{aligned}$$

Since this is less than 0.25", the flange is satisfactory.

Conclusion: The dome type secondary container will also withstand 25 psig external pressure; therefore, the inner product container should be unaffected.

ADDENDUM 2

Normal Conditions of Transport

Gaseous tritium permeates normal materials of construction at rates depending on temperature, pressure, and other factors. The term "no release" as used in AECM-0529 for normal conditions of transport is interpreted to mean no release which would expose any persons to a dose above that received by continuous exposure to the maximum permissible concentration allowed for the public. For transportation in a closed vehicle (the worst case), the maximum allowable release rate per package would be about 7×10^{-8} atm cc/sec of tritium. This value is derived by assuming that air in a closed vehicle is replaced about once a day, that a vehicle contains about 300 cubic feet of air for every package, and that a workman opening and unloading the vehicle would be exposed to the maximum concentration for no more than one minute. The maximum concentration in the vehicle is computed from the Maximum Permissible Concentration for 168 hour/week exposure set by the AECM-0524 Concentration Guide by the ratio of exposure time to 168 hours. The actual exposure would be much lower than calculated because actual tritium release rates will be greatly below the derived upper limit. (It is interesting to note that the proposed IAEA regulations would permit escape of 1.0×10^{-7} atm cc/sec, which by coincidence is very close to the figure of 7×10^{-8} atm cc/sec.)

1. HeatA. General Basis

The low pressure container consists of a 50-liter stainless steel inner vessel encased in a flanged aluminum outer vessel. The assembly is packed in an elongated 55-gallon drum insulated with "Celotex."

An estimate of the maximum temperatures attained in the package in normal transport is made below. Basic assumptions for the estimate are outlined below.

- 1) The package is in thermal equilibrium at the most severe environmental condition (130°F and sunlight).

- 2) Solar heating is applied to the top one side of the drum over a projected area equal to diagonal height times diameter.
- 3) There is no circumferential heat flow in the thin wall of the drum or in the "Celotex" insulation.
- 4) Heat escape through the bottom of the package is neglected.
- 5) The wall temperature of the aluminum vessel is uniform (high conductivity, low heat flux).
- 6) Heat passage from the sunny surfaces of the drum to the aluminum vessel, thence to the shaded surface of the drum, is calculated on the basis of a weighted average insulation thickness.

B. Definitions and Constants

- 1) Q_s = solar heat input = solar flux $\times$ projected area.

Solar flux = 135 pcu/(hr)(ft²) based on solar constant of 1.92 cal/(cm²)(min), atmospheric transmittance factor of 0.60, and absorptivity factor of 0.94 for painted drum.

Projected area = diagonal height $\times$ diameter

$$= \frac{45" \times 22.5"}{144 \text{ in}^2/\text{ft}^2} = 7.0 \text{ ft}^2$$

$$Q_s = 134 \times 7.0 = 940 \text{ pcu/hr}$$

- 2) Q_r = radioactive decay heat = 6.6 watts = 12.4 pcu/hr

- 3) A_d = surface area of drum (sunny side)
 = top surface + 1/2 cylindrical surface
 = 12.4 ft²

- 4) A'_d = surface area of drum (shaded side)
 = 1/2 cylindrical surface
 = 9.6 ft²

- 5) U_o = heat transfer coefficient through insulation (sunny side)

$$= \frac{K}{L} = \frac{0.039}{0.36} = 0.11 \text{ pcu/(hr)(ft}^2\text{)(}^\circ\text{C)}$$

K = thermal conductivity "Celotex" in temp range of 85 - 90°C
 = 0.039, estimated from room temp conductivity of 0.030
 pcu/(hr)(ft²)(°C/ft)

L = weighted average insulation thickness of 3.8" + 0.5"
 "Celotex" equivalent of air gaps = 0.36 ft

- 6) $U_o' =$ Heat transfer coefficient through insulation (shade side)
 $= \frac{K'}{L'}$ $K' = 0.036$ estimated ($\sim 70^\circ\text{C}$)
 $L' = 0.36$ ft
 $= \frac{0.036}{0.36} = 0.10$ pcu/(hr)(ft²)(°C)
- 7) $A_m =$ Mean heat transfer area (sun side)
 $=$ Mean area of drum top + mean area of cyl side
 $= 1.8 \text{ ft}^2 + 5.5 \text{ ft}^2 = 7.3 \text{ ft}^2$
- 8) $A_m' =$ Mean heat transfer area (shade side)
 $=$ Mean area of cyl side $= 5.5 \text{ ft}^2$
- 9) $T_d =$ Drum surface temperature — sun side, °C
- 10) $T_d' =$ Drum surface temperature — shade side, °C
- 11) $T_c =$ Wall temperature of aluminum vessel, °C
- 12) $T_a =$ Ambient temperature $= 54^\circ\text{C}$ (130°F)

C. Calculations

1. Heat Balances

For determination of temperatures T_d , T_d' , and T_c , heat balances are made on the entire package, the aluminum vessel and the separate sides of the steel drum.

$$\begin{array}{lcl}
 & \underline{Q \text{ in}} & \underline{Q \text{ out}} \\
 \text{Entire Package} & Q_s + Q_r & = Q_1 + Q_1' \\
 & 940 + 12.4 & = (h_c + h_r) A_d (T_d - T_a) + \\
 & & (h_c' + h_r') A_d' (T_d' - T_a)
 \end{array}$$

where: $h_c = 0.23 (\Delta T)^{1/3}$

$$h_r = F_a F_e \left[\frac{\left(\frac{T_d + 273}{100} \right)^4 - \left(\frac{T_a + 273}{100} \right)^4}{T_d - T_a} \right]$$

F_a = Angle factor = 1.0

F_e = Emissivity factor = 0.94

$$\begin{array}{lcl}
 & \underline{Q \text{ in}} & \underline{Q \text{ out}} \\
 \text{Aluminum} & Q_r + Q_2 & = Q_2' \\
 \text{Container} & Q_r + U_o A_m (T_d - T_c) & = U_o' A_m' (T_c - T_d') \\
 \text{Steel Drum} & & \\
 \text{Sun Side} & Q_s & = Q_1 + Q_2 \\
 \\
 \text{Steel Drum} & & \\
 \text{Shade Side} & Q_2' & = Q_1'
 \end{array}$$

By successive substitution of trial values in the above equations, it is found that the following set of temperatures is required for equilibrium.

Drum - Sunny Side (T_d) = 87°C

Drum - Shaded Side (T_d') = 55°C

Aluminum Vessel (T_c) = 83°C

2. Temperature Gradient Between Inner and Outer Vessels: To determine the temperature of the inner containment vessel (and tritium), it is necessary to estimate the temperature gradient between the inner and outer vessels.

T_c = Temperature of outer aluminum vessel = 83°C

T_s = Temperature of inner stainless steel vessel, °C

A_{co} = Area for heat transfer by conduction

= Cylindrical surface only (large clearances at top and bottom)

= 6.64 ft²

L = clearance between cylindrical surfaces = 0.17" = 0.014'

A_r = area for heat transfer by radiation

= entire surface of inner vessel = 8.36 ft²

$$\text{Heat balance: } Q_r = h_{co} A_{co} (T_s - T_c) + F_a F_e A_r \left[\left(\frac{T_s + 273}{100} \right)^4 - \left(\frac{T_c + 273}{100} \right)^4 \right]$$

where: Q_r = radioactive decay heat = 12.4 pcu/hr

h_{co} = heat transfer coefficient by conduction = $\frac{K_{air}}{L}$

$$= \frac{0.0179 \text{ pcu/(hr)(ft)} (C/ft)}{0.014 \text{ ft}} = 1.28 \text{ pcu/(hr)(ft)} (^\circ C)$$

F_a = angle factor = 1.0

F_e = emissivity factor

$$= \frac{1}{\frac{1}{\epsilon_s} + \frac{1}{\epsilon_c}} = 0.136$$

Solving, $T_s = 85^\circ C$

There will be no significant difference in temperature between the tritium and the inner vessel; therefore, the temperature of the tritium in normal transport will not exceed 85°C.

D. Pressure in the Primary Container

With an initial loading to 24.2 psia at 25°C, pressure will increase at 85°C to:

$$(24.2) \frac{(85 + 273)}{(25 + 273)} = 29.0 \text{ psia}$$

(the ability of this container to hold greater pressure at 110°C without rupture is shown in Addendum 3).

E. Tritium lost

Hydrogen permeation may be calculated from $P_\infty = \frac{D C_o A}{2L}$

where: P_∞ = equilibrium permeation rate, atm cc/sec

D = hydrogen diffusivity, cm²/sec

C_o = hydrogen solubility, cc H₂/cm³ metal

A = container surface area, cm²

L = container wall thickness, cm

The solubility is calculated from

$$\log C_o = - \frac{325}{\text{Temp K}} - 0.54 + \frac{1}{2} \log (\text{absolute pressure, psia})$$

A very long time is required to reach the equilibrium rate, thus the maximum permeation rate expected within a reasonable shipping period is a more realistic basis for determining loss.

The permeation rate after any interval of time is determined from a graphical plot of $\frac{P_t}{P_\infty}$ vs. $\frac{(D)(t)}{L^2}$.

where: P_t = permeation rate at time t

(The permeation equations and plots are derived and their use illustrated in DPSTWD 64-168, DPWD 1057, DPWD 1132, and DPSP 68-1321.)

At 85°C, with $D = 8 \times 10^{-11}$ cm²/sec

$A = 8040$ cm²

$L = 0.198$ cm,

and infinite time, the calculated $P_\infty = 3.2 \times 10^{-7}$ atm cc/sec. However, after 30 days, $P_t < 3.2 \times 10^{-10}$ atm cc/sec, and 312 days at 85°C would be required to reach 10^{-8} atm cc/sec, still below the proposed maximum acceptable. Because it is reasonable to expect the transportation to be completed within 30 days, no significant tritium permeation would occur. Loss through the container valve is also negligible ($< 10^{-8}$ atm cc/sec) as shown in the table on valve testing in Addendum 3.

[NOTE: Although tritium may be stored for several years in these containers, the temperature is normally less than 100°F. Permeation at this temperature is extremely slow (e.g., 50 years before rate reaches 1/10 of maximum permissible limit); consequently, it does not affect the conclusions drawn here or later for the hypothetical accident case (p 21).]

2. Cold

This package contains no liquids nor other materials harmfully affected by a temperature of -40°F.

3. Pressure

The maximum internal pressure in the secondary container is 17.6 psia under the full sun condition assuming perfect gases. With one-half standard atmospheric pressure on the outside of the container, the pressure differential across the wall is

$$P = 17.6 - (1/2)(14.7) = 10.2 \text{ psi differential}$$

The wall temperature is 83.0°C = 182°F. Allowable stresses are not listed in the ASME code for 356-T51 aluminum. SB-26-SG70A-T71 is similar and will be used.

$$\text{Allowable stress at } 182^\circ\text{F} = 5750 + \frac{200 - 182}{200 - 150} (250) = 5840 \text{ psi}$$

Properties of 356-T51 aluminum at 212°F

[1]

$$\text{Tensile strength} = 0.92 (23,000) = 21,100 \text{ psi}$$

$$\text{Yield strength} = 0.98 (16,000) = 15,700 \text{ psi}$$

Secondary container stresses ($P = 10.2 \text{ psig}$)

$$\text{Shell: } S = \frac{P(R + 0.6t)}{E_t} = \frac{10.2(6.75 + 0.14)}{1(0.234)} = 300 \text{ psi} < 5840 \quad \underline{\text{OK}}$$

$$\text{Bottom head: } S = CP\left(\frac{d}{t}\right)^2 = 0.3(10.2)\left(\frac{13.25}{0.312}\right)^2 = 520 \text{ psi} < 5840 \quad \underline{\text{OK}}$$

$$\text{Top head: } (356 - \text{T6 aluminum}) S_a = 6900 + \frac{14}{50}(500) = 7040 \text{ psi}$$

$$S = CP\left(\frac{d}{t}\right)^2 = 0.2(10.2)\left(\frac{13.375}{0.25}\right)^2 = 5810 \text{ psi} < 7040 \quad \underline{\text{OK}}$$

Flange and bolting

$$H_d = 0.785 B^2 P = 0.785 (13.5)^2 (10.2) = 1460 \text{ lb}$$

$$H_g = 2b\pi G_m P = 2(0.137)\pi(14.22)(1)(10.2) = 125 \text{ lb}$$

$$H_t = \pi(13.86)(0.36)(10.2) = 160 \text{ lb}$$

$$W_{m1} = 1625 \text{ lb}$$

$$1460 \text{ lb} \times 0.883 \text{ in.} = 1290 \text{ in.-lb}$$

$$125 \text{ lb} \times 0.638 \text{ in.} = 80 \text{ in.-lb}$$

$$160 \text{ lb} \times 0.82 \text{ in.} = 131 \text{ in.-lb}$$

$$M_o = 1501 \text{ in.-lb}$$

$$W_{m2} = \pi b G_y = \pi(0.137)(14.22)(200) = 1220 \text{ lb}$$

$$A_{m1} = \frac{1792}{20,000} = 0.0896 \text{ in}^2$$

$$A_b = 8(0.0317) = 0.253 \text{ in}^2$$

$$W = 1/2(A_m + A_b)S_a = 1/2(0.0896 + 0.253)(20,000) = 3426 \text{ lb}$$

$$M_o = W h_g = 3426(0.638) = 2190 \text{ in.-lb gasket seating}$$

$$\text{Bolt stress} = 3426/0.253 = 13,600 \text{ psi} \quad \underline{\text{OK}}$$

Flange stresses (see Addendum 1 for flange constants)

Gasket seating: ASME allowable stress = 6250 psi

$$S_H = \frac{f M_o}{L g_1^2 B} = \frac{3.6(2190)}{.714(.526)^2(13.5)} = 2960 \text{ psi} < 1.5 (6250) \quad \underline{\text{OK}}$$

$$S_R = \frac{(1.33 t_e + 1) M_o}{L t^2 B} = \frac{[(1.33)(.5)(.491) + 1]2190}{.714(.5)^2(13.5)} = 1200 \text{ psi} < 6250 \quad \underline{\text{OK}}$$

$$S_T = \frac{Y M_o}{t^2 B} - Z S_R = \frac{10.75(2190)}{(.5)^2(13.5)} - 5.55(1200) = 307 \text{ psi} < 6250 \quad \underline{\text{OK}}$$

Operating conditions: ASME allowable stress = 5840 psi

$$S_H = \frac{fM_o}{Lg_1^2 B} = \frac{3.6 (1501)}{0.714(0.526)^2 (13.5)} = 2020 \text{ psi} < 1.5 (5840) \quad \underline{\text{OK}}$$

$$S_R = \frac{(1.33 t_e + 1)M_o}{Lt^2 B} = \frac{[(1.33)(0.5)(0.491) + 1] 1501}{0.714 (0.5)^2 (13.5)} = 826 \text{ psi} < 5840 \quad \underline{\text{OK}}$$

$$S_T = \frac{YM_o}{t^2 B} - ZS_R = \frac{10.75 (1501)}{(0.5)^2 (13.5)} - 5.55 (826) = 200 \text{ psi} < 5840 \quad \underline{\text{OK}}$$

4. Vibration

The stainless steel and aluminum containers have been shipped for many years without vibration damage. The addition of the insulation and steel drum provides additional protection. Thus it is concluded that normal vibration will not damage the package.

5. Water Spray

A water spray will not affect the materials in this package.

6. Free Drop

The package has been dropped 30 ft without significant damage as discussed in Addendum 3 and would obviously pass the 4 ft drop.

7. Corner Drop

Not required for steel jacketed packages.

8. Penetration

A 13 lb 1-1/4 in. diameter rod was dropped on end four feet on the weakest areas of the drum. Maximum deflection of the container was 1/4 inch with no damage to the "Celotex" insulation.

9. Compression

An empty drum was uniformly loaded to 1700 lb (more than five times normal package weight) in the manner required in Annex 1 of AEC Appendix 0529 without visible damage or deformation.

ADDENDUM 3

Hypothetical Accident Conditions

Under accident conditions, no more than 10 curies of tritium gas may be released as stated in AECM 0529, F,1,(b)(2).

1. Free Drop, Puncture, and Thermal

A complete package was dropped on a flat surface and on a piston, then heated in a furnace, in the manner prescribed by AECM 0529. Two separate tests were performed. The appearance of the package at various stages during the first test is shown in figures 8 through 12 and during the second test in figures 13 through 16. The package was not significantly damaged from the drops in either test. Some installation damage was caused by smoldering near vent holes after the thermal tests, but the present design shown in figure 1 prevents this by the use of a noncombustible insulation in the vicinity of the three vent holes (these holes are provided to prevent drum damage by internal gas pressure during a fire). Before the tests, the primary container was pressurized to about 29.4 psia. Following the test, no pressure had been lost and there was no apparent damage to the container valve. During the thermal tests, the surface temperature of the aluminum secondary container was continuously measured. Maximum temperature at various points in the package was determined from the condition of pellets of known melting points. The temperature rise in the furnace test is low enough that tritium permeation and leakage are less than the 10 curie limit.

A. Furnace Test

A large annealing furnace was used for thermal tests on full-scale packages. After the furnace was raised to 1475°F, the package was inserted for 30 minutes, then removed for cooling. Using the first test as an example, furnace and package temperatures are shown in figures 17 and 18. The package thermocouple measured the temperature of the aluminum vessel just inside the insulation. The package tested contained no radioactive material and the initial temperature of the primary container was about 24°C. The

maximum temperature reached from the fire was 87°C (189°F), a rise of 63°C. The smoldering in the insulation began noticeably slowing the temperature decline after about 250 minutes, eventually causing it to level at an abnormally high value. However, extrapolation of the initial part of the decline, shown by the dashed line, produces a curve similar to what would be obtained without smoldering and allows an approximation of the time at elevated temperature for tritium permeation calculation.

B. Temperature Calculations

The maximum temperature of a loaded primary container in a fire is less than the sum of the following:

1. Calculated temperature of the aluminum vessel before the fire.
2. Measured temperature rise of the aluminum vessel during the furnace test (63°C).
3. Calculated temperature difference between the primary and aluminum vessels.
4. Calculated temperature rise of the primary and aluminum vessels caused by adiabatic self-heating while the temperature is elevated from the fire.

The temperature before the fire is calculated on the basis of still ambient air at 30°C without solar radiation. Using values of h_e and h_r as in Addendum 2, and an effective area of 20 ft² for dissipation of heat from the cylindrical surface and one end of the drum, it is found that the outer surface is about 1°C above ambient. For a mean heat transfer area of 12.8 ft² through the "Celotex," an effective thickness of 0.36 ft and a thermal conductivity of 0.030 pcu/(hr)(ft)(°C) (again see Addendum 2), the temperature drop through the "Celotex" is —

$$\frac{12.4 \text{ pcu/hr} \times 0.36 \text{ ft}}{12.8 \text{ ft}^2 \times 0.030 \text{ pcu/(hr)(ft)(°C)}} = 12^\circ\text{C}$$

The temperature drop between the aluminum vessel and the "Celotex" was taken into account in the effective thickness of the "Celotex." Therefore, the calculated temperature of the aluminum vessel is $30 + 1 + 12 = 43^\circ\text{C}$.

The temperature difference between the two inner vessels is calculated in Addendum 2 to be 1.5°C.

Self-heating following a fire is calculated as follows:

(Self-heating time from figure 18) × (tritium decay heat rate)
 ÷ (mass of primary container × specific heat of stainless steel
 + mass of aluminum vessel × specific heat of aluminum) = temperature rise.

$$\frac{(3 \text{ hours})(12.4 \text{ pcu/hr})}{(30.5 \text{ lb steel})[0.12 \text{ pcu/(lb)}(^{\circ}\text{C})] + (47 \text{ lb Al})[0.23 \text{ pcu/(lb)}(^{\circ}\text{C})]} = 3^{\circ}\text{C}$$

The sum of the preceding factors is the maximum primary container temperature following a fire, or about 110°C.

C. Container Pressure

The initial tritium loading pressure will be 24.2 psia at 25°C which will not cause yielding of the container at the fire temperature of about 110°C. This was determined as follows:

As the primary container temperature increases, the internal pressure increases, but the container yield pressure decreases (yield pressure is defined as that which produces a 0.2% permanent strain). For a cylinder, yield pressure is directly proportional to yield strength (yield strength of type 304L SS as a function of temperature is listed in the ASME Boiler and Pressure Vessel Code, section III, 1965 edition, Table N-424). Thus:

$$\frac{P_{110}}{P_{25}} = \frac{S_{110}}{S_{25}}$$

where: P = yield pressure, gage
 S = yield strength

The yield pressure at 25°C was determined experimentally to be 30 psig.

$$\frac{P_{110}}{30} = \frac{20,200}{25,000} \text{ or } P_{110} = 24.2 \text{ psig or } 38.9 \text{ psia}$$

An initial pressure of 24.2 psia at 25°C will be 31.1 psia at 110°C; therefore, the container pressure would not reach the yield pressure during the thermal accident.

D. Tritium Lost

Three slightly different valves are used on the primary containers; the valve shown in figure 7 is typical. Each type was tested for tightness by cycling between 25 and 110°C with the results shown in the following table:

Tempera- tures in Sequence	<u>Tritium Leak Rate, atm cc/sec</u>		
	Valve		
	Fulton 314A	Modified Fulton	Hoke
25°C	1.1×10^{-9}	3.8×10^{-9}	2.3×10^{-9}
110°C	1.1×10^{-9}	2.3×10^{-9}	1.5×10^{-9}
25°C	3.4×10^{-8}	1.5×10^{-9}	3.4×10^{-9}
110°C	2.9×10^{-8}	1.9×10^{-9}	1.9×10^{-9}

At 25°C, leakage from any valve is well below the 7×10^{-8} atm cc/sec limit. At 110°C, or 85°C under normal conditions, leakage is still insignificant, especially when compared to the 10 curie (3.9 cc) loss allowed under accident conditions.

Tritium permeation through the primary container walls at 110°C is calculated as shown in Addendum 2 except for the different value of the diffusivity constant, $D = 6.0 \times 10^{-10}$ cm²/sec. The time that the primary container is at an elevated temperature from the fire is shown in figure 18. For permeation calculations, it will be conservatively assumed that the container would be at the peak temperature of 110°C for 12 hours. The maximum permeation rate during this period would be $<2.9 \times 10^{-10}$ atm cc/sec.

If it is assumed that a container has completed its trip within 30 days following an accident, and the highest valve leak rate found is used, the total tritium released during and following the accident is about 0.2 curie.

E. Smoldering

After the first furnace test, smoldering continued in the insulation for several days, ultimately destroying a large amount of insulation as shown in figures 10 and 11. It was obvious in this and another package tested at the same time, that the smoldering centered on the vent holes in the side of the drum.

The second furnace test demonstrated that three 5/16" diameter vent holes equally spaced placed 1-inch under the rim at the top of the drum would greatly reduce smoldering yet allow escape of gas within the drum. The limited smoldering that did occur after the second test, again centered on the vent holes as shown in figure 15, can be eliminated by using noncombustible insulation near the vents as demonstrated on a third test with a similar package [LP-12]. The noncombustible insulation (figure 2), Johns-Manville Cera Form, will extend into the drum a greater distance than the maximum char depth, 1-1/2 inches, observed on any test. Cera Form is a light weight, refractory-fiber insulation having thermal and chemical stability up to 2100°F.

2. Water Immersion

The water immersion test was not done because water obviously cannot harmfully affect the safety of the package following an accident. In fact, had water been used, it would have stopped smoldering and prevented recognition of this hazard.

References

- [1] Alcoa Structural Handbook, 1960.
- [2] ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, paragraph U623 and Table UNF-23, 1965.
- [3] Standards for Aluminum Mill Products, The Aluminum Association, 1966.
- [4] The Aluminum Data Book, Reynolds Metal Company, 1965.

GENERAL NOTES:

1. WEIGHT 250 POUNDS MAXIMUM.
2. ARRANGEMENT SHOWN ON THIS DRAWING AND REFERENCED DRAWINGS HAS BEEN TESTED AND EVALUATED FOR SHIPMENT IN COMPLIANCE WITH AEC AND DOT REGULATIONS. NO DEVIATIONS ARE ALLOWED WITHOUT APPROPRIATE ANALYSIS.

OUTER SHIPPING CONTAINER LP-50 SPECIFICATION

DRUM, CARBON STEEL PER MILITARY STANDARD MS 63054 WITH THE FOLLOWING EXCEPTIONS:

1. BODY AND COVER TO BE .063 INCH THICK (16 GAGE) MATERIAL.
2. INSIDE HEIGHT TO BE 38.50 ± .12 INCHES (REFERENCE).
3. THREE ROLLING HOOPS REQUIRED EQUIDISTANT.
4. EDGE OF CURL AT TOP OF BODY TO BE SPOT WELDED TO BODY AT 6 INCH MAXIMUM INTERVALS.
5. THREE 5/16 INCH DIAMETER HOLES DRILLED 1 INCH BELOW TOP OF CURL OF BODY APPROXIMATELY 120° APART, EACH HOLE TO BE COVERED ON BOTH SIDES WITH LEAD TAPE OF MINIMUM THICKNESS OF .008 INCH.
6. LOCKING RING TO HAVE DROP FORGED LUGS. LUGS TO BE DRILLED WITH GOOD ALIGNMENT FOR 3/8 INCH BOLT. LUGS TO BE DRILLED 7/8 INCH DIAMETER, APPROXIMATELY 3/8 INCH ABOVE EDGE OF BOLT HOLES FOR SEAL WIRE. LENGTH OF LOCKING RING TO ALLOW 1/2 MINIMUM TO 3/4 MAXIMUM END SEPARATION WHEN COMPLETELY CLOSED WITHOUT GASKET.
7. LOCKING BOLT AND NUT TO BE 3/8 - 16 UNC HEX ZINC OR CADMIUM PLATED. BOLT 4 INCHES LONG WITH THREADS 2 3/4 INCHES LONG MINIMUM.
8. NO GASKET ALLOWED.
9. PAINT BODY, COVER, AND LOCKING RING AS FOLLOWS:
 - A. ALL SURFACES MUST BE CLEAN AND FREE OF RUST, OIL, AND OTHER FOREIGN MATERIAL. (SANDBLASTING MAY BE REQUIRED FOR RUSTED MATERIAL.)
 - B. PRIMER - APPLY ONE COAT SHERWIN-WILLIAMS "KROMIK" METAL PRIMER #E41N1 (MAY BE APPLIED OVER SHOP PRIMER) THICKNESS 1.5 MILS OR 300 SQ FT/GAL DRY 18 HOURS.
 - C. FINISH COATS - APPLY TWO COATS SHERWIN-WILLIAMS "KEM LUSTRAL" (KL) ENAMEL MIXED TO MATCH FEDERAL STANDARD 595 COLOR CHIP NUMBER 34087. # THICKNESS 2 MILS/COAT OR 250 SQ FT/GAL/COAT. MINIMUM RECOAT DRYING TIME - 16 HOURS. MINIMUM DRYING TIME FOR HANDLING - 24 HOURS.

SHERWIN-WILLIAMS NUMBER	PERCENT VOLUME
F 65B2	40
F 65Y2	20
D 64T1	30
F 65W3	10

* APPROXIMATE MIXING PROPORTIONS ARE ABOVE.

FIGURE 1. LP-50 SHIPPING CONTAINER PACKAGING - ASSEMBLY (Du Pont dwg S5-2-5733)

FIGURE 2. LP-50 SHIPPING CONTAINER PACKAGING - INSULATION (Du Pont dwg S5-2-5734)

GENERAL NOTES

1. Inside surface of container must be free of grease, oxide, dirt and other foreign matter. Pickling recommended as follows: immerse in bath composed of 10-15% hydrofluoric acid (by volume) for 10-15 minutes at a temperature of 120°-140°F. Thoroughly rinse in water and dry.
2. Maximum leakage of container under vacuum shall be not more than 0.1 micron cubic foot per hour.
3. Container shall be annealed in cracked natural gas at 1800°-2100°F. A bright stainless steel pickling operation to follow firing.
4. Castings shall be smooth and free of air holes.
5. All welds to be made with 1/16-diameter type ER 308L SS rod using inert gas arc.
6. Flow helium through can while welding.
7. Parts S5-2-187B and S5-2-187E to be impregnated with "Mogul Cast Seal" in accordance with spec. AN-1-36 to ensure leak-tightness. The parts are to be tested by submersion in water with 20-psig air pressure within the container.

		11	3	1/4-28 NF jam nut, zinc or cad plated	Std
		10	3	1/4-20 NC x 3/4 soc hd capscr, zinc or cad plated	Std
		9	3	1/4-28 NF x 2-1/2 hex hd capscr, zinc or cad plated	Std
		8	1	Hoke valve No. 450 comm	Std
S4-2-147		7	1	Vacuum tank valve	
		6	1	O-ring-linear No. 1820-84 comm	Std
		5	4	1/4-20 NC x 1 hex hd capscr, zinc or cad plated	Std
		4	8	1/4 flat washer, zinc or cad plated	Std
		3	8	1/4 lock washer, zinc or cad plated	Std
		2	4	1/4-20 NC x 1-1/8 hex hd capscr, zinc or cad plated	Std
		1	1	O-ring-linear No. 1820-74 comm	Std
S5-2-187E			1	Container-bucket cover, made from 485-C-02R	
S5-2-186D	485-A-18		3	Spring, zinc or cad plated	
S5-2-186C	485-B-17		2	Handle, made from 485-C-06R	
S5-2-186A	485-B-16		3	Bracket, made from 485-B-05R	
S5-2-186B	485-B-15		1	Retaining ring, made from 485-B-04R	
S5-2-187B	485-C-14		1	Container bucket, made from 485-C-03R	
S5-2-187A	485-C-13		1	Container assembly	
	485-B-12		1	Fitting, see 485-C-13	
	485-B-11		1	Head top, see 485-C-13	
S5-2-187C	485-A-10		1	Plug receptor	
S5-2-187F	485-A-09		1	Gasket washer	
S5-2-187D	485-A-08		1	Compression gasket	
S5-2-186E	485-A-07		1	Compressor plug	
PART NO.	DRAWING NO.	DEPT NO.	NO. REQD	DESCRIPTION	MAT'L

FIGURE 4. FLAT-TYPE SECONDARY CONTAINER
(Redrawn from Research Welding & Engg Co. dwg 485-D-01)

MATERIAL	REQD	MATL SIZE	PART NO.	PART NAME	PART & DWG NO.	SCALE
Al alloy #556 T6	1			UPPER RING	55-2-186A	6" x 1" O

MATERIAL	REQD	MATL SIZE	PART NO.	PART NAME	PART & DWG NO.	SCALE
Al alloy #556	1	As shown		Returning Ring	55-2-186B	6" x 1" O

GENERAL NOTES

- Inside surface of container must be free of grease, oxide, dirt and other foreign matter.
- Maximum leakage of container under vacuum shall be not more than 0.1 micron cubic foot per hour.
- Castings shall be smooth and free of air holes.
- All welds except the edge weld of items #3 & 4 on 55-2-187-A to be made with 5/16 inch Dia Type 308-L SST rod using Helarc.
- Flow Helium thru can while welding.
- Parts #2 & #7 to be impregnated with 'Mogul Cast Seal' in accordance with spec (MIL STD 278) to insure leak tightness. The parts are to be tested by submersion in water with 80 psig air pressure within the container.
- Epoxy resin (A B with activator 'A') to be used as a thread sealant on the valve threads between item 12 and 7.
- TORQUE ITEMS 5 TO 20²¹ IN-LB.

#2 DRILL 1/16" HOLE NEAR END OF INSIDE RING
#7 DRILL 1/16" HOLE NEAR END OF TUBE OF THREE BOLTS

ITEM	DESCRIPTION	QTY
21	Compl	4
20	Compl	1
19	Compl	6
18	55-2-186B	1
17	5	1
16	55-2-186F	4
15	55-2-186A	1
14	Compl	3
13	55-2-186E	1
12	Compl	1
11	55-2-187-C	1
10	55-2-187D	1
9	55-2-187F	1
8	55-2-187E	1
7	55-2-187B	1
6	Compl	1
5	Compl	1
4	55-2-186C	2
3	Compl	1
2	55-2-187B	1
1	55-2-187A	1
55-2-186A	DESCRIPTION

NOTE
All surfaces are as cast except as shown

TOLERANCES UNLESS OTHERWISE SPECIFIED	MATERIAL	REQD	MATL SIZE	PART NO.	PART NAME	PART & DWG NO.	SCALE
FRACT 1/16" ANG 1/2" DEC 1/16" FIN 1/16"	Al alloy #556	2			Handle Bracket	55-2-186C	6" x 1" O

MATERIAL	REQD	MATL SIZE	PART NO.	PART NAME	PART & DWG NO.	SCALE
304 SST	1	L 1" x 1" x 1/4"		Handle Bracket	55-2-186F	6" x 1" O

MATERIAL	REQD	MATL SIZE	PART NO.	PART NAME	PART & DWG NO.	SCALE
Brass	1	1/8" Hex stock 1/2"		Compressor Plug	55-2-186D	6" x 1" O

FIGURE 5. SECONDARY CONTAINER - ASSEMBLY & DETAILS (Du Pont dwg 55-2-186)

ITEM (4)
Scale 12" = 1'0"

4	3MSSST	/		3" O x 1/2" Hk
3	3MSSST	/		As shown
2	3MSSST	/		4 1/2" x 6 x 078
1	3MSSST	/		As shown
ITEM PART L		RIGID PER UNIT		DESCRIPTION OR MATERIAL SIZE
PART NAME				PART NUMBER
Centimeter				SCALE
				0" = 1/16"

TOLERANCES UNLESS	MATERIAL	REQD	MATL SIZE PATT NO	PART NAME	PART & DWG NO	SCALE
FRACT $\frac{1}{16}$ ANG DEC $\frac{0}{10}$ FIN $\frac{1}{16}$	Al alloy #356	1	As shown	Container Buckel	68-2-187B	6 1/4

MATERIAL	REQD	MATL SIZE	PART. NO	PART NAME	PART & DWG NO	SCALE
Brass	1	1 1/2" Max Stock, 1 1/2" ty		Plug Receptor	35-2-187C	12"=1'-1"

MATERIAL	REQD	MATL SIZE-PATTERN	PART NAME	PART # DWG NO	SCALE
Neoprene	1	As shown	Compressor Gasket	38-2-107D	1/8" = 1'

DETAIL (Z)
Scale 12" = 1'-0"

2	A/AI	3	Stud
1	G061 Tg	1	Cover
Read Per Pa 1		DESCRIPTION OR MATERIAL SIZE	
NAME		ReCD	PART & DWG NO
SCALE			
BUCKET COVER WELDMENT		1	56-2-187 E
			6" 1/0"

MATERIAL	REQD	MATL SIZE - PATT NO	PART NAME	PART QTY (ENG NO)	SCALE
304L SST	1	As shown	Cooled Water	35-W-107F	12 1/2"

FIGURE 7. PRIMARY-CONTAINER VALVE (Du Pont dwg S5-2-147)

FIGURE 8. FIRST FIRE TEST - EFFECT OF 30-FOOT DROP ON SIDE

FIGURE 9. FIRST FIRE TEST - EFFECT OF 40-INCH DROP ON 6-INCH PISTON

FIGURE 10. FIRST FIRE TEST - EFFECT OF SMOLDERING IN AREA OF VENT HOLES

FIGURE 11. FIRST FIRE TEST - UNBURNED "CELOTEX" AWAY FROM VENTS

FIGURE 12. FIRST FIRE TEST - EFFECT OF SMOLDERING ON BOTTOM "CELOTEX" DISK NEAR VENT

FIGURE 13. SECOND FIRE TEST - EFFECT OF 30-FOOT DROP ON END OF DRUM AND OF PISTON DROP

FIGURE 14. SECOND FIRE TEST - VIEW
IN FURNACE DURING TEST
(Tritium Container on Left)

FIGURE 15. SECOND FIRE TEST - EFFECT
OF SMOLDERING NEAR VENTS

FIGURE 16. SECOND FIRE TEST - SHOWING GOOD CONDITIONS OF
"CELOTEX" BELOW VENTS

FIGURE 17. FIRE TEST TEMPERATURE

FIGURE 18. ALUMINUM VESSEL TEST TEMPERATURE

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 RADIOACTIVE AND FISSILE MATERIALS

0529-01 POLICY

Fissile materials 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 standards for the packaging of fissile materials or large quantities of radioactive materials for transportation from facilities not subject to 10 CFR 71, and to establish responsibilities for issuing AEC letters of approval for such packages.

0529-03 RESPONSIBILITIES AND AUTHORITIES

031 Directors, Headquarters Divisions, provide guidance, instructions, standards, and criteria as described in chapter 0101-053b., consistent with this chapter, to assure the safe packaging of fissile and 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.

032 Managers of Field Offices, Space Nuclear Propulsion Office, and the Directors, Divisions of Headquarters Services, Naval Reactors, and Technical Information, consistent with guidance, instructions, standards, and criteria issued pursuant to 031, above:

- a. grant AEC approval for packages to be used for the transportation of fissile materials or large quantities of radioactive materials which meet the standards contained in appendix 0529.

- b. establish standards and grant AEC approval for packages which are shipped under a "National Security" exemption provided to the AEC by any Federal transportation regulatory agency.

- c. grant such exemptions from the standards set forth in appendix 0529 as they determine will not endanger life or property or the common defense and security, and within 30 days after granting an exemption, provide the Director, Division of Operational Safety, a detailed report of the reasons for granting it.

- d. conduct annual appraisals of contractor operations to assure compliance with the requirements of this chapter.

(NOTE: Contractors shall not be permitted to exercise any of the above authorities.)

033 The Manager, Albuquerque Operations Office, in addition to the responsibilities and authorities assigned in 032, above, is authorized to establish safety standards for, and to transport, atomic weapons. This authority is not delegated to any other field office manager.

034 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, radioactive and fissile materials for transportation, and renders interpretations of this chapter.
- b. provides a central point of coordination with the Director of Regulation for developing and revising health and safety codes, regulations, and guides pertaining to safety in the transportation of radioactive and fissile materials

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which are intended for use in the AEC Regulatory program or by other Federal agencies.

- c. conducts periodic appraisals to determine the adequacy of the implementation of this chapter.

0529-04 DEFINITIONS

041 AEC contractor, for the purposes of this chapter, means a prime contractor or subcontractor of the Atomic Energy Commission who introduces radioactive and/or fissile material into commerce and 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 Offices, Field Offices, and AEC contractors.

052 Coverage. This chapter and its appendix cover AEC offices and AEC contractors responsible for the preparation of fissile materials and other radioactive materials for shipment outside the boundaries of AEC-controlled sites by common, contract, or private carriers, including Government vehicles.

053 Federal Regulations. Each shipment of fissile materials and other radioactive materials shall be in compliance with the safety regulations of the Department of Transportation (DOT) or the Post Office Department, depending on the mode of transportation, when offered to the carrier.

054 International Atomic Energy Agency Regulations. Each shipment of fissile materials 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, Part C, "Requirements for Packaging and for Delivery of Packages to Transport," must be met to be in compliance with this chapter.

055 Package Standards for Fissile and/or Large Quantities of Radioactive Materials:

- a. Packages which have a DOT permit are deemed to meet the standards of this chapter and need not be issued a new AEC letter of ap-

proval. The original DOT permit shall be revalidated with DOT when used by subsequent shippers.

- b. DOT specification containers are considered to meet the standards of this chapter, and no specific AEC approval is required for their use.

- c. Atomic weapons shall be packaged and transported in accordance with the standards issued by the Manager, Albuquerque Operations Office.

- d. Packages which are shipped in the interest of "National Security" shall be in compliance with the standards established by the responsible field office manager.

- e. All other packages for fissile materials and large quantities of radioactive materials shall be designed, constructed, and used in accordance with the standards contained in the attached appendix. Upon determination that a design does meet the standards, an AEC letter of approval shall be issued to the contractor. A copy of each AEC letter of approval shall be forwarded to the Division of Construction, Headquarters.

In making application to the DOT for a special permit for a package, the contractor shall provide the DOT with a copy of the AEC letter of approval for the package.

Where an AEC office is the actual shipper, rather than a contractor, appropriate internal procedures shall be established by the responsible field office manager to assure compliance with the standards contained in the attached appendix.

056 Existing Packaging. An existing packaging for fissile materials and/or large quantities of radioactive materials, must meet the standards of this chapter. However, loss of shielding resulting from subjecting the packaging to the "Puncture Test" followed by the "Thermal Test" will not be considered cause for disqualifying an existing packaging that otherwise meets the standards of this chapter.

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SAFETY STANDARDS FOR THE PACKAGING
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057 References

a. Federal Regulations

49 CFR 171-178, DOT Regulations

14 CFR 103, DOT Regulations

39 CFR 124-125, Post Office Regulations

b. Chapter 0560, "AEC Atomic
Weapon Safety Program."

c. Chapter 2401, "Physical Protection of Classified Matter and Information," for security guidance.

d. Chapter 5201, "Transportation and Traffic Management," for guidance in general shipping requirements.

e. AEC Directory of Radioactive and Fissile Material Shipping Containers, for container design information.

0529-06 NATIONAL EMERGENCY
APPLICATION

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

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**SAFETY STANDARDS FOR THE PACKAGING
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AEC Appendix 0529

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 United States Post Office.
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 ex-

ternal 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	Transport Group						Special Form
	I	II	III	IV	V	VI-VII	
Radioactivity	20 curies	20 curies	200 curies	200 curies	5,000 curies	50,000 curies	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 concentra-

tion 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

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(2) 0.005 millicuries of Group II radionuclides; or

(3) 0.3 millicuries of Groups III or IV radionuclides.

NOTE: This includes, but is not limited to, materials of low radioactivity concentration such as residues or solution from chemical processing; wastes such as building rubble, metal, wood, and fabric scrap, glassware, paper and cardboard; solid or liquid plant waste, sludges, and ashes.

e. Objects of non-radioactive material 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 millicurie (220,000 disintegrations per minute) per square centimeter of Group I radionuclides or 0.001 millicurie (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, non-fissile 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 is not dissolved or converted into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F or in air at 86° F; or
 - 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 will retain its contents if subjected to the tests prescribed in annex 4, below; and which is constructed of materials which do not melt, sublime, or ignite in air at 1475° F, and do not dissolve or convert into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F. or in air at 86° F.

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

- a. Any radionuclide not specifically listed in one of the groups in annex 3, below, 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, for all groups present, of the ratio 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, except that if a radionuclide "x" has a half-life longer than that of that 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.

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 less than a large quantity of radioactive material, as defined in A.6., above, which may include one of the following:

1. Not more than 15 grams of fissile material; or
2. Thorium, or uranium containing not more than 0.72 percent by weight of fissile material; or
3. Uranium compounds, other than metal, (e.g., UF₄, UO₂, 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

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- 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; or
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; or
 - b. 800 grams of uranium-235, provided that the atomic ratio of hydrogen to fissile material is 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; or
 - c. 500 grams of uranium-233 and uranium-235, provided that the atomic ratio of hydrogen to fissile material is greater than 5200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content; or
 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.

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
 - a. If there is a system of lifting devices which is a structural part of the package, the system shall be capable of supporting 3 times the weight of the loaded

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 3 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 package 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 package shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the package.
4. Tie-down Devices
- a. If there is a system of tie-down devices which is a structural part of the package, the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.
 - b. If there is a structural part of the package 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.

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- c. Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this section A.

B. Structural Standards for Large Quantity Packaging

Packaging used to ship a large quantity of radioactive material, as defined in I, A.6., 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 ends 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 the 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; and
- 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, and
 - 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

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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 a large quantity of radioactive material, as defined in I, A.6., 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 increase 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; and
- 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 so designed and constructed and its contents so

limited that under normal conditions of transport, specified in annex 1, below, 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; and
- 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 on which nuclear safety is assessed;
- (2) reduction by more than 5 percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging; or
- (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 a large quantity of radioactive material as defined in I., A. 6., above, shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in annex 1, below, 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 a large quantity of radioactive material, as defined in I, A.6., above,

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or the shipment of fissile material when the package will contain more than .001 curie of Group I radionuclides, .05 curie of Group II radionuclides, 3 curies of Group III radionuclides, 20 curies of Group IV or Group V radionuclides, or radionuclides in special form, or 1000 curies of Group VI or Group VII radionuclides shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed 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 3 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 I, A.7., above, and is transported on a motor vehicle, railroad car, aircraft, inland water craft, 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 hypothetical accident conditions specified in annex 2, below,

as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed 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; and
- 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,

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the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together; and

- 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; and
2. two hundred and fifty such packages would be subcritical in any arrangement, if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed 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; and

- b. twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, with close reflection by water on all sides of the array 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. 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 of 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 Fissile Class III shipment shall be so designed and constructed and its contents so limited, and the number of packages in a Fissile Class III shipment shall be 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; and
2. the shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, with close reflection by water on all sides of the array and with the packages in the 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

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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.

III. 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; and
 - 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 a large 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 a large quantity of radioactive material 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 of this appendix, including determinations that:

1. the packaging has not been significantly damaged.
2. any moderators and non-fissile 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 II, E.1.d., above.

E. Records

The shipper shall maintain for a period of at least 2 years after its generation a record of each shipment of fissile material and of a large quantity of radioactive material, as defined in I, A.6., above, in a single package, showing where applicable:

1. identification of the packaging by model number;

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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;
6. date of the shipment;
7. for Fissile Class III, any special controls exercised;
8. name and address of the transferee;
9. address to which the shipment was made; and
10. results of the determinations required by C. and D., above.

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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 1 1/2 and 2 1/2 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.
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 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.
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.

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

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

<u>Element*</u>	<u>Radionuclides***</u>	<u>Group</u>	<u>Element*</u>	<u>Radionuclides***</u>	<u>Group</u>
Actinium (89)	Ac 227	I	Cesium (55)	Cs 131	IV
	Ac 228	I		Cs 134 m	III
				Cs 134	III
Americium (95)	Am 241	I		Cs 135	IV
	Am 243	I		Cs 136	IV
				Cs 137	III
Antimony (51)	Sb 122	IV	Chlorine (17)	Cl 36	III
	Sb 124	III		Cl 38	IV
	Sb 125	III	Chromium (24)	Cr 51	IV
Argon (18)	Ar 37	VI	Cobalt (27)	Co 56	III
	Ar 41	II		Co 57	IV
	**Ar 41 (Uncompressed)	V		Co 58 m	IV
				Co 58	IV
Arsenic (33)	As 73	IV		Co 60	III
	As 74	IV	Copper (29)	Cu 64	IV
	As 76	IV	Curium (96)	Cm 242	I
	As 77	IV		Cm 243	I
Astatine (85)	At 211	III		Cm 244	I
Barium (56)	Ba 131	IV		Cm 245	I
	Ba 133	II		Cm 246	I
	Ba 140	III	Dysprosium (66)	Dy 154	III
Berkelium (97)	Bk 249	I		Dy 165	IV
				Dy 166	IV
Beryllium (4)	Be 7	IV	Erbium (68)	Er 169	IV
				Er 171	IV
Bismuth (83)	Bi 206	IV	Europium (63)	Eu 150	III
	Bi 207	III		Eu 152 m	IV
	Bi 210	II		Eu 152	III
	Bi 212	III		Eu 154	II
Bromine (35)	Br 82	IV		Eu 155	IV
Cadmium (48)	Cd 109	IV	Fluorine (9)	F 18	IV
	Cd 115 m	III	Gadolinium (64)	Gd 153	IV
	Cd 115	IV		Gd 159	IV
Calcium (20)	Ca 45	IV	Gallium (31)	Ga 67	III
	Ca 47	IV		Ga 72	IV
Californium (98)	Cf 249	I	Germanium (32)	Ge 71	IV
	Cf 250	I			
	Cf 252	I	Gold (79)	Au 193	III
Carbon (6)	C 14	IV		Au 194	III
				Au 195	III
Cerium (58)	Ce 141	IV		Au 196	IV
	Ce 143	IV		Au 198	IV
	Ce 144	III		Au 199	IV

See footnotes at end of table.

Approved: February 15, 1969

TRANSPORT GROUPING OF RADIONUCLIDES--Continued

<u>Element*</u>	<u>Radionuclide***</u>	<u>Group</u>	<u>Element*</u>	<u>Radionuclide***</u>	<u>Group</u>
Hafnium (72)	Hf 181	IV	Molybdenum (42)	Mo 99	IV
Holmium (67)	Ho 166	IV	Neodymium (60)	Nd 147	IV
Hydrogen (1)	H 3 (see tritium)			Nd 149	IV
Indium (49)	In 113 m	IV	Neptunium (93)	Np 237	I
	In 114 m	III		Np 239	I
	In 115 m	IV	Nickel (28)	Ni 56	III
	In 115	IV		Ni 59	IV
				Ni 63	IV
				Ni 65	IV
Iodine (53)	I 124	III	Niobium (41)	Nb 93 m	IV
	I 125	III		Nb 95	IV
	I 126	III		Nb 97	IV
	I 129	III			
	I 131	III	Osmium (76)	Os 185	IV
	I 132	IV		Os 191 m	IV
	I 133	III		Os 191	IV
	I 134	IV		Os 193	IV
	I 135	IV			
Iridium (77)	Ir 190	IV	Palladium (46)	Pd 103	IV
	Ir 192	III		Pd 109	IV
	Ir 194	IV	Phosphorus (15)	P 32	IV
Iron (26)	Fe 55	IV	Platinum (78)	Pt 191	IV
	Fe 59	IV		Pt 193	IV
Krypton (36)	Kr 85 m	III		Pt 193 m	IV
	** Kr 85 m (uncompressed)	V		Pt 197 m	IV
	Kr 85	III		Pt 197	IV
	** Kr 85 (uncompressed)	VI	Plutonium (94)	Pu 238 (F)	I
	Kr 87	II		Pu 239 (F)	I
	** Kr 87 (uncompressed)	V		Pu 240	I
Lanthanum (57)	La 140	IV		Pu 241 (F)	I
				Pu 242	I
Lead (82)	Pb 203	IV	Polonium (84)	Po 210	I
	Pb 210	II			
	Pb 212	II	Potassium (19)	K 42	IV
Lutetium (71)	Lu 172	III		K 43	III
	Lu 177	IV			
Magnesium (12)	Mg 28	III	Praseodymium (59)	Pr 142	IV
Manganese (25)	Mn 52	IV		Pr 143	IV
	Mn 54	IV	Promethium (61)	Pm 147	IV
	Mn 56	IV		Pm 149	IV
Mercury (80)	Hg 197 m	IV	Protactinium (91)	Pa 230	I
	Hg 197	IV		Pa 231	I
	Hg 203	IV		Pa 233	II
Mixed Fission Products MFP		II			

See footnotes at end of table.

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SAFETY STANDARDS FOR THE PACKAGING
OF RADIOACTIVE AND FISSILE MATERIALS

AEC Appendix 0529
Annex 3

TRANSPORT GROUPING OF RADIONUCLIDES--Continued

<u>Element*</u>	<u>Radionuclide***</u>	<u>Group</u>	<u>Element*</u>	<u>Radionuclide***</u>	<u>Group</u>
Radium (88)	Ra 223	II	Tantalum (73)	Ta 182	III
	Ra 224	II			
	Ra 226	I	Technetium (43)	Tc 96 m	IV
	Ra 228	I		Tc 96	IV
Radon (86)	Rn 220	IV		Tc 97 m	IV
	Rn 222	II		Tc 97	IV
Rhenium (75)	Re 183	IV		Tc 99 m	IV
	Re 186	IV		Tc 99	IV
	Re 187	IV	Tellurium (52)	Te 125 m	IV
	Re 188	IV		Te 127 m	IV
	Re Natural	IV		Te 127	IV
Rhodium (45)	Rh 103 m	IV		Te 129 m	III
	Rh 105	IV		Te 129	IV
Rubidium (37)	Rb 86	IV	Terbium (65)	Te 131 m	III
	Rb 87	IV		Te 132	IV
	Rb Natural	IV			
Ruthenium (44)	Ru 97	IV		Tb 160	III
	Ru 103	IV	Thallium (81)	Tl 200	IV
	Ru 105	IV		Tl 201	IV
	Ru 106	III		Tl 202	IV
Samarium (62)	Sm 145	III		Tl 204	III
	Sm 147	III	Thorium (90)	Th 227	II
	Sm 151	IV		Th 228	I
	Sm 153	IV		Th 230	I
Scandium (21)	Sc 46	III		Th 231	I
	Sc 47	IV		Th 232	III
	Sc 48	IV		Th 234	II
Selenium (34)	Se 75	IV		Th Natural	III
Silicon (14)	Si 31	IV	Thulium (69)	Tm 168	III
				Tm 170	III
Silver (47)	Ag 105	IV		Tm 171	IV
	Ag 110 m	III	Tin (50)	Sn 113	IV
	Ag 111	IV		Sn 117	III
Sodium (11)	Na 22	III		Sn 121	III
	Na 24	IV		Sn 125	IV
Strontium (38)	Sr 85 m	IV	Tritium (1)	H 3	IV
	Sr 85	IV		H 3 (as gas, as luminous paint or absorbed on solid material)	VII
	Sr 89	III	Tungsten (74)	W 181	IV
	Sr 90	II		W 185	IV
	Sr 91	III		W 187	IV
	Sr 92	IV			
Sulphur (16)	S 35	IV			

See footnotes at end of table.

Approved: February 15, 1969

TRANSPORT GROUPING OF RADIONUCLIDES--Continued

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

* Atomic Number shown in parentheses.

** Uncompressed means at a pressure not exceeding one atmosphere.

*** Atomic weight shown after the radionuclide symbol.

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 into 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.

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