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**Safety Analysis Report for Packaging
(SARP) of the Oak Ridge National
Laboratory Garden Carrier No. 2
Revision 1**

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Pilot Plant Section

SAFETY ANALYSIS REPORT FOR PACKAGING (SARP) OF THE
OAK RIDGE NATIONAL LABORATORY GARDEN CARRIER NO. 2

Revision 1

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UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

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1 SAFETY ANALYSIS REPORT FOR PACKAGING (SARP) OF THE OAK RIDGE NATIONAL LABORATORY GARDEN CARRIER NO. 2

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ABSTRACT

An analytical evaluation of the Oak Ridge National Laboratory Garden Carrier No. 2 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.

I. INTRODUCTION

The ORNL Garden Carrier No. 2 was developed at the Oak Ridge National Laboratory. The design was analyzed in 1969¹ and reevaluated in 1975 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.

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 large quantities of fissile and radioactive materials as solids. The package is authorized to be shipped by motor vehicle and rail. It complies with the Nuclear Regulatory Commission (NRC) regulations contained in the *Code of Federal Regulations*, Title 10, Part 71,² 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

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

The Garden Carrier No. 2 was fabricated and assigned the Department of Transportation Specification No. 6088. An interim certificate of compliance has been issued by the Atomic Energy Commission (see Appendix B). The cask, as it is used, is shown in Fig. 1, mounted on its skid.

Preliminary analyses have indicated the need for a fire shield (see Fig. 2) to prevent the lead shielding from melting in the hypothetical accident sequence. This fire shield has been designed, and this analysis is based on its use.

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Fig. 1. Garden Carrier No. 2

Fig. 2 Section of Garden Carrier No. 2 with fire shield showing components

1.1 Description of the Package

The ORNL Garden Carrier No. 2 (see Figs. 1 and 2) is a lead-filled 304L stainless steel weldment, cylindrical in shape, and measuring approximately 25 in. OD by 45 in. high. The inner cavity is 7.065 in. ID by 24 in. high. It provides approximately 8-3 16 in. of lead shielding. It has a 43-in.-OD by 51-11 16-in.-high fire shield that fits over the cask and is secured in place when the cask is shipped. The fire shield has a 1 2-in.-thick steel outer shell and a 3 16-in.-thick inner shell with the void filled with 2 in. of Kaowool*, a ceramic fiber insulation material. The assembly consists essentially of the following elements: cask body, cask top plug, two drawers, four cask closure plates, fire shield, and skid.

The cask body has an outside shell made from 1 2-in.-thick 304L stainless steel plate rolled to form a cylinder 25-3 16 in. in diameter. The bottom of the body is a 2-1 2-in.-thick 304L stainless steel plate. This plate forms the bottom of the stepped rectangular opening in which the two drawers slide. The sides of the drawer openings are 1-in.-thick plate while the top is 3 8 in. thick. The top plate is 1-1 2-in.-thick 304L stainless steel with a 10-in.-diam by 4-in.-deep offset for the top plug. The sides and bottom of the offset are made from 3 8-in. plate as is the central tube, which forms the wall of the inner cavity. The inner cavity is 7-1 16 in. ID by 24 in. long from the end of the top plug to the top of the drawers.

The body is welded to a 1-in.-thick base plate which is 32 in. in diameter. In addition, 14 triangular gussets, 1 2 in. thick by 3-3 8 in. on the side, are welded to the body and base plate and strengthen the base-plate flange. The 1-1 2-in. top plate of the body has two 2-in.-diam lead filling holes which are closed by 3 8 in.-thick plate welded after the lead filling. On the outside of the body and running vertically on each side are two lifting ribs. Each lifting rib has a 2-in.-diam lifting trunnion top and bottom.

The plug has a 1 2-in.-thick plate cylindrical outer wall. The top plate is 1-1 2 in. thick and the bottom is 3 8 in. thick. The 4-in. top plug extension is 9-15 16 in. in diameter. The lead was poured through two 2-in.-diam holes in the extension face. The plug is held on the body by 12 socket-head cap screws, each 3 4 in. in diam by 6 in. long (16NF-2). Each of the screw heads is recessed in the plug, and the body of the bolt passes through a stainless sleeve that is seal-welded top and bottom to the plug. The plug is sealed to the body by a 19-in.-OD by 18-1 2-in.-ID by 1 4-in.-diam neoprene "O"-ring recessed in a groove in the top of the body. The plug has a wire cable receptacle and an offset 1 2-in.-OD by 1 8 in.-wall-tubing interconnection to the center of the plug. The receptacle is for storing wire cable used to raise the inner container into and lower it out of the inner cavity. The receptacle is closed by a 1 2-in.-thick 304L stainless steel cover and is sealed by a 1 16-in.-thick neoprene gasket. The receptacle cover is held in place by six 1 4-in.-diam by 3 4-in.-long (20 NC-2) bolts. The plug has the following directive engraved on its top: "this cover must be on carrier and seal wired in place except when using top plug lifting lug." The top cover is fabricated from 1 8-in.-thick aluminum and is used to deny use of the plug lifting lug to lift the cask; it is held to the plug by two 3 4-in. by 1-in.-long (10 NC-2) hex-head bolts, the heads of which are drilled for safety wires.

Two lead-filled drawers that overlap when closed are held in the closed position by eight

*Product of Babcock and Wilcox.

3 8-in. by 3 4-in. long (16 NC-2) hex-head cap screw in each drawer. The drawers each move back and forth on 14 cam rollers. The drawers are moved by an angle drive attached to the outside of the drawer which drives a screw (1-in. by 8 NC-2) on which the drive nut rides. The drive nut is held in place on the bottom of the drawer opening by two dowel-ended socket-head cap screws, each sealed by a stain-seal. Each of the drawers is covered during shipment by a stainless steel closure plate; this plate is secured by 20-1 2-in.-by 1-1 4-in.-long (13 NC-2) socket-head cap screws and sealed by a 1 16-in.-thick neoprene gasket.

The entrance to the bottom of the Garden Carrier through the base plate is sealed by a bottom closure plate held in place by eight 1 2-in.-by 1-in.-long (15 NC-2) hex-head cap screws and sealed by a 1 16-in.-thick neoprene gasket.

The Garden Carrier No. 2 is located and oriented on the skid by two locating pins. It is secured to the skid by eight 1 1 2-in.-by 3 1 2-in.-long (6 NC-2) socket-head cap screws made from 4140 annealed steel. Special 4140 annealed steel bolts are specified on the drawings; however, calculations prove that any steel bolt the proper size will be satisfactory.

The fire shield rests on a 1-in.-thick steel plate welded to the top of the skid. The fire shield has a 1 4-in.-thick inner shell which is welded to a ring which bolts to the plate mounted to the skid. Both the side inner shell and top (3 8 in. thick) are welded to a heavy steel ring at the top. Two inches of Kaowool insulation is applied to the outside of the inner plate, and it is held in place by clips secured on 6-in. centers. A 1 2-in. plate forms the outer shell of the fire shield.

An annular ring of maple wood fills the gap between the top of the Garden Carrier No. 2 and the fire shield. The clearance between the wood ring and the cask is 1 8 in. radially, but it contacts the cask vertically. Two maple pads are fastened to the inside of the fire shield in line with the drawer cover plates to prevent displacement of the drawers in the event of a catastrophic accident. A 1 8-in. clearance is found between the face of the drawer cover and the wooden pad. The fire shield has four lifting lugs, which are also used to tie the cask down to the vehicle by four cables. The skid is also tied to the vehicle with four tie-down cables fastened to the skid tie-down loops. The fire shield is oriented on the skid by two locating pins and secured by eight 1 1 2-in.-by 3 1 2-in.-long (6 NC-2) socket-head cap screws made from the same steel as used to bolt the cask to the skid.

The shipping skid is 5 ft by 5 ft by 6 in. high. The skid has four 1 1 2-in.-diam tie-down loops and has a 32-in.-diam plate matching the closure of the bottom of the cask. The skid has a Kaowool-insulated area directly under the cask. It also has a built-in locked tool box, which carries needed wrenches and other supplies.

The primary line of containment is the gasketed inner container. A secondary line of containment is considered to be the cask cavity that is sealed by five gasketed closures, three on the bottom and two at the top.

The Garden Carrier No. 2 weighs 8440 lb alone. The complete package, including the skid, fire shield, inner container, and contents weighs 12,400 lb.

1.2 Contents of the Package

The ORNL Garden Carrier No. 2 is used to ship large quantities of fissile and radioactive materials (not otherwise specified) in the form of unirradiated or irradiated fuel elements, contained sections of fuel elements, solid fission products, and waste products. The maximum thermal decay energy for shipments is 100 W. The pack content is limited to not more than 50 g of ^{235}U , 250 g of ^{239}Pu or plutonium, or 150 g of any combination thereof in solid form.

These shipments are contained in a Special DOT Spec. 2R inner container. The inner container is made as Type Class 1 and authorized for commercial surface transport. The inner container will be marked to a suitable strength such that the radiation level at the surface of the container will not exceed 0.05 mR/hr.

2. STRUCTURAL DESIGN AND ANALYSIS

The package complies with the structural requirements of the regulations (10 CFR 171.14 through 171.16). The calculations, test results, and engineering logic presented in the following sections demonstrate compliance with these performance criteria. The effects of both normal transport and specified accident conditions on the structural integrity of the package are considered.

2.1 Structural Design

The as-built drawings for the Garden Carrier No. 2 and all other applicable drawings are shown in Appendix A. The principal structural members of the cask are: (1) cask body, (2) top plug, and (3) two drawers. The welds of each of these fabricated pieces was checked by a dye-penetrant test and x-rayed. The weldment was then pressure-tested and filled with lead. Each member was filled slowly and the body heated at the time of filling. The heated zone of the cask body was raised as the level of the lead was raised so that (1) solidification was from the bottom, and (2) the solidifying metal was covered with molten metal until the top was reached. After finishing the filling operations, each hole was closed with a plug. When this was completed, the member was then machined to the required dimensions. The top plug and the drawers were similarly constructed.

2.2 Cask Weight

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

Table 1. Weight of components of Garden Carrier No. 2

Component	Weight (lb)
Cask body	6,530
Top plug	1,170
Drawer assembly (two drawers)	670
Drive unit covers	70
Skid	1,100
Fire shield	
Inner container	
Contents	
Total	10,540

2.3 Mechanical Properties of Materials

The mechanical properties of lead, carbon steel, and stainless steel are summarized in Table 2. The properties of the wood used in the fire shield are given in Table 3.

3. GENERAL STANDARDS FOR ALL PACKAGES

The general standards for all packaging include the chemical and galvanic reactions of the materials composing 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 lead. The lead is completely encased in stainless steel so that any contents of the package would contact stainless steel rather than lead.

The fissile and radioactive contents of the package are housed in inner containers (see Sect. 8).

Experience and inspection have indicated no chemical, galvanic, or other reaction between the cladding and the containers, or between the containers and their 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, when shipped, is completely covered by the fire shield, which is fastened to the skid by eight 1-1/2-in. bolts. This fire shield prevents the cask from being inadvertently opened.

3.3 Package Lifting Devices

The regulations require that any system of lifting devices that is a structural part of the package 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.

The Garden Carrier No. 2 has three separate systems of lifting devices that can be used to lift the package: (1) the four lifting trunnions, which are a part of the cask itself and are used to handle the cask; (2) the four lugs located at the top of the fire shield, which are normally used to lift the fire shield and package and to tie the package to the vehicle; and (3) the four loops located on the skid, which are also used to tie the package to the vehicle. A fourth device, which is the top plug lifting lug, will not be considered as a cask handling device since

Table 2. Mechanical properties of lead, mild steel, and stainless steel

Properties	Symbol	Stainless steel 304L	Lead (solid)	Low carbon steel
<u>Static properties</u>				
Tensile yield stress, psi	σ_y	$30 \times 10^3{}^a$	$2000{}^b$	30×10^3
Allowable shear stress, psi	τ_a	$15 \times 10^3{}^c$	—	$15 \times 10^3{}^c$
Ultimate shear strength, psi	τ_u	$61 \times 10^3{}^a$	$1825{}^b$	45×10^3
Young's modulus, psi	E	$30 \times 10^6{}^a$	$2 \times 10^6{}^b$	29×10^6
Poisson's ratio	ν	$0.3{}^b$	$0.40{}^b$	—
Weight density, lb/in. ³	γ	0.283	$0.41{}^b$	0.283
Thermal expansion coefficient, °F ⁻¹	α	9.6×10^{-6}	16.3×10^{-6}	6.5×10^{-6}
Melting point		—	$625^\circ\text{F}{}^b$	—
<u>Dynamic properties</u>				
Specific energy, in.-lb/in. ³	S min	$10 \times 10^4{}^d$		$10 \times 10^4{}^d$
	S max	$26 \times 10^4{}^d$		$26 \times 10^4{}^d$

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

^bMetals Handbook, 8th ed., Vol. 1, Properties and Selection of Metals, American Society For Metals, Novelty, Ohio, 1961.

^c50% of tensile yield stress.

^dJ. H. Evans, Experimental Study of the Stress-Strain Properties of Cask Materials Under Specified Impact Conditions, USAEC publication CONF-740901-P1, 232-44 (1974).

Table 3. Properties of maple wood^a

Compressive strength, ultimate, with grain	7830 psi
Compressive strength elastic limit, with grain	5390 psi
Compressive strength elastic limit, across grain	1810 psi
Shear strength, with grain	2430 psi
Density	0.025 lb/in. ³

^aR. J. Roark, p. 417 (Table XIX) in Formulas for Stress and Strain, 4th ed., McGraw-Hill, New York, 1965.

at all times, except when removing the top plug, it will be enclosed by a protective cover that is held in place by two wired and sealed bolts. It is necessary to demonstrate that the first three of these lifting systems are capable of meeting the requirements.

3.3.1 *Garden Carrier No. 2 lifting trunnions*

Four 2-in.-diam lifting trunnions, one at each of the two lifting ribs, are located on the side of the cask. These trunnions and lifting ribs are shown in Fig. 3; the body of the cask has been filled with lead, but the final machining has not been done. The lifting rib has a 3/4-in.-thick by 3-in.-wide outer plate. Typically, two of these lifting trunnions will be utilized at once.

The analysis of the stresses in the trunnions at locations A, B, and C of Fig. 4 will be used to assess the compliance with the established criteria. The weight ($\mathbb{W}$) as used in this document will refer to the weight of the system being considered. These criteria require that the lifting trunnions be capable of supporting a load equal to three times the weight ($3\mathbb{W}$) of the cask and its contents.

The case considered here involves the weight of the cask body, the contents, and the skid, which are assumed to be lifted with two of the four lifting trunnions.

The load, $\mathbb{W}$, used in the calculations below, is equal to 9800 lb (see Table I). This value includes the cask plus all the contents and skid, but it excludes the fire shield.

The schematic model used in the analysis is shown in Fig. 4 and has the following dimensions:

$$L_1 = 4.0 \text{ in.}$$

$$L_2 = 2.3875 \text{ in.}$$

$$a = L_1/2 = 1.938 \text{ in.}$$

$$I = (1/12)(3/4)(3/4)^3 = 0.105 \text{ in.}^4$$

$$I_1 = (\pi/64)(2)^4 = 0.79 \text{ in.}^4$$

$$E = 28.6 \times 10^6 \text{ psi.}$$

The analysis is based on the model given by Roark and Young (Table 4, page 122, case 5A, when $a = L_1/2$ and $L_2 = 0$).¹¹

The components of the flexibility-type matrix C are defined as follows:

$$C_{HH} = L_1^3/3EI_1 + L_2^2/L_1 EI_1,$$

$$C_{H1} = C_{1H} = L_1 L_2^2/2EI_1,$$

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Fig. 3 Body of Garden Carrier - lead filled before machining.

ORNL DWG 78-17792

Fig. 4. Model of cask lifting trunnion and beam superposition diagram.

$$C_{HH} = C_{MH} = L_1^2 2EI_1 + L_1 L_2 EI_2 \quad (1)$$

$$C_{VV} = L_1^3 3EI_1$$

$$C_{VM} = C_{MV} = L_1^2 2EI_1$$

$$C_{MM} = L_1 EI_1 + L_2 EI_2$$

The subscripts are defined as follows:

H = horizontal force,

V = vertical force,

M = moment at the base of the trunnion.

If the displacements at location A are all equal to zero (no rotations or translations allowed), the forces at A, given in terms of fixed end forces due to external loading, are equal to:

$$\begin{bmatrix} C_{HH} & C_{HV} & C_{HM} \\ C_{VH} & C_{VV} & C_{VM} \\ C_{MH} & C_{MV} & C_{MM} \end{bmatrix} \begin{bmatrix} H_A \\ V_A \\ M_A \end{bmatrix} = \begin{bmatrix} LF_H \\ LF_V \\ LF_M \end{bmatrix}, \quad (2)$$

where the vector of loading terms on the right side of the equality is defined as follows:

$$LF_H = \text{horizontal load force} = P(L_1 2EI_1)(L_1 - a)^2,$$

$$LF_V = \text{vertical load force} = P(C_{VV} - a C_{VM} + a^3 6EI_1), \text{ and} \quad (3)$$

$$LF_M = \text{moment load} = P(1 2EI_1)(L_1 - a)^2.$$

It follows that after substitution of Eq. (3) in Eq. (2) and solving for the vector of forces at A, the expressions for H_A , V_A , and M_A given in terms of P are equal to:

$$\text{axial force } V_A = 0.22628 P,$$

$$\text{shear force } H_A = 0.00823 P, \quad (4)$$

$$\text{moment } M_A = 0.01097 P.$$

These values were calculated using a small computer program implemented on the PDP-10 where expression (2) is solved in explicit form for the forces at A.

The forces and moments at location C are computed as follows:

$$F_x = 0.$$

$$H_c = H_A = 0.00823 P.$$

$$F_y = 0.$$

(5)

$$V_c = P - V_A = P - 0.32628 P = 0.67372 P.$$

$$M_c = 0.$$

$$M_c = (2.3875/2)P - M_A + 4H_A - 2.3875 V_A = 0.43676 P.$$

For the problem at hand, $2P = 3W$, where $W = 9800$ lb, it follows that

$$P = 3W/2 = -29,400/2 = -14,700 \text{ lb}$$

$$H_c = \text{axial force} = (0.00823)(-14,700) = -121.0 \text{ lb}$$

$$V_c = \text{shear} = (0.67372)(-14,700) = -9904 \text{ lb}$$

(6)

$$M_c = \text{moment} = (0.43676)(-14,700) = -7060 \text{ in-lb.}$$

The maximum bending moment is at location C, and the magnitude of the bending stresses is equal to

$$\sigma = Mc/I = (6420)(1)/0.79 = 8127 \text{ psi.}$$

(7)

The maximum shear is at the location of the applied force, and the magnitude of the shear is equal to

$$\tau = \alpha V/A = (1.5)(9904)/3.1416 = 4729 \text{ psi.}$$

(8)

where

α = cross-sectional shear factor (1.5).

These calculations are based on an equal distribution of the load on two trunnions and assuming the cable is at the center of the trunnion. In a real situation, the cable is probably near the fixed end of the trunnion and at an angle with the trunnion axis; thus the bending moment at the fixed end is lower than the value used in the calculation and the analysis is conservative.

Because of the location of the trunnion and the general geometry of the cask attached to

the skid, it would be impractical to lift the cask by one trunnion; thus this particular case was not considered in the analysis.

The stresses in the attachment welds are calculated as follows:

The total length of the 1/4-in. fillet weld is equal to

$$L = 2[(22-7/8) + 5] = 55.75 \text{ in.} \quad (9)$$

The total weld area undergoing shear is equal to

$$A = (1/4)(55.75)(0.707) = 9.854 \text{ in.}^2 \quad (10)$$

The shear stresses at the minimum weld section are equal to

$$\tau = W/A = 14,700/9.854 = 1492 \text{ psi.} \quad (11)$$

The stress analysis of the lifting trunnions was performed for the case where the combination of cask, contents, and skid are lifted from both trunnions. The criteria indicate that the stresses in the structural components when the load W is equal to three times the combined weight of the lifting elements shall be less than the allowables shown in Table 2. From the analysis presented, the calculated stresses are conservative since they do not exceed the allowable values.

3.3.2 Fire shield lifting lug

The analysis will show that three times the total combined weight of cask, cask contents, skid and fire shield, can be lifted from one fire shield lifting lug alone.

The mathematical model used in the analysis is shown in Fig. 5. This model is basically a straight beam with a length equal to the diameter of the hole and completely constrained at both ends (A-A and B-B). The stresses will be computed for this straight beam, and correction factors will be applied to compensate for the beam curvature, as well as the stress distribution associated with the beam curvature.

The load P is equal to three times the total combined weight of 12,400 lb. Therefore, the analysis load is equal to $(3)(12,400) = 37,200 \text{ lb.}$

The maximum bending moment in the beam model is expressed by

$$M = PL/8 = (P)(3.5)/8 = 0.4375 P, \quad (12)$$

where

L = length of beam.

The bending stresses (σ_b) for the straight beam are

ORNL DWG 78-17793

Fig. 5. Fire shield lifting lug.

$$\sigma_b = Mc/I, \quad (13)$$

where

c = distance from centroidal axis to extreme fiber = $4.5/2 = 2.25$ in. and

I = moment of inertia = $(1/12)(2.25)(4.5)^3 = 17.09 \text{ in}^4$

Substituting

$$\sigma_b = (0.4375 P)(2.25)/17.09 = 0.0576 P \text{ psi}$$

for the outside fibers, $\sigma_b = 0.0576 P$ and for the inside fibers, $\sigma_b = -0.0576 P$

for the outside fibers, $k = 0.70$

for the inside fibers, $k = 1.63$

The corresponding stresses in the curve beam are represented by

$$\sigma_{\text{outside}} = (+0.0576 P)(0.70) = 0.040 P,$$

$$\sigma_{\text{inside}} = (-0.0576 P)(1.63) = -0.094 P,$$

where

$$P = (3)(12,300) = 37,200 \text{ lb.}$$

$$\sigma_{\text{out}} = (0.040)(37,200) = 1488 \text{ psi.}$$

$$\sigma_{\text{in}} = (-0.094)(37,200) = -3496 \text{ psi.}$$

The shear stresses at sections A-A or B-B of Fig. 5 are equal to

$$\tau = \alpha V/A = (1.5)(37,200)/(2.25)(6.0) = 4134 \text{ psi.} \quad (14)$$

where

α = cross-sectional shear factor (1.5),

A = cross-sectional area (thickness times depth, as shown in Fig. 5) calculated at sections A-A or B-B.

The stress at the weld that connects the lifting lug to the body of the fire shield are calculated as follows. The lifting lug is considered to be a cantilever beam loaded axially and with a transverse load at the free end. The axial load (x direction, Fig. 5) is equal to the x component of the applied load:

$$P_x = P \sin 39.83^\circ = 0.641 P. \quad (15)$$

The shear load at the root of the beam is equal to

$$P_y = P \cos 39.83^\circ = 0.768 P. \quad (16)$$

The bending moment at the root of the beam is equal to:

$$\begin{aligned} M &= P_x r \cos \phi - P_y (L + r \sin \phi) \\ &= P_x (3.5/2) \cos 39.83^\circ - P_y [6.0 + (3.5/2) \sin 39.83^\circ] \\ &= P [1.75 \sin 39.83^\circ \cos 39.83^\circ - (6.0 + 1.75 \sin 39.83^\circ) \cos 39.83^\circ] \\ &= -4.61 P. \end{aligned} \quad (17)$$

where

r = radius of lifting eye.

L = distance from root of lifting eye to the center of the eye, and

ϕ = angle between load axis and the vertical axis.

The gross cross-sectional properties of the weld are shown in Fig. 6. Net properties at the minimum weld area sections are represented by

$$A = (0.707)(20) = 14.14 \text{ in.}^2, \quad (18)$$

$$I = (0.707)(392) = 277.15 \text{ in.}^4. \quad (19)$$

The maximum combined stresses at the lug root due to axial and bending loading are expressed by the following:

$$\sigma = P_x / A + M c / I,$$

$$\sigma = (0.641 P) / 14.14 + (4.61 P)(6.88) / 277.15 = 0.16 P. \quad (20)$$

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Fig. 6. Fire shield lifting lug weld area.

$$= (37.200)(0.16) = 5952 \text{ psi.}$$

where

$$c = 13.75 / 2 = 6.88 \text{ in.}$$

The shear stresses at the base of the lug are

$$\tau = \alpha P / A = (1.5)(768)(37.200) / 14.14 = 3032 \text{ psi.} \quad (21)$$

where

α = cross-sectional shear factor (1.5).

A = cross-sectional area.

The stresses that result when three times the combined weight of the cask, contents, skid, and the fire shield are lifted from one fire shield lug was analyzed. The bending stresses at the point of application of the load (which were calculated using the curved-beam theory) and the shear stresses (which were calculated using the straight-beam theory while assuming a single shear plane) are well below the allowable stresses. The stresses in the welds at the base of the lug are also shown to be small when compared to those allowed. Thus the lifting lug easily complies with the established criteria.

3.3.3 Skid loops

There are four skid loops located near the base of the cask, well below the center of gravity of the cask. It would be very impractical to lift the assembly from two loops, and it would be extremely dangerous to lift from only one loop. This analysis, therefore, considers that all four loops are used to lift the cask-fire shield-skid combination.

Figure 7 shows the general geometry and dimensions of the skid lifting loop.

The analysis is based on the model used by Seely and Smith, *Advanced Mechanics of Materials*, 1952, in the determination of loads in a closed ring subjected to a point load. The mathematical model used in this analysis is shown in Fig. 8.

The Z constant used in the Winkler-Bach formula for the determination of stresses in a curved beam is equal to:

$$\begin{aligned} Z &= 1.4(c/R)^2 + 1.8(c/R)^4 \\ &= 1.4(0.375)^2 + 1.8(0.375)^4 = 0.0376. \end{aligned}$$

where

Fig. 7. Skid fitting loop.

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Fig. 8. Skid lifting loop - mathematical model.

$$c/R = 0.75/2 = 0.375.$$

The bending moment at location A-A is equal to

$$\begin{aligned} M_A &= \frac{1}{2} PR \left[\frac{2}{\pi(1+Z)} - 1 \right] \\ &= \frac{2P}{2} \left[\frac{2}{\pi(1+0.0376)} - 1 \right] \\ &= -0.3865 P \end{aligned} \quad (23)$$

The bending moment at location B-B is equal to

$$\begin{aligned} M_B &= M_A + (P/2)R \\ &= (-0.3865 + 2/2) P = 0.6135 P. \end{aligned} \quad (24)$$

The bending stresses at any location in the curved portion of the beam are equal to:

$$\sigma = \frac{M}{AR} \left[1 + \frac{1}{Z} \left(\frac{y}{R+y} \right) \right] \quad (25)$$

where

$$A = \text{cross-sectional area} = \pi(0.75)^2 = 1.77 \text{ in.}^2$$

At location B, the outside fibers carry the + sign in y, and the inside fibers carry the - sign. It follows, therefore, that

$$\sigma_{B \text{ outside}} = 0.6135 P (1.77)(2) \left[1 + 1/0.0376 (0.75/2 + 0.75) \right] = 1.43 P.$$

$$\sigma_{B \text{ inside}} = 0.6135 P (1.77)(2) \left[1 + 1/0.0376 (-0.75/2 - 0.75) \right] = -2.59 P.$$

If $P = 3W/4 = (3)(12,400)/4 = 9300 \text{ lb}$, we have

$$\sigma_{out} = 1.43 (9300) = 13,300 \text{ psi.}$$

$$\sigma_{in} = 2.59 (9300) = 24,087 \text{ psi (compression).}$$

The shear at the point of application of the load, assuming the existence of a single shear plane, is

$$\tau = (\alpha)(V)/A = (1.5)(9300)/(1.77) = 7882 \text{ psi.} \quad (27)$$

where

n = cross-sectional shear factor (1.5).

A = cross-sectional area.

The stresses at the weld that connect the lifting lug to the skid are computed as follows:

The length of a 1/2-in. fillet weld is equal to

$$L = 2(\pi 1.5) = 9.42 \text{ in.} \quad (28)$$

The weld minimum area is

$$A = (1/2)(9.42)(0.707) = 3.33 \text{ in.}^2 \quad (29)$$

The weld stresses are

$$\sigma = P/A = 9300/3.33 = 2791 \text{ psi.} \quad (30)$$

Under the loading conditions stipulated in the first paragraph of this section, it has been shown that the allowable stresses exceed the calculated values in all cases; therefore, the lifting loop is easily in compliance with the requirements of the regulations.

3.4 Top Plug Lifting Device

The lifting device at the top plug will be analyzed using the same formulation presented in Sect. 3.3.2.

The maximum bending moment in the characteristic section is equal to

$$M = PL/8 = (P)(0.75)/8 = 0.094 P. \quad (31)$$

The straight beam stresses are given by

$$\sigma_b = Mc/I, \quad (32)$$

where

$$c = 0.3125 \text{ (from Fig. 9)}$$

$$I = (1.0/12)(0.625)^3 = 0.020 \text{ in.}^4,$$

$$\sigma_b = (0.094 P)(0.3125)/0.020 = 1.44 P.$$

For R/c of $0.6875/0.3125 = 2.2$, the corrections for the curved-beam geometry are the

Fig. 9. Top plug lifting lug.

following:

$$\text{for the outside fibers, } K = 0.746; \quad (33)$$

$$\text{for the inside fibers, } K = 1.476. \quad (34)$$

Therefore, the curved-beam stresses are:

$$\sigma_{\text{outside}} = (1.44 P)(0.746) = 1.074 P, \quad (35)$$

$$\sigma_{\text{inside}} = (1.44 P)(1.476) = 2.126 P \text{ (compression)}. \quad (36)$$

$$\text{If } P = 3(1170) = 3510 \text{ lb.},$$

$$\sigma_{\text{outside}} = (1.074)(3510) = 3770 \text{ psi}; \quad (37)$$

$$\sigma_{\text{inside}} = (2.126)(3510) = 7462 \text{ psi (compression)}. \quad (38)$$

The shear stress in the lifting lug is equal to

$$\tau = \alpha V / A = (1.5)(3510) / (0.625) = 8424 \text{ psi}, \quad (39)$$

where

α = cross-sectional shear factor (1.5),

V = total shear force equal to design load P ,

A = cross-sectional area.

The direct stresses in the weld at the root of the lifting lug are calculated as follows:

If the net section area is equal to A , then

$$A = (2.0)[2.0 + 1.0](3/8)(0.707) = 1.59 \text{ in.}^2, \quad (40)$$

and

$$P / A = 3510 / 1.59 = 2207 \text{ psi.}$$

The regulations require that the stresses associated with the lifting of a load equal to three times the weight of the top plug (1170 lb) shall not exceed the allowables shown in Table 2. In all of the cases discussed above, the calculated stresses fall within these acceptable limits; therefore, the top plug lifting device complies with the regulations.

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

The Garden Carrier No. 2 is normally shipped bolted to its skid and enclosed in its fire shield as shown in Fig. 2. The overall plan for tying the package to the vehicle is shown in Fig. 10. Eight wire ropes tie the package to the vehicle: (1) four (Nos. 1, 2, 3, and 4) run from the skid tie-down loops to the vehicle, and (2) four (Nos. 5, 6, 7, and 8) run from the fire shield tie-down lugs to the vehicle.

To demonstrate the adequacy of the tie-downs, it will be demonstrated that: (1) the tie-down of the Garden Carrier to the skid is adequate, (2) the tie-down of the fire shield to the skid is adequate, and (3) the stresses imposed on the fire shield tie-down lug and its attachment to the fire shield are acceptable.

3.5.1 Tie-down of Garden Carrier No. 2 to skid

There are 8 1-1/2-in.-diam bolts that secure the cask to the skid.

The vector sum of the applied loads is equal to

$$P = [(5W)^2 + (10W)^2]^{1/2} = 11.18 W. \quad (41)$$

This force acts at an angle $\alpha = \tan^{-1}(5/10) = 26.56^\circ$ measured clockwise from the fixed axis of the carrier (Fig. 11).

It is assumed that the tie-down scheme operates like a beam: tension is taken up by bolts, and compression is taken up by a portion of the cask. The first moment of this area about the neutral axis is equal to the first moment of the bolts about the same axis.

The neutral axis is found by simply equating the first moment of the compression area about the rim of the cask to the first moment of those bolts that lie away from the compression region.

The area under compression is equal to

$$A_c = R^2(\alpha - \sin \alpha \cos \alpha). \quad (42)$$

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Fig. 10. Tie-down of cask to vehicle.

Fig. 11. Bolting pattern and computational model for analysis of the tie-down system to the skid.

where R is the radial distance to the perimeter of the cask. The distance from the centroid of this area to the rim of the cask is equal to

$$y_c = R[1.0 - 2(\sin \alpha)^3 / 3(\alpha - \sin \alpha \cos \alpha)]. \quad (43)$$

The moment of the area about the rim is then equal to:

$$\begin{aligned} M_c &= R^3 (\alpha - \sin \alpha \cos \alpha) [1.0 - 2(\sin \alpha)^3 / 3(\alpha - \sin \alpha \cos \alpha)] \\ &= R^3 [\alpha - \sin \alpha \cos \alpha - (2/3)(\sin \alpha)^3]. \end{aligned} \quad (44)$$

The moment of the bolt areas about the cask rim is given by

$$M_b = A \Sigma b, \quad (45)$$

where

$$A = \text{bolt area} = 1.405 \text{ in.}^2.$$

(Σb is taken from Table 4).

The following expression is then obtained:

$$[\alpha - \sin \alpha \cos \alpha - (2/3)(\sin \alpha)^3] = 1/R^3 (A \Sigma b). \quad (46)$$

The quantity on the right side is easily calculated (Σb is equal to 125.96, which corresponds to seven bolts in tension); to obtain α , an iterative procedure has been implemented. The results of this procedure yield

$$\alpha = 43.662^\circ. \quad (47)$$

The second moment of the areas about the calculated neutral axis is calculated as follows. The neutral axis is located at a distance from the rim of the cask.

$$a = R(1 - \cos \alpha) = 16(1 - \cos(43.662^\circ)) = 4.425 \text{ in.} \quad (48)$$

Using the parallel axis theorem and assuming that the second moment of the bolts about their own centroidal axis is very small, it follows that the second moment of circular sector plus the second moment of bolts

$$\begin{aligned}
 I &= \frac{R^4}{4} \left[\alpha - \sin \alpha \cos \alpha + 2 \sin^3 \alpha \cos \alpha - \frac{16 \sin^5 \alpha}{9(\alpha - \sin \alpha \cos \alpha)} \right] \\
 &\quad + R^2(\alpha - \sin \alpha \cos \alpha) \left[\frac{2 \sin^3 \alpha}{3(\alpha - \sin \alpha \cos \alpha)} - \cos \alpha \right] + A \Sigma b^2 \\
 &= 2617.94 \text{ in.}^4.
 \end{aligned} \tag{49}$$

The axial stress in its most distant bolt ($b = 25.5$ in., Table 4), due to loading in bending, is:

$$\sigma_b = Mc / I = (P)(Z) / I = (11.18 \text{ W})(23.125)(25.545) / 2617.94 = 2.522 \text{ W}. \tag{50}$$

The axial stress due to the axial load ($2W$) uniformly distributed among all the bolts is

$$\sigma_A = 2W / 8A = 2W (8)(1.405) = 0.178 \text{ W}. \tag{51}$$

The total direct stress in the bolt at the most distant point away from the neutral axis is

$$\sigma = \sigma_b + \sigma_A = 2.522 \text{ W} + 0.178 \text{ W} = 2.700 \text{ W}. \tag{52}$$

where

$W = 8610$ lb, so that

$$\sigma = (2.7)W = (2.7)(8610) = 23,250 \text{ psi.}$$

The shear stress distributed uniformly in all the bolts is equal to

$$\tau = P / 8A = (11.18)(8610) / (8)(1.405) = 8564 \text{ psi.} \tag{53}$$

where

$P =$ the resultant force in the horizontal plane, $(5^2 + 10^2)^{1/2} W = 11.18 \text{ W}$.

$W =$ the weight of the carrier alone (excluding fire shield and skid, see Table 1), and

$A = 1.405 \text{ in.}^2$ in the tensile stress area for one 1 1/2-in.-diam bolt as defined in *Handbook H-28, Part I, Screw-Thread Standards for Federal Services, 1969*.

It is concluded that the tie-down system of the Garden Carrier No. 2 to the skid exceeds the requirements of the regulations since the computed stresses are well below the stresses of the bolting material.

Table 4. Values of b , $\bar{b}$, and $\bar{b}^2$ for cask tie-down

Distance of bolt center from edge of base plate ^a		b	$\bar{b}$	$(\bar{b})^2$
$b_1 = 16 - 14 (\cos 3.44)$	=	2.03 ^a	---	---
$b_2 = 16 - 14.75 (\cos 45.67)$	=	5.69	1.265 ^b	1.600
$b_3 = 16 - 14 (\cos 56.56)$	=	8.28	3.855	14.861
$b_4 = 16 - 14.75 (\cos 81.21)$	=	13.74	9.315	86.769
$b_5 = 16 + 14.75 (\sin 8.79)$	=	18.26	13.835	191.407
$b_6 = 16 + 14 (\sin 33.44)$	=	23.71	19.285	371.911
$b_7 = 16 + 14.75 (\sin 44.33)$	=	26.31	21.885	478.953
$b_8 = 16 + 14 (\sin 85.56)$	=	29.97	25.545	652.547

^aSee Fig. 10. $\Sigma b = 125.96^c$ $\Sigma b^2 = 1798.05$ ^b $(\bar{b} = b - a)$.^cFor seven bolts only.

3.5.2 Tie-down of fire shield to skid

The fire shield is secured to the skid with eight bolts of the same size and type as those used for the tie-down of the cask to the skid (see Sect. 3.5.1); the geometry for the fire shield bolts is shown in Fig. 12.

The computation for the stresses in the bolts follows the same procedure as the one described in Sect. 3.5.1, so that the same expressions will be used and made reference herein; only the numerical values are changed.

The area of the circular segment that undergoes compression is a function of the angle α which is computed by numerical iteration using expression (46) of 3.5.1. It follows after substitution of values, that $\alpha = 36.812^\circ$. Associated with this area, there are seven bolts. The quantity Σb from Table 5 is equal to 190.5.

The distance "a" that bounds the circular segment, as calculated in Eq. (48), is equal to:

$$a = 24[1 - \cos(36.812)] = 4.785 \text{ in.} \quad (54)$$

The second moment of the proposed beam cross section is calculated from Eq. (49) and is equal to

$$I = 7192.13 \text{ in.}^4, \text{ where the term } \Sigma b^2 \text{ used in expression (49) is equal to } 5013.27 \text{ from Table 5.}$$

The axial stress due to bending in the most distance bolt from the neutral axis ($b = 41.715$ in Table 5) is

$$\sigma_b = (P)(Z)/I = (11.18 \text{ W})(32.25)(41.715)/7192.13 = 2.091 \text{ W} \quad (55)$$

The axial stress due to the axial load ($2W$) uniformly distributed among all the bolts is equal to:

$$\sigma_A = 2W/8A = 2W(8)(1.405) = 0.178 \text{ W.} \quad (56)$$

The total direct stress in the bolt furthest away from the neutral axis is

$$\sigma = \sigma_b + \sigma_A = 2.091 \text{ W} + 0.178 \text{ W} = 2.269 \text{ W.} \quad (57)$$

where

$W = 2600 \text{ lb}$ (weight of fire shield alone), it follows that

$$\sigma = (2.269)(2600) = 5899 \text{ psi.}$$

The shear stress distributed uniformly in all eight bolts is equal to:

$$\tau = P/8A = (11.18)(2600)/(8)(1.405) = 2586.0 \text{ psi.} \quad (58)$$

Table 5. Values of b , $\bar{b}$, and $\bar{b}^2$ for fire shield tie-down

Distance of bolt center from edge of base plate ^a	b	$\bar{b}$	$(\bar{b})^2$
$b_1 = 24 - 22.75 (\cos 8.44)$	1.50 ^a	---	---
$b_2 = 24 - 22.75 (\cos 36.56)$	5.72	0.935 ^b	0.874
$b_3 = 24 - 22.75 (\cos 53.44)$	10.45	5.665	32.092
$b_4 = 24 - 22.75 (\cos 81.56)$	20.66	15.875	252.012
$b_5 = 24 + 22.75 (\sin 8.44)$	27.34	22.555	508.728
$b_6 = 24 + 22.75 (\sin 36.56)$	37.55	32.765	1073.545
$b_7 = 24 + 22.75 (\sin 53.44)$	42.28	37.495	1405.875
$b_8 = 24 + 22.75 (\sin 81.56)$	46.50	41.715	1740.141

^aSee Fig. 11. $\Sigma b = 190.5^c$ $\Sigma b^2 = 5013.27$ ^b $(\bar{b} = b - a)$.^cFor seven bolts only.

where

P = the resultant force in the horizontal plane, $(5^2 + 10^2)^{1/2} \underline{W} = 11.18 \underline{W}$.

$\underline{W}$ = the weight of the fire shield alone (see Table I), and

$A = 1.405 \text{ in.}^2$ or the tensile stress area for one 1 1/2-in.-diam bolt as defined in *Handbook H-28, Part 1, Screw-Thread Standards for Federal Services, 1969*.

The calculations show that the tie-down system that bolts the fire shield to the skid meets the requirements of the regulations since the computed stresses are below the stresses of the bolting material.

3.5.3 Tie-down of fire shield to vehicle

The analysis herein addresses the effect of loads on the tying wire ropes and subsequent loading on the fire shield lifting lug due to the postulated forces applied to the cask.

The tie-down scheme for the problem is shown in Fig. 10. Previous analysis has shown that wire rope numbers 3, 4, 7, and 8 go in compression when postulated loading ($10\underline{W}$ in x-direction, $5\underline{W}$ in y-direction and $2\underline{W}$ in z-direction) is applied. The problem then reduces to the determination of loads in wire ropes 1, 2, 5, and 6.

The analysis presented will neglect the load carrying capability of wire ropes 5 and 6 that attach the skid to the carrier. The effect of friction forces proportional to the normal reaction on the carrier is considered. The friction forces are considered in this analysis to relieve some of the loads in the tie-down cables since the cask itself is heavier than the one used in a similar work.¹² It can be shown that the loads resulting from this model are conservative, i.e., the magnitude is larger than the actual loads on these items. The analysis is carried through for a 45° angle between the vertical and the wire ropes attached to the fire shield ears and is specified as such in the tie-down procedures.

With reference to Fig. 13, summation of forces in the x, y, and z direction yields:

$$R_1^1 + R_2^1 + F_x = 10\underline{W}, \quad (59a)$$

$$-R_1^1 + R_2^1 + F_y = 5\underline{W}$$

$$R_1^2 + R_2^2 = 2\underline{W} + N, \quad (59b)$$

where F is the friction force, superscripts denote wire rope number, and subscripts denote component orientation. The vertical component of load due to the load in the cable, R_{1v} , is described in Fig. 14 and can be calculated as follows:

$$R_1^1 = R_{1v} \tan 45^\circ, \quad (59c)$$

$$R_2^1 = R_{2v} \tan 45^\circ.$$

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Fig. 13. Cask tie-downs to vehicle math model.

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Fig. 14. Forces due to the forward thrust on Garden Carrier No. 2.

where

$$R_{1n}^1 = [(R_{1n}^1)^2 + (R_{1n}^2)^2]^{1/2},$$

$$R_{2n}^2 = [(R_{2n}^1)^2 + (R_{2n}^2)^2]^{1/2}.$$

The friction force, F , can then be calculated by

$$F_r = F_t = \mu N \quad (60a)$$

where N is the normal force and can be determined from Eq. (59b) as

$$N = R_{1n}^1 + R_{2n}^1 - 2W.$$

and

R_{1n}^1 and R_{2n}^1 are given in Eq. (59c). Therefore,

$$N = (R_{1n}^1 \tan 45^\circ) + (R_{2n}^1 \tan 45^\circ) - 2W.$$

Substituting this into Eq. (60a) gives

$$F_r = F_t = \mu[(R_{1n}^1 \tan 45^\circ) + (R_{2n}^1 \tan 45^\circ) - 2W]. \quad (60b)$$

Also from Fig. 14,

$$R_{1r}^1 = R_{1n}^1 \cos 45^\circ, \quad (61)$$

and

$$R_{1t}^1 = R_{1n}^1 \sin 45^\circ.$$

A similar relationship exists for cable 2.

Substitution of Eqs. (60b) and (61) into Eq. (59a) yields

$$R_{1n}^1(\cos 45^\circ + \mu \tan 45^\circ) + R_{2n}^1(\cos 45^\circ + \mu \tan 45^\circ) = 10W + 2\mu W \quad (62)$$

$$-R_{1n}^1(\sin 45^\circ + \mu \tan 45^\circ) + R_{2n}^1(\sin 45^\circ + \mu \tan 45^\circ) = 5W + 2\mu W.$$

where

μ = the coefficient of static friction. (It will be assumed to be equal to 0.3, which is a

typical value for a steel-wood interface).

Thus, expression (62) reduces to

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} R^1_n \\ R^2_n \end{bmatrix} = \begin{bmatrix} 10.6 \underline{W} \\ 10.6 \underline{W} \end{bmatrix}, \quad (63)$$

where

$$A_{11} = \cos 45^\circ (1 + \mu \sin 45^\circ),$$

$$A_{12} = \cos 45^\circ (1 + \mu \sin 45^\circ),$$

$$A_{21} = -\sin 45^\circ (1 + \mu \sin 45^\circ),$$

$$A_{22} = \sin 45^\circ (1 + \mu \sin 45^\circ) \text{ since } \sin 45^\circ = \cos 45^\circ.$$

Substituting these values in Eq. (63) and solving for R^1_n and R^2_n , we have

$$R^1_n = [\underline{W} \cdot 2(1 + \mu \sin 45^\circ)] [10.6 \cos 45^\circ - 5.6 \sin 45^\circ] = 5\underline{W} [2(\sin 45^\circ + \mu)], \quad (64)$$

$$R^2_n = [\underline{W} \cdot 2(1 + \mu \sin 45^\circ)] [10.6 \cos 45^\circ + 5.6 \sin 45^\circ] = 16.2 \underline{W} [2(\sin 45^\circ + \mu)].$$

From Fig. 14, it follows that the resultant force in the cable due to the components of load in the horizontal plane is

$$R^1 = R^1_n \sin \theta \quad (65)$$

$$R^2 = R^2_n \sin \theta;$$

the load due to the vertical component of load is

$$R^1 = R^1_z \cos \theta \quad (66)$$

$$R^2 = R^2_z \cos \theta.$$

If the vertical load on the fire shield is equally distributed on cables 1 and 2, it follows from Eq. (59b) that

$$R^1 = R^2 = \underline{W} \cos \theta. \quad (67)$$

The total load on cables 1 and 2 is then equal to Eq. (67) plus Eq. (65) or

$$R^1 = 5\underline{W} [2(\sin 45^\circ + \mu) \sin \theta] + \underline{W} \cos \theta. \quad (68)$$

$$R^2 = 16.2 \underline{W} [2(\sin 45^\circ + \mu) \sin \theta] + \underline{W} \cos \theta.$$

As specified in the tie-down procedures, any angle from the vertical that is less than 45° has been excluded from the analysis. Substitution of $\theta = 45^\circ$ and $\underline{W} = 12,400$ lb. in Eq. (68), gives

$$R^1 = (5)(12,400) [2(\sin 45^\circ + 0.3)\sin 45^\circ] + 12,400 \cos 45^\circ = 61,068 \text{ lb.} \quad (69)$$

$$R^2 = (16.2)(12,400) [2(\sin 45^\circ + 0.3)\sin 45^\circ] + 12,400 \cos 45^\circ = 158,578 \text{ lb.}$$

The model used in the computation of stresses is the one discussed in Sect. 3.3.2, the maximum bending moment is equal to

$$M = PL/8 = (158,578)(3.5)/8 = 69,378 \text{ in.-lb.} \quad (70)$$

The straight beam bending stresses are

$$\sigma = Mc/I, \quad (71)$$

$$\sigma = (69,378)(2.25)/17.09 = 9134 \text{ psi,}$$

where

$$c = 2.25 \text{ in.,}$$

$$I = 17.09 \text{ in.}^4.$$

Applying the corrections for curvature of the beam, we have

$$\sigma_{out} = (0.70)(9134) = 6394 \text{ psi.}$$

$$\sigma_{in} = (1.630)(9134) = 14,888 \text{ psi (compression).}$$

The shear stress in the eye of the lifting lug is equal to

$$\tau = \alpha V/A = (1.5)(158,578)/(2.25)(6.0) = 17,620, \quad (72)$$

where

$$\alpha = \text{cross-sectional shear factor (1.5)}$$

V = maximum shear force equal to the applied load at the lifting lug.

A = cross-sectional area calculated at the section where the tangent is parallel to the axes of the force (A = thickness times depth = 2.25×6.0).

The stresses in the weld between the lifting lug and the body of the tire shield are computed next. The x component of force at the root of the lug is equal to

$$P_x = P \sin 45^\circ = 0.707 P, \quad (73)$$

The shear component is equal to

$$F_s = P \cos 45^\circ = 0.707 P, \quad (74)$$

and the bending moment, M, at this location is equal to

$$\begin{aligned} M &= P_x(1.75 \cos 45^\circ) - P_s(6.0 + 1.75 \sin 45^\circ) \\ &= P[1.75 \cos 45^\circ \sin 45^\circ - (6.0 + 1.75 \sin 45^\circ) \cos 45^\circ], \\ &= -4.243 P, \end{aligned} \quad (75)$$

where

$$P = 158,578 \text{ lb.}$$

The maximum combined load in the weld is then

$$\begin{aligned} \sigma &= P_x/A + Mc/I, \\ \sigma &= (0.707 P/14.14) + (4.243)(6.88)/277.1 = 0.155 P, \\ &= 0.155(158,578) = 24,580 \text{ psi.} \end{aligned} \quad (76)$$

where

$$c = 6.88,$$

$$I = 277.1 \text{ in.}^4,$$

$$A = 14.14.$$

The shear stress at the base of the lug is equal to

$$V = \sigma P, A = (1.5 \times 0.707 \times 158.578) 14.14 = 11.893 \text{ psi.} \quad (77)$$

The analysis addresses the case where the tie-down cables between the carrier and the vertical form an angle of 45° , and the carrier is attached to the vehicle bed. The calculated stresses at the tie-down lugs are in this case below the allowable values. Thus the tie-down lugs are capable of resisting the tie-down loads specified by the regulations.

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 Garden Carrier No. 2 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.

Both the cask and the fire shield will be analyzed.

4.1.1 Load resistance of Garden Carrier No. 2

The cross section of the cask is composed of the outer stainless steel shell, the lead shielding, and the inner stainless steel shell, as shown in Fig. 15. Since these components are symmetrical about the same axis, the moment of inertia of the composite section is the sum of the equivalent moments of inertia of the individual components. For a thin shell, the moment of inertia, I_s , about its center is expressed by the following equation:

$$I_s = \pi r_m^3 t. \quad (78)$$

where

r_m = the mean radius of the thin shell, in.,

t = the thickness of the shell, in.

The moment of inertia of a hollow cylinder (I_{ph}), such as the lead shielding, becomes

Fig. 15. The Garden Carrier No. 2 regarded as a simple beam and its equivalent cross section.

$$I_{ps} = A (r_o^2 + r_i^2 / 4), \quad (79)$$

where

r_o = outside radius, in.,

r_i = inside radius, in.,

A = cross-sectional area, $\pi (r_o^2 - r_i^2)$, in.², (80)

By the reinforced beam theory,⁵

modulus of elasticity of steel / modulus of elasticity of lead = $n = 30 \times 10^6 / 2 \times 10^6 = 15$, (80a)

and

$$n = \text{actual area of lead} / \text{equivalent area of steel} = A_{ps} / A_{es}, \quad (81)$$

where

$$A_{es} = A_{ps} / n = A_{ps} / 15. \quad (82)$$

In order to convert the lead to equivalent steel, the following substitutions should be made in Eq. (79):

$$I_{ps} = (A_{ps} / 15)(r_o^2 + r_i^2 / 4) = \pi / 60 (r_o^4 - r_i^4).$$

The moment of inertia of the section is determined by adding the three moments of inertia as follows:

$$\begin{aligned} I &= \pi R_m^4 / 4 + \pi / 60 (r_o^4 - r_i^4) + \pi r_m^4 / 4 \\ &= \pi (12.344)^4 / 4 + \pi / 60 [(12.094)^4 - (3.906)^4] + \pi (3.719)^4 / 4 \\ &= 4123 \text{ in.}^4. \end{aligned} \quad (83)$$

where

R_m = the mean radius of outer shell,

t = thickness of outer shell,

t_i = thickness of inner shell.

The maximum bending moment occurs at $L/2$ and can be determined from:

$$M_{max} = R/L/2 = \omega L^2/8 = 21,525(46.25)^2/8 = 249,000 \text{ in.-lb.} \quad (84)$$

where

ω = unit bending load in lb per lineal in.

The maximum stress is the bending stress at $L/2$ and can be calculated in the following manner:

$$S_p = M_{max}/R_m/L = 249,000(12.594)/4123 = 761 \text{ psi.} \quad (85)$$

The Garden Carrier No. 2 exceeds the requirements of the standards for load resistance.

4.1.2 Load resistance of the fire shield

The cross section of the fire shield area consists of two steel cylinders with insulation between them, as shown in Fig. 16. Since the insulation has no strength, only the outer shell will be considered. For a thin shell, the moment of inertia, I , about its center is determined as follows:

$$I = \pi R_m^3 t_m \quad (86)$$

$$I = \pi(21.25)^3 (0.5),$$

$$I = 15,070 \text{ in.}^4.$$

The maximum bending moment occurs at $L/2$ and is calculated in the following manner:

$$M_{max} = R/L/2 = \omega L^2/8 = 31,000(51.56)^2/8 = 399,750 \text{ in.-lb.} \quad (87)$$

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Fig. 16. The fire shield regarded as a simple beam and its equivalent cross section.

The maximum stress is the bending stress at $L/2$ and is expressed in the following equation:

$$S_b = M_{max}/R = I = 399,750(21.5)/15,070 = 570 \text{ psi.} \quad (88)$$

The fire shield therefore exceeds the requirements of the standards for 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.

Each opening of the Garden Carrier No. 2 is gasketed, and experience has demonstrated that the gaskets used, as they are applied, are suitable to an external pressure of over 25 psig. Primary reliance for containment is on the inner container, see Sect. 8. It is demonstrated that the outer shell of the Garden Carrier No. 2 is capable of withstanding more than 25 psig without damage by the following calculations based on the methods of the ASME Boiler and Pressure Vessel Code.

The capability of the outer shell (disregarding the lead backup material) to withstand external pressure (Paragraph UG-28) is calculated as follows:

$$L/d = 44.25/25.188 = 1.76, \quad (89)$$

$$D/t = 25.188/0.500 = 50.4, \quad (90)$$

where

L = inside length of cask, 44.25 in.,

d = outside diameter of cylindrical shell, 25.188 in.,

t = shell plate thickness, 0.500 in.,

and the maximum allowable working pressure (P_a) at a maximum temperature of 400 F is the following:

$$P_a = B/d \cdot t = 6200/50.4 = 123 \text{ psi.} \quad (91)$$

where $B = 6200$ from Fig. UHA-28.3 Appendix V.

The capability of the flat top of the cask (disregarding the lead backup material) to withstand external pressure (with reference to Paragraph 1 G-34) is calculated in the following manner:

$$P = \frac{S t^2}{d C} = \frac{11,000(1.5)^2}{(25.188)(0.25)} = \frac{24,750}{158.6} = 156 \text{ psi.} \quad (92)$$

where

P = design pressure, psi.

S = maximum allowable stress value, 11,000 psi (at 400° F).

t = plate thickness, 1.5 in..

d = inside diameter head, 25.188 in..

C = constant, 0.25.

Since the maximum allowable working pressure on the shell and head of the cask exceeds 25 psig, it is concluded that the carrier exceeds the requirements of the structural standards for external pressure.

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 Garden Carrier No. 2 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 penetrations.

5.1 Heat

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

5.1.1 Heat tests

Garden Carrier No. 2 is rated for an internal heat load of 100 Watts. This rating, which was based on classical conservative heat calculations, was evaluated by performing heat tests on the cask in the shade and in the sun early in the summer. The tests were performed in an asphalt-paved area at the Oak Ridge National Laboratory.

A 100-W heat source was suspended at the centerline of the internal cavity of the cask, turned and left on for several days until a periodic heating (daytime) and cooling (nighttime) cycle regularly repeated itself. Cyclic heating and cooling was measured with chromel-alumel thermocouples attached (1) to the top surface of the cask, (2) at the centerline of the internal cavity of the cask, and (3) placed in the ambient air about 3 feet from the external surface of the cask. All temperature measurements were made with a Brown chart recorder. The highest surface temperature occurred at mid-morning in the shade and mid-afternoon in the sun. Generally, for this latitude of 36° N, highest ambient temperatures occur in mid-afternoon.

The highest temperatures recorded were:

	<u>Mid-morn in the shade</u>	<u>Mid-afternoon in full sun</u>
Surface temperature at top of cask	40°C (104°F)	61°C (142°F)
Centerline temperature inside cavity	66°C (151°F)	74°C (165°F)
Ambient air temperature	33°C (92°F)	36°C (97°F)

The maximum surface temperature of the cask measured in the full sun was 61°C (142°F) with the maximum ambient temperature of 36°C (97°F). Thus, the solar heat load, imposed on the cask having a 100-W heat source in the cavity, did not cause a significant increase in the cask surface temperature. Consequently, at an ambient temperature of 130°F and in the sun, the cask surface temperatures should not exceed 175°F with the maximum internal heat load imposed. This is well below the 180°F limit stated in the regulations. In addition, the cask will not exceed 40°C (104°F) in shade with an ambient temperature of 38°C (100°F), well below the required 50°C (122°F).

Since the 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.

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

$$P_2 = (P_1 T_2) / T_1 = 11.65 \text{ psia.} \quad (93)$$

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 300 series stainless steel cladding, structural components, and fasteners which make up the cask. 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 fire shield and skid, made of mild steel, are not considered a part of the containment.

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 7.3 psia.

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:

$$P_2 = (P_1 T_2) / T_1 = (14.7)(625) / 530 = 17.3 \text{ psia (2.6 psig).} \quad (94)$$

where

P_1 = assembly pressure, 14.7 psia,

T_2 = temperature under heat load, 625°R (165°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 requirements for the reduced pressure condition of normal transport.

The pressure increases in the internal air gaps were estimated using ideal gas law, assuming constant volume, a sealing temperature, T_1 , of 70°F (530°R), and a sealing pressure, P_1 , of 14.7 psia. The final pressure, P_2 , can be expressed in terms of the final temperature, T_2 , and the initial conditions, P_1 and T_1 , as

$$P_2 = P_1(T_2 / T_1).$$

Table 6. Pressures in internal air gaps for 100-W load

Region ^a	Description	100°F Environment		130°F Environment	
		T _{air} (°F)	Pressure (psig)	T _{air} (°F)	Pressure (psig)
4	Between side of lead fill and outer shell top plug	124	1.51	181	5.02
9	Between top of lead and shell of body	126	1.55	182	5.05
10	Between bottom of lead and top plug shell	126	1.55	183	5.08
12	Between top of inner container and bottom of top plug	130	1.68	187	5.19
15	Between side of lead and shell of body	127	1.58	182	5.05
19	Between side of inner container and side of inner cavity	140	1.93	190	5.27
30	Between drawer at center	131	1.69	185	5.13
34	Between drawer and drawer closure plate	128	1.61	182	5.05
36	Between drawer and bottom closure plate	129	1.64	183	5.08
43	Between side of base plate and fire shield	119	1.37	171	4.74
47	Between side of carrier and inner shell of fire shield	121	1.41	178	4.94
52	Between top of carrier and inner shell of fire shield	120	1.39	178	4.94
56	Inside inner container	149	2.18	202	5.60

^aSee Fig. 21.

The internal pressures associated with the internal air gaps for the 100 F shade environment, for the 130 F direct sunlight environment, are presented in Table 6 for a decay heat load of 100 W.

5.4 Vibration

The package is of welded construction, and therefore vibrations received in transit are not expected to affect its integrity. 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 Garden Carrier No. 2 are not compromised by water spray, since all external surfaces of the fire shield are of steel and the cask is made 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 between 10,000 and 20,000 lb be capable of withstanding a free drop through a distance of 3 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 Garden Carrier No. 2 through a distance of 3 ft is expected to produce only minor denting of the outside steel shell of the cask itself. If the package is dropped 3 ft and minor repairable external damage did occur, 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., normally onto the exposed surface of the package that is expected to be the most vulnerable to puncture.

The outer shell of the fire shield is 1/2 in.-thick steel. Tests conducted on 1/2 in. thick stainless steel have shown that the damage produced by the 13-lb steel cylinder being dropped through a distance of 40 in. will be negligible and the effectiveness of the fire shield will not be reduced.

5.8 Compression

Since the Garden Carrier No. 2 weighs over 10,000 lb, this section of the regulations does not apply.

6. COMPLIANCE WITH STANDARDS FOR HYPOTHETICAL ACCIDENT CONDITIONS

The standards for the hypothetical accident conditions stipulate that a container used for the shipment of large quantities of fissile or 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 standards will 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 through a distance 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.

The Garden Carrier No. 2 is covered by the fire shield before being shipped. Damage to the package will be evaluated by assuming it impacts the unyielding surface with the following impact orientations and conditions:

1. A corner drop will be made on the fire shield.
2. A side drop will be made on the fire shield.
3. Using the negative accelerations determined by the corner and side drops, the ability of the bolts to restrain the top plug and the drawer will be demonstrated.

6.1.1 *Impact on top corner*

A computational analysis (see Appendix C) was applied to a simplified cylindrical cask model to estimate the deformation resulting from a 30-ft corner drop (see Fig. 17) with its line of action through the center of gravity. Results shown in Table 7 indicate by using specific energies of steel that vary from 100,000 to 260,000 in.-lb in.³, the deformation would vary from 2 to 1.4 in.; this deformation would occur primarily in the steel because of the large bending area between the steel, the wood distributor ring, and the carrier.

6.1.2 *Impact on side*

A computational analysis (see Appendix D) was applied to a simplified cylindrical cask model to estimate the deformation resulting from its impact on the side such that the edge of the skid and the top corner of the fire shield hit the immovable surface simultaneously (see Fig. 18). Some of the impact forces will be dissipated in bending the skid; however, the bending of the skid elements is being disregarded and all of the energy is assumed to deform the fire shield. The skid edge is a 6-in. by 6-in.-wide flange which has a 0.269-in.-thick flange. Results shown in Table 8 indicate that the deformation would vary between 1.4 to 1.0 in. when using specific energies of steel that vary from 100,000 to 260,000 in.-lb in.³.

6.1.3 *Bolts holding drawers*

A side drop in which the axis of the drawers would be vertical would place the bolts securing these drawers under the greatest strain.

Each drawer is restrained during transit by eight 3/8-in. by 3/4-in. long (16 NC-2) hex-head stainless steel cap screws which hold the face of the drawer onto the cask body. In addition, the drawer movement is restrained by two 1/32-in.-diam dowel ends on the stainless steel socket-head cap screws which hold the drive nut on the screw. After the two dowel ends are sheared off and the eight screws fail, the line of containment for the drawer would be a gasketed cover secured by twenty 1/2-in.- by 1-1/4-in.-long (13 NC-2) socket-head stainless steel cap screws.

Using the largest negative acceleration in Table 8 and applying it to the weight of the drawer, the force, F_p , is determined as follows:

$$F_p = W_d \times g = 335 \times 1046 = 350,410 \text{ lb.} \quad (95)$$

where

W_d = weight of drawer, 335 lb,

g = negative acceleration, 1046.

Fig. 17. Deformation geometry for corner impact orientation of Garden Carrier No. 2 in its fire shield.

Table 7. Impact on top corner - maximum negative acceleration and deformation resulting from high and low values of specific energy in steel

Specific energy (in.-lb/in. ³)	Maximum deformation corner drop (in.)	Maximum negative acceleration (g)
100,000	1.96	474
260,000	1.37	724

Table 8. Impact on side - maximum negative acceleration and deformation resulting from high and low values of specific energy in steel

Specific energy (in.-lb/in. ³)	Maximum deformation corner drop (in.)	Maximum negative acceleration (g)
100,000	1.36	693
260,000	0.95	1046

Fig. 18. Deformation geometry for side impact orientation of Garden Carrier No. 2 in its fire shield.

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

$$F_R = F_p \cos \theta = 350,410 (0.987) = 346,000 \text{ lb.} \quad (96)$$

where

θ = angle between axis of bolts and drawers and impact surface, 9.19° .

The force which the eight 3/8-in. cap screws will resist, F_s , is found as follows:

$$F_s = NS_s = 8(12,000) = 96,000 \text{ lb.} \quad (97)$$

where

N = number of screws, 8.

S_s = tensile yield force for 3/8-in. cap screws,¹⁰ 12,000 lb.

The force which the two dowel ends will shear, F_d , is found as follows:

$$F_d = N\pi d^2/4 \tau_u = 2\pi(13/32)^2 (61,000)/4 = 15,800 \text{ lb.} \quad (98)$$

where

N = number of dowels, 2.

d = diameter of dowel ends, 13/32 in.

The force that the twenty 1/2-in. socket-head screws will resist, F_H , is found as follows:

$$F_H = NS_u = 20(18,300) = 366,000 \text{ lb } [>346,000 \text{ lb. see Eq. (96)}]. \quad (99)$$

where

N = number of screws, 20.

S_u = tensile yield force for 1/2-in. screws,¹⁰ 18,300 lb.

The twenty socket-head cap screws that hold the drawer cover plate will, therefore, retain the drawer in the cavity. As a safeguard, a wood filler block is located on the inside of the fire shield in front of each of the two drawer closures (1/8-in. clearance).

The bolts will not shear in a flat bottom drop (due to the relative motion between the cask cover plate or drawer and the cask body) because of the small clearances that exist

between the cover plate and drawer and the recessed openings into which they fit.

If the bolts on the drawer closure were to break, containment would not be lost, since the primary line of containment is the inner container. The ability of the cask to meet the other requirements would not be altered.

6.1.4 Bolts holding top plug

A drop on the top of the cask (fire shield) would certainly drive the top plug more firmly into the top of the cask, probably deforming the walls of the top plug extension into its recess such that it would be very difficult to remove.

A corner drop will be used to demonstrate the behavior of the twelve 3/4-in. bolts holding the top plug to cask.

Using the largest deceleration in Table 7 and applying it to the weight of the top plug and the contents of the cask, the force, F_p , is determined as follows:

$$F_p = \underline{W}_p \times g = 1340 (724) = 970,160 \text{ lb.} \quad (100)$$

$\underline{W}_p$ = weight of top plug plus cask content (see Table 1), 1340 lb,

g = deceleration, 724.

The force, F_p , is applied to the cask in the direction of the drop. The component, F_B , of that force applied along the axis of the bolt and plug is found as follows:

$$F_B = F_p \cos \theta = 970,160 (0.768) = 745,100 \text{ lb.} \quad (101)$$

where

θ = angle between axis of bolts and impact surface, 39.83° .

The maximum force which the twelve 3/4-in. stainless steel bolts can resist before breakage is found as follows:

$$F_R = NS_u = 12(37,500) = 450,000 \text{ lb.} \quad (102)$$

where

N = number of bolts, 12.

S_u = tensile yield force for 3/4-in. cap screws,¹⁰ 37,500 lb.

A wooden block is placed in contact between the top of the cask and the inside of the fire shield. This block will absorb the energy of the top plug and will prevent the bolts from stretching to the point of breakage. This is shown as follows:

$$F_R = A \sigma_e = 430(5390) = 2,320,000 \text{ lb.} \quad (03)$$

where

A = area of wood, 430 in.²

σ_e = compressive strength elastic limit (see Table 3), 5390 psi.

Therefore, although the bolts are stressed beyond their yield strength, the wooden block will prevent their being stretched to the breaking point. Additionally, the wooden block will absorb the residual energy of the impact, and the fire shield will prevent the loss of the top plug shielding should the bolts fail.

6.2 Puncture

The second in the sequence of hypothetical accident conditions to which the cask must be subjected is a free drop through a distance 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 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.

The Garden Carrier No. 2 fire shield is fabricated with an outer shell of 0.5-in. steel and an inner shell of 3 8-in. steel at the top and 1 4 in. on the side. The gap between the outer and inner shells is filled with Kaowool insulation, a soft material that is assumed to provide no support for the outer shell during the puncture portion of the hypothetical accident. A shipping container with a similar type construction was tested, and the drop onto the piston did not puncture the outer shell. The package that was tested¹¹ had a 3 16-in.-thick outer shell and weighed 3800 lb. The Garden Carrier No. 2 has a 1 2-in.-thick outer shell and weighs 12,400 lb, which has a comparable weight to the outer shell ratio. It can, therefore, be assumed that the Garden Carrier No. 2 will also pass the puncture test.

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-3,⁹ was used to determine the temperature distribution when exposed to these thermal environments.

It was assumed that the cask was loaded with the maximum permissible decay heat load of 100 W for shipment of solids. The temperature distribution from the 100-F ambient condition for the 100-W internal heat load was input as the initial temperature distribution for the accident (fire) calculations.

The damage from the free drop and puncture portions of the hypothetical accident was 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 9.

6.3.3 Thermal accident analysis

The model used for the heat-transfer computations for solids shipment is illustrated in Fig. 19. The contents were modeled as a homogeneous cylinder occupying 25% of the available cavity volume. The thermal conductivity of the source was assumed to be ten times the thermal conductivity of water (see Table 9). This will provide a relatively uniform temperature distribution over a small section of the inner container which is similar to what might be encountered in shipping large pieces of source material. A thermal conductivity more nearly typical of metal, powders, etc., would give truer source temperatures but would not affect the container, cask, or fire-shield temperatures. Physical properties of stainless steel and the maximum decay heat load of 100 W, uniformly distributed, were used for the contents.

The sliding doors were modeled as a cylinder of lead encased in stainless steel. Internal air gaps associated with the door arrangement were incorporated into a single air gap external to the steel cylinder. Region 34 in the HEATING-3 model, Fig. 19.

The bottom of the cask was assumed to be insulated because insulation material will be secured in the skid.

It was determined that natural convection, in addition to radiation and conduction, was a significant mode of heat transfer in the interior gaps represented by Regions 12, 19, 34, 36, 43,

Table 9. Material properties of materials of construction
used in thermal analysis

Material	Temperature (°F)	Thermal conductivity (Btu/hr-ft-°F)	Density (lb/in. ³)	Heat capacity (Btu/lb-°F)	Latent heat (Btu/lb)
Lead	32.0	20.10	0.4109	0.031	11.3
	212.0	19.00			
	392.0	18.00			
	572.0	18.00			
	621.3				
SST 304	32.0	8.50	0.2824	0.12	
	260.3	9.80			
	440.3	10.60			
	620.3	11.40			
	752			0.135	
	800.3	12.20			
	980.3	13.00			
	1160.0	13.80			
Kaowool (insulation)	400.0	0.0250	3.47 x 10 ⁻³	0.255	
	600.0	0.0375			
	800.0	0.0517			
	1000.0	0.0692			
	1200.0	0.0833			
	1400.0	0.1100			
	1600.0	0.1367			
Aluminum	32.0	117.00	9.78 x 10 ⁻²	0.2106	
	212.0	119.00		0.2225	
	392.0	124.00		0.2344	
	572.0	133.00		0.2463	
	752.0	144.0		0.2582	
	932.0	155.0		0.2702	
	1112.0			0.2821	

Table 9. (continued)

Material	Temperature (°F)	Thermal conductivity (Btu/hr-ft °F)	Density (lb/in. ³)	Heat capacity (Btu/lb-°F)	Latent heat (Btu/lb)
Air	32.0	0.014	4.69 x 10 ⁻⁵	0.240	
	100.0	0.015	4.11 x 10 ⁻⁵	0.240	
	200.0	0.017	3.47 x 10 ⁻⁵	0.241	
	300.0	0.019	3.01 x 10 ⁻⁵	0.243	
	400.0	0.021	2.66 x 10 ⁻⁵	0.245	
	500.0	0.023	2.38 x 10 ⁻⁵	0.247	
	600.0	0.025	2.16 x 10 ⁻⁵	0.250	
	700.0	0.027	1.97 x 10 ⁻⁵	0.253	
	800.0	0.029	1.82 x 10 ⁻⁵	0.256	
	900.0	0.030	1.68 x 10 ⁻⁵	0.259	
	1000.0	0.032	1.57 x 10 ⁻⁵	0.262	
Polyethylene	1500.0	0.040	1.17 x 10 ⁻⁵	0.276	
	0.0	2.868	3.38 x 10 ⁻²	0.550	
	32.0	3.19	3.61 x 10 ⁻²	1.000	
	100.0	3.63			
	200.0	3.93			
	300.0	3.95			
	420.0	3.76			
	620.0	2.75

Fig. 19. Computational model to determine the effects of thermal tests on Garden Carrier No. 2 when carrying solids.

47, 52, and 56 in the HEATING-3 model. Natural convection was neglected in the remaining internal gaps, leaving radiation and conduction as the only modes of heat transfer across the air gaps. Internal convection is assumed to be significant if the Rayleigh number $[Ra = (p^2 g \beta C_p / \mu k)(\Delta T L^3)]$ based on the gap size, is greater than 1000.

The HEATING-3 computer program was used to determine the temperature distribution in the container that would result from the 30-min thermal exposure prescribed in the regulations. The steady-state temperature distribution computed for the heat condition of normal transport (100 F ambient shade with 100-W source) was taken as the starting point. A 100-W internal heat generation was used for the transient analysis.

6.3.4 *Temperatures as result of the thermal accident analysis*

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.

A plot of the temperatures in three different areas of the cask was made for the duration of the run and are presented. Figure 20 shows how the temperature varies from the side. The temperature for node 552 (see Fig. 19), which is located on the outside surface of the fire shield approximately half way up the side, responds to the fire condition, heating up to 1375 F and cooling down rapidly. The temperatures on the outside of the body of the carrier (node 546), the interior of the lead fill (node 564), and the gasket of the inner container (node 485) were at essentially the same temperatures, 166 F, at the end of 3 hr (see Fig. 21). The temperatures at the top of the assembly (see Fig. 21) show a maximum temperature in the lead (node 226) and the outside of the carrier (node 130) of approximately 155 F at the end of 3 hr. The temperatures in the drawer and drawer closure gasket are shown in Fig. 22. These temperatures are approximately 180 at the end of 3 hr.

The maximum centerline temperature remained at approximately 184 F throughout the 30-min test period and rose to approximately 220 F at the end of the 3-hr cool down (the maximum cask temperature was 230 F). With no artificial cooling, the maximum centerline temperature rose to 230 F after 5 hr of cool down which was also the maximum cask temperature.

The temperatures of that magnitude (230 F max) will have no deleterious effects on any of the gaskets used inside the inner container.

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.

6.3.5 *Maximum internal pressures*

The maximum pressures associated with the internal air gaps as a result of the thermal accident were estimated (see Table 10) using the same ideal relationship as before (see Sect. 5.3).

TEMPERATURE MONITOR FOR NODES 485, 546, 564, AND 552

Fig. 20. Temperatures on various points through the side of the Garden Carrier No. 2 shipping assembly as determined during and after the thermal accident conditions.

Fig. 21. Temperatures at various points at the top of the Garden Carrier No. 2 shipping assembly as determined during and after the thermal accident conditions.

Fig. 22 Temperatures at various points near the bottom side of the Garden Carrier No. 2 shipping assembly as determined during and after the thermal accident conditions.

Table 10. Pressures in internal air gaps for 100-W load

Region ^a	Description	1475 °F Fire	
		T _{air} (°F)	Pressure (psig)
12	Between top of inner container and bottom of top plug	165	4.58
19	Between side of inner container and side of inner cavity	184	5.11
30	Between drawers at center	190	5.27
34	Between drawers and drawer closure plate	187	5.19
36	Between drawer and bottom closure plate	192	5.33
43	Between side of base plate and fire shield	184	5.11
47	Between side of carrier and inner shell of fire shield	160	4.44
52	Between top of carrier and inner shell of fire shield	162	4.49
56	Inside inner container	188	5.22

^aSee Fig. 19.

Maximum internal pressures of this magnitude (5.3 psig) will have no deleterious effect on the shipping cask.

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.

The gaskets of the cask and the inner container will not have been damaged. The integrity of the cask and the inner containers after the 30-ft free-fall and fire test should be inviolate. The moderation afforded by the water is not determined (see Sect. 9).

7. CONTAINMENT

The radioactive material shipped in the Garden Carrier No. 2 is contained inside an inner container. The test and evaluation of the inner containers is described in Sect. 8.

7.1 Containment Requirements for Normal Conditions of Transport

The inner containers will withstand pressures and temperatures in excess of those encountered in normal transport. Section 5.3 indicates that the maximum normal operating pressure encountered in normal transport will be 5.6 psig at 202°F (see Table 6). Under these conditions, no release of radioactive material, loss of coolant (air), or contamination of coolant should occur.

7.2 Containment Requirements During the Hypothetical Accident

With conditions as described in Table 10 (inner container temperature of 188°F), pressure in the inner container will not exceed $8.94 \text{ psig} + 5.22 \text{ psig} = 14.16 \text{ psig}$, where 8.94 psig is the maximum pressure contributed by water vapor should it exist in the solid material. All 2R inner containers are capable of containing this pressure with no deleterious effects.

8. INNER CONTAINERS

The regulations²⁻⁵ require that packages in which fissile or large quantities of radioactive materials are shipped must maintain containment of radioactive contents under the stipulated normal and accident conditions of transport. The containment boundaries and capabilities of the Garden Carrier No. 2 cask are discussed in this section.

8.1 Containment Boundaries

The containment boundaries for the shipping options available with the Garden Carrier No. 2 cask are (a) the cask cavity sealed by its gaskets, (b) the Spec. 2R container sealed by its gasket, and finally (c) the metal capsules containing the solid radioactive material, sealed by welding, brazing, or swagging. This latter line of containment is considered the primary barrier.

8.2 2R Container Design

Typical inner 2R containers used at ORNL for shipment of solid radioactive material are illustrated in Figs. 23 through 26. The materials of construction and bolting for these containers are limited to austenitic stainless steels or other materials which maintain their ductility at temperatures as low as -40°F . These materials are purchased in accordance with ASME or ASTM specifications. The design temperature for the 2R container is taken as 165°F , which is the maximum temperature computed for the inner container under normal conditions of transport. When it is assumed that the 2R container and contents are assembled at an ambient temperature of 70°F and air pressure of 14.7 psia, a temperature of 165°F will produce a pressure inside the container of

$$P_2 = (P_1 T_2) / T_1 = (14.7)(625) / 530 = 17.3 \text{ psia (2.6 psig)}. \quad (104)$$

When it is assumed that the least external pressure experienced by the container will be 0.5 times the standard atmospheric pressure, the greatest gauge pressure experienced will be $25 - 7.35 = 17.7$ psig. The design pressure for the 2R container was therefore established conservatively as 20 psig. The design stress is 10,300 psi, which is the minimum listed in Sect. VIII¹⁶ tables for a temperature of 500°F .

The 2R containers used in the Garden Carrier No. 2 cask will have the minimum head and wall thicknesses given in Table II. These dimensions are based on the requirements of Specification 2R¹⁴ and Sect. VIII of the ASME Boiler and Pressure Vessel Code. The equations used to determine these thicknesses are the applicable equations for sizing pressure vessel shells and heads given in Sect. VIII of the ASME code. The applicable equation for determining the shell thickness of Eq. (1) in paragraph UG-27

$$t = \frac{P_r}{SE} - 0.6P, \quad (105)$$

where

t = wall thickness (in.).

ORNL DWG 74-3857

Fig. 23. Pipe element 2R container.

Fig. 24. Details of typical flanged 2R container.

ORNL DWG 75-501

Fig. 25. Typical threaded 2R container.

ORNL DWG 75-502

Fig. 26. Typical bolted 2R container

Table 11. Dimension schedule for Specification 2R containers

d	Dimensions (in.) for symbols shown in Fig. 25				Bolt	
	t_s	t_f	t_h	t_a	No.	Size
2	3/32	3/16	3/16	3/8	4	1/4-20
3	1/8	1/4	1/4	3/8	6	1/4-20
4	1/8	1/4	1/4	3/8	6	1/4-20
5	1/8	1/4	1/4	3/8	6	5/16-18
5 3/4	1/8	3/8	1/4	3/8	6	5/16-18

r = radius of container (in.).

S = allowable stress = 10,300 psi.

E = joint efficiency = 1 for 2R containers.

The applicable equation to determining the thickness of the top and bottom heads is Eq. (1) in paragraph UG-34:

$$t = d \left(\frac{CP}{S} \right)^{1/2}, \quad (106)$$

where

d = diameter of head (in.).

C = factor dependent upon method of attachment used for head.

The stress in the bolts of bolted 2R containers resulting from internal pressure is given by the equation

$$\sigma = (pA) / (nA_b) = (p\pi d^2) / (4nA_b),$$

where

p = internal gauge pressure (psi).

A = area of container lid exposed to internal pressure (in.²).

n = number of bolts.

A_b = stress area of one bolt (in.²).

d = diameter of container lid (in.).

The greatest stress on the 5 1/8-18 bolts (Table 8.1) will occur for the greatest value of d^2/nA_b . As indicated in Table 11, this will be when the diameter of the container lid is 5.75 in., the number of bolts is six, and the stress area of one 5 1/8-18 bolt is 0.0524 in.².¹⁶ The resulting stress is

$$\sigma = 20\pi(5.75)^2 / (4(0.0524)) = 1652 \text{ psi.} \quad (107)$$

The Specification 2R containers shipped in the Garden Carrier No. 2 cask are fabricated in accordance with ORNL Quality Assurance Procedures. Applicable approved ORNL procedures are used for welding, and all welds are inspected in accordance with approved ORNL weld inspection procedures. The bolting for the Specification 2R container is increased beyond that required for pressure tightness under the hypothetical accident conditions. Some dimensions of these containers are increased beyond the calculated values or those required by Specification 2R to facilitate fabrications. Silicone rubber gaskets or metallic gaskets made from metals with melting points higher than 800 F are used in 2R containers shipped in the Garden Carrier No. 2 cask.

9. CRITICALITY

The analysis for the single container given below is shown to be 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 776 in Appendix B).

Since the quantity of fissile isotopes carried is below all minimum critical masses for these isotopes under optimum moderation and reflection, and since the cask effectively isolates the contents from neutron interaction with packages of similar design, unlimited numbers could be stacked 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 Garden Carrier No. 2 is surrounded by a 0.375-in.-thick stainless steel inner shell and a 0.50-in.-thick outer stainless steel shell. The shielding cavity between the two is filled with lead that is 8-3/16 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 In actual use, a source containing $\cong 20,000$ ci of uranium (33g ^{235}U + 37g ^{239}Pu) gave readings of 32 mr/hr at contact and 1 mr/hr at 1 meter distance from the surface.

The conditions of normal transport and the hypothetical accident produce minor deformation of the fire shield and essentially no loss of shielding (see Sects. 5 and 6).

II. QUALITY ASSURANCE

II.1 Fabrication, Inspection, and Acceptance Tests

The Garden Carrier No. 2 container was built prior to the adoption of a formal quality assurance program by the DOE and ORNL. A formal quality assurance program has now been prepared (ORNL-IM-6471)¹⁵ and future shipping containers will be constructed in accordance with this program.

The fabrication of this cask was performed in the Oak Ridge National Laboratory Shops in accordance with normal shop fabrication procedures. Material was specified on the original drawings as "304L SS1." 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 cask has operated for six years without failures or loss of effectiveness. An inspection of the cask was made to verify its integrity (see Appendix E). The routine operating inspection procedures specify periodic weld inspections to verify weld integrity.

12. APPENDIXES

12.1 Appendix A: Drawings

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- REVISIONS**
1. CHORD GEAR DIVISION OF HARRINGTON & RICHARDS, INC., 312 PARK AVENUE, WORCESTER, MASS. 01601.
 2. PAPER SEAL CO., 1000 E. 10TH AVE., CLEVELAND, OHIO.
 3. KELTIE HARRINGTON COMPANY, INC., 1000 E. 10TH AVE., CLEVELAND, OHIO.
 4. Part Banded M 88 Molybdenum Carbide 24877 At Assembly.
 5. Part No. 83, Dwg. EM-018 E, Lateral Added To Dwg.
 6. Dwg. EM-018 E, Added Identification Plates.

- REVISIONS**
1. Part No. 6, This Dwg., Changed From Molybdenum Carbide To Steel.
 2. Part No. 1, Dwg. EM-018 E, Revised To Drawn Grade.
 3. Part No. 18, Dwg. EM-018 E, Shim Added To Drawn Grade.
 4. Part No. 18, Dwg. EM-018 E, Molybdenum Carbide Added To Part No. 83.
 5. Part No. 83, Dwg. EM-018 E, Lateral Added To Dwg.
 6. Dwg. EM-018 E, Added Identification Plates.

3

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6 more Equips, 5 more

(20) PORT COVER GASKET
NAIL NEOPRENE
1-REQUIRED
SC-10 F

1. 15 - Top Score
MAT - 86 to 100
IR - 80 to 90
Score - 100

36 - DRIVE HOLE COVER PLATE
MAY 1, 304L SST
2 REQUIRED
Scale 1" = 1"

After the Cover To Battery Excess Metal Hasamp Some Insured On
Soldered To Battery
Added 6 Bolt Nuts To Hold Drive Unit Cover

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204-314
304L SST
W/RED
2-1/16"

21 DRIVE SCREW
MATERIAL 304L SST
2 REQUIRED
Scale 1"=1"

23 SCREEN
3-1/2 in. Dia
MATERIAL 304L SST
Scale 1"=1"

3

GENERAL SPECIFICATIONS		TECHNICAL SPECIFICATIONS		REVISIONS		DATE		APPROVED	
<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>		<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>		<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>		<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>		<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>	

Assembly Form - P. 10-1		MATERIAL	
<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>		<p>1. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.</p> <p>2. TOLERANCES ARE AS FOLLOWS:</p> <p>3. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>4. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p> <p>5. ALL DIMENSIONS ARE TO BE HOLDING DIMENSIONS UNLESS OTHERWISE SPECIFIED.</p>	

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(2) MAIN BODY SECTION A-A
MATH. 304L ST. LEAD
REQUIRED

Garden Car of 110" Assembly		11/11/1952
REVISIONS		10
ON BACK REVISION LEADWORK		
UNION CARBIDE CORPORATION		
C.D. CASE		11/11/1952
GARDEN CARRIER No 2		
LEAD 3-55T No 3		
DATE	APPROVED	BY
11/11/1952	EM	015

NO.	QTY	DESCRIPTION	DATE	APPROVED	BY
1	1	304L ST. LEAD	11/11/1952	EM	015
2	1	304L ST. LEAD	11/11/1952	EM	015
3	1	304L ST. LEAD	11/11/1952	EM	015
4	1	304L ST. LEAD	11/11/1952	EM	015
5	1	304L ST. LEAD	11/11/1952	EM	015
6	1	304L ST. LEAD	11/11/1952	EM	015
7	1	304L ST. LEAD	11/11/1952	EM	015
8	1	304L ST. LEAD	11/11/1952	EM	015
9	1	304L ST. LEAD	11/11/1952	EM	015
10	1	304L ST. LEAD	11/11/1952	EM	015

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3

RECEIVED

⑦ MAIN BODY FRONT VIEW

2

GENERAL SPECIFICATIONS		PARTS LIST		REVISIONS	
UNLESS OTHERWISE SPECIFIED		FRACTIONS - 16		NO.	
1. ALL DIMENSIONS ARE IN INCHES		DECIMALS - 0.001		DATE	
2. ALL DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		ANGLES - 0		BY	
3. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		TOLERANCES - 0.001		CHECKED	
4. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		MATERIALS - 0.001		APPROVED	
5. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		FINISHES - 0.001		DATE	
6. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		PAINTS - 0.001		BY	
7. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		WELDING - 0.001		CHECKED	
8. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		ASSEMBLY - 0.001		APPROVED	
9. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		TESTING - 0.001		DATE	
10. DIMENSIONS ARE TO BE TAKEN FROM THE EXTERIOR UNLESS OTHERWISE SPECIFIED		STORAGE - 0.001		BY	

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As 9/16 Drill Thru Top
26-1014P 1/8\"/>

SECTION CC
FIND V. 332 EN DME

FRONT CORNER DETAIL

TYPICAL ROLLER ASSEMBLY
Scale 1\"/>

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INDEX OF FILMED

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2

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PARTS LIST			
PART	QTY	DESCRIPTION	UNIT PRICE

DRIVER: [REDACTED]
MAY 1983
[REDACTED]
[REDACTED]

Garden Carriage No 2 Assembly
 REFERENCE NUMBER NO
 One Horse Drawn Locomotive
 EQUIPMENT OF
 GARDEN CARRIAGE CORPORATION
 ONE HORSE, STEAM-POWERED
 GARDEN CAR
 REF 4130
 GARDEN CAR NO 2
 DETAIL SHEET NO 2
 111332 PM 016 0 01

[illegible]

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3

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Assembly / Details FIRE SHIELD		M286CD-283-6	
Garden Carrier No. 2 Assembly		U. 3814020	
REFERENCE DRAWINGS		NO.	
<p align="center">ONE RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE CORPORATION ONE RIDGE, TENNESSEE</p>			
C.T.D. CASE		BLDG. NO. 1500	
GARDEN CARRIER No. 2			
DETAIL SHEET No. 7			
SUBMITTED	ACCEPTED	APPROVED	
	<i>(Signature)</i>	<i>(Signature)</i>	
M	11332	EN1	017 D REV

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Top View

Elevation

Bottom

1/2 Drill 1/2 Deep
2 Holes

Cap Detail

Flange Detail

Each Container Shall Be
Marked (24-400) With Radioactive
Material Tag As Shown
2 1/2 inch x 1/2 inch Thick Plate And
Weld To The Container.

SHOWN CAN BE USED
FOR ACTIVE MATERIAL
PROPERTY OF
CNSC (CNSC) DIVISION
ONE DOES NOT
BUT MUST BE
PLEASE RETURN

Tag Detail

WELDING INSPECTION					
SPEC	NO	INSPE	DRAWING	WELDED BY	INSPECTED BY
WPS-302	1	RT			
"	2	RT			
"	3	V			
"	4	V			
"	5	V			

NO REPRESENTATION OR WARRANTY IS
MADE FOR THE USE OR APPLICATION OF
THESE OR PATENTS OR OTHERS IN THE
FUTURE. THESE OR OTHERS ARE NOT
TO BE USED FOR ANY PURPOSES OTHER
THAN THOSE FOR WHICH THEY WERE
DESIGNED AND ARE NOT TO BE USED
TO BE RETURNED UPON REQUEST OF

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- ## MATERIAL LIST

THREAD TABLE 6-12 PITCH

Yes, Mr. [redacted]

1-45 Charter

This Drawing Supersedes Drawing No. 332-EM-C13-D23

Garden Carrier No 2 Assembly		EM-510-E	
REFERENCE DRAWINGS		NUMBER	
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE			
		SCALE 1/8" = 1"	
GARDEN CARRIER No. 2 SCREW TOP INNER CONTAINER			
DESIGNED BY	DRAWN BY	CHECKED BY	APPROVED BY
W. L. ...	W. L. ...	...	...
M 11332	EM 019	D	REV.

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3x4"x20" ERM
COPE TO FIT

1/2" SPONGE RUBBER
JACKET ALL AROUND
CEMENT IN PLACE

SECTION B-B
SCALE: 1/4" = 1'

FISSILE RADIOACTIVE MATERIAL
DOT SP 5936
ORNL-8511-174 WEIGHT 11,600 LBS
RETURN TO
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE
FILL WITH YELLOW ENAMEL

DETAIL ITEM (20)
LOCATE AND WELD ON
FRONT & TOP OF
1" BRASS CENTER
DRY HOLE CHARGER ONLY

RELOCATED
2"x2" WROUGHT STEEL
BUTT MINNESOTA
WELD PINS & RELOCATE MASS

NOTES

FABRICATE SKID FROM MILD STEEL.
ALL JOINTS SHALL BE CONTINUOUSLY
WELDED FULL PENETRATION. PAINT
COMPLETED ASSEMBLY WITH 1 COAT OF
CHROME PRIMER & 2 COATS OF ZINC
MACHINE ENAMEL.

VIEW
S-10

SEE DATA
ITEM 12
REMOVE EXISTING
TIE DOWN PLACES
3" x 1/2"

SHIPPING SKID DETAIL
SCALE: NOTED

DETAIL ITEM (12)
SCALE: 1/2" = 1'

ALIGNMENT
SCALE: 1/2" = 1'

NOTES

1. Manufacturer must use discretion to avoid extreme build-up of rebar.
2. This drawing dimensioned for fabrication in our shop and is not to be sent outside for bids.
3. Remove A Section Of The Bottom Plate 12"x18". Place Two Plates 6"x18"x1/2" Thick 6" From E. Of Skid Weld All Around. Pack Cavity With 6 Thickness Of Insulation (M. No 01-267-0400) Replace Existing Plate And Weld All Around.

ON C.C.
1 1/2" x 1/2"
1 1/2" GNC 1/2" LONG & 20"
ANNEALED STEEL HEX HEAD
OR SOCKET HEAD BOLT
8-REGD TACK WELD WITH
BOLT CENTERED IN HOLE
HOLE CHARGER ONLY

LISTS OF DIMENSIONS
OTHERWISE SPECIFIED
FRACTIONS: 1/2"
DECIMALS: 1/16"
ANGLES: 1/2°
SCALE: NOTED

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1/2" SPONGE RUBBER
SHEET ALL AROUND
CEMENT IN PLACE

SECTION E-E
SCALE 1/2" = 1"

DETAIL ITEM (13)
SCALE 1/2" = 1"

DETAIL ITEM (12)
SCALE 1/2" = 1"

ALIGNMENT PIN
SCALE 1/2" = 1"

General Carrier No. 2 Screw Top Inner Container	CD-086-B
Fire Shield Assembly & Details G.C. No. 2	CD-083-E
Garden Carrier Assembly & Shield	EM-018-E
ASSEMBLY	EM-051-D
REFERENCE DRAWINGS	DWG. NO.
PRFP	CHEMICAL DEVELOPMENT NO. 3597
GARDEN CARRIER NO. 2 DRY HOLE CHARGER	
SHIPPING SKID-FIRE SHIELD & PAN	

OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
SUBMITTED R.C.G. & H. H. H.	APPROVED J.H. H. H.
DATE 8-1-55	REV. G

M-12124-CB-014-3-5

Drop all references
and is not to be used outside for info.

From Plate 18"x18". Place Two Plates 6"x18"x1/2" Thick
around, Peak Cavity with 4 Thickness of insulation
insulating Plate And Weld All Around.

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:	
FRACTIONS 1/8"	
DECIMALS 1/16"	
ANGLES 1/2°	
SCALE NOTES	

3

SHIPPING 3P.D.
3'0" x 3'0" x 7 1/4" H.H.H.
(NOT A PART OF THE PACKAGE)

TIE DOWN BOLTS - 1/2" UNC x 3 1/4" LONG
440 SIL. STEEL NO BOLT (6 Ea)

GRADE 11 CARBIDE No 2

SCALE - 3/16" = 1"

2

NO		REVISIONS		DATE	
DESIGNED	DATE	SUBMITTED	DATE		
DRAWN	DATE	APPROVED	DATE		
CHECKED	DATE	APPROVED	DATE		

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TOLERANCES UNLESS OTHERWISE SPECIFIED

FRACTIONS ±

DECIMALS ±

ANGLES ±

SCALE 3/16" = 1"

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"DR. CARRIER No. 2"
SCALE - 3/16" = 1"

INNER CONTAINER
FOR SOLIDS
SCALE - 1/2" = 1"

GARDEN CARRIER NO 2 SHOW TOP INNER CONTAINER		M-11932-EM Q97-D
AGE & DETAILS FIRE SHIELD		M-12166-CD Q43-D
GARDEN CARRIER NO 2 FIRE SHIELD INNER CONTAINER		M-11932-EM Q10-D
GARDEN CARRIER NO 2 - ALLIED WAY		M-11932-EM Q10-E
SHIPPING BOX		M-12124-CD C33-D
REFERENCE DRAWINGS		NUMBER
ONE HOUR RETURN LABORATORY OPERATED BY UNION CARBIDE CORPORATION ONE NUCLE, TENNESSEE		
		SLIP NO.
JANLEN CARR. SR NO. 2		
SEARCHED	INDEXED	FILED
		4 JAN 2 1965
M	12166	CD 337 D 4

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DETAIL ITEM ③
Scale 1/2"

DETAIL ITEM ②

DETAIL ITEM ④
Scale 1/2"

DETAIL ITEM ⑤

WELD NOTES:

NO.	DESCRIPTION	LOCATION
1	DRG. PENETRANT	Left Side
2	"	Top Center ② To Top
3	"	Right Side
4	"	Bottom Center
5	"	Right Side
6	"	Left Side
7	"	Top Center ② To Top
8	"	Bottom Center
9	"	Right Side
10	"	Left Side
11	"	Top Center ② To Top
12	"	Bottom Center
13	"	Right Side
14	"	Left Side
15	"	Top Center ② To Top
16	"	Bottom Center
17	"	Right Side
18	"	Left Side

DETAIL ITEM ③
Scale 1/2"

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WELD NOTES:

NO.	DESCRIPTION	LOCATION	QTY.	WELDING
1	One Penetrant	Top Outside	101	
2	"	Top Outside	101	
3	"	Top Outside	101	
4	"	Top Outside	101	
5	"	Top Outside	101	
6	"	Top Outside	101	
7	One Penetrant	Top Inside	101	
8	"	Top Inside	101	
9	"	Top Inside	101	
10	"	Top Inside	101	
11	"	Top Inside	101	
12	"	Top Inside	101	
13	Visual	Weld	101	
14	One Penetrant	Weld	101	
15	"	Weld	101	
16	"	Weld	101	

NOTES:

1. Item 9 Clip with Washer & Pin Base Plate. 2. Item 10. 3. Item 11. 4. Item 12. 5. Item 13. 6. Item 14. 7. Item 15. 8. Item 16. 9. Item 17. 10. Item 18. 11. Item 19. 12. Item 20. 13. Item 21. 14. Item 22. 15. Item 23. 16. Item 24. 17. Item 25. 18. Item 26. 19. Item 27. 20. Item 28. 21. Item 29. 22. Item 30. 23. Item 31. 24. Item 32. 25. Item 33. 26. Item 34. 27. Item 35. 28. Item 36. 29. Item 37. 30. Item 38. 31. Item 39. 32. Item 40. 33. Item 41. 34. Item 42. 35. Item 43. 36. Item 44. 37. Item 45. 38. Item 46. 39. Item 47. 40. Item 48. 41. Item 49. 42. Item 50. 43. Item 51. 44. Item 52. 45. Item 53. 46. Item 54. 47. Item 55. 48. Item 56. 49. Item 57. 50. Item 58. 51. Item 59. 52. Item 60. 53. Item 61. 54. Item 62. 55. Item 63. 56. Item 64. 57. Item 65. 58. Item 66. 59. Item 67. 60. Item 68. 61. Item 69. 62. Item 70. 63. Item 71. 64. Item 72. 65. Item 73. 66. Item 74. 67. Item 75. 68. Item 76. 69. Item 77. 70. Item 78. 71. Item 79. 72. Item 80. 73. Item 81. 74. Item 82. 75. Item 83. 76. Item 84. 77. Item 85. 78. Item 86. 79. Item 87. 80. Item 88. 81. Item 89. 82. Item 90. 83. Item 91. 84. Item 92. 85. Item 93. 86. Item 94. 87. Item 95. 88. Item 96. 89. Item 97. 90. Item 98. 91. Item 99. 92. Item 100.

ASSEMBLY

DETAIL ITEM 19

NO.	DESCRIPTION	LOCATION	QTY.	WELDING
1	One Penetrant	Top Outside	101	
2	"	Top Outside	101	
3	"	Top Outside	101	
4	"	Top Outside	101	
5	"	Top Outside	101	
6	"	Top Outside	101	
7	One Penetrant	Top Inside	101	
8	"	Top Inside	101	
9	"	Top Inside	101	
10	"	Top Inside	101	
11	"	Top Inside	101	
12	"	Top Inside	101	
13	Visual	Weld	101	
14	One Penetrant	Weld	101	
15	"	Weld	101	
16	"	Weld	101	

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12.2 Appendix B: Approval Documents

	<u>Page No.</u>
Department of Transportation Special Permit No. 6088 dated Oct. 1, 1969	102
First Revision DOT Special Permit No. 6088 dated Aug. 5, 1971	105
Interim AEC Certificate of Compliance AEC-OR USA 6088/BLF dated Sept. 21, 1973	106
ORNL Nuclear Safety Review NSR 742 dated June 17, 1974	107
Letter of Approval of SARP after Review by ORNL Transportation Committee, E. M. King to R. D. Seagren dated Nov. 30, 1977.	109

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20597

SPECIAL PERMIT NO. 6088

This special permit is issued pursuant to 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the August 11, 1969, petition by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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 number 69-014 dated August 4, 1969, and as further provided for herein.
2. Each shipper, under this permit, other than the petitioner named above, 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 lead-filled, steel cask weldment, which is a right cylinder approximately 25" in diameter by 49" high, weighing about 8500 pounds, with a 7" diameter by 24" deep cavity. Approximately 8 3/16" of lead shielding is provided. Contents are loaded within DOT Specification 2R or equivalent inner containment. The package is identified as the Garden Carrier Number 2 Shipping Cask, and is described on Oak Ridge National Laboratory's drawing number M-12166-CD-037-D and in the attachment to the USAEC Certification.
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 unirradiated and irradiated fuel elements and contained sections of fuel elements with solid and liquid mixed fission products, or waste products. Liquids will be contained in primary polyethylene or stainless steel bottles within

Continuation of SP 6088

Page 2

the DOT Specification 2R containment vessel. The maximum thermal decay energy of the contents is 100 watts. The fissile content is limited to not more than 500 grams of uranium-235, 350 grams of uranium-233 or plutonium, or 350 grams of any combination thereof.

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

6. The outside of each package must be plainly and durably marked "DOT SP 6088", 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. 6088", in connection with the commodity description thereon.

7. Each package must have its gross weight plainly and durably marked on the outside of the package.

8. This permit authorizes shipments only by motor vehicle, and rail.

9. 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.

10. Prior to each shipment authorized by this permit, the shipper shall notify the consignee 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.

11. 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 SP 6088

Page 3

12. This permit does not relieve the shipper or carrier from compliance with any requirement of the DOT regulations, except as specifically provided for herein.

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

Issued at Washington, D.C.:

W. R. Fiste
For the Administrator
Federal Highway Administration

25 September 1969
(Date)

Mac E. Rogers
For the Administrator
Federal Railroad Administration

OCT - 1 1969
(Date)

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

Dist: a, d, e, h, i

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

SPECIAL PERMIT NO. 6088
FIRST REVISION

Pursuant to 49 C.F.R. 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the July 28, 1971, petition by the Oak Ridge National Laboratory, Oak Ridge, Tennessee:

Special Permit No. 6088 is hereby amended by revising paragraph (13) to read as follows:

"13. 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 original issue and the First Revision.

Issued at Washington, D.C.:

John F. Miller
For the Administrator
Federal Highway Administration

2.13.1971
(DATE)

Mac E. Rogers
For the Administrator
Federal Railroad Administration

AUG 5 1971
(DATE)

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

Dist: 1, 2, 3, 4, 5
U.S. Atomic Energy Commission, Richland, Washington

Form AEC-416
 (1-77)
 AECM 1181

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

1a. Number AEC OR	USA 6088/BLF	1b. Revision No. 0	1c. Page No. 1	1d. Total No. Pages 1
----------------------	--------------	-----------------------	-------------------	--------------------------

2. Authority
 This certificate is issued pursuant to Sections 173.294, 173.295, and 173.296 of the Department of Transportation Hazardous Materials Regulations as amended (49 CFR 170-189 and 14 CFR 103), and AEC Manual Chapters 5201 and 0529.

3. CONDITIONS

3a. This certificate is issued on the basis of SAFETY ANALYSIS REPORT FOR PACKAGING (SARP): (1) Prepared by Oak Ridge National Laboratory P.O. Box X Oak Ridge, Tennessee 37830	(2) Number Letter of Request (M. E. Patton) (3) Date Expires July 6, 1969
---	---

3b. The packaging described in the SARP and further described in item 4 below, when constructed and assembled 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 number shown in item 1a on this form in accordance with the standards for markings in paragraph 173.24(b) of 49 CFR 173.

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

3e. Each user of packages 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 lead-filled, steel cask weldment, which is a right cylinder approximately 25" O.D. x 49" high with a 7" I.D. x 24" deep cavity. Lead shielding approximately 2-3/16" thick is provided. The top opening is closed by a stainless steel clad lead shield. The bottom opening has two stainless steel clad lead shielded opposing stepped sliding drawers. All openings are sealed with neoprene gaskets. Contents are loaded within DOT Specification 2P or equivalent inner containment. The gross weight is approximately 9500 lb.

B. The authorized contents of each package consists of fissile and large quantities of radioactive materials, UO₂, in the form of unirradiated and irradiated fuel elements and contained sections of fuel elements with solid and liquid mixed fission products, or waste products. Solids will be contained in primary polyethylene or stainless steel bottles within the DOT Specification 2P (containment vessel). The maximum thermal decay energy for solid nonfissile radioisotopes is 100 watts and for liquid nonfissile radioisotopes is 11.6 watts. The fissile content is limited to not more than 500 g of ²³⁵U, 350 g of ²³³U or ²³⁹Pu, or 350 g of any combination thereof.

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 motor vehicle and rail.

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:
 [Signature]
 5c. Name and Title of AEC Approving Official:
 William H. Travis, Director
 Safety & Environmental Control Division

6. Expiration Date of Application: September 21, 1973

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.

ORNL
CRITICALITY COMMITTEE

NSR 742

EXPIRATION DATE
July, 1979

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS (To be completed by the Control Area Supervisor)			
TITLE (FOR REFERENCE PURPOSES) Garden Carrier No. 2		DATE OF REQUEST 5/1/74	DATE REVIEWED 5/15/74
CONTROL AREA		CODE NO.	BUILDING ROOM 45005 DIVISION Chem. Tech.
TYPE AND FORM OF MATERIAL	Unirradiated or irradiated fuel elements and contained sections of fuel element, solid and liquid mixed fission products plus fissionable material		
ISOTOPIC ENRICHMENT (WT %)	Natural to fully enriched		
QUANTITY OF FISSIONABLE ISOTOPES	PER ISOLATED BATCH OR UNIT MAXIMUM 500 g ²³⁵ U, 350 g ²³³ U or Pu, or 350 g of any combination		
	TOTAL IN CONTROL AREA		
	TOTAL TO BE PROCESSED		
Concentration or Density of Fissile Material			
Spacing of Fissile Units	Class I Large Quantity Shipment use		
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material			
Limit on Moderation			
Limit on Neutron Absorbers			
Limit on Volume or Dimensions of Containers	8.1875 in. lead shielded cask 25-3/16 in. OD x 46-1/8 in. high, 7.065 in. ID x 24 in. deep, right cylinder		
THIS REQUEST (MODIFIES, REPLACES) NSR(S) NO. replaces NSR 395 which expires 5/15/74			
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.			

The 9-in.-thick lead-steel shield surrounding the fissile material, effectively isolates the limited quantity of fissile payload, thus eliminating effective interaction between similar, adjacent casks. The requirements of Fissile Class I are therefore met for this cask when loaded as described in this NSR. The proposed loadings are approved.

J. P. Nichols
CHAIRMAN, CRITICALITY COMMITTEE
6/17/74

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 6530. This shall include brief descriptions of the processes and/or all operations to be performed, plans and procedures for the operation of nuclear criticality safety, and the basic control parameters. Please attach 11 copies of referenced drawings and documents.

The SARP for the Carden Carrier No. 2 is in process of preparation. This document will be included as an appendix.

The masses of fissionable isotopes are the same as previously requested and approved on Nuclear Request Nos. 331, 345, and 335.

ORNL
CRITICALITY COMMITTEE

NSR 742

EXPIRATION DATE
July, 1986 1979

RADIATION CONTROL OFFICER

DIVISION

CONSENT AREA SUPERVISOR

EXPIRATION DATE

RADIATION CONTROL OFFICER

DIVISION

RADIATION CONTROL OFFICER

DIVISION

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

November 30, 1977

TC 75-6

To: R. D. Seagren
From: Transportation Committee
Subject: SARP of the ORNL Garden Carrier No. 2 --
Draft

The Committee has reviewed the subject draft dated November 10, 1977. Attached are comments made by individual members of the Committee for changes needed or suggested. The SARP is approved for technical content and approach -- with the expectation that you will make a positive response to the comments. (If you have any question concerning the comments, please contact the individual making the comments.)

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

EMK:bb

cc: Transportation Committee
G. H. 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 a 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

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

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.);

U = the kinetic energy.

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

$$dV = \frac{1}{2} XY dZ. \quad (C-2)$$

By trigonometry,

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

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

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

It follows that

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

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ORNL DWG 75-93

Fig. C.1. Model for corner drop calculations.

and

$$U = \sum dU = \sum SXYdZ \quad (C-7)$$

This expression can be readily solved using the computer. A value for the angle, A , can be assumed and B incremented from $-A$ to A or from 0 to A if the result is multiplied by two 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 , is found in the following manner.

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

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

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

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

$$\Delta KE = U = (M/2)(V_o^2 - V^2), \quad (C-10)$$

or

$$V = (V_o^2 - 2U/M)^{1/2} = [(2g/W)(Wh-U)]^{1/2}, \quad (C-10a)$$

where

V_o = initial velocity,

M = cask mass,

h = drop height,

g = gravitational constant,

W = weight of cask.

The time is computed from the following relationship:

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

or

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

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 versus deformation are given in Figs. C.2 and C.3.

Fig. C.2. Plot of negative acceleration vs deformation at a specific energy of 100,000 in.-lb/in.³ for steel for the 30-ft corner drop.

Fig. C.3. Plot of negative acceleration vs deformation at a specific energy of 260,000 in.-lb/in.³ for steel for the 30 ft side 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, CARL BIDGE 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 DIMENSION V(1000),AR(1000),P(1000),U(1000),T(1000),AN(1000),
C X(1000),AG(1000)
C PY=3.141596254
C S=0.0
C ANA = 0.0

C INPUT MATERIAL CONSTANT

C INPUT CASK GEOMETRY

1010 POPMAT(1H,30X)

W=12400.

R=21.5

C=51.5625

O=ATAN(2.*P/C)

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

```

      T1 = 0.0
      P(I) = 0.0
      U(I) = 0.0
      AP(I) = 0.0
14 CONTINUE
C ZERO NONSUBSCRIPTED VARIABLES
      TA = 0.0
      AP = 0.0
      A = 0.0
      AR = 0.0
      TX = 0.0
      U = 0.0
      IX = 0.0
      XA = 0.0
      UT = 0.0
      VV = SQRT((64.*H)/12.)
      DO 1 I = 1, 1000
        AR = 0.0
C INCREMENT ANGLE A
        A = A + AA
        CA = COS(A)
        B = 0.0
        AE = 0.0
        SUM0 = 0.0
10 DO 2 J = 1, 1000
C INCREMENT ANGLE B
        B = B + BB
        CB = COS(B)
C CALCULATE VOLUME DISPLACED
11 CC = (CB - CA)
        BY = TAN(O) * R * CC
        BX = R * CC
12 DZ = R * CB * BB
        DU = BY * BX * DZ * S
C CALCULATE ENERGY ABSORBED
        SUM0 = SUM0 + DU
C CALCULATE AREA
13 DA = 2. * BX * DZ / COS(O)
        AE = AE + DA
        IF (B.GE.A) GO TO 3
2 CONTINUE
3 U(I) = SUM0
      AR(I) = AE
C CALCULATE FORCE
      P(I) = AR(I) * S
C CALCULATE VELOCITY
      IF (U(I).GE.UT) GO TO 16
5 VA = SQRT(((64. / (12.*H)) * (UT - U(I)))
16 IF (U(I).GE.UT) VA = 0.0
C CALCULATE ACCELERATION
      AG(I) = P(I) / W
C CALCULATE DEFORMATION
      XA = (TAN(O) * COS(O) * R * (1. - CA))
      X(I) = XA
C CALCULATE TIME
      TX = (XA - XX) / ((VV + VA) * 6.)
7 TA = TA + TX

```

```

      T(I)=TA*1000.
      XX=XA
5     V(I)=VA
      VV=VA
      AN(I)=A*57.3
      IF(U(I).GE.UT) GO TO 4
1     CONTINUE
      CONTINUE
C     OUTPUT-WRITE LOOP
      K=I
      WRITE(51,1002)
      WRITE(51,1004)
1004  FORMAT(1H, 9X,37CASK GEOMETRY AND MATERIAL PROPERTIES)
      WRITE(51,1002)
      WRITE(51,1005)
1005  FORMAT(1H, 4X,6HRADIUS,8X,6HLENGTH,10X,6HHEIGHT,6X,
1      15HSPECIFIC ENERGY)
      WRITE(51,1006)
1006  FORMAT(1H, 4X,6HINCHES,8X,6HINCHES,10X,6HPOUNDS,8X
1      13HLB-IN/CU. IN.)
      WRITE(51,1002)
1002  FORMAT(1H0)
      WRITE(51,1007) P,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,12HILLISECONDS,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

```

CASK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CH. IN.
------------------	------------------	------------------	----------------------------------

21.500	51.563	12400.0	100000.0
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DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION G
-----------------------	----------------------	----------------------	-----------------	------------------	-------------------

0.0007	43.82	0.00131	0.0	0.0	0.0
0.0029	43.82	0.00524	180.59	0.19	0.01
0.0062	43.82	0.01178	782.36	1.84	0.06
0.0110	43.82	0.02095	2045.61	8.66	0.16
0.0172	43.82	0.03273	4211.11	28.04	0.34
0.0248	43.82	0.04712	7517.73	72.42	0.61
0.0337	43.82	0.06413	12205.85	160.63	0.98
0.0449	43.82	0.08376	18513.43	219.11	1.49
0.0557	43.81	0.10599	26678.64	583.25	2.15
0.0688	43.81	0.13083	36939.02	998.72	2.98
0.0832	43.81	0.15828	49531.50	1622.69	3.99
0.0990	43.81	0.18834	64690.68	2525.06	5.22
0.1162	43.80	0.22100	82651.81	3789.82	6.67
0.1347	43.79	0.25626	103647.31	5516.10	9.36
0.1546	43.78	0.29413	127910.50	7819.70	10.32
0.1759	43.76	0.33460	155671.75	10833.94	12.55
0.1985	43.75	0.37768	187158.81	14710.74	15.09
0.2225	43.72	0.42336	222602.69	19622.75	17.95
0.2478	43.69	0.47165	262225.81	25762.69	21.15
0.2745	43.65	0.52257	306257.13	33346.75	24.70
0.3025	43.61	0.57610	354914.94	42613.16	28.62
0.3319	43.55	0.63228	408424.38	53825.81	32.94
0.3626	43.49	0.69110	467002.00	67272.81	37.66
0.3947	43.41	0.75260	530864.19	83269.31	42.81
0.4281	43.31	0.81679	600226.94	102158.38	48.41
0.4628	43.20	0.88370	675303.88	124310.38	54.46
0.4989	43.07	0.95337	756302.63	150125.38	60.99
0.5363	42.93	1.02583	843431.44	180032.94	68.02
0.5750	42.75	1.10114	936897.44	214495.44	75.56
0.6150	42.55	1.17936	1036903.75	254005.56	83.62
0.6564	42.32	1.26056	1143649.00	299088.38	92.23
0.6990	42.06	1.34481	1257331.00	350302.50	101.40
0.7430	41.77	1.43223	1378145.00	408241.00	111.14
0.7883	41.43	1.52292	1506282.00	473531.13	121.47
0.8348	41.05	1.61703	1641928.00	546836.19	132.41
0.8827	40.61	1.71471	1785272.00	628852.44	143.97
0.9318	40.13	1.81617	1936500.00	720317.75	156.17
0.9823	39.58	1.92163	2095785.00	822002.38	169.01
1.0340	38.96	2.03137	2263310.00	934715.88	182.52
1.0870	38.27	2.14572	2439247.00	1059301.00	196.71
1.1412	37.49	2.26509	2623764.00	1196644.00	211.79
1.1968	36.61	2.38997	2817025.00	1347679.00	227.18
1.2535	35.62	2.52096	3019197.00	1513353.00	243.48
1.3116	34.51	2.65885	3230432.00	1694679.00	260.52
1.3708	33.26	2.80463	3450895.00	1892692.00	278.30
1.4313	31.83	2.95959	3680737.00	2108471.00	296.83
1.4931	30.20	3.12549	3920089.00	2343130.00	316.14
1.5561	28.33	3.30480	4169120.00	2597844.00	336.22
1.6203	26.15	3.50117	4427560.00	2873792.00	357.09
1.6857	23.57	3.72042	4696740.00	3172221.00	378.77
1.7523	20.42	3.97281	4975604.00	3494405.00	401.26
1.8201	16.36	4.28012	5264660.00	3841655.00	424.57
1.8891	10.34	4.71089	5564744.00	4215338.00	448.71
1.9593	0.0	5.84227	5873844.00	4616831.00	473.70

MAXIMUM OUTSIDE LIMITS X=0.0

Y=-.1100E 02

IPEN= 3

CISK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/IN. IN.		
21.500	51.563	12400.0	260000.0		
DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION X G
0.0007	43.82	0.00131	0.0	0.0	0.0
0.0028	43.82	0.00524	469.53	0.48	0.04
0.0062	43.82	0.01178	2034.14	4.79	0.16
0.0110	43.82	0.02095	5318.58	22.51	0.43
0.0172	43.82	0.03273	10948.89	72.89	0.88
0.0248	43.82	0.04712	19546.11	188.30	1.58
0.0337	43.82	0.06413	31735.21	417.65	2.56
0.0440	43.81	0.08376	48134.93	829.68	3.88
0.0557	43.81	0.10599	69364.44	1516.46	5.59
0.0688	43.81	0.13084	96041.44	2596.67	7.75
0.0832	43.80	0.15830	128781.88	4219.00	10.39
0.0990	43.79	0.18836	168195.75	6565.14	13.56
0.1162	43.77	0.22108	214894.69	9853.51	17.33
0.1347	43.75	0.25634	265483.00	14341.88	21.73
0.1546	43.72	0.29425	332567.31	20331.24	26.82
0.1759	43.68	0.33479	404746.63	28168.24	32.64
0.1985	43.63	0.37796	486613.06	38247.98	39.24
0.2225	43.57	0.42379	578767.13	51015.18	46.67
0.2478	43.49	0.47228	681787.13	66982.34	54.98
0.2745	43.39	0.52346	796268.56	86701.25	64.22
0.3025	43.27	0.57737	922778.41	110793.94	74.42
0.3319	43.13	0.63404	1061903.00	139946.69	85.64
0.3626	42.95	0.69353	1214205.00	174909.44	97.92
0.3947	42.74	0.75589	1380247.00	216500.56	111.31
0.4281	42.49	0.82120	1560590.00	265611.81	125.85
0.4628	42.20	0.88955	1755790.00	323207.63	141.60
0.4989	41.86	0.96105	1966386.00	390226.88	158.58
0.5363	41.46	1.03585	2192921.00	468087.06	176.85
0.5750	40.99	1.11411	2435933.00	557689.25	196.45
0.6150	40.45	1.19604	2695949.00	660415.38	217.42
0.6564	39.82	1.28191	2973488.00	777631.31	239.80
0.6990	39.09	1.37201	3269060.00	910787.63	263.63
0.7430	38.26	1.46675	3583177.00	1061426.00	288.97
0.7883	37.29	1.56663	3916334.00	1231175.00	315.83
0.8348	36.17	1.67228	4269013.00	1421767.06	344.29
0.8827	34.88	1.78454	4641707.00	1635006.00	374.33
0.9318	33.38	1.90454	5034901.00	1872815.00	406.04
0.9823	31.64	2.03382	5449042.00	2137196.00	439.44
1.0340	29.58	2.17463	5884606.00	2430248.00	474.56
1.0870	27.12	2.33040	6342042.00	2754180.30	511.45
1.1412	24.12	2.50688	6821786.00	3111285.00	550.14
1.1968	20.32	2.71509	7324266.00	3503973.00	590.67
1.2535	15.09	2.98233	7849912.00	3934738.30	633.06
1.3116	4.99	3.46410	8399123.00	4406183.00	677.35
1.3708	0.0	5.44514	8972328.00	4921018.00	723.57
PLOT CALL OUTSIDE LIMITS		X=0.0	Y=-.11002 02	IPEN= 3	
INCOPII 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. C-1 was 63° for the side drop.

The computer program is given and the results for specific energies for stainless steel of 100,000 and 260,000 in.-lb/in.² are given. The plots of the negative accelerations vs deformation are given in Figs. D-1 and D-2.

CASK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CU. IN.		
21.500	51.563	12400.0	100000.0		
DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION X G
0.0011	43.82	0.00202	0.0	0.0	0.0
0.0042	43.82	0.00807	868.95	1.38	0.07
0.0096	43.82	0.01816	3764.55	13.68	0.30
0.0170	43.82	0.03229	9542.97	64.20	0.79
0.0265	43.82	0.05045	20262.85	207.94	1.63
0.0382	43.82	0.07263	36173.57	537.14	2.92
0.0520	43.81	0.09886	58731.67	1191.36	4.74
0.0679	43.81	0.12911	89082.25	2366.72	7.18
0.0859	43.80	0.16339	128371.00	4325.80	10.35
0.1060	43.78	0.20170	177741.56	7407.18	14.33
0.1283	43.76	0.24405	238333.38	12034.98	19.22
0.1526	43.73	0.29045	311275.94	18727.54	25.10
0.1791	43.68	0.34091	397700.38	28107.83	32.07
0.2077	43.62	0.39544	498725.88	40911.19	40.22
0.2383	43.53	0.45409	615475.50	57996.29	49.64
0.2711	43.42	0.51690	749056.50	80351.63	60.41
0.3060	43.28	0.58391	900564.94	109104.69	72.63
0.3429	43.10	0.65521	1071113.00	145535.31	86.38
0.3819	42.87	0.73090	1261771.00	191073.31	101.76
0.4231	42.59	0.81111	1473638.00	247321.65	118.84
0.4663	42.24	0.89600	1707766.00	316047.69	127.72
0.5116	41.81	0.98579	1965235.00	399208.25	153.49
0.5589	41.30	1.08075	2247099.00	498941.63	181.22
0.6083	40.67	1.18123	2554382.00	617583.69	206.00
0.6598	39.93	1.28769	2888143.00	757677.19	232.91
0.7133	39.03	1.40069	3249394.00	921972.94	262.05
0.7689	37.96	1.52103	3639141.00	1113451.00	293.48
0.8266	36.68	1.64971	4058380.00	1335245.00	327.29
0.8862	35.15	1.78815	4508116.00	1590839.00	363.56
0.9480	33.31	1.93837	4989318.00	1883868.00	402.36
1.0117	31.08	2.10333	5502952.00	2218236.00	442.79
1.0774	28.33	2.28781	6049960.00	2598073.00	487.90
1.1452	24.85	2.50019	6631289.00	3027783.00	534.78
1.2150	20.23	2.75812	7247853.00	3512022.00	584.50
1.2868	13.25	3.11537	7900575.00	4055697.00	637.14
1.3605	0.0	4.04319	8590316.00	4663988.00	692.77
PLOT CALL OUTSIDE LIMITS		X=0.0	Y=-.11002 02	IPEN= 3	

CASK GEOMETRY AND MATERIAL PROPERTIES

RADIUS INCHES	LENGTH INCHES	WEIGHT POUNDS	SPECIFIC ENERGY LB-IN/CU. IN.
21.500	51.563	12400.0	260000.0

DEFORMATION INCHES	VELOCITY FT./SEC.	TIME MILLISECONDS	FORCE POUNDS	ENERGY LB-IN.	ACCELERATION X G
0.0011	43.82	0.00202	0.0	0.0	0.0
0.0047	43.82	0.00807	2259.27	3.60	0.18
0.0096	43.82	0.01816	9787.82	35.56	0.79
0.0170	43.82	0.03229	25591.73	166.92	2.06
0.0265	43.82	0.05045	52683.41	540.64	4.25
0.0382	43.81	0.07264	94051.25	1396.57	7.58
0.0520	43.80	0.09886	152702.31	3097.54	12.31
0.0679	43.79	0.12912	231613.88	6153.46	18.68
0.0859	43.76	0.16342	333764.69	11247.08	26.92
0.1060	43.72	0.20178	462128.19	19258.68	37.27
0.1283	43.66	0.24420	619666.88	31290.95	49.97
0.1526	43.58	0.29073	809317.44	48691.63	65.27
0.1791	43.46	0.34140	1034021.00	73080.25	83.39
0.2077	43.29	0.39628	1296687.00	106368.83	104.57
0.2383	43.07	0.45546	1600236.00	150790.00	129.05
0.2711	42.78	0.51908	1947546.00	208914.50	157.06
0.3060	42.40	0.58728	2341468.00	283672.63	188.83
0.3429	41.92	0.6603	2784894.00	378392.44	224.59
0.3819	41.31	0.73850	3280604.00	496791.25	264.56
0.4231	40.54	0.82225	3831459.00	643037.38	308.99
0.4663	39.56	0.91212	4440193.00	821724.56	358.08
0.5116	38.39	1.00892	5109613.00	1037942.38	412.07
0.5589	36.91	1.11374	5842455.00	1297244.00	471.17
0.6063	35.06	1.22819	6641794.00	1605712.00	535.60
0.6598	32.75	1.35471	7509174.00	1969953.00	605.58
0.7133	29.42	1.49732	8449424.00	2397173.00	681.32
0.7689	25.98	1.66337	9461769.00	2894923.00	763.05
0.8266	20.66	1.86933	10551788.00	3471645.00	850.95
0.8862	11.87	2.17503	11721101.00	4136194.00	945.25
0.9480	0.0	3.04118	12972229.00	4498078.00	1046.15

PLOT CALL OUTSIDE LIMITS X=0.0

Y=-.1100E 02

IPEN= 3

INCO02Y STOP 00030

Fig. D.1. Plot of negative acceleration vs deformation at specific energy of 100,000 in.-lb/in.³ for steel for the 30-ft side drop.

Fig. D.2. Plot of negative acceleration vs deformation at specific energy at 260,000 in.-lb/in.³ for steel for the 30-ft side drop.

12.5 Appendix I Report of Special Inspection
of Garden Carrier No. 2

The Garden Carrier No. 2 was constructed before quality assurance records were maintained at the ORNL shops. A thorough inspection was made of the cask and the letter report on that inspection is included in this appendix.

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

December 21, 1973

TO: B. B. Klima

SUBJECT: Inspection of shipping cask - Garden Carrier #2
Work Order A-3043C-AA Inspection Request 10927

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

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-11322-EM-010-E Rev. 2.

The cask is properly identified by stamped lettering.

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

Lifting attachments are adequate and of sound construction.

Liquid Penetrant Examination

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

Leak Test

A vacuum test was made on the assembled cask. The internal cavity was evacuated to 250 microns pressure. Pressure rise test indicated a return to atmospheric pressure in approximately 15 minutes.

Material Identification.

Thickness measurements were made on the load containing assembly. These thicknesses are in accordance with drawing specifications. All accessible parts were examined with a thermal electric comparator and determined to have been fabricated from 300 series stainless steel.

These inspections and tests indicate good quality materials and welds.

It is our opinion that the integrity of this cask is of equal quality to comparable shipping casks currently being fabricated.

INSPECTION ENGINEERING DEPARTMENT

O. J. Smith
O. J. Smith

OJS:pg

cc: J. R. McGuffey
J. E. Robinson
C. P. Starlin
IP-10527

12.6 Appendix F: Operating Procedures Applicable to the
Garden Carrier No. 2

The operating procedures* can vary from shipment to shipment depending upon the following: (1) the cell or place from which the contents are picked up or discharged into; (2) the type of inner container (whether or not it must be unloaded remotely using manipulators); (3) the design of the discharge hole (horizontal or vertical); and other contingencies. The operating procedures included are typical and more general. More detailed procedures will be developed to cover the specific contingencies.

<u>Procedure No.</u>	<u>Procedure Title</u>	<u>Page No.</u>
GC2-1	Operating procedure to load bagged inner container in empty carrier	132
GC2-2	Operating procedure to unload cask into hot cell or storage well, Bldg. 3597	135
GC2-10	Polyethylene Bottle Pressure Test	139
GC2-11	Test of Flanged Inner Container	141
GC2-12	Test of Screwed Top Inner Container	142
GC2-13	Inspection of Garden Carrier No. 2	143

* Operating procedures prepared by J. H. Goode, ORNL.

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Procedure GC2-1

Page 1 of 3

Date _____

Garden Carrier No. 2

AEC-OR-USA-6088/BLF

OPERATING PROCEDURE TO LOAD BAGGED INNER CONTAINER IN EMPTY CARRIER

1. Upon arrival (at discharge site) of Garden Carrier No.2, have Health Physics representative survey fire shield, skid, and vehicle for alpha and beta-gamma radiation and transferable contamination.

	α d/m/100 cm ²		$\beta - \gamma$		Inspector	Date
	Probe <300	Smear <30	Probe	Smear		
Fire shield						
Skid						
Vehicle						

Is decontamination necessary? _____

Decontamination completed. _____

2. Remove fire shield and cask from skid using large hex key wrench located in tool box on skid to loosen socket-head cap screws. Store bolts for reuse. Inspect bolts for defect. If bolts are reusable, stow in safe place. _____
If need replacement, record number and type of bolts used. _____
3. Raise cask and set it on firm supports (wood blocks) to permit access to and removal of the cover from the bottom discharge hole. Inspect bolts. _____ Necessary to replace bolts. _____
Bolts replaced (type number). _____
Inspect gasket seating surface. _____ Surface ok. _____
Needs rework. _____ Surface repaired. _____
Stow bolts, gasket, and cover for reuse. _____
4. Remove socket-head cap screws if the top plug is to be lifted to expose the cavity. The top plug may be lifted by eye-bolts inserted

Procedure GC2-1

Page 2 of 3

Date _____

into the bolt holes for the aluminum cover or by using a clevis or shackle through the lid lifting lug. _____

Monitor for radiation contamination as cover is being raised. _____

_____ Decontamination necessary. _____

Completed. _____

Inspect bolts. _____ Necessary to replace bolts. _____

Bolts replaced (type number). _____

Store bolts for reuse. _____

Check condition of "O"-ring gasket (neoprene 1/4-in.-diam by 18-1/2-in. ID x 19-in. OD) on body of cask. _____

"O"-ring gasket needs replacement. _____

"O"-ring gasket replaced. _____

5. To load empty inner container, place container in a remotely removable plastic bag.

Through the Top

- 5a. Remove wire rope hole cover. Insert nylon cord or braided stainless steel cable through hole at bottom of receptacle and attach it to lifting ring on inner container lid. Place bagged container in cask cavity, and carefully replace the top plug of cask to prevent cutting the cord or cable or damaging gasket.

Insert and tighten 12 socket-head cap screws holding plug in place.

_____ Coil excess string inside receptacle. (Be sure string is tied so it cannot slip down hole. Replace receptacle gasket and cover plate. _____)

Insert and tighten six socket head cap screws. _____

Through the Bottom

- 5b. (Do not remove the top plug.)

Remove bottom closure (see 4 above). _____

Remove drawer cover bolts. _____

Remove drawer covers. _____

Procedure GC2-1

Page 3 of 3

Date _____

Remove drawer bolts. _____

Store bolts and covers for reuse. _____

Remove wire rope hole cover bolts. _____

Remove wire rope hole cover plate. _____

Open drawers (check for radiation contamination). _____

Decontamination necessary. _____ Completed. _____

Insert nylon cord or braided stainless wire cable through hole and attach it to lifting ring on inner container lid. _____

Pull bagged inner container into cavity. _____

Close drawers. _____ Secure drawers with bolts. _____

Coil excess nylon cord or braided stainless wire cable inside receptacle. _____

Be sure string is knotted so it cannot slip down hole. Replace receptacle gasket cover. _____

Replace receptacle cover plate. _____

Insert and tighten six socket-head cap screws. _____

Replace drawer cover plates gasket and cover plates. _____

Inspect gaskets. _____ Need replacement. _____

Replaced. _____

Insert and tighten drawer cover plate bolts. _____

Replace bottom cover and gasket. _____

Insert and tighten bottom cover bolts. _____

Procedure GC2-2

Page 1 of 4

Date _____

Garden Carrier No. 2
AEC-OR-USA-6088/BLF

OPERATING PROCEDURE TO UNLOAD CASK INTO HOT CELL
OR STORAGE WELL, BLDG. 3597

1. Upon arrival (at discharge site) of Garden Carrier No. 2, have Health Physics representative survey fire shield, skid, and vehicle for alpha and beta-gamma radiation and transferable contamination.

	α d/m/100 cm ²		$\beta - \gamma$		Inspector	Date
	Probe <300	Smear <30	Probe	Smear		
Fire shield						
Skid						
Vehicle						

Is decontamination necessary? _____

Decontamination completed. _____

2. Remove fire shield and cask from skid using large hex key wrench located in tool box on skid to loosen socket-head cap screws. Store bolts for reuse. Inspect bolts for defects. If bolts are reusable, stow in safe place. _____
If need replacement, record number and type of bolts used. _____
3. Raise cask and set it on firm supports (wood blocks) to permit access to and removal of the cover from the bottom discharge hole. Inspect bolts. _____ Necessary to replace bolts. _____
Bolts replaced (type number). _____
Inspect gasket seating surface. _____ Surface ok. _____
Needs rework. _____ Surface repaired. _____
Stow bolts, gasket, and cover for reuse. _____
4. Position cask over hole into hot cell or storage well at Bldg. 3597.

Procedure GC2-2

Page 2 of 4

Date _____

5. Prepare cask for discharge of contents.

Remove drawer cover bolts. _____

Remove drawer covers. _____

Remove drawer bolts. _____

Store drawer bolts and covers with bolts and gaskets for reuse. _____

Remove string hole cover plate bolts. _____

Remove string hole cover and gasket. _____

Store string hole bolts, cover, and gasket for reuse. _____

Apply tension to string to lift inner container from the drawers. _____

Open drawers. _____

Open cell or storage well closure. _____

Lower inner container into cell or storage well. _____

Monitor (Health Physics) passage of contents into cell. _____

If inner container is to be retrieved, proceed. However, if inner container is to be left in cell or storage well, the string may be elected to be dropped into the container. _____

Retrieve the string. _____

Empty or fill inner container. _____

Raise inner container into the cask with string. _____

Monitor passage of inner container into cask. _____

Close drawers. _____

Lower inner container onto drawers. _____

Coil excess string in string hole. _____

String hole:

Inspect gasket seating surface body. _____

Inspect gasket seating surface flange. _____

Inspect gasket. _____

Gasket needs replacement. _____ Replaced _____

Seating surface needs refinishing. _____

Refinished. _____

Procedure GC2-2

Page 3 of 4

Date _____

Install gasket. _____ Install cover. _____

Install and tighten bolts. _____

Doors:

Door bolts installed. _____

Door Covers:

Inspect right gasket seating surface body. _____

Inspect left gasket seating surface body. _____

Inspect right gasket seating surface flange. _____

Inspect left gasket seating surface flange. _____

Gasket needs replacement. _____ Replaced. _____

Seating surface needs refinishing. _____

Refinished. _____

Install door cover gasket and door. _____

Install and tighten door cover bolts. _____

Inspect bottom cover gasket. _____

Inspect bottom cover gasket seating surface on cask. _____

Inspect bottom cover gasket seating surface on cover. _____

Gasket needs replacement. _____ Replaced. _____

Gasket seating surface needs refinishing. _____

Refinished. _____

Install bottom cover and gasket. _____

Install and tighten bottom cover bolts. _____

6. Survey cask for radiation and contamination on all surfaces. _____

	α d/m/100 cm ²		$\beta - \gamma$		Inspector	Date
	Probe <300	Smear <30	Probe	Smear		
Shipping cask						

Is decontamination necessary? _____

Decontamination completed. _____

7. Lifting cask on shipping skid. _____
8. Secure cask to shipping skid with bolts; tighten them. _____

Procedure GC2-2

Page 4 of 4

Date _____

9. Place fire shield over cask. _____

Insert and tighten bolts on fire shield. _____

10. Replace tools in tool box. _____

Lock tool box. _____

11. Survey assembly for radiation and contamination on all surfaces. _____

	α d/m/100 cm ²		β γ		Inspector	Date
	Probe <300	Smear <30	Probe	Smear		
Fire shield						
Skid						

Cask is ready for transmittal to shipping.

Procedure GC2-10

Page 1 of 2

Date _____

Garden Carrier No. 2

Test Procedure

GC2-10 Polyethylene Bottle Pressure Test

1. Inspect bottle for flaws.
2. Check "O"-ring (Viton - Fluorelastomer or approved equivalent).
3. Close with special cap. (180 in. lbs. Torque)
4. Pressurize to 25 psig using air.
5. Shut off air supply.
6. Submerge bottle in water and examine for leaks.

Frequency: Before use. (No container is used more than once.)

Record data on attached Table.

Polyethylene Bottle Pressure Test

[illegible]

Procedure GC2-11

Date _____

Garden Carrier No. 2

Test Procedure^{*}GC2-11 Test of flanged inner container for
(drawing M-11332-EM-020-D)1. Inner container fabricated in accordance with drawing.
_____2. Inner container assigned a serial number and so identified.

3. Bubble test 25 psig. _____

Container approved for use _____

Date _____

^{*}Test annually or on putting new container in service.

Procedure GC2-12

Date _____

Garden Carrier No. 2

Test Procedure^{*}

GC2-12 Test of screwed top inner container
(drawing M-11332-EM-019-0)

1. Inner container fabricated in accordance with drawing.

2. Inner container assigned a serial number and so identified.

3. Bubble test at 25 psig. _____

^{*} Test before each shipment.

Procedure GC2-13

Date _____

Garden Carrier No. 2

Test Procedure *

GC2-13 Test of Garden Carrier No. 2

1. Dye penetrant test all accessible welds and lifting attachments in accordance with ORNL-Standard NDE-30. Technique 1. "Color Contrast Solvent Removable"
-

2. Apply vacuum test to assembled cask. Evacuate to 250 microns. If pressure rise to atmospheric is less than 15 minutes, gaskets should be replaced or leakage source investigated.

initial vacuum _____ microns

final vacuum _____

elapsed time _____

Cask is acceptable to use

* Test biennially.

13. REFERENCES

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