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**Safety Analysis Report for Packaging (SARP)
of the Oak Ridge National Laboratory
Shipping Cask D-38**

B. B. Klima
L. B. Shappert
R. D. Seagren
W. D. Box

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SAFETY ANALYSIS REPORT FOR PACKAGING (SARP) OF THE

OAK RIDGE NATIONAL LABORATORY

SHIPPING CASK D-38

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**SAFETY ANALYSIS REPORT FOR PACKAGING (SARP) OF THE
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SHIPPING CASK D-38**

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

ABSTRACT

An analytical evaluation of the Oak Ridge National Laboratory Shipping Cask D-38 (solids shipments) was made to demonstrate its compliance with the regulations governing off-site radioactive material shipping packages. 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 cask complies with the applicable regulations.

1. INTRODUCTION

The ORNL Shipping Cask D-38 was developed at the Oak Ridge National Laboratory. The design was analyzed in 1968¹ and reevaluated in 1974 to demonstrate compliance with the regulations. The results of the analyses are presented in Sects. 2 through 10 of this report. The package was inspected to ensure that it was built in accordance with the drawings presented in Appendix A (Sect. 12.1).

The primary use of the container is to provide shielding, impact resistance, and thermal resistance for its contents during both normal transport and hypothetical accident conditions. The package is designed to ship fissile and large quantities of radioactive materials as solids. The package is authorized to be shipped by vessel and motor vehicle. It complies with the Nuclear Regulatory Commission (NRC) regulations contained in the *Code of Federal Regulations*, Title 10, Part 71,² *Department of Energy (DOE) Manual Chapter 0529*,³ and all Immediate Action Directives (IAD) in effect as of this report date. The cask also complies with U.S. Department of Transportation regulations published in the *Code of Federal Regulations*, Title 49, Part 173.⁴

The package is also certified by the Department of Transportation 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.

Calculations, engineering logic, and all related documents which demonstrate compliance with specifications are presented in subsequent sections of this report. Copies of the approval documents are reproduced in Appendix B (Sect. 12.2).

The shipping container was fabricated and originally assigned ORNL No. 4S1-148. Later, the Department of Transportation assigned Special Permit No. 5787 to the container. An interim certificate of compliance has been issued by the NRC.

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1.1 Description of the Package

The ORNL Shipping Cask D-38 (see Appendix 12.1) is illustrated in Fig. 1.1. The cask consists of a 22-5/8-in.-tall cylinder that has an outside diameter of 12-3/4 in. and a cavity measuring 6-1/16 in. in diameter by 13-13/16 in. deep. It is shielded by 2-3/4 in. of depleted uranium. The outside shell is 0.41-in.-thick (nominal) stainless steel, and the cavity wall is 0.28-in.-thick (nominal) stainless steel. The cask has a depleted uranium-filled closure plug that bolts into the top of the cask. This plug is sealed to the cask body by a neoprene gasket. The top of the cask is protected during shipment by a bolted-down shroud to prevent using the closure-plug lifting ears and the top of the cask lifting trunnions as tie-down points. The shroud is labeled, "Do Not Remove This Cover During Shipping." The shroud nuts are secured by lockwires and seals.

The cavity has a drain to permit water removal should the cask be loaded or unloaded underwater.

The cask has two 1-in.-diam lifting trunnions, each of which has a 3/8-in.-thick by 2-in.-wide outer support strap. The support strap is welded to the body and is given additional support by a triangular 1/2-in.-thick gusset plate.

Figure 1.2 shows the ORNL Shipping Cask D-38 disassembled on its skid with all of its components marked.

1.2 Contents of the Package

The cask is intended to be used to transport fissile and large quantities of radioactive material in the form of solids, including mixed fission products, fuel elements, and waste products. The solids will be shipped inside a spec 2R container or a welded inner container (see Sect. 8) placed inside the inner cavity. "Special Form" solids and "Special Form Containers" may be shipped in the inner cavity. The quantities of fissile materials carried are limited to 500 g of ^{235}U , 350 g of ^{233}U or ^{239}Pu , or 350 g of any combination.

The radioactive material shall not exceed a maximum thermal decay energy of 80 W. Quantities greater than 20 W may be carried only if the package is transported in a vehicle reserved for the sole use of the consignor. The dose rates external to the cask will be limited to those permitted by the Department of Transportation,² (DOT).

2. STRUCTURAL EVALUATION

The package complies with the structural requirements of the regulations (see Sects. 2-6). 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.

Fig. 1.1 Cross section of the ORNL Shipping Cask D-38.

Fig. 1.2 Disassembled view of the ORNL Shipping Cask D-38 and identification of its components.

2.1 Structural Design

2.1.1 Discussion

The as-built drawing for the D-38 cask is shown, and all other applicable drawings are listed in Sect. 12.1. The principal structural members of the cask are: (1) the cylinder of cast uranium, which forms the cask body and its stainless steel cladding; and (2) the closure plug, which consists of one piece of uranium also clad with stainless steel plate.

The uranium used to fabricate the shielding for this cask was depleted to 0.2% ^{235}U .

2.1.2 Fabrication procedure

Cask body. The 300-series stainless steel outer shell of the cask was fabricated using 12-in. sched 30 pipe to which was welded the 3/8-in.-thick bottom plate and the lifting trunnions. After assembly of this weldment, the interior of the outer shell was machined to ensure a 10-mil-diam clearance between it and the outer diameter of the uranium casting.

The 300-series stainless steel inner shell and top were welded as a unit; the outer diameter of the shell was then machined to ensure a 10-mil-diam clearance between it and the inside diameter of the uranium casting.

The hole for the drain tube was machined into the uranium casting; the entire casting was inspected for flaws, cracks, and other discontinuities and was found to be suitable for the shield of the D-38 cask.

The uranium casting was assembled inside the outer shell; the inner shell was then inserted into place. The drain tube was inserted into its prepared hole, and a seal weld was made to join the inner shell and the drain tube. After inspection of the weld, the exterior of the drain tube was seal welded to the outside of the cask. After inspection of the second weld, the final seal weld was run between the top of the outer shell and the top plate of the inner shell; this weld was not a full-penetration weld.

Cask cover. The closure plug was constructed in the same manner as the body. The top plate and outer shell were machined after fabrication to provide a 10-mil-diam clearance between the uranium casting and the plug assembly. After assembly of the uranium in the plug, the bottom closure plate was seal welded to the plug; this was not a full-penetration weld.

2.1.3 Eutectic formation

At an interface of stainless steel and uranium, an alloy with a melting point of about 1450 F can be formed under certain conditions. In the D-38 cask, this possibility is minimized because of the gap designed into the cask between the stainless steel weldment and the uranium shield. Helium was used to fill the gaps between the uranium shield and the stainless steel weldment. The helium atmosphere prevents oxidation of the uranium metal.

Tests have shown that after a sample sandwich of 304 stainless steel and uranium was heated to 1475°F for 1 hr, a small amount of eutectic was formed.⁶ It should be noted that in this test sandwich, the surfaces of the stainless steel and the uranium were honed for intimate contact. In the D-38 cask there is a 10-mil gap between the component parts; since stainless steel has a greater thermal coefficient of expansion, this gap will increase slightly between the outer shell and the uranium shield (see Table 2.1 in Sect. 2.3).

The fire in the "hypothetical accident" (discussed in Sect. 6.3) is of only a 30-min duration, and it is possible that some eutectic will be formed; however, (1) the removal of metal due to the eutectic formation is expected to be less than 1/4 in., and the cask shielding would still be adequate to shield the source without exceeding the requirements of DOE Manual, 0529; and (2) the tests⁶ indicate that insufficient eutectic would be formed under ideal conditions in a 30-min fire to erode through the sched 30 outer stainless steel shell.

2.1.4 Thermal cycling growth

The uranium metal, as cast, probably has radially orientated columnar crystals. Under adverse thermal cycling conditions, this type of crystal orientation could produce some alterations in the dimensions of the uranium castings.⁷ It has been noted that if the top temperature of cycling never exceeds 300 to 350°C (572 to 662°F), growth by thermal cycling is negligible.⁷ The temperatures experienced in normal transport are well below that range. The temperatures associated with the hypothetical accident thermal test are above that range, and a change in the size of the uranium castings can be expected. Should an actual fire befall the cask, the change in uranium casting size will depend on the rate of temperature rise, the duration and top temperature reached, and the rate of cooling. In any case, one cycle in which thermal ratcheting occurs will produce no effect on the integrity of the cask since the thermal expansion stresses will be at a minimum due to the similarity of physical properties of depleted uranium and 304L stainless steel.

2.2 Cask Weight

The weight of the package, its parts, and the contents are shown in Table 2.2.

2.3 Mechanical Properties of Materials

The mechanical properties of uranium and stainless steel are summarized in Table 2.1.

Table 2.1. Mechanical properties of uranium and stainless steel

Properties	Symbol	Stainless steel	
		300 series	Uranium ^a
<u>Static properties</u>			
Tensile yield stress, psi	σ_y	$30 \times 10^3{}^b$	$25 \times 10^3{}^c$
Allowable shear stress, psi	τ_a	$15 \times 10^3{}^d$	
Ultimate shear strength, psi	τ_u	$61 \times 10^6{}^b$	$35 \times 10^3{}^e$
Young's modulus, psi	E	$30 \times 10^6{}^b$	$24.7 \times 10^6{}^c$
Poisson's ratio	ν	$0.3{}^b$	$0.23{}^c$
Weight density, lb/in. ³	γ	$0.283{}^b$	$0.61{}^f$
Thermal expansion coefficient, °F	α	$9.6 \times 10^{-6}{}^b$	$8.04 \times 10^{-6}{}^g$
<u>Dynamic properties</u>			
Specific energy, in.-lb/in. ³	S min	$10 \times 10^4{}^e$	$4 \times 10^4{}^e$
	S max	$26 \times 10^4{}^e$	$12 \times 10^4{}^e$

^a Beta heat treated and oil quenched.

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

^c A. N. Holden, Physical Metallurgy of Uranium, Addison-Wesley, Reading, Mass., 1958.

^d Fifty percent of tensile stress.

^e J. A. Boutlet, J. H. Evans, and K. K. Chipley, Safety Analysis Report for Packaging: The ORNL Uranium-Shielded Shipping Cask, ORNL/ENC/TM-4 (1977).

^f Handbook of Chemistry and Physics, 45th ed., Chemical Rubber Co., Cleveland, 1964.

^g C. R. Herrington and A. E. Ruehle, Uranium Production Technology, Van Nostrand, New York, 1959.

Table 2.2. Weights of cask and contents

Component	Weight (lb)
Shroud	50
Cask body (without closure plug)	1100
Closure plug	150
Total cask weight	1300
Approximate weight of contents	50
Total weight	1350
Skid	175
Total shipping weight	1525

2.3.1 *Dynamic properties of uranium*

The literature contained little data concerning the dynamic compressive properties of uranium; however, tensile strength data were found in refs. 7-10. The uranium in the D-38 shipping container was cast in a graphite mold, and the grains in the casting are probably aligned. Tensile strength data for this material are plotted in Fig. 2.1. Conservative approximations for these data are shown in Figs. 2.1 (dashed line) and 2.2. Figure 2.2 also shows compressive curves obtained by multiplying the tensile stresses by $(1 + \epsilon)/(1 - \epsilon)$. It is assumed that the true stress-strain properties of the material are the same for tension and compression.

2.3.2 *Shear strength of uranium*

Information on the direct measurement of the ultimate shear strength of uranium was unavailable in the literature; however, ref. 11 indicates that, in general, ultimate shear strength is approximately 70% of ultimate tensile strength. Furthermore, since tensile specimens generally fail along a plane inclined 45° from the specimen axis, the ultimate shear strength (τ_u) is found as follows:

Fig. 2.1 Tensile strength data for uranium.

Fig. 2.2 Uranium stress-strain curves.

$$\tau_u = \sigma_u \cos 45^\circ = (50,000)(0.7) = 35,000 \text{ psi.} \quad (1)$$

where

σ_u = ultimate tensile strength, 50,000 psi.

3. GENERAL STANDARDS FOR ALL PACKAGES

The general standards for all packaging cover the chemical and galvanic reaction of the materials of the package, closure of the package, and the lifting and tie-down devices for the package.

3.1 Chemical and Galvanic Reactions

The package is fabricated from stainless steel and depleted uranium. The oxidation of uranium in air at elevated temperatures was recognized in the design; therefore, the atmosphere that is used to envelop the uranium is helium. The uranium is completely clad with stainless steel plate. The cask was built using full penetration welds; the exception was the final closure weld in which penetration was about 0.5 in. Recently, the shielding cavity was evacuated to determine that no weld had failed during previous operations with the cask and to backfill with helium to prevent oxidation of the uranium. Thus, no oxide film should form on the uranium.

When uranium is in contact with stainless steel, it exhibits a tendency to alloy at the interface at a temperature of about 1450°F (see Sect. 2.1.3). Under normal conditions of transport, cask temperatures should not exceed 300°F. Therefore, no reaction between the uranium and the stainless steel is possible.

The fissile and radioactive contents of the package are in solid form and are contained in inner containers (see Sect. 8). "Special Form" material may also be shipped in this package as well as material in "Special form containment." These containers and material will be in contact with the stainless steel cladding and will not react with the cladding.

Experience and inspection have indicated no chemical, galvanic, or other reaction between the cladding and the containers, or between the containers and their solid contents.

3.2 Package Closure

The standards specify that the package shall be equipped with a positive closure that will prevent inadvertent opening. The package closure is held in place by eighteen 1 1/2 in. by 13-NC studs. Two of the studs are short and the nuts rest directly on the top flange of the closure plug. The other 16 studs have a 3 1/4-in. tall by 1-1/8-in.-OD spacer between the plug top flange and the nut to provide an increased energy absorption capacity. Six of the taller studs are extra long to allow space for the protective shroud and the additional nuts that will hold this shroud in place. All of the studs are drilled and the nuts are slotted so that each nut can

be equipped with a seal wire. The cask closure is sealed with a 1/8-in.-thick neoprene gasket. Thus, with the nuts of the cover and the shroud safety wired, this package is equipped with a positive closure that will prevent inadvertent opening.

3.3 Package Lifting Devices

If there is a system of lifting devices that is a structural part of the package, the regulations require that this system shall 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.

A total weight of 1350 lb (see Table 2.1) was used for the cask and contents. The loading or force is calculated as follows:

$$P = FW = 3(1350) = 4050 \text{ lb.} \quad (2)$$

where

P = loading, lb.

F = factor, 3.

W = weight of cask and contents (see Table 2.2), 1350 lb.

A computational model of one of the cask lifting devices or trunnions is shown in Fig. 3.1. The approach used to analyze the casklifting device is similar to that used for a propped beam. The deflection, Δ , of the unrestrained end (the left end in Fig. 3.1) of the beam (1-in.-diam rod) is numerically equal to the elastic elongation of the 3/8 x 2 x 2-1/2 in. bar securing the left end. An expression for the elongation of the bar may be written as follows:

$$\Delta = -\epsilon L_b = (-S/E)L_b = -RL_b/AE = -R(2.50)/(0.75) \times 10^{-6} = -1.111(10^{-7})R \text{ in.,} \quad (3)$$

where

ϵ = strain, in./in.,

L_b = length of bar, 2.5 in.,

S = stress, psi,

E = modulus of elasticity, 30×10^6 lb/in.²,

R = reaction, lb. and

A = cross-sectional area of bar, 0.75 in.².

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Fig. 3.1 Model of cask lifting trunnion.

This beam was analyzed¹ and equations were derived to permit the calculation of R, as follows.

$$\Delta = RL^3/3EI - 5PL^3/48EI, \quad (4)$$

where

L_t = trunnion length, 1.5 in.,

I = moment of inertia, in.⁴.

Equating Eqs. (3) and (4), we find

$$RL^3/3EI - 5PL^3/48EI = 1.111(10^{-7}) R. \quad (5)$$

$$\text{Substituting, } R(1.5)^3/3(30 \times 10^6)\pi/64 - 5(4050)(1.5)^3/48(30 \times 10^6)\pi/64 + 1.111(10^{-7})R = 0$$

$$7.64R - 9673 + 1.11R = 0$$

$$R = 9673/8.75 = 1106 \text{ lb.}$$

The moment of inertia

$$I = \pi d^4/64 = \pi(1)^4/64 = \pi/64. \quad (6)$$

where

d = diameter of trunnion, 1 in.

Therefore, the reaction, V , at $X = 0$ is

$$V = P - R = 2944 \text{ lb.} \quad (7)$$

and the moment due to V at $X = 0$ is

$$M_V = RL_t - P L_t/2 \quad (8)$$

$$= 1106(1.5) - 4050/2(1.5)$$

$$= 1660 - 3038 = -1378 \text{ in.-lb.}$$

The moment at the midpoint of the trunnion is

$$M = kL_t/2 = 1106(1.5/2) = 830 \text{ in.-lb.} \quad (9)$$

Load, shear, and moment diagrams for the cask lifting trunnion are shown in Fig. 3.2.

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Fig. 3.2 Load, shear, and moment diagrams for cask lifting trunnion.

The maximum bending stress, S_b , in the cask lifting trunnion occurs at the midpoint, $X = L/2$, where the bending is maximum.

$$S_b = Mr/I = 830(0.5)/\pi(0.5)^4 = 8459 \text{ psi.} \quad (10)$$

where

r = radius of the beam, 0.5 in.

The maximum horizontal shearing stress (maximum shearing stress, S_s) occurs in the length from $X = 0$ to $X = L/2$ at the neutral axis of the section where the bending stress is 0. That is,

$$S_s = 1.38 V/\pi r^2 = 1.38(2944)/\pi(0.5)^2 = 5175 \text{ psi.} \quad (11)$$

where

r = radius of the trunnion, 0.5 in.

Since the maximum shearing stress, S_s , is below the allowable shear stress for stainless steel (see Table 2.1), it is concluded that the cask lifting device exceeds the requirements.

The ratio of the trunnion to outer-shell welds was considered. Since the trunnion (see Fig. 1.1) is recessed in the outer shell, the welds are considered to be adequate for the vertical loads imposed. Should the package lifting device fail due to excessive load, containment would not be lost and the ability of the package to meet the other requirements would not be impaired.

3.4 Closure-Plug Lifting Device

If there is a system of lifting devices that is a structural part of the lid (closure plug) only, the regulations require that this system shall be capable of supporting three times the weight of the lid (closure plug) and any attachment without generating stress in any material of the lid in excess of its yield strength. It is further required that, unless rendered useless for lifting during transport of the package, the lid lifting or any other system of lifting devices shall conform to the requirements for the package lifting system.

The cask analyzed in this study has two closure-plug lifting ears, as shown in Fig. 3.3.

It is assumed that the closure plug is lifted with a 45° two-leg sling. The resulting load on the ears is illustrated in Fig. 3.3.

The load on the lifting ear may be calculated by:

$$P = 3W_L/2 \sin 45^\circ = 3(150)/2(0.707) = 320 \text{ lb.} \quad (12)$$

(a) CLOSURE PLUG LIFTING EAR

(b) STRESS DISTRIBUTION
AT PLANE A-B

Fig. 3.3 Analytical model of the closure-plug lifting ear.

where

P = load on ear at 45° , lb.

W_L = weight of lid (see Table 2.2), 150 lb.

The load may be broken into vertical (v) and horizontal (h) components as follows:

$$P_v = P \sin 45^\circ = 225 \text{ lb.} \quad (13)$$

$$P_h = P \cos 45^\circ = 225 \text{ lb.} \quad (14)$$

The vertical component, P_v , will result in bending stress in the portion of the ear above plane AB, and this must be analyzed by using curved-beam theory. Plane AB is loaded in tension, and the exact distribution is unknown. Observation of data on plates with a large width-to-hole-diameter ratio leads to the conclusion that a good approximation of the distribution may be made by assuming a parabolic distribution of the form

$$S = (X^2/a) - S_o, \quad (15)$$

where

S = stress on inside fibers, psi.

X = amount of metal above plane AB, 0.25 in.,

a = constant, (to be determined),

S_o = stress on outside fibers, psi.

The stress in the outside fibers, S_o , is determined as follows:

$$S_o = P_v/tL = 225 (0.50)(1.25) = 360 \text{ psi,} \quad (16)$$

where

t = thickness of lifting ear,

L = width of lifting ear,

The constant, a , is determined as follows:

$$P_v/2 = \int tS \, dx. \quad (17)$$

Substituting Eq. (15) into Eq. (17), and establishing the limits of x ,

$$P_z/2 = \int_0^{x=0.25} [bx^2 + a + S_y] dx \quad (18)$$

Integrating and solving for a , we find:

$$a = \left(\frac{X^3}{3} \right) \frac{1}{(P_z/2) - S_y X} = \frac{(0.25)^3}{3} \left(\frac{1}{[225/2(0.5)] - 360(1.4)} \right) = 3.86 \times 10^{-6} \quad (19)$$

At $X = 0.25$, on plane AB, substituting in Eq. (16), we find S_T (total stress):

$$S_T = (0.25)^2 / (3.86 \times 10^{-6}) + 360 = 1980 \text{ psi.} \quad (20)$$

and the average stress on plane AB is:

$$S_{avg} = P_z / (L - d) = 225 / 0.5(1.25 - 0.75) = 900 \text{ psi.} \quad (21)$$

where

d = diameter of hole in ear, 0.75 in. at point 5.

The shearing stress on plane AB is:

$$S_s = P_s / A = 225 / 0.5(0.25) = 1800 \text{ psi.} \quad (22)$$

where

A = area of metal ear

and

$$S_{max} = S_T/2 + (S_T^2/2 + S_s^2)^{1/2} = (1980/2) + [(1980/2)^2 + (1800)^2]^{1/2} = 3040 \text{ psi.} \quad (23)$$

The stress concentration factor (K) for the assumed parabolic stress distribution is

$$K = S_T / S_{avg} = 1980 / 900 = 2.20. \quad (24)$$

The notation used in ref. 12 was used to check the assumption of a parabolic loading distribution on plane AB.

$$H/L = 0.625 / 1.25 = 0.5, \quad (25)$$

where

H = distance from center of hole to end of plate, 0.625 in.,

L = width of plate, 1.25 in.,

$$2r/L = 0.75/1.25 = 0.6.$$

From these data and Fig. 2-7 in *Design of Machine Elements*,¹³ K is calculated to be 2.3. It can thus be seen that the assumption of the curve equation was reasonably accurate. The bending moment caused by this distribution at the center line [the position of maximum moment; see Fig. 3.3(b)] is found by

$$M_{max} = t \int_0^{0.25} bS \, dX = t \int_0^{0.25} [L/2 - X] S \, dX \quad (27)$$

Substituting in Eq. (15) and integrating between limits, it is found that

$$M_{max} = 17 \text{ in.-lb.}$$

The moment of inertia is determined as follows:

$$I = 1/12 t(r - L/2)^3 = 1/12 (0.5)(0.625 - 0.75/2)^3 = 6.5 \times 10^{-4} \text{ in.}^4. \quad (28)$$

Using the data in ref. 14,

$$r/c = 0.5/0.125 = 4 \quad (29)$$

where

r = distance from centroid to neutral axis,

c = distance from neutral to outer fiber,

K = stress concentration factor, 1.29.

The maximum bending stress

$$S = -K Mc/I = \left[-1.2(17)(0.125) \right] / (6.5 \times 10^{-4}) = -3920 \text{ psi.} \quad (30)$$

All stresses are below the limits shown in Table 2.1. It is thus concluded that the closure-plug lifting ear exceeds the regulation requirements, since all the stresses are less than the yield stress of 300-series stainless steel.

The 3/16-in. fillet weld (1800-lb allowable load per linear inch)¹⁵ that secures the ear to closure plug is 3.5 in. long for each of the two ears. Each of the ears is therefore capable of a shear load of 6300 lb. It is, therefore, apparent that the welds are sufficiently strong and that they meet other requirements of the regulation.

Should the lifting ear or the weld fail due to excessive load, containment would not be lost and the ability of the package to meet other requirements would not be impaired.

3.5 Tie-down Device

The regulations require that if there is a system of tie-down devices which is a structural part of the package, this system shall be capable of withstanding a static force applied to the center of gravity of the package with a vertical component of two times the weight of the package and its contents, a horizontal component along the direction of travel of ten times the weight of the package and its contents, and a horizontal component in the transverse direction of five times the weight 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 ORNL Shipping Cask D-38 is normally shipped bolted to its skid as shown in Fig. 1.2. The overall plan for tying the cask to the vehicle is shown in Fig. 3.4. Four wire ropes tie the skid to the vehicle (wire ropes 1, 2, 3, and 4). In addition, two wire ropes run through the opening below the trunnions and tie the cask directly to the vehicle (wire ropes 5 and 6). The manner in which the wire ropes pass through the opening below the trunnions and the way the shroud denies use of the top of the trunnion as a tie down are shown in Fig. 3.5.

To demonstrate the adequacy of the tie-downs, calculations show that bolting the tie-down to the skid is adequate and that the stresses in the cask body resulting from the wire rope tie-down are acceptable.

3.5.1 Tie down of cask to skid

The system used for tying the cask to the skid that was analyzed in this study consists of four 1 in. by 8-NC bolts that are used to secure the cask, as shown in Fig. 3.6.

To analyze the tie-down system, the cask is considered to be a cantilevered beam. At the plane of attachment, this hypothetical beam consists of the bolts loaded in tension and a strip, a_x or a_y , loaded in compression. The X, Y, and Z direction solutions are superimposed to determine the maximum stress, which occurs in the left rear bolt. The neutral axes of the

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Fig. 3.4 Plan for tie down of the ORNL Shipping Cask D-38 to the vehicle.

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Fig. 3.5 Cask tie down below trunnions.

(DIMENSIONS IN INCHES)

Fig. 3.6 Bolting pattern and computational model for analysis of cask tie down to skid.

sections occur at the centroids of the stressed areas. For a first trial, it was assumed that only the rear bolts in each direction are loaded; that is, the forward bolts are in the compression area and, therefore, are not loaded. The reduction in the compression area resulting from the presence of the bolt holes was not considered. The moments about the X_c axis are determined:

$$\left[(a_x)^2 b + 2 \right] + 2A_b a_x - 2A_b b_{2x} = 0, \quad (31)$$

where A_b = tensile area of a 1-in. by 8-NC bolt, 0.606 in.²,¹⁵ thus

$$\begin{aligned} 14 + 2(a_x)^2 + 2(0.606)a_x - 2(0.606)(12.75) &= 0 \\ 7a_x^2 + 1.212a_x - 15.453 &= 0, \\ (a_x)^2 + 0.173a_x - 2.208 &= 0. \end{aligned}$$

Using the quadratic formula and rejecting the negative solution,

$$a_x = -0.173 + [(0.173)^2 - (4)(1)(-2.208)]^{1/2} = 1.40.$$

Since $a_x = 1.40 > b_{1x} = 1.25$, the assumption that the forward bolts were not loaded was correct. By symmetry,

$$a_x = a_y = 1.40 \quad (32)$$

Computing the moments of inertia $I_x = I_y$,

$$\begin{aligned} I_x &= 1/3(a_x)^3 b + 2A_b(b_{2x})^2 \\ &= 1/3(1.40)^3(14) + 2(0.606)(12.75 - 1.40)^2 = 169 \text{ in.}^4. \end{aligned} \quad (33)$$

The bending stress

$$S_B = Mc/I, \quad (34)$$

$$S_{B \max} = 10WZ(b;x)/I_x + 5WZ(b;y)/I_y. \quad (35)$$

Since $I_{yx} = I_y$, $b_{2x} = b_{2y} = b$,

$$\begin{aligned} S_{B \max} &= 10WZb_2/I(1.5) \\ &= 10(1350)(10.5)(11.35)(1.5)/169 = 14,300 \text{ psi.} \end{aligned}$$

where W = weight of cask plus contents, 1350 lb.

The direct tensile stress, S_T , is equally divided between the four bolts.

$$S_T = \frac{2W}{4A_B} = \frac{2(1350)}{4(0.606)} = 1114 \text{ psi.} \quad (36)$$

The shearing stress, S_s , is also equally divided between the four bolts. The resultant, P , of the 5 and 10 W loads is

$$P = [(10W)^2 + (5W)^2]^{1/2} = 11.18 W, \quad (37)$$

and

$$S_s = \frac{P}{4A_s} = \frac{11.18(1350)}{4(0.785)} = 4800 \text{ psi.} \quad (38)$$

where A_s = shear area (full area) of 1 in. by 8-NC bolt, 0.785 in.².

From Mohr's circle of stress,

$$\begin{aligned} S_{max} &= S_T + S_B/2 + [(S_T + S_B/2)^2 + (S_s)^2]^{1/2} \\ &= 7707 + [(7707)^2 + 4800^2]^{1/2} = 16,800 \text{ psi.} \end{aligned} \quad (39)$$

Since these stresses are below those shown in Table 2.1, the tie-down system exceeds the requirements of the regulations when any grade of steel bolt is used.

3.5.2 Tie down of cask to vehicle

The wire rope can pull against the gusset (see Fig. 3.5) or the body of the cask. The force imposed on the cask and/or the gusset by the wire rope tie-down is then determined. The vertical, forward, and transverse loads (F_z , F_x , and F_y) are determined by assuming the tie-downs are at a 45° angle to the direction of travel and to the vertical direction. These loads will be added and compared to the strength of the weld holding the tie-down to the cask. In the final calculation no additional credit is taken for the skid tie-downs.

Vertical load application. The forces on the tie-down (F_z) resulting from the application of a vertical load applied to the center of gravity of two times the weight of the package are found by a summation of the vertical forces (see Fig. 3.7).

$$\Sigma F_v = 0, + = \uparrow \quad (40)$$

$$\Sigma F_v = 0 = 2W - W - 2F_z$$

$$F_z = \frac{W}{2} = \frac{1525}{2} = 763 \text{ lb.}$$

Fig. 3.7 Forces due to vertical thrust on ORNL Shipping Cask D-38.

where

$\underline{W}$ = cask plus contents and skid weight (see Table 2.2), 1525 lb.

The tension in the wire rope from the $2\underline{W}$ load is

$$T_z = F_z/2(\sin 45^\circ) = 763/2(0.707) = 540 \text{ lb.} \quad (41)$$

Forward load application. The forces on the tie-down (F_x) resulting from the application of a horizontal force applied to the center of gravity in the direction of travel of ten times the weight of the package are found by summing the horizontal forces (see Fig. 3.8).

$$\Sigma F_H = 0, + = - \quad (42)$$

$$\Sigma F_H = 0 = 10\underline{W} - F_x$$

$$F_x = 10\underline{W} = 10(1525) = 15,250.$$

The tension in the cable from the $10\underline{W}$ load is

$$T_x = F_x/2(\cos 45^\circ)(\cos 45^\circ) = 15,250/2(0.707)(0.707) = 15,250 \text{ lb.} \quad (43)$$

Transverse load application. The forces on the tie-down (F_y) resulting from the application of a horizontal force applied to the center of gravity transverse to the direction of travel of five times the weight of the package are found by a summation of the forces in the transverse direction (see Fig. 3.9).

$$\Sigma F_{TV} = 0, + = - \quad (44)$$

$$\Sigma F_{TV} = 0 = 5\underline{W} - 2F_y$$

$$F_y = 5\underline{W}/2 = 5(1525)/2 = 3810 \text{ lb.}$$

The tension in the cable from the $5\underline{W}$ transverse load is

$$T_y = F_y/2(\cos 45^\circ)(\cos 45^\circ) = 3810/(0.707)(0.707) = 7620 \text{ lb.} \quad (45)$$

Combined load application. The forces produced for the forward (T_x), transverse (T_y), and vertical (T_z) applied loads may be added to determine the total tension in the tension member.

$$T_T = T_x + T_y + T_z = 15,250 + 7620 + 540 = 23,410 \text{ lb.} \quad (46)$$

Fig. 3.8 Forces due to forward thrust on ORNL Shipping Cask D-38.

Fig. 3.9 Forces due to transverse thrust on ORNL Shipping Cask D-38.

This load is applied to the cask body and to the weld holding the trunnion to the cask. The force applied to the weld is

$$T_w = 2 T_T \sin 45^\circ = (2)(23,410) (0.707) = 33,100 \text{ lb.} \quad (47)$$

The 5 16-in. fillet weld of the 2- by 3 8-in. bar to the cask (S-1 of Fig. 3.5) is 8 in. long. It is capable (3000 lb allowable shear load per linear inch of weld)¹⁵ of a shear load of 24,000 lb.

The 3 16-in. fillet weld of the gusset to the cask (S-2 in Fig. 3.5) is 5.75 in. long. It is capable (1800 lb allowable load per linear inch of weld)¹⁵ of a shear load of 10,350 lb.

The welds therefore are capable of resisting a total force of 34,350 lb. The tie-downs impose a load of 33,100 lb on the weld. The tie-downs are sufficiently strong to meet the requirements of the regulations.

If the external support strap of the cask lifting trunnion were to pull out of the cask due to excessive loads, containment would not be lost, and the ability of the cask to meet other requirements would not be impaired.

The lifting ear of the cavity closure plug is not strong enough to be used as a package tie down; therefore, a shroud is provided which securely covers this part during transport in such a manner as to prevent its use for that purpose. The shroud is held in place by nuts which have a sealed lockwire.

4. STANDARDS FOR TYPE B AND LARGE-QUANTITY PACKAGING

The structural standards for large-quantity packaging include load resistance of the packaging and the external pressure which the package must withstand. Compliance of the ORNL Shipping Cask D-38 with these requirements is discussed in the following subsections.

4.1 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; it should not generate stress in any material of the cask in excess of the yield strength of that material.

The equivalent cross section of the cask analyzed in this study is illustrated in Fig. 4.1.

The maximum bending moment (M) is at $L/2$.

$$\begin{aligned} M_{max} &= (R_1 L/2) - \omega L^2/8 \\ &= 3380(20/2) - 338(20)^2/8 = 16,900 \text{ in. lb.} \end{aligned} \quad (48)$$

where ω = unit bending load in lbs per lineal in.

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(a) CASK AS SIMPLE BEAM

(b) EQUIVALENT CROSS SECTION OF CASK

Fig. 4.1 Analytical model to determine load resistance of ORNL Shipping Cask D-38.

The moment of inertia, I , of the cross section,

$$\begin{aligned} I &= \pi/4 (r_o^4 - r_i^4) \\ &= \pi/4 (6.375^4 - 3.063^4) = 1228 \text{ in.}^4. \end{aligned}$$

The maximum bending stress, S_b , is

$$S_b = Mr_o / I = 16,900(6.375) / 1228 = 88 \text{ psi.} \quad (50)$$

The maximum horizontal shear, S_x , occurs at each end of the neutral axis.

$$S_x = (4/3)R_1 \pi(r_o^2 - r_i^2) = (4/3)3380 (\pi)(6.375^2 - 3.063^2) = 46 \text{ psi.} \quad (51)$$

The cask exceeds the requirements of the regulations from the standpoint of load resistance.

4.2 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.

The shell of the containment vessel is evaluated from the standpoint of withstanding external pressure with reference to Paragraph UG-28 of the ASME Boiler and Pressure Vessel Code.¹⁶

$$L/d_o = 12/4.75 = 2.52 \quad (52)$$

$$d_o/t = 4.75/0.125 = 39.5. \quad (53)$$

and the maximum allowable working pressure

$$P_a = B D_o / t = 9500/39.5 = 240.5 \text{ psig.} \quad (54)$$

where $B = 9500$ (from Fig. UNF-28.8 on p. 232 of ASME Boiler and Pressure Vessel Code, Appendix V).¹⁶ Since the maximum allowable working pressure on the shell of the containment vessel exceeds 25 psig, it is concluded that the cask exceeds the regulation requirements of the structural standards for external pressure.

External pressure would load the flat ends of the stainless steel cladding. The maximum thickness required for the end plates is calculated from the formula in Paragraph UG-34 of the ASME Boiler and Pressure Vessel Code;¹⁶ since the minimum thickness of either end plate is 0.500 inches, the external container structure and the massive uranium shields provide sufficient support to prohibit significant deflection of the flat ends due to external pressure.

Gaskets have been used at differential pressures significantly greater than 25 psig and have been found to satisfy the requirements. Hence, the regulations are met.

5. 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 so 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 ORNL Shipping Cask D-38 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.

5.1 Heat

The package must be able to withstand direct sunlight at an ambient temperature of 130°F in still air without reducing the effectiveness of the packaging. A modified version of the HEATING-3¹⁷ computer program was used to compute the steady-state temperature distribution in the cask and its contents under the specified conditions.

5.1.1 Thermal properties of materials

The thermal properties of materials used to compute the temperature distribution are listed in Table 5.1.

5.1.2 Thermal model

The computational model representing the ORNL Shipping Cask D 38 is illustrated in Fig. 5.1. The contents were modeled as a homogeneous cylinder with the decay heat-generation rates of 20 W and 80 W uniformly distributed throughout the volume.

It was assumed that natural convection was a significant mode of heat transfer in the larger interior air gaps. Natural convection was neglected in the remaining internal gaps, leaving radiation and conduction as the only modes of heat transfer across these gaps.

In calculating the steady-state temperature for the 130°F environment in direct sunlight, it was assumed that a solar-heat flux of 144 Btu hr⁻¹ft⁻¹ was incident upon the entire outer surface of the cask, and the fraction of the incident solar flux that is absorbed by the cask is equal to the absorptivity (0.6) of the outer surface of the cask. A second steady-state analysis assumed that the ambient temperature was 100°F and that the solar heat load was reduced to zero.

Table 5.1. Thermal properties of materials of construction

Material	Temperature (°F) ^a	Thermal conductivity [Btu hr ⁻¹ ft ⁻¹ (°F) ⁻¹]	Density (lb in. ⁻³)	Heat capacity [Btu lb ⁻¹ (°F) ⁻¹]
SS-304	NTD	9.4	0.29	0.12
Uranium	NTD	19.0	0.683	0.028
Neoprene	NTD	0.11	0.05	0.471
Air ^b	0.0	0.013	4.97 x 10 ⁻⁵	0.239
	200.0	0.017	3.47 x 10 ⁻⁵	
	400.0	0.021	2.46 x 10 ⁻⁵	
	600.0	0.025	2.16 x 10 ⁻⁵	
	800.0	0.029	8.17 x 10 ⁻⁶	0.256
Source	NTD	31.8	0.0361	1.0

^aTemperatures denoted as NTD indicate nontemperature dependent constants.

^bAir fills the large voids in the cavity and its values are used as a substitute for helium in the internal gaps.

Fig. 5.1 Computational model to determine the effect of thermal tests on the ORNL Shipping Cask D-38.

5.1.3 Maximum temperature

Calculated temperatures of points of interest throughout the cask are presented in Table 5.2 for the 130°F ambient plus solar-heat load case as well as for the 100°F ambient-shade case.

The maximum accessible external surface temperature for the 100°F ambient no-solar-heat-load case and using the 80-W approved limit for the cask was found to be 161°F. When the internal heat load was reduced to 20 W, the maximum external temperature was 121°F. Since this is less than the 122°F limit specified by the DOT regulations,¹⁸ the container does not require exclusive use shipping conditions. However, between 20 and 80-W loadings, when the external temperature exceeds 122°F, the container must be shipped in a transport vehicle consigned for the sole use of the consignor. Under these conditions the container complies with the regulations.

For the 130°F ambient solar-heat load case with an internal heat load of 80 W, the maximum calculated temperature of the inner container seal was 290°F, that of the neoprene gasket which forms the closure seal was 242°F, and that of the "O" ring drain seal was 247°F. Since these temperatures are well within the operating limits of the gaskets and seals, the integrity of the cask and its inner container will be unaffected by these thermal boundary conditions. Therefore, the container complies with the regulations.

5.2 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 assuming no internal heat load, 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:

$$P_2 = (P_1 T_2) / T_1 = 11.65 \text{ psia.} \quad (55)$$

The resulting pressure differential is less than the 25-psig differential pressure investigated in Sect. 4.2. 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 under the stipulated cold condition is not likely because the temperatures of these components are above their ductile-to-brittle transition temperatures.

The preceding 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.

5.3 Pressure

The regulations for normal conditions of transport specify that the package should be able to withstand an atmospheric pressure of 0.5 times the standard atmospheric pressure, with the resulting pressure being 7.35 psia.

Table 5.2. Maximum temperatures as a result of computer evaluation of thermal test

	Internal heat load (°F)	
	80 W	20W
<u>100°F - No solar-heat load</u>		
Inner container seal	220	138
External temperature (max)	165	121
<u>130°F - Ambient solar-heat load</u>		
Inner container seal	290	
Neoprene gasket closure seal	242	
"O" ring drain seals	247	

When the model is under full-heat load, trapped air in the cavity will expand and exert internal pressures. Assuming assembly at 70°F and 14.7 psia, the resulting pressure of any trapped air is:

$$P_2 = (P_1 T_2) / T_1 = (14.7)(750) / 530 = 20.8 \text{ psia (13.4 psig)}, \quad (56)$$

where

P_1 = assembly pressure, 14.7 psia,

T_2 = temperature under heat load, 750° R (290° F),

T_1 = assembly temperature, 530° R (70° F).

The cask and its gasketed seals will be able to withstand this pressure without damage or reduction in effectiveness of the packaging, and the container conforms to the requirement for the reduced pressure condition of normal transport (see Sect. 4.2.).

5.4 Vibration

The container is of welded construction and, therefore, vibrations received in transit are not expected to affect the integrity of the cask. In addition, the cask, which was built several years ago, has operated in the transportation environment and has suffered no ill effects as a result of the vibrations that were encountered.

5.5 Water Spray

The containment capabilities of the ORNL Shipping Cask D-38 are not compromised by water spray, since all external surfaces are of stainless steel. The closure seal is impervious to water.

5.6 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 in which maximum damage is expected to result. A free drop of the ORNL Shipping Cask D-38 through a distance of 4 ft is expected to produce only minor denting of the outside steel shell. If the package were dropped flat on its top, repairable external damage would occur; however, the effectiveness of the package would not be reduced. (See the analysis of the 30-ft free fall, Sect. 6.1).

5.7 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 type shipping casks and the results indicate that the effectiveness of the stainless steel jacket will not be reduced. (See appendix 12.7).

5.8 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.

The stress, S_w , is created in the steel shell by a weight imposed on the head of five times the weight of the package. This is determined:

$$S_w = 5(W) \pi(d)(T) = 5(1350) \pi(12)(0.38) = 470 \text{ psi } (<15,000 \text{ psi}), \quad (58)$$

where

W = weight of fully loaded container, 1350 lb,

d = diameter of container, 12 in.,

T = thickness of container shell, 0.38 in.

The stress, S_p , created in the steel shell by a pressure of 2 psi on the head is determined:

$$S_p = 2(\pi d^2) / 4(\pi d)(T) = 2(\pi)(12)^2 / 4(\pi)(12)(0.38) = 16 \text{ psi} (< 15,000 \text{ psi}). \quad (59)$$

The stress developed in the shell by the imposed weight of five times the package weight of 470 psi was greater than the potential stress, and it did not exceed the strength of the shell of the container. No credit for the additional strength resulting from the uranium cask filling was taken.

6. 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 conditions 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.

6.1 Free Drop

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

Damage to the ORNL Shipping Cask D-38 was evaluated by assuming the cask struck the unyielding surface in one of three different orientations. These included impact on: (1) the top corner, (2) the top end, and (3) the side.

6.1.1 Impact on top corner

A computational analysis (see Appendix 12.3) was applied to a simplified cylindrical cask model to estimate the deformation resulting from a 30-ft corner drop (see Fig. 6.1) with its line of action through the center of gravity. Results shown in Table 6.1 indicate that by using

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Fig. 6.1 Deformation geometry for corner impact orientation of cask.

specific energies for stainless steel that vary from 100,000 to 260,000 in.-lb in.³, the deformation would vary from 1.0 to 0.7 in.; this deformation would occur primarily in the steel because of the large bearing area between the steel and the uranium.

When the cask impacts on its top corner with its line of action through the center of gravity, the studs holding the inner cavity plug, the corner of the inner cavity plug flange, and the corner of the cask will all contact the unyielding surface at essentially the same instant, assuming that the steel shroud is neglected. Neglecting the strength of the steel shroud is justified because it is thin, will readily collapse, and is not designed to resist impact forces. As a result, the flange, and, therefore, the inner cavity closure plug will be jammed back into its cask cavity before motion of the plug relative to the cask body can impose a significant load on the studs in tension. In addition, the studs cannot be loaded in shear because of the small clearance that exists between the cask body cavity and the plug. Deformation of the corner of the cask is expected to displace the top steel plate of the cask to further lock the closure plug in place. Because of this combination of effects, the total deformation of the top corner of the cask is expected to be less than that shown in Table 6.1.

It is concluded that the inner cavity plug will remain in place if the cask were to drop on its top corner when the line of action is through the center of gravity.

Table 6.1. Impact on top corner - maximum acceleration and deformation resulting from high and low values of specific energy in stainless steel

Specific energy (in.-lb/in. ³)	Maximum deformation corner drop ^a (in.)	Residual shielding on corner ^b (in.)	Maximum negative acceleration (g)
100,000	0.97	3.50	941
260,000	0.66	3.81	1380

^a Measured along diagonal through center of gravity.

^b Measured from corner to closest proximity to inner cavity; 4.47 in. before drop. This may be compared to a shielding distance of 3.31 in. at the side of the cask.

6.1.2 Impact on top end

The effect of a 30-ft free fall onto the flat top of the cask was investigated to determine whether the cast uranium would fracture.

A computational model of the top end-impact orientation of the cask and idealized stress-strain curves for the two materials, stainless steel and uranium, that are involved are shown in Fig. 6.2. Equations are written for the idealized curves in the slope intercept form of a straight line.

$$S = m\epsilon + S_o \quad (60)$$

$$\epsilon = (S - S_o) / m$$

where

S_o = the S intercept (approximate yield stress) of the line.

m = the slope of (S ultimate - S_o) / ϵ ultimate,

ϵ = strain .

For the stainless steel cladding or outer shell.

$$\epsilon = (S - 40,000 \text{ psi}) / (80,000 - 40,000) = 1.25 \times 10^{-5} S - 0.50.$$

For the uranium biological shielding.

$$\epsilon = (S - 25,000 \text{ psi}) / (90,000 - 25,000) = 1.23 \times 10^{-5} S - 0.05.$$

It was assumed that stress in the column of uranium varies only with time and position, or stated mathematically, $S = f(T, X)$. It was further assumed that the stress in the 0.63-in.-thick stainless-steel-top plate varies only with time; that is, the stainless steel was assumed to be weightless and $S = f(T)$. With this assumption, the compressive stress in the stainless steel, S_{sst} , is equal to the stress in the uranium at $X = L$, the point of maximum stress, S_m , in the uranium. To simplify the mathematics without affecting the accuracy, the area, A , was assumed to be unity. The kinetic energy of the cask must be stored in the uranium body and the stainless-steel-top plate in the form of strain energy.

$$\begin{aligned} u &= \frac{1}{2} M u^2 = \frac{1}{2} \rho L h = \int_0^L F_u d\Delta_u + \int_0^L F_{sst} d\Delta_{sst} \\ &= \int_0^L S_u A(\epsilon) d\epsilon + \int_0^L S_{sst} A(\epsilon) d\epsilon \end{aligned} \quad (61)$$

$$S(X=L) = S_m \quad (62)$$

$$S = S_m X / L$$

Fig. 6.2 Computational model of the top-end impact orientation of cask and idealized stress-strain curves for uranium and stainless steel.

Substituting for S and ϵ and dropping $A = 1$ and $t = 1$, the strain energy,

$$u = \int_{X=L=0}^{X=L=20.1} \left[\frac{S_m X}{L} - \frac{2S_m X}{L} (10^{-6}) - 0.05 \right] dX + S_m [1.25S_m (10^{-5}) - 0.50] \quad (63)$$

$$= \int_{X=L=0}^{X=L=20.1} \left[\frac{2S_m^2 X^2}{L^2} (10^{-6}) - 0.05 \frac{S_m X}{L} \right] dX + 1.25S_m^2 (10^{-5}) - 0.5S_m$$

Integrating,

$$u = \left[\frac{2S_m^2 X^3}{3L^2} (10^{-6}) - 0.05 S_m X^2 / 2L \right]_{X=L=0}^{X=L=20.1} + 1.25S_m^2 (10^{-5}) - 0.5S_m$$

Substituting values

$$1(20.1)(0.61)360 = \frac{2}{3} S_m^2 (20.1)(10^{-6}) - 0.05 \frac{2 S_m (20.1)}{2} + 1.25 \times 10^{-5} S_m^2 - 0.5 S_m$$

Simplifying,

$$S_m^2 - (3.87 \times 10^4) S_m - 1.74 \times 10^5 = 0,$$

and solving the equation, we find

$$S_m = 42,800 \text{ psi.}$$

Since the maximum stress, S_m , is less than the ultimate stress for uranium (see Fig. 6.2), it is concluded that the uranium biological shield will not fracture as a result of the cask impacting on either of its flat ends nor will there be any damage to the shield that could be considered hazardous.

6.1.3 Impact on side

Impact on the side of the cask such that the edge of the skid and the top cover of the cask hit the immovable surface simultaneously (Fig. 6.3) will allow most of the studs to be loaded in tension. The impact forces will be dissipated in bending the skid and deforming the steel corner of the cask. Neglecting the energy absorbed in bending and deforming the skid and assuming all energy is dissipated by deforming the stainless steel in the corner of the cask, a computer analysis was made (see Appendix 12.4) to determine the negative acceleration rates and resultant deformations. Results shown in Table 6.2 indicate that by using specific energies of stainless steel which vary from 100,000 to 260,000 in.-lb in.³ (see Table 2.1), the deformation would vary from 1.1 to 0.7 in.; from Detail A-A it can be seen that this deformation would occur principally in the steel, thus tending to confirm the original assumption.

It will be assumed that the larger calculated negative accelerations will act on the inner cavity plug. The following calculations demonstrate that the bolts are sufficiently strong to hold the plug.

Fig. 6.3 Deformation geometry for side impact orientation of cask.

Table 6.2. Impact on side - maximum acceleration and deformation resulting from high and low values of specific energy in stainless steel

Specific energy (in.-lb/min. ³)	Maximum deformation side drop (in.)	Residual shielding on corner ^a (in.)	Maximum negative acceleration (g)
100,000	1.06	3.37	852
260,000	0.72	3.72	1262

^a Measured from corner to closest proximity to inner cavity, 4.47 in. before drop. This may be compared to a shielding distance of 3.31 in. at the side of the cask.

Using the largest deceleration in Table 6.2 and applying it to the weight of the cask lid and contents, the force, F_p , on the eighteen 1/2-in. studs holding the shielding plug is determined as follows:

$$F_p = W_c \times g = 200 \times 1262 = 252,400 \text{ lb.} \quad (64)$$

where

W_c = weight of plug plus contents of inner cavity, 200 lb.

g = deceleration, 1262.

The force, F_p , is applied to the cask in the direction of the drop. The component, F_d , of that force applied along the axis of the bolts and the plugs is found as follows:

$$F_d = F_p \sin \theta = 252,400 (0.457) = 115,000 \quad (65)$$

where

θ = angle between line of studs and impact surface, 27°.

Sixteen of the studs have an unengaged length of 1-3/8 in. and the other two have an unengaged length of 5/8 in. Each of the 16 long studs has a 3/4-in. washer that has a cross-sectional area of 0.142 in.²,¹⁹ which is the same area as that of the stud. From an energy

storage standpoint, this additional area increases the effective length of the long studs to 2-1 8 in. The studs are made from annealed 4140-series steel that has the idealized stress-strain curve shown in Fig. 6.4.²¹ It is assumed that the two short studs will fail in tension.

The force, F_s , that is required in the short studs to cause failure is found:

$$F_s = 2(S_u)(A) = 2(90,000)(0.142) = 25,600 \text{ lb.} \quad (66)$$

The elongation, Δ , of the short studs at failure is found:

$$\Delta = \epsilon L = 0.27(0.625) = 0.169 \text{ in.} \quad (67)$$

At that time the long studs have elongated by the same length and the strain is determined by

$$\epsilon = \Delta / L = 0.169 / 2.125 = 0.080 \text{ in./in.} \quad (68)$$

The idealized curve of the slope intercept form for the 4140 steel is

$$S = m\epsilon + S_{yp} \quad (69)$$

$$S = (90,000 - 63,000 / 0.27) \epsilon + 63,000 = 100,000 \epsilon + 63,000.$$

The stress in the remaining long studs is

$$S = 100,000 (0.080) + 63,000 = 71,000 \text{ psi.} \quad (70)$$

The force, F_L , which the long studs will resist without further elongation is found

$$F_L = 16(71,000)(0.142) = 161,300 \text{ lb.} \quad (71)$$

$$F_L + F_s = 161,300 + 25,600 = 186,900 \text{ lb} > 115,000 \text{ lb.} \quad (72)$$

Since the sum of the force required to break the two short studs plus the force which can be carried by the long studs is less than the force applied to the studs [see Eq. (65).], it is concluded that the inner cavity plug will remain fastened to the cask in the side drop.

6.2 Puncture

The second in the sequence of hypothetical accident conditions to which the cask must be subjected is a free drop of 40 in. to strike, in a position in which maximum damage is expected, the top end of a vertical mild steel bar mounted on an essentially unyielding horizontal surface. The mild steel bar shall have a diameter of 6 in., with the top horizontal

Fig. 6.4 Stress-strain curve for annealed 4140-series steel.

and its edge rounded to a radius of not more than 1 4 in.; 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 that assumes all the energy absorbed by the cask is absorbed by the outer stainless steel shell with no consideration being given to the uranium shielding.

The energy of impact will be absorbed by the 0.41-in.-thick cask stainless steel outer shell. Figure 6.5 illustrates the configuration for this computational model. The absorbed energy, U , is found:

$$U = \underline{W}h = 1525 (40) = 61,000 \text{ in.-lb} \quad (73)$$

where

$\underline{W}$ = weight of cask, 1525 lb,
 h = drop height, 40 in.

The maximum energy imparted to the cask is 61,000 in.-lb. Conservatively, 100,000 in.-lb is required to deform 1 in.³ of stainless steel (see Table 2.1); therefore, the energy of impact would deform about 0.61 in.³ of material. When the cask strikes the bar, the depth of penetration of the stainless steel shell would not exceed the depth of a sector having a volume of 0.61 in.³ The area, A , of the displaced segment of the stainless steel shell is given by:

$$A = V d = 0.61 / 6 = 0.102 \text{ in.}^2, \quad (74)$$

where

d = diameter of bar, 6 in.

The height of the displaced segment of the stainless steel may be found by solving the following equation for h .

$$A = r^2 \cos^{-1}(r - h/r) - (r - h)(2rh - h^2)^{1/2} \quad (75)$$

where

h = height of segment (or depth of penetration), in.,

r = radius of cylinder, 6.375 in.

The depth of penetration is found to be 0.019 in. Damage of this magnitude would not reduce the effectiveness of the cask.

Fig. 6.5 Model used for puncture analysis.

6.3 Thermal Evaluation

6.3.1 *Hypothetical thermal accident condition discussion*

The third in the sequence of hypothetical accident conditions specified by the regulations to which the cask must be subjected is exposure for 30 min within a source of radiant heat 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.

A modified version of the computer program, HEATING-3,¹⁷ was used to determine the temperature distribution of the cask when it is exposed to these thermal environments.

It was assumed that the container was loaded with the maximum permissible decay heat load of 80 W. The temperature distribution from 100°F ambient condition was used as input for the starting temperatures in the hypothetical thermal accident (fire) calculation.

The damage from the free drop and puncture portions of the hypothetical accident would not adversely affect the performance of the container in the hypothetical thermal accident. Hence, the undamaged configuration was assumed.

6.3.2 *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 5.1 (see Sect. 5.1.1).

6.3.3 *Thermal accident analysis*

The computational model previously used and described in Sect. 5.1.2, representing half of the container, was also used for the thermal accident analysis. The HEATING-3 computer program was used to determine the temperature distribution in the container that would result from the prescribed 30-min thermal exposure; the material constants given in Table 5.1 were used as computer input. The steady-state temperature distribution computed for the heat condition of normal transport (100°F ambient shade) was assumed to be the starting point, and 80-W internal heat generation was included in the transient analysis.

6.3.4 *Container temperatures*

Cask temperatures were followed for 3 hr after the conclusion of the fire, since regulations specify that the cask cannot be artificially cooled prior to this time unless the temperature in the center of the cask has begun to fall.

The stainless steel uranium-shielded cask is an excellent conductor of heat with few air gaps to act as insulation. The cask heats and cools quickly. The neoprene gaskets on the closure plug and the O-rings on the inner-cavity drain plug will be destroyed in the hypothetical thermal accident. The temperature of the inner container (see Fig. 6.6) reaches a maximum of 741° F at 96 min after the start of the test, or 66 min after the end of the "fire."

Temperatures of that magnitude will cause no damage to the inner container or to the solid contents. Consequently, if the cask is subjected to the high-temperature thermal environment, it is capable of withstanding it with no loss of contents and, therefore, meets this part of the regulations.

6.4 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 a period of not less than 8 hr.

It is assumed that the external gaskets of the cask will have been destroyed in the fire. The gaskets for the inner container will not, however, have been destroyed, and the integrity of these containers after the 30-ft free drop and fire test should be inviolate. The moderation afforded by the water is not detrimental (see Sect. 9) and provisions are available in the cask so that any water inside the cavity may be drained.

7. CONTAINMENT

The radioactive materials shipped in the ORNL Shipping Cask D-38 are solids contained inside an inner container. The test and evaluation of the inner containers are described in Sect. 8.

"Special Form" material and material in "Special Form Containment"²⁰ may be shipped in the ORNL Shipping Cask. Each "Special Form" material and container must, however, be qualified before usage.

7.1 Containment Requirements for Normal Conditions of Transport

The inner containers are designed to withstand 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.

7.2 Containment Requirement During the Hypothetical Accident

The inner containers are designed to withstand pressures and temperatures in excess of those encountered in the hypothetical accident.

Fig. 6.6 Time vs temperature plot for inner-container seals as determined by HEATING-3 analysis of ORNL Shipping Cask D-38.

8. INNER CONTAINERS

A spec 2R inner container has been developed, approved by ORO and tested for use with the ORNL Shipping Cask D-38. Welded inner containers may also be used.

Fabrication of these welded containers will be in accordance with ORNL Quality Assurance Procedures for Quality Level III fabrication. Applicable approved ORNL procedures will be used for welding. All welds will be appropriately inspected in accordance with approved ORNL weld inspection procedures. Containers shall be leak tested using bubble techniques or helium leak-detection methods.

8.1 Inner Container

The spec 2R container is shown in Fig. 8.1. The inner container needs to be only long enough to contain the material inside it.

The nature of the radioactive contents of the inner container in the cask are specified as solids. The inner container pressure that will develop due to the expansion of the contained gas will be assumed to be "the most severe anticipated case." With a maximum 80-W container loading, a pressure equivalent to the temperature of 741°F would be developed (see Fig. 6.6). The pressure is calculated as follows:

$$P_F = T_F P_s T_s = (1201)(14.7) 530 = 33.3 \text{ psia (18.6 psig)} \quad (76)$$

where

P_F = inner container pressure at 741°F,

T_F = maximum inner container temperature after fire, 741°F + 460°.

P_s = starting inner container pressure, 14.7 psia,

T_s = starting inner container temperature, 70°F + 460°.

Acceptability will be demonstrated by showing that the welded inner container meets the requirements of Sect. VIII of the ASME Boiler and Pressure Vessel Code.¹⁶

8.1.1 Inner container wall thickness

From Paragraph UG-27,¹⁶ the minimum wall thickness for the cylindrical portion of the inner container is determined by

$$t = P_r S E - 0.6P, \quad (77)$$

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Fig. 8.1 Screw-top inner container.

where

P = pressure, 18.6 psig.

r = inside radius of shell, 2.875 in.,

S = design stress, 7800 psi (Table UHA-23),¹⁶

E = joint efficiency, 1.0.

The minimum allowable wall thickness

$$t = (18.6)(2.875) / 7800(1.0) = 0.007 \text{ in.}$$

The wall thickness of the cylindrical portion of the screw top inner container is 0.125 in., which exceeds the requirements of the ASME Code.

8.1.2 Inner container bottom-flat-head thickness

From Paragraph UG-34,¹⁶ the minimum thickness of the bottom flat head of the inner container is determined by

$$t = d (CP/S)^{1/2}, \quad (78)$$

where

d = diameter inside, 5.75 in.,

C = design constant, 0.3 in.,

P = pressure, 18.6 psig.

S = design stress, 7800 psi (see Table UHA-23),¹⁶

$$t = 5.75 [0.3(18.6) / 7800]^{1/2} = 0.154 \text{ in.}$$

The bottom flat head of the screw top inner container is 3/16-in. thick and meets the requirements of the ASME Code.

8.1.3 Inner container top-head thickness

From Paragraph UG-34,¹⁶ the minimum thickness of the screw top head of the inner container is determined by

$$t = d(CP/S)^{1/2} \quad (83)$$

where

d = diameter inside, 5.75 in.,

C = design constant, 0.75,

P = pressure, 18.6 psig,

S = design stress, 7800 psi (see Table UHA-23),¹⁶

$$t = 5.75 [(0.75)(18.6)/7800]^{1/2} = 0.243. \quad (83a)$$

The screw top head of the screw top inner container is 1.4 in. thick and exceeds the requirements of the ASME Code.

8.2 Special Form and Special Form Containers

Material may be shipped in this cask as "Special Form" material or in "Special Form Containers." When this type of shipment is contemplated, the "Special Form" material or container must be qualified by specially designated ORNL personnel who can certify this type of shipment.

9. CRITICALITY

The analysis for the single cask given below is adequate for an infinite array of similar containers.

9.1 Evaluation of a Single Package

A criticality analysis has been made (see Nuclear Safety Review 758 in Appendix 12.2).

Since the quantity of fissile isotopes carried is below all minimum critical masses for these isotopes under optimum moderation and reflection, and the cask effectively isolates the contents from neutron interaction with packages of similar design, unlimited numbers could be stacked with no criticality problem occurring. Thus, the package is adequate for Fissile Class I Shipments.

10. SHIELDING EVALUATION

10.1 Discussion and Results

The cavity in the ORNL Shipping Cask D-38 is surrounded by a 0.28-in.-thick stainless steel inner shell and a 0.41-in.-thick outer stainless steel shell. The shielding cavity between the two is filled with depleted uranium that is 2-3 4-in. thick. In addition, the cask contents are limited to a source strength that will not exceed the allowable radiation dose limits of the DOT regulations.⁵

The shielding effectiveness will not be reduced by the conditions of normal transport or by the hypothetical accident.

11. QUALITY ASSURANCE

11.1 Fabrication, Inspection, and Acceptance Tests

This container was fabricated in the ORNL and Y-12 Machine Shops in accordance with normal shop fabrication procedures. Material was specified on the original drawings as "300 Series SST." Material was withdrawn from Stores stock. The cask was inspected by ORNL Shop Inspection 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 the casks have operated for 6 years without failures or loss of effectiveness. An inspection of the cask was made to verify its integrity (see Appendix 12.5). The routine operating inspection procedures specify periodic weld inspections to verify weld integrity.

11.2 Operating Procedures and Routine Inspections

The 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 NRC regulations, as well as all ORNL procedures and regulations. A copy of typical procedures and checklists are presented in Appendix 12.6. The completed records are kept in Bldg. 4500N, Room A-16.

11.3 Periodic Maintenance and Inspections

Shipments will be inspected biennially and before each shipment is made, as outlined in Appendix 12.6. Maintenance will be performed when inspections indicate damage. The completed records are kept in Bldg. 4500N, Room A-16.

12. APPENDIXES

12.1 Appendix A: Drawings

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ORNL Shipping Cask D-38 Assembly and Details M-12133-CD-126-E	63

Other Associated Drawings

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Specification 2R Inner Container for Radioactive Material M-12166-EM-022-D	67

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CERTIFICATE OF COMPLIANCE
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FIBRILLATE RADIOACTIVE MATERIAL
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ORNL-451-148 WEIGHT 1300 LBS
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ORNL ORNL LABORATORY
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NOTES

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NOTE: THIS DRAWING REPLACES DWG. NEM-12133-CD-100-REV 4

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A. DETAILS		GENERAL SPECIFICATIONS		MATERIALS		FINISHES		PAINTS		COATINGS		TOLERANCES		WELDING		INSULATION		LABELING		MARKING		STORAGE		HANDLING		DISPOSAL		RECYCLING		ENVIRONMENTAL		SAFETY		SECURITY		COMPLIANCE		AUDIT		REVISIONS		APPROVALS		SIGNATURES		DATE		TIME		LOCATION		PROJECT		CLIENT		CONTACT		PHONE		FAX		EMAIL		WEBSITE		ADDRESS		CITY		STATE		COUNTRY		ZIP		P.O. BOX		STREET		APARTMENT		SUITE		OFFICE		LABORATORY		INDUSTRY		GOVERNMENT		MILITARY		ACADEMIC		RESEARCH		ANALYSIS		DESIGN		ENGINEERING		ARCHITECTURE		LANDSCAPE		INTERIOR		EXTERIOR		PAINTING		SCULPTURE		CERAMICS		TEXTILES		LEATHER		JEWELRY		WATCHES		CLOCKS		CALENDARS		PHOTOGRAPHS		VIDEOS		AUDIO		VIDEO		SOFTWARE		HARDWARE		PERIPHERALS		NETWORKS		SECURITY		COMPLIANCE		AUDIT		REVISIONS		APPROVALS		SIGNATURES		DATE		TIME		LOCATION		PROJECT		CLIENT		CONTACT		PHONE		FAX		EMAIL		WEBSITE		ADDRESS		CITY		STATE		COUNTRY		ZIP		P.O. 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H7 x H6 E

SEAL WIRE HOLE
EACH BOLT

RADIATION
MATERIAL

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185

58" DIA

INNER COAT
SCALE - 1/8" = 1"
STAINLESS

NO REPRESENTATION OR WARRANTY, EXPRESSED OR
IMPLIED, IS MADE BY THE U.S. GOVERNMENT OF THE
ACCURACY OR COMPLETENESS OF THE INFORMATION
CONTAINED HEREIN. THE U.S. GOVERNMENT IS NOT
RESPONSIBLE FOR ANY DAMAGE TO PERSONS OR
PROPERTY, OR FOR ANY LOSS OF PROFITS, OR FOR
ANY OTHER CONSEQUENCES ARISING FROM THE
USE OF THE INFORMATION CONTAINED HEREIN.

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1 x 3/4" LONG HEX. IN BOLT

WIRE NUT BOLT

LIFTING RING

SLATE - O-RING SEAL

RING TO TIE PALLET TO CONVEYANCE

4 BOLTS SAFETY WIRE

PROTECTIVE COVER

PALLET
SCALE 1/8" = 1"
STEEL

URANIUM SHIELDED CASK
MOUNTED ON PALLET
PROTECTED AS SHIPPED

INNER CONTAINER
SCALE: 1/8" = 1"
STAINLESS STEEL

REFERENCE DRAWINGS		REVISIONS
Oak Ridge National Laboratory OPERATED BY Union Carbide Corporation Oak Ridge, Tennessee		
URANIUM SHIELDED CASK D-38 (B.O. & 1221)		
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100	AS SHIPPED	11-16-66

ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE. DATE 11-16-66 BY 11166 CD 022 0 J

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SCALE 1 X

49-WELDING TO BE DONE IN ACCORDANCE
WPS-902. INSPECTION MGT. WR 201 9

NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE THAT THE USE OR DISCLOSURE OF ANY INFORMATION APPEARING HEREON OR HEREIN FURNISHED IN THESE DRAWINGS WILL NOT INFRINGE PRIVATE RIGHTS OF OTHERS. THE USER ASSUMES FULL RESPONSIBILITY FOR ANY SUCH INFRINGEMENTS. THE DRAWINGS ARE BEING MADE AVAILABLE TO THE USER UNDER THE APPLICABLE TERMS OF PROTECTIVE DISCLOSURE OF THESE DRAWINGS. THE DRAWINGS ARE BEING MADE AVAILABLE TO THE USER UNDER THE TERMS AND ARE TO BE USED FOR OTHER PURPOSES, AND ARE TO BE RETURNED UPON REQUEST OF THE PROVIDING CONTRACTOR.

GENERAL SPEC

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MATERIAL MAY
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MACHINED SURF
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12.2 Appendix B: Approval Documents

	<u>Date</u>	<u>Page</u>
Second Revised Special Permit No. 5787	Oct. 1, 1969	70
Third Revision Special Permit No. 5787	Aug. 26, 1971	74
Interim Certificate of Compliance AEC OR USA 5787/BLF	Sept. 21, 1973	75
ORNL Criticality Committee Nuclear Safety Review Request No. 777	May 23, 1975	76
Letter ORNL Transportation Committee of Approval of Internal Review of SARP	Nov. 4, 1977	78

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

**SECOND REVISED SPECIAL PERMIT NO. 5787
(COMPLETE REVISION)**

This special permit is revised 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 August 19, 1969, petition by the Oak Ridge National Laboratory and their original petition dated September 17, 1968.

1. Shipments of fissile and large quantities of radioactive materials, n.o.s., 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), 173.396(c)(3), 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 dated August 29, 1968, and as further provided for herein.

2. Each shipper, under this permit, other than the petitioner named above, and the other previously identified petitioner: USAEC, Oak Ridge, Tennessee, shall register his identity with this Board prior to his first shipment, and shall have a copy of this permit in his possession before making any shipment.

3. The packaging authorized by this permit consists of a stainless-steel clad, depleted uranium-shielded cask, which is a right cylinder, 12 3/4" O.D. by 22 5/8" high with a 6" diameter by 13 13/16" deep central cavity. The uranium shielding thickness is 2 3/4". Cask closure is by means of a plug-type uranium-shielded top lid, with bolted, gasketed closure. The cask weight is about 1300 pounds. Contents must be loaded within DOT Specification 2R or equivalent, primary inner containment, with liquids to be additionally contained in polyethylene or stainless steel bottles. The package is identified as the Model No. D-38 Uranium Shielded Shipping Cask, and is described on Oak Ridge National Laboratory's drawing numbers M-12166-CD-022-D and 68-4126.

4. The contents of each package authorized by this permit consist of fissile and large quantities of radioactive material n.o.s., in the form of solid and liquid mixed fission products, fuel elements, or waste products. The maximum thermal decay energy of the contents shall not exceed 80 watts and the total radioactivity shall not exceed 500 curies. The fissile radioactive material contents shall not exceed 500 grams of uranium-235, 350 grams of uranium-233 or plutonium-239, or 350 grams of any combination thereof.

5. The authorized packaging meets the requirements for shipment as Fissile Class I. The transport index must be assigned based on external radiation levels.

6. 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-6.2.2 - The package design meets the requirements for Type B packaging for radioactive materials.

b. 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.

c. Marginal C-6.2.4 - The package design meets the requirements for Fissile Class I shipments.

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

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

7. The outside of each package must be plainly and durably marked "USA DOT SP 5787" and "TYPE B", 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. 5787", in connection with the commodity description thereon.

8. Each package must have its gross weight plainly and durably marked on the outside of the package.
9. This permit authorizes shipments only by vessel and motor vehicle.
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 shipper is required to furnish an experience report to this Board before expiration of the permit and when any amendment is requested. This report must include the approximate number of packages shipped, and the number of packages involved in any loss of contents. The modes of transportation used for these shipments must also be shown.
12. Prior to each shipment authorized by this permit, the shipper shall notify the consignee and, for export shipments, the competent authority of any country into or through which the package will pass, of the dates of shipment and expected arrival. The shipper shall notify each consignee of any special loading/unloading instructions prior to his first shipment.
13. Any incident involving loss of contents of the package must be reported to this Board at the earliest feasible moment following the incident.

Continuation of 2nd Rev SP 5787

Page 4

14. This permit does not relieve the shipper or carrier from compliance with any requirement of either the DOT regulations, including 46 CFR Parts 146 to 149 of the USCG Regulations, except as specifically provided for herein, or the regulations of any foreign government into or through which the package will be carried.

15. This permit expires September 30, 1971, and may be revoked for cause at any time.

Issued at Washington, D.C.:

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

1 October 1969
(Date)

W. R. Fiste
For the Administrator
Federal Highway Administration

25 September 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, b, d, h, i
USAEC, Oak Ridge, Tennessee/

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

SPECIAL PERMIT NO. 5787
THIRD 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 July 22, 1971, petition by the Oak Ridge National Laboratory, Oak Ridge, Tennessee:

Special Permit No. 5787 is hereby amended by revising paragraph (15) to read as follows:

"15. This permit expires on September 30, 1973."

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

Issued at Washington, D.C.:

R.G. Schuring, Capt.
For the Commandant
U.S. Coast Guard

21 AUG 1971

(DATE)

W.R. Fiste
For the Administrator
Federal Highway Administration

26 AUG 1971

(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, h, i

Form AEC-41*
(8-73)
AECN 5300

U.S. ATOMIC ENERGY COMMISSION
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages

1a. Number AEC OR USA 5787/BLF	1b. Revision No. 0	1c. Page No. 1	1d. Total No. Pages 1
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2. Authority

This certificate is issued pursuant to Sections 173.304, 173.326, and 173.326 of the Department of Transportation Hazardous Materials Regulations as amended 49 CFR 170-199 and 14 CFR 103, and AEC Manual Chapters 5201 and 0525.

3. CONDITIONS

3a. This certificate is issued on the basis of SAFETY ANALYSIS REPORT FOR PACKAGING (SARP)

(a) Prepared by

Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

(b) Number

ORNL-TM-2220

(c) Date Published

October 1968

3b. The packaging described in the SARP and further described in item 4 below, when constructed and submitted as prescribed in the SARP, with the contents as authorized herein, meets the standards prescribed in DOT regulations.

3c. The outside of each package must be plainly and durably marked with the letters and figure shown in item 1a. on this form in accordance with the standards for markings in paragraph 173.24(d) of 49 CFR 173.

3d. This certificate does not relieve the consignor from compliance with the regulations of the U.S. Department of Transportation or other regulatory agencies.

3e. Each user of package approved under this certificate shall register his name and address with the issuing office.

4. Description of Packaging and Authorized Contents, Restrictions, and References

- A. The packaging consists of a stainless-steel clad, depleted (0.2 wt% ^{235}U) uranium shielded cask, which is a right circular cylinder, 12-3/4" O.D. x 22-5/8" high with a 6" I.D. x 13-13/15" deep central cavity. The uranium shield is 2-3/4" thick. Cask closure is by means of a plug-type uranium-shielded top lid, which is bolted and sealed with two neoprene "O"-rings. Contents must be loaded within a DOT Specification 2R or equivalent, primary inner containment, with liquids to be additionally contained in polyethylene or stainless bottles. The gross weight of the package is about 1300 lb.
- B. The authorized contents of each package consist of fissile and large quantities of radioactive material H.O.S. in the form of solid and liquid mixed fission products, fuel elements, or waste products. The maximum thermal decay energy of the contents shall not exceed 20 watts and the total radioactivity shall not exceed 500 curies. The fissile radioactive material contents shall not exceed 500 g of ^{235}U , 350 g of ^{233}U or ^{239}Pu , or 350 g of any combination.
- C. Shipments are authorized as Fissile Class I. The Transport Index is assigned on the basis of external radiation levels.
- D. Shipments are authorized by vessel and motor vehicle.

TO BE COMPLETED BY AEC

5a. Address of AEC Approving Office

U.S. Atomic Energy Commission
P.O. Box E
Oak Ridge, Tennessee 37830

5b. Signature of AEC Approving Official

William H. Travis

5c. Name of Official of AEC Approving Office

William H. Travis, Director
Safety & Environmental Control Division

5d. Expiration Date (if appropriate)

7. Date

September 21, 1973

INTERIM

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 the Division(s) to which fissile material will be transferred.

CRITICALITY COMMITTEE

NR 777

EXPIRATION DATE
July, 1986 1980

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

(To be completed by the Control Area Supervisor)

TITLE (FOR REFERENCE PURPOSES)		DATE OF REVIEW	DATE OF RE-EVALUATION
Uranium Shielded Cask D-38, with fire shield		5/23/75	5/23/75
CONTROL AREA	CODE NO.	BUILDING ROOM	DIVISION
Not applicable			Chem. Tech. Div.
TYPE AND FORM OF MATERIAL	Mixed fission products, fuel elements or waste products in either solid or liquid form		
ISOTOPIC ENRICHMENT (WT. %)	300 grams ^{235}U or 350 grams of ^{235}U or ^{239}Pu , or 350 grams of any combination		
QUANTITY OF FISSILE ISOTOPES	PER ISOLATED BATCH OR UNIT		
	See above		
	TOTAL IN CONTROL AREA		
	Not applicable		
	TOTAL TO BE PROCESSED		
	Not applicable		
Concentration or Density of Fissile Material	Not limited		
Spacing of Fissile Units	Class I		
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material	Not applicable		
Limit on Moderation	Not applicable		
Limit on Neutron Absorbers	Not applicable		
Limit on Volume or Dimensions of Containers	Cavity 6 in. diam by 13-13/16 in. deep		
THIS REQUEST MODIFIES, REPLACES: NSR NO.			
673, 496, 331, 758			

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.

Limiting the fissile content of this cask to the above quantities will permit it to be shipped in the Fissile Class I category. Additional criticality safety is afforded by non-fissile diluent materials that will normally accompany any fissile material shipment such as is found in irradiated fuel samples, etc.

A. G. Affel for

CHAIRMAN, CRITICALITY COMMITTEE

7/25/75

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 AEC Manual, Chapter 0539. 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.

A fire shield has been added to the Uranium Shielded Cask D-36 to allow liquids to be shipped in the cask. The maximum thermal decay energy permitted is 20 watts for the liquid shipments.

ORNL CRITICALITY COMMITTEE MR 777 <small>EXPIRATION DATE</small> July, 1980

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR	BUILDING
		<i>[Signature]</i>	4500 N
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER	DIVISION
		<i>[Signature]</i>	CTD

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

November 4, 1977

To: R. D. Seagren
From: Transportation Committee
Subject: SARP - ORNL Shipping Cask D-38

The Committee has reviewed your Draft dated October 17, 1977, for the subject cask. The SARP is approved for technical content and approach in performing the analysis.

Attached are comments from some individuals of the Committee for changes needed or suggested.

E. M. King

E. M. King

cc: Transportation Committee
H. G. Burger
J. A. Cox

12.3 Appendix C: Computer Program to Calculate Corner-Drop Negative Acceleration Forces

Program 1001 Cask Derivation of Equations

When a cask constructed of single ideally plastic material impacts on its top corner, the major portion of the kinetic energy will be dissipated through displacement of material in the impact area. An ideally plastic material is a material that has a constant stress for all values of strain.

The expression

$$dU = S dV, \quad (12-1)$$

where

S = the quantity of energy required to displace a unit volume of material,

V = the displaced volume of material and can be used as a basis for determining the effect of the top-corner impact. The lack of an accurate numerical value of S necessitates a conservative estimation of its value.

With reference to the computational diagram illustrated in Fig. 12-1, it may be said that

$$dV = 1/2 XY dZ. \quad (12-2)$$

By trigonometry,

$$X = r(\cos B - \cos A), \quad (12-3)$$

$$Y = X \tan \alpha = \tan \alpha r(\cos B - \cos A), \quad (12-4)$$

$$dZ = r \cos dB. \quad (12-5)$$

It follows that,

$$dU = SXYdZ/2 \quad (12-6)$$

and

$$U = \sum dU = \sum SXYdZ/2. \quad (12-7)$$

This expression can be readily solved using the computer. The value for the angle A can

Fig. 12.1 Model for corner drop calculations.

be assumed, and B can be incremented from -A to A or from 0 to A if the result is multiplied by 2 and the energy required for the assumed deformation is computed. A is started small, incremented, and the energy required is compared with the cask's potential energy. In this manner a calculated impact history is produced. The program also computes other variables using the expressions below. The maximum deformation, Δ ,

$$\Delta = \sin \alpha (1 - \cos A) (r). \quad (12-8)$$

The applied force, F, $F = dU/d\Delta$, and the acceleration, a, was computed from the equation

$$= F/Wg. \quad (12-9)$$

The velocity at any increment is found from the kinetic energy principle

$$\Delta KE = U = (M/2)(V_0^2 - V^2) \quad (12-10)$$

or

$$V = (V_0^2 - 2U/M)^{1/2} = \left[(2g/W)(Wh - U) \right]^{1/2}$$

where

V_0 = initial velocity,

M = cask mass,

$\underline{W}$ = weight,

h = drop height,

g = gravitational constant.

The time is computed from the relationship

$$a = dV/dt \quad (12-11)$$

or

$$dt = dV/a$$

and summary techniques.

The computer program is given and the results for specific energies of 100,000 and 260,000 in./lb in.³ are given. The plots of the negative accelerations vs deformation are given in Figs. 12.2 and 12.3.

ORNL DWG 75-803

Fig. 12.2 Plot of negative acceleration vs deformation at specific energy of 100,000 in.-lb/in.³ for stainless steel shipping container during a 30-ft corner drop.

Fig. 12.3 Plot of negative acceleration vs deformation at specific energy of 260,000 in.-lb/in.³ for stainless steel shipping container during a 30-ft corner drop.

***PTN,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.

C GLOSSARY OF NOTATION
 C R=RADIUS OF CASK
 C C=CASK LENGTH
 C S=YIELD STRESS OR FLOW PRESSURE
 C W=CASK WEIGHT
 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 AN=ANGLE IN CONTACT / THE SURFACE
 C

C DIMENSION V(1000),AR(1000),P(1000),U(1000),T(1000),AN(1000),
 1 X(1000),AG(1000)
 C PI=3.141596254
 C S=0.0
 C ANA = 0.0

C INPUT MATERIAL CONSTANT

C INPUT CASK GEOMETRY

1010 FORMAT(1H,30X,'URANIUM SHIELDED CASK D-38';

W=1525.

R=6.375

C=22.625

O=ATAN(1.9626)

DO 90 NH=1,2

H=48

IF(NH.EQ.2) H=360.

DO 90 H=1,2

S=100000.

IF(H.EQ.2) S=260000.

C INPUT TEST CONDITION

C INPUT ANGLE INCREMENTS

30 BB=.01

AA=.01

WRITE (51,1002)

WRITE (51,1002)

WRITE (51,1010)

WRITE (51,1002)

WRITE (51,1002)

C ZERO SUBSCRIPTED VARIABLES

DO 14 I=1,1000

AN(I)=0.0

AG(I)=0.0

V(I)=0.0

X(I)=0.0

```

      T(I)=0.0
      F(I)=0.0
      U(I)=0.0
      V(I)=0.0
      W(I)=0.0
      X(I)=0.0
      Y(I)=0.0
      Z(I)=0.0
      C ZERO UNSUBSCRIBED VARIABLES

      DO 1 I=1,1000
      V=SQRT((64.*H)/12.)
      U=U+H
      Y=0.0
      X=0.0
      Z=0.0
      W=0.0
      F(I)=0.0
      U(I)=0.0
      V(I)=0.0
      C INCREMENT ANGLE A
      A=0.0
      DO 2 J=1,1000
      C INCREMENT ANGLE B
      B=0.0
      B=B+B
      CB=CB(B)
      C CALCULATE VOLUME DISPLACED
      11 CC=(CB-CA)
      BI=TAN(O)*R*CC
      BX=R*CC
      12 DZ=B*CB*DB
      DU=BI*B*DX*0.25
      C CALCULATE ENERGY ABSORBED
      SUBD=SUBD+DU
      C CALCULATE AREA
      13 DA=2.*BX*DB/COS(O)
      A=A+DA
      IF(B-GR.A) GO TO 3
      2 CONTINUE
      3 U(I)=SUBD
      V(I)=A
      C CALCULATE FORCE
      F(I)=A*(I)*S
      C CALCULATE VELOCITY
      IF(U(I)-GR.UT) GO TO 16
      5 VA=SQRT((64.*H)/12.*W))*(U1-U(I)))
      16 IF (U(I)-GR.UT) VA=0.0
      C CALCULATE ACCELERATION
      AG(I)=F(I)/W
      C CALCULATE DEFORMATION
      XA=(TAN(O)*COS(O)*W*(1.-CA))
      X(I)=XA
      C CALCULATE TIME
      TX=(XA-XI)/((VA+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
      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,6HWEIGHT,6X,
1       15HSPECIFIC ENERGY)
      WRITE(51,1006)
1006  FORMAT (1H, 4X,6HINCHES,8X,6HINCHES,10X,6HPOUNDS,8X
1       13HLB-IN/CU. IN.)
      WRITE(51,1002)
1002  FORMAT (1H0)
      WRITE(51,1007) E,C,W,S
1007  FORMAT (F11.3,F14.3,F16.1,F18.1)
      WRITE(51,1002)
      WRITE(51,1000)
1000  FORMAT (1H.,4X,11HDEFORMATION,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       6HPOUNDS,10X,6HLB-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
      CALL QWIKPL(X,AG,K,'LINEAR','J.H.EVANS')
20     CONTINUE
90     CONTINUE
      STOP
      END

```

GRANITE ENCLOSED CASE D-36

CASE GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC WEIGHT LB-IN./CU. IN.		
6.375	22.625	1525.0	100000.0		
DEPTH INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION G
0.0003	43.02	0.00054	0.0	4.0	2.0
0.0011	43.02	0.00216	26.06	0.01	0.02
0.0026	43.02	0.00406	116.36	0.11	0.08
0.0045	43.02	0.00664	304.24	0.53	0.20
0.0071	43.02	0.01350	626.31	1.72	0.41
0.0102	43.02	0.01944	1110.10	4.44	0.73
0.0139	43.02	0.02646	1615.35	9.05	1.19
0.0182	43.02	0.03455	2753.06	19.50	1.81
0.0230	43.02	0.04372	3967.85	35.78	2.60
0.0284	43.02	0.05397	5493.85	61.27	3.60
0.0343	43.01	0.06529	7366.60	99.55	4.83
0.0408	43.01	0.07769	9621.27	154.92	6.31
0.0479	43.01	0.09116	12292.59	232.51	8.86
0.0556	43.00	0.10570	15415.19	330.62	10.11
0.0638	43.00	0.12132	19023.02	479.75	12.47
0.0726	43.79	0.13800	23152.68	664.67	15.10
0.0819	43.70	0.15576	27835.71	902.52	18.25
0.0910	43.77	0.17450	33107.20	1203.00	21.71
0.1022	43.75	0.19440	39000.27	1580.57	25.57
0.1132	43.78	0.21545	45500.13	2045.86	29.87
0.1248	43.71	0.23740	52785.71	2614.36	34.61
0.1369	43.69	0.26059	60704.02	3302.27	39.83
0.1496	43.65	0.28478	69456.13	4127.27	45.50
0.1620	43.61	0.31003	78954.19	5100.65	51.77
0.1766	43.57	0.33637	89270.38	6267.51	58.54
0.1909	43.51	0.36380	100436.25	7626.57	65.86
0.2050	43.45	0.39231	112402.69	9210.34	73.76
0.2212	43.37	0.42192	125441.25	11045.22	82.26
0.2372	43.29	0.45263	139341.88	13159.52	91.37
0.2537	43.19	0.48446	154215.69	15503.50	101.13
0.2704	43.00	0.51741	170091.50	18349.39	111.54
0.2863	42.95	0.55150	186999.19	21491.43	122.62
0.3065	42.81	0.58675	204967.44	25046.03	134.40
0.3252	42.64	0.62317	224025.00	29051.65	146.90
0.3444	42.46	0.66080	244199.75	33540.99	160.13
0.3641	42.25	0.69964	265519.00	38500.00	174.11
0.3844	42.02	0.73974	288011.13	44192.29	188.86
0.4052	41.76	0.78113	311701.75	50430.77	204.39
0.4265	41.47	0.82385	336610.13	57345.04	220.73
0.4484	41.16	0.86795	362784.30	64989.52	237.89
0.4700	40.78	0.91349	390227.31	73415.50	255.87
0.4937	40.30	0.96051	418970.01	82641.44	274.73
0.5171	39.94	1.00910	449039.06	92845.01	294.45
0.5410	39.45	1.05935	480456.44	103970.44	315.05
0.5655	38.91	1.11136	513245.44	116110.75	336.55
0.5904	38.31	1.16524	547420.56	129356.00	358.97
0.6159	37.65	1.22113	583020.00	143753.00	382.31
0.6419	36.91	1.27919	620044.06	159300.44	406.60
0.6684	36.10	1.33964	658561.75	176310.19	431.84
0.6953	35.20	1.40271	698536.75	194619.00	458.04
0.7220	34.21	1.46869	740011.00	214305.44	485.25
0.7500	33.16	1.53794	783002.25	235469.94	513.44
0.7793	31.87	1.61099	827530.06	258155.31	542.64
0.8092	30.49	1.68840	873612.06	283247.31	572.84
0.8377	28.93	1.77100	921264.25	309676.00	604.11
0.8676	27.17	1.85993	970505.19	337985.25	636.40
0.8980	25.14	1.95603	1021350.56	368273.63	669.70
0.9289	22.78	2.06427	1073814.00	400633.01	704.14
0.9603	19.95	2.18660	1127912.00	435163.06	739.61
0.9921	16.41	2.33251	1183650.00	471961.00	776.17
1.0244	11.51	2.52534	1241045.00	511127.94	813.81
1.0572	0.0	2.99993	1300146.00	552767.01	852.55
/NOT CALL OUTSIDE LINES		X=0.0	T=-.11000 02	TYPE=	3

URANIUM SHIELDED CASE D-30

CASE GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CC. IN.		
6.375	22.625	1525.0	260000.0		
DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION G
0.0003	43.02	0.00054	0.0	0.0	0.0
0.0011	43.02	0.00216	69.03	0.03	0.05
0.0026	43.02	0.00406	302.53	0.29	0.20
0.0045	43.02	0.00664	791.02	1.30	0.52
0.0071	43.02	0.01350	1620.40	4.47	1.07
0.0102	43.02	0.01944	2907.05	11.55	1.91
0.0139	43.02	0.02646	4719.90	25.62	3.10
0.0182	43.02	0.03455	7150.99	50.90	4.69
0.0230	43.01	0.04372	10316.41	93.04	6.76
0.0284	43.01	0.05397	14204.02	159.31	9.37
0.0343	43.01	0.06529	19153.30	254.00	12.56
0.0400	43.00	0.07769	25015.30	402.70	16.40
0.0479	43.79	0.09117	31960.73	604.52	20.96
0.0556	43.70	0.10572	40079.50	879.89	26.20
0.0630	43.77	0.12134	49461.94	1207.34	32.03
0.0726	43.75	0.13804	60196.98	1720.15	39.47
0.0819	43.72	0.15502	72372.01	2304.55	47.46
0.0910	43.69	0.17467	86070.69	3130.00	56.45
0.1022	43.65	0.19461	101400.69	4109.40	66.49
0.1132	43.61	0.21563	118427.19	5319.22	77.66
0.1240	43.55	0.23774	137242.01	6797.32	90.00
0.1349	43.47	0.26095	157934.44	8505.87	103.56
0.1496	43.39	0.28527	180505.94	10730.87	118.42
0.1620	43.20	0.31070	205200.94	13202.55	134.61
0.1766	43.16	0.33726	232103.00	16295.57	152.20
0.1909	43.02	0.36477	261134.38	19829.13	171.24
0.2050	42.05	0.39385	292455.06	23946.96	191.77
0.2212	42.66	0.42391	326147.25	28717.63	213.87
0.2372	42.43	0.45519	362209.00	34214.03	237.57
0.2537	42.17	0.46773	400960.01	40517.10	262.93
0.2700	41.67	0.52155	442237.94	47700.50	289.99
0.2803	41.53	0.55672	486197.94	55077.00	310.82
0.3065	41.10	0.59329	532915.44	65119.76	349.45
0.3252	40.69	0.63132	582465.13	75534.00	381.94
0.3444	40.19	0.67091	634919.31	87226.94	416.34
0.3641	39.61	0.71215	690345.50	100309.50	452.69
0.3844	38.96	0.75515	748029.00	114899.44	491.04
0.4052	38.23	0.80007	810424.56	131119.30	531.43
0.4265	37.40	0.84700	875207.13	149090.69	573.91
0.4400	36.46	0.89641	943239.38	168971.94	618.52
0.4700	35.39	0.94033	1014591.00	190800.00	665.31
0.4937	34.10	1.00319	1089324.00	214972.69	714.21
0.5171	32.00	1.06147	1167501.00	241400.31	765.57
0.5410	31.22	1.12379	1249106.00	270324.31	819.14
0.5655	29.40	1.19102	1334430.00	301909.94	875.04
0.5900	27.27	1.26443	1423314.00	336329.63	933.32
0.6159	24.76	1.34603	1515072.00	373761.30	994.01
0.6419	21.70	1.43923	1612171.00	413991.13	1057.16
0.6600	17.07	1.55090	1712260.00	458000.19	1122.79
0.6953	12.26	1.70057	1816195.00	506011.13	1190.95
0.7220	6.0	2.07412	1924020.00	557404.31	1261.66
PLOT CALL OUTSIDE LIMITS		X=0.0	Y=-.1100E 02	IPR=	3
INC0021 STOP 00000					

12.4 Appendix D: Computer Program to Calculate Side-Drop Negative Acceleration Forces

The computer program was the same as derived in Appendix C; however, the program was changed to reflect the change in the angle of impact. The angle, α , in Fig. 12.1 was 63° for the side drop.

The computer program is given and the results of specific energies are given for stainless steel of 100,000 and 260,000 in.-lb in.³. The plots of the negative accelerations vs deformations are given in Figs. 12.4 and 12.5.

Fig. 12.4 Plot of negative acceleration vs deformation at specific energy of 100,000 in.-lb/in.³ for stainless steel shipping container during a 30-ft side drop.

Fig. 12.5 Plot of negative acceleration vs deformation, at specific energy of 260,000 in.-lb/in³ for stainless steel shipping container during a 30-ft side drop.

12.5 Appendix E

Inspection of ORNL Shipping Cask D-38
to Verify Integrity of Fabrication

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INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

November 16, 1973

TO: B. B. Klima

SUBJECT: Inspection of Shipping Cask D-38
W.O. A-3044C-AA - Inspection Request 10926

This inspection was performed to verify the integrity of this shipping cask.

After disassembly, the cask was surveyed by ORNL Health Physics and found to be free of radioactive contamination.

Visual Inspection

This cask conforms to the characteristics of Drawing M-12133-CD-126-E rev. 9.

No structural defects were observed in the cask, cover shroud or shipping pallet.

Wall thickness readings of the outer shell (part #8) revealed a thickness of .385" - .428".

The cask is identified on the shroud and top plug by stamped lettering.

Liquid Penetrant Examination

All accessible welds and the lifting attachments were examined with liquid penetrant in accordance with ORNL NDE 30, Technique 1, "Color Contrast Solvent-removable", and were found to be satisfactory.

Leak Test

The cask was helium leak tested in accordance with the Inspection Engineering Manual, Section 7, App. 4. This test indicated a leak rate not greater than 1×10^6 scc/sec. (Leak test report is attached).^a

^aLeak Test Report in Quality Assurance file in Room A-16, Bldg. 4500N, ORNL

Metal Identification:

All accessible parts of the cask were examined with a thermoelectric comparator and determined to have been fabricated from 300 series stainless steel. (Instrument calibration data and test results are attached.)^a

These inspections and tests indicate good quality welds and material. It is our opinion that the integrity of this cask is good.

INSPECTION ENGINEERING DEPT.

O. J. Smith

OJS:bc

Attachment:

cc: J. R. McGuffey
J. N. Robinson
C. R. Starlin
IR-10926

^a Available in Quality Assurance file, Room A-16, Bldg. 4500N, ORNL.

12.6 Appendix F: Operating and Inspection Procedures

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Inspection Check List	96
Operating Procedure - Incoming Shipments	98
Operating Procedure - Outgoing Shipments	100

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ORNL SHIPPING CASK D-38
DOT APPROVED 5787
ORNL DWG. NO. M12133-CD-126-D

Inspection Check ListInspection Type

Routine _____

Biennial _____

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

_____ |
| 2. | _____ | _____ | Inner cavity plug flange gasket, condition:
_____ good _____ replaced
_____ poor |
| 3. | _____ | _____ | Drain plug "O" ring gaskets, condition:
_____ good _____ replaced
_____ poor |
| 4. | _____ | _____ | Inner cavity plug flange gasket, sealing surface condition:
_____ good _____ reworked
_____ needs reworking _____ cleaned
_____ needs cleaning |
| 5. | _____ | _____ | Nuts, condition:
_____ good
_____ replaced |
| 6. | _____ | _____ | Studs, condition:
_____ good
_____ replaced |
| 7. | _____ | _____ | Locating pins, condition:
_____ good
_____ replaced |
| 8. | _____ | _____ | Safety wire holes are free:
_____ Yes _____ Cleaned
_____ Needs Cleaning |

Inspection Check List
(Continued)

Inspection Type

Routine _____

Biennial _____

<u>Date</u>	<u>Time</u>	<u>By</u>	
9. _____	_____	_____	Visually inspect welds (Biennial only).
10. _____	_____	_____	Fire shield all welds secure (dye penetrant test) (biennial only)
11. _____	_____	_____	Fire Shield Wooden Block
Intact _____ Should be replaced _____
Replaced _____
12. _____	_____	_____	Skid Lifting loops and welds (dye penetrant) (biennial only)

Cask ready for shipment _____ Date _____

Page 1 of 2

Date _____

File in Room A-16Building 4500N

OPERATING PROCEDURE, D-38 CASK

NRC-OR-USA 5787/BLF

INCOMING SHIPMENTSInitials

1. Fire Shield and Skid checked for leakage and damage. _____
2. Tamper wire inspected for damage. _____
3. Fire Shield removed. _____
4. Cask visually checked for leakage and damage. _____
5. Exterior of cask and skid probed and smeared by Health Physics for radiation and/or contamination. _____
6. Radiation data on cask and skid exteriors: _____

	<u>Contact</u>	<u>3 ft.</u>
--	----------------	--------------

Alpha _____

Beta/Gamma _____

Neutron _____

7. Radiation data on lid (outside top): _____

	<u>Contact</u>	<u>3 ft.</u>
--	----------------	--------------

Alpha _____

Beta/Gamma _____

Neutron _____

Steps 8-10 applicable only to cask which was loaded under water.

8. Drain plug removed. Water drained from inner cavity. _____
9. Drain plug "O" ring condition: _____

OK _____	Replaced _____
----------	----------------

10. Drain plug replaced. _____

NRC-OR-USA-5787-BLF

Page 2 of 2

INCOMING SHIPMENTSInitials

11. Cask removed from skid and moved to Hot Cell area. _____
12. Lid bolts removed. Lid-lifting device attached. _____
13. Outside of cask masked or bagged with plastic or paper to protect cask from contamination. _____
14. Cask moved into Hot Cell (if necessary), lid raised, and contents removed. _____
15. Lid replaced, cask removed from Hot Cell and checked for radioactive contamination. _____
16. Radiation data on cask:

Contact 3 ft.

Alpha _____

Beta/Gamma _____

Neutron _____

17. Cask and lid decontaminated to within established shipping tolerances. Survey tag attached to cask. _____
18. Radiation data on cask and lid:

Contact 3 ft.

Alpha _____

Beta/Gamma _____

Neutron _____

19. Gaskets on lid and drain plug inspected. _____

Gasket condition:

Lid OK _____ Replaced _____

20. Cask, and protective cover reassembled, placed on the skid. _____

21. Fire shield placed over cask and moved to storage area. _____

Above Information Certified By: _____

Date: _____

Date _____

File in Room A-16Building 4500N

Page 1 of 2

OPERATING PROCEDURE, D-38 CASK

NRC-OR-USA 5787/BLF

OUTGOING SHIPMENTSInitials

1. Depleted uranium metal biological shielding adequate for quantity of radioactive material to be shipped. _____

2. Cask moved to loading area, opened, and gasket inspected.
Gasket condition: _____

Lid OK _____ Replaced _____

3. Cask body and lid covered with plastic or paper to minimize radioactive contamination. _____

4. Inner container gasket (silicone rubber) condition: _____

Material _____ OK _____ Replaced _____

5. Radioactive material to be shipped placed into Specification 2R container (or approved equivalent). Concentrated heat sources must be placed in heat sink. Exterior of container has been decontaminated. _____

6. Inner container properly sealed (bolts or lid tightened as appropriate). _____

7. Radiation data on inner container: _____

Contact 3 ft.

Alpha _____

Beta/Gamma _____

Neutron _____

8. Inner container loaded into cask. Cask gasket in place. Lid replaced. _____

9. Cask removed from loading area. Lid lifting device removed. _____

10. If loaded under water, drain plug removed. Water drained from inner cavity. Drain plug replaced. _____

11. Lid and cask decontaminated to the established tolerances for off-site shipment. _____

NRC-OR-USA 5787/BLF

Page 2 of 2

OUTGOING SHIPMENTSInitials

12. Radiation data on loaded cask:

	<u>Contact</u>	<u>3 ft.</u>
Alpha	_____	
Beta/Gamma	_____	_____
Neutron	_____	_____

13. Cover nuts replaced and tightened.

14. Tamper seals attached through predrilled nuts and studs.

15. Cask placed on skid. Four 1 in. diam. nuts tightened.

16. Health Physics smeared and probed cask.

	<u>Contact</u>
Alpha	_____
Beta/Gamma	_____

17. Fire Shield replaced and attached to studs with nuts.

18. Health Physics smeared and probed fire shield.

19. Riggers called to move cask.

Cask certified ready for shipment by:

Date:

13. REFERENCES

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5. Code of Federal Regulations, Title 49, Part 173, Paragraph 173.393(5).
6. R. A. Johnston, "Alloying of Uranium and Stainless Steel in Uranium Shielded Casks," p. 11 in Paducah Plant Laboratory Progress Report, January-June 1966, KY-L-419, Part I (Sept. 27, 1966).
7. A. N. Holden, Physical Metallurgy of Uranium, Addison-Wesley, Reading, Mass., 1958.
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18. Code of Federal Regulations, Title 49, Part 173, Paragraph 173.393 (e)(2).
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