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**Safety Analysis Report for Packaging:
The ORNL HFIR Spent-Fuel-Element
Shipping Cask**

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operated by
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ABSTRACT

The Oak Ridge National Laboratory High Flux Isotope Reactor (HFIR) spent-fuel-element shipping cask is used to transport HFIR, Oak Ridge Research Reactor (ORR), and other reactor fuel elements. The cask was analytically evaluated to determine its compliance with the applicable regulations governing containers in which radioactive materials are transported, and that evaluation is reported herein. Computational procedures and tests were used to determine behavior of the cask relative to the general standards for the hypothetical accident conditions. The results of the evaluation show that the cask is in compliance with the applicable regulations.

0. GENERAL INFORMATION

0.1 Introduction

The High Flux Isotope Reactor (HFIR) spent-fuel-element shipping cask was designed in 1964 by the Oak Ridge National Laboratory (ORNL) General Engineering and Construction Division. Fabrication by ORNL and Y-12 shops was completed in 1964. The cask is now the property of the ORNL Operations Division. Both the design and the fabricated cask complied with the Atomic Energy Commission (AEC) regulations¹ in effect at that time, and a report² demonstrating compliance was prepared and published. The cask has been used since the HFIR was placed in operation in 1966 to ship spent elements for reprocessing. To date, all shipments have been made without incident via highway trailer, but the cask can also be used for rail and water transport.

Minor revisions will be made to the cask to make it adaptable for shipping Oak Ridge Research Reactor (ORR) and other similar spent-fuel elements, to improve the versatility of the cask, and to protect the closure. The cask will undergo the modification upon approval of this safety analysis report for packaging (SARP) by the Oak Ridge Operations

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Office (ORO) of the Department of Energy (DOE). All analyses and description of the cask presented here reflect the modifications to be made. These revisions are illustrated in the as-built drawings in Appendix A. The revised cask complies with DOE, *Code of Federal Regulations*, Title 10, Part 71,³ ERDA Manual Chapter 0529,⁴ and all Immediate Action Directives (IAD) in effect at the date of this report. The cask also complies with U.S. Department of Transportation (DOT) regulations, *Code of Federal Regulations*, Title 49, Part 173.⁵ Calculations, engineering logic, test results, and documents demonstrating compliance are presented in later sections of this report. Copies of the approval documents are reproduced in Appendix B.

0.2 Package Description

The salient features of the cask are illustrated in Fig. 0.1. As-built fabrication drawings are in Appendix A. The cask and contents weigh 23,000 lb. The cast-in-place lead shielding is clad with type 347 stainless steel. The cask is 72-1/2 in. overall length by 46-3/8 in. OD. There is one cavity, 17-7/8 in. ID by 32 in. long. The cask has one drain line and one penetration for sampling the cavity atmosphere and pressure testing. The closure is the cavity shield plug. The plug is secured to the body by fourteen 1-1/2-in. alloy steel studs, one of which is drilled for seal wiring. Nuclear subcriticality for the HFIR element is ensured by the poison post and poison annulus. For shipping ORP elements, a magazine with poison-containing partitions replaces the HFIR post and liner. Sixteen 4-in. sched.-80 pipes are welded to the cask to enhance heat transfer. Eight of these pipes are extended above the cask for energy absorption. The internal heat transfer connectors are tinned to enhance bonding for heat transfer purposes. The closure (top) and the bottom of the cask are protected by impact energy-absorbing structures. The top absorber is a carbon steel ring-shaped piece held in place by 4-3/4-in. bolts and captured by surrounding pipes and gussets. The containment vessel is formed by the cavity wall, the bottom head, the lower surface of the shield plug, and the cask gasket. The gasket is a

Fig. 0.1. HFIR cask loaded with a complete HFIR core.

flat silicone rubber gasket 18-1/2 in. ID by 21 in. OD by 1/8 in. thick. Biological shielding is provided by a nominal lead thickness of 8-3/4 in. and 1 in. of type 347 stainless steel cladding.

0.2.1 Operational features

The cask is designed for pool loading and unloading. After the cask is removed from the pool, water is removed from the cavity via the drain penetration (Fig. 0.1) by introducing air pressure to the cavity sampling and pressurizing penetration in the plug. To ensure that essentially all the water is removed, air is circulated through the loaded cask for a period of 30 min with the vent connected to an off-gas system. The cask is lifted by two lifting lugs located on top of the cask and a special lifting device (Appendix A, Fig. A.6). The plug is lifted for removal or installation by a single lifting bar located on top of the plug. The cask is designed to be secured to a vehicle bed by bolting the cask base to a base plate, which is, in turn, bolted to the vehicle frame (Fig. 1.9).

The cask internals are exchangeable to adapt to either ORR- or HFIR-type elements. For shipment of HFIR elements the poison post and liner (Fig. 0.1 and drawings, Appendix A) are installed. When ORR elements are shipped, the post and liner are removed, and the ORR fuel magazine (Fig. 0.2 and drawings, Appendix A) is installed in their place. Due to geometrical differences in elements, it is not possible to load elements with the wrong internals in the cask.

0.2.2 Contents

The cask is designed to transport one spent HFIR core consisting of an inner and an outer element as shown in Fig. 0.1. The HFIR elements are shown in Fig. 0.3. Detailed drawings of the elements are included in Appendix C, and detailed specifications are contained in ORNL Specifications.⁶ The cask design basis was for an HFIR operating cycle² of 15 days at 100 MW(t) followed by a 270-day post-operation decay period. The current cycle is about 23 days at 100 MW(t) followed by a 240-day post-irradiation decay period. Conservatism in the design from the standpoint

Fig. 0.2. HFIR cask with ORR elements loaded.

Fig. 0.3. HFIR element.

of shielding and heat transfer made shipping of elements from the current operating cycle with a shorter decay period feasible.

The cask has been adapted to transport a maximum of 17 ORR, Bulk Shielding Reactor (BSR), or Puerto Rico Nuclear Center (PRNC) (MTR Type) spent fuel elements. Typical elements are illustrated in Fig. 0.4, and detailed drawings appear in Appendix C. The fuel element end fittings are removed by sawing before shipment.

The operating histories of ORR, BSR, and PRNC elements vary considerably. The design operating history outlined below offers a conservative basis for evaluating cask performance from the standpoint of heat transfer, shielding, and criticality. The operating cycle has no significant effect on the structural integrity of the cask, except as related to decay heat dissipation. For the purpose of calculating decay heat, the element is assumed to remain in the reactor throughout its life. In reality, the element is cycled in and out of the reactor in various core positions depending on the amount of ^{235}U remaining.

The calculated thermal energy release (Appendix D) for the element after the 150-day decay period, is 210 W per element or 3570 W per shipment. The conservatism of this value is demonstrated in the addendum to Hamrick's report in Appendix D. Data demonstrating that PRNC elements have lower heat generation rates are also in Appendix D.

The cask will be used infrequently to transport ORNL Tower Shielding Facility (TSF) spent elements and the ORNL Health Physics Research Reactor (HPRR) spent elements. These elements have significantly lower heat generation and radiation levels than either the HFIR, ORR, BSR, or PRNC elements. The TSR II and/or HPRR elements generate a maximum heat load of about 500 W. Hence this load is not significant when compared with the heat loads considered in the preceding section. These elements will be loaded in racks or blocked in place so that the movement of elements within the cask is limited to 1/2 in. during shipment.

1. STRUCTURAL EVALUATION

The package complies with the structural requirements of the regulations.³⁻⁵ The calculations, test results, and engineering logic presented in the following sections demonstrate compliance with these

Photo 41728

Fig. 0.4. Typical ORR-type elements.

performance criteria. The effects of both normal and specified accident conditions on the structural integrity of the package are considered.

1.1 Mechanical Properties of Materials

The static properties of the materials used in the cask are listed in Table 1.1. The properties of the stainless steel are taken from data published by the International Nickel Company.⁷ The properties of AISC4340 are taken from data published in *The Ferrous Metals Book*.⁸

Table 1.1. Static mechanical properties of cask materials

Property	Symbol	304L stainless steel	AISC4340 steel	347 stainless steel
Yield stress, psi	σ_y	30,000	109,000	30,000
Ultimate tensile strength, psi	σ_u	75,000	109,000	75,000
Modulus of elasticity, psi	E	29×10^6	30×10^6	29×10^6
Elongation, %		40.0	22.0	40.0
Density, lb·in. ³	ρ	0.283	0.283	0.283
Maximum allowable shear = $\sigma_y/2$, psi	$\tau_{\max}$	15,000	54,500	15,000
Coefficient of expansion, in./in.·°F	α		9.2×10^{-6}	9.2×10^{-6}
Ultimate shear stress	τ_{ult}		61,000	53,000

The volumetric expansion properties of lead as reported by Shappert¹⁰ are used to evaluate the effects of thermal gradients. Figure 1.1 is reproduced from Shappert's report.

The programs used to estimate the response of the cask impacting on the corner and side are based on the assumption that the cask is constructed of ideally plastic materials. An ideally plastic material is a material which has a constant value of stress for all strains. It is recognized that normally used cask materials do not behave in this manner. However, conservative solutions can be effected if care is used in selecting the

Fig. 1.1. Volumetric expansion of lead and stainless steel as a function of temperature.

material property constant, dynamic yield stress or specific energy, and in interpreting the results. To accomplish this objective numerical values for ideal dynamic yield stress or specific energy which bound the real stress-strain curve must be selected. The lower value will result in a calculated deformation which is greater than actual. The higher value will result in calculated accelerations of greater magnitude than actual. It can then be seen from Fig. 1.2 that the selected values of 6000 psi and 14,000 psi for the dynamic compressive yield stress for lead will effect a conservative solution for a lead-shielded cask. This figure is the result of experimental data obtained by Evans.⁹

The dynamic tensile properties of stainless steel reported by Clark¹¹ (Fig. 1.3) and the dynamic compressive properties of steel and stainless steel reported by the author¹² (Fig. 1.4) were used in the impact analyses. For gross deformations, the curves support the selection of 100,000 and 240,000 psi as limits for dynamic compressive yield-stress for stainless steel for those techniques employing this concept. In all impact analyses it is assumed that steel, stainless steel, and lead are incompressible.

1.2 General Standards for All Packages

The general standards for all packaging cover the chemical and galvanic reactions of the materials of the package, closure of the package, and the lifting and tie-down devices for the package. As shown in the as-built drawings, the containers are constructed of type 347 and 304L stainless steel and chemical lead (ASTMB29, 99.9% lead minimum). There has been no evidence of any significant chemical, galvanic, or other reaction between these materials, nor has there been any experience of reaction between these materials of construction and the intended package contents.

1.2.1 Closure

The cask is equipped with a positive closure consisting of fourteen 1-1/2-in.-diam studs which secure the lid and prevent inadvertent opening of the cask. Additionally, a seal wire is applied through a drilled hole in one stud so that any tampering with the closure will be revealed.

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Fig. 1.2. Dynamic compressive stress-strain diagram for lead.

Fig. 1.3. Dynamic tensile stress-strain curves for 18-8 stainless steel.

Fig. 1.4. Dynamic compressive stress-strain curves.

1.2.2 Cask-lifting devices

If there is a system of lifting devices that is a structural part of the package, the regulations require that this system 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 cask is designed to be lifted by two lugs located on the top of the cask (Fig. 0.1). The lug design is such that a special lifting sling is required (Appendix A, Fig. A.6). This sling ensures that the loads are applied axially to the lug.

The dimensions of the lifting lug are shown in Fig. 1.5. The load is

$$P = (3)(\text{weight of cask}) = (3)(23,000) = 69,000 \text{ lb or } 34,500 \text{ lb/lug} .$$

The allowable stress = 30,000 psi, which is the yield stress of type 347 stainless steel.

1.2.2.1 Average tensile stress in lifting lug at section A-A of Fig. 1.5.

$$\sigma_{av} = P/A = 34,500 / (4.969)(3.25) = 2.40 \text{ ksi} .$$

1.2.2.2 Shear stress in pin (double shear). The shear stress τ in the pin is

$$\tau = P/2A = F/2(\pi d^2/4) = (34,500)/(2)(\pi/4)(2.25)^2 = 4350 \text{ psi} ,$$

where d = diameter of pin (in.) .

The limiting stress = $0.5S_{yp} = 15,000 \text{ psi} .$

1.2.2.3 Bearing stress in the lug. The bearing stress σ in the lug is

$$\sigma = P/A ,$$

ORNL DWG 64-9094-R2

SECTIONS B-B, C-C, AND
D-C ARE IN FIG. 1.7

SECTION A-A

ALL DIMENSIONS
GIVEN IN INCHES

Fig. 1.5. Cask-lifting lug.

where A = cross-sectional area of lifting lug eye (in.) ,

$$\sigma = 34,500 / (3.25)(2.25) = 4718 \text{ psia} .$$

1.2.2.4 Shear stress in welds that attach lifting lugs to cask. As shown in Fig. 1.6, the weld-shear area A for the welds that attach the lifting lugs to the cask are given below:

$$\text{Section B-B: } A = (2)(1.0)(3.25) + (2)(1.0)(3.625) = 13.750 \text{ in.}^2$$

$$\text{Section C-C: } A = (2)(1)(7.219) = 14.438$$

$$\text{Section D-D: } A = (2)(0.5)(3.25) = \underline{3.25}$$

$$\text{Total weld-shear area} = 31.438 \text{ in.}^2$$

The average weld shear stress is

$$\tau = P/A_T = 34,500 / 31.438 = 1100 \text{ psi} .$$

All normal stresses in the cask-lifting device are less than the yield stress of 30,000 psi for type 347 stainless steel, and all shear stresses are below the allowable of 15,000 psi; therefore, the device exceeds the requirements of the regulations.

1.2.3 Lid-lifting devices

The regulations require that if there is a system of lifting devices that is a structural part of the lid only, this system shall be capable of supporting three times the weight of the lid and any attachment without generating stress in any material of the lid in excess of its yield strength. It is further required that unless rendered useless for lifting during transport of the package, the lid-lifting system or any other system of lifting devices shall conform to the requirements for the package-lifting system. The lid-lifting device is covered during transit, rendering it unavailable for lifting; thus, it is exempt from this requirement.

ORNL DWG. 64-9089-R1

NOTE: SECTION
LOCATIONS ARE
SHOWN IN FIG. 1.5

ALL DIMENSIONS
GIVEN IN INCHES

Fig. 1.6. Lifting-lug sections.

The lid-lifting lug is illustrated in Fig. 1.7. The design load is

$$P = 3(\text{weight of lid}) = 3(2100) = 6300 \text{ lb.}$$

The allowable stress = yield stress of type 347 stainless steel = 30,000 psi.

Fig. 1.7. Lid-lifting lug.

The 1-1/2-in. square rods are actually stiffened by the fins on the lid. Thus the 1-1/2-in. round rod acts almost as if it were a beam with fixed ends and as if the length of that beam were only the clear span between the square rods. However, the calculations will be based on a far more conservative basis wherein the weldment of three rods is taken as a rectangular frame with fixed ends. Then, using formulas published by Product Engineering,³¹

$$M_{\text{base}} = PL/8D ,$$

where

$$D = 2 + (I_o/I_{sq})(h/L) ,$$

$$I_o = \pi d^4/64 = \pi(1.5)^4/64 = 0.249 ,$$

$$I_{sq} = s^4/12 = (1.5)^4/12 = 0.422 ,$$

$$D = 2 + (0.249/0.422)(3.75/3.75) = 2.59 ,$$

$$M_{base} = 3(2100)(3.75)/8(2.59)$$

$$= 1140 \text{ in.}\cdot\text{lb} ,$$

in which

P = three times the actual 2100-lb weight,

L = the span between the post centers (in.),

I_o = moment of inertia, round rod (in.⁴),

I_{sq} = moment of inertia, square rod (in.⁴),

h = height of posts to center of header (in.),

d = diameter of rod (in.),

s = length of side of square rod (in.).

The tensile stress must be added to find the total stress:

total stress at base = P/A + bending stress

$$= 3(2100)/1.5(1.5) + 1140(0.75)/I_{sq}$$

$$= 2800 + 1140(0.75)/0.422$$

$$= 4830 \text{ psi} .$$

At the junction of a post and the square rod, the bending stress is twice as great, so the total is

$$\text{total stress at junction} = 2800 + 2(1140)(0.75)/0.422$$

$$= 6850 \text{ psi} .$$

The bending stress in the round rod, a maximum at the central load, is

$$\begin{aligned}
 S &= M/Z = 2M_b / (\pi d^3/32) \\
 &= 2(1140) / [\pi(1.5)^3/32] \\
 &= 6890 \text{ psi ,}
 \end{aligned}$$

where $2M_b$ = moment at the end (lb·in.).

Since the resulting stresses, determined by a conservative technique, in the lid-lifting lug are less than the yield point stress for type 347 stainless steel, the cask exceeds the requirements of the regulations.

1.2.4 Tie-down devices

If a system of tie-down devices is a structural part of the package, the regulations require that this system be capable of withstanding a static force applied to the center of gravity of the package with a vertical component of two times the weight of the package and its contents, a horizontal component in the direction of travel of ten times the weight of the package and its contents, and a horizontal component in the transverse direction of five times the weight of the package and its contents. This applied force shall not generate stresses in any material of the package in excess of the yield strength of that material. It is also required that any tie-down device that is a structural part of the package shall be so designed that failure of the device under excessive load will not impair the ability of the package to meet other requirements of the regulations. The cask is designed to be bolted directly to the bed of a transport vehicle as shown in Fig. 1.8. Calculations demonstrating the adequacy of the cask for this configuration follow.

1.2.4.1 Bolted cask tie-down. The cask is secured by bolting the cask base plate to the truck or rail car bed using sixteen 1-1/2-in.-diam bolts as shown in Fig. 1.8. Alternatively, the cask can be attached to a special purpose plate which is bolted to the truck bed.

Fig. 1.8. Bolted cask tie-down (direct to truck bed).

1.2.4.2 Determination of stress in bolts for vertical load of two times weight of cask.

$$\sigma = P/A ,$$

where

$$P = \text{load} = 2(23,000) = 46,000 \text{ lb} ,$$

$$A = \text{tensile stress area}^{13} \text{ of 16 bolts} = 16(1.405) = 22.48 \text{ in.}^2 .$$

Therefore the stress is

$$\sigma = 46,000/22.48 = 2050 \text{ psi} .$$

1.2.4.3 Determination of stress in bolts for horizontal components of ten times and five times weight of cask. For a horizontal load, the bolts are subjected to two stresses: a shear stress and a tensile stress. By summation of moments about A (Fig. 1.9), the maximum force in a bolt can be determined by the technique published by Berger¹⁴ below. In the interest of calculational simplicity and conservatism, the line of action of the resultant of the horizontal load is assumed to be in line with a bolt.

This force is

$$\alpha = L/D = 2/42 = 0.047619 ,$$

$$k_3 = (1 + \alpha)/(0.375 + \alpha + \alpha^2) = 1.047619/(0.375 + 0.047619 + 0.002268)$$

$$= 2.4656 ,$$

$$M = (32.75)(257,140) = 8.421,000 \text{ lb}\cdot\text{in.} ,$$

$$f_h = (k_3/DN)(M) = 2.4656(8.421 \times 10^6)/(42)(16) = 30.900 \text{ lb} ,$$

Fig. 1.9. Force diagram.

where

f_h = tensile force in most heavily loaded bolt (lb) .

M = moment about edge of flange (in.-lb) ,

L = distance from edge of flange to bolt circle (in.) ,

D = diameter of bolt circle (in.) ,

N = number of bolts ,

α, k_3 = constants .

The resulting tensile stress is

$$\sigma_B = F_{\max}/A = 30,900/1.405 = 22,000 \text{ psi} ,$$

where A = tensile stress area¹³ per 1-1/2 6UNC bolt (in.²).

The shear stress per bolt is

$$\begin{aligned} \tau &= P/A = 257,140/N(\pi d^2/4) = 4(257,140)/(16)(\pi)(1.5)^2 \\ &= 9,090 \text{ psi} . \end{aligned}$$

1.2.4.4 Determination of stress with all loadings combined. The maximum tensile stress $\sigma_T = \sigma_a + \sigma_B = 2050 + 22,000 = 24,050 \text{ psi}$. From Mohr's circle of stress, the maximum principle stress is

$$\begin{aligned} &\sigma = 0.5\sigma_T + [(0.5\sigma_T)^2 + \tau^2]^{1/2} \\ &= 12,025 + [(12,025)^2 + (9090^2)]^{1/2} = 27,100 \text{ psi} . \end{aligned}$$

Thus the bolted system exceeds the requirements of the regulations since the bolts are of a material having a yield stress in excess of this.

1.3 Compliance with Structural Standards for Packaging

The structural standards for large-quantity packaging cover load resistance of the packaging and the external pressure which the package must withstand. Compliance of the HFIR cask with these requirements is discussed in the following subsections.

1.3.1 Load resistance

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

1.3.1.1 Determination of bending stress. Assume that the lead has no resistance to bending. The bending stress σ_b is calculated from the well-known expression

$$\sigma_b = Mc/I ,$$

where

M - maximum bending moment (in.-lb) ,

c = distance from neutral axis to outermost fiber (in.) ,

I = moment of inertia of section (in.⁴) .

For determination of the moment of inertia of the outer shell and sixteen 4-in. sched.-80 pipes equally spaced around the outer shell as shown in Fig. 1.10,

I_c = moment of inertia of composite element (in.⁴) ,

I_s = moment of inertia of outer shell (in.⁴) ,

I_p = moment of inertia of a 4-in. sched.-80 pipe (in.⁴) ,

A_p = area of 4-in. sched.-80 pipes (in.²) ,

y = distance from the center line of pipe .

Fig. 1.10. Arrangement of pipes around outer shell.

All I's are taken about axis X-X. Therefore,

$$I_c = I_s + 16I_p + 4A_p (y_1^2 + y_2^2 + y_3^2 + y_4^2) ,$$

where the following values are used:

$$\begin{aligned} y_1 &= 21 \sin 11.25 = 4.1 & y_1^2 &= 16.8 \\ y_2 &= 21 \sin 33.75 = 11.7 & y_2^2 &= 136.1 \\ y_3 &= 21 \sin 56.25 = 17.5 & y_3^2 &= 304.9 \\ y_4 &= 21 \sin 78.75 = 20.6 & y_4^2 &= 424.2 \\ y_1^2 &= y_2^2 = y_3^2 = y_4^2 & &= 882.0 . \end{aligned}$$

$$\begin{aligned} I_s &= \pi/4(R_o^4 - R_i^4) = \pi/4(18.75^4 - 18.25^4) = 9950 \text{ in.}^4 , \\ I_p &= 9.61 \text{ in.}^4 , \\ A_p &= 4.407 \text{ in.}^2 , \\ I_c &= 9950 + 16(9.61) + 4(4.407)(16.8 + 136.1 + 304.9 + 424.2) \\ &= 25,650 \text{ in.}^4 . \end{aligned}$$

The maximum bending moment $M_{\max}$ occurs at the midpoint of the cask and is

$$\begin{aligned} M_{\max} &= WL/8 = 115,000(72.5)/8 \\ &= 1.042 \times 10^6 \text{ in.}\cdot\text{lb} , \end{aligned}$$

where

$$\begin{aligned} W &= \text{five times cask weight (lb)} , \\ L &= \text{the cask length (in.)} . \end{aligned}$$

For distance c ,

$$c = y_4 + \text{pipe radius} = 20.6 + 2.2 = 22.8 \text{ in.}$$

The maximum bending stress σ_b is

$$\sigma_b = 1.042 \times 10^6 (22.8) / 25,650 = 930 \text{ psi} .$$

Because this stress is small when compared with the yield stress, the cask therefore complies with the requirements of the regulations governing the load resistance of packaging. It can be seen by inspection that other radial orientations will result in stresses of the same magnitude.

1.3.2 External pressure

The regulations require that 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.

A potential consequence of the application of external pressure is buckling of the cylindrical shells of the shipping container. For calculational purposes, the portions of the container within the containment vessel (secondary) were assumed to be at atmospheric pressure. Simplified models of the outer container were used to obtain a conservative evaluation. These models consist of a right circular cylinder with closed ends.

The critical (buckling) pressure for this container can be determined by using equations presented by Faupel.¹⁵ For axisymmetric (bellows-type) buckling, the critical pressure p_r is given by the following equation:

$$p_r = 2E(t/r)^2 / [3(1 - \mu^2)]^{1/2} ,$$

where

E = modulus of elasticity = 29×10^6 psi ,

t = thickness of cylinder wall ,

r = radius of cylinder ,

μ = Poisson's ratio = 0.3 .

The critical pressure p_r for lobular buckling is given by the equation¹⁵

$$p_r = \left[\frac{1.345 E}{(1 - \mu^2)^{3/4}} \right] \left[\frac{(t/r)^{5/2}}{1.57(L/R) - (t/r)^{1/2}} \right] ,$$

where L = the length of the cylinder.

The critical pressure p_r for hoop stress is given by the equation

$$p_r = st/r ,$$

where

s = yield stress ,

r = cylinder radius ,

t = cylinder thickness .

The model for the cask body has a radius of 18.75 in., a thickness of 0.5 in., and a length of 52 in. For axisymmetric buckling,

$$p_r = 2(29) \times 10^6 (0.5/18.75)^2 / [3(1 - 0.3^2)]^{1/2} = 25,000 \text{ psi} .$$

For lobular buckling,

$$p_r = \left[\frac{1.345(29 \times 10^6)}{(1 - 0.3^2)^{3/4}} \right] \left[\frac{(0.5/18.75)^{5/2}}{1.57(52/18.75) - (0.5/18.75)^{1/2}} \right]$$

$$= 1,160 \text{ psi} .$$

For hoop stress,

$$p_r = 30,000(0.5)/18.75 = 800 \text{ psi} .$$

The model for the plug has a radius of 10.5 in., a thickness of 0.5 in., and a length of 10.25 in.; the plug, therefore, by inspection has a higher buckling pressure than the calculated values for the body.

The flat heads of the cask are braced by external and/or internal heat-transfer fins or surfaces. These situations are not readily calculable; thus, the conservative approach, which neglects the contributions of the bracing, will be taken. The bottom head is the most vulnerable and has a radius of 18.75 in. and a thickness of 0.5 in.

The equation from Timoshenko¹⁶ used to compute bending stress is

$$\sigma_x = (3/4)(qa^2/h^2) ,$$

where

q = pressure ,

a = radius of the plate ,

h = thickness of the plate ;

therefore,

$$\sigma_x = (3/4)[(25)(18.75)^2/0.5^2] = 26,400 .$$

Because the stresses are less than the yield stress and the calculated critical buckling pressures are high, no damage from the external pressure is anticipated. Similar seal configurations have been used considerably in excess of 25 psig. It is therefore concluded that the cask complies with the requirements for external pressure.

1.4 Compliance with Standards for Normal Conditions of Transport

The regulations for normal conditions of transport for a single package require that the effectiveness of the package will not be substantially reduced by the normal conditions of transport and that there will be no release of radioactive material from the containment vessel. The contents of the cask are so limited that there will be no gases or vapors in the package that could reduce the effectiveness of the packaging.

There is no circulating coolant other than atmospheric air, and no mechanical cooling device is required or provided. The cask is so designed that the contents will not be vented to the atmosphere under normal conditions of transport. The applicable normal conditions include the effects of heat, cold, pressure, free drop, penetration, and compression.

1.4.1 Heat

The package must be able to withstand direct sunlight at an ambient temperature of 130°F in still air without reducing the effectiveness of the packaging. A computer program, HEATING-3,¹⁷ modified to account for material phase changes, was used to compute the steady-state temperature distribution in the basic cask model and its contents under the specified conditions. The calculational model (Fig. 2.1) and computer input (material constants) in Sect. 2 were used in this computation, and the resulting computed temperatures at locations of concern are given in Tables 2.3 and 2.4.

These temperatures will have no adverse effect on the cask, nor will the container materials of construction suffer a significant loss of physical properties at these temperatures. The allowable continuous operating temperature limit of the silicone rubber gasket is 500°F,¹⁸ which is significantly higher than the temperatures calculated for the container seals. The maximum temperature calculated for the surface of the container is below that allowable⁵ for sole-use vehicles.

The calculated pressures (Sect. 2.3.4) are 6.4 psig for the cavity, 4.4 psig for the plug-shielding cavity, and 3.61 psig for the body-shielding cavity. See Sect. 1.4.3 for the combined effects of these pressures with the reduced atmospheric pressure and Sect. 1.6 for containment vessel design calculations establishing allowable vessel pressure.

1.4.2 Cold

The shipping package must be able to withstand an ambient temperature of -40°F in still air and shade. When the condition of no internal heat load is assumed and the same methods of analysis used for the heat condition (Sect. 2.3.4) are used for -40°F (420°R), the final or maximum pressure (p_2) in any container cavity sealed at a temperature of 70°F (530°R) and a pressure of 14.7 psia will be

$$p_2 = p_1 T_2 / T_1 = 14.7(420) / 530 = 11.65 \text{ psia.}$$

The resulting pressure differential is not significant when compared with that resulting from the pressure requirements of the regulations for normal transport (Sect. 1.4.3).

A temperature of -40°F is within the operating temperature range of the materials of the cask. Brittle fracture of these materials under the stipulated cold condition is not credible because the temperature of all the container components will be above their ductile-to-brittle transition temperatures of the materials of construction. Therefore, the stipulated cold condition will not reduce the effectiveness of the packaging, and it is concluded that the cask complies with the requirements for the cold condition of normal transport.

1.4.3 Pressure

The regulations for normal conditions of transport specify that the package be able to withstand an atmospheric pressure of 0.5 times the standard atmospheric pressure (7.35 psia). If the effect of reduced pressure is combined with pressure due to cavity temperature rise (Sect. 2.3.4), the resulting absolute pressures are as shown in Fig. 1.11. The maximum pressure differentials are approximately 12 psi on each of the outer shell and heads of the cask, top head and outer shell of the plug, and the seal. By comparison with the allowable pressure calculations (Sect. 1.6), the specified hydrostatic test pressure of 25 psig for the for the lead cavities and the 20-psig pneumatic test pressure for the cask cavity (Appendix A, Fig. A.7), it is concluded that these pressures will not reduce the effectiveness of the cask.

1.4.4 Vibration

The regulations require the cask to withstand the vibration experienced in normal transport. Transport vibrations will not, and have not, degraded the cask structurally nor redistributed the shielding. All threaded connections and fasteners are equipped with locking devices such as lockwashers or seal wires; therefore, they will not loosen due to vibration. Properly installed threaded pipe fittings do not loosen under transport conditions; thus the cask will withstand transport vibrations.

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Fig. 1.11. Absolute pressure diagram.

1.4.5 Water spray

It is required that the cask withstand a water spray sufficiently heavy to keep the entire exposed surface, except the bottom, continuously wet for a period of 30 min. The exposed surfaces of the HFIR cask are of type 347 and 304L stainless steel and will be unaffected by water spray.

1.4.6 Free drop

The regulations for normal conditions of transport require that a package weighing between 20,000 and 30,000 lb be capable of withstanding a free drop through a distance of 2 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position in which maximum damage is expected to result. The energy to be dissipated is the cask's potential energy, $U_p = Wh = 23,000(24) = 552,000 \text{ lb}\cdot\text{in}$. The cask would impact on the external heat transfer surfaces (fins or pipes) for all impact orientations. It cannot be determined by inspection which orientation would result in maximum damage. Therefore, impact orientations of (1) top corner, (2) top with the axis of the cask vertical, (3) side, and (4) various other orientations will be considered. Demonstration of compliance with this requirement by analytical methods is difficult because experimentally verified analytical techniques do not exist, and all the necessary material properties data are not available. Drop tests have not been performed on the cask configuration under consideration. The following analyses are presented to conservatively characterize cask response and so demonstrate compliance with the regulations. It is concluded that the cask is adequate to sustain the hypothetical conditions.

1.4.6.1 Corner impact. If the cask were dropped on its corner from 2 ft so that the point of impact and the center of gravity of the cask were in a common vertical plane, the radial orientation of the cask resulting in maximum damage would be as determined in Sect. 1.5.1.3. If the pipe extensions contacted the impact surface, they would plastically (permanently) deform and absorb the energy. Model tests (Sect. 1.5.1.3) indicated that a drop from 10 ft would result in a deformation of 7.7 in.

If it is assumed that the energy is absorbed during deformation at a constant rate, the expression for the deformation for a 2 ft drop is

$$\Delta_2 = \Delta_{10}(2/10) = 7.7(0.2) = 1.54 \text{ in. ,}$$

where

Δ_2 = deformation at a 2-ft drop ,

Δ_{10} = deformation at a 10-ft drop .

In actuality, this approach is conservative because structural members generally absorb a greater quantity of energy during the first portion of collapse or buckling-type failure. Davis¹⁹ published data on fins which support this. A deformation of this magnitude would not result in plastic (permanent) deformation in any other cask components. The damage to the pipes would not compromise the cask's containment or shielding capabilities. The reduction in heat transfer capabilities resulting from local buckling of the four pipes would not be significant. Routine inspection (Sect. 6) would detect the damage, and repairs would be effected prior to additional use.

The corner drop might also occur at such an orientation so that the carbon steel top-impact absorber first contacts the impact surface. This absorber is designed with the express purpose of absorbing all the energy from a 30-ft drop, and a 2-ft drop will only bend the outer ring. No damage to cask or loss of shielding will result.

1.4.6.2 Impact on the top. If the cask impacts on its top, the extended pipes will contact the impact surface first and deform (Fig. 0.1). From test data (Sect. 1.5.1.1) it is estimated from Fig. 1.23 that the deformation will be 0.4 in. The acceleration would not result in stresses in the closure system in excess of the yield strength as indicated by comparison with Sect. 1.5.1. The eight extended pipes would fail by buckling and would require replacement. The damage would be detected by routine inspection, and repair would be effected.

1.4.6.3 Impact on the cask's side. If the cask impacted on its side, the heat transfer surfaces would deform and absorb the kinetic energy. Two radial orientations will be considered. The first orientation will be where the cask's vertical centerline is equidistant between two of the pipes. The second is where the vertical centerline coincides with the center of one of the pipes (Fig. 1.27). A computer program (Sect. 1.5.1) was used to evaluate response of the cask and determine the resulting damage. Figures 1.12, 1.13, 1.14, and 1.15 are machine plots of the energy vs deformation and the acceleration vs deformation. For the first orientation the resulting deformation is 0.88 in. and the maximum acceleration is 37.2 g's. In the second orientation the deformation of the pipe is 1.55 in., and the maximum acceleration is 18.6 g's. These deflections would not significantly affect the cask's heat transfer capabilities. Structural integrity and containment capabilities would not be reduced by an acceleration of this magnitude. The shielding would not be redistributed, nor would its effectiveness be reduced. The geometry of the contents and cask internals would not be altered.

1.4.6.4 Other orientations. A drop on the bottom would locally damage the bottom support structure and cause localized buckling of the vertical heat transfer surfaces in the reduced section at this base. A drop on a bottom corner would also result in similar damage. An oblique drop would result in less damage than the corner drop considered in Sect. 1.4.6.1. All these would, as before, cause damage that would require repair, but the damage would be detected by pre-usage inspections.

1.4.7 Penetration

The regulations for normal conditions of transport stipulate that the package be capable of withstanding the impact of the flat end of a vertical steel cylinder which weighs 13 lb, has a diam of 1-1/4 in., and is dropped from a height of 4 ft, normally onto the exposed surface of the package that is expected to be the most vulnerable to puncture. This condition will not reduce the effectiveness of the HFIR cask and will result in no more

Fig. 1.12. Two-ft drop impact on side - case I.

Fig. 1.13. Two-ft drop impact on side - case 1.

Fig. 1.14. Two-ft drop impact on side - case II.

Fig. 1.15. Two-ft drop impact on side - case II.

than a possible superficial dent in the stainless steel surface of the container.

1.5 Compliance with Standards for Hypothetical Accident Conditions

The standards for the hypothetical accident conditions stipulate that a cask used for the shipment of a large quantity of fissile or radioactive material shall be so designed and constructed and its contents so limited that if it is subjected to the specified free drop, puncture, thermal, and water immersion conditions, the reduction in shielding would not be sufficient to increase the external radiation dose rate to more than 1000 millirems/hr at a distance of 3 ft from the outside surface of the package, 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, and the contents would remain subcritical.

The first in the sequence of hypothetical accident conditions to which the package 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 second in the sequence of hypothetical accident conditions to which the package 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 cylindrical mild steel bar. The 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., and the bar shall be of such length that it will cause maximum damage to the cask, but shall not be less than 8 in. long. The long axis of this bar shall be normal to the surface of the package upon impact.

The third in the sequence of hypothetical accident conditions to which the package 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 calculation 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 has expired and the temperature at the center of the package has

begun to fall. The effect of the thermal part of the accident is discussed in Sect. 2.4.

The fourth and last condition in the sequence of hypothetical accident conditions to which the package must be subjected is immersion in water to the extent that all portions of the package are under at least 3 ft of water for a period of not less than 8 hr. The cask remains sealed after the impact and thermal exposure and is constructed of stainless steel; hence it would suffer no ill effects from the water immersion.

1.5.1 Thirty-ft free fall

Demonstration of compliance with this requirement by analytical methods is difficult because experimentally verified analytical techniques do not exist, and all the necessary material properties data are not available. Drop tests have not been performed on the cask configuration under consideration. The following analyses are presented to conservatively characterize cask response and so to demonstrate compliance with the regulations. It is concluded that the cask is adequate to withstand the hypothetical conditions.

It cannot be determined by inspection which orientation would result in maximum damage if the cask were dropped from 30 ft onto an unyielding surface. The cask's length-to-diameter ratio of 1.4 to 1 does indicate that out-of-plane bending is not a realistic consideration. Therefore, an oblique drop (that is, one in which the axis passing through the center of gravity of the cask and the point of impact is not normal to the impact surface) is not as significant as a full side impact or a corner impact. It is also obvious that a drop onto a bottom corner is less damaging than a drop onto a top corner due to the proximity of the closure to the top corner. Therefore the effects of a drop onto the top and bottom with the axis of the cask vertical, a drop onto the side with the axis of the cask horizontal, and a drop onto the top corner with the plane passing through the center of gravity of the cask and the point of impact vertical, will be determined.

1.5.1.1 Drop onto the top. When the cask impacts on its top (with the axis vertical), the eight extended 4-in. sched.-80 pipes will contact the surface first; these pipes will fail and absorb energy, and the cask body will also plastically deform and absorb energy. The majority of the cask's kinetic energy will be dissipated in these two modes. For the calculation, it will be assumed that all the energy is absorbed in this manner. We will assume that the entire cask accelerates as a unit, that is, that all parts of the cask have the same acceleration with respect to time. The approach of solving two separate problems, one in which energy is absorbed only in the pipes and one in which energy is absorbed in the cask body, and superimposing the results, will be used.

The ORNL computer program CEIR²⁰ is used to evaluate the energy absorbed and deformations in the cask body. CEIR is written to calculate the response of a cylindrical, metal-clad, lead-shielded cask to an impact with an unyielding surface. The top head of the cask is assumed to be rigid, and the effect of the internal heat transfer connectors (fins) on the movement of lead will be neglected. The strengthening effect of these connectors on the shell in the circumferential direction was conservatively estimated by using an effective shell thickness based on the cross-sectional area of the fins. This relationship is

L_e = effective thickness

= shell thickness + (no. fins)(area of fins)/cask length ,

$L_e = 0.5 + (13)(1)(1/4)/50.5 = 0.564$ in.

This thickness is used in the computer calculation for end impact.

The response of the pipes could not be calculated based on theory, and no applicable experimental data could be found. Three 2.35-to-1 scale models were tested as described in the test procedures and reports in Appendix E. The test model is illustrated in Figs. 1.16 and 1.17. The damage to the models is shown in Fig. 1.18. Force data with respect to time were taken for each impact and converted to force-deflection relationships as described in refs. 19, 21, and 22. Scaling laws were used to convert the model data to data applicable to the full-sized absorbers. These laws are $F = F_m(SF)^2$ and $\Delta = \Delta_m(SF)$, where

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Fig. 1.16. 2.35-to-1 test model (drawing).

Photo 0678-74

Fig. 1.17. 2.35-to-1 test model (photograph).

Photo 1004-74

Fig. 1.18. Damaged models.

- F = force applied to the full-sized absorber (lb) ,
 F_m = force applied to the model (lb) ,
 SP = scale factor or ratio of dimensions = $\frac{\text{actual dimensions}}{\text{model dimensions}}$,
 Δ = deflection of the full-sized absorber (in.) ,
 Δ_m = deflection of the model (in.) .

A machine plot of the force-deflection curves applicable to full-sized absorbers is shown in Fig. 1.19. An 11th-order polynomial equation representing these data was written, and a plot of the equation is also shown in Fig. 1.19.

An existing ORNL computer program, 1010 CASK, which employs summation techniques and a force and deflection equation to compute absorbed energy, was used to calculate the response of the absorbers. The derivation of equations and a program listing are in Appendix F. The eleven constants shown in the listing are the constants associated with the polynomial equation.

Machine plots of absorbed energy vs acceleration for the cask body, calculated using CEIR, and for the pipes, calculated using 1010 CASK, are shown in Figs. 1.20 and 1.21. The plot for the pipe absorbers was idealized as shown to simplify the solution described below. It was determined by trial and error that all the cask's energy of 8.28×10^6 in.-lb would be absorbed by deforming the pipes and the cask body when the cask's acceleration reached about 125 g's (Figs. 1.20 and 1.21).

From Fig. 1.22, a machine plot of the deformation of the shielding vs the acceleration as compiled by CEIR, it can be seen that shielding would deform 1.24 in. The actual deformation would be somewhat less than this since the effects of lead bonding and the internal fins were neglected. From Fig. 1.23, a machine plot of absorbed energy vs deflection for the eight pipes as computed by 1010 CASK, it can be seen that the deflection of the pipes would be about 1.57 in. It is recognized that the deformation would be somewhat greater than calculated due to assumptions made about the body. This is of no concern since the pipes have the capacity to absorb all the cask's energy of 8.28×10^6 in.-lb while deforming 3.08 in.

Fig. 1.19. Model data.

Fig. 1.20. End impact, energy absorbed in eight extended pipes.

Fig. 1.21. End impact, energy absorbed in the cask body.

Fig. 1.22. End impact — deformation of lead shielding.

Fig. 1.23. End impact — deformation of eight extended pipes.

With an acceleration of 125 g's, the cask plug, which weighs 2100 lb, would exert a force

$$F = W_a/g = 2100/8(125 \text{ g}) = 262,500 \text{ lb} ,$$

on the fasteners securing the plug. The stress in the fourteen 1-1/2-in. studs is therefore

$$\sigma = F/NA = 262,500/(14)(1.4) = 13,400 \text{ psi} ,$$

where

N = number of studs ,

A = stress area¹³ of one stud .

Since the calculated stress is below yield stress (Fig. 1.3), the studs will not fail.

1.5.1.2 Drop onto the side. If the cask were dropped onto the side, the vertical heat transfer pipes would contact the surface first. Some energy would be dissipated in flattening these pipes. The remaining energy would be dissipated by deforming the body (shielding, end plates, and shell). There are two radial cask orientations of interest (Fig. 1.24). It cannot be determined by inspection which orientation will result in maximum cask damage; hence, the response of the cask will be determined for both orientations. The general approach, superposition of results, will be utilized; that is, the energy, forces, and/or accelerations associated with collapse of the pipes will be determined and added to the corresponding values for deforming the cask body. The information, test results, and techniques to be used to effect these separate solutions are discussed in the material below.

In 1971, while testing the tube in the pipe energy absorber, a number of 4-in.-long sections of 1-1/4-, 1-1/2-, and 2-1/2-in. sched.-40 stainless steel pipes were impacted in a manner described in *Structural Analysis of Shipping Casks*.²¹ Testing indicated that the pipe sections

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Fig. 1.24. Side-drop orientations.

would not absorb a quantity of energy sufficient to make them applicable as energy absorbers for large casks; hence, the data were filed but not included in the report.²¹ The test parameters are given in Table 1.2.

Table 1.2. Test Parameters

Test no.	OD (in.)	Wall thickness (in.)	Weight dropped (lb)	Drop distance (in.)	Length (in.)
1	1.660	0.140	99.0	160.3	4.0
2	1.660	0.140	99.0	132.3	4.0
3	1.660	0.140	25.0	360.0	4.0
4	2.875	0.203	99.0	216.0	4.0
5	2.875	0.203	99.0	276.0	4.0
6	2.875	0.203	99.0	359.3	4.0
7	2.375	0.154	99.0	205.0	4.0
8	2.375	0.154	25.0	360.0	4.0
9	2.875	0.203	25.0	360.0	4.0

These data include the test parameters of pipe size, drop height, impacting weight, and a photographic record of the applied force with respect to time. These data were input into an existing computer program CIDR²² that performs two successive numerical integrations of the force-time data to produce force-deflection data. Scaling theory was applied to the force-deflection values obtained to make them applicable to the 4-in. sched.-80 pipes around the circumference and on the bottom of the HFIR cask. The scale factor used is an average of the scale factor for the outside diameter and the wall thickness.

$$\text{Scale factor} = (D_4/D_T + T_4/T_T)/2.0 ,$$

where

$$D_4 = 4\text{-in.-OD sched.-80 pipe} = 4.5 \text{ in.} ,$$

$$D_T = \text{OD of test model} ,$$

$$T_4 = \text{wall thickness of 4-in. sched.-80 pipe} = 0.337 \text{ in.} ,$$

$$T_T = \text{wall thickness of test model} .$$

A machine plot of force-deflection data converted to be applicable to the HFIR case (4-in. sched.-80 pipe) is shown in Fig. 1.25. A polynomial equation of the data resulted in the equation

$$F = F(X) = A + BX + CX^2 + DX^3 + EX^4 + GX^5 + HX^6 + IX^7 + JX^8 + KX^9 + LX^{10} + MX^{11} ,$$

where

F = applied force (lb/in. of pipe length) ,

X = deformation (in.) ,

A = 93.8673136 ,

B = -1543.76612 ,

C = 167064.376 ,

D = -572233.512 ,

E = 908127.888 ,

G = -833589.816 ,

H = 479988.152 ,

I = -178859.680 ,

J = 43092.56 ,

K = -6478.59232 ,

L = 552.37508 ,

M = -20.3866008 .

This equation is best solved by computer. A less accurate equation,

$$F = 1689 + 2993X ,$$

suitable for hand calculation, was also written. F and X are as above. The curves produced from the polynomial equation are plotted with the data from which they were written, as in Fig. 1.25. These data will be used to establish the energy dissipated in flattening the pipes for both cases.

A general program, 1010 CASK, was modified with these 11 constants and used to compute the response of a cask equipped with empty pipe absorbers. A listing of the program with another set of data is presented

Fig. 1.25. Pipe impact data.

in Appendix F. This is the same approach as used in Sect. 1.5.1.1 for the eight extended pipes.

That portion of energy dissipated in deforming the cask body is estimated using an existing ORNL computer program, 1005 CASK (see Appendix F for equation derivations and listing). Both the top and bottom heads of the cask are stiffened with external structural bracing. Since the program is written for unbraced flat heads, the stiffening effect of the bracing is estimated as outlined below.

As the top head is compressed, at least three of the 3/8- by 7-1/2-in.-high gussets will also be compressed. Taking a section at A-A in Fig. 1.24, case II, the length X is

$$X = R_o (\sin 45^\circ) = 18.75 (\sin 45^\circ) = 13.26 .$$

The area in compression, A_T at this place, is

$$A_T = 2Xt + (N)(t_g)(L_g) = 2(13.26)(1) + (3)(3/8)(7.5) = 34.96 ,$$

where

- t = thickness of the flat head (in.) ,
- X = distance as shown in Fig. 1.24 (in.) ,
- N = number of gussets ,
- t_g = gusset thickness (in.) ,
- L_g = length of the gussets (in.) .

A plate thickness t_h to give an equivalent area is

$$2Xt_h = A_T ,$$

$$t_h = A_T / 2X = 34.96 / 2(13.26) = 1.32 \text{ in.}$$

Likewise the 1/2-in.-thick bottom head is stiffened by one 4-in. sched.-80 pipe and the 1-in.-thick base plate. The failure mode of the base ring would probably be a complex combination of bending and local compression. Also the base ring will absorb energy well in advance of any

deformation of the shell and lead. In the interest of calculational simplicity and because it results in a conservative damage estimate, the effect of the base ring will be ignored. Hence the equivalent thickness T_{hh} for the bottom head taking a reference plane as for the top head is

$$\begin{aligned} T_{hh} &= 2Xt + A_p/2X = 2(13.26)(0.5) + 4.407/2(13.26) \\ &= 0.666 \text{ in. ,} \end{aligned}$$

where

A_p = area of pipe in compression .

The program is based on materials having ideal dynamic stress-strain properties. It can be seen from Figs. 1.1 and 1.2 that this is not true for lead and stainless steel. A conservative solution is effected by calculating the response, taking values for dynamic yield stress which envelop the actual curve, and effecting two solutions. The solution using the lower stress value for both materials will indicate a deformation which is greater than actual deformation. Likewise, the higher value will predict an acceleration which is higher than actual. The values taken for this calculation are those outlined in Sect. 1.1.

For the orientation identified as case I, Fig. 1.24, two pipes adjacent to the vertical centerline, identified as a and b, will completely collapse before the shell begins to deform. From Fig. 1.26, a machine plot from the program 1010 CASK, it can be determined that 3.45×10^6 lb·in. of the energy would be absorbed in flattening the two pipes to their solid height. The remaining energy (4.83×10^6 lb·in.) would be dissipated in deforming the shell and deforming pipes e and d (Fig. 1.24). It can be seen that pipes e and d would begin to collapse slightly before the shell contacted. In the interest of simplicity we will neglect this and assume that these pipes and the shell begin to deform simultaneously. By trial and error it was found that at a deflection of 1.19 in., the remaining 4.83×10^6 lb·in. of energy would be absorbed by the combination of the cask body and pipes e and d, if we assumed the lower values for dynamic yield stress. (See Fig. 1.26, the energy-deflection curve for the two

Fig. 1.26. Side-drop responses of two pipes.

pipes, and Fig. 1.27, an energy-deflection plot of the results computed with 1005 CASK assuming the lower values for dynamic yield stress.) Similarly, taking the dynamic yield stress at the upper value, the deflection would be 0.69 in. (Figs. 1.26 and 1.28). The acceleration would be a maximum for the upper value of dynamic yield stress and would be the sum of the acceleration attributable to pipes e and d and the body. From Figs. 1.29 and 1.30 it can be seen that at a deflection of 0.69 in., the accelerations are

$$a_p = 37 \text{ g's} ,$$

$$a_b = 425 \text{ g's} ,$$

where a_p is the acceleration component attributable to the pipes and a_b is the component attributable to the body. The acceleration of the cask is 462 g's.

For case II, the pipe on the vertical centerline, identified in Fig. 1.24 as n, would contact the impact surface first and deflect about 1.7 in. before pipes m and o would contact the surface. The energy dissipated during this portion of the impact is found to be 0.6×10^6 lb·in. from Fig. 1.31, an energy-deformation plot for one pipe. Pipe n will deflect to solid height and pipes m and o will deflect 2.1 in. before the body begins to deform. At this point, the energy dissipated is the sum of that absorbed by pipes m, n, and o. The numerical value can be found from Fig. 1.31 at the applicable deflection of 3.83 in. and Fig. 1.26 at the applicable deflection of 2.1 in. The energy absorbed by the three pipes is 3.27×10^6 lb·in. The remaining 5×10^6 lb·in. will be dissipated in deforming the body and in the continued deflection of pipes n and o. As before, the deformation can be found from Figs. 1.26, 1.27, and 1.28. For the lower value of dynamic yield stress applicable to the materials in the cask body, the body deflection is slightly less than for case I at 1.18 in. Similarly, for the upper value of dynamic yield stress, the deflection is found to be 0.68 in. The resulting acceleration would be slightly less than for case I.

Fig. 1.27. Side-drop dynamic yield stress = 6000 psi.

Fig. 1.28. Side-drop dynamic yield stress = 14,000 psi.

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Fig. 1.29. Side-impact dynamic yield stress = 14,000 psi.

Fig. 1.30. Side-impact response of two pipes.

Fig. 1.31. Energy deflection curve for one pipe.

By comparison with Sect. 4, it is concluded that the calculated local reduction in shielding of 1.19 in. would not result in radiation doses in excess of those allowable. For the peak calculated acceleration of 462 g's, the plug would exert a downward force on the tapered seating surface (Fig. 1.32). The magnitude of this vertical force F_p is found from Newton's law

$$F_p = Wa/g = 2300(462 \text{ g})/g = 1.06 \times 10^6 \text{ lb} ,$$

where

W = weight of the plug (lb) ,

a = acceleration (g's) ,

g = gravitational constant .

This force system acting on the plug is shown in Fig. 1.32. From the summation of vertical forces, $F_v = F_p = 1.06 \times 10^6 \text{ lb}$. Also,

$$F_H = F_v \tan 15^\circ = 1.06 \times 10^6 \tan 15^\circ = 2.84 \times 10^5 \text{ lb} .$$

The force F_B represents the initial bolt load and the force F_s the force the plug exerts on the tapered seat per linear in. The reactions F_v and F_H are taken as concentrated loads, and friction is neglected. The forces F_1 thru F_6 are increased bolt load resulting from the dynamic load. By summing moments about A, we can write

$$\Sigma M_A = 5.5F_p + 21.68F_H + \int y dF_s - \sum_{n=1}^{n=7} F_B y_n - \sum_{n=1}^{n=6} F_m y_n = 0 .$$

The terms $\int y dF_s$ and $\sum_{n=1}^{n=7} F_B y_n$ are numerically equal and of opposite sign;

hence, they may be dropped . If the flanges are considered rigid, the expression

$$\Delta_1/y_1 = \Delta_2/y_2 = \Delta_3/y_3 = \Delta_4/y_4 = \Delta_5/y_5 = \Delta_6/y_6 ,$$

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Fig. 1.32. Plug force diagram.

is true, Δ being defined as the elongation in the bolts due to the inertia forces and y as the moment arm (Fig. 1.29) from A to the individual bolts. Also, $F = \Delta E/L$; hence,

$$F_1/y_1 = F_2/y_2 = F_3/y_4 = F_5/y_5 = F_6/y_6 ,$$

and all the forces can be expressed in terms of F_6 . The largest force numerically in the closure bolts is

$$F_1 = y_1 F_6 / y_6 .$$

The moment equation now becomes

$$\Sigma M_A = 5.5F_p + 21.68F_H - (2F_6/y_6)(y_1^2 + y_2^2 + y_3^2 + y_4^2 + y_5^2 + y_6^2) = 0 .$$

Substituting known values and solving for F_6 , it is found that

$$F_6 = 95.600 \text{ lb} .$$

The maximum stress in the 1-1/2-in. AISC4340 studs is

$$\sigma = F_6/A = 95,600/1.404 = 68,000 \text{ psi} ,$$

which is below the yield stress for AISC4340 steel in the annealed condition. It is concluded that containment will be maintained during and after the side drop.

1.5.1.3 Impact on a corner with the point of impact and center of gravity having a vertical axis. If the cask impacted on its top corner, the extended pipes could contact the surface first and deform. After a maximum deformation of 2 in., the removable carbon steel top-energy absorber would also contact the surface. The magnitude of the pipe deformation depends on the radial orientation. There are some radial orientations in which the absorber would contact the surface first and the pipes would absorb energy in a secondary fashion. The top-energy absorber will deform in compression and absorb energy. Simultaneous with this absorption, energy will be absorbed in the cask body as discussed in Sect. 1.5.1.1.

The response of the pipes in a corner impact cannot be readily calculated from theory, nor have similar members been tested. Two 1-to-2.56 models of an extended pipe energy absorber were fabricated. The model is shown in Figs. 1.33 and 1.34. These models were bolted to the bottom of the variable weight-drop hammer at the ORNL Drop Tower and impact tested to establish their capability for absorbing energy. The first model test was with a hammer weight of 252 lb dropped from 30 ft. The resulting damage is shown in Fig. 1.35. The model had totally failed, and no conclusion as to the absorber's ability to absorb energy could be reached. The second model was secured to the hammer still loaded with 252 lb, hoisted to 10 ft, and released. The resulting damage is shown in Fig. 1.36. The measured deflection of the model was 3 in. The absorbed energy $U_m = (252)(120) = 3.02 \times 10^4$ in.·lb. The energy U^1 applicable to one full-sized absorber would be $U^1 = U_m (SF)^3 = 3.02 \times 10^4 (2.56)^3 = 5.45 \times 10^5$ in.·lb. The deformation associated with a full-size absorber would be $(2.56)(3.0 \text{ in.}) = 7.7 \text{ in.}$ This is small compared with the total potential energy of the cask at 30 ft, which is 8.28×10^6 in.·lb. Since the energy absorbed by the pipes is small compared with the potential energy and there is uncertainty as to the radial orientation of the cask during impact, the energy absorbed by the pipes will be neglected. This is a conservative assumption.

The top-energy absorber and the cask body must, therefore, be capable of absorbing all the cask's kinetic energy. The program CEIR²⁰ was

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Fig. 1.33. Corner-impact model.

Photo 2203-74

Fig. 1.34. Corner-impact model.

Photo 2466-74

Fig. 1.35. Damage to corner-impact model from 30 ft.

Photo 2467-74

Fig. 1.36. Damage to corner-impact model from 10 ft.

modified to calculate the quantity of the energy absorbed relative to the axial component, a' , of the cask's acceleration. The equation $a' = a(\cos \theta)$, where a is the acceleration of the cask along the line of impact and θ is the angle the cask axis forms with the vertical, was used to accomplish this. The energy absorbed in the top-energy absorber was calculated using the program 1015 CASK. This program uses plastic deformation theory¹⁶ to calculate the energy absorbed in a ring-type absorber failing in compression. The derivations of equations and program listing are shown in Appendix F. It is noted that the absorber is designed so that the majority of the deformation occurs in the uppermost 4 in. (Fig. 0.1 and Appendix A, Fig. A.12). For this calculation it is assumed that all the deformation occurs in this portion of the absorber. Figure 1.37 is a machine plot of acceleration vs energy absorbed in the top absorber as calculated using 1015 CASK; and Fig. 1.38 is a similar plot for the energy absorbed in the cask body calculated using CEIR. By trial and error, it was found that when the cask's acceleration reached 139 g's (Figs. 1.37 and 1.38), a quantity of energy equal to the cask's potential energy had been absorbed and the cask had come to rest. From Fig. 1.39, a machine plot of the deformation of the shielding vs acceleration as computed using CEIR²⁰, it can be seen that the shielding deformation will reach 1.26 in. From Fig. 1.40, a machine plot of the deformation top absorber vs acceleration, it can be seen that the absorber will deform 2.38 in.

The axial acceleration is

$$\begin{aligned} a' &= a \cos \theta = 139 \cos[\tan^{-1} (D/L)] \\ &= 139 \cos[\tan^{-1} (37.5/72)] = 123 \text{ g} . \end{aligned}$$

The inertia force F applied to the plug bolting is

$$\begin{aligned} F &= m_a = W_p a' = 2100(123) \\ &= 2.58 \times 10^5 \text{ lb} , \end{aligned}$$

Fig. 1.37. Corner impact - energy absorber.

Fig. 1.38. Corner impact - cask body.

Fig. 1.39. Corner impact -- shielding deformation.

Fig. 1.40. Corner impact - absorber deformation.

where

- W_p = weight of the plug (lb) ,
- a = cask acceleration (g's) ,
- a' = cask acceleration in axial direction (g's) ,
- θ = angle the cask axis makes with a vertical axis ,
- L = cask length (in.) ,
- D = cask diameter (in.) .

The tensile stress σ in the closure bolting is

$$\sigma = F/AN = 2.58 \times 10^5 / 1.4(14) = 13,200 \text{ psi} .$$

Since this is below yield stress, the bolts will not fail in tension and the plug will be retained. The transverse load will be small when compared with the force in the side drop.

1.5.2 Puncture

The second in the sequence of hypothetical accident conditions to which the package 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 cylindrical 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., and the bar shall be of such length that it will cause maximum damage to the cask but shall not be less than 8 in. long. The long axis of this bar shall be normal to the surface of the cask upon impact.

The sides (cylindrical surfaces) and bottom of the cask are partially protected (from the 6-in. bar) by the 4-in. schedule 80 pipe heat-transfer fins. The 1/2-in. shell and bottom head are, however, adequate to resist puncture without this protection. Data by Nelms²³ (Fig. 23, Nelms' report) indicate that one 1/2-in. cylindrical jacket of a material having an ultimate tensile strength of 75,000 psi would not puncture under a cask weight of 23,000 lb. Similar data by Spaller²⁴ for flat plates indicate

that a 1/2-in. bottom plate of type 347 stainless steel would not puncture for the specified test condition and the HFIR cask geometry.

If the cask impacted on the top, protection would be afforded by the 1-in.-thick plate in the top-energy absorber. The acceleration would be less than in those examples previously considered.

1.6 Containment Vessel Design Pressure

The containment vessel is shown in simplified form in Fig. 1.41. The allowable or design pressure for the vessel is established by using the equations, design stress values, and philosophies of Sect. VIII of the ASME Code 26. The contribution of local shielding and, in the case of the top head, the internal heat transfer surfaces (connectors) will be neglected in the interest of computational simplicity. It can be determined by inspection that the plug or top head will be the component which limits the allowable pressure. Equation (1) of paragraph UC-34 of the Code considers a case in which S is equal to 16,400 psi (Table UHA 23 of Code), the temperature does not exceed 300°F, and the plate is of type 347 stainless steel. From Table 2.2, the normal operating temperature of the vessel is below this value for the condition of 130°F in bright sunlight; therefore,

$$P = St^2/d^2C = 16,400(0.5)^2/(20)^2(0.3) = 34.2 \text{ psi} .$$

At this pressure the load on the plug is

$$F = \pi d^2/4(P) = \pi(20)^2/4(34.2) = 10,740 \text{ lb} .$$

When distributed to the 14 studs securing the core, this load is small and well within the load tolerance.

1.7 Thermal and Thermal Expansion Stresses

The HFIR cask is subjected to internal and external sources of heat. The thermal stresses and stresses which result from differential expansion off dissimilar materials are evaluated below.

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Fig. 1.41. Containment vessel.

1.7.1 Normal conditions of transport

The temperature gradients (Sect. 2) which result from the internal and normal solar heat loads are not sufficient to cause significant thermal or expansion stresses.

1.7.2 Accident conditions

As above, the thermal gradients are not sufficient to cause significant thermal stresses. Differential expansion of the solid and melted lead will result in significant expansion stresses. Because the expansion of lead is greater than that of stainless steel, the heated lead will strain the shell. In calculating this strain, the volume of melted lead shown in Fig. 1.42(a) was modeled as shown in Fig. 1.42(b). Using Fig. 2.3 as a key, the peak temperatures at various points in the cask were read from Figs. 2.5 and 2.6. From this information, the following average temperatures were computed:

Air in the plug void	585°F
Melted lead	621°F
Unmelted lead in plug	585°F
Unmelted lead in main cavity	565°F
Inside of steel shell of plug	750°F
Main steel shell	800°F

The fabrication conditions were taken to be 70°F and 14.7 psia. The void volume that exists is approximately 5/16 in. wide and is shown on the engineering drawings in Appendix A.

In the plug, the cavity volume inside the steel jacket before the fire is

$$V_{SST} = 2831.3 \text{ in.}^3 ,$$

and the volume of the lead before the fire is

$$V_{Pb} = 2734.2 \text{ in.}^3 .$$

Fig. 1.42. Diagram of lead melt.

After the fire, the volume of the cylinder is

$$V'_{SST} = V_{SST}(1 + \alpha \Delta T)^3 ,$$

where

α = coefficient of linear thermal expansion for stainless steel ,

ΔT = temperature change from 70°F to heated condition .

$$V'_{SST} = 2831.3[1 + 9.6 \times 10^{-6}(750 - 70)]^3 = 2887.1 \text{ in.}^3 .$$

The volume of the expanded lead is

$$V'_{Pb} = V_m(1 + B) + V_u(1 + \alpha \Delta T)^3 ,$$

where

V_m = unexpanded volume of lead which will melt ,

V_u = unexpanded volume of lead which will not melt ,

B = percent volumetric expansion of lead from 70°F through the melting point,

α = coefficient of linear thermal expansion for lead ,

ΔT = temperature change from fabrication conditions to heated condition .

$$V'_{Pb} = .312.6(1 + 0.062) + 2421.6[1 + 16 \times 10^{-6}(585 - 70)]^3$$

$$= 2813.9 \text{ in.}^3 .$$

Hence, the void in the plug is sufficiently large to allow for the expansion of the lead without straining the steel cylinder.

The pressure of the air in the void in the plug is increased by the fire. From the perfect gas law,

$$P_1 V_1 / T_1 = P_2 V_2 / T_2 ,$$

where

p = pressure,

V = volume ,

T = temperature (absolute) .

For the air in the void,

$$V_1 = V_{SST} - V_{Pb} ,$$

$$V_2 = V'_{SST} - V_{Pb} ,$$

$$p_1 = 14.7 \text{ psia} ,$$

$$T_1 = 70^\circ\text{F} = 530^\circ\text{R} ,$$

$$T_2 = 585^\circ\text{F} = 1,045^\circ\text{R} .$$

Hence,

$$p_2 = (T_2/T_1)(V_1/V_2)(p_1) = (1,045/530)(2831.3 - 2734.2)/(2887.1 - 2813.9)(14.7)$$

$$= 38.5 \text{ psi} .$$

The hoop stress in the plug is

$$\sigma = pr_1/t ,$$

where

r_1 = the inner radius of the void ,

t = the thickness of the void wall .

$$\sigma = 38.5(9.938)/0.5 = 764.0 \text{ psi} .$$

This stress is far less than the allowable.

In the main body of the cask, the volume of the lead-filled cavity before heating is

$$\begin{aligned} V_{SST} &= [(18.25^2)50.5 - (11^2)9.25 - 9.438^2(32.25)]\pi \\ &= 40,300 \text{ in.}^3 . \end{aligned}$$

After expansion, the volume of the cavity formed by the steel is

$$\begin{aligned} V'_{SST} &= V(1 + \alpha\Delta T)^3 \\ &= 40,300[1 + 9.6 \times 10^{-6}(800 - 70)]^3 \\ &= 41,153 \text{ in.}^3 . \end{aligned}$$

The volume of the expanded lead is

$$\begin{aligned} V'_{Pb} &= V_m(1 + B) + V_u(1 + \alpha\Delta T)^3 \\ &= 8,731(1 + 0.062) + 31,329[1 + 16 \times 10^{-6}(565 - 70)]^3 \\ &= 41,352 \text{ in.}^3 , \end{aligned}$$

where V_m and V_u are calculated from dimensions given in Fig. 1.42 as follows:

$$\begin{aligned} V_m &= \pi[(18.25^2 - 16.95^2)(50.5) + (16.95^2 - 11^2)(0.8) + (16.95^2)1.3] \\ &\quad - [0.5(1.3 - 0.9)(16.95)][(2\pi)(16.95/3)] \\ &= 8730.8 \text{ in.}^3 . \end{aligned}$$

$$V_u = V_{SST} - V_m = 40,300 - 8,731 = 31,569 \text{ in.}^3 .$$

Because of the restraining effect of the external pipes, it is reasonable to assume that the resulting longitudinal strain in the outer shell will be negligible when compared with the resulting radial strain. Further,

one may conservatively assume that the inner shell and unmelted lead form a radially unyielding inner wall. Thus, radial strain of the outer shell must compensate for differential volumetric growth between the lead and its container as the temperature rises. First, it is assumed that the expanded lead volume is equal to the expanded and stretched volume contained by the steel shell.

$$V'_{Pb} = V''_{SST}$$

Since volume is directly proportional to the square of the radius,

$$\frac{R''^2}{R'^2} = \frac{V''_{SST}}{V'_{SST}},$$

where

V''_{SST} = steel cavity volume after thermal expansion and stretching,

R' = radius before stretching ,

R'' = radius after stretching .

The radius before and after is related by the amount of strain which the shell undergoes,

$$R'' = R'(1 + \epsilon) .$$

Therefore,

$$[R'(1 + \epsilon)]^2 / R'^2 = V''_{STT} / V'_{STT} .$$

The radius terms cancel, leaving

$$(1 + \epsilon) = (41,352/41,153)^{1/2}$$

$$\epsilon = 0.0048 \text{ in./in.}$$

Strains of this magnitude do not approach even the room-temperature ultimate strains of 347 stainless steel and thus are not serious.

2. THERMAL EVALUATION

2.1 Discussion

The package must be able to withstand direct sunlight at an ambient temperature of 130°F in still air without reducing the effectiveness of the packaging. The regulations⁵ set forth by the DOT also stipulate that the temperature of any accessible surface of the fully loaded shipping package shall not exceed 122°F when the package is in the shade in still air at an ambient temperature assumed to be 100°F for this evaluation. Further, if the package is transported in a transport vehicle consigned for the sole use of the shipper, the maximum surface temperature shall not exceed 180°F. This condition applies to the HFIR cask since it is always shipped in a closed, sealed highway trailer.

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 to 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 has expired and the temperature at the center of the package has begun to fall.

A computer program, HEATING-3,¹⁷ applicable to the IBM 360 computer, was modified to evaluate phase change of materials and was used to determine the temperature distribution, quantity, and location of material which had undergone a change of phase when exposed to a source of heat.

The cask will be used to transport HFIR and the ORR, BSR, PRNCR, and other miscellaneous fuel elements. Thermal calculations were made for the HFIR loading and for a maximum loading of the ORR type elements. The other elements have significantly lower heat generation rates than these; thus, calculations need not be made. The normal temperature distributions for these loadings were similar; hence, an analysis of the fire condition was made only for the HFIR loading.

The ORIGIN code²⁵ was used to compute the decay heat power of the HFIR elements. The inner element generated 1.18 kW and the outer element 2.08 kW for a total of 3.26 kW. The total had previously been calculated by Arrol² to be 3.31 kW. The former values were used in the calculations discussed in preceding pages.

Hamrick²⁶ calculated the thermal energy released from ORR (BSR) elements to be 210 W per element based on an assumed, but conservative, operating cycle (Sect. 0.2.2 and Appendix D). Total heat load for 17 elements would be 3570 W. The heat load from the geometrically similar PRNC reactor elements would be significantly lower than this (Appendix D).

2.2 Thermal Properties of Materials

Thermal properties of materials used to compute the temperature distribution and material phase change are listed in Table 2.1 for the HFIR core loading and Table 2.2 for the ORR loading. Emissivity for the cask surface was assumed to be 0.6.

In an enclosed gas space, heat transfer due to natural convection may be significant. This depends primarily on the ΔT across the space, the surface-to-surface spacing of the gas space, and the fluid properties. These parameters are conveniently represented in a dimensionless group called the Rayleigh number (Ra).

$$Ra = (\rho^2 g \beta C_p / \mu k) \Delta T L^3 .$$

The term in parentheses is a grouping of properties of the gas in the gas space, ΔT is the temperature difference between opposing surfaces of the gas space, and L is the distance between these opposing surfaces.

For values of $Ra < 1000$, internal convection has been experimentally shown to be insignificant, and the heat transfer mechanisms across the gas space are conduction and radiation. For values of $Ra > 1000$, the effect of convection can be simulated using an effective conductivity, k_e , for the gas which is larger than the normal molecular conductivity of the gas.

Table 2.1. Material properties for HFIR loading

Material	Temperature (°F)	Thermal conductivity (Btu/hr·ft·°F)	Density (lb/in. ³)	Heat capacity (Btu/lb·°F)	Latent heat (Btu/lb)
Lead ^a	0	20.52	0.4113	0.035	11.3
	620	17.28	0.3974		
	622	8.50	0.3860		
	1100	9.22	0.3766		
	1600	12.10	0.3622		
347 SST ^b	0	8.14	0.286	0.100	
	800	11.45			
	1800	15.77	0.272		
Aluminum ^c	0	110.16	0.0978	0.214	
	1220	159.84			
Air-Aluminum ^d	0	55.44	0.0375	0.210	
	1220	79.92			
Fuel ^e	0	41.76	0.0617	0.210	
	1220	59.76			
Air ^f	0	0.01312	0.0000500	0.240	
	250	0.01923		0.242	
	500	0.02458		0.248	
	1000	0.03370		0.263	
	1500	0.04137	0.0000117	0.270	
Air-2 ^f	0	0.063	0.0000500	0.240	
	1500	0.1656	0.0000117	0.270	

^aFor comparable values of thermal conductivity of lead see *A Compilation of Thermal Property Data for Computer Heat-Conduction Calculations*, UCRL-50589 (1969). The specific heat and the thermal conductivity of lead were obtained from S. S. Kutateladze et al., *Liquid Metal Heat Transfer Media*, Chapman & Hall, Ltd., London, 1959. The density of lead was obtained from *Analysis of HFIR Irradiated Fuel Element Shipping Cask*, ORNL-TM-959 (January 1965). The latent heat of lead was obtained from W. M. Rohsenow and J. P. Hartnett, *Handbook of Heat Transfer*, McGraw-Hill, New York, 1973.

^bFor comparable properties of 347 stainless steel see F. Kreith, *Principles of Heat Transfer*, International Textbook, Scranton, Pa., 1958.

^cFor comparable properties of aluminum see J. P. Holman, *Heat Transfer*, McGraw-Hill, New York, 1972.

^dThe properties of air-aluminum are for a homogenized mixture of aluminum and air.

^eThe fuel is a homogenized mixture of uranium oxide and aluminum.

^fFor comparable properties of air see F. Kreith, *Principles of Heat Transfer*. Air-2 has been given an enhanced thermal conductivity to simulate natural convection.

Table 2.2. Material properties used in thermal analysis for ORR loading

Material	Temperature (°F)	Thermal conductivity (Btu/hr·ft·°F)	Density (lb/in. ³)	Heat capacity (Btu/lb·°F)
Lead ^{a,b}	32	20.52	0.410	0.0299
	80.3	20.30		
	122			0.0304
	170.3	20.09		
	212			0.0309
	260.3	19.51		
	302			0.0315
	392			0.0323
	440.3	18.79		
	482			0.0334
	527			0.0341
	572			0.0348
	599			0.0355
	620	11.38		
	800	12.17		
	980	13.03		
	1160	13.82		
	1340	14.62		
Fuel 1 ^c	32		0.0516	0.086
	122	120.96		
	212	123.12		0.0926
	302	125.28		
	572	127.44		
	1022			0.1217
Fuel 2 ^c	32		0.0360	0.086
	122	120.96		
	212	123.12		0.0926
	302	125.28		
	572	127.44		
	1022			0.1217
Fuel 3 ^c	32		0.03	0.086
	122	120.96		
	212	123.12		0.0926
	302	125.28		
	572	127.44		
	1022			0.1217
SST 304 ^d	32	8.49	0.286	0.120
	80.3	8.78		
	170.3	9.36		
	260.3	9.82		
	350.3	10.2		
	440.3	10.6		
	620.3	11.4		

Table 2.2. (continued)

Material	Temperature (°F)	Thermal conductivity (Btu/hr·ft·°F)	Density (lb/in. ³)	Heat capacity (Btu/lb·°F)
SST 304 ^d	752.0			0.135
	800.3	12.2		
	980.3	13.0		
	1160.0	13.8		
	1340	14.6		
	1520	15.4		
	1700	16.2		
	1880	17.0		
	2060	17.9		
	2240	18.7		
	2420	19.5		
	2537	20.0		
Air ^e	32	0.0140	4.69×10^{-5}	0.240
	100	0.0154	4.11×10^{-5}	0.240
	200	0.0174	3.47×10^{-5}	0.241
	300	0.0193	3.0×10^{-5}	0.243
	400	0.0212	2.66×10^{-5}	0.245
	500	0.0231	2.38×10^{-5}	0.247
	600	0.0250	2.16×10^{-5}	0.250
	700	0.0268	1.97×10^{-5}	0.253
	800	0.0286	1.82×10^{-5}	0.256
	900	0.0303	1.68×10^{-5}	0.259
	1000	0.0309	1.57×10^{-5}	0.262
	1500	0.0400	1.17×10^{-5}	0.276
Air 2.0 ^e	32	0.02794	4.69×10^{-5}	0.240
	100	0.03082	4.11×10^{-5}	0.240
	200	0.03485	3.47×10^{-5}	0.241
	300	0.03859	3.01×10^{-5}	0.243
	400	0.04234	2.66×10^{-5}	0.245
	500	0.04622	2.38×10^{-5}	0.247
	600	0.04997	2.16×10^{-5}	0.250
	700	0.05357	1.97×10^{-5}	0.253
	800	0.05717	1.87×10^{-5}	0.256
	900	0.06062	1.68×10^{-5}	0.259
	1000	0.06379	1.57×10^{-5}	0.262
	1500	0.08006	1.17×10^{-5}	0.276
Air 5.0 ^e	32	0.06984	4.69×10^{-5}	0.240
	100	0.07704	4.11×10^{-5}	0.240
	200	0.08712	3.47×10^{-5}	0.241
	300	0.09648	3.01×10^{-5}	0.243

Table 2.2. (continued)

Material	Temperature (°F)	Thermal conductivity (Btu/hr·ft·°F)	Density (lb/in. ³)	Heat capacity (Btu/lb·°F)
Air 5.0 ^e	400	0.10584	2.66×10^{-5}	0.245
	500	0.11556	2.38×10^{-5}	0.247
	600	0.12492	2.16×10^{-5}	0.250
	700	0.13392	1.97×10^{-5}	0.253
	800	0.14292	1.82×10^{-5}	0.256
	900	0.15156	1.68×10^{-5}	0.259
	1000	0.15948	1.57×10^{-5}	0.262
	1500	0.20016	1.17×10^{-5}	0.276

^aThe thermal conductivity values for lead were obtained from T. S. Touloukian, *Thermal Conductivity*, Plenum, New York, 1970.

^bFor comparable values for the heat capacity and specific heat of lead, see *A Compilation of Thermal Property Data for Computer Heat-Conduction Calculations*, UCRL-50589 (1969).

^cThe properties of fuel 1, fuel 2, and fuel 3 represent homogenized properties of the mixtures of aluminum and uranium that occur in the inner, middle, and outer cores.

^dThe thermal properties of 304 stainless steel were taken from UCRL-50589.

^eThe thermal properties of air were taken from F. Kreith, *Principles of Heat Transfer*, International Textbook, Scranton, Pa., 1970. The thermal conductivities of air 2.0 and air 5.0 have been increased to account for natural convection.

There are many expressions for k_e depending mainly on the actual geometry. However, a rather simple expression derived from Kraussold's work²⁷ will produce sufficient accuracy for most cask calculations. The expression is

$$k_e/k = A(Ra)^b.$$

The coefficients A and b depend on the range of the Rayleigh number as follows:

<u>Ra</u>	<u>A</u>	<u>b</u>
10^3-10^4	0.251	0.2
10^4-10^6	0.100	0.3
10^6-10^8	0.398	0.2

This type of convection modeling was used in the analysis of the cask carrying ORR elements. The materials, Air-2.0 and Air-5.0, are used to model the effects of natural convection by increasing the effective conductivity of the air.

2.3 Thermal Evaluation for Normal Conditions of Transport

The evaluations for the normal conditions of transport are outlined below.

2.3.1 Thermal model

The computational model representing the HFIR cask and its intended contents is illustrated in Figs. 2.1 and 2.2. Figure 2.1 is a two-dimensional model of the cask loaded with the HFIR core, and Fig. 2.2 represents it loaded with 17 ORR-type elements. In both cases, the fuel is modeled as a homogeneous material (fuel 1, fuel 2, and fuel 3) with conductivity, density, and heat generation adjusted. The three fuels used in the ORR loading, fuel 1, fuel 2, and fuel 3, represent homogenized materials in the inner core, middle core, and outer core, respectively.

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Fig. 2.1. Heat transfer model cask loaded with HFIR core.

ORNL DW 74-8960

Fig. 2.2. Heat transfer model cask loaded with 17 ORR elements.

The efficiency of the fins has been previously calculated,² and the coefficient for the outer surface was raised to compensate for the exclusion of the fins from the model.

In calculating the steady-state temperature for the 130°F environment in direct sunlight, it was assumed that a solar heat flux of 144 Btu/hr·ft² was incident upon the cask. The fraction of the incident solar flux that is absorbed by the cask is equal to the absorptivity of the cask, assumed conservatively to be 1.0. The ends are not insulated.

2.3.2 Maximum temperatures

Maximum temperatures are presented in Tables 2.3 and 2.4 for the environments of 130°F in direct sunlight and 100°F in the shade. For the 100°F-in-the-shade environment, the maximum accessible surface temperature was 151°F when loaded with the HFIR core and 178°F when loaded with 17 ORR-type elements at an elevation of 16-1/2 in. on the cylindrical portion of the cask. Since this is less than 180°F, the container complies with the latter environmental requirement. Calculated temperatures are well within the operating ranges for all materials, and no cask structural materials exhibit a significant loss of mechanical properties at these temperatures. The primary seal (silicone rubber gasket) is satisfactory for the calculated temperatures. The fuel temperatures will not cause failure of cladding.

Actual temperature measurements were made on the cask in 1967.³² The cask was loaded with an HFIR element having a total decay heat output of 3.2 kW. After 19 hr, the maximum inner temperature reached 198°F, while the maximum accessible surface temperature reached 124°F. This reflects the conservatism used in the calculations.

2.3.3 Minimum temperatures

Reduced or zero heat loads would lower temperatures throughout the container. This situation would not affect the safe operation of the container nor the margin of safety (see Sect. 1.4.2 for discussion of the low temperature effects).

Table 2.3. Cask temperatures with HFIR core

No. ^a	Location	Temperature (°F)	
		130°F air in sunlight	100°F air in shade
1	Maximum accessible surface	220	151
2	Bottom corner outer skin	202	148
3	Center line bottom of cavity	317	262
4	Bottom inner radius of cavity	239	179
5	Mid-elevation inner Poison post	391	340
6	Mid-elevation inner fuel element	415	375
7	Mid-elevation outer Poison post	353	345
8	Mid-elevation outer fuel element	364	316
9	Mid-elevation inner radius of cavity	223	158
10	Mid-elevation outer skin	212	141
11	Primary seal	202	139
12	Cavity air	260	202
13	Plug cavity	202	145
14	Top corner outer skin	184	126
15	Center line, top, outer skin	181	131

^aSee Fig. 2.3 for locations.

Table 2.4. Cask temperatures with 17 ORR elements

No. ^a	Location	Temperature (°F)	
		130°F air in sunlight	100°F air in shade
1	Maximum accessible surface	221	178
2	Mid-elevation center element	730	703
3	Mid-elevation 2d-row element	715	690
4	Mid-elevation 3d-row element	617	590
5	Mid-elevation inner cavity wall	240	184
6	Mid-elevation outer shell (surface)	220	165
7	Cask gasket	228	170
8	Top cask surface	222	158
9	Mean plug lead	223	160
10	Body lead at mid-elevation	228	175
11	Mean air in plug cavity	225	193
12	Mean air in shield cavity	228	175
13	Mean air in cask cavity	300	263

^aSee Fig. 2.4 for locations.

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Fig. 2.3. Temperature location diagram (HFIR core).

ORNL DWG 75-12974

Fig. 2.4. Temperature location diagram (ORR loading).

2.3.4 Maximum internal pressure

There would be a rise in pressure in the cask cavity and shielding cavities due to the increase in temperature. The resulting pressures are calculated from the thermodynamic laws assuming constant volume, a sealing temperature T_1 of 70°F (530°R), an atmospheric sealing pressure P_1 of 14.7 psia, and the relationship

$$P_2 = P_1 T_2 / T_1$$

The pressure in the cavity would be

$$P_2 = 14.7(760)/530 = 21.1 \text{ psia} = 6.4 \text{ psig}$$

The pressure in the lead cavity would be

$$P_2 = 14.7(688)/530 = 19.1 \text{ psia} = 4.4 \text{ psig}$$

The pressure in the plug cavity would be

$$P_2 = 14.7(685)/530 = 19.0 \text{ psia} = 4.3 \text{ psig}$$

2.4 Hypothetical Thermal Accident Evaluation

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

2.4.1 Thermal model

The analytical model described in Sect 2.3.1 was used for the accident evaluation.

2.4.2 Thermal accident analysis

The HEATING-3¹⁷ computer program was used to determine the temperature distribution and the quantity and location of the lead that would melt as a result of the prescribed 30-min thermal exposure. The material constants from Table 2.1 were used as input. The steady-state temperature distribution computer for normal conditions of transport for the HFIR core loading (Sects. 2.4.2 and 2.4.3) was used for initial temperatures.

2.4.3 Analysis results

Temperatures with respect to time for the locations of concern for the specified exposure and subsequent cool-downs are presented in Figs. 2.3, 2.5, and 2.6. The quantity and locations of the lead that would melt are shown in Fig. 1.42.

2.4.4 Internal pressures

The pressure in the cask cavity may be calculated from the perfect gas laws. With reference to Fig. 2.3 and 2.5, the maximum temperature of the cask cavity air is reached at time equal to 60 min or 30 min after the fire is extinguished (see curve 12, Fig. 2.5). The temperature reaches 460°F (920°R). Assume constant volume and that the cavity was sealed at a temperature T of 70° (530°R) and at an atmospheric pressure of 14.7 psia. The maximum cavity pressure P_2 is

$$P_2 = P_1 T_2 / T_1 = 14.7(920)/530 = 25.5 \text{ psia} = 10.8 \text{ psig} ,$$

which is less than the design pressure adjusted for temperature per the Code.²⁵

3. CONTAINMENT

3.1 Containment Boundaries

Primary containment is formed by the cask cavity, plug, and seal as indicated in Fig. 1.41. An additional line of containment is formed by

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Fig. 2.5. Temperature of cask loaded with HFIR during fire simulation.

ORNL DWG 74-9650

Fig. 2.6. Temperature of cask loaded with HFIR core.

the fuel elements' cladding. Primary containment is routinely pressure tested (Appendix G) after the cask is loaded.

3.2 Requirements for Normal Transport

The containment vessel is designed to maintain containment during normal conditions of transport. The evaluations of Sects. 1.4, 1.6, and 2 demonstrate the adequacy of the design. The cask has been in use since 1966 without loss of containment. The routine pressure tests periodically demonstrate adequacy of the containment vessel.

3.3 Containment Requirements During the Hypothetical Accident

The cask will maintain containment during and after the specified hypothetical accident. The evaluations of Sect. 1.7 demonstrate that there will be no stresses in the containment vessel exceeding the static yield stress. The thermal evaluation in Sect. 2 demonstrates that the temperatures in the vessel are within the operating limits of the materials. The silicone rubber gasket reaches a maximum temperature of 550°F. It has been reported¹⁸ (Fig. 3.1) that the useful service life of a silicone rubber gasket at 550°F is about 5 hr. With reference to Fig. 2.5, it can be seen that time above 500°F is only about 40 min. The useful service life of a silicone rubber gasket at 500°F is approximately 11 hr (Fig. 3.1). Similarly, the time above 400°F is 1 hr 25 min; the useful service life at 400°F is in excess of 1000 hr. It is concluded, therefore, that the seal will not fail as a result of the thermal exposure; thus, if the cask is immersed, the in-leakage of water would not occur.

4. SHIELDING

Biological shielding from gamma radiation is effected by a minimum thickness of 8.75 in. of lead and 1 in. of stainless steel cladding.

4.1 Normal Conditions

A detailed shielding analysis was prepared and presented in the original cask design report.² This analysis was based on an operating

Fig. 3.1. Gasket service temperatures (ref. 19).

cycle of 15-day irradiation of the fuel at 100 MW(t) followed by 270-day cooling. Conservatism in the analysis was sufficient to allow shipment of elements from current operating cycle of 23-day irradiation at 100 MW(t) followed by a 240-day cooling period. A routine portion of preshipment inspection (Appendix G) is determining the dose rate at the surface of the cask and 3 ft from the surface as required by the regulations.⁴ This scan is performed by the ORNL Health Physics Division prior to the cask's leaving the confines of ORNL. A written report of this inspection is prepared for every shipment. A copy of a typical report is presented in Appendix G. This report demonstrates that the HFIR cask, when loaded with the spent HFIR element that has experienced the current operating cycle, complies with the requirements of the regulations with regard to dose rate under normal conditions. The dose rate at the cask surface was measured at 20 millirems/hr, as compared with the allowable rate⁵ of 200 millirems/hr. At a distance of 3 ft from the cask surface, the measured rate was 2.3 millirems/hr as compared with an allowable rate⁵ of 10 millirems/hr. It is therefore evident that the cask complies with the regulations from the standpoint of shielding for normal conditions.

4.2 Accident Conditions

The redistribution of shielding resulting from the 30-ft and 40-in. free-falls is small (Sect 1.7). If subjected to the 30-min thermal exposure as specified, a portion of the shielding would melt (Fig. 1.42). It is not anticipated that the shell would rupture and that shielding would be lost. Some redistribution of the shielding could result when the lead solidified. This redistribution could result in a reduction of shielding, particularly in the plug where a void volume was provided in the lower part of the plug. A prediction of the amount and location of the shielding redistribution cannot be made with confidence; thus, a calculation was made assuming loss of the melted shielding. J. R. Knight of the Computer Sciences Division of Union Carbide Corporation-Nuclear Division (UCC-ND) performed the calculation. A copy of his report is presented in Appendix H. In summary, this evaluation found that the dose rate at the surfaces and at 3 ft would increase by a factor of 22 above

the nonaccident dose rates. Based on the allowable limits for shipments of 200 millirems at the surface and 10 millirems/hr at 3 ft, the accident condition rate would be 220 millirems/hr at 3 ft - much lower than the 1000 millirems/hr allowable by the regulations.

5. CRITICALITY

The ORNL criticality committee has evaluated the container and its contents as described in Sect. 0.2 and the as-built drawings in Appendix A. These evaluations, presented in Appendix I, demonstrate compliance with the regulations. Critical experiments reported by Johnson²⁸ and by Rafferty and Thomas²⁹ for the HFIR elements and by Johnson and Reedy³⁰ for the ORR-type elements form the bases for committee approval. The PRNC elements are of similar geometry to ORR elements and contain less ²³⁵U at lower enrichments; hence, their shipment complies with the regulations by comparison with the ORR elements. Accelerations of the magnitude computed for the accident conditions will not alter the element geometry. Therefore, the contents will remain subcritical after the accident.

6. QUALITY ASSURANCE

The majority of the fabrication work on the cask was performed prior to the requirements for a formal quality assurance program. The fabrication was performed at ORNL and Y-12 shops in accordance with normal shop procedures. Material was specified on the original drawings (Appendix A) to conform to American Society for Testing Material (ASTM) specifications. Material was withdrawn from UCC-ND stores stock or purchased in accordance with the applicable ASTM specifications. Stores stock was purchased in accordance with the appropriate specifications. Material certifications were procured for all material purchased from vendors specifically for the cask. However, these documents were not retained. Welding was specified to conform to formal ORNL welding and inspection procedures (Appendix A). The cask was inspected for total fabrication by 0th inspection personnel to ensure compliance with the welding requirements. Dimensional inspections were also made at appropriate intervals during fabrication and on the completed cask. The acceptance tests specified

by the drawings were performed. The fabrication records for the cask are on permanent file at Oak Ridge National Laboratory.

The modifications to the cask are to be performed in accordance with the drawings, notes, and the ORNL quality assurance procedures applicable to quality level III fabrication. The welds will be made in accordance with the specified WPS specifications and inspected as specified on the drawings. The material used in modifications will be withdrawn from ORNL stores stock, which was purchased in accordance with the drawing specifications. Dimensional inspections of the modified cask are to be performed. Quality assurance program plans for the modifications are in Appendix J.

6.1 Operating Procedures and Routine Inspection

The ORNL Operations Division has established operating and routine inspection procedures and standard checklists to ensure that all shipments are safe and comply with Federal regulations^{3,4,5} and with all ORNL procedures and regulations. Copies of the procedures and checklists are presented in Appendix G.

6.2 Periodic Maintenance and Inspection

Inspections are performed prior to each shipment as outlined above. Maintenance is required when inspections indicate damage. There are no time-degradable materials (except the gaskets) used in the construction of the containers. The gaskets are replaced routinely (Appendix G).

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Appendix A
AS-BUILT DRAWINGS

Fig. A.1. Drawing no. M10191-EL-001-D.

Fig. A.2. Drawing no. M10191-EL-002-D.

Fig. A.3. Drawing no. M10191-EL-003-D.

Fig. A.4. Drawing no. M10191-EL-004-D.

FIG. A.5. Drawing no. M10191-EL-005-D.

GENERAL NOTES:					PARTS LIST																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
<p>II. WELDING</p> <p>1. ALL CLASS I WELDS SHALL BE MADE PER PS-13 AND INSPECTED PER NET-40-201, SCHEDULE D.</p> <p>2. ALL CLASS II WELDS SHALL BE MADE PER PS-13 AND INSPECTED PER NET-40-201, SCHEDULE E.</p> <p>3. ALL CLASS III WELDS SHALL BE MADE PER PS-13 ON WITH THE METAL ARC PROCESS AT THE FABRICATOR'S OPTION AND INSPECTED PER NET-40-201, SCHEDULE F.</p> <p>4. ALL WELDS EXCEPT THOSE IN THE LEAD CAVITIES SHALL BE SMOOTH OR MACHINED TO A FINISH EQUAL TO OR SUPERIOR TO THAT SPECIFIED ON THE JOINED PARTS. GRINDING IS NOT REQUIRED ON WELDS INTERIOR TO THE LEAD CAVITIES.</p> <p>5. ALL WELDS SHALL BE CONTINUOUS UNLESS OTHERWISE NOTED.</p> <p>III. MATERIAL</p> <p>1. PLATE</p> <p>A. ALL STAINLESS STEEL PLATE SHALL CONFORM TO ASTM-A240 TYPE 307 HOT ROLLED AND ANNEALED NO. 1 FINISH OR SUPERIOR.</p> <p>B. ALL STEEL PLATE SHALL CONFORM TO ASTM-A205, GRADE C FINE BOX QUALITY.</p> <p>2. BAR STOCK - ALL ROUND, SQUARE, OR RECTANGULAR BAR STOCK SHALL CONFORM TO ASTM-A276, TYPE 307 HOT ROLLED AND ANNEALED.</p> <p>3. PIPE - ALL PIPE SHALL CONFORM TO ASTM-A312, TYPE 307, SEAMLESS.</p> <p>4. PIPE FITTINGS - ALL PIPE FITTINGS SHALL CONFORM TO ASTM-A102, TYPE 307, FORGED.</p> <p>IV. PROOF TEST</p> <p>THE CASH LIFTING L. S. SHALL BE PROOF TESTED AT A TOTAL LOAD (FOR BOTH LUGS) OF 40,000 POUNDS APPLIED PARALLEL TO THE AXIS OF THE CASH; THE LID LIFTING DEVICE SHALL BE PROOF TESTED AT A TOTAL LOAD OF 4500 POUNDS APPLIED AT THE AXIS OF THE LID.</p> <p>V. LEAK TESTS</p> <p>1. THE CASH AND PLUG LEAK CAVITIES SHALL BE LEAK TESTED AS FOLLOWS: (A) 5 PSIG AIR SOAP TEST, (B) 25 PSIG HYDROSTATIC TEST. NO LEAKS PERMITTED.</p> <p>2. THE ELEMENT CAVITY SHALL BE AIR TESTED AT A PRESSURE OF 20 PSIG WITH THE RELIEF VALVE (1) REMOVED. THERE SHALL BE NO DETECTABLE DROOP IN PRESSURE OVER AN EIGHT-HOUR PERIOD.</p> <p>3. THE CRACKING PRESSURE OF THE RELIEF VALVE SHALL BE TESTED AT LEAST 5 TIMES AS DESCRIBED BELOW. WITH THE RELIEF VALVE INSTALLED ON THE CASH, AIR PRESSURE NOT TO EXCEED 20 PSIG SHALL BE APPLIED TO THE ELEMENT CAVITY. THE CRACKING PRESSURE FOR THE RELIEF VALVE SHALL BE IN THE RANGE OF 10-16 PSIG. ANY DEVIATION FROM THIS VALUE, EXCLUDING THE FIRST OF THE 5 TESTS WILL REQUIRE ADJUSTMENT, REPAIR, OR REPLACEMENT OF THE RELIEF VALVE. AFTER ANY ADJUSTMENT OR REPAIR, THE TEST SHALL BE REPEATED UNTIL THE VALVE CRACKS IN THE 10-16 PSIG RANGE FOR 3 CONSECUTIVE TIMES. AFTER ANY REPLACEMENT, THE TEST SHALL BE STARTED OVER.</p> <p>VI. MISCELLANEOUS</p> <p>1. THE MILD STEEL WENT TRANSFER RINGS IN THE CASH BODY AND PLUG SHALL BE "TIMED" WITH 50 PER CENT LEAD-50 PER CENT TIN SOLDER.</p> <p>2. ATTACH ORIGIN CASE IDENTIFICATION TAG NUMBER PS-23-176 AT MID-POINT OF ONE VERTICAL PIPE FIN.</p>					<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 5%;">PART NO.</th> <th style="width: 15%;">QTY. REQ.</th> <th style="width: 10%;">P.C. REQ.</th> <th style="width: 50%;">DESCRIPTION (QTY., DIM., MTL.)</th> <th style="width: 20%;">REMARKS</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1</td> <td>1</td> <td>FILTER, HOSE END SERIES, 2-5 MICRON FILTER ELEMENT PART NO. 2251133/516 STAINLESS STEEL</td> <td>55T</td> </tr> <tr> <td>2</td> <td>1</td> <td>1</td> <td>RELIEF VALVE CIRCLE SEAL PART NO. 5190-1-2-00-1</td> <td>55T</td> </tr> <tr> <td>3</td> <td>1</td> <td>1</td> <td>SLANG STOCK 1/4" SCH 40</td> <td>55T</td> </tr> <tr> <td>4</td> <td>1</td> <td>1</td> <td>CASH BODY</td> <td>55T</td> </tr> <tr> <td>5</td> <td>1</td> <td>1</td> <td>LID</td> <td>55T</td> </tr> <tr> <td>6</td> <td>1</td> <td>1</td> <td>CENTRAL POST</td> <td>55T</td> </tr> <tr> <td>7</td> <td>1</td> <td>1</td> <td>PLUG</td> <td>55T</td> </tr> <tr> <td>8</td> <td>1</td> <td>1</td> <td>CLAMP RING</td> <td>55T</td> </tr> <tr> <td>9</td> <td>1</td> <td>1</td> <td>NUT, M8, 1/2-13NC-2</td> <td>55T</td> </tr> <tr> <td>10</td> <td>1</td> <td>1</td> <td>WASHER 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<td>55T</td> </tr> <tr> <td>136</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 125</td> <td>55T</td> </tr> <tr> <td>137</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 126</td> <td>55T</td> </tr> <tr> <td>138</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 127</td> <td>55T</td> </tr> <tr> <td>139</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 128</td> <td>55T</td> </tr> <tr> <td>140</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 129</td> <td>55T</td> </tr> <tr> <td>141</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 130</td> <td>55T</td> </tr> <tr> <td>142</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 131</td> <td>55T</td> </tr> <tr> <td>143</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 132</td> <td>55T</td> </tr> <tr> <td>144</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 133</td> <td>55T</td> </tr> <tr> <td>145</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 134</td> <td>55T</td> </tr> <tr> <td>146</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 135</td> <td>55T</td> </tr> <tr> <td>147</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 136</td> <td>55T</td> </tr> <tr> <td>148</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 137</td> <td>55T</td> </tr> <tr> <td>149</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 138</td> <td>55T</td> </tr> <tr> <td>150</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 139</td> <td>55T</td> </tr> <tr> <td>151</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 140</td> <td>55T</td> </tr> <tr> <td>152</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 141</td> <td>55T</td> </tr> <tr> <td>153</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 142</td> <td>55T</td> </tr> <tr> <td>154</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 143</td> <td>55T</td> </tr> <tr> <td>155</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 144</td> <td>55T</td> </tr> <tr> <td>156</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 145</td> <td>55T</td> </tr> <tr> <td>157</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 146</td> <td>55T</td> </tr> <tr> <td>158</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 147</td> <td>55T</td> </tr> <tr> <td>159</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 148</td> <td>55T</td> </tr> <tr> <td>160</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 149</td> <td>55T</td> </tr> <tr> <td>161</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 150</td> <td>55T</td> </tr> <tr> <td>162</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 151</td> <td>55T</td> </tr> <tr> <td>163</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 152</td> <td>55T</td> </tr> <tr> <td>164</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 153</td> <td>55T</td> </tr> <tr> <td>165</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 154</td> <td>55T</td> </tr> <tr> <td>166</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 155</td> <td>55T</td> </tr> <tr> <td>167</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 156</td> <td>55T</td> </tr> <tr> <td>168</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 157</td> <td>55T</td> </tr> <tr> <td>169</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 158</td> <td>55T</td> </tr> <tr> <td>170</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 159</td> <td>55T</td> </tr> <tr> <td>171</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 160</td> <td>55T</td> </tr> <tr> <td>172</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 161</td> <td>55T</td> </tr> <tr> <td>173</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 162</td> <td>55T</td> </tr> <tr> <td>174</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 163</td> <td>55T</td> </tr> <tr> <td>175</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 164</td> <td>55T</td> </tr> <tr> <td>176</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 165</td> <td>55T</td> </tr> <tr> <td>177</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 166</td> <td>55T</td> </tr> <tr> <td>178</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 167</td> <td>55T</td> </tr> <tr> <td>179</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 168</td> <td>55T</td> </tr> <tr> <td>180</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 169</td> <td>55T</td> </tr> <tr> <td>181</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 170</td> <td>55T</td> </tr> <tr> <td>182</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 171</td> <td>55T</td> </tr> <tr> <td>183</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 172</td> <td>55T</td> </tr> <tr> <td>184</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 173</td> <td>55T</td> </tr> <tr> <td>185</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 174</td> <td>55T</td> </tr> <tr> <td>186</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 175</td> <td>55T</td> </tr> <tr> <td>187</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 176</td> <td>55T</td> </tr> <tr> <td>188</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 177</td> <td>55T</td> </tr> <tr> <td>189</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 178</td> <td>55T</td> </tr> <tr> <td>190</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 179</td> <td>55T</td> </tr> <tr> <td>191</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 180</td> <td>55T</td> </tr> <tr> <td>192</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 181</td> <td>55T</td> </tr> <tr> <td>193</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 182</td> <td>55T</td> </tr> <tr> <td>194</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 183</td> <td>55T</td> </tr> <tr> <td>195</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 184</td> <td>55T</td> </tr> <tr> <td>196</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 185</td> <td>55T</td> </tr> <tr> <td>197</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 186</td> <td>55T</td> </tr> <tr> <td>198</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 187</td> <td>55T</td> </tr> <tr> <td>199</td> <td>1</td> <td>1</td> <td>WASHER RING, NO. 188</td></tr></tbody></table>				PART NO.	QTY. REQ.	P.C. REQ.	DESCRIPTION (QTY., DIM., MTL.)	REMARKS	1	1	1	FILTER, HOSE END SERIES, 2-5 MICRON FILTER ELEMENT PART NO. 2251133/516 STAINLESS STEEL	55T	2	1	1	RELIEF VALVE CIRCLE SEAL PART NO. 5190-1-2-00-1	55T	3	1	1	SLANG STOCK 1/4" SCH 40	55T	4	1	1	CASH BODY	55T	5	1	1	LID	55T	6	1	1	CENTRAL POST	55T	7	1	1	PLUG	55T	8	1	1	CLAMP RING	55T	9	1	1	NUT, M8, 1/2-13NC-2	55T	10	1	1	WASHER RING, NO. 1	55T	11	1	1	NUT, M8, 3/8-16NC-2	55T	12	1	1	NUT, M8, 1-1/4-16NC-2	55T	13	1	1	WASHER RING, NO. 2	55T	14	1	1	WASHER RING, NO. 3	55T	15	1	1	WASHER RING, NO. 4	55T	16	1	1	WASHER RING, NO. 5	55T	17	1	1	WASHER RING, NO. 6	55T	18	1	1	WASHER RING, NO. 7	55T	19	1	1	WASHER RING, NO. 8	55T	20	1	1	WASHER RING, NO. 9	55T	21	1	1	WASHER RING, NO. 10	55T	22	1	1	WASHER RING, NO. 11	55T	23	1	1	WASHER RING, NO. 12	55T	24	1	1	WASHER RING, NO. 13	55T	25	1	1	WASHER RING, NO. 14	55T	26	1	1	WASHER RING, NO. 15	55T	27	1	1	WASHER RING, NO. 16	55T	28	1	1	WASHER RING, NO. 17	55T	29	1	1	WASHER RING, NO. 18	55T	30	1	1	WASHER RING, NO. 19	55T	31	1	1	WASHER RING, NO. 20	55T	32	1	1	WASHER RING, NO. 21	55T	33	1	1	WASHER RING, NO. 22	55T	34	1	1	WASHER RING, NO. 23	55T	35	1	1	WASHER RING, NO. 24	55T	36	1	1	WASHER RING, NO. 25	55T	37	1	1	WASHER RING, NO. 26	55T	38	1	1	WASHER RING, NO. 27	55T	39	1	1	WASHER RING, NO. 28	55T	40	1	1	WASHER RING, NO. 29	55T	41	1	1	WASHER RING, NO. 30	55T	42	1	1	WASHER RING, NO. 31	55T	43	1	1	WASHER RING, NO. 32	55T	44	1	1	WASHER RING, NO. 33	55T	45	1	1	WASHER RING, NO. 34	55T	46	1	1	WASHER RING, NO. 35	55T	47	1	1	WASHER RING, NO. 36	55T	48	1	1	WASHER RING, NO. 37	55T	49	1	1	WASHER RING, NO. 38	55T	50	1	1	WASHER RING, NO. 39	55T	51	1	1	WASHER RING, NO. 40	55T	52	1	1	WASHER RING, NO. 41	55T	53	1	1	WASHER RING, NO. 42	55T	54	1	1	WASHER RING, NO. 43	55T	55	1	1	WASHER RING, NO. 44	55T	56	1	1	WASHER RING, NO. 45	55T	57	1	1	WASHER RING, NO. 46	55T	58	1	1	WASHER RING, NO. 47	55T	59	1	1	WASHER RING, NO. 48	55T	60	1	1	WASHER RING, NO. 49	55T	61	1	1	WASHER RING, NO. 50	55T	62	1	1	WASHER RING, NO. 51	55T	63	1	1	WASHER RING, NO. 52	55T	64	1	1	WASHER RING, NO. 53	55T	65	1	1	WASHER RING, NO. 54	55T	66	1	1	WASHER RING, NO. 55	55T	67	1	1	WASHER RING, NO. 56	55T	68	1	1	WASHER RING, NO. 57	55T	69	1	1	WASHER RING, NO. 58	55T	70	1	1	WASHER RING, NO. 59	55T	71	1	1	WASHER RING, NO. 60	55T	72	1	1	WASHER RING, NO. 61	55T	73	1	1	WASHER RING, NO. 62	55T	74	1	1	WASHER RING, NO. 63	55T	75	1	1	WASHER RING, NO. 64	55T	76	1	1	WASHER RING, NO. 65	55T	77	1	1	WASHER RING, NO. 66	55T	78	1	1	WASHER RING, NO. 67	55T	79	1	1	WASHER RING, NO. 68	55T	80	1	1	WASHER RING, NO. 69	55T	81	1	1	WASHER RING, NO. 70	55T	82	1	1	WASHER RING, NO. 71	55T	83	1	1	WASHER RING, NO. 72	55T	84	1	1	WASHER RING, NO. 73	55T	85	1	1	WASHER RING, NO. 74	55T	86	1	1	WASHER RING, NO. 75	55T	87	1	1	WASHER RING, NO. 76	55T	88	1	1	WASHER RING, NO. 77	55T	89	1	1	WASHER RING, NO. 78	55T	90	1	1	WASHER RING, NO. 79	55T	91	1	1	WASHER RING, NO. 80	55T	92	1	1	WASHER RING, NO. 81	55T	93	1	1	WASHER RING, NO. 82	55T	94	1	1	WASHER RING, NO. 83	55T	95	1	1	WASHER RING, NO. 84	55T	96	1	1	WASHER RING, NO. 85	55T	97	1	1	WASHER RING, NO. 86	55T	98	1	1	WASHER RING, NO. 87	55T	99	1	1	WASHER RING, NO. 88	55T	100	1	1	WASHER RING, NO. 89	55T	101	1	1	WASHER RING, NO. 90	55T	102	1	1	WASHER RING, NO. 91	55T	103	1	1	WASHER RING, NO. 92	55T	104	1	1	WASHER RING, NO. 93	55T	105	1	1	WASHER RING, NO. 94	55T	106	1	1	WASHER RING, NO. 95	55T	107	1	1	WASHER RING, NO. 96	55T	108	1	1	WASHER RING, NO. 97	55T	109	1	1	WASHER RING, NO. 98	55T	110	1	1	WASHER RING, NO. 99	55T	111	1	1	WASHER RING, NO. 100	55T	112	1	1	WASHER RING, NO. 101	55T	113	1	1	WASHER RING, NO. 102	55T	114	1	1	WASHER RING, NO. 103	55T	115	1	1	WASHER RING, NO. 104	55T	116	1	1	WASHER RING, NO. 105	55T	117	1	1	WASHER RING, NO. 106	55T	118	1	1	WASHER RING, NO. 107	55T	119	1	1	WASHER RING, NO. 108	55T	120	1	1	WASHER RING, NO. 109	55T	121	1	1	WASHER RING, NO. 110	55T	122	1	1	WASHER RING, NO. 111	55T	123	1	1	WASHER RING, NO. 112	55T	124	1	1	WASHER RING, NO. 113	55T	125	1	1	WASHER RING, NO. 114	55T	126	1	1	WASHER RING, NO. 115	55T	127	1	1	WASHER RING, NO. 116	55T	128	1	1	WASHER RING, NO. 117	55T	129	1	1	WASHER RING, NO. 118	55T	130	1	1	WASHER RING, NO. 119	55T	131	1	1	WASHER RING, NO. 120	55T	132	1	1	WASHER RING, NO. 121	55T	133	1	1	WASHER RING, NO. 122	55T	134	1	1	WASHER RING, NO. 123	55T	135	1	1	WASHER RING, NO. 124	55T	136	1	1	WASHER RING, NO. 125	55T	137	1	1	WASHER RING, NO. 126	55T	138	1	1	WASHER RING, NO. 127	55T	139	1	1	WASHER RING, NO. 128	55T	140	1	1	WASHER RING, NO. 129	55T	141	1	1	WASHER RING, NO. 130	55T	142	1	1	WASHER RING, NO. 131	55T	143	1	1	WASHER RING, NO. 132	55T	144	1	1	WASHER RING, NO. 133	55T	145	1	1	WASHER RING, NO. 134	55T	146	1	1	WASHER RING, NO. 135	55T	147	1	1	WASHER RING, NO. 136	55T	148	1	1	WASHER RING, NO. 137	55T	149	1	1	WASHER RING, NO. 138	55T	150	1	1	WASHER RING, NO. 139	55T	151	1	1	WASHER RING, NO. 140	55T	152	1	1	WASHER RING, NO. 141	55T	153	1	1	WASHER RING, NO. 142	55T	154	1	1	WASHER RING, NO. 143	55T	155	1	1	WASHER RING, NO. 144	55T	156	1	1	WASHER RING, NO. 145	55T	157	1	1	WASHER RING, NO. 146	55T	158	1	1	WASHER RING, NO. 147	55T	159	1	1	WASHER RING, NO. 148	55T	160	1	1	WASHER RING, NO. 149	55T	161	1	1	WASHER RING, NO. 150	55T	162	1	1	WASHER RING, NO. 151	55T	163	1	1	WASHER RING, NO. 152	55T	164	1	1	WASHER RING, NO. 153	55T	165	1	1	WASHER RING, NO. 154	55T	166	1	1	WASHER RING, NO. 155	55T	167	1	1	WASHER RING, NO. 156	55T	168	1	1	WASHER RING, NO. 157	55T	169	1	1	WASHER RING, NO. 158	55T	170	1	1	WASHER RING, NO. 159	55T	171	1	1	WASHER RING, NO. 160	55T	172	1	1	WASHER RING, NO. 161	55T	173	1	1	WASHER RING, NO. 162	55T	174	1	1	WASHER RING, NO. 163	55T	175	1	1	WASHER RING, NO. 164	55T	176	1	1	WASHER RING, NO. 165	55T	177	1	1	WASHER RING, NO. 166	55T	178	1	1	WASHER RING, NO. 167	55T	179	1	1	WASHER RING, NO. 168	55T	180	1	1	WASHER RING, NO. 169	55T	181	1	1	WASHER RING, NO. 170	55T	182	1	1	WASHER RING, NO. 171	55T	183	1	1	WASHER RING, NO. 172	55T	184	1	1	WASHER RING, NO. 173	55T	185	1	1	WASHER RING, NO. 174	55T	186	1	1	WASHER RING, NO. 175	55T	187	1	1	WASHER RING, NO. 176	55T	188	1	1	WASHER RING, NO. 177	55T	189	1	1	WASHER RING, NO. 178	55T	190	1	1	WASHER RING, NO. 179	55T	191	1	1	WASHER RING, NO. 180	55T	192	1	1	WASHER RING, NO. 181	55T	193	1	1	WASHER RING, NO. 182	55T	194	1	1	WASHER RING, NO. 183	55T	195	1	1	WASHER RING, NO. 184	55T	196	1	1	WASHER RING, NO. 185	55T	197	1	1	WASHER RING, NO. 186	55T	198	1	1	WASHER RING, NO. 187	55T	199	1	1	WASHER RING, NO. 188
PART NO.	QTY. REQ.	P.C. REQ.	DESCRIPTION (QTY., DIM., MTL.)	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
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Fig. A.10. Drawing no. M10191-EM-010-D.

Fig. A.11. Drawing no. M30191-EM-011-D.

Fig. A.12. Drawing no. M10191-EM-012-D.

Appendix B

APPROVAL DOCUMENTS

1. **ORNL Transportation Committee Approval**
2. **Oak Ridge Operations Office (ORO) Approval**

INTRA-LABORATORY CORRESPONDENCE
OAK RIDGE NATIONAL LABORATORY

June 3, 1975

TC 75-1 ✓

To: J. H. Evans, R. V. McCord
From: Transportation Committee
Subject: Approval of SARP for the ORNL HFIR Spent Fuel Element Shipping Cask

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

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

E. M. King

E. M. King, Chairman
Transportation Committee

EMK:bb

cc: Transportation Committee

BLANK PAGE

Form AEC 618
(12-73)
10 CFR 71
AECM1301

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

1a. Certificate Number 5507	1b. Revision No. 6	1c. Package Identification No. USA/5507;H.F. (DWP-OR)	1d. Page No. 1	1e. Total No. Pages 3
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2. PREAMBLE

2a. This certificate is issued to certify Sections 173.302a, 173.304, 173.305, and 173.306 of the Department of Transportation Hazardous Materials Regulations (49 CFR 173-189 and 14 CFR 163) and Sections 146-19-10a and 146-19-10b of the Department of Transportation Dangerous Goods Regulations (49 CFR 146-149), as amended.

2b. The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."

2c. This certificate does not relieve the shipper from compliance with any requirements of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

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

(1) Prepared by (Name and address): Oak Ridge National Laboratory Post Office Box X Oak Ridge, TN 37830	(2) Title and identification of report or application: a. Safety Analysis Report for Packaging (SARP) - HFIR Spent Fuel Element Shipping Cask Report No.: ORNL/ENG/TM-12 (Continued on next page)	(3) Date: November 1977
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4. CONDITIONS

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

5. Description of Packaging and Authorized Contents, Model Number, Freight Class, Other Conditions, and References:

(a) Packaging:

(1) Model: HFIR* Spent Fuel Element Shipping Cask

(2) Description:

Packaging for irradiated fuel elements. The inner cavity is 17 7/8 in. diameter x 32 in. deep. The internal configuration is determined by the type of fuel elements being shipped as follows:

(i) For HFIR fuel elements - a removable post consisting of aluminum wrapped with cadmium is centered in the cavity. The fuel assembly (1 inner element and 1 outer element) is positioned in the cavity by a concentric fuel basket fabricated of stainless steel clad cadmium.

(ii) For ORR (Oak Ridge Research Reactor) type fuel elements which also includes BSR (Bulk Fuel Element Reactor) fuel elements, for PRR (Puerto Rico Research Reactor) fuel elements, and for CP-5 (Chicago Pile No. 5) fuel assemblies - the fuel elements are positioned in the cavity by a magazine fabricated of stainless steel clad cadmium. The center post is removed.

*High Flux Isotope Reactor

6a. Date of Issuance October 18, 1977	6b. Expiration Date FOR THE U.S. ATOMIC ENERGY COMMISSION
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7a. Address of Issuing Office: Department of Energy Post Office Box E Oak Ridge, TN 37830	7b. Signature, Name, and Title of Approving Official: William H. Travis William H. Travis, Director Safety & Environmental Control Division
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3.(2)a. (Continued)

- b. Memorandum from R. M. Moser to William H. Travis, December 30, 1975.
- c. Memorandum from R. M. Moser to William H. Travis, October 27, 1976.

5. (Continued)

- (iii) For PRNC (Puerto Rico Nuclear Center) TRIGA/FLIP type fuel assemblies - the fuel assemblies are positioned in the cavity by a steel, aluminum and elastomer basket. The center post is removed.

Shielding consists of a nominal 8 3/4 in. thickness of lead between 1/2 in. thick stainless steel inner and outer liners. Overall dimensions are 46 3/8 in. diameter x 72 1/2 in. high. Access to the cavity is through a top plug having 14 - 1 1/2 in. alloy steel studs. The gross weight is 23,000 lb.

(3) Drawings:

The cask and modifications are described in Oak Ridge National Laboratory Drawings: W-10191-EL-001-D through -006-D, -007-C, and -008-D through 012-D.

The PRNC TRIGA/FLIP fuel basket is described in Argonne National Laboratory Drawing No.: W-0170-0090-DE-00.

(b) Contents:

(1) Type and Form of Material

Solid, large quantity of radioactive materials, fissile encased in metal cladding as irradiated fuel elements.

(2) Maximum quantity of fissile material per package

- (i) One HFIR irradiated fuel assembly containing up to 9,500 g of ^{235}U as uranium oxide at a ^{235}U enrichment up to 93%.
- (ii) Seventeen ORR-type irradiated fuel elements each containing up to 265 g of ^{235}U as uranium-aluminum alloy at a ^{235}U enrichment up to 93% for a maximum ^{235}U content of 4,505 g.

- (iii) Seventeen irradiated PWR fuel elements each containing up to 192 g of ^{235}U as uranium oxide as a ^{235}U enrichment up to 20% for a maximum ^{235}U content of 3,264 g.
- (iiii) Seventeen irradiated AML-CP-5 fuel assemblies each containing up to 170 grams of ^{235}U as uranium-aluminum alloy at a ^{235}U enrichment up to 93% for a maximum ^{235}U content of 2,890 grams.
- (iiiii) Forty-eight PWR TRIGA/FLIP irradiated fuel assemblies, cooled for at least 30 days, each containing up to 125 grams ^{235}U as a uranium-zirconium hydride mixture, with a ^{235}U enrichment of 70%, for a maximum ^{235}U content of 6,000 grams.

The heat load is ≤ 3.75 kw.

(c) Fissile Class.

III

Appendix C

ELEMENT DRAWINGS:

HFIR-ELEMENT DRAWINGS, ORR ELEMENTS

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Fig. C.4. Drawing no. M-20394-EJ-002-D.

Fig. C.5. Drawing no. M-20394-EJ-001-D.

Fig. C.6. Drawing no. M-20394-EJ-004-D.

Appendix D

DECAY HEAT CALCULATIONS FOR ORR ELEMENT

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

March 11, 1974

TO: F. T. Binford

FROM: T. P. Hamrick

SUBJECT: Determination of Energy Release from a Single ORR Fuel Element
as a Function of Decay Time

In order to determine the energy released from a single ORR fuel element during its decay period prior to shipment for reprocessing, some assumptions must be made regarding its history during reactor operation.

Assumptions

1. The element is assumed to remain in the reactor throughout its life. In reality, the element is cycled in and out of the reactor in various core positions depending on the amount of ^{235}U remaining.
2. The element produces one megawatt of power during reactor operation. In reality, the element produces more at the beginning of life. However, since the element is in a low flux position at beginning of life and a high flux position at end of life, the power produced by the element can be assumed to be constant.
3. The element is in the reactor for one hundred (100) days during its lifetime. This assumption is based on the fact that approximately one hundred twenty (120) grams of ^{235}U has been consumed by burnup and conversion to ^{236}U .

Approach to the Problem

Much has been written regarding the decay of fission products. Advantage was taken of four previous investigations.

Way-Wigner

Way and Wigner suggested a simple expression for the decay of fission products. (1) This expression has been modified as follows: (2)

$$\frac{P}{P_0} = 6.1 \times 10^{-3} [(\tau - \tau_0)^{-0.2} - \tau^{-0.2}]$$

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where P and P_0 can be expressed in any convenient, but identical units, since the ratio is dimensionless. In the expression, $\tau - T_0$ is the time in days after shutdown, i.e., the cooling period, and τ is the total time in days from startup to the end of the cooling time.

Under the assumptions previously listed, the expression can be further modified to:

$$P = 6.1 \times 10^3 [(\tau - 100)^{-0.2} - \tau^{-0.2}] \text{ watts}$$

where P is the energy produced by the fuel element when P_0 is 1.0×10^6 watts. Figure 1 shows the relationship between energy produced and time after shutdown using the Way-Wigner expression.

Perkins and King

Perkins and King's earlier work⁽³⁾ was reproduced in part in the Reactor Handbook⁽⁴⁾, and it was this source that was used. An error in the reproduction of the curves for the decay rates after shutdown of the reactor operating at 1 watt for 1, 10, 100, and 1000 hours was discovered. The curve labeled "D" in the set of curves is listed in the Reactor Handbook as the total disintegration energy which would lead one to believe that the units are Mev/sec-watt as shown in the figures. If one refers to the original article by Perkins and King on page 738 under results, they say:

"The ordinates are labeled Mev/sec, corresponding to energy release; the curve for total disintegration rate is in units of disintegrations per second, using the same numerical scale."

For this reason, new curves were constructed using the total disintegration by adding the total β and the total γ disintegration energies for 1, 10, 100, and 1000 hours of reactor operation prior to shutdown. These curves were combined and extrapolated to form a new curve for 2400 hours (100 days) of reactor operation prior to shutdown. This curve is shown in Figure 2.

Points were read from this extrapolated curve and calculated in the same units as Figure 1. These results are shown in Figure 3. Since accuracy is lost due to reading several points from several graphs and extrapolating, a method of data smoothing was used to obtain the results in Figure 3.⁽⁵⁾

ORNL DWG 77-15608

Fig. 1. Energy release by one ORR fuel element as a function of cooling time after reactor shutdown (Way-Wigner method).

Fig. 2. Decay rate for total energy emitted after shutdown of reactor operating at 1 W for 2400 hr.

Fig. 3. Energy released by one ORR fuel element as a function of cooling time after reactor shutdown (Perkins-King method).

F. T. Binford

-6-

March 11, 1974

Blomeke and Todd

Blomeke and Todd⁽⁶⁾ show the relationship of total fission product power as a function of irradiation time and shutdown time for various thermal neutron fluxes. As in the case of the Perkins and King data mentioned previously, it was necessary to construct a new curve for an irradiation time of 100 days from the graph presented on page 357 of the reference. Since the average flux to which the element is exposed is for all practical purposes near 1×10^{14} n/cm²/sec, this curve was used without modification. The same smoothing method was used as in the case of the Perkins and King data. The results of the analysis are shown in Figures 4 and 5.

Shappert

The final method used by Shappert⁽⁷⁾ consists of a combination of a computer code and experimental data for calculating decay heat. As in the case of Perkins and King and Blomeke and Todd, it was necessary to extrapolate Shappert's curve to a 100-day reactor operating time using Figure 5.1 on page 127 of the reference material. These results are shown in Figure 6.

Comparison of Results

Table 1 shows the comparison of the four methods studied. Figure 7 is a graphical comparison of all the methods studied. The 95% confidence level was calculated using the average of the four methods as the correct result. On this basis, the accuracy of a single determination for any one of the four methods at the 95% confidence level would be:

Way-Wigner	-5 ± 12%
Perkins-King	-6 ± 17%
Blomeke-Todd	+10 ± 5%
Shappert	+2 ± 5%

One can be fairly certain that an ORR fuel element after 100 days decay will be generating 319 ± 52 watts of energy.

Empirically, the energy production can be represented by a 3 half-life mixture

$$P = 705(e^{-0.008105t} + 2.027e^{-0.048462t} + 2.189e^{-0.198t}) \text{ watts}$$

where t is the time after reactor shutdown in days.

T. P. Hamrick

T. P. Hamrick

TPH:aw

cc: C. D. Cagle
W. R. Casto
J. A. Cox

S. S. Hurt
J. H. Swanks
J. H. Evans

Fig. 5. Energy released by one ORR fuel element as a function of cooling time after reactor shutdown (Blomeke-Todd method).

Fig. 6. Energy released by one ORR fuel element as a function of cooling time after reactor shutdown (Shappert method).

Fig. 7. Comparison of the four methods used to determine the energy released by one ORR fuel element as a function of closing time after reactor shutdown following one hundred days of operation.

TABLE 1
Energy Released by One ORR Fuel Element as a Function of Cooling Time
After Reactor Shutdown from 100 Days of Reactor Operation

Cooling Time (Days)	Energy Released (watts)					From Formula Page 13
	Way-Wigner	Perkins-King	Blowke-Todd	Shappert	Average	
10	1466	1922	1784	1800	1743	1743
20	1009	1250	1230	1200	1172	1171
30	785	910	943	893	883	891
40	646	715	771	714	712	716
50	550	582	649	601	596	597
60	479	491	563	518	513	512
70	424	420	493	453	448	448
80	380	361	446	402	397	398
90	344	318	398	354	354	358
100	314	282	360	321	319	323
110	289	255	324	289	289	296
120	267	231	296	269	266	271
130	248	209	272	246	244	243
140	232	192	252	225	225	228
150	217	176	234	210	209	210

REFERENCES

- (1) K. Way and E. P. Wigner, Phys. Rev., 73:1318 (1948).
- (2) S. Glasstone and A. Sesonske, Nuclear Reactor Engineering, pp. 98-100, D. van Nostrand (1963).
- (3) J. F. Perkins and R. W. King, Nuclear Sci. and Eng., 3:726 (1958).
- (4) E. P. Blizard and L. S. Abbot (eds), Reactor Handbook, Volume 3, Part B, Shielding, pp. 27-31, Interscience (1962).
- (5) A. G. Worthing and J. Geffner, Treatment of Experimental Data, p. 6, Wiley (1960).
- (6) J. O. Blomeke and M. F. Todd, Uranium-235 Fission Product Production as a Function of Thermal Neutron Flux, Irradiation Time, and Decay Time. 1. Atomic Concentrations and Gross Totals, p. 357, ORNL-2127, Part 1, Volume 2 (1957).
- (7) L. B. Shappert, Cask Designers Guide - A Guide for the Design, Fabrication, and Operation of Shipping Casks for Nuclear Applications, pp. 125-129, ORNL-NSIC-68 (1970).

Addendum

At full operation, approximately seven elements per month are declared spent at the ORR. This means that after a minimum of 150-days decay, there are, on the average, seven elements with 150-days decay, seven elements with 180-days decay, and three elements with 210-days decay. This gives an overall average decay time of 170-days decay per element. This amounts to an average heat generation rate of 180 ± 30 W per element. Taking the conservative approach and using the upper limit, there will be no more than 210 W generated per element on a shipment of seventeen spent elements. The attached graph shows the decay period of interest. Further, the fuel elements are not left in the reactor for 100 consecutive days but in reality are cycled in and out of the reactor during a six-month period — a fact which adds to the conservatism of this analysis.

ORNL DWG. 77-17020

Fig. 8. Energy release vs decay time for a single ORR fuel element.

PUERTO RICO NUCLEAR CENTER

Operated by the UNIVERSITY OF PUERTO RICO for the U. S. ATOMIC ENERGY COMMISSION

Address reply to: Puerto Rico Nuclear Center, Caparra Heights Station, San Juan, P.R., 00935 — Cable: Nuclear, Puerto Rico

September 20, 1974

Mr. Joseph A. Lenhard, Director
Research and Technical Support Division
Oak Ridge Operations Office
U. S. Atomic Energy Commission
P.O. Box E
Oak Ridge, Tennessee 37830

Dear Mr. Lenhard:

The following information on the irradiated fuel elements stored in the PRNC reactor pool is provided in response to your cable inquiry of September 9, 1974.

Enclosed is a list of fuel assemblies identifying the fuel elements and the total energy generated by each in megawatt-days. We can not state the power generated per element since, during their operating history, each element was operated in several locations within the core in which the power generation rates were different. The average power output per element was 33.3 kilowatts. This information was obtained from the fuel burn-up data in the fuel element operating history ledger.

As seen from the list of fuel assemblies, the last group of fuel elements came out of the core on March 12, 1971. They have been "cooling" down since then for a total of 3-1/2 years. All other elements have longer decay periods.

Assigning the highest peak to average, $\frac{6}{8}$, neutron flux ratio in the core to each element (in order to be conservative for calculation purposes) measured as 1.8 in the one megawatt MTR type core (PRNC 57), we obtain a maximum heat generation rate of 60 kilowatts per element. Using decay heat curves for irradiated elements (infinite reactor operating time; U.S. Reactor Containment Technology, Vol. I, 5.127) we obtain that after a minimum of 3-1/2 year decay the power generation is 0.06% of the original operating power, that is, 36 watts. This number is well below the 210 watts per element limit of the HFIR cask.

Sincerely yours,

Lawrence S. Ritchie
Director

LSR/nc
Incls.

IRRADIATED FUEL ASSEMBLIES

#	<u>Fuel Assembly No.</u>	<u>Last Day in Core</u>	<u>MWD</u>
1	PC-1	3-12-71	339.730
2	PS-3	3-12-71	725.039
3	PS-4	3-12-71	241.911
4	PS-5	3-12-71	541.642
5	PP-5	3-12-71	343.812
6	PC-6	3-12-71	415.310
7	PP-6	3-12-71	104.659
8	PS-7	3-12-71	266.723
9	PC-7	3-12-71	703.577
10	PP-7	3-12-71	104.659
11	PS-8	3-12-71	226.103
12	PS-9	3-12-71	581.956
13	PC-10	3-12-71	62.895
14	PS-11	3-12-71	213.496
15	PS-12	3-12-71	722.166
16	PC-12	3-12-71	30.326
17	PS-15	3-12-71	425.771
18	PS-18	3-12-71	541.322
19	PS-21	3-12-71	182.441
20	PS-24	3-12-71	473.839
21	PS-29	3-12-71	154.659
22	PS-30	3-12-71	104.659
23	PS-33	3-12-71	104.659
24	PS-35	3-12-71	703.577
25	PS-39	3-12-71	703.577
26	PS-40	3-12-71	703.577
27	PS-43	3-12-71	99.504
28	PS-44	3-12-71	99.504
29	PS-47	3-12-71	778.545
30	PS-55	3-12-71	30.602
31	PS-1	12-20-66	303.922
32	PP-1	8-13-69	118.402
33	PS-2	9-11-68	399.926
34	PC-2	3-26-69	526.775
35	PP-2	3-26-69	594.778
36	PC-3	3-26-69	594.645
37	PP-3	3-26-69	529.339
38	PC-4	3-26-69	603.507
39	PP-4	11-27-67	381.902
40	PC-5	7-16-69	97.139
41	PS-6	3-26-69	551.202
42	PC-8	9-3-70	327.819
43	PS-10	9-1-70	248.702
44	PP-10	12-1-69	231.752
45	PC-11	4-23-70	180.819

#	<u>Fuel Assembly No.</u>	<u>Last Day in Core</u>	<u>MWD</u>
46	PP-11	12-9-63	66.912
47	PS-14	12-1-69	122.848
48	PS-16	12-1-69	396.353
49	PS-17	12-10-69	297.760
50	PS-19	3-26-69	563.188
51	PS-20	3-13-67	304.346
52	PS-22	3-26-69	547.290
53	PS-23	12-1-69	599.685
54	PS-25	8-12-69	97.405
55	PS-26	12-10-69	124.419
56	PS-31	4-4-67	95.777
57	PS-32	9-30-65	95.804
58	PS-34	11-21-68	170.523
59	PS-36	3-26-69	526.775
60	PS-37	3-26-69	526.455
61	PS-38	3-26-69	551.766
62	PS-42	8-27-68	253.929
63	PS-45	3-26-69	624.586
64	PS-49	12-1-69	415.424
65	PS-51	2-27-67	251.660
66	PS-52	9-1-70	676.185

Note: Assemblies designated PC are control assemblies.
Assemblies designated PS are standard assemblies.
Assemblies designated PP are partial assemblies.

Appendix E
TEST RESULTS AND MODEL

ORNL Impact Test Description 74-2:
HFIR Cask Top Impact

Purpose

The test outline below will be conducted to establish the response of the HFIR cask (DOT Special Permit 5507) to top impact (with the axis of cask vertical). It is proposed that the cask be modified as shown on the attached sketch (Fig. E.1). The data taken will be used to establish the response of the modified cask in the 30-ft free-fall accident specified in the regulations.¹ Of particular importance is the ability of the plug studs to withstand the dynamic forces while maintaining the primary seal. Calibration data for the ORNL peak recording accelerometer will be taken incidental to the tests.

Model Description

The test model is a 2.35-to-1 scale model of one of the four 4-in. schedule 80 pipes added to the cask pipe fin structure (see Fig. E.1). The model is illustrated in Fig. E.2. Five models and one mounting plate were fabricated and inspected in accordance with this drawing.

Test Procedure

The variable-weight drop hammer will be loaded with 436 lb. This is the 2.3-to-1 scale equivalent of one-fourth the weight of the loaded HFIR cask. The 3000-K load cell will be secured to the impact surface. The instrumentation setup shown schematically in Fig. E.3 will be used to record the force applied to the model with respect to time. The initial length, outside diameter, and wall thickness will be measured and recorded on the attached data sheets. The model will be centered on the load cell and impacted with the free-falling weight from 30 ft. The final deformed length will be measured and recorded on the data sheets. Calibration data for the ORNL recording accelerometer will be taken per test description 73-1 and recorded on the attached supplemental data sheets.

Fig. E.2. HFIR impact test model.

Fig. E.3. Typical load cell hook-up.

 UNION
CARBIDE

INTERNAL CORRESPONDENCE

NUCLEAR DIVISION

POST OFFICE BOX X OAK RIDGE, TENNESSEE 37830

To Name: N. C. Bradley
 Division: R. E. Harris, ORO
 Location: L. B. Shappert
 L. V. Wilson
 R. V. McCord
 R. W. Schaich

Date: April 24, 1974
 Originating Dept.: Experimental Equipment
 Engineering

Answering letter date

Copy to

Subject: Impact Tests 74-1 and 74-2

Ref.: (1) ORNL Impact Test Description
 74-1 LiOH Container Top Impact
 (2) ORNL Impact Test Description
 74-2 HFIR Cask Top Impact

On April 18, 1974, N. C. Bradley and I performed the subject impact tests. Five models per 74-1 and three models per 74-2 were tested. The tests were witnessed by Raymond E. Harris of AEC-ORO. The test results are summarized below in Tables I and II.

Table I. Summary of Test 74-1

Specimen Number	Drop Height ¹ in.	Weight ² Dropped lb	Final Deformation in.	Maximum Acceleration x g
74-1-1	360	125	2.53	190
74-1-2	360	125	2.36	200
74-1-3	360	125	2.26	200
74-1-4	360	125	2.53	200
74-1-5	360	125	2.12	210

Table II. Summary of Test 74-2

Specimen Number	Drop Height ¹ in.	Weight ² Dropped lb	Final Deformation in.	Maximum Acceleration x g
74-2-1	360	425	2.34	--- ³
74-2-2	360	237	1.19	200
74-2-3	360	342	1.77	200

¹Drop height $\pm 1/2$ in.²Includes wt. of specimen mounting hardware.³Acceleration-time record not usable due to use of excessive weight.

Distribution

2

April 24, 1974

Test description 74-1 was followed rather closely. (There were no significant deviation.) Specimens numbered 74-1-1, 74-1-2, and 74-1-4 failed by buckling at about their mid-point. Specimens 74-1-3 and 74-1-5 failed by the weld joining the two angles splitting. It appears that this was because the welds were not complete penetration. A more knowledgeable opinion will be sought to verify this.

There were significant deviations from description 74-2. The load cell data system described was not used. Instead, the system described in 74-1 was used since it was set up, working, and was applicable. After specimen number 74-2-1 was dropped, it was obvious that force required for failure was significantly less than anticipated and that the use of four extended pipes for the HFIR was impractical. It was also probable that the rubber used to secure the model to mounting plate had contributed significantly to the energy absorption. Drop weight was adjusted first to simulate eight pipe extensions for the cask and then to simulate six. After this, the test was suspended and the two untested specimens saved for possible testing at a later date. The data taken will be evaluated to determine if six or eight are practical for the full-size cask. The failure mode for all their specimens was lobar buckling.

The tested specimens are now being photographed.

John H. Evans

JHE:g1

Appendix F

COMPUTER DERIVATIONS

1010 CASK

1005 CASK

1015 CASK

Program 1005 CASK
Derivation of Equations

When a cylindrical cask fabricated from a homogeneous material impacts on its side, the deformation can be approximated as shown in Fig. F.1. The volume V of material displaced, shown shaded in Fig. F.1, is expressed as

$$V = LR^2/2(2\theta - \sin 2\theta) .$$

$$V = R^2L(\theta - \sin \theta \cos \theta) .$$

For this derivation it is assumed that the cask is fabricated from an ideal plastic material; that is, a material which has a stress-strain relationship which can be represented by a horizontal line. For such a material, the product of the specific energy S (the quantity of energy required to displace a unit volume of material) and the volume displaced is equal to the absorbed energy U , as below:

$$U = SV = SR^2L(\theta - \sin \theta \cos \theta) .$$

This equation can be solved by trial and error by assuming values of θ and calculating until

$$U = Wh ,$$

where W is the cask weight and h is the drop height.

The deflection X is

$$X = R(1 - \cos \theta) .$$

The area A at the surface is

$$A = 2LR \sin \theta .$$

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ORNL DWG 74-9725

Fig. F.1. Cask model.

It follows that the force F is

$$F = SA ,$$

and the acceleration a is

$$a = F/M = Fg/W .$$

A computer program can be written to solve these equations for increasing values of θ until the deformation is sufficient for U to equal the cask's potential energy Wh . In this fashion an acceleration deflection and energy history of the impact can be calculated. Also velocity V can be computed from the kinetic energy relationship:

$$U = \Delta KE ,$$

and the lapsed time from the relationship is

$$dt = dv/a .$$

**PTN,L,E,G.

PROGRAM NUMBER 1005-CASK

THIS PROGRAM ANALYZES THE IMPACT OF A CASK HAVING EIGHT
CYLINDRICAL GEOMETRY, IMPACTING WITH ITS AXIS HORIZONTAL, CODED BY
JOHN EVANS P.E., GEN.ENGR. DIV. ORNL, JUNE 1973.

NPIR CASK

GLOSSARY OF NOTATION

X=DEFLECTION(INCHES)
U=ENERGY(LB-INCHES)
P=FORCE(POUNDS)
AG=ACCELERATION(G'S)
V=VELOCITY(FT/SEC)
W=WEIGHT OF THE CASK(POUNDS)
H=DROP HEIGHT(INCHES)
C=CASK LENGTH(INCHES)
R=CASK RADIUS(INCHES)
O=ANGLE SUBTENDED BY THE DEFORMED AREA(RADIANS)
UT-TOTAL POTENTIAL ENERGY OF THE CASK(LB-INCHES)
T=SHELL THICKNESS(IN.)
TH=HEAD THICKNESS,PLUG END(IN.)
TAN=HEAD THICKNESS,BOTTOM END(IN.)
W=CASK WEIGHT(POUNDS)
SL-SPECIFIC ENERGY OF SHIELDING MATERIAL(IN-LB/CU.IN)
SC-SPECIFIC ENERGY OF CLADDING IN COMPRESSION(IN-LB/CU IN)
OO=INCREMENT OF ANGLE O
TH=TIME(SEC.)
G=ACCELERATION(FT/SEC/SEC)
VL=VOLUME OF SHIELDING DISPLACED(CU.IN.)
UH=ENERGY DISSIPATED IN DEFORMING THE HEADS(IN.LB.)
UL=ENERGY DISSIPATED IN DISPLACING SHIELDING(IN.LB.)
ZZ=ENERGY DISSIPATED IN DEFORMING COOLING PINS(IN-LB)

DIMENSION U(1000),X(1000),P(1000),G(1000),AG(1000),TH(1000)

1,AP(1000),V(1000)

ZZ=0.

C INPUT CASK GEOMETRY

T=.500

TAN=.6666

TH=1.32

W=23000.

R=18.75

CL=52.375

C INPUT TEST CONDITION

66 DO 20 NN=1,2

R=36.

IP(WN.EQ. 2) R=360.

C CALCULATE CASK POTENTIAL ENERGY

UT=W*H - ZZ

C INPUT INCREMENT OF ANGLE,O

OO=.01

INPUT MATL. PROPERTIES

SC=120000.

```

DO 326 KC=1,2
SL=6000.
IF(KC.EQ.2) SL=14000
ZERO SUBSCRIPTED VARIABLES
DO 1 I=1,1000
X(I)=0.0
U(I)=0.0
TH(I)=0.0
G(I)=0.0
P(I)=0.
AG(I)=0.0
AP(I)=0.0
V(I)=0.0
1 CONTINUE
C ZERO NONSUBSCRIPTED VARIABLES
UL=0.0
UH=0.0
DT=0.0
TS=0.0
PU=0.0
VV=0.0
JU=0.0
PP=0.0
XX=0.0
O=0.0
V(1)=SQRT((64.*R/12.))
VV=V(1)
DO 2 I=1,1000
IF(I.EQ.1) GO TO 21
O=O+OO
SO=SIN(O)
SOO=SIN(2.*O)/2.
CO=COS(O)
C CALCULATE VOLUME OF SHIELDING DISPLACED
C EQUATION 1
VL=(R*R*CL*(O-SOO))
C CALCULATE ENERGY DISSIPATED IN DISPLACING SHIELDING
C EQUATION 2
UL=SL*VL
C EQUATION 6
QO=O-SOO
C EQUATION 12
VH=(TH+TAH)*R*R*QO
C EQUATION 13
UH=SC*VH
ARL=2.*R*SO*CL
FORL=ARL*SL
ARR=2.*R*SO*(TH + TAH)
FORH=ARR*SC
U(I)=UH + UL
C COMPUTE DEFORMATION
X(I)=R*(1.-CO)
C COMPUTE APPLIED FORCE
P(I)=FORL + FORH
C COMPUTE ACCELERATION
G(I)=(P(I)*32.)/W
AG(I)=P(I)/W

```

10

11

12

17

18

21

19

40

39

38

37

102

EQ. 1

EQ. 2

EQ. 6

EQ. 13

108


```

      IF(U(I).GT.UT) GO TO 7
      COMPUTE VELOCITY
      8 V(I) = SQRT((UT-U(I)) * (64./(N*12.)))
      7 CONTINUE
      COMPUTE LAPSED TIME
      DT=0.
      IF(G(I) .NE. 0.) DT=(VV-V(I))/G(I)
      TS=TS+DT
      TH(I)=TS*1000.
      C COMPUTE PERCENTAGE ENERGY STORED
      PU=U(I)/UT
      21 CONTINUE
      2 XX=X(I)
      UU=U(I)
      VV=V(I)
      PP = P(I)
      IF(U(I).GE.UT) GO TO 4
      2 CONTINUE
      4 CONTINUE
      J=I - 1
      C OUTPUT-WRITE LOOP
      WRITE(51,1009)
      WRITE(51,1009)
      WRITE(51,1002)
      WRITE(51,1008) N
      1008 FORMAT(1H ,25X,'H P I R CASK',P10.3)
      WRITE(51,1002)
      WRITE(51,1009)
      WRITE(51,1009)
      WRITE(51,1002)
      WRITE(51,1004)
      WRITE(51,1002)
      WRITE(51,1005)
      WRITE(51,1006)
      WRITE(51,1002)
      1002 FORMAT(1H0)
      1004 FORMAT(1H ,30X,13HCASK GEOMETRY)
      1005 FORMAT (1H ,4X,6HRADIUS,9X,6HLENGTH,8X,10HSHELL THK.,5X,
      1 9HHEAD THK.,5X,9HHEAD THK.,7X,6HWEIGHT,5X,
      2 15HSPECIFIC ENERGY)
      1006 FORMAT (1H ,4X,6HINCHES,9X,6HINCHES,9X,6HINCHES,9X,6HINCHES,
      1 8X,6HINCHES,8X,6HPOUNDS,7X,11HIN-LB/CU IN)
      WRITE(51,1007) R,CL,T,TH,TAN,W,SI
      1007 FORMAT(1H ,P10.3,4P15.3,P15.1,P12.0)
      WRITE(51,1002)
      WRITE(51,1009)
      WRITE(51,1009)
      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)
      .009 FORMAT(1H, X,49H*****
      1 55H*****

```

114

117

150

151

152

160

161

162

0

2

5

11A 18 8

11B 19 9

11A 18 8

12

13

14

15

17

11A 18 8

```

2      14#####)
      DO 11 I=1,J
      WRITE(51,1003) X(I),V(I),TH(I),P(I),U(I),AG(I)
1003  FORMAT(1H ,F12.4,F13.2,F15.4,F18.2,F16.2,F12.2)
      11 CONTINUE
      CALL QUIKPL(X,AG,J,'LINEAR','J.H.EVANS')
326  CONTINUE
20  CONTINUE
      STOP
      END

```

1007

Program 1015 CASK

Derivation of Equations for Solution of an Impact with the
Cask Equipped with a Toroidal Energy Absorber

When a cask with a toroidal energy absorber which fails in compression (Fig. F.2) impacts an unyielding surface, the deformed surface of the absorber will be as shown in Fig. F.2. For any differential area dA , the applied force dF is

$$dF = \sigma dA = cR \, dR \, d\theta \, ,$$

where

$$\sigma = \text{stress at } dA.$$

There exists an expression such that

$$\sigma = f(\epsilon) = f(X_a/L_a) \, ,$$

where

$$\epsilon = \text{strain},$$

$$X_a = \text{deflection at } dA.$$

It can be written

$$X = y \tan \alpha = \tan \alpha (R \cos \theta - R_0 \cos \phi) \, .$$

Since

$$\sigma = f[\tan \alpha (R \cos \theta - R_0 \cos \phi)/L_a] \, ,$$

and

$$dF = f[\tan \alpha (R \cos \theta - R_0 \cos \phi)/L_a] R \, dR \, d\theta \, .$$

Fig. F.2. Cask model.

The total force F is

$$F = \int_{R=R_1}^{R=R_u} \int_{\theta=0}^{\theta=\phi} f[\tan \alpha(R \cos \theta - R_0 \cos \phi)/L_a] R dR d\theta .$$

The differential energy dU is

$$dU = dF X_a .$$

Total energy U is

$$U = \int_{R=R_1}^{R=R_0} \int_{\theta=0}^{\theta=\phi} \tan \alpha(R \cos \theta - R_0 \cos \phi) f \\ \times \{ \tan \alpha[R \cos \theta - R_0 \cos \phi/L_a] R dR d\theta \} .$$

If these summations are effected for increasing values of ϕ until a value of ϕ is found such that the energy U equals the cask's potential energy, a force and energy vs deformation history of the impact can be estimated. Other impact parameters such as acceleration, velocity, etc., are estimated using the basic principles of applied mechanics. The following FORTRAN program effects these summations and other calculations.

**PT1.L.E.G.

PROGRAM 1015 CASK

C THIS PROGRAM COMPUTES THE RESPONSE OF A RIGID CASK EQUIPPED WITH AN ENERGY,
C ABSORBER WHICH DEFORMS IN PURE COMPRESSION. THE CASK IMPACTS AT AN ANGLE
C SUCH THAT THE POINT OF IMPACT AND THE CENTER OF GRAVITY OF THE CASK ARE IN
C A VERTICAL PLANE. CODED BY JOHN EVANS P. E. OAK RIDGE NATIONAL LABORATORY
C AUGUST 1974

GLOSSARY OF NOTATION

C
C EE=AMOUNT STRAIN IS INCREMENTED-IN./IN.
C DEP=ABSORBER DEFORMATION IN.
C DU=DIFFERENTIAL ENERGY IN.LB.
C FORCE=FORCE LB.
C ENER=ENERGY DISSIPATED IN DEFORMING THE ABSORBER IN.LB.
C ACC=ACCELERATION X G
C STL=STEEL MILD OR LOW CARBON
C SST=STAINLESS STEEL 300 SERIES
C ALUM=ALUMINUM TYPE 6061-T6
C DE=STRAIN IN./IN.
C DS=STRAIN IN./IN.
C ANATI=ABSORBER MATERIAL
C WT=CASK WEIGHT LB.
C A,B,C,D,E,G,H,O,P,Q,R=CONSTANTS IN THE STRESS EQUATION
C AB,AC=CONSTANTS IN THE STRAIGHT LINE STRESS EQUATION
C HT=CROF HEIGHT IN.
C UT=CASKS TOTAL POTENTIAL ENERGY IN.LB.
C ANGL=ANGLE AT POINT OF CALCULATION ON THE ABSORBER
C RO=OUTSIDE RADIUS OF THE ABSORBER IN.
C RI=INSIDE RADIUS OF THE ABSORBER IN.
C CL=OVERALL CASK LENGTH INCLUDING THE ABSORBER IN.
C DA=AMOUNT ANGL (ANGLE) IS INCREMENTED
C RAL=CASK RADIUS IN.
C ZL=DISTANCE FROM POINT OF IMPACT ON THE ABSORBER TO
C CASK CENTER OF GRAVITY IN.
C AL=ACTIVE LENGTH OF THE ABSORBER IN.
C DR=AMOUNT RADIUS IS INCREMENTED IN.
C ALPH=ANGLE CASK AXIS MAKES WITH THE VERTICAL.
C THETA=ANGLE AT POINT OF CALCULATION, MEASURED FROM
C RADIUS THROUGH POINT OF FIRST IMPACT
C RR=RADIUS AT POINT OF CALCULATION IN.
C STRES=STRESS PSI
C SSI=INTEGRAL OF THE STRESS EQUATION
C DAREA=DIFFERENTIAL AREA SQ:IN.
C DU=DIFFERENTIAL ENERGY IN.LB.
C DFOR=DIFFERENTIAL FORCE LB.

C
C DIMENSION DEF(500),FORCE(500),ACC(500),ENER(500),ANGL(500)
1000 FORMAT(1H ,8X,'B F I R CASK - IMPACT ON TCP CORNER')
1001 FORMAT (1H0)
1002 FORMAT(1H ,1X,49H*****
1 55H*****
2 14H*****)
1003 FORMAT(1H ,23X,24HENERGY ABSORBER GEOMETRY)
1004 FORMAT(1H ,11X,14HOUTSIDE RADIUS, 6X,13HINSIDE RADIUS,6X,
1 14HABSORBER DEPTH)
1005 FORMAT(3F20.3)
1006 FORMAT (1H ,16X,33HCASK GEOMETRY AND TEST CONDITIONS)

```

1007 FORMAT(1H ,12X,11BCASK WEIGHT,3X,11BCROP HEIGHT,3X,9HPOTENTIAL,
1      X, 6HEENERGY)
1008 FORMAT(1H ,F21.1,F14.1,F17.1)
1009 FORMAT(1H , 1X,12HACCELERATION,2X,11HCEFORMATION,6X,5HFORCE,6X,
1      5HANGLE,8X,6HEENERGY)
1010 FORMAT(1H , 5X,3HX 6,10X,6HINCHES, 9X,4HIBS.,7X,7HDEGREES,
1      9X,5HIB-IN)
1011 FORMAT(1H ,F10.1,F13.3,F16.1,F12.1,F12.1)
      STL=2.0
      SSI=1.0
      ALUM=3.0
60 EE=.005
      DS=0.0
      RO=18.69
      RI=18.00
      CL=72.0
      RAD=18.75
      WT=23000.
      ZL=40.5
      AL=4.0
      DA=.01
      ALPH=ATAN((RAC)/ZL)
C INPUT CROP HEIGHT
      HTA=48.
      IF(HT.GE.10000.) HTA=36.0
      IF(WT.GE.20000.) HTA=24.0
      IF(HT.GE.30000.) HTA=12.0
      HTB=360.
      ANATL=STL
C BUILD STEEL COEFFICIENTS
      IF(ANATL.NE.2.0) GO TO 6
      A=-4.36337724E+02
      B=3.52674012E+C6
      C=-5.84344912E+07
      D=8.44752080E+08
      E=-1.00790838E+10
      F=8.32241264E+10
      G=-4.42875864E+11
      H=1.50685484E+12
      O=-3.25535392E+12
      P=4.51754272E+12
      Q=-3.20487884E+12
      R=1.01910658E+12
      AA=0.5
      AB=345000.
      AC=73000.
6 CONTINUE
      IF(ANATL.NE.1.0) GO TO 5
C STAINLESS STEEL COEFFICIENTS
      A=-6.60046824E+02
      B=3.27884020E+06
      C=-1.74360076E+C8
      D=5.78280072E+C9
      E=-9.29116096E+10
      F=8.46509048E+11
      G=-4.79173280E+12
      H=1.75760146E+13

```

```

O=-4.20115552E+13
P=6.33579656E+13
Q=-5.48432768E+13
R=2.07901540E+13
AA=0.35
AB=642000.
AC=50300.
5 CONTINUE
IF (AMATL.NE.3.0) GO TO 12
A=-2.37529992E+02
B=8.77222216E+05
C=-2.10395908E+07
D=7.92526976E+08
E=-1.19710816E+10
F=9.28522728E+10
G=-4.24976496E+11
H=1.21919694E+12
Q=-2.22403424E+12
P=2.51118460E+12
Q=-1.60332062E+12
R=4.43286884E+11
AA=0.5
AB=209100.
AC=27900.
12 CONTINUE
DH= ((EO-RI)/10.)
SUMU=0.0
DS=0.
DO 20 M=1,2
HT=HTA
IF (M.EQ. 2) HT=HTB
DO 56 I=1,500
DEF (I)=0.0
FORCE (I)=0.0
ACC (I)=0.0
ENEE (I)=0.0
56 ANGI (I)=0.0
UT=UT+HT
DO 50 I=1,500
IF (I.EQ.1) GO TO 50
PHI=CA*FLOAT (I)+.1
DEF (I)=RO*(1.-COS (PHI))*TAN (ALPH)
ANGI (I)=PHI*57.3
SUMF=0.0
SUMT=0.0
DO 51 JJ=1,500
THETA=DA*FLOAT (JJ)
IF (TBETA.GE.PHI) GO TO 54
DO 52 KK=1,10
RR=EO-(DR*(FLOAT (KK)+.5))
DAREA=(RR*DE*DA)
Y= ((ER*COS (THETA))- (RO*COS (PHI)))*TAN (ALPH)
IF (Y.LE.0.0) GO TO 53
DS=Y/AL
C SIBBS EQUATION
IF (DS.GT.AA) GO TO 21
STRS=A+ (B*DS)+ (C*DS*DS)+ (D*(DS**3.))+ (E*(DS**4.))+ (F*(DS**5.))+

```



```

1 (G*(DS**6.))+(H*(DS**7.))+[O*(DS**8.))+[P*(DS**9.))-
2 (Q*(DS**10.))+[R*(DS**11.))
C INTEGRAL OF THE STRESS EQUATION
SSI=A*DS+[(B*DS*DS)/2.]+[(C*(DS**3.))/3.]+[(E*(DS**4.))/4.]+
1 [(F*(DS**5.))/5.]+[(P*(DS**6.))/6.]+[(G*(DS**7.))/7.]+
2 [(H*(DS**8.))/8.]+[(O*(DS**9.))/9.]+[(P*(DS**10.))/10.]+
3 [(Q*(DS**11.))/11.]+[(R*(DS**12.))/12.)
21 CONTINUE
IF(AS-LE.AA) GO TO 22
C STRAIGHT LINE STRESS EQUATION
STRS=(AB*DS)+AC
C INTEGRAL OF THE STRAIGHT LINE STRESS EQUATION
SSI=(AB*DS*DS)/2.0)+(AC*DS)
22 CONTINUE
C CALCULATE DIFFERENTIAL ENERGY
DU=SSD*BARIA*AL
C CALCULATE DIFFERENTIAL FORCE
DFOB=STRS*BARIA
C SUM FORCE
SUMF=SUMF+DFOB
C SUM ENERGY
SUMU=SUMU+DU
53 CONTINUE
52 CONTINUE
51 CONTINUE
50 CONTINUE
FORCE(I)=SUMF*2.*COS(ALPH)
ACC(I)=FORCE(I)/WT
ENR(I)=SUMU*2.
IF(ENR(I).GE.AL) GO TO 55
IF(ENR(I).GE.UT) GO TO 55
50 CONTINUE
55 CONTINUE
J=I
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1001)
WRITE (6,1000)
WRITE (6,1001)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1001)
WRITE (6,1003)
WRITE (6,1001)
WRITE (6,1004)
WRITE (6,1001)
WRITE (6,1005) NO,RL,AL
WRITE (6,1001)
WRITE (6,1002)
WRITE (6,1001)
WRITE (6,1006)
WRITE (6,1001)
WRITE (6,1007)
WRITE (6,1001)
WRITE (6,1008) WT,UT,UT
WRITE (6,1001)
WRITE (6,1002)

```

```

WRITE (6,1002)
WRITE (6,1001)
WRITE (6,1009)
WRITE (6,10C1)
WRITE (6,1010)
WRITE (6,1001)
DO 10 I=1,200
WRITE (6,1011),ACC(I),DEF(I),FORCE(I),ANGL(I),ENER(I)
IF (I-GE-J) GO TO 11
10 CONTINUE
11 CONTINUE
WRITE (6,1001)
WRITE (6,1001)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1002)
WRITE (6,1001)
WRITE (6,1001)
CALL QWIKPL (DEF,ACC,J,'LINEAR','J.B.EVANS')
CALL QWIKPL (DEF,ENER,J,'LINEAR','J.B.EVANS')
CALL QWIKPL (ACC,ENER,J,'LINEAR','J.B.EVANS')
20 CONTINUE
100 CONTINUE
STOP
END

```

Program 1010 CASK
Derivation of Equations

The program 1010 CASK is used to compute the response of a cask equipped with an energy absorber for which the force deflection relationship is known and an expression exists such that

$$F = f(X) ,$$

where

F = force,

X = deflections.

The program works by computing values of force for assigned values of deflection incremented in equal increments of ΔX , calculating the corresponding energy from the summing expression,

$$U = \sum (F_{n-1} + F_n) \Delta X ,$$

and composing the energy absorbed with the casks potential energy until the energy dissipated equals the potential energy as the absorbers' maximum deflection is reached.

Glossary of Notation

OD	- outside diameter of pipe
THK	- wall thickness
W	- weight
SD	- outside diameter of model
DEFM	- model deformation
SF	- scale factor
DX	- incremental deformation
ANP	- number of pipes
DRH	- drop height
P	- force applied to pipes
Y	- deformation of pipes
E	- energy dissipated
A, B, C, D, F, G, H, AA, BE, CC, DD	- polynomial constants

**FTN,L,H,E,G,A.

PROGRAM 1010 CASK

C

C

THIS PROGRAM COMPUTES THE IMPACT RESPONSE OF 300 SERIES STAINLESS STEEL
C PIPES, IMPACTED PARALLEL TO THE AXIS. BASED ON TEST DATA WITH SCALE FACTORS
C APPLIED. CODED BY JOHN EVANS P.E. OAK RIDGE NATIONAL LABOTORY MAY 1974

C

```

      DIMENSION P(50),Y(50),Z(50),Z(50)
1000 FORMAT(1H,32X,12HWH.P.I.R CASK)
1001 FORMAT(1H,7X,9HPIPE O.D.,7X,9HWALL THK.,8X,6HLENGTH,6X,
1      12HSCALE FACTOR)
1002 FORMAT(1H,2F15.3,2F15.2)
1003 FORMAT(1H,12X,10HDEPLETION,12X,5HFORCE,13X,6HEENERGY)
1004 FORMAT(1H,P20.3,2F20.1)
1005 FORMAT(1H,13X,6HWEIGHT,14X,6HHEIGHT,9X,16HPOTENTIAL ENERGY)
1006 FORMAT(1H,P20.1,P20.2,P20.1)
1007 FORMAT(1H,X,49H*****),
1      1 55H*****),
1      2 14H*****),
1008 FORMAT(1H0)
C INPUT PIPE GEOMETRY
      OD=4.5
      THK=.337
C INPUT WEIGHT AND HEIGHT
      W=23000.
      SD=4.5
      ST=.337
      DIPH=3.25
      SF=((OD/SD)+(THK/ST))/2.
      A=-2505.15268
      B=652918.648
      C=3727206.64
      D=-16252851.8
      Q=27507583.6
      F=-26050928.8
      G=15472004.8
      H=-6033794.88
      LA=1553211.38
      BB=-254827.696
      CC=24146.8376
      DD=-1004.38592
      DX=.1
      ANP=8.
      DO 50 I=1,50
      E(I)=0.0
      Y(I)=0.0
      Z(I)=0.0
50 P(I)=0.0
      DRH=360.
      U=0.
      FP=0.
      XEP=C.
      UT=W*DRH
      WRITE(51,1007)
      WRITE(51,1008)
      WRITE(51,1000)
      WRITE(51,1009)

```

```

WRITE(51,1007)
WRITE(51,1008)
WRITE(51,1001)
WRITE(51,1008)
WRITE(51,1002) OD,THK,CL,SP
WRITE(51,1008)
WRITE(51,1005)
WRITE(51,1009)
WRITE(51,1006) W,DRH,UT
WRITE(51,1008)
WRITE(51,1007)
WRITE(51,1008)
WRITE(51,1007)
WRITE(51,1008)
WRITE(51,1003)
DO 1 I= 1,50
  X=-DX + DX*FLOAT(I)
  SPFO=A+(B*X)+(C*X*X)+(D*(X**3.))+(Q*(X**4.))+(F*(X**5.)) +
1 (G*(X**6.))+(H*(X**7.))+(AA*(X**8.))+(BB*(X**9.))+(CC*(X**10.)) +
2 (DD*(X**11.))
  FORCE=SPFO*ANP
  IF(I .EQ. 1) FORCE=0.
  P(I)=FORCE
  Z(I)=P(I)/W
  DEF=X*SP
  Y(I)=DEF
  DU=((FORCE+PF)/2.)*(DEF-XEF)
  U=U+DU
  Z(I)=U
  PF=FORCE
  XEF=DEF
  WRITE(51,1008)
  WRITE(51,1004) DEF,FORCE,U
  IF(U.GT.UT)GO TO 2
  IF(U.EQ.UT)GO TO 2
  IF(DEF.GE.DEFN) GO TO 2
1 CONTINUE
2 J=Y
  CALL QWIKPL(Y,P,J,'LINEAR','J.H.EVANSS')
  CALL QWIKPL(Y,Z,J,'LINEAR','J.H.EVANSS')
  CALL QWIKPL(Y,E,J,'LINEAR','J.H.EVANSS')
  CALL QWIKPL(E,Z,J,'LINEAR','J.H.EVANSS')
3 CONTINUE
  STOP
  END

```

Appendix G

**OPERATING PROCEDURES AND
INSPECTION CHECKLISTS**

OAK RIDGE NATIONAL LABORATORY
OPERATED FOR U. S. ATOMIC ENERGY COMMISSION BY
UNION CARBIDE CORPORATION
DUNBAR, TENNESSEE

63392

FILE COPY

ONE MOLE, TENNESSEE 37830

INVOICE NO. 2850		SCHEDULED DATE 15-2-74		CUSTOMER'S ORDER NO.		ISOTOPE ORDER NO. S-27-0140	
CHARGE TRANSPORTATION AND HANDLING COST TO A/C 332564-25				SHIP TO E. I. DU PONT DE NEMOURS & COMPANY, INC. SAVANNAH RIVER PLANT DUNBAR, SOUTH CAROLINA ATTN: K. S. KOTI FZC-DZA-215 FOR: TOM BOWEN			
Note: This is not an invoice. Upon receipt of invoice please make checks payable to Union Carbide Corporation, Nuclear Division Contract Acct.							
BILLING INSTRUCTIONS CREDIT 3631 WITH HANDLING COST				ROUTE AND SHIPPING INSTRUCTIONS MOTOR FREIGHT - PREPAID CHARGE 332564-25			
CUSTOMER TYPE		CUSTOMER CODE		FISSILE CLASS III EXCLUSIVE USE OF VEHICLE			
SALE CODE		MATERIAL TYPE SS MATERIAL					
DOT SPECIAL PERMIT NO. SP 5507		FOREIGN APPROVAL NO.					
CONTAINER NO. OS-23-176		CONTAINER WEIGHT 23,000 LBS.					
ORDERED	SHIPPED	DESCRIPTION		UNIT PRICE	EXTENSION		
.2 MEGACURIES		ENRICHED URANIUM, IRRADIATED HFIR ASSEMBLY			N/C		
CHEMICAL FORM		AS SOLID		TECHNICAL SERVICE CHARGE			
BATCH NO.		NORMALITY		HANDLING CHARGE			
				\$75.00			
CONCENTRATION		RADIOCHEMICAL PURITY		CONTAINER DEPOSIT			
VOLUME OR PRODUCT WEIGHT		TOTAL SOLIDS OR		TOTAL AMOUNT			
				\$75.00			
SPECIFIC ACTIVITY		MASS & CHEMICAL ANALYSIS		*Account No.			
REMARKS:		PRODUCED 2270-M/D IN REACTOR 5-11-73 OUT OF REACTOR 6-3-73					
ELEMENTS 89-1 AND 89-0 U WT. 7656 GRAMS U-235 WT. - 6537 GRAMS U-236 WT. 443 GRAMS		APPROVED FOR SHIPMENT BY <i>[Signature]</i>					
WARNING		HEALTH PHYSICS SURVEY OUTSIDE OF PACKAGE SEE ATTACHED IF MORE THAN ONE PACKAGE					
This shipment must not be opened until adequate health and safety measures are taken (such as placed in hood, glove box, cell) so as to protect the handler from excessive exposure to the body as result of radiation and/or contamination.		Radiation at Surface <u>20</u> mrem/h Radiation Three Feet from Surface <u>2.3</u> mrem/h Transport Index <u>2.3</u> Approved for Shipment By <u>[Signature]</u> M. P. GRIFFIN					

CAUTION: NEW DRUG LIMITED BY FEDERAL LAW TO INVESTIGATIONAL USES
THIS MATERIAL HAS NOT BEEN STERILIZED OR TESTED FOR PYROGENIC MATERIAL

9

OAK RIDGE NATIONAL LABORATORY RADIOACTIVE MATERIALS PACKAGING INFORMATION

THIS FORM IS REQUIRED FOR ALL SHIPMENTS GREATER THAN 1 MILLICURIE ALPHA OR 3 CURIES
BETA/GAMMA SOLID, LIQUID, OR GAS AND ALL EMPTY RETURNABLE CONTAINERS

GENERAL INFORMATION	
1. Origin (Division) _____	2. Destination _____
3. Method of Transport _____	4. Weight _____
5. Special Instructions _____	
Special Instructions Complied by _____	
RADIOACTIVE CONTENTS	
1. All major activities in curies and/or grams _____	
2. Specify (a) ☐ Normal Form (b) ☐ Special Form Special Form No. _____	
(c) ☐ Fissile (d) ☐ Non-Fissile	
3. Radioactive Material Form: ☐ Solid ☐ Liquid ☐ Gas	
4. Heat Load (watts): Calculated _____ Estimated _____ By _____	
SHIPPING CONTAINER	
1. Certificate of Compliance No. USA- _____	
2. DOT Specification No. _____ 3. Nuclear Safety Review No. _____	
4. Container determined proper for contents by _____ Date _____	
INTERNAL CONTAINER	
1. Internal Containment: ☐ Glass Bottle ☐ Plastic Bottle ☐ "2R" ☐ Canoseal ☐ Welded Capsule (specify capsule material): _____	
☐ Other (explain) _____	
2. Contamination level on internal container: Estimated _____ Sealed _____	
3. Radiation level from internal container: Measured _____ Calculated _____	
4. Gaskets or seals (valves) properly installed _____ By _____	
5. Leak tests of internal container _____ By _____	
EXTERNAL CONTAINER	
1. Moderator and neutron absorber present for fissile material? ☐ Yes ☐ By _____	
2. External container examination _____ ☐ Yes ☐ By _____	
3. Gaskets or seals properly installed _____ ☐ Yes ☐ By _____	
4. Leak test _____ ☐ Yes ☐ By _____	
5. Bolts torqued to _____ ft. lbs. _____ ☐ Yes ☐ By _____	
6. Tie down to skid checked _____ ☐ Yes ☐ By _____	
7. Tamper seal installed _____ ☐ Yes ☐ By _____	
8. Lid eye bolt removed and wired to the outside of the carrier _____ ☐ Yes ☐ By _____	
RADIATION SURVEY	
1. Surface contamination level: Alpha _____ dpm, β - γ _____ dpm	
2. External radiation level _____ mrem/hr @ contact	
3. Domestic shipments _____ mrem/hr @ 3 ft from surface	
4. Foreign shipments _____ mrem/hr @ 1 meter from center	
5. Health Physics Surveyor _____ Date _____	
TRUCK TIE-DOWN AND SHORING	
1. Tie-down and shoring in accordance with SARP and Designed Layout checked by _____	
(Inspection Engineering) _____	
Shipment Approved By _____	Date _____

LOADING AND SHIPPING PROCEDURE FOR DEPLETED HFIR ELEMENTS

1. As soon as the shipping cask is received, flush the inside thoroughly to the ILW system. The inside volume is approximately 40 gal.; therefore, a flush of approximately 80 gal. is required. This is accomplished by connecting the demineralized water supply to nozzle no. 2 and the ILW drain line to nozzle no. 1 (Fig. E.1).
2. The outside of the cask shall be decontaminated to less than 1000-dpm transferable β - γ and 30-dpm transferable alpha.
3. Arrange the depleted elements in the pool to facilitate their loading.
4. Attach the lifting sling assembly (Appendix A, Fig. A.6) to the 50-ton overhead crane.
5. Attach the cask-lifting sling assembly to the transfer cask, and attach the lid-lifting device. Remove the fourteen 1-1/2-in. lid holddown nuts.
6. Remove the lid and determine that the center Poison post and liner are in the cask and secured in place.
7. Visually inspect the cask gasket; replace if damaged.
8. Lift the assembly 1 in. off the floor and check the rigging to ensure that a proper and adequate hookup has been made.
9. Attach the aluminum disc to the button of the cask.
10. Move the transfer cask to the spent fuel shipping container pad in the west clean pool. CAUTION: When making this move, do not permit the cask to pass over the vessel or any stored elements.

11. Raise the lid to clear and move it aside.
12. Remove the outer element holddown ring with the tool provided.
13. Load the outer element into the cask.
14. Load the inner element and insert the outer element holddown ring. Make sure the cask plug gasket is in place.
15. Replace the transfer cask lid.
16. While continuously monitoring the radiation intensity, slowly raise the transfer cask. Stop raising the cask when it is high enough to permit replacement of the lid holddown nuts.
17. While monitoring the radiation intensity, raise the cask all the way out of the water and rinse it thoroughly with demineralized water.
18. When the cask has dripped dry, transfer it to the decontamination pad while monitoring the radiation intensity.
19. Replace the holddown nuts and torque to 100 ft·lb using a crossing pattern in steps of 50 ft·lb.
20. Perform pressure tests as follows:
 - a. Pressurize the cask lead cavity to 10 psig using nozzle no. 4 (Fig. E.1). Close valve; disconnect air supply. There shall be no detectable loss of pressure after a period of 15 min as measured on pipe plug in nozzle no. 4.
 - b. Pressure-check the cask plug cavity as in a; use nozzle no. 3. Replace pipe plug in nozzle no. 3.
 - c. Pressurize the element cavity to 20 psig using nozzles no. 1 or no. 2 (Fig. E.1). Close valve; disconnect air supply. There shall be no detectable loss of pressure after a period of 15 min.

21. While continuing to monitor the radiation intensity, remove the water from the element cavity to the ILW. This is accomplished by applying 5-psi air pressure at nozzle no. 2 and connecting the ILW drain line to nozzle no. 1. Continue water removal for at least 30 mins. ERDA regulations require that the dose rate at the surface should not exceed 200 millirems/hr nor 10 millirems/hr at a distance of 1 m.
22. Decontaminate the outside of the cask to less than 1,000-dpm β - γ and 30-dpm alpha transferable contamination.
23. Have the Health Physics Division representative check and tag the cask.

PROCEDURE FOR LOADING THE FUEL CASK AT THE ORR

A. Remove the cask from the delivery truck.

1. Place blotting paper on the floor area west of the 2d-level C-zone (an area slightly larger than the base of the cask is adequate).
2. Using the A-frame assembly and the 20-ton overhead crane, remove the cask from the delivery truck and place it on the blotting paper. Ensure that the lifting device is properly attached to the 20-ton hook and that none of the chain lines are twisted (Fig. 3.6a).
3. If removing the cask from the delivery truck is the only objective at this time, remove and store the A-frame lifting assembly. However, if it is anticipated that the cask can be loaded soon after delivery to the ORR, the dam must be installed between the reactor and center pools before the crane is used for the A-frame operation.

B. Prepare the cask for the pool.

1. Have the health physicist check the cask for transferable contamination. NOTE: If the cask is contaminated (that is, >1000 dpm per 100 cm² beta-gamma and/or >30 dpm per 100 cm² alpha), the cask must be cleaned before it is placed in the pool water.
2. Examine the cask for (1) possible damage incurred during transit, (2) radiation-identification and/or other tags, (3) debris, and (4) a wire used to seal the lid. Remove any tags, debris, and/or the wire seal.
3. Remove the nuts securing the top.
4. Inspect the gasket. (CAUTION: To accomplish this, the lid must be raised slightly using the chain hoist on the A-frame; have the health physicist monitor the radiation level of the cavity as the lid is raised.)
5. Inspect the inside of the cask; that is, the ORR fuel element magazine should be in place, secured, and free of damage.

C. Place the cask into the center pool.

NOTE: If applicable, raise the cask 1 in. off the floor to be sure that a proper hookup has been made.

1. Raise the cask to the upper-limit travel of the 20-ton crane.
2. Position the cask over the center pool.
3. Attach a 1-in.-diam rope to the cask top; the remainder of the rope should be placed on the motorized bridge.

Fig. 3.6. Transfer cask.

4. Spray the cask with demineralized water. (This step is found to be somewhat effective in "sealing" the porous metal surface of the cask from the contaminated pool water and, consequently, facilitates the decontamination procedure upon removal.)
5. Slowly lower the cask into the pool until the top of the cask is at about the same depth as the top of the two 7-element storage racks located on the grating. Position the cask as close as practical to the storage racks. (Normally it will be lowered into the pool on the east side then moved westward.) Due to the size of the cask, extreme care must be exercised in manipulating the crane controls for the positioning of the cask. (CAUTION: Ensure that the cask is not allowed to collide with the pool liner or any in-pool equipment. The shift engineer must observe this activity.)
6. Using the chain hoist, raise the cask top until the base of the top plug is about 2 in. above the vertical pipe sections and fins on the cask sides.
7. Secure the 1-in.-diam rope to the motorized bridge and move the bridge eastward until the top is moved away from the mouth of the cask.

D. Load the cask.

1. Place the electrical breaker for the overhead crane in the OFF position (located on the southside walkway of the 3d level). This switch must remain in the OFF position until the 17 elements are loaded and the cask's top plug is positioned over the mouth of the cask.
2. Using the pincer-like swivel tool, raise a fuel element from the 7-element storage rack. Monitor the radiation level at the pool parapet during this step.
3. Identify the element number; it should correspond to one listed under "element number" of the fuel element shipping form.
4. Place the element in one of the 17 positions in the shipping cask basket.
5. Record on the fuel element shipping form (see example) the position in which the element was placed relative to the yellow lifting lug inside the element basket or magazine. (NOTE: The yellow lug location will have to be indicated on the schematic diagram of the basket positions shown on the shipping form.)
6. Repeat steps 2 through 5 until the 17 elements have been loaded into the cask. (CAUTION: Do not attempt to expedite the loading procedure by either transferring more than one fuel piece at a time or by removing the cask's 17-position basket.)

FUEL ELEMENT SHIPPING CASK

The ORR spent 1st element magazine has been inserted in cask _____ ORR Supervisor _____

[illegible]

CARRIER _____

E. Install the top on the loaded cask.

1. Move the motorized bridge westward until the cask top is positioned over the mouth of the cask.
2. Using the chain hoist, lower the cask top into the seated position. (Two guide pins are provided on the cask to facilitate the necessary alignment.)
3. Carefully inspect the cask top for proper seating. If one side appears uneven, raise the lid and repeat step 2.
4. Place the electrical breaker for the overhead crane in the ON position.

F. Remove the loaded cask from the pool.

1. Position the cask in the pool so that it can be raised without obstruction from in-pool equipment. (CAUTION: Ensure that the cask is not allowed to collide with the pool liner or any in-pool equipment. The shift engineer must observe this activity.)
2. Have a health physicist monitor the radiation level of the cask as it is slowly raised from the water. If the radiation level is in excess of 200 millirems/hr at contact, inform the reactor supervisor.
3. As the cask is being raised, rinse it with demineralized water.
4. When access to the cask top is achieved (while standing on the motorized bridge), place the nuts on the studs and secure them, torque to 100 ft·lb in 50-ft·lb increments.
5. Remove the 1-in.-diam rope.
6. Using rags, wipe all surface areas of the cask while it remains suspended over the pool, preferably before it is allowed to dry.
7. Return the cask to its original position in the truck bay; however, leave the cask suspended about 4 ft above the floor level.
8. Have the health physicist obtain a smear of the bottom surface of the base. If the transferable contamination level is <1000 dpm per 100 cm² beta-gamma and <30 dpm per 100 cm² alpha, lower the cask to the floor. If it is contaminated in excess of the specified limits, repeat the cleaning operation of the cask base.
9. Remove the A-frame assembly and return it to storage if applicable (that is, if the cask is not to be shipped relatively soon).

G. Perform pressure tests as follows:

NOTE: See Fig. 3.6 for nozzle location. In each case below, apply air pressure. Close inlet air valve and disconnect air line. Observe gauge. If pressure decreases before end of test period, notify supervision.

1. The cask lead cavity should hold an air pressure of 10 psig for ~15 min. Nozzle no. 5 is used for this test.
2. The plug lead cavity should hold an air pressure of 19 psig for ~15 min. Nozzle no. 3 is used for this test.
3. The element cavity should be pressure-tested at 20 psig for ~30 min. Nozzle nos. 1 or 2 may be used for this test.

H. Purge the pool water from the cavity of the cask.

1. Connect the clear Tygon-hose end of the drainline assembly to the ILW valve located on the north balcony (labeled A2). (NOTE: "Clear" Tygon hose is used for this application to allow the easy viewing of the purged water; however, in order to comply with the requirement of using only "colored" Tygon hose at the ORR to ensure visibility in the event any of the plastic would ever be placed in the pool, a colored-tape wrapping is secured to the hose at various locations.)
2. Remove the cap from the cask's drainline.
3. Connect the other end of the drainline assembly to connection 1 on the cask top (Fig. 3.6b).
4. Ensure that all connections are secure, then open the valve to the ILW system.
5. Remove the cap and plug from the cask's connection no. 2.
6. Connect the end of the air-purge supply line into the cask's top vent.
7. Connect the other end of the air-purge supply line to the plant air-supply line (located by the stairway) (Fig. 3.6c).
8. Ensure that all connections are secure. (NOTE: If the connections are not secure, the contaminated pool water will be forced out around the gasket area, and it will recontaminate the cask. In addition, an inadequate purge will be established due to the loss of air pressure.)
9. Adjust the air regulator until the pressure gauge indicates 5 psig. (CAUTION: Do not pressurize the cavity over 5 psig without explanation.)

10. Open the air-supply valve to the cask. At this time water should be observed leaving the cask through the clear Tygon hose.
(CAUTION: The radiation level of the water must be monitored.)
 11. After all the water has been removed (normally after ~10 min the water flow through the clear tubing will cease), purge the cask with dry air for 1/2 hr to remove all water and then close the air-supply valve and verify that the pressure (indicated on the gauge) decreases to zero.
 12. Remove the drainline fitting from the cask and allow the negative pressure of the ILW system to remove any residual water in the Tygon hose.
 13. Install the cask's drainline cap.
 14. Remove the air-supply line from the cask and install the plug and cap. (NOTE: Wrap a piece of pipe tape around the threads of the plug before reinstalling it.)
 15. Place the air-purge and drainline equipment in a plastic bag and return them to the storage box.
- I. Prepare the cask for shipment.
1. Have the health physicist determine the contamination and radiation status of the purged cask. Continue the cleaning operation as needed to decontaminate the cask to the specified limits listed previously. The beta-gamma radiation level, after removing the water from around the fuel pieces, should not exceed 200 millirems/hr at contact anywhere on the cask; if it does, the reactor supervisor should be notified.
 2. Have the health physicist prepare a radiation-identification tag (that is, a Radiation Hazard Materials Transfer tag), and secure it to the cask.
 3. Inform the reactor operations foreman in charge of maintenance that the cask is prepared for shipment from the ORR building, and submit to him the fuel element shipping cask form. He will initiate the arrangements for the transfer of the cask from the ORR building.

HFIR Cask Loading Check List

Date _____

Shipment No. _____

Type Shipment ☐HFIR Element ☐ORR Elements ☐

Other _____

No.	Operation	By	Date
1	Cask visually inspected for external damage		
2	Cavity flushed		
3	Exterior of cask checked for contamination.		
4	Lead Cavity pressure checked		
5	Plug Cavity pressure checked		
6	Cask Cavity Pressure checked		
7	Proper internal in place		
8	Cask gasket inspected and identified as silicone rubber		
9	Rigging Checked		
10	Elements Loaded		
11	Fuel Element Shipping Sheet Completed (required for ORR elements only)		
12	Cask gasket in place		
13	Hold down nuts torqued		
14	Cask Rinsed		
15	Pool Water removed		
16	Exterior contamination checked		
17	Health physics tag in place		
18	Torque plug hold down nuts		
19	Interior of Cask dried.		
20	Cask cavity pressure checked.		

Appendix H

ACCIDENT SHIELDING ANALYSIS

RADIATION SAFETY EVALUATION OF THE HFIR ELEMENT SHIELDED TRANSFER CASK

A study of the radiation safety of the HFIR element shielded transfer cask using the ANISN¹ discrete ordinates transport code and 18-group gamma cross sections was made. For the purpose of this study, a source of gamma rays for a 240-day postirradiation period after 15 days of operation² was used. It was assumed that the relative number of gamma rays at various energies at 15-days exposure would not be significantly different from those at 23-days exposure desired for this study. An infinite cylinder geometry with the gamma source uniformly distributed over the fuel region was assumed since such a representation should give dose rates as great as those obtained from the real cylindrical cask.

The centering post was described for the problem as a homogenized mixture of aluminum, stainless steel, and void. Similarly, the fuel region was made up of homogenized uranium, aluminum, and void. The amount of each material in the homogenized mixture was determined from the volume fractions of that material in the actual cask assembly. Type 304 stainless steel was used for all stainless steel parts. The only damage considered was the loss of melted lead due to a fire.

The same gamma source was used for the undamaged and the damaged casks. Dose rates at the surface and 3 ft from the surface were scaled to a source yielding 10 millirems/hr at 3 ft from the undamaged cask. The results are given in Table 1.

Table 1. Dose rates from HFIR element transfer cask

Condition	At surface (millirems/hr)	3 ft from surface (millirems/hr)
Undamaged	31	10
Damaged	688	222

The dose rates at the surface and at 3 ft from the surface of the damaged cask are about 22 times as high as the rates for the undamaged cask. Since the allowable dose rate for the damaged cask at 3 ft from

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the surface is 1000 millirems/hr as compared with the calculated value of 222 millirems/hr, the cask satisfies the requirements for safety under the conditions assumed for purposes of this evaluation.

References

1. W. W. Engle, *A User's Manual for ANISN*, K-1693 (March 1967).
2. J. H. Evans et al, *Analysis of HFIR Irradiated Fuel Element Shipping Cask*, ORNL/TM-959 (January 1965).

Appendix I
CRITICALITY REVIEW FORMS

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

July 18, 1973

TO: R. G. Affel

SUBJECT: NSR Request 467

NSR Request 467 concerning routine shipments of spent HFIR fuel elements at the HFIR expired in March, 1973. Routine shipments of spent HFIR fuel elements and operating procedures have not changed since Request 467 was approved. Please extend the expiration date of this Request as appropriate.

B. L. Corbett

B. L. Corbett

A. A. Walls

A. A. Walls

BLC:kjf

July 30, 1973

To: Criticality Committee

B. L. Corbett

A. A. Walls

NSR Request 467 is approved to be extended through July, 1975, based on the above statement. Should changes occur in the shipping procedures during that time, this office must be notified.

R. G. Affel

Safety & Radiation Control

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INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

August 29, 1975

TO: R. G. Affel

SUBJECT: NSR Request 467

NSR Request 467 concerning routine shipments of spent HFIR fuel elements at the HFIR expired in July, 1975. Routine shipments of spent HFIR fuel elements and operating procedures have not changed since Request 467 was approved. Please extend the expiration date of this Request as appropriate.

B. L. Corbett
B. L. Corbett

A. A. Walls
A. A. Walls

BLC:kjf

October 17, 1975

To: B. L. Corbett
A. A. Walls

Based on your statement above, NSR 467 is hereby extended for three years, to expire in October, 1978.

R. G. Affel
R. G. Affel
Criticality Committee

cc: Criticality Committee

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

July 12, 1977

JUL 12 1977

TO: G. H. Burger

FROM: S. S. Hurt *S. S. Hurt*

SUBJECT: Renewal of N.S.R.'s Nos. 683, 688, and 747

Please renew the subject NSR's which, correspondingly, pertain to the transfer of fuel from one approved storage facility to another, the BSR underwater fuel racks, and the HFIR carrier for ORR elements.

There have been no changes in equipment used, nor in the procedures related to its use.

SSH:gt

cc: F. T. Binford
R. K. Branam
J. A. Cox
T. P. Hamrick
E. D. Lance
R. V. McCord

August 1, 1977

To: S. S. Hurt
B. L. Corbett

NSRs 683, 688, and ~~747~~ are extended for one year, to expire in August, 1978. This extension is based on the statement that no changes have been made in the equipment or procedures involved in these NSRs.

NSR 747 was replaced by 7851, which is good until January 1979.

J. T. Thomas
J. T. Thomas, Chairman
Criticality Committee

cc: Criticality Committee
J. A. Cox

REQUEST FOR NUCLEAR SAFETY REVIEW

TITLE FOR REFERENCE PURPOSES Routine Shipments of Spent HFIR Fuel Elements			DATE REVIEW REQUIRED March 30, 1970	
DIVISION Operations			BALANCE AREA 26	
DATE OF REQUEST February 27, 1970	BLDG 7910	ROOM OR BING 13	OPERATING AREA 7900	
DESCRIPTION OF EQUIPMENT: (Please attach sketch, engr. dwg. nos., etc. If a shipment, describe the inner container of the bird cage here and give the outer dimensions of the bird cage under "Interaction" in the table below.)				
DIMENSIONS 17 17/64 OD x 31 3/4 in.		ORNL-TM-959 Page 3	VOLUME ~8100 in. ³	SHAPE Cylindrical with two Cd poison cylinders
CHARACTERISTICS OF OPERATION:				
Type & Form of Material 93% ²³⁵ U ₃ O ₈ - Al cermet, Al cladding				
Masses of Fissionable Isotopes 9.4 kg ²³⁵ U - Inner element 2.6 kg				
Concentration or Density of Fissionable Material Inner element has 171 plates with 15.18 g ²³⁵ U per plate Outer element has 369 plates with 18.44 g ²³⁵ U per plate				
Isotopic Enrichment (Wt. %) 93				
Reflecting Materials Stainless Steel and Lead				
Interaction (proximity of other fissionable material) total Lead 9 in. Thickness of cask - 10 in. Steel 1 in.				
PROPOSED PROCEDURE: (Specify, concisely, what procedures or equipment are proposed, or what limits are requested.)				
<p>The HFIR fuel element shipping cask is designed to transport one HFIR fuel assembly from ORNL to the site of the fuel processor. The fuel elements are loaded into the shipping cask in the 20-ft-deep HFIR pool. The northwest section of the center pool is designed as the loading area. This area is 2 ft from the closest fuel storage rack. The elements are loaded into the cask one at a time by first loading the outer element and then the inner element. Two cadmium poison cylinders are provided on an integral part of the shipping cask to assure subcriticality even though a maximum reactivity (new) fuel assembly is loaded into the cask. After loading the elements into the cask and installing the lid, the cask is removed from the pool and a radiation survey is made to assure that the radiation level at the surface of the container is acceptable for shipment. The cask is then decontaminated and loaded for shipment on a truck in the reactor bay. The weight of the cask is 23,000 lbs. Adequate bracing and holding down devices are provided to stabilize the cask while in transit. If it should become necessary to load the inner and outer elements into the cask simultaneously because the elements are stuck together, ¹⁰B poison strips will be used to poison the elements during the loading operation.</p> <p>The Bureau of Explosives No. 1997 has been assigned to this shipping cask.</p> <p>This request is to replace NSR 210.</p>				

SIGNED

J. H. Swank
RADIATION CONTROL OFFICER

SIGNED

B. R. Conkey
REQUESTER

(See reverse side for Recommendations)

RECOMMENDATION

Unless otherwise indicated, the recommendation below expresses general acceptance of the nuclear safety precautions incorporated in this equipment or operation subject to the comments below. This recommendation is based on our present understanding of the procedure or process (whether acquired verbally or in writing) and is subject to review and cancellation.

The Committee has reviewed the cask as described in ORNL-TM-959 and drawings M-16191 EL-G01D-005D and has concluded that the cask meets the requirements for shipment of irradiated fuel elements according to AEC Manual Chapter 0529. In its considerations results of the criticality experiments were reviewed. These experiments indicate the following:

9.4 kg core submerged in water	- 1.5\$
Poison post in center	- 9.0\$
CD sleeve between elements	-12.0\$
Optimum void in post	+ 4.0\$
Steel and lead reflector	+ 2.0\$
Net	-16.5\$

The procedure described is also recommended for approval, but it is suggested that administrative procedure to insure the presence of the cadmium poison be incorporated in the procedures and that copies be submitted to the Committee.

The Committee recommends approval of this request with the understanding that elements requiring boron poisoning or canning be case not covered here.

Oct. 1978

March, 1973

March, 1973

DATE REVIEWED BY COMMITTEE

DATE OF REVIEW EXPIRATION

3/24/70

DATE ISSUED

Jere P. Nichols
CHAIRMAN, CRITICALITY COMMITTEE
Jere P. Nichols

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

NS-747

EXPIRATION DATE
July, 1977

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

(To be completed by the Control Area Supervisor)

TITLE (FOR REFERENCE PURPOSES)		DATE OF REQUEST	DATE REVIEW REQUIRED
HFIR Carrier for 17 ORR Elements		8-1-74	ASAP
CONTROL AREA	CODE NO.	BUILDING ROOM	DIVISION
Transfer Carrier	20	3042	Operations
TYPE AND FORM OF MATERIAL			
ORR type fuel elements			
ISOTOPIC ENRICHMENT (WT. %)			
~93%			
PER ISOLATED BATCH OR UNIT			
QUANTITY OF FISSILE ISOTOPES	265 g ²³⁵ U		
TOTAL IN CONTROL AREA			
TOTAL TO BE PROCESSED			

Concentration or Density of Fissile Material	~24 wt % uranium, remainder aluminum
Spacing of Fissile Units	Refer to attached drawing.
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material	17 units with 9-in. lead reflector
Limit on Moderation	Immersed in light water
Limit on Neutron Absorbers	Internals include four 30 mil thick Cd absorbers between inner rows of element - see attached drawing.
Limit of Volume or Dimensions of Containers	Container dimensions: 37-1/2" OD x 52-3/8" tall with 46-3/8" diameter base plate and superstructure of sixteen vertical 4" schedule 80 pipe struts welded to the carrier OD. The inner cavity is 32" deep x 18-7/8" ID.
THIS REQUEST MODIFIES REPLACES NSR'S NO. _____	

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.

An 3 x 8 array of 64 each 300-g Spert D elements with 0.025 in. thick cadmium between rows was subcritical when spaced 0.5 in. for optimum moderation.¹ The arrangement proposed for 17 each 265-g ORR elements in the HFIR Shipping Cask having 0.030 inch thick cadmium between rows will also be subcritical and is approved for use.

The presence of the cadmium should be verified after construction of the partitions for the cask as part of the Quality Assurance Procedures.

¹E. B. Johnson & R. K. Reedy, "Critical Experiments with Spert-D Fuel Elements," ORNL-TM-1207 (July, 1965)

R. G. Affel for CHAIRMAN, CRITICALITY COMMITTEE

8/27/74

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 0530. This shall include brief descriptions of the process and/or all operations to be performed, plans and procedures for the operations for nuclear criticality safety, and the basic control parameters. Please attach 11 copies of referenced drawings and documents.

The HFIR element shielded transfer cask will receive the 17 place basket (drawing attached) which is equipped with four cadmium-filled dividers between the innermost rows of spaces. So equipped, the HFIR cask will be used to transfer 17 ORR or BSR elements from ORNL to off-site chemical processing plants. The elements shipped are normally depleted (120 g ^{235}U /element) but may contain as much as 265 g ^{235}U /element.

Elements will be transferred under water from approved storage locations to the compartments within the basket, after the basket itself has been placed in the HFIR cask. The elements, minus end fittings, will rest against the perforated plate in the bottom of the basket, and will occupy ~25-1/2" of the available 29-1/2" of head room. After the elements are loaded, the cask lid will be replaced underwater. At this point in the procedure, the basket will be surrounded on all sides by ~9" of lead shielding contained in ~1/2" stainless walls. The water envelope around the fuel will vary in thickness from 4" at the top to less than 1" at selected points on the sides.

ORNL
CRITICALITY COMMITTEE

NSR 747

EXPIRATION DATE

July, 1977

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR	BUILDING
		<i>H. Hunt</i>	3042
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER	DIVISION
		<i>A. G. Hall</i>	<i>Operations</i>

Copy to H. C. Austin

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 7851

EXPIRATION DATE

January, ~~1978~~ 1979**TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS**

(To be completed by the Control Area Supervisor)

TITLE (FOR REFERENCE PURPOSES)

HFIR Carrier for 17 ORR Elements

CONTROL AREA

Transfer Carrier

CODE NO.

20

BUILDING

ROOM

3042

DATE OF

REQUEST

11/12/75

DIVISION

Operations

DATE REVIEW

REQUIRED

1-1-76

TYPE AND FORM OF MATERIAL

ORR type fuel elements

ISOTOPIC ENRICHMENT (WT. %)

~93%

PER ISOLATED BATCH OR UNIT

QUANTITY

OF

FISSILE

ISOTOPES

TOTAL IN CONTROL AREA

300 g ²³⁵U

TOTAL TO BE PROCESSED

17

Concentration or Density
of Fissile Material

~27 wt % uranium, remainder aluminum

Spacing of Fissile Units

Refer to attached drawing.

Proximity and Type of Neutron Reflectors
or Adjacent Fissile Material

17 units with 9-in. lead reflector

Limit on Moderation

Immersed in light water

Limit on Neutron Absorbers

Internals include four 30 mil thick Cd absorbers between inner rows of element - see attached drawing.

Limit on Volume or Dimensions
of Containers

Container dimensions: 37-1/2" OD x 52-3/8" tall with 46-3/8" diameter base plate and superstructure of sixteen vertical 4"

THIS REQUEST MODIFIES, REPLACES NSR NO.

schedule 80 pipe struts welded to the carrier OD. The inner cavity is 32" deep x 18-7/8" ID.

747

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.

Seventeen (17) 300 g elements having 30 mil Cd between rows will be subcritical. (Ref. ORNL-TM-1207). This request is approved.

R. G. Affel for

CHAIRMAN, CRITICALITY COMMITTEE

12/5/75

DATE

PROVISIONS FOR NUCLEAR CRITICALITY SAFETY

(To be completed by the Control Area Supervisor)

Provisions for nuclear criticality safety shall be described below in accordance with Appendices II and III of the AEC Manual Chapter 0530. This shall include brief descriptions of the process and/or all operations to be performed, plans and procedures for the operations for nuclear criticality safety, and the basic control parameters. Please attach 11 copies of referenced drawings and documents.

ORNL
CRITICALITY COMMITTEE

NSR 7851

EXPIRATION DATE
Jan. 1979

RADIATION CONTROL OFFICER	DIVISION	CONTROL AREA SUPERVISOR	BUILDING
		<i>M. Hunt</i>	3042
RADIATION CONTROL OFFICER	DIVISION	RADIATION CONTROL OFFICER	DIVISION
		<i>C. G. Staples</i>	Operations

Appendix J

QUALITY ASSURANCE PROGRAM PLANS

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

October 1, 1974

To: Distribution**Subject:** Quality Assurance Program Plan OP-11481 for the Fabrication
of ORR Spent Fuel Element Storage Magazine

The subject approved plan is transmitted for your information and use.

E. F. Roy

EFR:gc

Enclosure

Distribution: G. A. Bowden
C. D. Cagle
W. R. Casto
J. A. Cox
J. H. Evans ✓
S. S. Hurt
R. H. Jones
J. R. McGuffey
F. H. Neill
G. E. Pierce

QUALITY ASSURANCE PROGRAM PLAN

OP-11481

FABRICATION OF ORR SPENT FUEL ELEMENT STORAGE MAGAZINE

SEP 24 1974

Approved:

Design Engineer

John H. Evans 9-20-74

QAC, Operations

W. H. Hinkle 9-12-74

Project Leader

S. S. Hunt 9/20/74

Laboratory QA Director

F. H. Hinkle 9/26/74Submitted by:

Project Engineer

E. F. Roy 9-12-74

QUALITY ASSURANCE PROGRAM PLAN
FOR THE
FABRICATION OF ORR SPENT FUEL ELEMENT STORAGE MAGAZINE

1. INTRODUCTION

The HFIR spent fuel element shipping cask is a lead filled carrier that meets the standards of DOT for the transportation of depleted fuel elements between the HFIR and its spent fuel element reprocessing plant. This plan is to cover the fabrication of an ORR spent fuel element storage magazine that will fit inside the HFIR cask and further utilize its services.

1.1 Scope

This plan describes the quality assurance requirements and designates the responsibilities for the fabrication of an ORR spent fuel element storage magazine.

1.2 Quality Level

In accordance with ORNL SPP-39 and QA-L-1-102 fabrication shall comply to Quality Assurance Standards Level II. Designation as Quality Level II work is appropriate because the ORR spent fuel element storage magazine when in use will preclude the possibility of a criticality problem.

2. PLANNING

Planning shall be in accordance with ORNL QA procedures and Operations Division supplements.

2.1 Responsibility

The assignment of project responsibility is shown in Figure 1 and Table 1.

- a. Quality assurance planning by Operations Division.
- b. Storage magazine design by the Project Leader and ORNL Engineering.
- c. Technical review by Operations Division personnel not involved in the actual project work. Criticality review by Director's Division Criticality Committee.
- d. Design approval by the Project Leader, the Design Engineer, and the Quality Assurance Coordinator.
- e. Preparation of procurement documents and specifications by the Project Leader and the Design Engineer.
- f. Fabrication by ORNL P&E Division.
- g. All material, weld, and dimensional acceptance by job inspector.
- h. QA audit by Operations Division. Audit to be performed in accordance with ORNL QA-L-8-100 after the fabrication of fuel storage magazine.

2.2 Design and Manufacturing Documentation

The following are required:

- a. Design criteria is on file in Bldg. 1600, Room 229C.
- b. Material specifications.
- c. Design drawing (by ORNL): M-10191-EL-010-D.
- d. Procedures for fabrication and inspection.
- e. Technical review approvals as shown on drawings and/or in writing.

2.3 Nonconformance Documentation

In accordance with ORNL QA-L-6-101 nonconforming items shall be identified. Any nonconformance shall be documented with copies to

Project Leader, participating QAC, and the QAD. Only those nonconforming items approved by Project Leader, Design Engineer, and Operations QAC may be used.

2.4 Quality Records

The following documents are required and are subject to audit.

- a. Design and manufacturing documents (see Section 2.2).
- b. Document control tabulation.
- c. Material certifications, including inspection reports.
- d. Manufacturing and inspection plans.
- e. Reports as required by Inspection Engineering Manual, Sections 2, 3, and 4.
- f. Welding procedures.
- g. Welder qualification test reports if required by the specified welding procedures.
- h. Certification of all test results and test reports.
- i. Dimensional inspection reports as specified and nonconformance reports as required by ORNL QA Manual, Section 6.
- j. Failure and incident reports, if any, as required by ORNL QA Manual, Section 6.

The quality records will be located as shown in Table II.

2.5 Approvals

All manufacturing and inspection plans shall be approved by the Project Leader and the participating QAC before fabrication starts.

3. DESIGN

Design is in accordance with ORNL drawing M-10191-EL-010-D.

The requirements of the following specifications and standards will be met:

- a. ORNL Quality Assurance Program Requirements.
- b. Inspection Engineering Manual.
- c. All specifications as listed in the Document Control Tabulation.

4. PROCUREMENT

Operations Division will be responsible for the procurement of all material. This includes, if required, the preparation of all purchase requisitions and material specifications.

5. FABRICATION

The ORR spent fuel element storage magazine will be fabricated by the ORNL P&E Division.

5.1 Instrument Calibration

All instruments used for measuring and testing of fabricated elements for acceptance shall be calibrated before use in accordance with ORNL QA Procedure QA-L-14-100.

5.2 Final Acceptance

Final acceptance of the storage magazine will be by the Project Leader or his designated representative.

6. STORAGE

The storage magazine will be stored in Bldg. 3042.

Figure 1. Functional Organization Chart
Fabrication of ORR Spent Fuel Element Storage Magazine

When approval of this SARP is received, a quality assurance program plan similar to the preceding document will be prepared for the cask modifications.