PORTIONS
OF THIS
DOCUMENT
ARE
ILLEGIBLE

2
23-80
p112
DR. 1370

ORNL-5147/R1

ORNL

MASTER

OAK
RIDGE
NATIONAL
LABORATORY

**Safety Analysis Report for
Packaging (SARP) of the
Oak Ridge National Laboratory
TRU Curium Shipping Container**

W. D. Box
B. B. Klima
R. D. Seagren
L. B. Shappert
G. A. Aramayo

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

SAFETY ANALYSIS REPORT FOR PACKAGING (SARP) OF THE
OAK RIDGE NATIONAL LABORATORY
TRU CURIUM SHIPPING CONTAINER

W. D. Box
B. B. Klima*
R. D. Seagren
L. B. Shappert
G. A. Aramayo**

*Retired. Present address: Roane State Community College, Harriman, Tennessee.

**UCC-ND Engineering.

Date Published: June 1980

DISCLAIMER

This book and frequent as an account of work sponsored by an agency of the United States Government
neither the United States Government nor any agency thereof, nor any of their employees, makes any
warranty, express or implied, or assumes any legal liability or responsibility for the accuracy or
completeness or usefulness of any information, apparatus, product, or process disclosed, or
represents that its use would not infringe privately owned rights. Reference herein to any specific
commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does
not necessarily constitute or imply its endorsement, recommendation, or favor by the United
States Government or any agency thereof. The views and opinions of authors expressed herein do not
necessarily state or reflect those of the United States Government or any agency thereof.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

TABLE OF CONTENTS

	<i>Page</i>
ABSTRACT	1
1. INTRODUCTION	1
1.1 Description of TRU Curium Shipping Container	2
1.2 Contents of Package	5
2. STRUCTURAL EVALUATION	
2.1 Mechanical Properties of Materials	5
2.2 General Standards for All Packages	5
2.2.1 Reactions between materials of construction and package contents	5
2.2.2 Closure	7
2.2.3 Lifting devices	7
2.2.4 Tie-down devices	16
2.3 Standards for Type B and Large-Quantity Packaging	25
2.3.1 Load resistance	26
2.3.2 External pressure	27
3. COMPLIANCE WITH STANDARDS FOR NORMAL CONDITIONS OF TRANSPORT	28
3.1 Heat	28
3.2 Cold	30
3.3 Pressure	30
3.4 Vibration	30
3.5 Water Spray	30
3.6 Free Drop	31
3.7 Penetration	31
3.8 Compression	31
4. COMPLIANCE WITH STANDARDS FOR HYPOTHETICAL ACCIDENT CONDITIONS	32
4.1 Free Drop	33
4.1.1 Impact on side	33
4.1.2 Impact on top flange	33
4.1.3 Impact on top corner	37
4.2 Puncture	38
4.3 Thermal Evaluation	39
4.3.1 Thermal properties of materials	39
4.3.2 Thermal accident analysis	39
4.4 Water Immersion	41

5. CONTAINMENT	41
5.1 Containment Boundaries	41
5.2 Special-Form Shipments	41
5.3 Containment Requirements for Normal Conditions of Transport	46
5.4 Containment Requirements During the Hypothetical Accident	46
6. CRITICALITY	47
7. SHIELDING EVALUATION	48
8. QUALITY ASSURANCE	48
8.1 Fabrication, Inspection, and Acceptance Tests	48
8.2 Operating Procedures and Routine Inspection	48
8.3 Periodic Maintenance and Inspection	48
9. APPENDIXES	49
9.1 Drawings	51
9.2 Approval Documents	55
9.3 Computer Programs to Calculate Corner Drop Deceleration Forces	71
9.4 Operating and Inspection Procedures	81
10. REFERENCES	91

**SAFETY ANALYSIS REPORT FOR PACKAGING (SARP)
OF THE OAK RIDGE NATIONAL LABORATORY
TRU CURIUM SHIPPING CONTAINER**

W. D. Box, B. B. Klima, R. D. Seagren,
L. B. Shappert, and G. A. Aramayo

ABSTRACT

An analytical evaluation of the Oak Ridge National Laboratory Transuranium (TRU) Curium Shipping Container was made to demonstrate its compliance with the regulations governing offsite shipment of packages containing radioactive material. The evaluation encompassed five primary categories: structural integrity, thermal resistance, radiation shielding, nuclear criticality safety, and quality assurance. The results of the evaluation show that the container complies with the applicable regulations.

I. INTRODUCTION

When a package is to be used in offsite shipment of radioactive or fissile material, it is subject to regulations governing its structural integrity, heat dissipation capabilities, shielding ability, nuclear criticality safety, and quality assurance. The safety standards for the packaging of such material are set forth in the *Code of Federal Regulations*, Title 10, Part 71,¹ and DOE Manual Chapter 0529.² To secure approval for shipment, it must be shown, either by testing or by experimental or computational methods, that the package complies with the regulations. The Oak Ridge National Laboratory (ORNL) TRU Curium Shipping Container was evaluated to determine whether it complies with the applicable regulations. The methods used and the results of the evaluation are reported here.

The TRU Curium Shipping Container is illustrated in Fig. 1.1. Three of the shipping containers that have been fabricated are in service at ORNL (ORNL Shipping Cask Nos. 4S2-209, -210, and -213). The Department of Transportation (DOT) assigned Special Permit Number 5461 to this container. A certificate of compliance (Sect. 9.2) has been issued, and approval of this Safety Analysis Report for Packaging (SARP) by the Department of Energy (DOE) will complete the requirements of the certificate. The IAEA Certificate of Competent Authority is also in Sect. 9.2. The cask is intended to be used to transport isotopes of americium, curium, berkelium, californium, einsteinium, fermium, and plutonium in the form of metal, oxide, chloride, or other salt.

The cask consists of a 30-in.-tall, 29-in.-high cylinder with a 6-in.-diam internal cavity that is 8-in. deep (Fig. 1.1). The shielding consists of approximately 1 in. of lead and 9-3/4-in. of Blackburn limonite concrete. The cask has a bolted-in-place top plug that is protected by a bolted-down cover plate. The cover-plate nuts are secured by a seal lockwire. The TRU Curium Shipping Container weighs 2640 lb. In the normal mode of shipment, the carrier is mounted on a special skid that permits forklift handling. The combined weight of the container and the skid is 2800 lb.

Fig. 1.1 TRU Curium Shipping Container.

Computational procedures were used to evaluate the TRU Curium Shipping Container and to determine that it meets the requirements for offsite transportation of radioactive materials. The results of this analysis, which are presented here, show that the cask complies with the regulations. In addition to the evaluation, this SARP contains operating and inspection procedures.

1.1 Description of TRU Curium Shipping Container

A detailed cross section of the TRU Curium Shipping Container is shown in Fig. 1.2. The outer shell sides and bottom are 3/8-in.-thick 304L stainless steel. The outside diameter of the shell is 29 in., and the height is 30-7/8 in. The top of the outer shell is 1/4-in.-thick 304L stainless steel. The inner cavity shell, which is fabricated from 1/4-in.-thick 304L stainless steel plate, is 8-1/4 in. ID by 19-1/4 in. deep and is recessed from the top by a 1-3/8-in.-deep offset. The inner cavity in which the radioactive or fissile material package is placed for shipment has a diameter of 6 in. and height of 8 in. and is surrounded by 7/8-in.-thick lead contained in a pocket of 1/4-in.-thick stainless steel. The lead was cast in place through two 1-in.-diam pour holes in the bottom of the inner shell. These holes were welded shut after filling was complete. Twelve I-shaped reinforcement rods were welded to the inside of the outer shell. In addition to the I-reinforcement, two cylinders of 6- by 6-in., 10-gage wire mesh

Fig. 1.2 Cross section of TRU Curium Shipping Container (all dimensions are in inches).

reinforcement were used in the body of the concrete. The annulus between the outer and the inner shell was filled with limonite concrete that was added through two 4-in.-diam pour holes located in the bottom of the outer shell. These holes were welded shut after filling was complete.

The inner cavity is closed with a plug of concrete and lead cast in a shell built from 1/4-in.-thick 304L stainless steel plate. The steel shell was first filled with lead to a depth of 1 in. and then filled with limonite concrete. After the limonite concrete had cured, the top plate was welded on the plug.

The gasket that makes a seal between the top flange of the plug and the body is made of 1/16-in.-thick Neoprene. The flange and gasket are held to the body by eight 1/2-in. x 13 NC-2 nuts on studs. The plug is lifted by a 3/8-in.-diam 304L stainless steel bail.

The top flange and bail of the plug are protected by a 1/4-in.-thick 304L stainless steel plate cover that is held to the top of the container by six 1/2-in. x 13 NC-2 nuts on studs. When the plug is secure and the cover is in place, the six nuts are safeguarded from accidental removal by a seal lockwire.

There are four 1/2-in.-thick x 2-1/2-in.-wide x 6-in.-long lifting and tie-down ears welded to the top of the side of the container body. Each ear has two 1-in.-diam holes.

Figure 1.3 shows the carrier mounted on its skid.

ORNL DWG. 70-14610C1

Fig. 1.3 Skid for TRU Curium Shipping Container.

1.2 Contents of the Package

The TRU Curium Shipping Container will be used to transport any isotope of plutonium, americium, curium, berkelium, californium, and fermium in the form of metal, oxide, chloride, or other salt. Any of these isotopes can be alpha or beta emitters, may fission spontaneously, or have a fission cross section. The maximum quantity of $^{239,241}\text{Pu}$, ^{242}Am , $^{243,245,247}\text{Cm}$, and/or ^{252}Cf shipped will be 10 g. The maximum quantity of ^{251}Cf shipped will not exceed 3 g. The remaining isotopes will be limited by heat (500 Btu/hr) or source strength such that the external dose rate will not exceed the levels specified in the DOT regulations. The container, with its contents, is rated Fissile Class 1.

The contents will be singly or doubly encapsulated, as described in Sect. 5, in a welded container or in special form containers which may occasionally be placed within another container for handling purposes. The package may be shipped by any commercial surface transportation system.

2. STRUCTURAL EVALUATION

Three TRU Curium Shipping Containers have been fabricated for use at ORNL. Two were constructed in 1967; the third was constructed in 1970. The package complies with the structural requirements of the regulations (see Sects. 2-4). The calculations, test results, and engineering logic presented in the following sections demonstrate compliance with these performance criteria. The effects of both normal transport and specified accident conditions on the structural integrity of the package are considered.

2.1 Mechanical Properties of Materials

The mechanical properties of 304L stainless steel and limonite concrete are summarized in Table 2.1.

2.2 General Standards for All Packages

The general standards for all packages include an evaluation of the following: (1) the chemical and galvanic reactions between the materials of construction and the intended package contents; (2) the method used for closure; (3) the cask-lifting devices; (4) the lid-lifting devices; and (5) the tie-down devices used in securing the package to the trailer.

2.2.1 *Reactions between materials of construction and package contents*

The container is constructed, as shown in the as-built drawing (see Fig. 1.1 and Sect. 9.1), of type 304L stainless steel, limonite concrete, and lead. No evidence of any significant chemical, galvanic, or other reaction between these materials has been noted; additionally, past experience has not revealed any indication of reactions between these materials of construction and the intended package contents. Even if the contents were shipped in the chloride form, they would be welded into a primary container capable of withstanding the action of chloride and thus present no reaction problem to the cask materials.

Table 2.1. Mechanical properties of 304L stainless steel and limonite concrete

	Symbol	Stainless steel 304L	Limonite concrete
Static properties			
Tensile yield stress, psi	σ_y	30×10^{3a}	
Allowable shear stress, psi	τ_a	15×10^{3b}	
Ultimate shear strength, psi	τ_u	$61,000^a$	
Young's modulus, psi		30×10^{6a}	
Poisson's ratio	ν	0.3^a	
Weight density, lb/in. ³	γ	0.29^c	0.101^d
Thermal expansion coefficient, per °F	α	9.6×10^{-6}	
Dynamic Properties			
Specific energy, in.-lb/in. ³	s min	10×10^4	
	s max	26×10^4	
Yield stress, psi	σ_s	61.2×10^{3e}	

^aInternational Nickel Company, Inc., Mechanical and Physical Properties of Austenitic Chromium-Nickel Stainless Steel at Ambient Temperatures, 1963.

^bTensile yield stress x 50%.

^cL. B. Shappert, Cask Designers Guide, ORNL/NSIC-68 (February 1970).

^dB. B. Klima and L. B. Shappert, The TRU Ten-Ton Californium Shipping Container, ORNL/TM-3505 (November 1971).

^eBased on minimum ratio of yield/ultimate values for bolts as indicated in Table 5.1 and on minimum tensile strength of 95,000 psi, p.55 in D. D. Cannon's Structural Analysis of Shipping Casks, vol. 12, Energy Absorption Characteristics of Stainless Steel Bolts Under Impact Loading, ORNL-1312, vol. 12 (May 1972).

2.2.2 Closure

The inner cavity is sealed with the Neoprene gasketed plug and eight 1/2-in. nuts on studs. The plug is protected by a cover secured by six 1/2-in. nuts on studs. These nuts and studs are manufactured with mating holes so that a seal wire must be broken before the nuts can be removed from the studs. The package can thus be equipped with a positive closure that will prevent inadvertent opening.

2.2.3 Lifting devices

If there is a system of lifting devices that is a structural part of the package, the regulations stipulate that this system must be capable of supporting three times the weight of the loaded package without generating stress in any material of the package in excess of its yield strength. In addition, 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.

Plug-lifting evaluation. The bail on the plug is not strong enough to lift the package; therefore, a cover is provided that prevents this part from being used for that purpose. Use is denied by a lockwire and seal. Analysis of the plug-lifting device, based on three times the weight of the plug, is given below. The plug-lifting mechanism is a bail constructed from a 3/8-in.-diam steel rod shaped like an inverted "U" and welded upside down at each end to the top of the plug.

The stress (S_s) in the lifting bail is determined as follows:

$$S = \frac{3W}{A} = \frac{3(81)}{0.1107} \quad (1)$$
$$= 2194 \text{ lb.-in.}^{-2},$$

where

S = stress as if it were a straight beam, lb/in.²,

W = weight of plug, 81 lb,

A = cross-sectional area of 3/8-in.-diam rod, 0.2208 in.²

The value of S is corrected to account for the curvature in the bail using factors k_o and k_i from R. J. Roark's formulas for curved beams.³

The stress (S_o) on the outside fibers is

$$S_o = k_o S = 0.91 (2194) \quad (2)$$
$$= 1997 \text{ psi } (<30,000 \text{ psi}).$$

where

$k_s = 0.91$ at an R/c value of 8.0,

R = radius of curvature measured to centroid of section.

c = radius of rod.

The stress (S_i) on the inside fibers is

$$\begin{aligned} S_i &= k_s S = 1.10 (2194) \\ &= 2413 \text{ psi } (< 30,000 \text{ psi}), \end{aligned} \quad (3)$$

where

$k_s = 1.10$ at an R/c value of 8.0.

Therefore, the metal of the lifting bail is adequate to lift the plug.

Weld between plug and plug-lifting bail. The nominal thickness of the required weld may be calculated as follows:

$$\begin{aligned} t &= \frac{3W}{L\tau} = \frac{243}{(2.35)(15,000)} \\ &= 0.01 \text{ in. } (< 0.375 \text{ in.}), \end{aligned} \quad (4)$$

where

t = nominal weld thickness, in.,

W = the plug weight, 81 lb,

L = weld length, 2.35 in.,

τ = allowable shear stress, 15,000 psi.

The 3/8-in. weld is thus adequate. Hence, the bail and its weld to the plug are capable of meeting the requirements of supporting three times their weight without generating stresses in excess of the yield stress.

Cask-lifting evaluation. Maximum stresses in the combination lifting and tie-down ears are calculated for the most severe lifting condition. This condition would exist if the cask-skid combination were lifted from only one of the four tie-down devices, as shown in Fig. 2.1. Normally, two of the four are used for lifting purposes, which results in the cask-skid combination being lifted at an angle of about 47° with the vertical. For calculational purposes, it is also assumed that the center of mass is at the geometric center of the cask.

Fig. 2.1 Cask attitude during lifting from one tie-down point.

The lifting tie-down device is shown in Figs. 2.2-2.5. A generalized load may be applied via cables or shackle to either solid shaft that connects the two tie-down ears. These shafts are of the same diameter as the holes in the ears so that the load is distributed uniformly in the loaded portion of the perimeter of the hole. The sum of the distributed uniform load shown in Fig. 2.6 is equal to one-half the load applied at the half point of the connecting 1-in.-diam shaft. The mathematical model of the tie-down, shown in Fig. 2.7, is idealized as a straight beam of length equal to the diameter of the hole and loaded by a uniform load. It is assumed that the boundaries of the beam are constrained.

Summation of the force in the y-direction in Fig. 2.1 gives

$$\sum F_y = 0 \uparrow, \text{ positive direction}; \quad (5)$$

therefore,

$$P = 3W \quad (6)$$

so that the force P' , shown in Fig. 2.7, is equal to

$$P' = \frac{P}{2} = \frac{3W}{2} \quad (7)$$

ORNL DWG. 79-11327

Fig. 2.2 Lifting and tie-down device.

ORN. DWG. 79-11328R

Fig. 2.3 Tie-down device.

ORNL DWG. 79-13245

Fig. 2.5 Tie-down device, Sect. "D-B".

ORNL DWG. 79-11329R

Fig. 2.4 Tie-down device, Sect. "A-A".

ORNL DWG. 79-13218R

Fig. 2.6 Tie-down load model.

ORNL DWG. 79-13247R

$$I = \frac{1}{12} \left(\frac{5}{8} \right) (2)^3 = 0.42 \text{ in.}^4$$

$$A = (2) \left(\frac{5}{8} \right) = 1.25 \text{ in}$$

$$W = \frac{P}{2L}$$

MOMENT DIAGRAM

$$M = \frac{WL^2}{12} = \frac{P'L}{24}$$

Fig. 2.7 Mathematical model of tie-down load.

The maximum bending moment in the ring segment occurs at the edges; the magnitude is equal to

$$M = \frac{P'L}{24} = \frac{2W(1.5)}{2(24)} \quad (8)$$

$$= 263 \text{ in-lb.}$$

The bending stresses for the straight beam are:

$$\sigma_b = \pm \frac{Mc}{I} = \frac{(263)(0.5)}{0.42} \quad (9)$$

$$= 312.5 \text{ psi.}$$

The bending stresses in the corresponding curved beam shown in Fig. 2.6 are equal to

$$\sigma_c = k\sigma_b = k(312.5) \text{ psi.} \quad (10)$$

The factor k takes into consideration the shifting of the neutral axis as well as the parabolic distribution of stresses in the cross section of the curved beam. For the beam under consideration.

$$k = 0.67 \text{ for the tension side, and}$$

$$k = 1.86 \text{ for the compression side.}^4$$

It follows that the stress in the outside fiber is 733 psi and in the inside fiber it is 1969 psi.

The maximum shear strain occurs at the clamped end of the beam. From straight-beam theory, the shear strain in the vicinity of the neutral axis is equal to

$$\tau = \frac{V}{A} \alpha \quad (11)$$

where

$$\alpha = \text{cross section of shear factor.}$$

For a rectangular cross section,

$$\tau = \left(\frac{P'}{2}\right) \frac{1}{A} \left(\frac{3}{2}\right) = \frac{9(2800)}{8(1.69)} \quad (12)$$

$$= 1864 \text{ psi.}$$

where A is the gross cross section at the location of maximum shear. The stresses at the welds of the tie-down to cask interface are calculated on the basis of the free-body diagram shown in Fig. 2.8. From this diagram, it follows that

$$P'' = \frac{3W}{2} \sin 47^\circ = \frac{3(2800)}{2} \sin 47^\circ \quad (13)$$

$$= 3072 \text{ lb.}$$

$$V = \frac{3W}{2} \cos 47^\circ = \frac{3(2800)}{2} \cos 47^\circ \quad (14)$$

$$= 2864 \text{ lb.}$$

$$M = P'' [2.0 + (0.5 \cos 47^\circ)] - V [2.0 + (0.5 \sin 47^\circ)] \quad (15)$$

$$= 3072(2.34) - 2864(2.37) = 401 \text{ in.-lb.}$$

Fig. 2.8 Loads at welds between tie-down and cask body.

Maximum stresses at the weld, assuming the car behaves like a cantilever beam, are given by the expression

$$\sigma = \frac{P}{A} + \frac{Mc}{I} \quad (16)$$

where A is the net area of the weld at the point of minimum area and

$$\begin{aligned} A &= 2[(0.707)(8)(0.5)] \\ &= 5.66 \text{ in}^2. \end{aligned} \quad (17)$$

The parameter I is the *net* second moment of the weld pattern, calculated at the minimum section area of the weld. The gross I is calculated in Fig. 2.9 and is equal to 72.05 in⁴; the net value of I is equal to

$$I = (0.707)(72.05) = 50.94 \text{ in}^4. \quad (18)$$

Fig. 2.9 Moment of inertia diagram for weld pattern.

From Eq. (16), it follows that the tensile stresses at the weld pattern at point A, Fig. 2.8, are:

$$\sigma = \frac{3072}{5.66} + \frac{(401)(4.5)}{50.94} \quad (19)$$

$$= 578 \text{ psi.}$$

The peak shear stress at the weld pattern is equal to

$$\tau = \frac{V}{A} = \frac{3}{2} \left(\frac{2864}{5.66} \right) \quad (20)$$

$$= 759 \text{ psi.}$$

Therefore, it has been shown that the available welds that attach the tie-down device to the cask shell are adequate to support the proposed load equal to three times the combined weight of the cask and skid. It has also been shown that one tie-down device by itself is adequate to support the $3W$ load.

The shear stresses at the pins are calculated as follows:

$$\tau = \frac{V}{A} = \frac{3W}{2A} = \frac{3(2800)}{2(0.7854)} \quad (21)$$

where A is the gross shear area of the pin, 0.7854 in.^2 , and

$$\tau = 5348 \quad (22)$$

This value is also smaller than the allowable shear stress.

2.2.4 Tie-down devices

The regulations require that if there is a system of tie-down devices which is a structural part of the package, this system must be capable of withstanding a static force applied to the center of gravity of the package with (1) a vertical component of two times the weight ($2W$) of the package and its contents, (2) a horizontal component along the direction of travel of ten times the weight ($10W$) of the package and its contents, and (3) a horizontal component in the transverse direction of five times the weight ($5W$) of the package and its contents. This applied load shall not generate stresses in any material of the package in excess of the yield strength of that material. In addition, any tie-down device that is a structural part of the package must be designed so that failure of the device under excessive load will not impair the ability of the package to meet other requirements of the regulations.

The cask is tied down to its skid by four cables that run between the lower trunnion bar (see Fig. 2.2) and the skid. It is attached to the vehicle by four cables that run between the upper trunnion bar and the tie-down points on the bed of the vehicle. The analysis of the tie-down points on the cask is given below.

To demonstrate the adequacy of the tie-downs, it will be demonstrated that: (1) the tie down of the Curium carrier to the skid is adequate, and (2) the tie down of the cask-skid combination to the truck is also adequate.

Evaluation of requirements stated in Sect. 2.2.4. For the general case of any angle θ of the tie-down angle (measured from the vertical, Fig. 2.10), the forward cables go in compressions and therefore do not sustain any load. The stationary potential energy of the system is used to solve for the redundant forces. This is a general analysis for either cask to skid or a combination of cask to skid to vehicle. The only variation is in the numerical values assigned to the variables.

When the cables that undergo slack are removed the system becomes overspecified. This problem is easily solved by superimposing the loads that lie in the horizontal plane to the vertical load case. The results are also given for a general angle θ with the vertical axis.

Let T force be tension in cables

$$\Sigma F_x = 0 \rightarrow \quad (23)$$

$$R_x^1 + R_x^2 - R_x^3 - R_x^4 = 10W.$$

where superscripts denote cable number and subscripts denote component orientation (see Figs. 2.10 and 2.11).

$$\Sigma F_y = 0 \rightarrow \quad (24)$$

$$-R_y^1 + R_y^2 + R_y^3 - R_y^4 = 5W.$$

$$\Sigma F_z = 0 \uparrow \quad (25)$$

$$R^1 + R^2 + R^3 + R^4 = 2W$$

For a typical cable, n , the components of force along the axis system are given by the expressions

$$R_x^n = R_{xy}^n \cos 45^\circ \quad (26)$$

and

$$R_y^n = R_{xy}^n \sin 45^\circ \quad (27)$$

where R_{xy}^n is the resultant force of the cables in the xy plane. In this expression, the angle of 45° is chosen because it represents the angle that is fixed by the physical dimensions of the cask-skid combination.

The relationship that exists between the total resultant load in the typical cable, n , the resultant force in the xy plane (R_{xy}^n), and the angle θ that exists between this total resultant force (R^n) and the vertical axis is given by the expression:

$$R_{xy}^n = R^n \sin \theta \quad (28)$$

ORNL DWG. 78-17798

Fig. 2.10 Schematic of cask tie down.

ORNL DWG. 78-17797

Fig. 2.11 Mathematical model of cask tie downs to vehicle.

therefore, substitution of Eq. (28) into Eq. (27) yields:

$$R_x^n = R_y^n = R^n \cos 45^\circ \sin \theta$$

(29)

where

$n = 1, 2, 3, \text{ or } 4$ for cables 1, 2, 3, or 4.

and

$$R_z^n = R^n \cos \theta \quad (30)$$

is the vertical component of load in the cable due to a total reactive load equal to R^n .
Substitution of Eqs. (29) and (30) in Eq. (24) yields:

$$\begin{aligned} R^1 + R^2 - R^3 - R^4 &= \frac{10W}{\cos 45 \sin \theta} \\ -R^1 + R^2 + R^3 - R^4 &= \frac{5W}{\cos 45 \sin \theta} \\ R^1 + R^2 + R^3 + R^4 &= \frac{2W}{\cos \theta} \end{aligned} \quad (31)$$

If R is the redundant force, Eq. (31) reduces to:

$$\begin{aligned} R^2 - R^3 - R^4 &= \frac{10W}{\cos 45 \sin \theta} - R^1 = F^1 \\ R^2 + R^3 - R^4 &= -\frac{5W}{\cos 45 \sin \theta} + R^1 = F^2 \\ R^2 + R^3 + R^4 &= \frac{2W}{\cos \theta} - R^1 = F^3 \end{aligned} \quad (32)$$

or, in matrix form,

$$\begin{bmatrix} 1 & -1 & -1 \\ 1 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} R^2 \\ R^3 \\ R^4 \end{bmatrix} = \begin{bmatrix} F^1 \\ F^2 \\ F^3 \end{bmatrix} \quad (33)$$

or

$$\begin{bmatrix} R^2 \\ R^3 \\ R^4 \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 \\ 1 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} F^1 \\ F^2 \\ F^3 \end{bmatrix} = \begin{bmatrix} 1/2 & 0 & 1/2 \\ -1/2 & 1/2 & 0 \\ 0 & -1/2 & 1/2 \end{bmatrix} \begin{bmatrix} F^1 \\ F^2 \\ F^3 \end{bmatrix} \quad (34)$$

hence,

$$\begin{aligned} R^2 &= \frac{F^1}{2} + \frac{F^2}{2} = \frac{10W}{2 \cos 45 \sin \theta} + \frac{2W}{2 \cos \theta} - R^1 \\ R^3 &= -\frac{F^1}{2} + \frac{F^2}{2} = -\frac{10W}{2 \cos 45 \sin \theta} + \frac{5W}{2 \cos 45 \sin \theta} + R^1 \\ R^4 &= -\frac{F^2}{2} + \frac{F^3}{2} = -\frac{5W}{2 \cos 45 \sin \theta} + \frac{W}{\cos \theta} - R^1 \end{aligned} \quad (35)$$

The unit load method is used to solve for the unknowns of the system.

The elongations in cables 2, 3, and 4 are computed as follows: elongations $= e = (\text{force})[L/EA] = (F)(K)$, since all the cables have the same length and stiffness characteristics; substitution into Eq. (35) (where F is substituted by R^1 , R^3 , and R^4) yields:

$$\begin{aligned} e_1 &= (K) R^1 \\ e_2 &= (K) R^2 \\ e_3 &= (K) R^3 \\ e_4 &= (K) R^4 \end{aligned} \quad (36)$$

The loads in cables 2, 3, and 4 due to a unit load applied at cable 1 and all other external loads are removed:

$$\begin{aligned} r_1 &= -1 \\ r_2 &= -1 \\ r_3 &= 1 \\ r_4 &= -1 \end{aligned} \quad (37)$$

The reduction in length of the first cable $[e_1 = (R^1)(K)]$ is equal to $\sum e_i r_i$ from Eqs. (35)–(37).

$$\begin{aligned} -R^1 K &= \left[\frac{10W}{2 \cos 45^\circ \sin \theta} + \frac{2W}{\cos \theta} - R^1 \right] (-1) + K \left[-\frac{10W}{2 \cos 45^\circ \sin \theta} + \right. \\ &\quad \left. \frac{5W}{2 \cos 45^\circ \sin \theta} + R^1 \right] (1) + K \left[-\frac{5W}{\cos 45^\circ \cos \theta} + \frac{2W}{\cos \theta} - R^1 \right] (-1) \end{aligned} \quad (38)$$

Solving for R^1 :

$$R^1 = \frac{10W}{4 \cos 45^\circ \sin \theta} - \frac{5W}{4 \cos 45^\circ \sin \theta} + \frac{2W}{4 \cos \theta} = \frac{5W}{4 \cos 45^\circ \sin \theta} + \frac{W}{\cos \theta} \quad (39)$$

where

$\theta = 30^\circ$, and substitution of Eq. (39) into Eq. (35) gives:

$$\begin{aligned} R^1 &= \frac{5W}{4 \cos 45^\circ \sin 30^\circ} + \frac{W}{\cos 30^\circ} = 4.12 W \\ R^2 &= \frac{5W}{\cos 45^\circ \sin 30^\circ} + \frac{W}{\cos 30^\circ} - 4.12 W = 11.18 W \\ R^3 &= -\frac{10W}{2 \cos 45^\circ \sin 30^\circ} + \frac{5W}{2 \cos 45^\circ \sin 30^\circ} + 4.12 W = -2.95 W \\ R^4 &= \frac{5W}{2 \cos 45^\circ \sin 30^\circ} + \frac{W}{\cos 30^\circ} - 4.12 W = -10.04 W \end{aligned} \quad (40)$$

The signs in cables 3 and 4 are reversed, indicating that the assumption made (+ force $\cong$ tension in all cables) is not valid.

Since it has been shown that two of the cables go in compression (a condition not usually realistic in cables), the system will be reduced by the removal of these cables and the loads will be solved in the remaining cables.

If R^3 and R^4 are each equal to zero, the expressions in Eq. (23) reduce to

$$R_x^1 + R_x^2 = 10W \quad (41)$$

and Eqs. (24) and (25) reduce to

$$-R_y^1 + R_y^2 = 5W \quad (42)$$

$$R_z^1 + R_z^2 = 2W$$

The system is overspecified. Equation (42) is decoupled from Eq. (41) and can be solved independently. Operating in Eq. (41), it follows that after substituting expression (29) into (41), these equations become:

$$R_{xy}^1 \cos 45^\circ + R_{xy}^2 \cos 45^\circ = 10W \quad (43)$$

$$-R_{xy}^1 \sin 45^\circ + R_{xy}^2 \sin 45^\circ = 5W$$

or

$$\begin{bmatrix} \cos 45^\circ & \cos 45^\circ \\ -\sin 45^\circ & \sin 45^\circ \end{bmatrix} \begin{bmatrix} R_{xy}^1 \\ R_{xy}^2 \end{bmatrix} = \begin{bmatrix} 10W \\ 5W \end{bmatrix} \quad (44)$$

and

$$\begin{aligned} \begin{bmatrix} R_{xy}^1 \\ R_{xy}^2 \end{bmatrix} &= \begin{bmatrix} \cos 45^\circ & \cos 45^\circ \\ -\sin 45^\circ & \sin 45^\circ \end{bmatrix}^{-1} \begin{bmatrix} 10W \\ 5W \end{bmatrix} \\ &= \frac{1}{2} \begin{bmatrix} \frac{1}{\cos 45^\circ} & -\frac{1}{\sin 45^\circ} \\ \frac{1}{\cos 45^\circ} & \frac{1}{\sin 45^\circ} \end{bmatrix} \begin{bmatrix} 10W \\ 5W \end{bmatrix} \end{aligned} \quad (45)$$

$$R_{xy}^1 = \frac{10W}{2 \cos 45^\circ} - \frac{5W}{2 \sin 45^\circ} = \frac{5W}{2 \cos 45^\circ} \quad (46)$$

$$R_{xy}^2 = \frac{10W}{2 \sin 45^\circ} + \frac{5W}{2 \sin 45^\circ} = \frac{15W}{2 \cos 45^\circ} \quad (47)$$

This results in R_{xy}^1 and R_{xy}^2 in the xy plane for cables 1 and 2 respectively. These reactions, given in terms of the axial load on the cable, become:

$$R = \frac{R_{xy}}{\sin \theta} \quad (48)$$

so that

$$R^1 = \frac{5W}{2 \cos 45^\circ \sin \theta} \quad (49)$$

Similarly,

$$R^2 = \frac{15W}{2 \cos 45^\circ \sin \theta} \quad (50)$$

The vertical load on the cables, from $F_z = 0$, is resolved as follows:

$$R_z^1 + R_z^2 = 2W \quad (51)$$

if it is assumed that the total vertical load is equally resisted by each cable, Eq. (51) becomes

$$R_z^1 = R_z^2 = W; \quad (52)$$

and, from Eq. (30), the components of R^1 and R^2 due to the vertical load only are:

$$R^1 = R^2 = \frac{W}{\cos \theta} \quad (53)$$

The total load on the cables is

$$R^1 = \frac{5W}{2 \cos 45^\circ \sin \theta} + \frac{W}{\cos \theta}$$

$$R^2 = \frac{15W}{2 \cos 45^\circ \sin \theta} + \frac{W}{\cos \theta} \quad (54)$$

$$R^3 = R^4 = 0.$$

For the cases when the loads on the tie-down device are associated with the cask-skid combination to the truck bed, $W = 2800$ lb. Thus, the loads in cables 1 and 2 are:

for $\theta = 30^\circ$

$$R^1 = 17,960 \text{ lb,}$$

$$R^2 = 62,630 \text{ lb;}$$

for $\theta = 45^\circ$

$$R^1 = 17,110 \text{ lb,}$$

$$R^2 = 45,960 \text{ lb;}$$

for $\theta = 60^\circ$

$$R^1 = 17,030 \text{ lb,}$$

$$R^2 = 39,893 \text{ lb.}$$

The bending stresses in the eye (Fig. 2.12) are calculated using the same model discussed previously in the lifting analysis. For the cask-to-skid case when $\theta = 30^\circ$, these stresses are:

$$M = \frac{(R^2)L}{24} = \frac{R^2}{24} \quad (55)$$

$$\sigma_{\text{outside}} = \frac{(0.67)(R^2)}{24} \frac{(0.75)}{(0.18)} = \frac{(0.67)(62630)(0.75)}{24(0.18)} \quad (56)$$

$$= 7285 \text{ psi.}$$

ORNL DWG. 79-13250

Fig. 2.12 Geometry of cask-to-skid tie down.

$$\sigma_{\text{inside}} = \frac{(1.80)(R^2)(0.75)}{(24)(0.181)} = \frac{1.80}{0.67}(7.285) \quad (57)$$

$$= 19,572 \text{ psi.}$$

Bending stresses associated with the combination cask-skid to truck-bed cases are minimal, since these cables are attached to the upper ear of the lifting device and the cables do not significantly load the curved portion of the eye in this upper-ear case.

The shear stresses for the cask-to-skid case are also computed using the formulation used in the cask lifting device analysis where the shear stresses are given by the expression

$$\tau = \frac{V}{A} = \left(\frac{R^2}{2}\right) \frac{1}{2A} \left(\frac{3}{2}\right) = \frac{3(R^2)}{8A} \quad (58)$$

$$= \frac{(3)(62,630)}{(8)(1.91)\left(\frac{5}{8}\right)}$$

$$= 19,674 \text{ psi.}$$

For the other cases when the combination is tied to the truck bed, the shear strain is equal to

$$\tau = \frac{V}{A} \quad (59)$$

where A is the total shear area equal to the sum of the areas at the tangent planes that are parallel to the direction of the force applied:

for $\theta = 30^\circ$

$$\tau = \frac{62,630}{\left(\frac{5}{8}\right)(14.7 + 3.1)} = 12,847 \text{ psi} \quad (60)$$

for $\theta = 45^\circ$

$$\tau = \frac{39,893}{\left(\frac{5}{8}\right)(3.3 + 2.3)} = 11,398 \text{ psi.} \quad (61)$$

The stresses in the welds at the tie-down device and cask interface due to tie-down loads are also calculated using the model described in the lifting device analysis. It will be sufficient to show that the stresses at these welds due to the largest tie-down case (when $\theta = 30^\circ$) satisfy the criteria. With reference to Fig. 2.8, the following parameters are calculated:

$$P' = \frac{R^2}{2} \sin 30^\circ = \frac{62,630}{2} \sin 30^\circ \quad (62)$$

$$= 15,658 \text{ lb.}$$

$$V = \frac{R^2}{2} \cos 30^\circ = \frac{62,630}{2} \cos 30^\circ \quad (63)$$

$$= 27,120 \text{ lb.}$$

$$M = P'(2.0 + 0.5 \cos 30^\circ) = V(2.0 + 0.5 \sin 30^\circ)$$

$$= 15,658(2.43) - 27,120(2.25) \quad (64)$$

$$= -22,971 \text{ in.-lb.}$$

The maximum tensile stress at the minimum section area of the weld is:

$$\sigma = \frac{P}{A} + \frac{Mc}{I} = \frac{15,658}{5.66} + \frac{(22,971)(4.5)}{50.94} \quad (65)$$

$$= 4,796 \text{ psi.}$$

The peak shear stress at the weld pattern is equal to:

$$\tau = \alpha \frac{V}{A} = \frac{3}{2} \left(\frac{27,120}{5.66} \right) \quad (66)$$

$$= 7,187 \text{ psi.}$$

The analysis shows that the tie-down device is adequate to meet the specified criteria when subjected to the loads associated with the tie-down for the cask to skid and combination cask-skid to carrier bed. The analysis shows that the shear stress at the tie bolt is about 20 percent in excess of the allowable shear quantity; this calculated stress is a peak value when calculated using straight beam theory; it can safely be shown that the average shear stress in the shear plane is less than this value; therefore, there is a certain amount of conservatism in the calculation scheme shown.

The evaluation of the shear stresses at the pins associated with the tie-down loads follows. The maximum foreseeable load in the pins is equal to 62,630 lb which occurs when the cask-skid combination is tied down to the carrier bed; the shear stress in the pins is

$$\tau = \frac{P}{2A} = \frac{62,630}{2(0.7854)} \quad (67)$$

$$= 39,870 \text{ psi}$$

If it is specified that the material of the pins is steel with designation AISI type 4140, which has a minimum yield stress of 100 ksi (and a minimum shear stress allowable of 50 ksi), the computed value is within the allowable stress.

The pins should be threaded at the ends and bolted permanently to the cars.

2.3 Standards for Type B and Large-Quantity Packaging

The structural standards for large-quantity packaging of the regulations include load resistance of the packaging and the external pressure that the package must withstand.

Compliance of the TRU Curium Shipping Container with these requirements is discussed in the following subsections.

2.3.1 Load resistance

When regarded as a simple beam supported at its ends along any major axis, the container must be capable of withstanding a static load, normal to and uniformly distributed along its length, that is equal to five times its fully loaded weight without generating stress in any material of the cask in excess of the yield strength of that material.

Load evaluation. The TRU Curium Shipping Container, loaded as required as a simple cylindrical beam, is shown in Fig. 2.13. The reactant force acting on the end of the simple beam (R_1) is found as follows:

$$\begin{aligned} R_1 &= \frac{CW}{2} \\ &= 7000 \text{ lb.} \end{aligned} \quad (68)$$

where

C = factor, 5.

W = weight of the container, 2800 lb.

The unit loading, W_u , is found as follows:

$$\begin{aligned} W_u &= \frac{CW}{L} \\ &= 453 \text{ in.-lb.} \end{aligned} \quad (69)$$

where

L = length of the beam, 30.875 in.

ORNL DWG. 71-7831R2

Fig. 2.13 Loading diagram of the TRU Curium Shipping Container regarded as a simple beam.

From these loadings, the maximum bending moment (M_{max}), which is in the center of the beam, is calculated as follows:

$$M_{max} = \left(\frac{R_1 L}{2} \right) - \left(\frac{W_u L^2}{8} \right) \quad (70)$$

$$= 54,084 \text{ in.-lb.}$$

The moment of inertia (I) is calculated as follows:

$$I = \left(\frac{\pi}{4} \right) (r_o^4 - r_i^4) = 3455 \text{ in.}^4, \quad (71)$$

where

r_o = radius of outside of drum, 14.5 in.,

r_i = radius of inside of drum, 14.125 in.

The maximum bending stress (S_b), which is also at the center of the beam, may be calculated as follows:

$$S_b = \frac{M_{max} r_o}{I} \quad (72)$$

$$= 227 \text{ psi } (< 30,000 \text{ psi}).$$

Since the maximum bending stress is well below the yield stress, the TRU Curium Shipping Container exceeds the load resistance requirement. The concrete, which was not considered in this calculation, will also help the drum to resist bending.

2.3.2 External pressure

The regulations require that the design of the shipping package be adequate to ensure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 psig.

Evaluation of requirements stated in 2.3.2 The inner containment vessel will not suffer loss of contents if and when the shipping container is subjected to an external pressure of 25 psig.

The critical unit load for thin-wall cylinders⁵ may be calculated as follows:

$$p' = \frac{\left(\frac{t}{r} \right) S_y}{1 + 4 \frac{\left(\frac{t}{r} \right) S_y}{E \left(\frac{r}{t} \right)^2}} = \frac{\left(\frac{0.065}{0.625} \right) (25,000)}{1 + (4 \times 25,000)} \quad (73)$$

$$= 1956 \text{ lb/in.}^2 (> 25 \text{ lb/in.}^2).$$

where

p_c = critical unit load, lb/in.².

t = wall thickness, in.,

r = mean radius, in.,

S_y = yield strength, lb/in.².

E = Young's modulus, lb/in.².

The inner container calculations were compared to the values listed in the "Table of Maximum Uniform External Pressure for Steel Pipe" (ref. 5) and were found to have external pressure resistance many times greater than the required 25 lb/in.².

3. COMPLIANCE WITH STANDARDS FOR NORMAL CONDITIONS OF TRANSPORT

The regulations stipulate that a single package must be able to withstand the normal conditions of transport without substantially reducing the effectiveness of the package and without releasing radioactive material from the containment vessel. The contents of the container are limited such that the package will contain no gases or vapors that could reduce the effectiveness of the packaging. No circulating coolant other than atmospheric air is used, and no mechanical cooling device is required or provided. The TRU Curium Shipping Container and its inner containers are designed so that the contents will not be vented to the atmosphere under normal conditions of transport. These normal conditions include the effects of heat, cold, pressure, free drop, and penetration.

3.1 Heat

The cask must be designed and constructed so that if it were subjected to direct sunlight at an ambient temperature of 130°F in still air, its effectiveness would not be reduced. In addition, the temperature of the accessible external surfaces of the cask must not exceed 122°F in the shade when fully loaded, assuming still air at ambient temperatures. If the cask is transported in a vehicle assigned for the sole use of the consignor, the maximum accessible external surface temperatures shall not exceed 180°F.

To evaluate the adequacy of the curium shipping cask under normal operating conditions, heat transfer tests were conducted both in the shade and in the sun.

The first test performed at ORNL simulated full-shade conditions. The second test simulated exposure to the sun. In the first test, the cask was placed in the crane bay of a building where the ambient temperature was controlled at 70°F. A heat source of 150 W was placed inside of the inner container. The cask was closed in its normal way and the resultant temperatures were monitored for 4 days by use of chromel-alumel thermocouples. One thermocouple was attached to the outside of the cask, one was located at the inside bottom corner of the inner container, and a third was placed in the ambient air, approximately 6 in. from the external surface of the cask.

The temperature in the inner container reached equilibrium approximately 32 hr after the start of the test. The surface temperature equilibrated about 8 hr after the inner cavity. Table 3.1 lists these recorded temperatures and the corresponding extrapolated temperatures.

The test to measure the effects of direct sun was conducted during the first week of December and the thermocouples again measured the same locations as in the "shade" test. The weather was clear and cool with bright, sunny days.

The cask and its skid were placed outside on a bitumen surface in full sunlight and the heater in the inner container was adjusted to 150 W. The temperature in the cavity reached a maximum in about 42 hr and remained there for the remainder of the test. The surface temperature also took about 42 hr to equilibrate and it remained constant thereafter. Table 3.2 lists the temperatures attained at the three locations and the temperatures calculated for 130°F ambient conditions.

The neoprene gasket area reached a temperature of approximately 105°F (192°F extrapolated). Since the maximum operating temperature of the neoprene gasket material is 300°F, the package will operate properly under normal temperature conditions required by the regulations.

**Table 3.1. Cask temperatures with a 150 W source,
determined in the shade
(inside crane bay)**

Measurement location	Measured temp (°F)	Extrapolated temp (°F)
Ambient	70	100
Outside surface	91	121
Inside cavity	185	215

**Table 3.2. Cask temperatures with a 150 W source,
determined in the sun
(on bitumen surface)**

Measurement location	Measured temp (°F)	Extrapolated temp (°F)
Ambient	43	130
Outside surface	70	152
Inside cavity	145	232

3.2 Cold

The shipping package must be able to withstand an ambient temperature of -40°F in still air and shade.

If $T_1 = -40^{\circ}\text{F}$ (420°R) and no internal heat load is assumed, the final or maximum pressure (P_2) in any cavity sealed at a pressure of 14.7 psia and a temperature of 70°F (530°R) is

$$P_2 = \frac{(P_1 T_2)}{T_1} \quad (74)$$

$$= 11.65 \text{ psia.}$$

The resulting pressure differential is less than the 25-psia differential pressure investigated in Sect. 2.3.2. A temperature of -40°F is within the operating temperature range of the seals and the stainless steel cladding, structural components, and fasteners. Brittle fracture of these components are above their ductile-to-brittle transition temperatures.

The above considerations indicate that the stipulated cold conditions will not reduce the effectiveness of the packaging, and that the container conforms to the requirements for the cold condition of normal transport.

3.3 Pressure

The regulations for normal conditions of transport specify that the package must be able to withstand an atmospheric pressure of 0.5 times the standard atmospheric pressure; the resulting pressure is 7.35 psia.

Pressure evaluation. The radioactive material is shipped in containers described in Sect. 5. In addition, the inner cavity is sealed with a gasketed closure and the cover is also gasketed. All seals are capable of withstanding a differential pressure of 0.5 atm. Checklists (Sect. 9.4) are used to determine that the gasket is in place and that the bolts are adequately tightened. The integrity of the package will, therefore, not be reduced should the ambient pressure be reduced to 0.5 atm.

3.4 Vibration

The container is of welded construction, and vibrations received in transit are not expected to affect the integrity of the weldment. All fasteners are equipped with lock washers and are not expected to loosen during such vibrations.

In addition, the casks built several years ago have operated in the transportation environment, suffering no ill effects as a result of vibrations encountered.

3.5 Water Spray

The containment capabilities of the TRU Curium Shipping Container are not compromised by water spray since all external surfaces are of stainless steel. The closure seal is impervious to water.

3.6 Free Drop

The regulations for normal conditions of transport require that a package weighing less than 10,000 lb shall be capable of withstanding a free drop through a distance of 4 ft onto a flat, essentially unyielding horizontal surface, striking the surface in a position at which maximum damage is expected to result.

Free-drop evaluation. A free drop of the TRU Curium Shipping Container through a distance of 4 ft is expected to produce a denting of the outside steel shell and some fracturing of the concrete. The fractured concrete is expected to be contained, and there should be no reduction in effectiveness of the package or loss of contents because of the 4-ft free drop. Analysis of the hypothetical accident involving a 30-ft free drop indicates that damage from a 4-ft drop will, at most, be superficial. If the package were dropped flat on its top, the top bail cover would be crushed. However, no other damage would result, and the effectiveness of the package would not be reduced.

3.7 Penetration

The regulations for normal conditions of transport stipulate that the package must be capable of withstanding the impact of the hemispherical end of a vertical steel cylinder that weighs 13 lb, has a 1-1/4 in. diam, and is dropped from a height of 40 in. onto the exposed surface of the package that is expected to be the most vulnerable to puncture.

Tests have been conducted on similar shipping casks and the results indicate that the effectiveness of the stainless steel jacket will not be reduced.

3.8 Compression

The package must be able to withstand the greater of two compressive loads equal to either five times the weight of the package or 2 lb./in.² multiplied by the maximum horizontal cross section of the package. The load shall be applied uniformly against the top and bottom of the package for 24 hr in the position in which the package would normally be transported.

Compression evaluation of carrier shell. The stress (S_c) created in the steel shell by imposing on the head a weight of five times the weight of the package is determined as follows:

$$S_c = \frac{5W}{\pi dt} = \frac{5(2640)}{\pi(29)(0.375)} \quad (75)$$

$$= 386 \text{ psi. } (<30,000 \text{ psi}),$$

where

W = weight of fully loaded container, 2640 lb,

d = diameter of container, 29 in.,

t = thickness of container shell, 0.375 in.

The stress (S_d) created in the steel shell by a pressure on the top of the package of 2 psi is determined as follows:

$$S_d = \frac{2\pi d^2}{4\pi dt} = \frac{2(\pi)(29)^2}{4(\pi)(29)(0.375)} \quad (76)$$

$$= 39 \text{ psi } (<30,000 \text{ psi}).$$

The stress that was developed in the shell by imposing a weight of five times the weight of the package of 386 lb was the greater of the two compressive loads required. This stress did not exceed the strength of the shell of the container; therefore, the TRU Curium Shipping Container meets the requirements. No allowance was made for the additional strength that results from the cask being filled with concrete.

Compression evaluation of inner cavity cover. The stress (S_s) created in the inner cavity by a weight imposed on the head of five times the weight of the package is determined as follows:

$$S_s = \frac{5W}{\pi dt} = \frac{5(2640)}{\pi(12)(0.250)} \quad (77)$$

$$= 1400 \text{ psi } (<30,000 \text{ psi}).$$

where

W = weight of fully loaded container, 2640 lb,

d = diameter of inner cavity cover, 12 in.,

t = thickness of inner cavity cover, 0.250 in.

The stress (S_d) created in the inner-cavity cover walls by a pressure on the inner cavity cover of 2 psi is determined as follows:

$$S_d = \frac{2\pi d^2}{4\pi dt} = \frac{2(\pi)(12)^2}{4(\pi)(12)(0.250)} \quad (78)$$

$$= 24 \text{ psi } (<30,000 \text{ psi}).$$

The stress of 1400 psi developed in the inner-cavity cover walls by the weight imposed of five times the weight of the package was the greater, and it did not exceed the strength of the shell of the cover. Therefore, both the carrier shell and the cover for the inner cavity can withstand the conditions of the compression test.

4. COMPLIANCE WITH STANDARDS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The standards for the hypothetical accident conditions stipulate that a container used for the shipment of fissile or large quantities of radioactive material shall be designed and constructed in such a manner and its contents limited so that, if it is subjected to the specified

free-drop, puncture, thermal, and water-immersion conditions, the following requirements would be met:

1. The reduction in shielding would not be sufficient to increase the external radiation dose rate to more than 1000 mR/hr at a distance of 3 ft from the outside surface of the package.
2. No radioactive material would be released from the package except for gases containing total radioactivity not to exceed 0.1% of the total radioactivity of the contents of the package.
3. The contents would remain subcritical.

4.1 Free Drop

The first in the sequence of hypothetical accident conditions to which the cask must be subjected is a free drop through a distance of 30 ft onto a flat, essentially unyielding horizontal surface, striking the surface in a position at which the maximum damage is expected to occur.

Damage to the ORNL Curium Shipping Cask was evaluated by assuming the cask struck the unyielding surface in one of three different orientations. These included impact on the side, the top end, and the top corner.

4.1.1 *Impact on side*

A series of tests was performed at the Brookhaven National Laboratory (BNL) in which three concrete-shielded waste-vault containers were dropped 30 ft onto a 10-in.-thick slab of armor plate.⁶ The container, having outside dimensions of 4 x 8 x 4 ft and designed with a concrete shielding thickness of 17 in., survived the impact with only hairline cracks observable. Its shielding efficiency was reportedly unimpaired.

The BNL containers were of bare concrete made from normal type stone. Review of these test results indicates that concrete in rapid compression (such as in an impact) will crumble and shear on fault planes; however, in the case of the TRU Curium Container, the fragments formed will be held in place by the reinforcing wire and the outer steel shell, which will become distorted only in the impact area.

These tests, together with observations made of high-speed impact onto reinforced concrete bridge abutments, suggest that the concrete in the immediate area of the impact will fragment; however, the concrete only slightly removed from the impact area will be undamaged. Because the concrete fragments will remain approximately in their original area as a result of the reinforcing wire and the stainless steel shell, the shielding is not expected to be significantly reduced. In addition, cracking, probably all hairline, would not be in a straight line and would not allow streaming of radiation.

4.1.2 *Impact on top flange*

It can be demonstrated that the shell of the cavity "top-hat" cover fails by compression in lieu of buckling.

The buckling load is calculated as follows:

$$F_{BK} = \left[\frac{Et^3}{3(1-\nu^2)} \right]^{1/2} \left(\frac{1}{R} \right) \quad (79)$$

$$= 190,800 \text{ in.-lb.}$$

where

E = modulus of elasticity, 29×10^6 .

t = thickness of cover shell, 0.25 in..

ν = Poisson's ratio, 0.300.

R = inside shell radius, 5.75 in.

The compression load is calculated as follows:

$$F_{CP} = \sigma t = 15,000 \text{ in.-lb.} \quad (80)$$

where

σ = dynamic yield steel, 60,000 psi.⁴

t = thickness of cover shell, 0.25.

Because the cavity top-hat cover will fail under compression with a load of only 15,000 lb.-in., or less than 10% of the load required for failure in buckling, it can be assumed that the cover will fail under compression when an axial load is applied. The energy required to crush the side walls of the top-hat cover is found as described below.

The energy absorbed in deforming the cover side walls a distance, $d\Delta$, is calculated as follows:

$$du = F d\Delta \quad (81)$$

where

du = incremental energy absorbed,

F = force, lb.

$d\Delta$ = incremental deformation.

The length of the deformed side is calculated as follows:

$$\Delta = \epsilon L \quad (82)$$

where

Δ = deformation, in.,

ϵ = fraction deformed, in./in.,

L = length of side, in.

Differentiating Eq. (82), it is determined that

$$d\Delta = L d\epsilon \quad (83)$$

Force is found as follows:

$$F = \sigma_e A_i \quad (84)$$

where

σ_e = stress, psi,

A_i = cross-sectional area of metal in sides of cover, in.²,

because

$$\sigma_e = f(\epsilon) \quad (85)$$

where

$f(\epsilon)$ = function of ϵ .

Substituting Eq. (85) into Eq. (84) gives:

$$F = f(\epsilon) A_i \quad (86)$$

Further, substituting Eqs. (86) and (83) into Eq. (81) yields:

$$du = f(\epsilon) A_i L d\epsilon \quad (87)$$

Integrating Eq. (87),

$$U = A_i L \int f(\epsilon) d\epsilon \quad (88)$$

It has been determined that

$$f(\epsilon) = \sigma_e = 4.33 \times 10^5 \epsilon + 60,000 \text{ (see ref. 9);} \quad (89)$$

therefore, substituting Eq. (88):

$$U = A_i L \int_0^{\epsilon} (4.33 \times 10^5 \epsilon + 60,000) d\epsilon \quad (90)$$

Integrating Eq. (90) and solving within the limits of zero of ϵ , we find that

$$U = \left[\frac{4.33 \times 10^5}{2 \epsilon^2 + 60,000 \epsilon} \right] A_i L = (54,125 + 30,000)(18.46) \\ = 1.553 \times 10^6 \text{ in.-lb.,} \quad (91)$$

where

$$\epsilon = 0.4.$$

$$A_i = \text{area of metal in shell wall, } 9.23 \text{ in.}^2.$$

$$L = \text{length of sides of shell wall, } 2.0 \text{ in.}$$

The maximum energy (U_m) available is the energy of the falling cask, which is calculated as follows:

$$\begin{aligned} U_m &= W_T h = 2640(360) \\ &= 0.9504 \times 10^6 \text{ in.-lb. available,} \end{aligned} \quad (92)$$

where

$$W_T = \text{weight of cask, } 2640 \text{ lb.}$$

$$h = \text{drop height, } 360 \text{ in.}$$

The energy, U_m , that is available when a cask is dropped is not as great as the energy required to crush the side walls of the top hat [U, Eq. (82)]. An intermediate value of ϵ is therefore determined using the available energy found in Eq. (92). It was found that

$$\epsilon = 0.368. \quad (93)$$

The stress in the cover sides attained as the actual final value by solving Eq. (85) was

$$\sigma = 2.195 \times 10^5 \text{ psi.} \quad (94)$$

The force was determined by solving

$$\begin{aligned} F &= \sigma A_i = (2.195 \times 10^5)(9.23) \\ &= 2.026 \times 10^6 \text{ lb.} \end{aligned} \quad (95)$$

The maximum acceleration (g_m) was found as follows:

$$\begin{aligned} g_m &= \frac{F}{W_T} = \frac{2.026}{2640} \times 10^6 \\ &= 767 \times g \end{aligned} \quad (96)$$

The force on the eight 1/2-in. studs holding the shielding plug is determined from

$$\begin{aligned} F_P &= W_S g_m = 103 \times 767 \\ &= 79,000 \text{ lb.,} \end{aligned} \quad (97)$$

where

$$F_P = \text{force on studs,}$$

$$W_S = \text{weight of shielding plug and contents, } 81 + 22 \text{ lb.}$$

The stress on each bolt is determined as follows:

$$\sigma = \frac{F_p}{NA} = \frac{79,000}{8(0.142)} = 69,500 \text{ psi.} \quad (98)$$

where

N = number of bolts, 8.

A = area of bolt, 0.142 in.².

The stress of 69,500 psi is such that the bolts, under the extreme accident condition of dropping the cask on its top, will yield but not break. (Figure 4.1 indicates that stress would have to exceed 90,000 psi before bolt fracture would occur).¹⁰

The bolts will not rupture or break to release the shielding plug; in any case, the plug could not fall out because the cask is resting on it. Containment of the cavity will have been broken; however, this will happen in the fire when the plug gasket is destroyed. The contents of the inner cavity must therefore be contained in a 2R-type container or be encapsulated as described in Sect. 5.

4.1.3 Impact on top corner

The ability of the bolts to hold the shielding plug in the cavity when the cask is dropped on its top corner depends on their capability to withstand the stresses generated in an impact as a result of cask deceleration. These deceleration forces will act on the plug and the contents of the inner cavity. Upon impact on an edge, the steel shell and concrete immediately behind it

Fig. 4.1 Stress-strain curve for annealed 4140-series steel.

will start to crush. A computer program was developed (see Sect. 9.3) to analyze the forces and acceleration involved in an edge drop. This program calculates the cask deceleration as a function of the specific energy (in.-lb in.³) of concrete.

As a result of the analysis, it was found that a specific energy of 28,000 in.-lb in.³, which is considered to be very high for concrete encased in steel, produces a deceleration of 450 g. Applying this g-level to the weight of the cask lid and contents, the force (F_p) on the eight 1/2-in. studs holding the shielding plug is determined as follows:

$$\begin{aligned} F_p &= W_s g = 103(450) \\ &= 46,350 \text{ lb.} \end{aligned} \quad (99)$$

where

W_s = weight of plug plus contents of inner cavity, 103 lb.

The stress (σ) on each bolt is determined from:

$$\begin{aligned} \sigma &= \frac{F_p}{NA} = \frac{46,350}{8(0.142)} \\ &= 40,800 \text{ psi } (<90,000 \text{ psi}), \end{aligned} \quad (100)$$

where

N = number of bolts, 8.

A = tensile stress area of bolt, 0.142 in.².

Because the stress in the bolts is below the yield stress, the bolts are adequate and the plug will remain sealed on the top corner drop.

The computer program described in Sect. 9.3 was used to experimentally calculate the deformation resulting from a 30-ft corner drop. Results indicate that the shielding remaining after the deformation is more than adequate to safely shield the cask.

4.2 Puncture

The second in the sequence of hypothetical accident conditions requires that the cask must be subjected to a free drop through a distance of 40 in. striking the top end of a vertical mild-steel bar mounted on an essentially unyielding, horizontal surface. At the moment of impact, the cask must be in a position at which maximum damage is anticipated. The mild-steel bar shall have a diameter of 6 in., with the top horizontal and its edge rounded to a radius of 1/4 in., and the bar shall be of such length that it will cause maximum damage to the cask, but not less than 8 in. long. The long axis of this bar shall be normal to the surface of the cask upon impact.

To analyze the puncture accident, a rather conservative model can be used which assumes that all the energy absorbed by the cask is absorbed by the outer stainless steel and none is absorbed by the concrete shielding. A testing program, conducted at ORNL, evaluated the resistance to puncture of cast 2 x 4 x 8 in. limonite concrete bricks. These approximate twelfth-scale, 16-lb concrete bricks covered with 30-mil stainless steel sheet were dropped from

40 in. onto a 1 2-in.-diam punch. The 30-mil stainless steel sheet covering the brick did not puncture, but there was extensive fracture of the brick and some fracture of the limonite aggregate. Full-size aggregate was used in all tests. To estimate the effect of the puncture test on the full-size cask, these tests were scaled up based on the linear dimension of the punch (a factor of 12). The scaled-up weight of the test is then 16 lb x 12³, or 27,648 lb, and the scaled-up shell or cover plate thickness is 0.030 in. x 12, or 0.36 in.

Because the TRU Curium Shipping Container weighs 2640 lb, which is considerably less than 10% of the scaled-up weight, the 3 8-in. side and bottom plates are more than adequate, and the 1 4-in. top plate is also adequate to resist puncture in the prescribed test of the 40-in. drop onto a 6-in.-diam piston. On the basis of a different set of test data,¹¹ 1 4-in. 304L stainless steel was determined to be adequate for a cask weighing 2640 lb.

4.3 Thermal Evaluation

The third in the sequence of hypothetical accident conditions specified by the regulations to which the cask must be subjected is a 30-min exposure to a source of radiant heat (fire) having a temperature of 1475°F and an emissivity coefficient of 0.9 or equivalent. For calculational purposes, it shall be assumed that the package has an absorption coefficient of 0.8. The package shall not be cooled artificially until after the 30-min test period and the temperature at the center of the package has begun to fall, or until 3 hr following the test period.

4.3.1 Thermal properties of materials

The thermal properties of materials used to compute the temperature distribution under steady-state and transient conditions are listed in Table 4.1 (see Sect. 3.1.1).

4.3.2 Thermal accident analysis

A thermal analysis of the TRU Curium Shipping Container (using the HEATING5 code),¹² assumed that the container was exposed to the hypothetical accident conditions described above. The temperature distribution in the cask was initialized, assuming an internal heat source of 500 Btu/hr, an ambient temperature of 100°F, a solar heat load of 144 Btu/hr imposed on the projected container surface area, and dissipation of heat from the sides and top of the cask by convection and radiation. The container was then exposed to the 1475°F radiation heat source for 30 min, after which the original ambient conditions were reimposed.

The inner cavity temperature was initially 179°F; this temperature increased and peaked at 412°F approximately 3 hr after the end of the fire. At this temperature, any residual moisture (<0.1%) would increase the internal pressure of the inner container by less than 1 atm. The lead shielding remained below this temperature. The maximum concrete temperature occurred at the outer surface, reaching 919°F at the end of 30 min.

As a result of these temperatures, the TRU Curium Shipping Container gaskets are expected to be destroyed,¹³ and some water may be driven out of the concrete. Only the outer 2 to 2 1/2 in. of concrete is expected to be affected by temperatures above 212°F; consequently, the effectiveness of the shielding will not be impaired to any significant extent.

Table 4.1. Thermal properties of materials used to
compute temperature distribution

Material	Temperature (°F)	Thermal conductivity [Btu hr ⁻¹ ft ⁻¹ (°F) ⁻¹]	Density (lb in. ⁻³)	Heat capacity [Btu lb ⁻¹ (°F) ⁻¹]
Fuel		6.62	0.0978	0.214
Seal		0.143	0.0347	0.469
Stainless steel, 304L	32.0	7.736	0.282	0.130
	212.0	9.428		
	932.0	12.571		
	1292.0	14.989		
	1472.0	15.000		
Air	32.0	0.017	4.11 x 10 ⁻⁵	0.240
	212.0	0.018		
	392.0	0.022		
	572.0	0.026		
	752.0	0.029		
Concrete		0.600	0.090	0.21

Only limited experimental data are available on the temperature distribution in concrete exposed to a fire.¹⁴ Table 4.2 confirms that concrete, when exposed to a fire of 30-min duration, is not affected to any great depth.

The source inside the TRU Curium Shipping Container will always be contained in either a steel 2R container or a welded capsule. Cavity temperatures below 400°F will have essentially no effect on the integrity of these inner containers.

Table 4.2. Measured temperatures in concrete exposed to a 1300°F fire^a

Distance from face (in.)	Temperature after 15 min (°F)	Temperature after 30 min (°F)
0.5	716	950
1	356	608
2	158	230

^aData based on ref. 14.

4.4 Water Immersion

The fourth in the sequence of hypothetical accident conditions to which the cask must be subjected is immersion in water in such a manner that all portions of the package are under at least 3 ft of water for not less than 8 hr.

It is assumed that all rubber gaskets will be destroyed in the fire. However, since the solid radioactive material is contained in sealed capsules whose integrity has remained intact throughout the accident sequence, no material will be lost. In addition, the moderation afforded by the water is not detrimental. Therefore the cask will meet the water immersion requirements.

5. CONTAINMENT

Containment for radioactive material transported in the TRU Curium Shipping Container is provided by welded special-form capsules. These capsules are occasionally enclosed in a 2R¹⁵ container for ease of handling.

5.1 Containment Boundaries

The containment boundaries for the shipping options available with the curium cask are the cask cavity sealed by its gaskets (see Fig. 1.2) and an inner container that meets special form requirements. Any material carried in a 2R container will be enclosed in a welded capsule. In all cases, there will be at least one welded seal between the source and the cask cavity.

5.2 Special-Form Shipments

The welded encapsulation provides primary containment for all special-form shipments (see Figs. 5.1 through 5.4 for examples of special-form encapsulations). If the material is doubly

ORNL DWG. 70-11675R1

Fig. 5.1 Assembly for TRU shipment of ^{252}Cf (for details see Drawing M-12175-CP-335-D), a typical special-form inner container.

Fig. 5.2 Standard neutron source container (for details see Drawing M-12175-CP-636-D), a typical special-form inner container.

ORNL DWG. 79-19-71

5.3 Curium shipping capsule used at the TRU processing plant.

JRNLDWG. 73-12731

Material: 304L SST

5.4 Singly encapsulated container for shipping powder.

encapsulated, the outer welded capsule provides secondary containment. Visual inspection of these lines of containment are performed on a routine basis, and the welds are radiographed. The cask seals form an additional line of containment. The cask is equipped with gasketed closures that are leaktight during normal transport. An accident might result in a rupture of the seals, but the contents in their primary containers would remain in the cavity.

The ORNL Operations Division is authorized by Laboratory management to certify that a material conforms to the special form requirements of Appendix D of 10 CFR Part 71.¹⁶ The tests prescribed have been performed on a number of capsule designs. When a capsule is similar in design to a capsule previously tested (i.e., in relation to size, mass, wall thicknesses, materials, weld, etc.), the design is certified as passing the special-form requirements based on previous test results. If this similarity does not exist, it is required that a prototype be tested as prescribed.

5.3 Containment Requirements for Normal Conditions of Transport

The test sequence for containers of special-form materials is more severe than for those with normal conditions of transport. The pressure increases that are encountered will be less than those experienced in the thermal test for special-form materials. No loss of primary coolant (air) is expected.

The 2R containers, housing a welded capsule, are designed for pressures and temperatures in excess of those encountered in normal transport. No release of radioactive material, loss of coolant (air), or contamination of coolant should occur.

5.4 Containment Requirements During the Hypothetical Accident

The test series for special-form containers demonstrates that special-form encapsulation will not fail or leak the contents as the result of the free falls. The thermal test temperatures of special-form containers exceed those experienced by the inner cavity contents during the hypothetical accident (see Sect. 4.3 2); hence, no release will occur during the thermal exposure. The water immersion test for special-form containers is identical to that specified in the hypothetical accident conditions.

The 2R containers, housing a welded capsule, are designed for pressures and temperatures in excess of those encountered in the hypothetical accident.

6. CRITICALITY

The analysis for the single container given below is adequate for an infinite array of similar containers because the concrete shielding assures essentially no interaction.

A study¹⁷ has been made of the criticality of curium and other transuranium elements under conditions of optimum moderation and water reflection. The results are presented in Table 6.1.

The quantity of fissile isotopes to be carried by this cask will be limited to 10 g with the exception of ²⁵¹Cf which will be limited to 2 g. Approval of the use of this cask for that quantity of fissile material has been granted by an ORNL Nuclear Safety Review (see Sect. 9.5).

Since the quantities of fissionable isotopes carried is below all minimum critical masses for these isotopes under optimum moderation and reflection, and since the cask effectively isolates the contents from neutron interaction with packages of similar design, unlimited numbers could be stacked together without creating a criticality problem. Thus the package is adequate for Fissile Class I shipments.

Table 6.1. Minimum critical masses of fissile transportation nuclides

Nuclide	Mass (g)		Concentration ^a (g/liter)
	Critical	Subcritical limit	
^{242m} Am	23	10	5
²⁴³ Cm	213	150	40
²⁴⁵ Cm	42	25	15
²⁴⁷ Cm	159	120	60
²⁴⁹ Cf	32	20	20
²⁵¹ Cf	10	3	6

^a Approximate concentration at which minimum critical mass occurs.

7. SHIELDING EVALUATION

7.1 Discussion and Results

The TRU Curium Shipping Container is designed so that its cavity is surrounded by 1 4-in.-thick stainless steel and a 3 8-in.-thick outer shell. The shielding between the two is filled with 9-3 4-in. Blackburn limonite concrete and approximately 1 in. of lead. The shielding effectiveness has been checked with transuranium sources and found to be adequate. A 48.8-g source of ^{244}Cm produced a reading of 1-mrem hr gammas and 3-mrem hr neutrons at a distance of 6 ft from the side of the truck. In this case the driver's compartment registered approximately 1 mrem hr. The cask contents will be limited so that the source will not exceed the allowable radiation dose limits of the DOT regulations.¹⁸ The shielding effectiveness will not be reduced by the hypothetical 30-ft drop accident, because concrete fractures in an intergranular manner providing a labyrinthine pathway for radiation, allowing no possibility of radiation streaming.

8. QUALITY ASSURANCE

8.1 Fabrication, Inspection, and Acceptance Tests

This container was fabricated in the ORNL shops in accordance with normal shop fabrication procedures and prior to the adaption of a formal quality assurance program by the DOE and ORNL. Material was specified on the original drawings as "304L SST." Material was withdrawn from Bill of Materials Stores stock. The casks were inspected by ORNL Shop Inspection Department personnel for conformance to the drawings, quality of workmanship, and compliance with welding requirements when fabricated. In the opinion of the inspecting personnel, the weldments were made in accordance with the drawings and specifications. This is further supported by the fact that these casks have operated for as many as 13 years without failures or loss of effectiveness. The routine operating inspection procedures specify periodic weld inspections to verify weld integrity.

A formal quality assurance program has now been prepared,¹⁹ and future shipping containers will be constructed in accordance with provisions set forth in this program.

8.2 Operating Procedures and Routine Inspection

The Transuranium Processing Plant, Chemical Technology Division, has established operating and routine inspection procedures and standard checklists to ensure that all shipments are safe and that they comply with DOE regulations as well as all ORNL procedures and regulations. A copy of typical procedures and checklists are presented in Sect. 9.4

• 8.3 Periodic Maintenance and Inspection

Inspections are required prior to each shipment, or biennially (see Sect. 9.4). Maintenance will be required only when routine inspections indicate damage.

9. APPENDICES

9.1 Drawing

TRU Curium Shipping Container Assembly and Details - M-12175-CP-078-E-3

SECRET

① CARRIAGE
MAY 20 1885

CARRIER IDENTIFICATION LABELS			
CPCL #	IDENTIFICATION NUMBER	PROPERTY #	WEIGHT
103-100	ACC OF USA-6961 1 BL	1-102770	10.00
103-101	ACC OF USA-6961 2 BL	1-102771	10.00
103-102	ACC OF USA-6961 3 BL	1-102772	10.00

EACH CARRIER IDENTIFIED WITH NUMBERS ABOVE AND MARKED "TRANSMISSION CARRIER SHIPPING CONTAINER", "RADIOACTIVE MATERIALS". THIS AND SHIPMENT IS ENGRAVED ON PLATES WELDED TO THE CARRIER.

ASSEMBLY

1. COVER
1.0000
MATERIAL: 506. 587

2. COVER
1.0000
MATERIAL: 506. 587

3. PLATE
1.0000
MATERIAL: 506. 587 (Lead Filled)

TO: [Name]		FROM: [Name]	
DATE: [Date]		TIME: [Time]	
PROJECT: [Project Name]		DRAWING: [Drawing Number]	
REVISION: [Revision Number]		APPROVED: [Signature]	
PROJECT: [Project Name]		DRAWING: [Drawing Number]	
REVISION: [Revision Number]		APPROVED: [Signature]	

9.2 Approval Documents

DOE Form EV-18
(11-77)
10 CFR 71

U.S. DEPARTMENT OF ENERGY
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages

1a Certificate Number	1b Revision No	1c Package Identification No	1d Page No	1e Total No. Pages
5461	1	USA/5461/BL (DOE-OR)	1	2

2 PREAMBLE

- 2a This certificate is issued to certify Sections 173.393b, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189).
- 2b The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."
- 2c This certificate does not relieve the consignee from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or over which the package will be transported.

3 This certificate is issued on the basis of a safety analysis report of the package design or application.

(1) Prepared by (Name and address)

(2) Title and Identification of report or application

(3) Date

Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37830

Safety Analysis Report for Packaging
(SARP) of the Oak Ridge National Laboratory
TRU Curium Shipping Container

Dec. 1979

Report No.: ORNL-5147/R1

4 CONDITIONS

This certificate is conditional upon the fulfilling of the requirements of Subpart D of 10 CFR 71, as applicable, and the conditions specified in item 5 below.

5 Description of Packaging and Authorized Contents, Model Number, Feeble Class, Other Conditions, and References

a. Packaging:

(1) Model: ORNL TRU Curium Shipping Container

(2) Description:

Packaging for solid radioactive materials. The container is a right circular cylinder 29 in. in diameter and 30 7/8 in. high with a 304L stainless steel outer shell, which is 3/8 in. thick for the bottom and sides and 1/4 in. for the top. The shell for inner cavity is 8 1/4 in. diameter x 19 1/4 in. deep, is fabricated from 1/4 in. thick 304L stainless steel plate, and is recessed 1 3/8 in. from the top. The cavity shell is a cylinder 8 1/4 in. diameter x 19 1/4 in. high and is fabricated from 1/4 in. thick 304L stainless steel. The inner cavity for the radioactive materials is 6 in. diameter x 8 in. high and fabricated from 1/4 in. thick 304L stainless steel. Seven-eighths in. thick lead fills the space between the sides and bottom of the cavity shell and the inner cavity. The annulus between the outer shell and inner shell is filled with limonite concrete.

The inner cavity is closed with a concrete-and-lead plug which is enclosed in 1/4 in. 304L stainless steel plate. A 1/16 in. thick neoprene gasket serves as a seal between the top flange of the plug and the cask body. Eight

6a Date of Issuance **October 1, 1979**

6b Expiration Date

FOR THE U.S. DEPARTMENT OF ENERGY

7a Address for DOE Issuing Office

7b Signature, Name, and Title for DOE Approving Official

U. S. Department of Energy
Post Office Box E
Oak Ridge, TN 37830

William H. Travis
William H. Travis, Director
Safety and Environmental Control Division

Page 2 - Certificate of Compliance USA/5461/BL

(2) Description (continued)

1/2 in. x 13 NC-2 nuts on studs hold the plug flange to the cask body. A 3/8 in. diameter 304L stainless steel bail is used to lift the plug.

A 1/4 in. thick 304L stainless steel plate, which covers the top flange and bail, is held to the top of the cask by six 1/2 in. x 13 NC-2 nuts on studs.

The cask is equipped with four 1/2 in. thick lifting and tie-down ears with two 1 in. diameter holes per ear. The cask is also mounted on a skid for handling with a forklift.

The gross weight of the cask and skid is 2800 lb.

(3) Drawing:

The packaging for the TRU Curium Shipping Container is constructed in accordance with Oak Ridge National Laboratory Drawing No. M-12175-CP-078-E-3.

b. Contents:(1) Type and Form of Material:

Any isotope of plutonium, americium, curium, berkelium, californium, and fermium in the form of metal, oxide, chloride or other salt.

(2) Maximum quantity of material per package:

- (i) A total of 10g of ^{239}Pu , ^{241}Pu , ^{242}Am , ^{243}Cm , ^{245}Cm , ^{247}Cm , and/or ^{249}Cf .
- (ii) 3g of ^{251}Cf .
- (iii) The balance of the transuranic and other non-fissile radioactive materials will be limited to a heat load of 500 Btu/hr. and to the external radiation levels specified in US DOT Regulations 49 CFR Part 173.393.
- (iv) Contents are either singly or doubly encapsulated in a welded container meeting special form requirements and may be further placed in another I/T Specification 22 container for handling purposes.

**DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590**

SPECIAL PERMIT NO. 5461

This special permit is issued pursuant to the authority of 49 CFR 173.22(a)(1), Department of Transportation (DOT) Hazardous Materials Regulations, as amended.

1. The OAK RIDGE NATIONAL LABORATORY, Oak Ridge, Tennessee, is hereby authorized to ship radioactive material, n.o.s., further described as transuranium isotopes, under the provisions of 49 CFR 173.393(f)(9), and 173.393(m) of the DOT Regulations, in accordance with the provisions of the U. S. Atomic Energy Commission (USAEC), Oak Ridge Operations Office, approval dated October 31, 1967, and as further provided for herein.

2. The authorized packaging shall consist of a lead and concrete shielded cask, with a stainless steel shell, 30 inches long and 29 inches in diameter, identified as the TRU Curium Shipping Container. The package is described on ORNL drawing number H-12175-CP-373.

3. For shipment of nitrate solutions, no polyethylene bottle may be used which has also been used as a storage vessel for nitrate solutions for more than 30 days. Any internal pressure within the polyethylene bottle must have been relieved within 48 hours prior to shipments. An O-ring seal (Viton-Fluorelastomer, or approved equivalent) must be used as a part of the cap closure. The cap must be subjected to at least 15 foot-pounds of torque during closure. Venting is not authorized. Bottles must conform to the requirements for DOT Specification 2S, 2T, or 34, with a minimum wall thickness of 0.045 inches, as measured at any point on the bottle. The package is not authorized for nitrate solutions containing nitric acid in strength exceeding 20%.

4. The closure device must have affixed to it a tamperproof lock wire and seal adequate to prevent inadvertent opening of the container, and of a type that must be broken if the package is opened.

REVISED SPECIAL PERMIT NO. 5461

Pursuant to the authority of 49 CFR 173.22(a)(1), Department of Transportation (DOT) Hazardous Materials Regulations, as amended:

Special Permit No. 5461, authorizing the shipment of not more than 10 grams of certain transuranium isotopes in the TRU Curium Shipping Container, is hereby amended by adding the U. S. ATOMIC ENERGY COMMISSION as an authorized shipper under the terms of the permit, and by changing paragraph (3) to read as follows:

"3. For shipment of nitrate solutions, no polyethylene bottle may be used which has also been used as a storage vessel for nitrate solutions for more than 30 days. Any internal pressure within the polyethylene bottle must have been relieved within 48 hours prior to shipments. An O-ring seal (Viton-Fluorelastomer, or approved equivalent) must be used as a part of the cap closure. The cap must be subjected to at least 15 foot-pounds of torque during closure. Venting is authorized. Bottles must conform to the requirements for DOT Specification 34. The package is not authorized for nitrate solutions containing free nitric acid in strength exceeding 6 molar. The package is exempted from the provisions of Para. 173.268 of the DOT regulations.

All other terms of the permit remain unchanged.

Issued at Washington, D.C., this 7th day of June 1968.

W. R. Fiste
For the Administrator
Federal Highway Administration

Mac E. Rogers
For the Administrator
Federal Railroad Administration

Address all inquiries to: Secretary, Hazardous Materials Regulations Board, U.S. Department of Transportation, Washington, D.C. 20590. Attention: Special Permits.

Continuation of SP 5461

Page 2

5. The authorized contents of each package shall consist of not more than 10 grams (large quantity) of any isotope of Americium, Curium, Berkelium, Californium, Einsteinium, or Fermium in the form of metal, oxide, or nitrate solution.
 6. Prior to each shipment authorized by this permit, the consignee shall be notified of the dates of shipment and expected arrival.
 7. The outside of each package shall be plainly and durably marked "DOT SP 5461" and "RADIOACTIVE MATERIAL", in connection with and in addition to the other markings and labels prescribed by the DOT Regulations. Each shipping paper issued in connection with shipments made under this permit must bear the notation "DOT SPECIAL PERMIT NO. 5461" in connection with the commodity description thereon.
 8. The permit does not relieve the shipper from compliance with any requirement of the DOT Regulations, except as specifically provided for herein.
 9. Shipments are authorized only by motor vehicle, rail freight, and rail express.
 10. This permit shall expire December 15, 1969.
- Issued at Washington, D.C., this 13th day of December 1968.

W. R. Fiste

W. R. Fiste
For the Administrator
Federal Highway Administration

H. R. Longmire

H. R. Longmire
For the Administrator
Federal Railroad Administration

Address all inquiries to: Chairman, Hazardous Materials
Regulations Board, U.S. Department of Transportation,
Washington, D.C. 20590. Attention: Special Permits.

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590

SECOND REVISED SPECIAL PERMIT NO. 5461

Pursuant to 49 CFR 170.13 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the May 2, 1959, petition by the Oak Ridge National Laboratory, Oak Ridge, Tennessee:

Special Permit No. 5461, authorizing the shipment of certain transuranium isotopes in the TNJ Gamma Shipping Container, is hereby amended by changing paragraphs (1), (3), and (5), to read as follows:

"1. Shipments of large quantities of radioactive materials, n.o.c., are hereby authorized in the packaging as described in this special permit. This packaging, when constructed and assembled as prescribed herein, with the contents as authorized herein, meets the standards prescribed in the DOT regulations, Sections 173.395(c)(2) and 173.398(c). Shipments must be in accordance with the provisions of the U. S. Atomic Energy Commission (USAEC), Oak Ridge Operations Office approval No. 69-010, dated April 15, 1959, and as further provided for herein.

"1a. Each user of this permit, other than the petitioner named above and the previously identified petitioners (U. S. Atomic Energy Commission, Savannah River and Richland Operations Office) shall register his identity with this Board prior to his first use of the permit.

"3. For shipment of nitrate solutions, no polyethylene bottle may be used which has also been used as a storage vessel for nitrate solutions for more than 30 days. Any internal pressure within the polyethylene bottle must have been relieved within 48 hours prior to shipment. An O-ring seal, (Viton Fluoroelastomer, or approved equivalent) must be used as part of the cap closure. The cap must be subjected to at least 15 foot-pounds of torque during closure. Venting is authorized. Bottles must conform to the requirements for DOT Specification 3B, except for §§178.19-2(b), 178.19-5, and 178.19-7(c)(2). The package is not authorized for nitrate solutions containing free nitric acid in strength exceeding 6 molar. The package is exempted from the provisions of § 173.268 of the DOT regulations.

Continuation of 2nd Rev SF 5451

Page 2

"5. The authorized contents of each package consists of large quantities of radioactive material, as any isotope of americium, curium, berkelium, californium, einsteinium, or fermium, in the form of metal, oxide, or nitrate solution, except that for americium-242-II, curium-245, curium-247, californium-249, and californium-251, not more than 10 grams per package is authorized. The balance of the isotopes shall be limited to 500 BFU/hr heat content."

All other terms of the permit remain unchanged. The complete permit currently in effect consists of the original issue and the First and Second Revisions.

Issued at Washington, D.C.:

D. W. Morrison
 D. W. Morrison
 For the Administrator
 Federal Highway Administration

MAY 28, 1969
 (Date)

Mac E. Rogers
 Mac E. Rogers
 For the Administrator
 Federal Railroad Administration

MAY 27 1969

(Date)

Address all inquiries to: Secretary, Hazardous Materials Regulations Board, U.S. Department of Transportation, Washington, D.C. 20590. Attention: Special Permits.

Dist: a, d, e, h, i
 U. S. Atomic Energy Commission, Richland, Wash.
 U. S. Atomic Energy Commission, Aiken, South Carolina

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590

THIRD REVISED SPECIAL PERMIT NO. 5461

Pursuant to 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the October 20, 1969, petition by the Oak Ridge National Laboratory, Oak Ridge, Tennessee:

Special Permit No. 5461 is hereby amended by revising paragraph (10) as follows:

"10. This permit expires on December 15, 1971, and may be revoked for cause at any time."

All other terms and conditions of this permit as revised remain unchanged. The complete permit currently in effect consists of the original issue and the Second and Third Revisions.

Issued at Washington, D.C.:

W. R. Piste
W. R. Piste
For the Administrator
Federal Highway Administration

3 December 1969
(Date)

Mac E. Rogers
Mac E. Rogers
For the Administrator
Federal Railroad Administration

DEC 10 1969
(Date)

Address all inquiries to: Secretary, Hazardous Materials Regulations Board, U. S. Department of Transportation, Washington, D.C. 20590. Attention: Special Permits.

Dist: a, d, e, h, i
U. S. Atomic Energy Commission, Aiken, S.C.
U. S. Atomic Energy Commission, Richland, Wash.
Oak Ridge Associated Universities, Inc., Oak Ridge, Tenn.

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590

FOURTH REVISED SPECIAL PERMIT NO. 5461

Pursuant to 46 CFR 146.02-25 of the U. S. Coast Guard (USCG) Dangerous Cargo Regulations and 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the February 10, 1970, petition by the Oak Ridge National Laboratory, Oak Ridge, Tenn.:

Special Permit No. 5461 is hereby amended by revising paragraphs (9) and (10), and by adding new paragraphs (11) and (12) as follows:

"9. This permit authorizes shipments only by ocean vessel, motor vehicle, and rail.

"10. For shipments by water:

a. A copy of this permit must be carried aboard any vessel transporting radioactive material under these terms.

b. The shipper or agent shall notify the USCG Captain of the Port in the port area through which the shipment is to be made, of the name of the vessel on which the shipment is to be made, and of the time, date, and place of loading or unloading. When the initial notification is given in a port area, it must be accompanied by a copy of this permit, addressed to the attention of that Captain of the Port.

c. Packages shall not be overstowed with any other cargo. If stowed below decks, the hold or compartment in which stowed must be ventilated.

"11. The authorized package described herein is hereby certified as meeting the specific requirements of the International Atomic Energy Agency's (IAEA) "Regulations for the Safe Transport of Radioactive Material", Safety Series No. 6, 1967 edition, as follows:

a. Marginal C-6.2.3 - The package design meets the requirements for Type B packaging for large quantity (source) radioactive materials. Specifically, the packaging design meets the requirements of Marginal C-6.2.3.1(a) for unilateral approval.

b. Marginal C-2.4.3 - The packaging design is based on the ambient conditions.

c. Marginal C-6.5 - No special transport controls are necessary during carriage and no special arrangements have been prescribed, except as specified herein.

"12. This permit expires on February 28, 1972, and may be revoked for cause at any time."

All other terms of this permit as revised remain unchanged. The complete permit currently in effect consists of the original issue and the Second and Fourth Revisions.

Issued at Washington, D.C.:

m. E. Grundy, Capt.
E. G. Grundy, Capt.
For the Commandant
U. S. Coast Guard

3-6-70
(Date)

W. R. Fiste
W. R. Fiste
For the Administrator
Federal Highway Administration

2-19-72
(Date)

Mac E. Rogers
Mac E. Rogers
For the Administrator
Federal Railroad Administration

FEB 26 1970
(Date)

Continuation of 4th Rev SP 5461

Page 2

Address all inquiries to: Secretary, Hazardous Materials
Regulations Board, U.S. Department of Transportation,
Washington, D.C. 20590. Attention: Special Permits.

Dist: a, b, d, e, h, i

U. S. Atomic Energy Commission, Richland, Wash.

U. S. Atomic Energy Commission, Aiken, South Carolina

Lawrence Radiation Laboratory, Livermore, California.

Oak Ridge Associated Universities, Inc., Oak Ridge, Tenn.

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590

SPECIAL PERMIT NO. 5461
FIFTH REVISION

Pursuant to 46 CFR 146.02-25 of the U. S. Coast Guard (USCG) Dangerous Cargo Regulations and 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the November 5, 1970, petition by the Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee:

Special Permit No. 5461 is hereby amended as follows:

1. Paragraph 1 is changed to require that shipments involving the contents as described in paragraph (5a) must be in accordance with the provisions of the USAEC, Oak Ridge Operations Office approval No. 70-006, dated October 19, 1970, or other equivalent USAEC approval.

2. A new paragraph 5a is added to read as follows:

"5a. As an alternate, the contents of each package authorized by this permit may consist of large quantities of any non-fissile radioactive material, n.o.s., further limited to a maximum thermal decay energy of not more than 500 Btu/hr. Contents will be either singly or doubly encapsulated, or contained within DOT Specification 2R inner containers."

All other terms of this permit, as revised remain unchanged. The complete permit currently in effect consists of the original issue and the Second, Fourth, and Fifth Revisions.

Continuation of 5th Rev SP 5461

Page 2

Issued at Washington, D.C.:

[Signature]
 R. G. Sebring, Capt.
 For the Commandant
 U. S. Coast Guard

[Signature]
 (DATE)

[Signature]
 R. H. Fista
 For the Administrator
 Federal Highway Administration

2 December 1970
 (DATE)

[Signature]
 Mac E. Rogers
 For the Administrator
 Federal Railroad Administration

DEC 9 1970
 (DATE)

Address all inquiries to: Secretary, Hazardous Materials
 Regulations Board, U.S. Department of Transportation,
 Washington, D.C. 20590. Attention: Special Permits.

Dist: a, b, d, e, h, i
 University of Georgia, Athens, Ga.
 Brookhaven National Laboratory, Upton, N.Y.
 Lawrence Radiation Laboratory, Livermore, Calif.
 Los Alamos Scientific Laboratory, Los Alamos, N.M.
 Oak Ridge National Laboratory, Oak Ridge, Tennessee
 U. S. Atomic Energy Commission, Aiken, South Carolina
 U. S. Atomic Energy Commission, Richland, Washington
 Oak Ridge Associated Universities Inc., Oak Ridge, Tenn.

INTRA-LABORATORY CORRESPONDENCE**OAK RIDGE NATIONAL LABORATORY****August 7, 1974****TC 74-3****To: B. B. Klima, L. B. Shappert****From: Transportation Committee****Subject: Approval of SARP of ORNL TRU Cesium Shipping Container**

The ORNL Transportation Committee has reviewed your submission of the subject SARP to fulfill the requirements (internal review) of paragraph B of AEC Immediate Action Directive 5201-3. Particular attention was given the five areas of structural integrity, thermal resistance, radiation shielding, nuclear criticality safety, and quality assurance.

The results of the evaluation show that the container meets the requirements of AECM 0529 and the SARP is approved for submission to the AEC for request of a Certificate of Compliance for approval of the cask for use for offsite shipments of fissile and radioactive materials.

E. M. King

**E. M. King, Chairman
Transportation Committee**

EMK:bb**cc: Transportation Committee**

9.3 Computer Program to Calculate Corner Drop Deceleration Forces

The computer program shown in the following pages was developed by John H. Evans, Engineering Division, ORNL, to calculate the deformation of a cask undergoing a 30-ft corner drop. It utilizes an assumed specific energy absorption for the concrete-steel body of the cask. A high specific energy of 28,000 lb-in./in.³ was used to calculate the maximum stress in the bolts holding the plug. This value is considered to give conservative deceleration rates on which the stress calculations were based.

The lowest specific energy assumed was 4000 lb-in./in.³, which is conservative for this cask construction. This value produces a deformation of 4.15 in. Higher specific energies will produce less deformation and higher deceleration rates.

L = distance from corner of cask to inner container, 16.1 in.,

D = deformation resulting from 30-ft corner drop, 4.15 in.,

$L - D$ = minimum thickness,

$$16.1 - 4.15 = 11.95 > 11.5.$$

The minimum shielding thickness necessary to shield the cask safely is 11.5 in.; thus, the above calculations indicate that the cask will be shielded adequately.

**FTN, L, E, G.

C PROGRAM NUMBER 1001-CASK
C MADE OF A HOMOGENEOUS MATERIAL / AN IDEAL STRESS-STRAIN RELATIONSHIP
C IMPACTING AN UNYIELDING SURFACE. THE CASK IMPACTS ON ITS CORNER
C THIS PROGRAM COMPUTES THE RESPONSE OF A CASK HAVING RIGHT CYLINDRICAL
C GEOMETRY.
C BY JOHN EVANS P.E., GENERAL ENGINEERING DIVISION, OAK RIDGE NATIONAL LAB.

GLOSSARY OF NOTATION

C R=RADIUS OF CASK
C C=CASK LENGTH
C S=YIELD STRESS OR FLOW PRESSURE
C H=CASK HEIGHT
C H=DROP HEIGHT
C O=ANGLE AT WHICH CASK IMPACTS
C U=ENERGY
C F=FORCE
C T=TIME
C AG=ACCELERATION
C UT=TOTAL ENERGY
C V=VELOCITY
C X=DEFORMATION
C AY=ANGLE IN CONTACT / THE SURFACE

C DIMENSION V(1000), AK(1000), F(1000), U(1000), T(1000), AN(1000),
C I X(1000), AG(1000)
C S=0.0
C ANA = 0.0

C INPUT MATERIAL CONSTANT
C INPUT CASK GEOMETRY

C R=15.00
C C=30.6750
C H=2640.
C O=212.12.0 R/C
C INPUT TEST CONDITIONS
C DO 20 N=1,2
C H=45.
C IF (NR.NE.1) GO TO 30
C H=360.

C INPUT ANGLE INCREMENTS

C 30 BE=0.1
C AN=0.1
C DO 20 N=1,7
C S=FLAT(1)*4000.
C WRITE (51,1002)
C WRITE (51,1002)
C WRITE (51,1010)

1010 FORMAT(1H,5CX,'TESTING OF UPSIDE CASKS, TEST 1')

C ZERO SUBSCRIPTED VARIABLES
C DO 14 I=1,1000
C AN(I)=0.0
C AG(I)=0.0
C V(I)=0.0
C X(I)=0.0
C Y(I)=0.0

```

      F(I)=0.0
      U(I)=0.0
      AR(I)=0.0
14  CONTINUE
C  ZERO NONSUBSCRIPTED VARIABLES
      TA=0.0
      AE=0.0
      A=0.0
      AR=0.0
      TX=0.0
      U=0.0
      XX=0.0
      XA=0.0
      UT=6.*H
      VV=SQRT((64.*H)/12.)
      DO 1 I=1,1000
      AR=0.0
C  INCREMENT ANGLE A
      9  A=A+AA
      CA=COS(A)
      B=0.0
      AE=0.0
      SUPU=0.0
10  DO 2 J=1,1000
C  INCREMENT ANGLE B
      B=B+BB
      CB=COS(B)
C  CALCULATE VOLUME DISPLACED
11  CC=(CB-CA)
      BY=TAN(D)*R*CC
      BX=R*CC
12  DZ=R*CB*DB
      DU=BY*BX+DZ*S
C  CALCULATE ENERGY ABSORBED
      SUMU=SUMU+DU
C  CALCULATE AREA
13  DA=2.*BX*DZ/COS(D)
      AC=AF+DA
      IF(B.GE.A) GO TO 3
2  CONTINUE
3  U(I)=SUMU
      IF(U(I).GE.UT) GO TO 4
      AR(I)=AE
C  CALCULATE FORCE
      F(I)=AR(I)*S
C  CALCULATE VELOCITY
      5  VA =SQRT((64./(12.*H))*(UT-U(I)))
C  CALCULATE ACCELERATION
      AC(I)=F(I)/W
C  CALCULATE DEFORMATION
      XA =(TAN(D)*COS(D)*R*(1.-CA))
      X(I)=XA
C  CALCULATE TIME
      TX=(XA-XX)/((VV+VA)*6.)
7  TA=TA+TX
      T(I)=TA*1000.
      XX=XA

```

```

6 V(I)=VA
8 VV=VA
  AN(I)=A*57.3
  IF(U(I).GE.UT) GO TO 4
1 CONTINUE
4 CONTINUE
C   OUTPUT-WRITE LOOP
  K=I-1
  WRITE (51,1002)
  WRITE(51,1004)
1004 FORMAT (1H, 9X,37HCASK GEOMETRY AND MATERIAL PROPERTIES)
  WRITE (51,1002)
  WRITE(51,1005)
1005 FORMAT (1H, 4X,6HRADIUS,8X,6HLENGTH,10X,6HHEIGHT,6X,
1      15HSPECIFIC ENERGY)
  WRITE(51,1006)
1006 FORMAT (1H, 4X,6HINCHES,8X,6HINCHES,10X,6HPCUNDS,8X
1      15HLB-IN/CU. IN.)
  WRITE(51,1002)
1002 FORMAT(1H3)
  WRITE(51,1007) R,C,W,S
1007 FORMAT (F11.3,F14.3,F16.1,F18.1)
  WRITE(51,1002)
  WRITE(51,1000)
1000 FORMAT (1H,4X,21HDEFORMATION,4X,8HVELOCITY,7X,4HTIME,13X,5HFORCE,
1      10X,6HENERGY,5X,12HACCELERATION)
  WRITE(51,1001)
1001 FORMAT (1H, 6X,6HINCHES,7X,8HFT./SEC.,4X,12HMILLISECONDS,8X,
1      6HPCUNDS,10X,6HLE-IN.,10X,3HX G)
  WRITE(51,1002)
  DO 15 I=1,K
  WRITE(51,1003) X(I),V(I),T(I),F(I),U(I),AG(I)
1003 FORMAT(1H ,F14.4,F13.2,F16.5,F15.2,F16.2,F12.2)
  15 CONTINUE
  IF(N.NE.1.AND.N.NE.7) GO TO 20
  CALL GWXPL(X,AG,K,'LINEAR','M.C.JURGENSEN')
  20 CONTINUE
  STOP
  END

```

CASK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CU. IN.		
14.500	30.875	2640.0	4000.0		
DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION X G
C.0005	43.42	0.00094	0.0	0.0	0.0
0.0023	43.42	0.00378	3.40	0.00	0.00
0.0045	43.42	0.0039	15.00	0.03	0.01
0.0079	43.42	0.01510	37.21	0.12	0.01
0.0124	43.42	0.02399	60.73	0.39	0.03
0.0179	43.42	0.03597	144.11	1.00	0.05
0.0243	43.42	0.04024	233.58	2.22	0.05
0.0317	43.42	0.06938	354.69	6.41	0.13
0.0492	43.42	0.07661	511.42	8.06	0.19
0.0656	43.42	0.09432	760.10	13.20	0.27
0.0800	43.42	0.11411	949.50	22.43	0.36
0.0914	43.42	0.13577	1240.69	34.50	0.47
0.0933	43.42	0.15931	1504.43	52.37	0.60
0.0972	43.42	0.18472	1960.88	76.25	0.75
0.1115	43.42	0.21200	2451.59	100.07	0.93
0.1204	43.42	0.24115	2924.17	149.72	1.13
0.1431	43.41	0.27210	3567.76	203.30	1.36
0.1634	43.41	0.30303	4267.20	271.16	1.62
0.1756	43.41	0.33977	5020.75	330.09	1.90
0.1974	43.41	0.37035	5570.81	400.65	2.22
0.2131	43.40	0.41403	6003.57	500.91	2.50
0.2393	43.40	0.45505	7029.31	743.07	2.97
0.2614	43.40	0.49723	8452.21	929.71	3.39
0.2865	43.79	0.54122	10170.42	1150.78	3.85
0.3080	43.79	0.58734	11533.03	1411.62	4.30
0.3236	43.76	0.63700	12945.25	1717.96	4.90
0.3396	43.77	0.68420	14457.49	2076.73	5.49
0.3664	43.76	0.73552	16108.20	2483.05	6.12
0.4145	43.75	0.78068	17959.63	2969.32	6.60
0.4636	43.74	0.84367	19676.96	3510.34	7.53
0.4732	43.72	0.90047	21923.25	4133.38	8.30
0.5039	43.71	0.95910	24102.47	4841.14	9.13
0.5356	43.69	1.01955	26415.42	5541.06	10.01
0.5583	43.67	1.08182	28374.75	6344.14	10.99
0.6019	43.64	1.14591	31475.11	7557.20	11.92
0.6364	43.62	1.21181	34223.00	8690.00	12.90
0.6718	43.59	1.27954	37122.01	9954.70	14.06

0.7082	43.56	1.34908	40175.52	11359.96	15.22
0.7454	43.52	1.42044	43386.95	12917.65	16.43
0.7836	43.48	1.49362	46759.59	14639.46	17.71
0.8227	43.43	1.56863	50296.71	16537.61	19.05
0.8628	43.39	1.64546	54001.48	18624.87	20.46
0.9037	43.33	1.72413	57876.98	20914.52	21.92
0.9455	43.27	1.80463	61926.41	23420.46	23.46
0.9883	43.21	1.88698	66152.44	26156.98	25.08
1.0319	43.14	1.97116	70558.13	29139.02	26.73
1.0764	43.06	2.05724	75146.50	32382.07	28.46
1.1218	42.98	2.14518	79920.19	35902.15	30.27
1.1681	42.89	2.23500	84881.94	39715.76	32.15
1.2152	42.80	2.32673	90034.31	43839.97	34.10
1.2633	42.69	2.42036	95379.95	48292.58	36.13
1.3122	42.58	2.51594	100920.75	53091.59	38.23
1.3615	42.45	2.61346	106599.95	58255.79	40.46
1.4125	42.32	2.71296	112595.50	63696.41	42.85
1.4640	42.18	2.81447	118741.38	69506.09	44.98
1.5163	42.03	2.91800	125088.31	75634.06	47.38
1.5699	41.88	3.02360	131661.50	82096.81	49.86
1.6234	41.69	3.13130	138483.56	88904.00	52.43
1.6783	41.50	3.24113	145576.19	96024.00	55.07
1.7337	41.29	3.35315	152961.31	103312.75	57.79
1.7904	41.08	3.46739	160660.50	111535.81	60.56
1.8476	40.85	3.58390	168775.44	120515.19	63.48
1.9057	40.60	3.70276	177207.88	130471.06	66.44
1.9646	40.34	3.82402	186058.94	141392.19	69.49
2.0243	40.05	3.94775	195329.44	153238.00	72.62
2.0848	39.75	4.07403	205022.56	166088.81	75.84
2.1460	39.43	4.20295	205737.75	180020.69	79.14
2.2081	39.09	4.33461	217070.69	195059.19	82.53
2.2709	38.73	4.46911	227040.25	207831.00	86.00
2.3344	38.35	4.60657	236429.81	222562.65	89.56
2.3988	37.93	4.74713	246045.81	239081.81	93.20
2.4638	37.50	4.89093	255889.00	256415.75	96.93
2.5297	37.03	5.03814	265959.88	271592.25	100.74
2.5962	36.54	5.18895	276259.81	289640.19	104.64
2.6635	36.01	5.34357	286788.13	308587.38	108.63
2.7316	35.45	5.50225	297546.25	328463.83	112.71
2.8003	34.85	5.66525	308533.69	349270.94	116.87
2.8698	34.21	5.83289	319750.94	371117.56	121.12
2.9400	33.53	6.00553	331197.94	393955.25	125.45
3.0103	32.80	6.18360	342875.44	417860.00	129.88
3.0824	32.02	6.36756	354782.44	442800.94	134.39
3.1546	31.19	6.55805	366919.06	468869.31	138.98
3.2275	30.30	6.75571	379285.19	496070.25	143.67
3.3011	29.33	6.96139	391860.25	524450.88	148.44
3.3754	28.30	7.17612	404704.75	554024.69	153.30
3.4503	27.18	7.40117	417750.19	584820.44	158.24
3.5258	25.96	7.63610	431035.25	616893.63	163.27
3.6020	24.62	7.88223	444541.63	650251.38	168.39
3.6789	23.16	8.13720	458273.09	684931.03	173.59
3.7563	21.53	8.40007	472230.63	720966.44	178.88
3.8344	19.70	8.76168	486411.56	758380.69	184.25
3.9131	17.59	9.11331	500815.13	797225.13	189.70
3.9923	15.10	9.51753	515441.06	837507.44	195.24
4.0722	11.94	10.00894	530280.44	879270.00	200.87
4.1527	7.50	10.69701	545352.00	922542.88	206.57

CASK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CU. IN.	OFF ORIENTATION DEGREES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION X G
14.100	30.875	2640.0	28000.0						
0.000	43.02	0.00094	0.0				0.0	0.0	0.0
0.000	43.02	0.00378	24.23				0.02	0.02	0.01
0.000	43.02	0.00449	104.44				0.18	0.18	0.04
0.000	43.02	0.01510	274.49				0.64	0.64	0.10
0.000	43.02	0.02259	569.08				2.71	2.71	0.21
0.000	43.02	0.03397	1009.78				7.01	7.01	0.38
0.000	43.02	0.04024	1637.67				13.54	13.54	0.62
0.000	43.02	0.06038	2484.20				30.67	30.67	0.94
0.000	43.02	0.07041	3579.92				50.42	50.42	1.36
0.000	43.02	0.08032	4950.73				93.02	93.02	1.60
0.000	43.02	0.11411	6646.43				150.98	150.98	2.52
0.000	43.02	0.13777	8080.65				244.27	244.27	3.29
0.000	43.02	0.15931	11090.79				360.02	360.02	4.20
0.000	43.02	0.15473	13000.13				533.62	533.62	5.27
0.000	43.02	0.21202	17163.95				750.47	750.47	6.50
0.000	43.02	0.24118	20839.17				1048.07	1048.07	7.91
0.000	43.02	0.27221	25114.34				1423.11	1423.11	9.51
0.000	43.02	0.30511	29870.40				1898.29	1898.29	11.51
0.000	43.02	0.33738	35167.29				2492.27	2492.27	13.53
0.000	43.02	0.37051	41095.68				3225.99	3225.99	15.57
0.000	43.02	0.41302	47624.59				4122.37	4122.37	18.04
0.000	43.02	0.45540	54805.18				5207.05	5207.05	20.76
0.000	43.02	0.49709	62605.49				6507.93	6507.93	23.74
0.000	43.02	0.54178	71234.88				8055.43	8055.43	26.98
0.000	43.02	0.58779	80542.50				9862.73	9862.73	30.51
0.000	43.02	0.63569	90616.75				12025.72	12025.72	34.32
0.000	43.02	0.68548	101485.88				14223.00	14223.00	38.44
0.000	43.02	0.73719	113177.38				17410.31	17410.31	42.87

0.4145	43.34	0.75081	125719.25	20750.19	47.62
0.4434	43.25	0.84636	139138.81	24572.34	52.70
0.4732	43.15	0.90387	153462.75	28933.68	58.13
0.5039	43.03	0.96336	168717.25	33808.07	63.91
0.5356	42.90	1.02484	184925.94	39493.04	70.05
0.5683	42.75	1.08835	202123.25	45809.18	76.50
0.6019	42.58	1.15392	220325.75	52900.66	83.40
0.6364	42.39	1.22160	239561.00	60634.89	90.74
0.6718	42.18	1.29143	259854.06	69082.75	98.43
0.7082	41.94	1.36347	281220.63	78219.56	106.53
0.7454	41.68	1.43777	303708.63	90423.38	115.04
0.7830	41.39	1.51441	327317.13	102475.63	123.98
0.8227	41.06	1.59348	352070.94	115762.75	133.36
0.8626	40.70	1.67507	378010.31	130373.56	143.19
0.9037	40.30	1.75928	405138.88	146401.13	153.40
0.9455	39.86	1.84626	433484.88	163642.63	164.20
0.9883	39.37	1.93615	463067.25	183098.25	175.40
1.0314	38.83	2.02912	493907.13	203972.69	187.09
1.0754	38.24	2.12539	526025.81	226673.88	199.25
1.1218	37.58	2.22519	559441.56	251314.44	211.91
1.1691	36.86	2.32882	594173.69	278009.55	225.07
1.2172	36.06	2.43661	630240.50	306879.44	238.73
1.2653	35.17	2.54899	667659.56	338047.25	252.90
1.3122	34.19	2.66647	706445.38	371640.50	267.59
1.3613	33.11	2.78908	746619.73	407789.81	282.81
1.4125	31.80	2.91943	788190.81	446630.13	298.50
1.4640	30.35	3.05677	831189.75	488299.75	314.84
1.5163	29.04	3.20306	875618.19	532441.75	331.67
1.5695	27.33	3.36022	921490.75	580701.50	349.05
1.6234	25.37	3.53094	968824.94	631727.13	366.98
1.6783	23.10	3.71941	1017033.50	686173.63	385.47
1.7339	20.41	3.93253	1067929.00	744190.88	404.52
1.7904	17.03	4.18352	1119723.00	805956.31	424.14
1.8476	12.62	4.50493	1173028.00	871815.00	444.33
1.9057	4.26	5.07745	1227855.00	941341.13	465.10

9.4 Operating and Inspection Procedures

Transuranium Processing Plant
 ORNL NOS. 4S2-209, 210 and 213
 DOT APPROVED 5461
 ORNL DWG. NO. 12175-CP-073E

PROCEDURE FOR USE OF: TRU CURIUM SHIPPING CONTAINER

Shipping Container No. _____

Date	Time	By	
1. _____	_____	_____	Materials to be shipped _____; quantity _____; to _____.
1a. _____	_____	_____	Quantity Certified by _____.
2. _____	_____	_____	Move carrier to loading area following clothing procedures of that area.
3. _____	_____	_____	With health physics personnel present, remove hex nuts from plug cover and remove cover.
4. _____	_____	_____	Remove hex nuts from plug.
5. _____	_____	_____	While surveying with cutie pie carefully remove plug Rdg. _____ mrem.
6. _____	_____	_____	Have cavity smeared for alpha and gamma contamination. _____ c/m/cm ² alpha _____ c/m/cm ² gamma
7. _____	_____	_____	Clean if above smears exceed 30 c/m/cm ² alpha and 300 c/m/cm ² gamma.
8. _____	_____	_____	Plug gasket seating surfaces clean and do not need repair.
8a. _____	_____	_____	Plug gasket present and in good condition.
9. _____	_____	_____	Using appropriate procedures to limit personnel exposure to < 20 mrem, load material into cavity. Exposure _____ mrem.
10. _____	_____	_____	Replace plug into carrier.
11. _____	_____	_____	Carrier loaded shall not have over the following readings. 200 mr at surface. 10 mr at 3 ft.
12. _____	_____	_____	Replace hex nuts on plug studs and tighten.

Shipping Container No. _____

	Date	Time	By	
13.	_____	_____	_____	Cover gasket seating surfaces clean and do not need repair.
13a.	_____	_____	_____	Cover gasret present and in good condition.
14.	_____	_____	_____	Replace cover and tighten hex nuts.
15.	_____	_____	_____	Container tied to skid in approved manner.
16.	_____	_____	_____	Approved for shipment.

(This procedure may not be used for shipments of liquids until a letter or procedure has been executed indicating compliance with paragraph 3 of DOT Special Permit 5461.)

ORNL NOS. 452-209, 210 and 213
 DOT APPROVED 546i
 ORNL DWG. NO. 12175-CP-078E

TRU CURIUM SHIPPING CONTAINER

Shipping Container
 Number _____

Inspection Check List

Routine _____

Annual _____

	<u>Date</u>	<u>Time</u>	<u>By</u>	
1.	_____	_____	_____	General condition of carrier checked.
Remarks: _____

_____ |
| 2. | _____ | _____ | _____ | Cover gasket present condition:
_____ good _____ poor
_____ replaced |
| 3. | _____ | _____ | _____ | Plug gasket present condition:
_____ good _____ poor
_____ replaced |
| 4. | _____ | _____ | _____ | Sealing surface condition:
_____ good _____ needs
reworking or cleaning |
| 5. | _____ | _____ | _____ | Nuts condition:
_____ good _____ replaced |
| 6. | _____ | _____ | _____ | Studs condition:
_____ good _____ replaced |
| 7. | _____ | _____ | _____ | Welds inspected (visually)
_____ good _____ need repair
repaired |
| 8. | All needed repairs and final inspections completed. Cask is in good condition to use. | | | |

Approved _____ Date _____

9.5 ORNL-Nuclear Safety Review

REQUEST FOR NUCLEAR SAFETY REVIEW

This request covers operations with fissile material in a control area and/or fissile material transfers that originate within the control area. The control area supervisor shall complete the blocks below and describe the process and/or operations to be performed, emphasizing the provisions for nuclear criticality safety on the reverse side of this page. This request shall be approved by the Radiation Control Officers of the originating Division and of Division(s) having active NSRs in the Control Area.

ORNL	
CRITICALITY COMMITTEE	
NSR NO.	369
<div style="display: flex; justify-content: space-between;"> Submission Date July, 1984 </div>	

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

To be completed by the Control Area Supervisor

TITLE (FOR REFERENCE PURPOSES): TRU Curium Shipping Container		DATE OF REQUEST 10/31/79	DATE REVIEWED 11/15/79
CONTROL AREA: Transuranium Processing Plant (TRU), Bldg. 7220		BALANCE AREA 72	BUILDING NUMBER 7920
TYPE AND FORM OF MATERIAL Isotopes of Pu, Am, Cm, Bk, Cf, Es, and Fm in solid form.		DIVISION Chemical Technology	
ACTIVE NSRs IN THE CONTROL AREA			
NEAR ISOLATED BATCH OR UNIT - MASS AND ISOTOPIC PERCENTAGE			
QUANTITY OF FISSILE ISOTOPES	TOTAL TO BE PROCESSED		
TOTAL FISSILE ISOTOPES IN CONTROL AREA			
Concentration or Density of Fissile Material			
Spacing of Fissile Units			
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material			
Limit on Moderation			
Limit on Neutron Absorbers			
Limit on Volume or Dimensions of Containers			
THIS REQUEST: ☐ Modifies ☐ Replaces NSR No. _____ ☒ New NSR			

RECOMMENDATIONS

(To be completed by the Criticality Committee)

This endorsement is based on our present understanding of the operation (whether acquired verbally or in writing) and is subject to review and cancellation.

Recommended maximum per isolated batch or unit	
Recommended maximum for the Control Area	

This request is approved.

 Chairman, Criticality Committee

4/5/79
 DATE

PROVISIONS FOR NUCLEAR CRITICALITY SAFETY
(To be completed by the Control Area Supervisor)

Provisions for nuclear criticality safety shall be described below in accordance with Appendices II and III of the DOE Manual Chapter 3530. This shall include brief descriptions of the process and/or all operations to be performed, plans and procedures for the operations for nuclear criticality safety, and the basic control parameters. Please attach 11 copies of referenced drawings and documents.

The TRU Cask Shipping Container is used to transport any isotope of plutonium, americium, curium, berkelium, californium, einsteinium, or fermium in a solid form as metal, oxide, or salt.

The maximum quantities of Pu-239, Pu-241, Am-242m, Cm-243, Cm-245, Cm-247, and/or Cf-249 permitted to be shipped is a total of 10 grams; Cf-251 will be limited to 3 grams. The balance of the isotopes is limited by heat evolution with a maximum of 150 W (560 Btu/hr) being allowed. The source strength is limited such that external dose rate will not exceed the level specified in the DOT regulations.

The cask, which is shown on Dwg. M-12175-CF-078-E, consists of a 0.78 m tall cylinder, which has a 0.74 m outside diameter and an internal cavity 152 mm in diameter by 203 mm deep. The shielding consists of approximately 25 mm of lead and 248 mm of Blackburn Limonite concrete. The outside shell and bottom of the cask are type 304L stainless steel, 9.5 mm thick, and the top and inner shell are 6.4 mm-thick 304L stainless steel. The lead on the side and bottom of the cavity is encased in 6.4 mm-thick 304L stainless steel. The inner cavity is closed with a plug made from 6.4 mm-thick 304L stainless steel plate. During construction, the plug was first filled to a depth of 25 mm with lead and then filled with limonite concrete. After the limonite concrete had cured, the top plate was welded on the plug.

ORNL CRITICALITY COMMITTEE
NSR NO. 869
EXPIRATION DATE July, 1984

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR	BUILDING
		<i>Z. King</i>	792
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER	DIVISION
		<i>J. B. Rush</i>	CTD

10. REFERENCES

1. *Code of Federal Regulations*, Title 10, Part 71.
2. *Safety Standards for the Packaging of Fissile and Other Radioactive Material*, DOE Manual Chapter 0529 (June 14, 1973).
3. R. J. Roark, *Formulas for Stress and Strain*, 4th ed., McGraw-Hill, New York, 1965.
4. Seely and Smith, *Advanced Mechanics of Materials*, Table 5, p. 149, 2nd ed., Wiley, New York.
5. S. Crocker, *Piping Handbook*, rev. 4th ed., McGraw-Hill, New York, 1945.
6. S. G. Pearsall, S. Majeski, and L. Gemmel, "Design and Testing of a Shipping Container for Large Quantities of Radioactive Waste," in *Proceedings of the Second International Symposium on Packaging and Transportation of Radioactive Materials*, CONF-68:001 (1968), pp. 624-36.
7. J. H. Faupel, *Engineering Design*, Eq. 8.253, p. 541, Wiley, New York, 1964.
8. D. S. Clark, "The Influence of Impact Velocity on the Tensile Characteristics of Aircraft Materials and Alloys," Tech. Note 868, National Advisory Committee for Aeronautics, Washington, D. C. (October 1942).
9. L. B. Shappert and J. H. Evans, *Analysis of the SARP 25-ton Target Tube Cask*, ORNL/TM-3531 (January 1972), Appendix V, pp. 89-91.
10. M. F. Spotts, *Design of Machine Elements*, 2nd ed., p. 459, Prentice-Hall, London, 1954.
11. H. A. Nelms (thesis), *Structural Analysis of Shipping Casks Effects of Jacket Physical Properties and Curvature on Penetration Resistance*, ORNL/TM-1312, vol. 3 (June 1968).
12. W. D. Turner, D. C. Elrod, and I. I. Simon-Tov, *HEATING5, An IBM 360 Heat Conduction Program*, ORNL/CSD/TM-15 (March 1977).
13. *Seal Compound Manual*, Catalog C5702, Parker Seal Company, Cleveland, Ohio (April 1971).
14. T. N. W. Akroyd, *Concrete, Properties and Manufacture*, p. 265, Pergamon, New York, 1962.

15. Agent R. M. Grazianos' Tariff No. 29, *Hazardous Materials Regulations of the Department of Transportation Including Specifications for Shipping Containers* (issued Dec. 15, 1974; effective Jan. 14, 1975), paragraph 178.34.
16. *Code of Federal Regulations*, Title 10, Part 71, Appendix D.
17. E. D. Clayton, "The Nature of Fission and the Criticality Process (from Protactinium to Californium and Beyond)," *Proceedings of Short Course on Nuclear Criticality Safety*, Taos, NM, May 7-11, 1973, USAEC TID-26286 (1974), p.1.
18. *Code of Federal Regulations*, Title 49, part 173.393 (j).
19. W. D. Box, K. D. Seagren, and C. D. Watson, *The ORNL Chemical Technology Division Quality Assurance Program for Radioactive Material Packaging*, ORNL TM-6471 (September 1979).