Safety Analysis Report
For The
4-45 Shipping Cask

90010002

Submitted By:

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for the
4-45 Shipping Cask

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1.0 GENERAL INFORMATION

1.1 Introduction

This report presents a safeguard evaluation of the design and use of the Whitehead and Kales (W&K) Shipping Cask, Model No. 4-45, for transporting irradiated Peach Bottom Unit No. 1, fuel elements (1-5)* to the Idaho Chemical Processing Plant (ICPP), Idaho Falls, Idaho, or a similar facility. All fuel elements will be individually sealed in aluminum fuel element canisters or aluminum salvage canisters. Salvage canisters may also be transported that may contain various core components, including control rods, fuel elements encased in a removal tool, or fragments of an element, providing that the salvage canisters are not in any way more radioactive or release more decay heat than fuel elements.

All shipments will be made according to Nuclear Regulatory Commission (NRC) and Department of Transportation (DOT) regulations, 10CFR71[6] and 49 CFR171-179[7], respectively, for transporting large quantities of Fissile Class II radioactive materials by motor vehicle assigned for the sole use and will be unloaded from the motor vehicle by the ICPP personnel or other consignee.

Summary

A safety evaluation has been made of the W&K Model No. 4-45 shipping cask (package) in accordance with NRC regulations 10CFR71 and DOT regulations 49CFR171-179. The results of the evaluation indicate that:

(a) The package satisfies the standards specified in Subpart C of 10CFR71

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* References can be found at the end of the text.

(b) Five (5) similar packages (Fissile Class II) may be assembled in accordance with § 71.39 of 10-CFR-Part 71

(c) Radiation dose rates are within the limits specified in § 173.393(j) of 49-CFR-Part 173 for transport in a motor vehicle assigned for sole use.

1.2 PACKAGE DESCRIPTION

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1.2.1 Packaging

A design layout of the W&K Model No. PB-1 shipping cask for transporting irradiated Peach Bottom No. 1 reactor fuel elements is shown in Drawing 9123-0001. The cask has a calculated loaded weight of 62,800 lbs. It has an outer diameter of 42.5 in., an overall length of 191.12 in., including impact limiters, and a width across the trunnions of 50.0 in.

The cask internal cavity is 26.0 in. in diameter and 159.0 in. long. A maximum of 19 canned fuel elements may be positioned within the cavity in the fuel-element basket shown in the drawing.

The cylindrical cask body is constructed with a 0.25-in., 304 stainless-steel cavity liner, a maximum of 6.25-in. chemical lead, a 1.50-in. mild-steel outer shell, and a 0.25-in., 304 stainless-steel overlay. The cavity liner is seam welded and polished to a No. 3 finish. It is welded at both ends to offset cones which form cavities for the end closures. The lead thickness is 5.25 in. from the bottom of the cavity to 24.5 in. above the bottom; it is 6.25 in. thick from 24.5 in. above the bottom to 134.5 in. above the bottom; and it is 5.25 in. thick over the remainder of the length. Since lead shrinks upon solidification, a patented fin arrangement* is used to attach the lead to the inside of the outer shell. The fins bridge the gap between the lead and outer shell and enhance the transfer of heat. A venting device** for the lead cavity prevents a buildup of excessive pressure from either moisture or lead during a fire-temperature excursion. The stepped outer shell is constructed by welding three co-axial, formed and welded, mild-steel cylinders. The overlay is welded to the outer shell at the end of each cylinder, and at cutouts around each trunnion. It is spaced from the outer shell by 1/16-in. spot welded spacers on the outer shell and serves as a heat shield to inhibit lead melting during the hypothetical fire-temperature excursion. A pressure relief plug in the overlay shell prevents a buildup of excessive pressure from moisture.

The end covers have 4.00 in. of chemical lead sandwiched between two 1.50-in. 304 stainless-steel plates. An impact limiter is attached to each end which also serves as a heat shield. The covers are tapered to allow easier alignment during closure under water.

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* Edward Lead Company - U.S. Patent.
** Edward Lead Company - U.S. Patent.

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Guide pins provide final alignment of the cover bolt holes with tapped holes in the ends of the cask body. Twelve 1.25-in. diamter ASTM A325 cadmium-plated steel bolts secure each cover. A silicone-rubber O-ring gasket seal is used between the cask seat at each end to provide secondary containment of the cask contents.

The fuel-element basket is a welded structure of 5-in. I.D. x 5.25-in. O.D. 6061-T6 aluminum alloy tubes spaced in concentric circles. One tube is placed at the center with six tubes positioned around it in a circular array. The outermost circular array contains 12 tubes for a total of 19. The tubes are integrally connected to enhance heat conduction through the basket and to facilitate handling of the basket. A 0.25-in. plate at the bottom of each tube supports the fuel canisters with their tops above the basket and allows ready access and use of the fuel handling fixtures. Five-inch long spacers are inserted in the tubes beneath the shorter fuel-element canisters. Lifting devices which are welded into place between tubes also limit the free motion of the basket in the cask cavity. One-quarter inch thick aluminum plates are welded between the outer tubes to approximate a cylindrical outer surface. The plates are anodized to enhance radiant transfer of heat to the cavity liner. The basket contains no materials intended sole as nonfissile neutron absorbers or moderators.

All heat rejection is accomplished by conduction through the cask walls and radiation and convection from the cylindrical wall of the cask. The cask is designed to operate either wet or dry; however, these shipments are planned to be dry with air as the only heat transfer medium from the contents of the cavity liner of the cask.

Four 8.0-in. diameter lifting and pivoting trunnions are welded to the outer shell. An 0.5-in. thick 304 stainless steel patch plate is welded to the outer shell at each trunnion for added strength. The trunnions permit changing the cask from the horizontal to the vertical position and vice versa with a minimum effort. They also serve as a convenient method of attaching the cask to the transport-vehicle-mounting cradle. The trunnions are hollow and provide protective housings for the drain valves, flush valve, pressure gauge, pressure-relief valve, and valve exhaust filter.* The pressure-relief valve is set at the sea test pressure of 100 psig. Pipe plugs may be used as seals for the pressure gauge, vent and drain lines.

The cask is mounted horizontally and handled during transport in a structural steel cradle that is designed to spread the load. Trunnion sockets on the vehicle-mounting-cradle support and secure the cask trunnions. They allow rotation of the cask from the vertical to the horizontal shipping position. One set of trunnion sockets is adjustable to accommodate changes in the length of the cask due to temperature changes. Pads on the vehicle-mounting cradle provide additional support to the cask when it is in the horizontal position.

An impact limiter is attached to each end cover with four of the twelve 1.25-in. cover bolts in order to limit the impact load on the fuel canisters after an accidental 30-foot drop. The impact limiters are constructed by welding a

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* Since fuel loading is always accomplished under water, a drain system is provided to remove the water after the cover is in place on the cask.

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bundle of 2 1/2 in. nominal diameter x 18 gauge mechanical tubing between 1/4 in. 304 stainless steel plates and enclosing the bundle with a 1/16 in. 304 stainless steel shell as shown on Drawing 9123-0001*. A 4 in. long skirt fits over the cask for added resistance to radial motion in a corner drop.

Construction Specifications

Complete detailed drawings with construction specifications for the W&K Model No. PB-1 shipping cask will be furnished to the cask fabricator. Quality control procedures will be performed by experienced Battelle personnel to verify that construction and material specifications are met. Standard construction specifications and procedures that will be followed are presented in Appendix A, Section 7.

1.2.2 Operational Features

Not applicable.

1.2.3 Contents of Packaging

In accordance with the requirements of § 71.22(b) of 10CFR71, Subpart B, the materials planned for shipment in the W&K Model No. PB-1 Cask are described as follows:

(1) Identification and maximum radioactivity of radioactive constituents.

(a) Irradiated Peach Bottom Unit 1, whole or partial fuel elements, circular in cross section, 3 1/2 inches in diameter and up to 144 inches long, sealed in canisters in a helium atmosphere. In case that the canisters are found not to be leaktight, salvage canisters shall be provided to ensure containment. The maximum U-235 loading of each fuel element is 300 gm and the minimum atom ratio of thorium-232 to uranium-235 is 5.37, except that one such element per package may have a loading of 415 grams U-235 and minimum thorium-232 to uranium-235 atom ratio of 4.0. The maximum enrichment of U-235 shall be 93.5 weight percent.

(b) Solid non-fissile irradiated hardware and neutron source components, maximum weight of contents, including any container shall be 10,000 pounds. As needed, appropriate component spacers shall be used in the cask cavity to limit movement of contents during shipment.

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* Drawing is enclosed.

Transport Group*	Quantity (curies)
II mixed fission products	6.62×10^5
Pa^{233}	4.56×10^5

(2) Identification and Maximum Quantities of Fissile Constituents

The cask filled with 19 unirradiated Peach Bottom No. 1, fuel elements will contain the following fissile constituents:

U-235 . . . . 5529 grams

Irradiated fuel elements will contain uranium-233 and plutonium, but the effective neutron multiplication will be less because of U-235 consumption.

(3) Chemical and Physical Form

The package may contain 19 irradiated Peach Bottom No. 1, fuel elements individually sealed in fuel element canisters or salvage canisters. They will be spaced and supported by the fuel-element basket described by Drawing 9123-0001. Pertinent details of the fuel elements, fuel-element canisters, and salvage canisters are presented in the next section.

(4) Extent of Reflection, Neutron Absorbers, and Moderator Ratio

Reflection, absorption, and moderator characteristics of the package contents are summarized as follows:

Extent of reflection	Maximum reflection
Nonfissile neutron absorbers	None assumed (although fuel elements contain varying amounts of Th-232, Rh-103, and natural boron)
Atomic ratio of moderator to fissile constituents:	C/U-235 1727

(5) Maximum Weight

The maximum weight of the package contents, excluding the fuel-element basket, is 3420 lbs.

(6) Maximum Rate of Decay Heat

The cask and fuel-element basket are designed for a decay energy release rate of 750 Btu/hr-element with 668 Btu-hr-element deposited in the contents of the cask. Thus, the maximum decay heat load in the cask contents may be 12,690 Btu/hr or 3715 watts.

* As defined in § 173.390 of 49 CFR and Appendix C of 10-CFR-71.

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Fuel Element Specifications

The W&K shipping cask, Model No. PB-1, is designed for transporting nineteen Peach Bottom No. 1, fuel elements in either fuel-element canisters or salvage canisters. Specifications of the fuel elements were obtained from the Final Hazards Summary Report(1-5) for the Peach Bottom Atomic Power Station or derived from data obtained from that report. Details of the spent-fuel-element canister were obtained from the same report and the Philadelphia Electric Company(8). Specifications of the salvage canister also were provided by Philadelphia Electric.

Specifications used for these components in these analyses are listed below.

Fuel Elements. The reactor core of Peach Bottom Unit No. 1 contains 804 fuel elements of the same external geometry. Each fuel element is a complete assembly that is handled and located individually within the reactor. There are four different basic types of fuel elements which differ in their uranium, thorium, rhodium, and boron content. Outwardly, each fuel element has the appearance of a solid graphite cylinder 3.50 inches in diameter by 144 inches long, with a grappling knob at the top for handling.

The fuel element shown in Figure 1, consists of an upper reflector section, a fuel-bearing middle section, and a bottom reflector section. The primary components making up the fuel element are a bottom connector, a sleeve, a screen, an internal fission product trap assembly, a lower reflector piece, fuel compacts, spines, burnable poison compacts (in selected elements), a fuel cap, and an upper reflector assembly. Component dimensions used in the design of this shipping cask are given in Table 2.

All components, except the fuel compacts and burnable poison compacts that are placed in the hollow spines of some fuel elements, are made of graphite. The fuel compacts consist of uranium (93.15 percent enriched) and thorium carbide substrate coated in pyrolytic carbon uniformly dispersed as particles in a graphite matrix.

Four types of fuel elements (Types 1, 2, 3, and 4) are required for the Peach Bottom Reactor. The fuel elements are loaded with the four types of fuel compacts and the burnable poison compacts as shown in Table 3 and Figures 2 and 3. Design loadings for four types of fuel compacts (Types A, B, C, and D) are shown in Table 4. The total design loading within the active core is given in Table 5.

The tolerance on loading of thorium is ± 3.5 percent and of uranium is ± 2.5 percent for any completely assembled fuel element. The tolerance for the boron content of poison spines is ± 5 percent in any fuel element, and the tolerance on rhodium loading is ± 20 percent for individual compacts.

Average compositions and densities used in these calculations for the fuel element components are presented in Table 6. These are based on a sleeve density of 1.90 g/cm^3, a spine density of 1.65 g/cm^3, compact densities given in Table 4, and an average fuel-element weight of 90 pounds. The nominal U-235 loading of each Type 1, 2, or 3 fuel-element is 0.291 kilogram.

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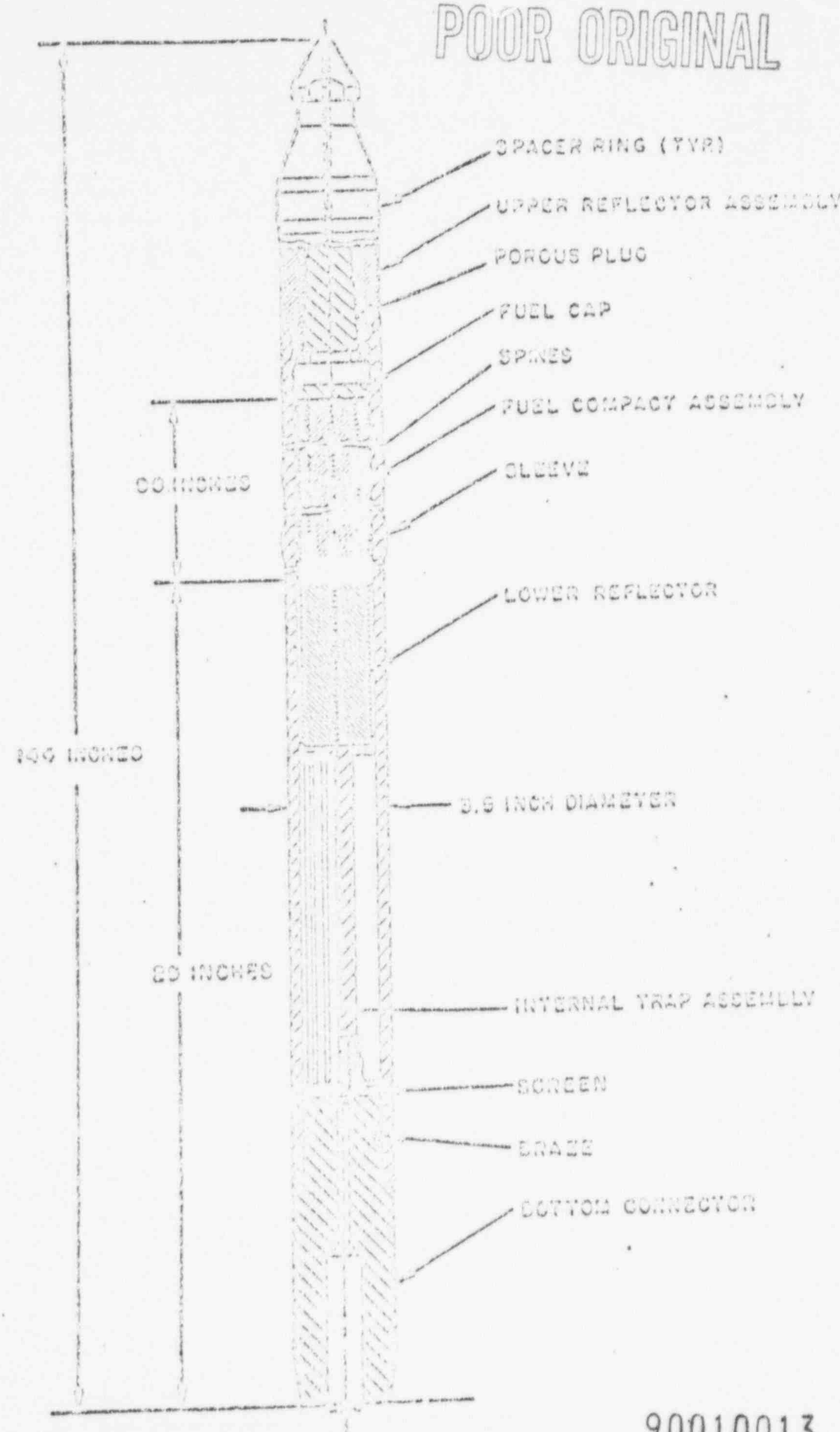

FIGURE 1. FUEL ELEMENT

TABLE 2. FUEL ELEMENT DIMENSIONS

	Axial Dimensions, inches		
Fuel element	0.0	-	144.0
Connector and trap	0.0	-	23.0
Lower reflector	23.0	-	29.0
Fueled section	29.0	-	119.0
Type A compacts	29.0	-	56.0
Type B or C compacts	56.0	-	110.0
Type A compacts	110.0	-	119.0
Upper reflector	119.0	-	129.0

	Diameter, inches	
	I.D.	O.D.
Spine	0.0	1.73
Fuel compacts	1.75	2.74
Sleeve	2.75	3.5

TABLE 3. TYPES OF FUEL ELEMENTS BASED ON NUCLEAR PROPERTIES

	Fuel Element Type			
	1	2	3	4
Description	Heavy Rhodium	Light Rhodium	Light Rhodium with Burnable Poison	Heavy Thorium, Light Uranium
Spine	Solid graphite	Solid graphite	Hollow with poison	Solid graphite
Compact type:				
In upper 9 inches	A	A	A	D
In middle 54 inches	B	C	C	D
In lower 27 inches	A	A	A	D
Number for nominal core loading	54	564	84	102

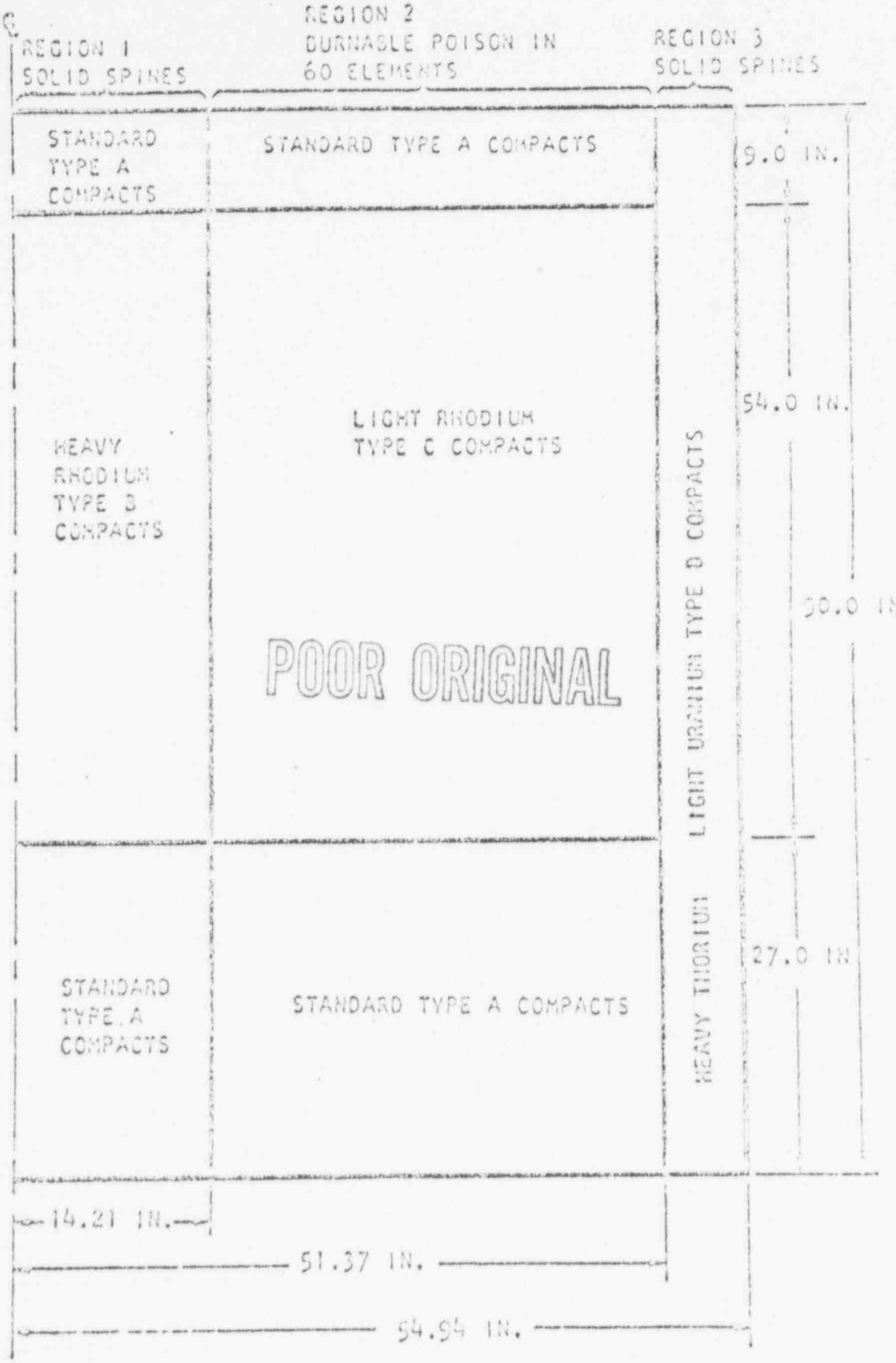

FIGURE 2. CORE ZONING

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∘ ⊙ ◎ 804 Fuel Elements

□ 36 Control Rods

⊠ 19 Emergency Control Rods

Region 1

∘ 54 Heavy Rhodium Elements (Type I Elements)

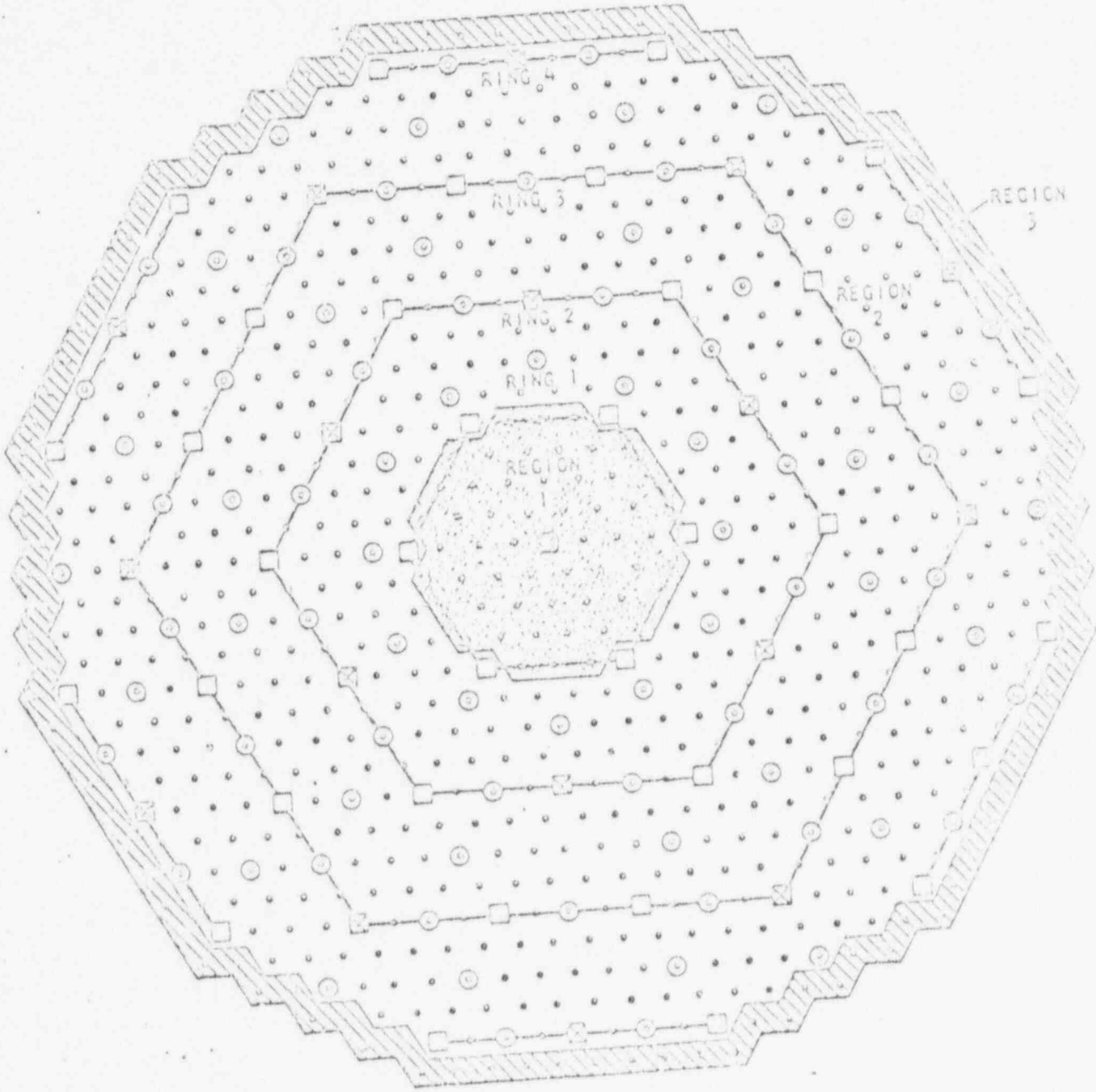
Region 2

∘ 564 Light Rhodium Elements (Type II Elements)

◎ 84 Light Rhodium Elements (Type III Elements)

Region 3

∘ 102 Light Uranium Heavy Thorium Elements (Type IV Elements)



FUEL ELEMENT AND CONTROL ROD POSITIONS

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TABLE 4. FUEL COMPACT LOADINGS
(loading per 3 inch of compact[gm])

Compact Type	A	B	C	D
Description	Standard	Heavy Rhodium	Light Rhodium	Heavy Thorium
Th-232	52.10	52.10	52.10	115.36
U-234 (max)	0.156	0.156	0.156	0.082
U-235	9.70	9.70	9.70	5.14
U-236 (max)	0.052	0.052	0.052	0.028
U-238	0.505	0.505	0.505	0.268
Rh-103	0.	1.028	0.342	0.
Carbon	285.00	285.00	285.00	273.00

TABLE 5. NOMINAL CORE LOADINGS

Description	
Th-232	1450.0 kg
U-234	3.[illegible] kg
U-235	[illegible] 0 kg
U-236	[illegible].18 kg
U-238	11.46 kg
Rh-103	5.00 kg
Boron (natural)	1.10 kg

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TABLE 6. FUEL ELEMENT COMPOSITION

Fuel compacts	See Tables 2 and 3
Spine	Graphite 1.85 g/cm^3
Sleeve	Graphite 1.90 g/cm^3
Lower reflector	Graphite 1.85 g/cm^3
Connector and trap	Graphite 1.57 g/cm^3 average
Upper reflector	Graphite 1.57 g/cm^3 average

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Peach Bottom Reactor No. 1 was operated for 451.5 equivalent days at a full power of 115.5 Mw(t). The fuel elements are designed to generate 112.7 Mw(t) with the remaining 2.8 Mw(t) being produced by nuclear heating in other reactor internals. The power generated in an average fuel element is 140 kw(t). The design peak power generated in a hottest fuel element is approximately 174 kw(t) at 900 days of equivalent full power operation.

Predicted fission density distributions are shown in Figures 4 and 5 for the beginning-of-life and the end-of-life, respectively.

Fuel Element Canisters - Before removal from the reactor building, all fuel elements will be individually sealed in a canister that contains an inert Helium gas atmosphere. The canister is a composite of a 6061-H 112 aluminum alloy outer wall and 1020 mild steel inner liner. The inner liner is 10 .eet long by 1/16 in. thick and has an outer diameter of approximately 4.1 in. The steel liner is provided to add weight so that the cans will not float in the spent fuel pit. An aluminum cap is hermetically sealed to the can by magnetic swagging after the element has been inserted, thus forming a unit with the following outside dimensions: 4.500 ± 0.005 in. O.D. x 12 ft. 8 15/16 ± 1/32 in. The wall thickness is 0.065 in. Design external pressure on the unit is 15 psig. with a can temperature of 500°F. Many of the fuel element canisters will contain a fuel element encased in a special broken element removal tool and a steel liner.

The magnetic swagging process is a closure technique which has previously been tested and found acceptable for sealing the fuel element canister. The results of these tests form part of the data submitted to obtain the HNPF shipping cask license. The HNPF file is available under Docket No. 70-72, Amendments 71-6 and 71-7.

About 1 in. clearance is provided between the top of the "cold" canister and the cask cover. With a fuel element in the canister, the length of the canister will increase over 1/2 in. due to thermal expansion. For the case of the shorter fuel element canisters, a spacer (Drawing N9123-6PB-0001, Area C-2) will be placed in the bottom of the basket. Thus, the design provides for minimal clearance between the canister and the cover for both sizes of canisters.

Salvage Canister - The salvage canister is the same construction and configuration as the fuel element canister except that the unit dimensions are 4.750 ± 0.005 in. x 13 ft. 1 7/8 ± 1/32 in. A leaking fuel element canister will be placed in a salvage canister.

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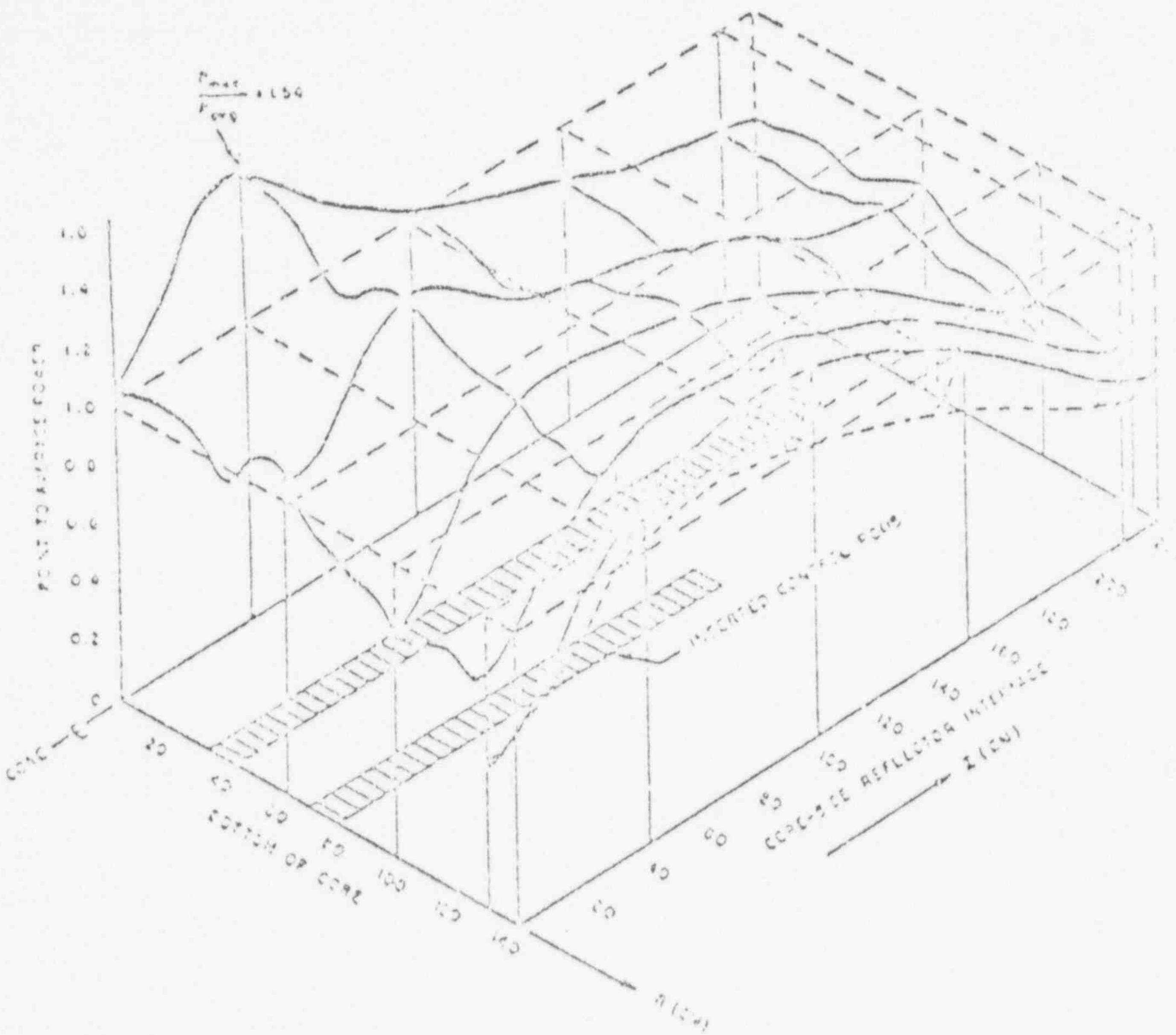

FIGURE 4. [illegible] DENSITY (LOCAL/AVERAGE)(BEGINNING-OF-LIFE, HOT CRITICAL WITH EQUILIBRIUM Xe AND Sm)

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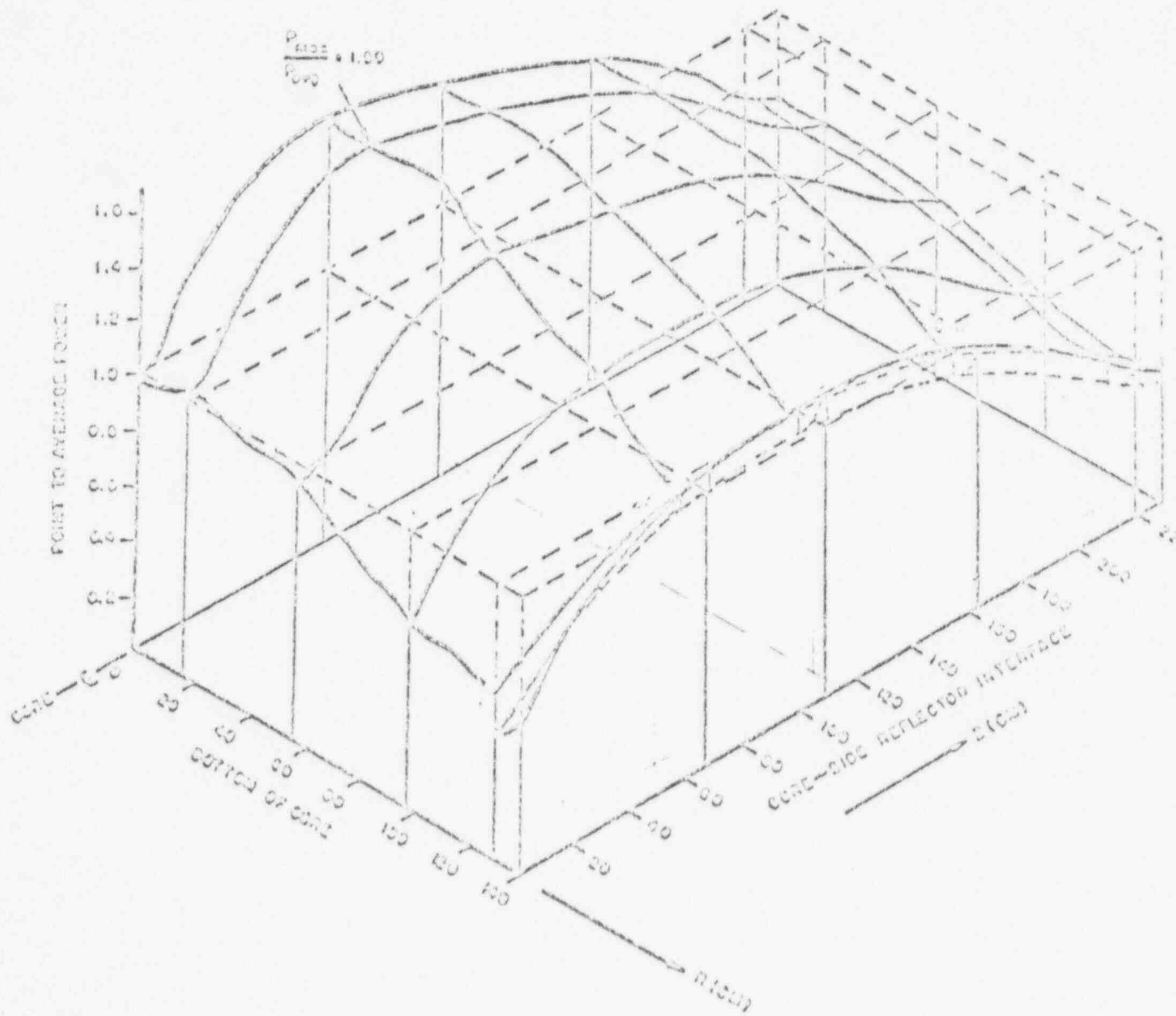

FIGURE 5. FISSION DENSITY (LOCAL/AVERAGE) (END-OF-LIFE, HOT CRITICAL WITH EQUILIBRIUM Xe AND Sm)

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1.3 Appendix

1.3.1 References

(1) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 1", Philadelphia Electric Company, Docket 50171-2 (March 3, 1964).

(2) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 2", Philadelphia Electric Company, Docket 50171-3 (March 3, 1964).

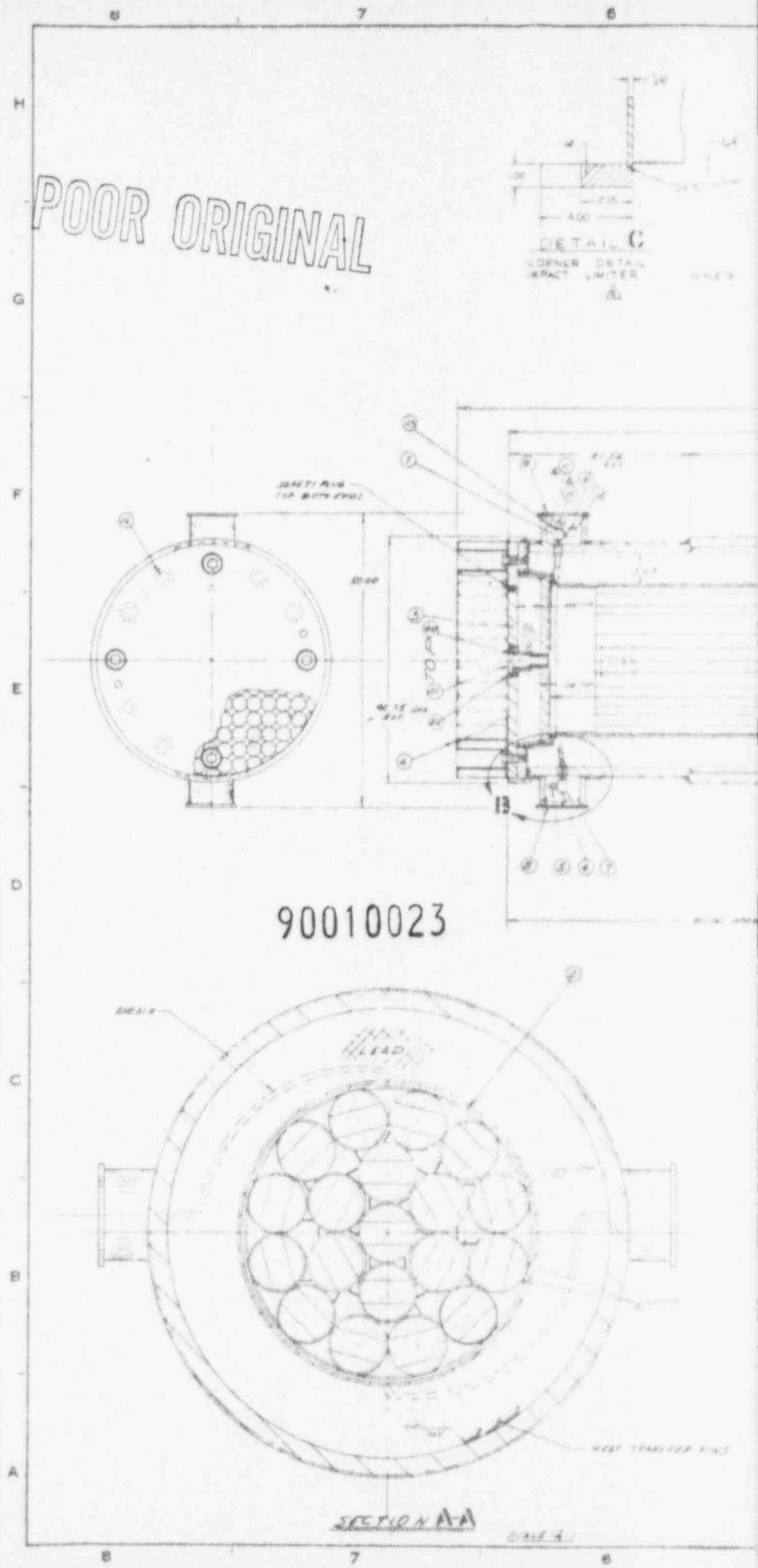
(3) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 3", Philadelphia Electric Company, Docket 50171-4 (March 3, 1964).

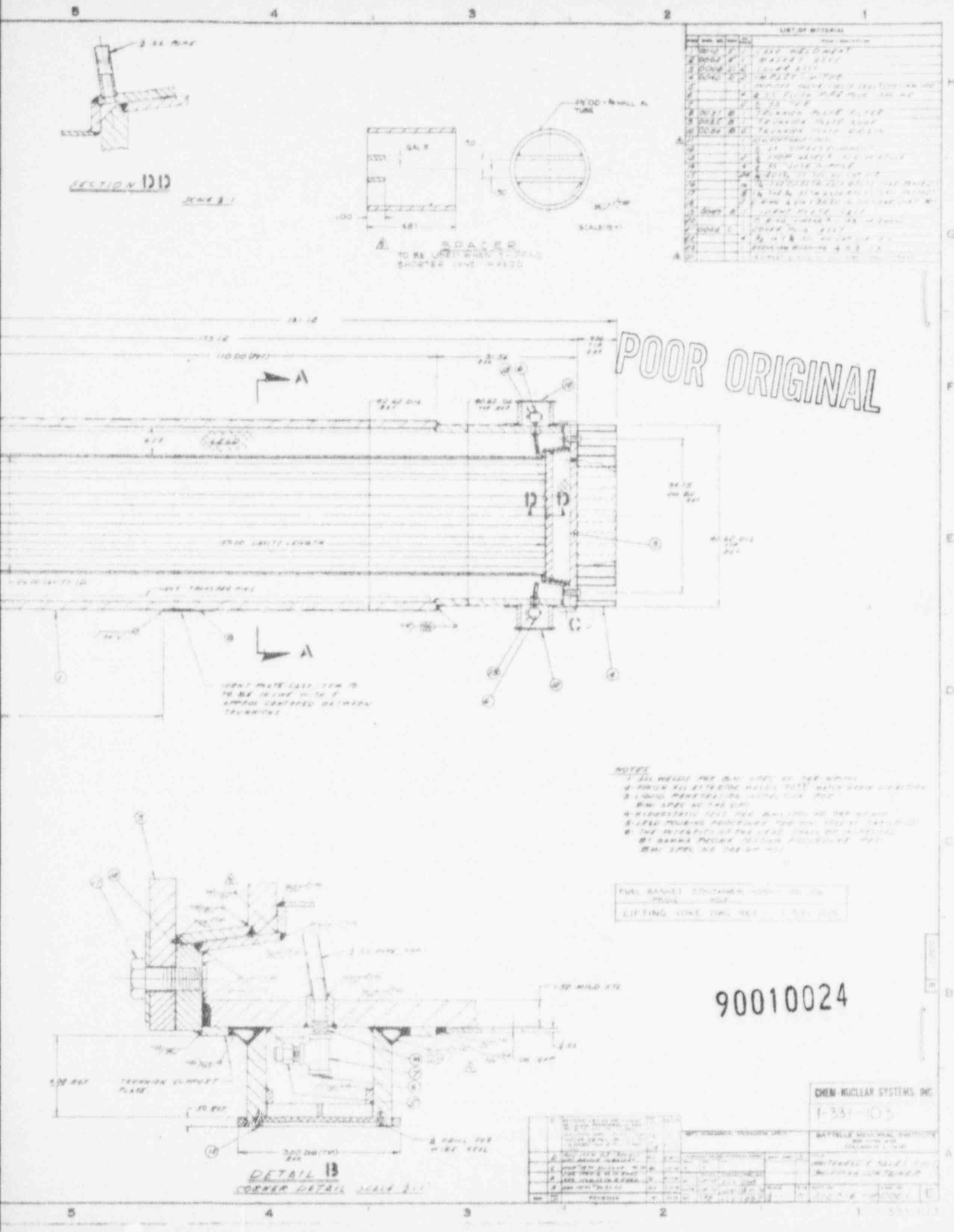
(4) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 4", Philadelphia Electric Company, Docket 50171-5 (March 3, 1964).

(5) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 5", Philadelphia Electric Company, Docket 50171-7 (August 11, 1964).

(6) "Packaging of Radioactive Material for Transport", Code of Federal Regulations, Title 10, Part 71 (December 31, 1968).

(7) "Radioactive Materials and Other Miscellaneous Amendments", Code of Federal Regulations, Title 49, Parts 171-179 (October 4, 1968).


POOR ORIGINAL
DETAIL C
CORNER DETAIL
IMPACT LIMITER
90010023
LEAD
HEAT TRANSFER FINS
SECTION A-A


LIST OF MATERIAL
SECTION D-D
SPACER
POOR ORIGINAL
NOTES
DETAIL B
CORNER DETAIL
CHEM-NUCLEAR SYSTEMS, INC.
1-331-103
BATTELLE MEMORIAL INSTITUTE
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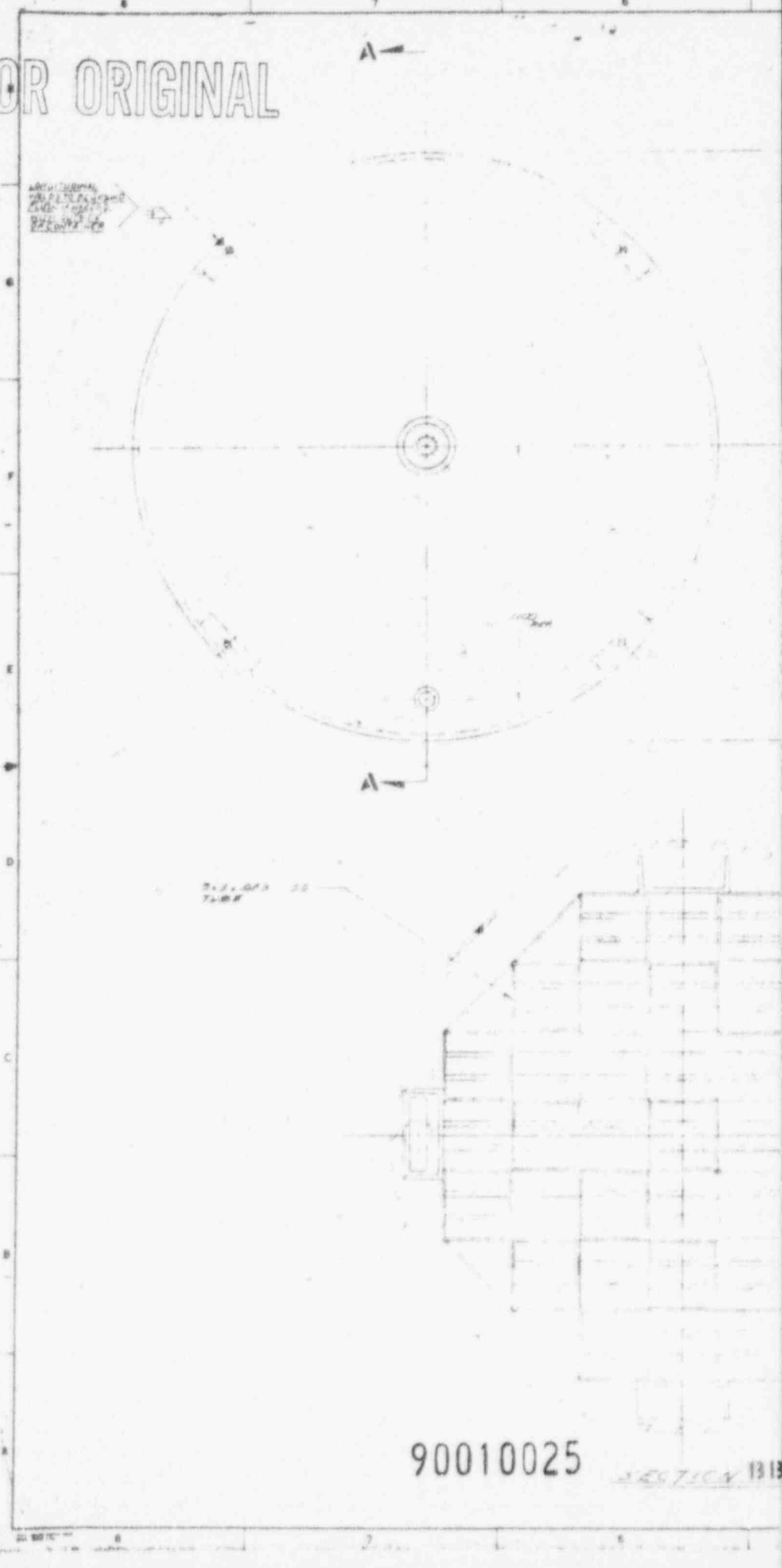

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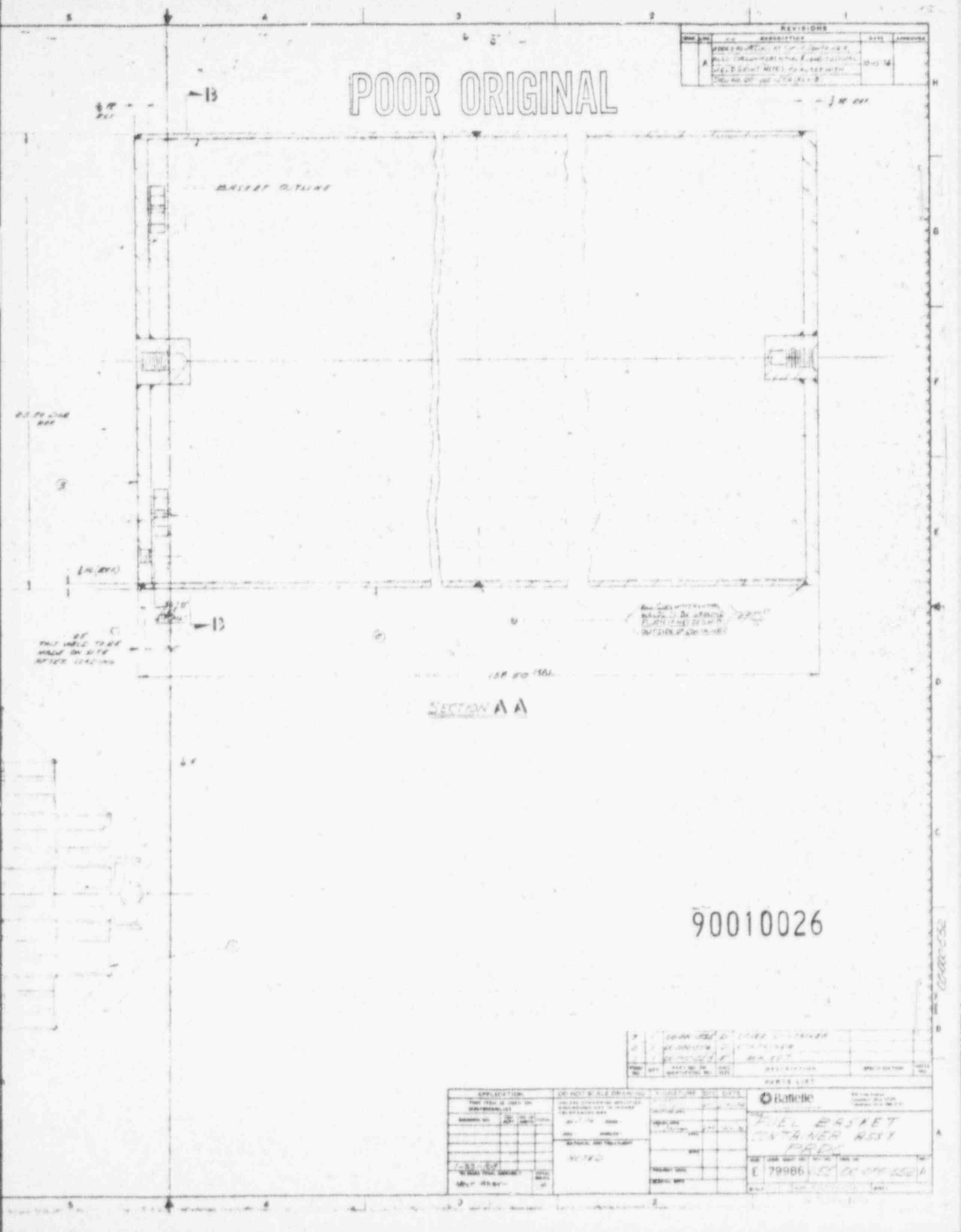
POOR ORIGINAL
BASKET OUTLINE
SECTION A A
REVISIONS
PARTS LIST
DO NOT SCALE DRAWING
Battelle
FUEL BASKET
CONTAINER ASSY
PRDC
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2.0 STRUCTURAL EVALUATION

2.1 Structural Design

The structural integrity analysis of the W&K Model No. PB-1 shipping cask was performed to show compliance with the applicable structural requirements designated in 10CFR71. The materials used in the structural components of the cask include mild steel, Type 304 stainless steel, cold drawn mechanical tubing (carbon steel), and ASTM A325 bolts. For purposes of analysis, the properties of AISI 1025 carbon (i.e., a general purpose steel) were assumed for the mild steel properties.

2.2 Weights and Centers of Gravity

Table 1. Whitehead & Kales Model No. PB-1 Cask Weight

Component	Weight, lbs.
Body	53,110
Covers (1,995 each)	3,990
Impact limiters (630 each)	1,260
Basket	920
Fuel and fuel canisters	3,420
TOTAL	62,700

2.3 Mechanical Properties of Materials

Material properties for AISI 1025, 304 stainless steel, and the ASTM A325 bolts were obtained from MIL-HDBK-5A[9]. In the cases where a value for a specific property was not quoted, it was estimated by proportioning the values given for other similar properties for the material considered. The bolts correspond to the Type 4 fasteners included in MIL-HDBK-5A.

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The surface temperature of the cask was taken to be 180 F, and the structural properties were degraded accordingly by the use of data presented in MIL-HDBK-5A. Table 7 summarizes the properties of materials used in the design.

TABLE 7. MATERIAL PROPERTIES UTILIZED IN W&K MODEL NO. PB-1 CASK DESIGN

Material	Property	Value, psi
[illegible]25	Tensile yield stress Tensile ultimate stress Shear yield stress	34,500 54,500 22,000
Type 304 stainless steel	Tensile yield stress Tensile ultimate stress Shear yield stress Shear ultimate stress	28,000 68,000 15,000 36,500
Mechanical tubing (cold drawn .10 - .25 carbon)	Tensile yield stress	60,000
ASTM A325 bolts (Type 4 fasteners)	Tensile ultimate stress Shear ultimate stress	121,000 90,000
Commercial wrought steel eyebolts, 1-in. nominal	Working load	4 tons

The mechanical tubing is used in the impact limiters for the cask. Material properties were obtained from vendor catalogs. The impact limiters were designed utilizing design curves and data presented in Technical Report No. 32-639(10)

2.4 General Standards for All Packages

2.4.1 Chemical and Galvanic Reactions - The material used, mild steel, stainless steel, and lead, do not react with each other in such a way as to cause deleterious amounts of corrosion products.

2.4.2 Positive Closure - Positive closure of the cask is accomplished by 12 ASTM Type A325 bolts during normal shipping conditions. The closure with respect to accident conditions is analyzed in a subsequent section.

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2.4.3 Lifting Devices.

2.4.3.1 Support three times the loaded weight. The cask is provided with two 8-in. diameter trunnions at each end. These trunnions provide a means of lifting as well as tying down the cask during transportation. For use as lifting devices, only two trunnions would be used. Therefore, the total load on each trunnion will be

$$P = 3\,\frac{W}{2} = \frac{3}{2}\,(62{,}800) = 94{,}200 \text{ lbs.}$$

Failure of the lifting device can occur in any one of the four modes: fiber stress in the cask shell, fiber stress in the trunnion, shear stress in the trunnion, and combined stress in the trunnion-to-shell weld.

2.4.3.1.1 Fiber stress in the shell. The shell was conservatively assumed to be a flat plate. The stress was computed using Equations 5 and 10 of Table X of Roark[11]. These equations were solved with the aid of a computer program. The equations and a computer program flow chart are presented in Appendix B. Figure 6 is a sketch of the problem (W = 0 for this case), and Figure 7 is a copy of the printout of the computer solution of the analysis. The maximum shell stress as shown in Figure 7 is 9,690 psi, and the margin of safety assuming the properties for stainless steel (from which the patch plate is made) is 1.89.

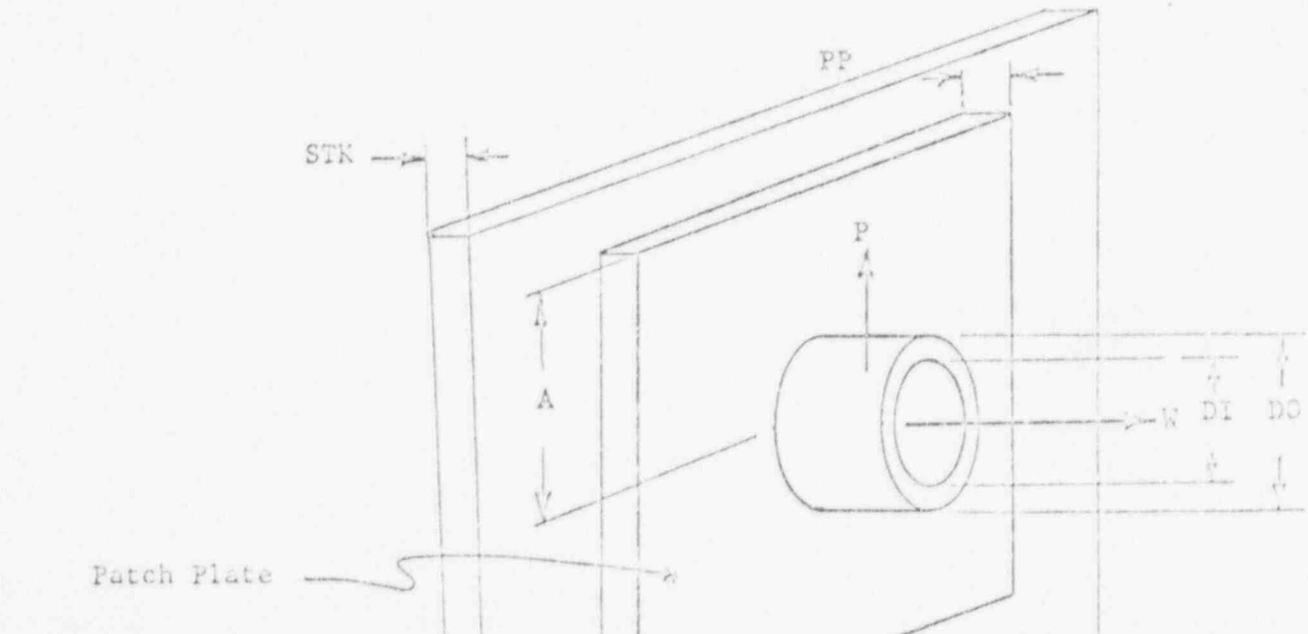

FIGURE 6. SKETCH OF PROBLEM FOR SOLUTION OF SHELL AND TRUNNION STRESSES FOR USE OF TRUNNION AS A LIFTING DEVICE AND A TIE-DOWN DEVICE

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TRUNNUN 16:38 CY MON 01/05/70

LONGITUDINAL-VERTICAL LOAD 94800.00
TRANSVERSE LOAD .00
SHELL THICKNESS 1.50
PATCH PLATE THICKNESS .50
PATCH PLATE RADIUS 6.50
TRUNNION LENGTH 4.00
TRUNNION OUTSIDE DIAMETER 8.00
TRUNNION INSIDE DIAMETER 6.00
TENSILE DESIGN STRESS 28000.00
SHEAR DESIGN STRESS 15000.00

LOG OF ZERO OR NEGATIVE ARGUMENT IN TRUNNION
EQUATION 2, (0.45*A=/<R), EQUATION 2 BYPASSED

SHELL STRESS, LONG-VERT LOAD, AT R, RADIAL, EQ 1 9692.7446
SHELL STRESS, LONG-VERT LOAD, AT,R, RADIAL, EQ 2 .00
MAXIMUM RADIAL STRESS AT 'R' 9692.7446
MAXIMUM TANGENTIAL STRESS AT 'R' .00
MAXIMUM RADIAL STRESS AT 'A' .00

MARGIN OF SAFETY AT 'R' IN RADIAL DIRECTION 1.8888

MAXIMUM TENSILE STRESS IN TRUNNION 10965.876
SHEAR STRESS IN TRUNNION 4233.5316

MARGIN OF SAFETY OF TRUNNION IN BENDING 1.5534
MARGIN OF SAFETY OF TRUNNION IN SHEAR 2.5015

FIGURE 7. COMPUTER SOLUTION OF THE ANALYSIS OF THE STRESSES IN THE CASK SHELL AND TRUNNION FOR THE LIFTING CONDITION

2.4.3.1.2 Fiber Stress in the Trunnion - In the trunnion-to-cask attachment arrangement, a 28,000 psi design stress and a 15,000 psi shear design stress for stainless steel material was used rather than the higher values for mild steel. Since the trunnion is welded to both the mild steel cask outer shell and the stainless steel patch plate, a weighted average design strength for these materials could have been used. However, a more conservative choice was made to use the lower of the two values for these materials. The maximum fiber stress was determined from Equation 5 in Appendix B. A sketch of the problem is presented in Figure 6 and a copy of the computer printout of the solution is presented in Figure 7. The maximum fiber stress is 10,970 psi, and the margin of safety is 1.55.

2.4.3.1.3 Shear stress in the trunnion. The maximum shear stress was determined from Equation 6 in Appendix B. A sketch of the problem is presented in Figure 6, and a copy of the computer print out of the solution is presented in Figure 7. The maximum shear stress is 4,280 psi, and the margin of safety is 2.50.

2.4.3.1.4 Combined stress in weld of trunnion to shell. The combined fiber and shear stress in the weld is the vectoral sum of the two separate forces. Since the fiber stress is the result of the bending moment of the force "P" in Figure 6, it can be computed from Equation 5 and the shear stress can be computed from Equation 6 in Appendix B. However, the dimensions for the problems are as shown in Figure 8.

POOR ORIGINAL

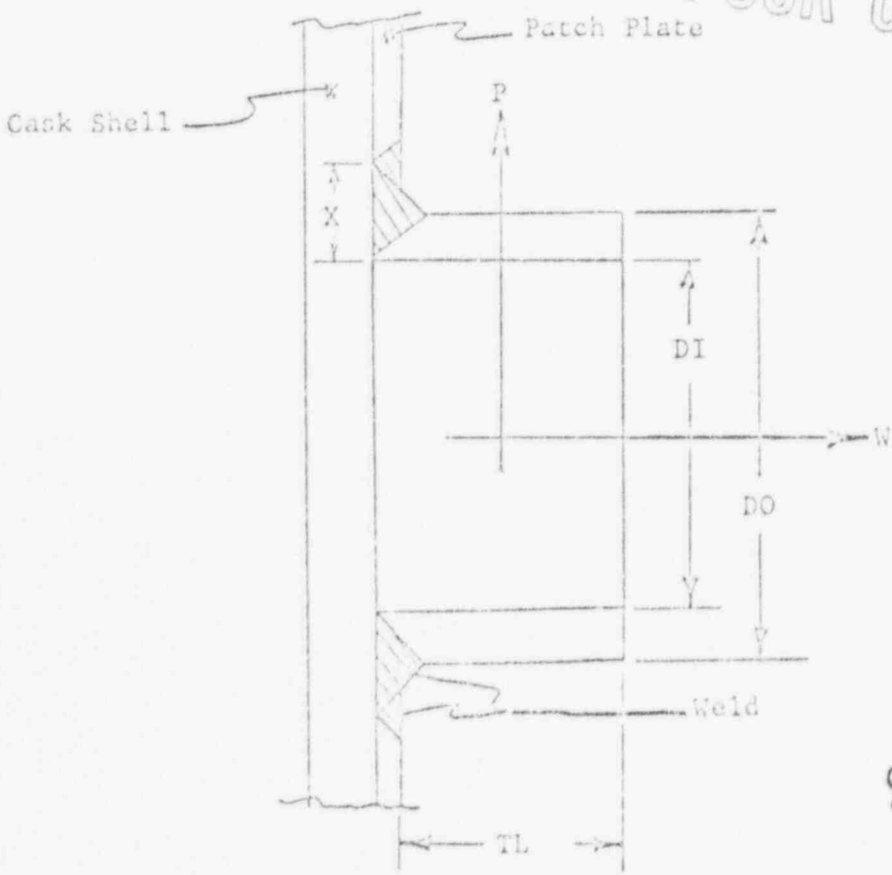

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Figure 8 Trunnion-Cask Shell Weld Problem

In this case, W = 0. The effective outside diameter of weld area can be approximated by DW = DI + 2X (cos 45).

Then for X = 2.0 in.
and DI = 6.0 (RI = 3.0)
DW = 6.0 + (2) (707) (2) = 8.828 (r_o = 4.414)

A copy of the computer solution print out for this problem is presented in Figure 9. The maximum fiber stress is 7,090 psi, and the maximum shear stress is 2,860 psi. The combined stress is

$$\sigma_{comb} = \sqrt{\sigma_f^2 + \sigma_{sh}^2}$$

$$= \sqrt{7,909^2 + 2,860^2}$$

$$= 7,650 \text{ psi}$$

The margin of safety is $\frac{FT_y}{\sigma_{comb}} - 1 = \frac{28,000}{7,650} - 1 = 2.66$

2.4.3.2 Support three times the weight of the lid. The lid lifting device consists of two 1-in. steel eye bolts screwed in the cask lid. The bolts are locat on a diameter of the lid at the location of the bolt circle of the lid closure bolts, Figure 10. As shown in this figure, it is assumed that a two-leg cable sling be used to lift the lid and that the worst probable included angle of the sling will be 90 degrees.

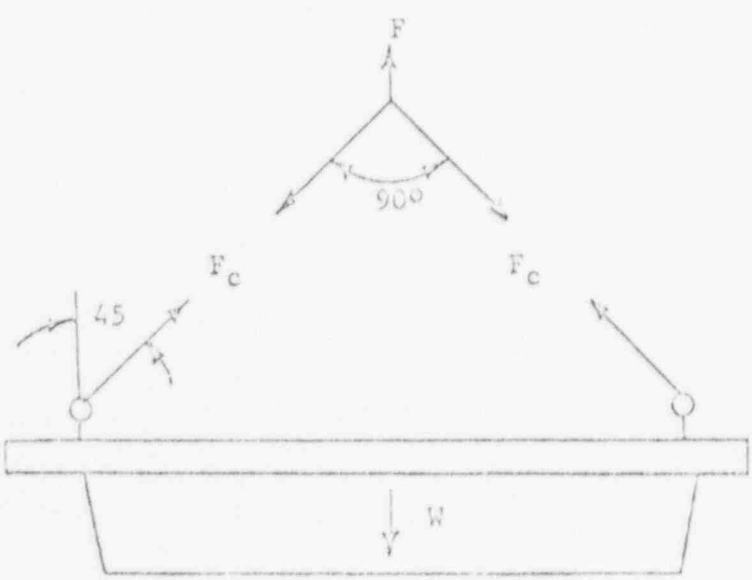

FIGURE 10. LID LIFTING DEVICE PROBLEM

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```
TRUNNIN    16:31   CY M2N 01/05/70

LONGITUDINAL-VERTICAL LOAD    94200.00
TRANSVERSE LOAD            .00
SHELL THICKNESS           1.50
PATCH PLATE THICKNESS          .50
PATCH PLATE RADIUS          6.50
TRUNNION LENGTH           4.00
TRUNNION OUTSIDE DIAMETER         8.828  (Effective weld O.D.)
TRUNNION INSIDE DIAMETER        6.00


MAXIMUM TENSILE STRESS IN TRUNNION     7091.5568 (Weld Stress)
SHEAR STRESS IN TRUNNION     2560.2107  (Weld Stress)
```

FIGURE 9. COMPUTER SOLUTION OF THE ANALYSIS OF STRESS IN THE WELD OF THE TRUNNION TO THE CASK FOR THE LIFTING CONDITION

POOR ORIGINAL

Load = 94,200 lbs

Trunnion length = 4.0 in.

Moment arm = 2.0 in.

Moment = 189,000 in.-lb

Section modulus = $\frac{\pi}{32}\left[\frac{(8.828)^4 - (6.0)^4}{8.828}\right]$ = 53.1 in.^{4}

Fiber stress = 3,560 psi

Shear stress = 2,800 psi

Combined stress = 4,560 psi

Margin of safety = 5.15

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Then if the weight of the lid is 1,970 lbs., the cable force, F_c, is:

$$F_c = 1/2(\frac{3W}{\cos 45}) = 1/2 \frac{(3)(1970)}{.707}$$

$$F_c = 4,200 \text{ lbs.}$$

The eye bolts are commercial 1 in. eye bolts, rated for four tons load working strength with any load orientation. The margin of safety thus is:

$$M.S. = \frac{F_{work}}{F_c} -1 = \frac{8,000}{4,200} -1 = 0.91$$

If the bolts were pulled from the lid, the threads in the lid would fail in shear. The shear force on each hole is:

$$F_{sh} = (1/2)\ 3W = \frac{(3)(1970)}{2} = 2960 \text{ lbs.}$$

The effective area for shear was taken as one bolt diameter deep.

Thus: $A = (d)(\pi d) = \pi(1)(1) = 3.14$ sq. in.

The shear stress is:

$$\sigma_{sh} = \frac{F_{sh}}{A} = \frac{F_{sh}}{(d)(\pi d)} = \frac{2960}{(1)(31410)(1)} = 940 \text{ psi}$$

The margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_{sh}} -1 = \frac{15,000}{940} -1 = \text{Large}$$

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2.4.3.3 Basket Lifting Attachment

The criteria require that this attachment must be able to support three times the loaded basket weight or

$$F = 3W = (3)(4,340) = 13,000 \text{ lb}$$

The shear stress on the threads of the aluminum attachment is

$$\sigma_{sh} = \frac{F}{A} = \frac{F}{\pi d l}$$

where d = 1 in.

l = d = 1 in.

$$\sigma_{sh} = \frac{13,000}{(\pi)(1)(1)} = 4,140 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{28,000}{4,140} - 1 = 5.76.$$

The shear stress on the threads of the stainless steel lifting rod is

$$\sigma_{sh} = \frac{F}{\pi d l}$$

where d = root diameter = 0.843

l = 1 in.

$$\sigma_{sh} = \frac{13,000}{\pi(0.843)(1)} = 4,910 \text{ psi.}$$

The margin of safety for the stainless steel rod is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{36,500}{4,910} - 1 = 6.43$$

The aluminum lifting attachment is welded to the top of the fuel tube with a 1/8-in. weld all the way around. The stress in the weld is

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$$\sigma_w = \frac{F}{A} = \frac{F}{(.707)\pi dt}$$

POOR ORIGINAL

where d = weld diameter = 5.12 in.

t = weld thickness = .12.

Then

$$\sigma_w = \frac{13,000}{(.707)(\pi)(5.12)(.12)} = 9,500 \text{ psi}$$

The margin of safety is

$$M = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{28,000}{9,500} - 1 = 1.95.$$

In the event of an incident where the cask would impact on its top, the lifting attachment would not be required to take any load. The band around the outside of the basket at the top would accept the entire impact load.

The finding of the above analyses is that the lifting attachment is more than adequate and does not in any way compromise the cask design.

2.4.3.4 Nonlifting attachments covered or locked - The lid lifting device is designed to be removed during shipment. All nonlifting attachments are located within the trunnions and are protected by them.

2.4.3.5 Failure of the lifting device would not impair containment or shielding. Impairment of containment or shielding due to failure of the lifting device would be less severe than in the case of the 30 ft. drop which is considered in a subsequent section.

2.4.4 Tiedown Devices

2.4.4.1 No yielding with 10G longitudinal, 5G transverse, and 2G vertical forces. The four trunnions are designed for tying down the cask in addition to lifting. For the application of the 10G and 2G force components, all four trunnions would resist the load. For the application of the 5G force component, it was assumed that only two trunnions would resist the load as shown in Figure 11.

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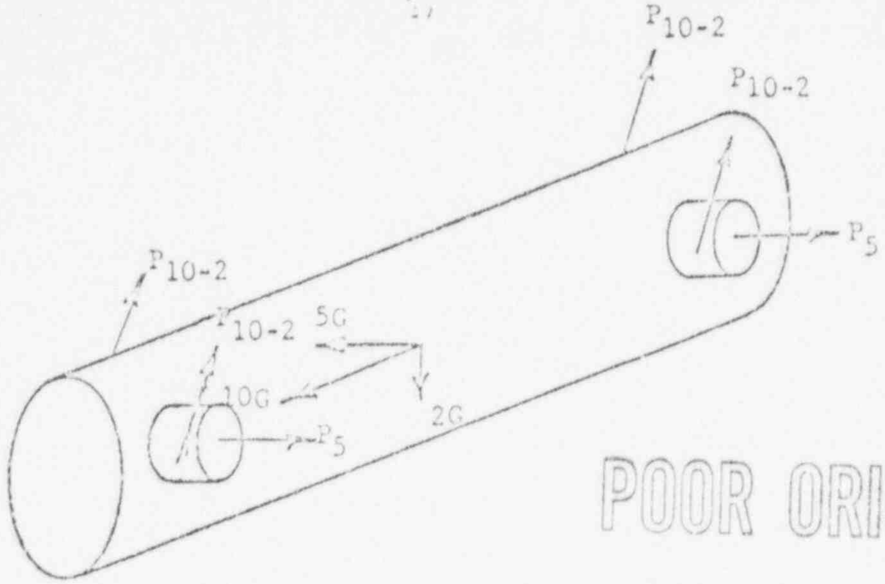

FIGURE 11. SKETCH OF FORCES APPLIED DURING APPLICATION OF NORMAL TRANSPORTATION LOADING

Then

$$P_{10-2} = \frac{W}{4} \sqrt{10^2 + 2^2} = \frac{10.2}{4} W = 2.55 W$$

$$P_5 = \frac{W}{2} (5) = 2.5 W$$

The weight of the cask, W, is 62,800 lbs.

Therefore,

$$P_{10-2} = (2.55) (62,800) = 160,000 \text{ lbs.}$$

$$P_5 = (2.5) (62,800) = 157,000 \text{ lbs.}$$

Failure of the tie down device can occur by anyone of four modes: fiber stress in the cask shell, fiber stress in the trunnion, shear stress in the trunnion, and combined stress in the weld between the trunnion and the cask shell.

2.4.4.1.1 Fiber stress in the shell. As in Paragraph c.1.1, the shell was assumed to be a flat plate. The stresses were computed using Equations 5, 10, 18, and 20 from Roark[11], Table X. A sketch of the problem is presented in Figure 6, where $P = P_{10-2}$ and $W = P_5$. Appendix B presents the flow diagram of the computer code used to solve these equations and determine the worst possible stress condition at each location in the shell adjacent to the trunnion. A copy of the print out of the computer code is presented in Figure 12. The maximum fiber stress in the shield is 27,010 psi. The margin of safety using the properties of the patch plate (stainless steel) is 0.037.

2.4.4.1.2 Fiber stress in the trunnion. The maximum fiber stress was determined from Equation 5 in Appendix B. A sketch of the problem is presented in Figure 6, and a copy of the computer print out of the solution is presented in Figure 12. The maximum fiber stress is 25,760 psi, and the margin of safety is 0.087.

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TRUNIN     16:23    CY MIN 01/05/70
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POOR ORIGINAL

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LONGITUDINAL-VERTICAL LOAD  160000.00
TRANSVERSE LOAD  157000.00
SHELL THICKNESS          1.50
PATCH PLATE THICKNESS   -     .50
PATCH PLATE RADIUS          6.50
TRUNNION LENGTH          4.00
TRUNNION OUTSIDE DIAMETER          8.00
TRUNNION INSIDE DIAMETER          6.00
TENSILE DESIGN STRESS   28000.00
SHEAR DESIGN STRESS   15000.00

LOG OF ZERO OR NEGATIVE ARGUEMENT IN TRUNNION
EQUATION 2, (0.45*A*/<R), EQUATION 2 BYPASSED

SHELL STRESS, LONG-VERT LOAD, AT R, RADIAL, EQ 1    16463.261
SHELL STRESS, LONG-VERT LOAD, AT R, RADIAL, EQ 2          .00
SHELL STRESS, TRANS LOAD, AT R, RADIAL, EQ 4  -10549.291
SHELL STRESS, TRANS LOAD, AT R, TANGENTIAL, EQ 3   -5002.4059
SHELL STRESS, TRANS LOAD, AT A, RADIAL, EQ 3    14350.649
SHELL STRESS, TRANS LOAD, AT A, RADIAL, EQ 4     7649.3623

MAXIMUM RADIAL STRESS AT 'R'    27012.552
MAXIMUM TANGENTIAL STRESS AT 'R'     5002.4059
MAXIMUM RADIAL STRESS AT 'A'   14350.649

MARGIN OF SAFETY AT 'R' IN RADIAL DIRECTION          .0366
MARGIN OF SAFETY AT 'R' IN TANGENTIAL DIRECTION          4.5973
MARGIN OF SAFETY AT 'A' IN RADIAL DIRECTION          .9511

MAXIMUM TENSILE STRESS IN TRUNNION   25764.933
SHEAR STRESS IN TRUNNION     7275.6375

MARGIN OF SAFETY OF TRUNNION IN BENDING          .0567
MARGIN OF SAFETY OF TRUNNION IN SHEAR        1.0617
```

90010039

FIGURE 12. COMPUTER SOLUTION OF THE ANALYSIS OF STRESSES IN THE CASK SHELL AND TRUNNION FOR THE TRANSPORTATION TIEDOWN CONDITION

2.4.4.1.3 Shear stress in trunnion. The maximum shear stress was determined from Equation 6 in Appendix B. A sketch of the problem is presented in Figure 6. Figure 12 is a print out of the computer solution of the problem. The maximum shear stress is 7,280 psi, and the margin of safety is 1.06.

2.4.4.1.4 Combined stress in weld of trunnion to the cask shell. A sketch of the problem is presented in Figure 8. As in Paragraph c.1.4, the computer code presented in Appendix B, Equations 5 and 6 were used to solve the problem. The dimensions of the problem are as in Paragraph c.1.4, X = 2.0 in., RI = 3.0 in., r_o = 4.414 in. The applied loads for this problem are $P = P_{10-2}$ = 180,000 lbs. and $W = P_5$ = 157,000 lbs. A print out of the computer solution is presented in Figure 13. The maximum fiber stress if 16,810 psi, and the maximum shear stress is 4,860 psi. The combined stress is

$$\sigma_{comb} = \sqrt{16,810^2 + 4,800^2}$$
$$= 17,500 \text{ psi}$$

POOR ORIGINAL

The margin of safety is

$$MS = \frac{F_{ty}}{\sigma_{comb}} - 1 = \frac{28,000}{17,500} - 1 = .60$$

2.4.4.2 Nontiedown devices covered or locked. The nontiedown devices will be located within the trunnions and protected by them as described in Paragraph 2.4.3.3

2.4.4.3 Failure of the tiedown device would not impair meeting other requirements. Failure of the tiedown device would not impair meeting other requirements of the cask as described above in Paragraph 2.4.3.4 and in the subsequent sections that discuss the accident conditions.

2.5 Standards for Type B and Large Quantity Packaging

2.5.1 Load Resistance. The requirement for load resistance is that when simply supported at its ends, the cask must be able to withstand a uniformly distributed load equal to five times the cask weight. Conservatively, the outer shell alone is assumed to support this load. For this cask, the stresses at three locations must be analyzed, at the midlength of the cask, at the reduced outer diameter of the stepped outer shell at the weld, and in the weld between the two shell diameter sections. Referring to Figure 14, the locations are A, B, and C, respectively. The stress in the outer shell at locations A and B can be evaluated from the equation,

$$\sigma_f = \frac{MC}{I}$$

For the stress in the weld, location C, the combined shear and fiber stress must be evaluated.

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```
50   P102=160000.
90   P5=157000.
RUN

TRUNUN     16:33    CY MON 01/05/70

LONGITUDINAL-VERTICAL LOAD  160000.00
TRANSVERSE LOAD  157000.00
SHELL THICKNESS       1.50
PATCH PLATE THICKNESS          .50
PATCH PLATE RADIUS         6.50
TRUNNION LENGTH          4.00
TRUNNION OUTSIDE DIAMETER          8.828
TRUNNION INSIDE DIAMETER          6.00

MAXIMUM TENSILE STRESS IN TRUNNION   16812.65
SHEAR STRESS IN TRUNNION     4858.1073

AT LINE NO. 1520: STOP END
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FIGURE 13. COMPUTER SOLUTION OF THE ANALYSIS OF STRESSES IN THE WELD OF THE TRUNNION TO THE CASK FOR THE TRANSPORTATION TIEDOWN CONDITION

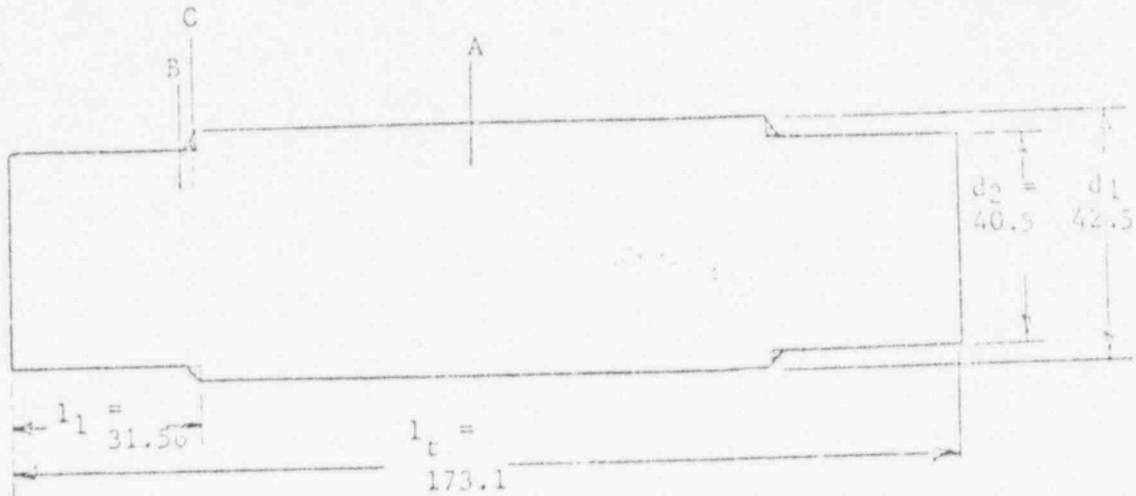

FIGURE 14. SKETCH OF CASK SHOWING LOCATIONS ANALYZED FOR LOAD RESISTANCE

2.5.1.1 Fiber stress at the midlength. The properties of the section at the midlength, location A, are

$$M = 5 \frac{Wl_t}{8} = \frac{(5)\ (61,540)\ (173.1)}{8}$$

$$= (6.68)\ (10^6)\ \text{in.-lbs.}$$

$$C = \frac{d_1}{2} = \left(\frac{42.5 - .5}{2}\right) = 21.0\ \text{in.}$$

$$I \cong \pi \left(\frac{d_1}{2}\right)^3 t = \pi\ (21)^3\ (1.5) = 43,600\ \text{in.}^4$$

It is noted that d_1 was taken as the outside diameter of the 1.50-in. thick mild steel shell and that the effect of the laminated 1/4 in-thick stainless steel shell is neglected. Also, the weight is the weight of the loaded cask without the impact limiters. The fiber stress is

$$\sigma_f = \frac{(6.68)\ (10^6)\ (21)}{43,600} = 3,220\ \text{psi.}$$

The margin of safety is

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{34,500}{3,220} - 1 = 9.7$$

2.5.1.2 Fiber stress in reduced diamter outer shell. The properties of the section at location B, of Figure 14 are

$$M = 5\,\frac{W}{2}\,(l_1 - \frac{l_1^2}{l_t}) = \frac{5}{2}\,(61{,}540)\,(31{,}56 - \frac{(31.56)^2}{173.1})$$

$$M = 3.97\,(10^6)\ \text{in.-lb.}$$

$$C = \frac{d2}{2} = (\frac{40.5 - .5}{2}) = 20.0\ \text{in.}$$

$$I \cong \pi\,(\frac{d_2}{2})^3\,t = \pi\,(20^3)\,(1.50) = 37{,}700\ \text{in.}^4$$

$$\sigma_f = \frac{(3.97)\,(10^6)\,(20)}{37{,}700} = 2{,}110\ \text{psi}$$

The margin of safety is

$$MS = \frac{34{,}500}{2{,}110} - 1 = \text{large}$$

2.5.1.3 Combined stress in weld between two steps in outer shell. The properties of the section at the weld, location C, is

$$M = 5\,\frac{W}{2}\,(l_1 - \frac{l_1^2}{l_t}) = 3.97\,(10^6)\ \text{in.-lb.}$$

$$C = \frac{d_2}{2} = 20\ \text{in.}$$

$$I \cong \pi\,(\frac{d_2}{2})^3\,t_{weld} - (\pi)\,(20)^3\,(.707)\,(1.0)$$

$$I = 17{,}800\ \text{in.}^4$$

$$\sigma_f = \frac{MC}{I} = \frac{(3.97)\,(10^6)\,(20)}{17{,}800} = 4{,}460\ \text{psi}$$

The shear stress in the weld is

$$\sigma_{sh} = \frac{V}{A}$$

$$V = 5\,\frac{W}{2}\,(1 - \frac{2\,l_1}{l_t}) = \frac{5}{2}\,(61{,}540)\,(1 - \frac{(2)\,(31.56)}{173.1})$$

$$= 97{,}600\ \text{lbs.}$$

$$A = \pi\,d_2\,t_{weld} = (\pi)\,(40.5 - .5)\,(.707)\,(1.00)$$

$$= 88.9\ \text{in}^2$$

$$\sigma_{sh} = \frac{97{,}600}{88.9} = 1{,}100\ \text{psi}$$

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The combined stress is

$$\sigma_{comb} = \sqrt{\sigma_f^2 + \sigma_{sh}^2} = \sqrt{4{,}460^2 + 1{,}100^2}$$

$$\sigma_{comb} = 4,560 \text{ psi}$$

POOR ORIGINAL

The margin of safety is

$$MS = \frac{34,500}{4,560} - 1 = 6.56$$

2.5.2 External Pressure. The requirement for external pressure is that the cask must be able to withstand an external pressure of 25 psig without loss of contents. The outer shell was conservatively assumed to withstand this pressure with no assistance from the lead in which case the shell could fail by stress failure of the end plates, stress failure of the cylindrical shell, or collapse of the outer shell. These cases are analyzed individually below.

2.5.2.1 Stress failure of end plates. The severest stress condition exists when the edges of the end plate are assumed to be simply supported. According to Roark[12], Case 1, the maximum stress in the end plate may be described as:

$$\sigma_f = \frac{3}{32} \left(\frac{D}{t}\right)^2 p \, (3 + \nu) ,$$

where

D = mean diameter = (40.5 - .5) - 1.5 = 38.5

t = 1.50 in.

p = 25 psig

ν = 0.3.

$$\sigma_f = \frac{3}{32} \left(\frac{38.5}{1.5}\right)^2 (25) \, (3 + 0.3) = 5,100 \text{ psi}$$

and the corresponding margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{34,500}{5,100} - 1 = 5.76$$

2.5.2.2 Stress failure of cylindrical shell - small diameter section. The stress in the shell is given by Roark[13], Case 1, as:

$$\sigma_{hoop} = \frac{pD}{2t}$$

where the dimensions are the same as above. Therefore, the fiber stress is:

$$\sigma_f = \frac{(25)\,(38.5)}{(2)\,(1.50)} - 320 \text{ psi.}$$

and the margin of safety is:

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$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{34,500}{320} - 1 = \text{large.}$$

2.5.2.3 Collapse of the cylindrical shell - small diameter section. The critical collapsing pressure of a shell is given by Roark[13], Case 1, as:

$$p_c = \frac{2t}{D} \left(\frac{F_{ty}}{1 + \frac{F_{ty}}{E} \left(\frac{D}{t}\right)^2} \right) ,$$

POOR ORIGINAL

where

E = elastic modulus = 29×10^6 psi.

$$p_c = \frac{(2)\ (1.50)}{(38.5)} \left(\frac{34,500}{1 + \frac{34,500}{(29)\ (10^6)} \left(\frac{38.5}{1.5}\right)^2} \right) = 1,510 \text{ psi},$$

and the margin of safety is:

$$MS = \frac{p_c}{p} - 1 = \frac{1,510}{25} - 1 = \text{large}.$$

2.5.2.4 Stress failure of cylindrical shell - large diameter section. The stress in the shell is given by Roark[13], Case 1, as:

$$\sigma_{hoop} = \frac{pD}{2t}$$

where the dimensions are the same as above except that d = (42.5 - .5) - 1.5 = 40.5. Therefore, the fiber stress is:

$$\sigma_f = \frac{(25)\ (40.5)}{(2)\ (1.5)} = 340 \text{ psi},$$

and the margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{34,500}{340} - 1 = \text{large}.$$

2.5.2.5 Collapse of the cylindrical shell - large diameter section. The critical collapsing pressure of a shell is given by Roark[13], Case 1, as:

$$p_c = \frac{2t}{D} \left(\frac{F_{ty}}{1 + \frac{F_{ty}}{E} \left(\frac{D}{t}\right)^2} \right) ,$$

where

E = elastic modulus = 29×10^6 psi.

$$P_c = \text{[illegible]} = 1,370 \text{ psi},$$

and the margin of safety is:

$$MS = \frac{P_c}{P} - 1 = \frac{1,370}{75} - 1 = \text{Large}$$

POOR ORIGINAL

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2.6 Normal Conditions of Transport

Effect of Transport Environment on Safety of Cask.

Normal Transport Conditions (Appendix A of 10CFR71) - The analyses in the sections below show that the cask will be in submission to:

> "A package used for shipment of fissile material (and) a large quantity of licensed material . . ., shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Appendix A of this part (cited below)"

the package will meet the requirements specified in 71.35 a and 71.35 b.

2.6.1 Heat - The conditions of subjecting the cask to direct sunlight at an ambient temperature of 130°F in still air were analyzed in the Thermal Analysis Section, 3.4.

2.6.2 Cold - Section 3.4 includes an analysis of the cask subjected to an ambient temperature of -40°F in still air and shade.

2.6.3 Pressure - The pressure requirement of 0.5 times normal atmospheric pressure is usually considered for packages which may be transported in aircraft. The Peach Bottom Cask will not be transported in an aircraft. However, it is conceivable that it may experience reduced pressure when transported over high mountain passes so the more extreme reduction of 0.5 atmosphere pressure is reasonable to consider. This pressure is approximately the same as that used in the fire accident analysis which shows that containment is maintained.

2.6.4 Vibration - The effects of transportation vibration on the massive cask are considered to be less severe than the transportation shock forces (10, 5, and 2G tiedown forces) discussed above and the hypothetical accident conditions described below.

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2.6.5 <u>Water Spray</u> - The cask is constructed of corrosion resistant materials and is thus unaffected by water spray.

2.6.6 <u>Free Drop</u> - Since there is no coolant to be lost, the free drop from a height of 1 ft. will be less severe than the 30 ft. accident drop. From the puncture accident analysis it is shown that the present cask design will withstand the 40 in. drop of a 6 in. diameter cylinder. Since the trunnions are 8 in. in diameter, the case for the 6 in. diameter cylinder is more severe. Therefore, a free drop on any trunnion will not cause puncture of the cask outer shell.

The trunnions must be analyzed, however, to ensure their integrity during conditions of normal transport. The analysis which follows is based on the assumption that the cask drops 1 ft. sideways onto one of the trunnions. The resulting impact force will cause the trunnion to deflect the cask outer shell in order to absorb the impact energy. If the cask were to strike at any angle greater than 17° from the horizontal, then the end impact limiters would attenuate part of the impact. At any angle between 0°-17°, the horizontal component of the impact force would be less than 30% of the vertical component, and due to the short length of the trunnion, create a negligible bending component in either the trunnion or the cask shell.

From conservation of energy:

$$(1) \quad WH = \frac{Pd}{2}$$

Where:

W = cask weight = 68,460 lbs.

h = free drop height = 12 in.

P = impact load, lb.

d = cask shell deformation, in.

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From Roark[5], Table 13, Case 10, the deflection of a cylinder wall due to a load P applied to both sides of the cask is given by

(2) $$d = (6.5)\,\frac{P}{Et}\left(\frac{R}{t}\right)^{1.5}\left(\frac{L}{R}\right)^{-3/4} ,$$

where

E = modulos of elasticity of cask shell

$= 2.9 \times 10^{7}$ psi

t = cask shell chicknoss = 1.5 in.

R = mean radius of cask shel = 19.5 in.

L = length of cask shell = 173.1 in.

Solving both equations for P yields

(3) $$P = \left[(.308)\, W h E t \left(\frac{L}{R}\right)^{.75}\left(\frac{t}{R}\right)^{1.5}\right]^{.5}$$

$$= 1.10 \times 10^{6} \text{ lb.}$$

The compressive stress in the trunnion is, therefore,

$$\sigma = \frac{P}{A} ,$$

where

$$A = \frac{\pi(D_1^2 - D_0^2)}{4} ,$$ where D_1 = 8 in. and D_0 = 6 in.

$$= 21.99 \text{ in.}^2$$

$$\sigma = \frac{1.10 \times 10^{6}}{21.99}$$

$$\sigma = 50{,}023 \text{ psi.}$$

The ultimate strength of the trunnions has been found to be 84,700 psi. The margin of safety is

$$MS = \frac{84{,}700}{50{,}023} - 1$$

$$MS = 0.69.$$

The above analysis is conservative in that no credit was taken for energy absorption by the load shielding or the trunnion.

2.6.7 Corner Drop. The corner drop from a height of 1 foot will cause less damage to the cask than the accident (30-foot drop) case will. The reduction in lead shielding for the 30-foot fall accident condition is greatest for the lead slump in the end drop, from which the external dose at 3 feet from the cask surface increases to only 30 mrem/hr. Consequently, the 1-foot corner drop will not cause a loss of containment or result in unacceptable shielding doses.

2.6.8 Penetration

2.6.8.1 Outer Shell Penetration

Objective of Analysis. To demonstrate that the cask will withstand impact of free falling bar on most vulnerable region of exterior.

The requirements stipulate the cask must withstand impact of a 13 lb, 1-1/4-inch-diameter bar falling from 40 inches. The most vulnerable exterior cask element is the 1.5-inch-thick outer shell. The shell is assumed to be perfectly rigid, and the kinetic energy of the falling bar will be absorbed by shear of the shell. This is conservative since any deformation of the shell will also absorb energy, and reduce the tendency to shear failure. Marks[11] indicates the energy required to cause shear can be expressed as

$$E_s = P_s t f_p (1.0 + f_f) \quad ,$$

where

E_s = energy absorbed in shear, in.-lb

P_s = maximum shear force = $f_s \pi D t$

f_s = maximum shear stress = 35,000 psi for 0.1 percent C steel (Table 2, pp 13-25, Marks)

D = bar diameter = 1.25 inches

t = plate thickness = 1.5 inches

f_p = fraction of plate thickness penetrated by punch before complete shear failure has occurred = 0.50 for 0.1 percent C steel (Table 2, pp 13-25, Marks)

f_f = contribution of friction to resisting shear $\simeq$ 0.1.

Thus the energy which the 1.5-inch-thick plate can absorb before the 1.25-inch-diameter bar will produce shear failure is (neglecting the 0.25-inch 304 stainless steel overlay)

90010050

$$E_s = (35{,}000)\pi(1.25)(1.5)^2(0.50)(1 + 0.1)$$

$$E_s = 170{,}100 \text{ in.-lb} \quad .$$

The kinetic energy of the falling bar is

$$E_b = (13 \text{ lb})(40 \text{ in.}) = 520 \text{ in.-lb} \quad .$$

Thus the margin of safety is large by inspection and the most vulnerable part of the cask will not be penetrated by the falling bar.

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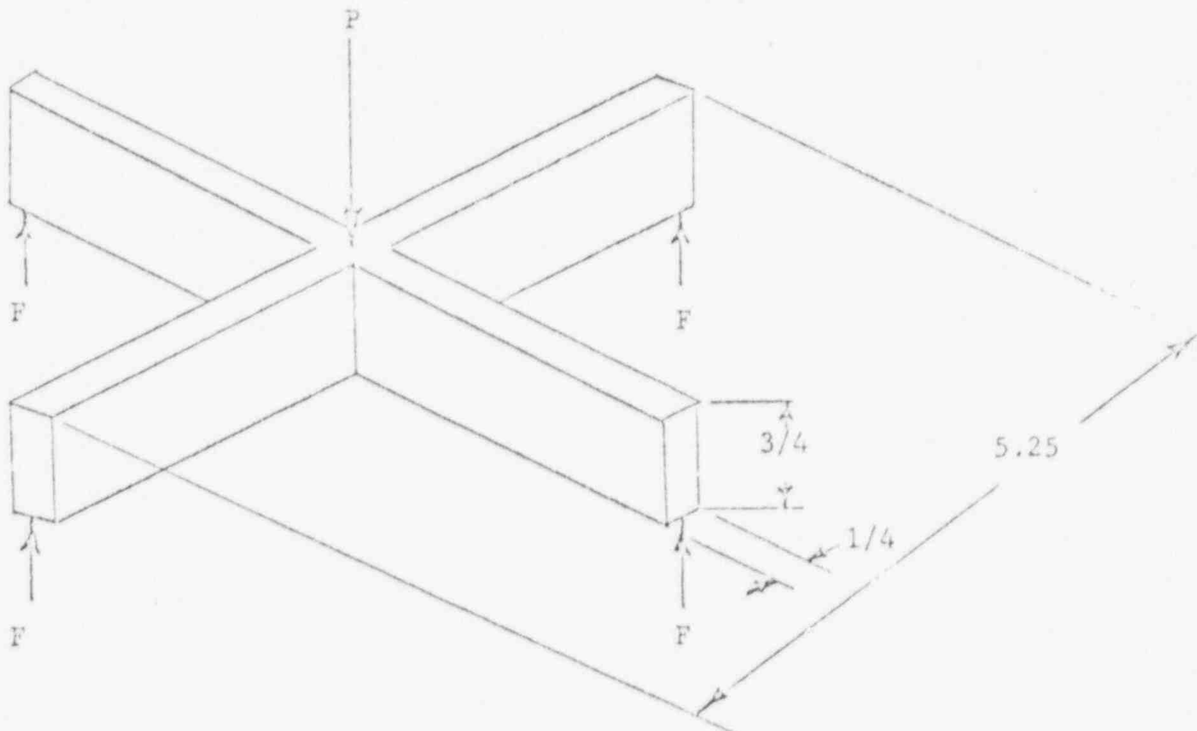
2.6.8.2 Porous Stainless Steel Plate - The design of the plate assures protection of the valves. The modification is shown in Drawing No. 9123-6PB-0001, Revision E.

The design includes the addition of a cross-structure to the bottom side of the porous plate. The structure, made of 1/4 in. x 1/4 in. stainless steel is welded to the bottom surface of the plate. The ends of the cross rest on lugs welded to the inner wall of the trunnion.

In the event of impact by a 1-1/4 in. bar, the contribution of the porous plate is neglected. Thus, the situation can be represented by the sketch below.



The force, P, at which yielding of the cross will occur is

$$P = \frac{4M}{L}$$

where

$$M = \frac{I\sigma}{c} = \frac{I\ F_{Ty}}{c}$$

$$I = 2\left(\frac{bh^3}{12}\right)$$ (the factor "2" is used since the two equal arms of the cross resist the load)

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$b = .25$ in.

$h = .75$ in.

$F_{ty} = 28,000$ psi

$c = h/2 = .375$ in.

$L = 5.25$ in.

Then

$$I = \frac{(2)(.25)(.75)^3}{12} = .01758 \text{ in.}^4$$

$$M = \frac{(.01758)(28,000)}{.375} = 1310 \text{ in.lb}$$

$$P = \frac{(4)(1,310)}{5.25} = 1,000 \text{ lb}$$

The kinetic energy of the 13-lb bar at impact is taken up by the strain energy of the cross, thus

$$WH = Pd$$

where

W = bar weight = 13 lb

H = drop height = 48 in.

P = 1,000 lb

d = deflection of the cross.

Then

$$d = \frac{WH}{P} = \frac{(13)(48)}{1,000} = .624 \text{ in.}$$

It is assumed that the deformed cross forms the arc of a circle. The radius of curvature can be determined by considering the sketch below.

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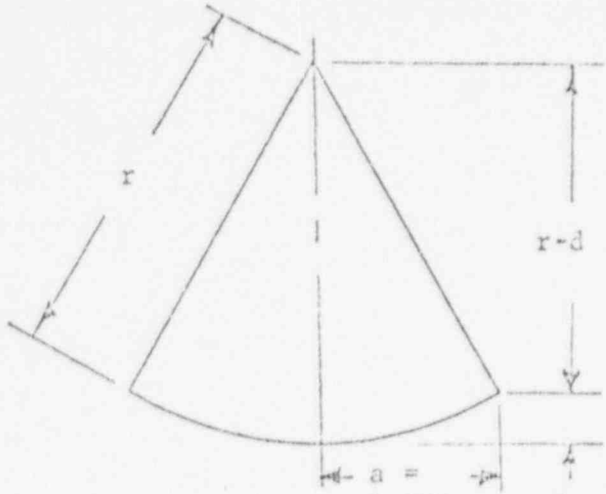


Then

$$r^2 = (r-d)^2 + a^2$$

$$r^2 = r^2 - 2rd + d^2 + a^2$$

$$r = \frac{d^2 + a^2}{2d}$$

$$= \frac{(.624)^2 + (2.625)^2}{(2)(.624)} = 5.83$$

The maximum fiber strain is

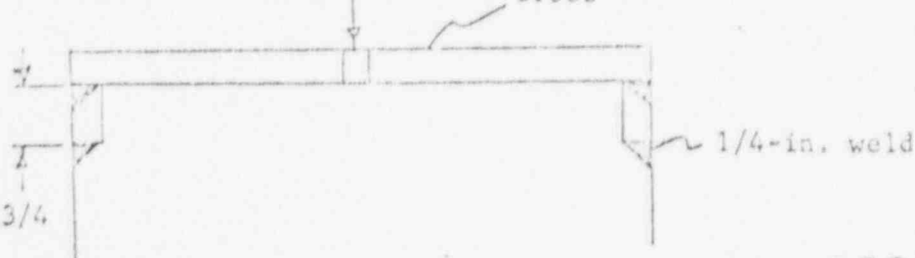
$$\varepsilon = \frac{h}{r + h} = \frac{.75}{5.83 + 7.5} = .114 = 11.4 \text{ percent.}$$

Since the elongation of stainless steel is 50 percent, the cross will not fracture.

Each end of the cross rests on a stainless steel pad 1/2 x 3/4 x 3/8 in. thick welded all the way around to the inner wall of the trunnion as shown below. Each pad supports 1/4 of the applied load of 1,000 lb or 250 lb The weld shear area is

$$A = 2(h + w)(1/4)(.707) = (2)(3/4 + 1/2)(1/4)(.707)$$

$$= .441 \text{ in.}^2$$



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The shear stress is

$$\sigma_{sh} = \frac{250}{.441} = 570 \text{ psi.}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{36,500}{570} - 1 = \text{large.}$$

2.6.8.3 Solid stainless plate. The solid stainless plates covering the ends of two trunnions were assumed to be simply supported at their edges. The load from the 1-1/4 bar was assumed applied as a uniform concentric load as shown in Roark, Table X, Case 3[2]. The force required to cause yielding of the disc is

$$W_y = \frac{F_{ty}\, 2\pi m t^2}{3} \left[\frac{1}{\frac{1}{2}(m-1) + (m+1)\ln\left(\frac{a}{r_o}\right) - \frac{1}{2}(m-1)\frac{r_o^2}{a^2}} \right]$$

where

F_{ty} = yield strength = 28,000 psi

m = 1/poissons ratio = 3.33

t = plate thickness = .25 in.

a = radius of the support = 5.25/2 = 2.625 in.

r_o = radius of the applied load = 1.25/2 = .625 in.

Then

$$W_y = 1,670 \text{ lb}$$

The deflection of the center of the plate is determined by equating the strain energy to the kinetic energy, or

$$d = \frac{Hw}{W_y} = \frac{(48)(13)}{1670} = .374 \text{ in.}$$

---

(2) Ibid., p. 217.

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The radius of curvature is

$$r = \frac{d^2 + a^2}{2d} = \frac{(.374)^2 + (2.625)^2}{(2)(.374)} = 9.41 \text{ in.}$$

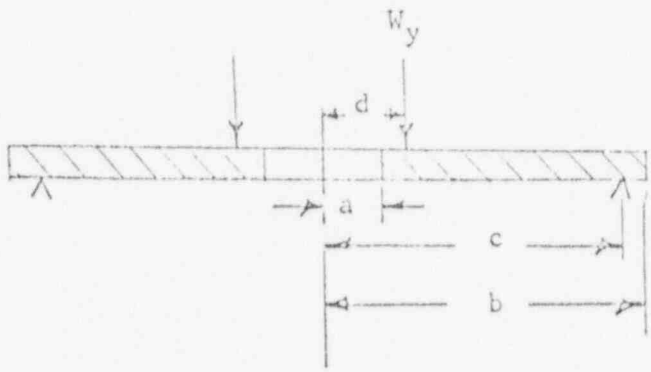
The strain is

$$\epsilon = \frac{t}{r + t} = \frac{.25}{9.41 + .25} = .026 = 2.6 \text{ percent.}$$

2.6.8.4 Stainless plate with hole. One trunnion is covered with a stainless steel plate with a 1-in. hole for viewing a pressure gauge. The applied load is assumed concentric as above and the minimum force required to cause yielding is from Roark, Table X, Case 15.

$$W_y = \frac{F_{ty}\, 2\pi\, m\, t^2}{3} \left[\frac{a^2 - b^2}{2a^2\ (m + 1)\ \ln\left(\frac{c}{d}\right) + (m - 1)\ (c^2 - d^2)}\right]$$

where F_{ty}, m and t are as above and a, b, c, and d are shown on the sketch below.



a = .5 in.

b = 3.0 in.

c = 2.625 in.

d = .625 in.

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Then W_y = 840 lb

The deflection of the plate is

$$\delta = \frac{HW}{W_y} = \frac{(48)(13)}{840} = .74 \text{ in.}$$

The radius of curvature is

$$f = \frac{\delta^2 + c^2}{2\delta} = \frac{(.74)^2 + (2.625)^2}{(2)(.74)} = 5.03 \text{ in.}$$

The strain is

$$\epsilon = \frac{t}{r + t} = \frac{.25}{5.03 + .25} = .047 = 4.7 \text{ percent.}$$

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2.6.9 Compression - Not applicable as the package exceeds the 10,000 lb. weight limitation.

2.7 Hypothetical Accident Conditions

2.7.1 Free Drop - Thirty-foot free drop onto a flat surface. The first condition which the cask must withstand in the hypothetical accident sequence is a 30 ft. fall onto a flat unyielding surface. There are three critical orientations which the cask can assume at the moment of impact. These include direct impact on an end, direct impact on the cylindrical side, and impact on an edge at such an angle that the reaction force is directed through the center of mass of the cask. These conditions are evaluated individually below.

2.7.1.1 End Drop - In the case of a direct end impact, the force is evenly distributed over the end of the cask. Furthermore, the kinetic energy of the cask at the moment of impact must be absorbed by deformation of the impact limiter. The impact limiter was designed from design data presented by McFarland[10]. The following analysis based on McFarland's results is discussed in greater detail in Appendix C.

For the impact limiter, the specific energy absorption for axial impact is defined as

$$E_{sp} = \frac{\sigma_{mc}\,\eta}{\rho_u}$$

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where

E_{sp} = specific energy, in lb. per lb.

σ_{mc} = mean crushing stress (gross area), psi

η = thickness efficiency

ρ_u = unit weight, lb. per cu. in.

The mean crushing strength, thickness efficiency and unit weight can be expressed in terms of the dimensionless ratio, t/s where

t = the wall thickness of the tubes comprising the impact limiter
s = the mean tube diameter.

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McFarland presents data which closely agrees with an equation derived to describe a rigid-plastic mode of collapse of the limiter. Then, as described in Appendix C, the mean crushing strength of an impact limiter using a loose pack tube arrangement is

$$\sigma_{mc} = 47.74\ \sigma_y\ (\frac{t}{s})^2$$

where σ_y = the yield strength of the material.

Then for an impact limiter made of cold drawn carbon steel "mechanical" tubing, having a yield strength of 60,000 psi,

$$\sigma_{mc} = (47.74)\ (60{,}000)\ (\frac{t}{s})^2 = (2.86)\ (10^6)\ (\frac{t}{s})^2$$

The impact limiter is made of nominal 2 1/2 in O.D. (2.310 in. I.D.) tubing with 13 gauge (.095 in.) wall thickness. Then,

$$t/s = \frac{.095}{2.310 + .095} = .0395$$

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and the mean crushing stress is

$$\sigma_{mc} = (2.86)\ (10^6)\ (.0395)^2 = 4{,}450 \text{ psi}$$

The expression for thickness efficiency was assumed to be the same as experimentally determined by McFarland; thus

$$\eta = 88.13 - 329\ (\frac{t}{s})$$

$$= 88.12 - 329\ (.0395) = 88.13 - .130 = 75 \text{ percent}$$

The unit weight for the "loose packed"* tube arrangement is from geometry

$$\rho_u = \pi\rho\ \frac{t}{s}$$

where ρ = the density of the limiter material = .283 lb. per cu. in.,

then

$$\rho_u = (3.1416)\ (.283)\ (.0395) = .0351 \text{ lb. per cu. in}$$

The specific energy absorption in the limiter then is

$$E_{sp} = \frac{\sigma_{mc}\ \eta}{\rho_u} = \frac{(4{,}450)\ (.75)}{.0351} = 95{,}000 \text{ in.-lb. per lb.}$$

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* Illustrated in Appendix C, Figure C-1.

The weight of the impact limiter then is

$$w = \frac{E_k}{E_{sp}}$$

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where E_k = the kinetic energy of the cask = WH

W = cask weight = 62,800 lbs.

H = drop height = 360 in.

The limiter weight can also be expressed as

$$w = Ah \rho_u$$

where

A = gross area of the limiter = $\frac{\pi d^2}{4}$

d = cask diameter = 40.5 in.

h = limiter height

ρ_u = unit weight of the limiter = 0.0351 lb. per cu. in.

Then

$$\frac{E_k}{E_{sp}} = Ah \rho_u$$

or

$$h = \frac{E_k}{E_{sp} A \rho_u} = \frac{(62,800)\ (360)\ (4)}{(95,000)\ (3.1416)\ (40.5)^2\ (.0351)} = 5.26 \text{ in.}$$

Thus, the minimum height required for the impact limiter is 5.26 in. Since the active height of the impact limiter is 8.5 in., the design is acceptable and no lead will be deformed.

The maximum decelerating force which the impact limiter will exert during impact is

$$F = \sigma_{mc} A = (4,450)\ \frac{(3.1416)\ (40.5)^2}{4}$$

$$= (5.74)\ (10^6) \text{ lb.}$$

The deceleration is

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$$a = \frac{F}{W} = \frac{(5.74)\ (10^6)}{62,800} = 91.5 \text{ G}$$

The fuel cans in the cask were designed for the Hallam shipping cask and will withstand up to 150G without failure(14). Then the margin of safety of the fuel can is:

$$M.S. = \frac{150}{91.5} - 1 = .64$$

The basket has been designed to assure that in the event of an impact on the top, the basket will not crush the failed fuel cans. A ring, 1/8 in. thick and 7 in. high welded to the outer edge of the basket at the top end (see Drawing 9123-6PB-0001) will support the basket in the event of an impact on the top of the cask. The basket weighs 920 lbs. For end impact, the impact load is 91.5G. The total impact force then experienced by the basket is:

$$F_{Imp} = (920)(91.5) = 84,100 \text{ lbs.}$$

The area of the ring:

$$A = 2\pi rt$$

Where:

r = mean radius = 25.44 in.

t = wall thickness = .125 in.

Then:

$$A = 2\pi(25.44)(.125) = 20.0 \text{ in.}^2$$

The stress is:

$$\sigma_{Imp} = \frac{F_{Imp}}{A} = \frac{84,100}{20.0} = 4,200 \text{ psi}$$

The margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_{Imp}} - 1 = \frac{37,000}{4,200} - 1 = 7.8$$

A stepped plug is inserted flush with the cask cover and the end impact limiter bears directly upon the outboard fare of the plug; therefore, the impact limiter would be quite adequate to prevent the plug from breaking free due to its own inertive loading.

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2.7.1.2 Side Drop In the case of direct impact on the side, the deformation of the lead is the only mechanism available to absorb the kinetic energy. Figure 18 is a sketch of the cask during side impact. The problem presented in Figure 18 neglects the impact limiters on the ends. It assumes that the larger diameter step of the cask deforms uniformly in the radial direction until the smaller diameter sections at each end come into contact with the unyielding surface. The, the lead along the entire length of the cask deforms until all the kinetic energy is absorbed. The decelerating force at any instant during the impact is the product of the lead flow pressure, customary taken as 10,000 psi, and the area of lead in contact with the unyielding surface, at that instant A_c in Figure 18. The problem was solved in a manner similar to that used for the case of the corner impact. The area, A_c, was computed at a deformation of "d" and at "d + Δd". The arithmetic average of the two areas was used with the lead flow pressure to compute an average decelerating force which acted through the distance, Δd. The change in velocity was computed and subtracted from the velocity at the time when the deformation equaled "d". The procedure was repeated through successive increments of Δd until the cask velocity was reduced to zero. The computer program is discussed in greater detail in Appendix E.

A copy of the print out of the computer solution is presented in Figure 19. The maximum deceleration is 370 G, and the total amount of lead deformed measured along the diamter of the larger diameter section of the cask is 1.70 in. Since the lead thickness at the 42.5-in. diameter section is 6.25 in, the thickness of the residual lead is 4.55 in.

The G load, when applied to the cask cover, must be resisted by the 12 cover bolts. The shear stress on the bolts is

$$\sigma_{sh} = \frac{G\ W_c}{(A)\ (N)}$$

where

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G = the impact load = 370 G
W_c = cover weight = 1,970 lbs.

A = area of each bolt = 1.035 in^2
N = number of bolts = 12

Then the shear stress is

$$\sigma_{sh} = \frac{(370)\ (1,970)}{(1.035)\ (12)} = 58,600 \text{ psi}$$

The margin of safety in the A325 bolts is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{90,000}{58,000} - 1 = .53$$

Due to the stepped side body construction of the cask, during a side impact a moment would be applied to the impact limiter which would be resisted by tensile forces in the four bolts used to hold the limiter on the cask, Figure 20. The moment would act about point "O" where the skirt of the impact limiter is welded to the bottom end plate of the limiter.

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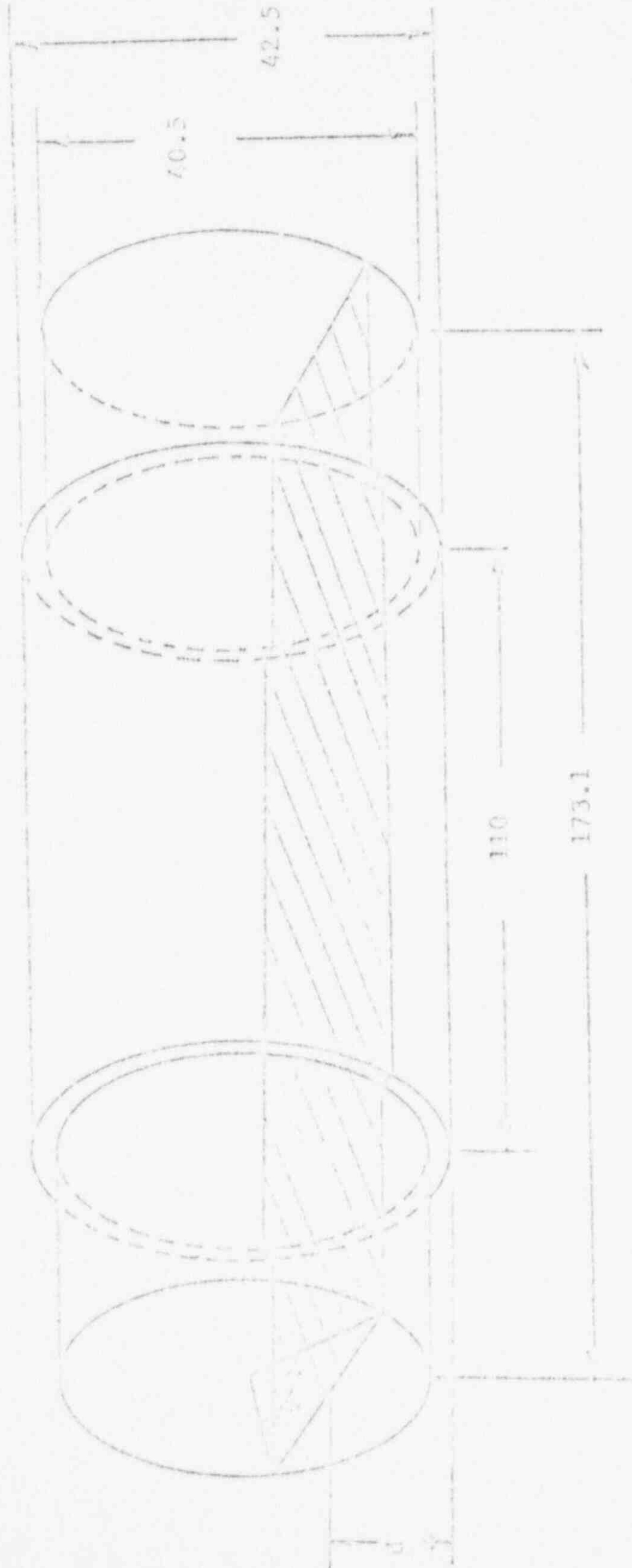

FIGURE 18. SKETCH OF CASK ORIENTATION DURING SIDE IMPACT

RUN

SIDE2 15:52 CY TUE 01/06/70

THIS IS THE SOLUTION TO THE SIDE DROP OF A ROUND CASK
HAVING A STEPPED SIDE CONFIGERATION, TWO DIAMETERS ONLY
(ASSUMES NO LEAD EXPANSION SPACE AT THE 'CORNERS')

CASK WEIGHT= 62800.00 LB
CASK DIAMETER= 42.50 IN.
CASK HEIGHT= 173.12 IN.
OUTER SHELL THICKNESS= 1.75 IN.
TOP PLATE THICKNESS= 3.00 IN.
BOTTOM PLATE THICKNESS= 3.00 IN.
DEFORMATION INCREMENT= .01 IN.
INITIAL DEFORMATION= .00 IN.
INITIAL VELOCITY= 44.00 FPS
LEAD FLOW PRESSURE= 10000.00 PSI
LENGTH OF LEAD UNDER IMPACT= 167.12 IN.
LENGTH AT 40.50 IN. CASK DIAMETER= 57.12 IN.
LENGTH AT 42.50 IN. CASK DIAMETER= 110.00 IN.

DEFORMED DISTANCE, IN.	VELOCITY FPS	AVG DECCEL G'S	TIME MSEC
.10	43.7207	67.325	.1899
.20	43.2011	96.3581	.3316
.30	42.5196	118.5	.5759
.40	41.6993	136.79 3	.7738
.50	40.7501	152.93 1	.9759
.60	39.6755	167.4601	1.1831
.70	38.4747	180.7508	1.3963
.80	37.1433	193.0654	1.6167
.90	35.6733	204.5803	1.8455
1.00	34.0524	215.4237	2.0845
1.10	32.0703	259.7421	2.3363
1.20	29.6924	284.1915	2.606
1.30	26.388	304.6488	2.9004
1.40	23.5372	322.9003	3.2308
1.50	19.3833	339.6448	3.6168
1.60	13.7399	355.2504	4.1213
1.695	1.9229	369.5868	5.1274
1.6962	1.1023	370.0338	5.1963
1.6969	.00	370.1678	5.2888

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FIGURE 19. COMPUTER SOLUTION OF THE ANALYSIS OF THE DECELERATION OF THE CASK DURING A SIDE IMPACT

FIGURE 20. SKETCH OF PROBLEM FOR IMPACT LIMITER UNDER SIDE IMPACT

The moment is

$$M_{IL} = (G)\ (W_{IL})\ (\frac{h}{2})$$

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and the stress in the bolts is

$$\sigma_t = \frac{(M_{IL})\ (C)}{I}$$

where

G = impact loading = 370 G
W_{IL} = weight of impact limiter = 630 lbs.
h = height of the impact limiter (including end plate) = 9.0 in.
C = distance from "O" to farthest bolt = 37.62
I = summation of bolt area moments about "O" = 2,322 in.^{4}

Then

$$\sigma_t = \frac{(630)\ (370)\ (37.62)\ (9)}{(2,322)\ (2)} = 17,000 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{tu}}{\sigma_t} - 1 = \frac{131,000}{17,000} - 1 = 6.71$$

The impact loading would also produce a transverse force tending to cause shear failure between the base of the impact limiter and the skirt. The force ...

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$$F_{tr} = (G)\ (W_{IL})$$

If it is assumed that only one-third of the circumferential distance resists this force, the stress developed is

$$\sigma_{tr} = \frac{F_{tr}}{(1/3)\ (\pi)\ (d)\ (t)} = \frac{(370)\ (630)\ (3)}{(3.1416)\ (40.5)\ (.875)}$$

$$= 6,300 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_{tr}} - 1 = \frac{36,500}{6,300} - 1 = 4.80$$

The side impact would also produce a stress in the weld between the stepped sides of the cask. Since the skirt of the impact limiter would strike the impacting surface at the same instant as the larger diameter step of the cask shell, the force on the weld would be a shear force only. Then, the stress is

$$\sigma_{sh} = \frac{g\ \frac{We}{2}}{A}$$

where

g = the maximum deceleration = 215 G (at deformation = 1.0 in., Figure 19)
We = the weight of the small diameter cask step = 8,080 lbs.
A = area of the weld = πdt
$d \cong 40.5 - .5 \cong 40.0$ in.
$t = (1.0)\ (.707) = .707$ in.

The stress then is

$$\sigma_{sh} = \frac{(215)\ (8,080)}{(\pi)\ (40)\ (.707)\ (2)} = 9,800 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{36,500}{9,800} - 1 = 2.72$$

2.7.1.3 Corner Drop - In the case of impact on a "corner" of the cask, the worst case is for the orientation where the line of action is from the point of impact on the "corner" through the center of mass of the cask, Figure 15. For this cask, it can be assumed that the center of mass is the geometric center of the cask.

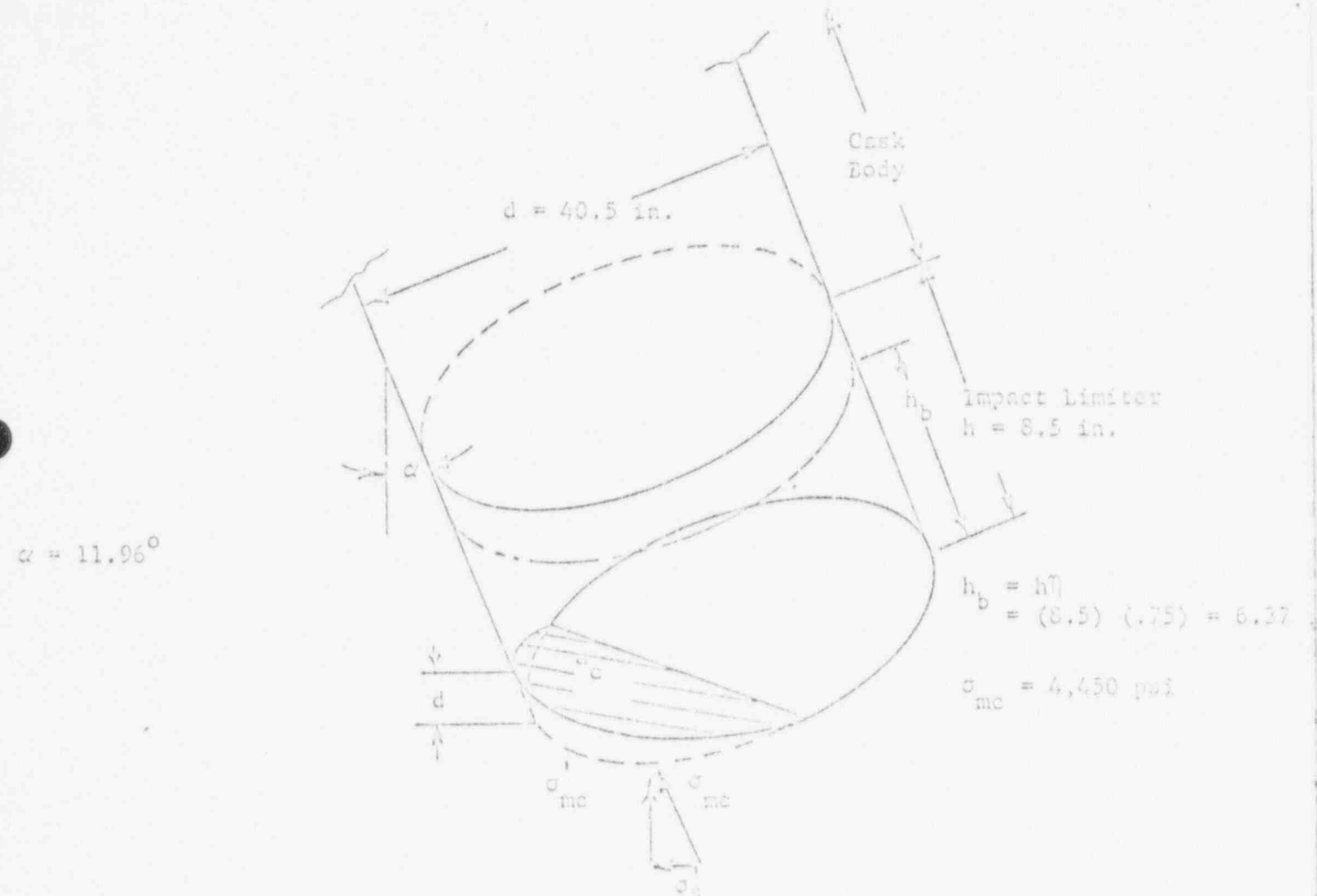

FIGURE 15 Orientation of Cask During Corner Impact

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During impact on the corner, part of the kinetic energy will be absorbed by deformation of the impact limiter; and the remaining energy is assumed to be absorbed by deformation of the lead. As is customary, it was conservatively assumed that no energy is absorbed by deformation of the steel shell of the cask. Since the impact limiter is designed primarily for axial impact loading, it will perform less efficiently for corner or oblique loading. Therefore, it was assumed that the effective resistance and energy absorption of the impact limiter during oblique impact could be expressed as a function of the impacting angle, or

$$E'_{sp} = E_{sp} \cos \alpha$$

The specific energy, however, is directly proportional to the mean crushing stress of the impact limiter. Therefore,

$$\sigma'_{mc} = \sigma_{mc} \cos \alpha$$

where

σ'_{mc} = an effective mean crushing stress acting on the area of the deformed impact limiter

σ_{mc} = mean crushing stress for axial loading = 4,450 psi

From Figure 15, it is seen that as the cask deforms during impact and the deformation distance, d, increases, the area, a_c, upon which the effective crushing stress (σ'_{mc}) acts also increases and the decelerating force increases. In order to establish the maximum value of the decelerating force, a computer program was written to calculate the area, a_c, for any value of d, Figure 15. The deformation d, was then increased by an increment, Δd and a new value of the area, $a_{c\Delta d}$ was calculated. The arithmetic mean of the two areas, a_c and $a_{c\Delta d}$, was multiplied by the effective crushing stress, σ'_{mc}, to determine a mean decelerating force during the distance interval, Δd. The change in the velocity of the cask caused by the decelerating force acting during the time for deformation through the distance Δd was then calculated and subtracted from the velocity at the beginning of the deformation increment. When the cask velocity was reduced to zero by successive incremental iterations, the problem was terminated. The computer program is discussed in greater depth in Appendix D.

The impact limiter is not effective over its full height. The effective height is indicated by the thickness efficiency term which is the ratio of the distance the limiter will deform until fully collapsed (bottomed) to the original height. Thus, in Figure 15, the impact limiter will collapse a distance h_b before "bottoming". It was assumed that no more energy could be absorbed by any portion of the limiter which was fully deformed and all forces were transferred without diminution through the collapsed structure and the cask shell into the lead filled wall of the cask. There, the remaining energy was absorbed by deformation of the lead whose flow pressure is 10,000 psi.

A copy of the print out of the computer program used to perform this analysis is presented in Figure 16. As noted in this figure, the deformation increments used were 0.10 in. The condition of the problem was printed out every

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THIS IS THE SOLUTION TO A CASK CORNER DROP USING THE INCREMENTAL DISPLACEMENT METHOD TO CALCULATE G FORCES ASSUMING THAT THE IMPACT FORCE ACTS VECTORIALLY IN THE IMPACT LIMITER AND DIRECTLY ON THE TRUNCATED SURFACE OF THE DEFORMED LEAD

CASK WEIGHT= 42800.00 LB
CASK DIAMETER= 40.50 IN.
CASK HEIGHT= 173.12 IN.
CASK HEIGHT INCLUDING IMPACT LIMITERS= 191.12
SHELL THICKNESS, SIDE= 1.75 IN.
SHELL THICKNESS, END= 3.00 IN.
LEAD WALL THICKNESS, SIDE= 5.25 IN.
LEAD WALL THICKNESS, END= 4.00 IN.
IMPACT LIMITER ACTIVE HEIGHT= 8.50 IN.
IMPACT LIMITER THICKNESS EFFICIENCY= 75.00 PER CENT
DEFORMATION INCREMENT= .10 IN.
INITIAL DEFORMATION= .00 IN.
INITIAL VELOCITY= 44.00 FPS
LEAD FLOW PRESSURE= 10000.00 PSI
IMPACT LIMITER MEAN CRUSHING STRENGTH= 4450.00 PSI
IMPACT ANGLE= 11.9647

DEFORMED DISTANCE, IN.	VELOCITY FPS	AVG DECCEL G'S	TIME MSEC
1.00	43.8551	5.4288	1.8958
2.00	43.2008	15.2536	3.802
3.00	41.8371	27.0012	5.7651
4.00	39.605	39.5468	7.8081
5.00	36.3228	51.9918	9.999
6.00	31.7164	63.4133	12.4433
6.2365	30.0115	66.1624	13.2532
7.2365	22.4624	81.213	16.4131
8.2365	5.3209	94.3193	22.3319
8.2865	1.6476	95.3952	23.5278
8.2904	1.0527	95.7794	23.7206
8.2912	.5521	95.8134	23.8529
8.2916	.3223	95.8276	23.9574
8.2917	.0585	95.8319	24.0429
8.2918	.0165	95.8333	24.0564
8.2918	.00	95.8334	24.0618

MINIMUM THICKNESS OF LEAD LEFT AT CORNER= 2.9462 IN.

FIGURE 16. COMPUTER SOLUTION OF THE ANALYSIS OF THE DECELERATION OF THE CASK DURING A CORNER IMPACT

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10 increments or every 1.00 in. of deformation. At a deformation distance, d, of 6.24 in., the edge of the limiter nearest the impacted corner had "bottomed". The computer code was so constructed that a solution at this point was also printed out and further incremental deformation (now representing deformation of lead in additio to portions of the impact limiter not yet "bottomed") was referenced from this point. The maximum deceleration occurred at the end of the deformation and was 95.8 G. The margin of safety of the fuel canister designed to withstand 150 G is

$$MS = \frac{150}{95.8} - 1 = .57$$

The thickness of the lead remaining at the corner after deformation is 2.95 in. as indicated in Figure 16.

The impact limiter structure will be loaded in shear due to the sideward thrust during impact, illustrated by shear stress, σ_s', in Figure 15. The shear force is

$$F_{sh} = GW \tan \alpha$$

where

G = the deceleration calculated in Figure 16, G
W = cask weight = 62,800 lbs.
α = 11.96 degrees

The maximum value of F_{sh} will occur at the maximum deceleration produced by the impact limiter alone. This is when the impact limiter first begins to "bottom", h_b = 6.37 in., Figure 15. At this point, the deformation distance, d in Figure 15, is 6.24 in. from Figure 16, and the deceleration is 66.2 G.

Then

$$F_{sh} = (66.2)\ (62,800)\ (.2118) = 880,000 \text{ lbs.}$$

The shear stress at this instant is

$$\sigma_{sh} = \frac{F_{sh}}{A_c}$$

where

A_c = the area of the crushed volume.

From Figure 17, the area A_c may be found as follows:

$$a = \frac{h_b}{\tan \alpha} - r$$

$$\cos(\theta) = \frac{a}{r}; \quad \theta = \arccos\left(\frac{a}{r}\right)$$

$$A_c = [(\pi r^2) - (\pi r^2 \left(\frac{2\theta}{2\pi}\right) + (r \sin\theta)\ (r \cos\theta)]\ \frac{1}{\cos \alpha}$$

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$$A_c = \frac{r^2}{\cos \alpha} [\pi - \theta + (\sin \theta)(\cos \theta)]$$

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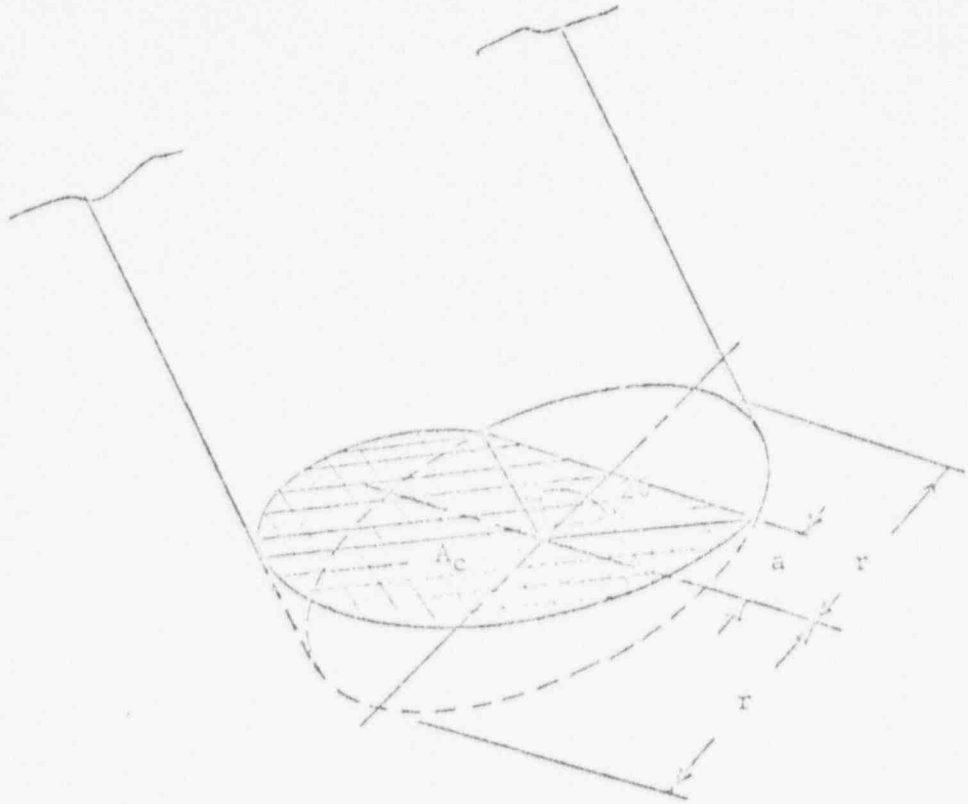

FIGURE 17. SKETCH OF AREA UNDER IMPACT FORCES DURING CORNER IMPACT

Then

$$h_p = 6.37 \text{ in.}$$
$$\alpha = 11.96 \text{ degrees}$$
$$\tan \alpha = .2115$$
$$\cos \alpha = .9783$$
$$r = 20.25$$

and

$$a = \frac{6.37}{.2118} - 20.25 = 9.85$$

$$\theta = \text{arc cos} \frac{9.85}{20.25} = 60.9 \text{ degrees} = 1.062 \text{ radians}$$

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$$A_c = \frac{(20.25)^2}{.9783} [3.1416 - 1.062 + (.8738)(.4863)]$$

$$= 1,050 \text{ sq. in.}$$

$$\sigma_{sh} = \frac{F_{sh}}{G_c} = \frac{880,000}{1,050} = 840 \text{ psi}$$

The value of the shear yield strength of metals is commonly accepted as 60 percent of the yield strength. Similarly, then, the shear strength of the impact limiter can be taken as 60 percent of the mean crushing stress.

Then

$$\sigma_{shc} = .60\, \sigma_{mc} = (.60)\,(4,450)$$

$$= 2,670 \text{ psi}$$

Since the shear stress produced in the impact limiter is only 840 psi, the structure wil not fail in "sideways" shear due to the sideward thrust during the oblique impact.

The transverse force will also produce a shear stress in the weld of the skirt to the endplate of the impact limiter. It is assumed that the four bolts do not contribute to resisting the transverse force.

Further, it is assumed that only one-third of the circumferential distance of the skirt resists the tranverse force. Then the stress is

$$\sigma_u = \frac{F_t}{1/3\ A} = \frac{F_t}{1/3\ \pi d\ t}$$

where

F_t = tranverse force at 66.2 G = 880,000 lbs.

d = skirt diameter = 40.25

t = effective skirt thickness = .875

Then

$$\sigma_u = \frac{(880,000)\ (3)}{(3.1416)\ (40.25)\ (0.875)} = 23,900 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_u} - 1 = \frac{36,500}{23,900} - 1 = .53$$

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2.7.2 Puncture

Forty-inch Drop on Six-inch Steel Cylinder

Second in the sequence of hypothetical accident conditions to which the cask must be subjected is the 40 in. drop onto a 6 in. diameter cylinder. An empirical equation for the minimum steel shell thickness required for lead filled casks has been developed by the Oak Ridge National Laboratory[15]. The equation has the form:

$$t = \left(\frac{W}{F_{tu}}\right)^{.71}$$

Where:

t = minimum shell thickness, in.

W = weight of lead-lined cask, lb.

F_{tu} = ultimate tensile strength, psi.

Therefore, the required shell thickness is:

$$t = \left(\frac{W}{F_{tu}}\right)^{.71} = \left(\frac{68,460}{54,500}\right)^{.71} = 1.18 \text{ in.}$$

On the basis of an outer shell thickness of 1.75 in., the present cask design is shown to comply with the regulatory puncture criteria.

2.7.3 Thermal - The results of the thermal transient analysis indicate that the cask inner cavity liner temperature reaches a maximum value of 416°F, 60 minutes after the fire begins. This increase in temperature causes a pressure rise inside the fuel can given as:

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$$P_2 = \frac{P_1 T_2}{T_1}$$

$$= (14.7 \text{ psia}) \left(\frac{416 + 460}{70 + 460}\right)$$

$$= 24.3 \text{ psia} = 9.6 \text{ psig.}$$

From Roark[11], Table 13, Case 30, an analysis was performed for a 1/4 in. thick can wall with a 1/2 in thick cover and an internal pressure of 10 psig. The maximum stress was 12,740 in the axial direction at the joint between the wall and cover. Obviously the stress will be lower for a 3/4 in thick cover; hence, the can will not yield during the hypothetical fire accident.

2.8 Special Form

Not applicable

2.9 Fuel Rods

In the event of a drop of the cask on its side, the fuel elements are protected by the fuel basket and failed fuel cans acting together. The 2 in. long tabs welded bewteen adjacent tubes at 12 in. intervals are intended primarily to maintain tube alignment during fabrication and basket geometry during normal

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use. Although they will provide structural support to the basket unit in the event of a side impact no credit has been taken for them.

The following sketch shows the orientation of the basket tubes. It is assumed that the load of the thirteen upper tubes and the canned fuel elements shown with cross hatch, is uniformly supported by the six tubes (not cross hatched) located in the outer portion of the lower half of the basket. Then the total load which must be supported by each of the six tubes is

$$L = (w_f + w_t)g \frac{13}{6}$$

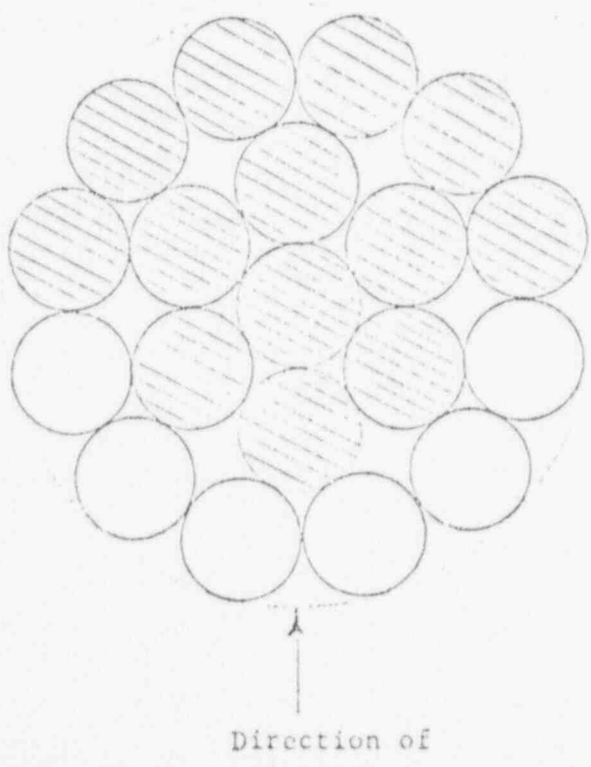
where

w_f = axial line load of canned fuel elements = 1.25 lb/in.

w_t = axial line load of basket tube = .20 lb/in.

g = side impact load = 370 G

13/6 = the ratio of cross hatched tubes to the supporting tubes



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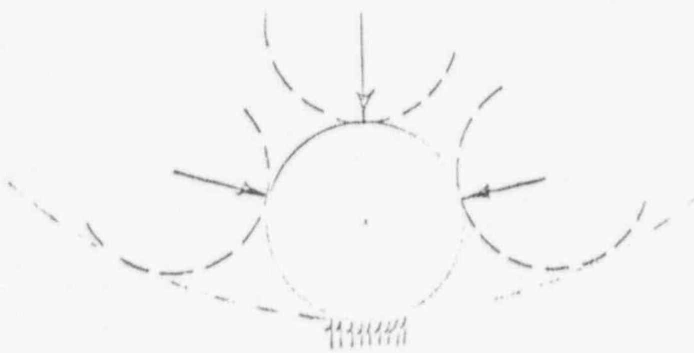
It should be noted that the use of the impact load as 370 G is conservative. This value was calculated for the point of impact on the external surface of the cask. Since the cask body will attenuate the shock wave, the impact force experienced by the contents will be less than 370 G. No credit has been taken for this attenuation however.

Then

$$L = (1.25 + .20)(370)(\frac{13}{6}) = 1162 \text{ lb/in.}$$

In examining the orientation and welded construction of the basket it can be seen that the load is generally applied as three concentrated line loads and one area load as shown in the sketch below.



In order to facilitate the analysis it was conservatively assumed that the load pattern can be represented by five equal forces as shown in the following sketch. It was moreover assumed that the forces are applied at equally distant angular locations. Since, from statics, the total load of

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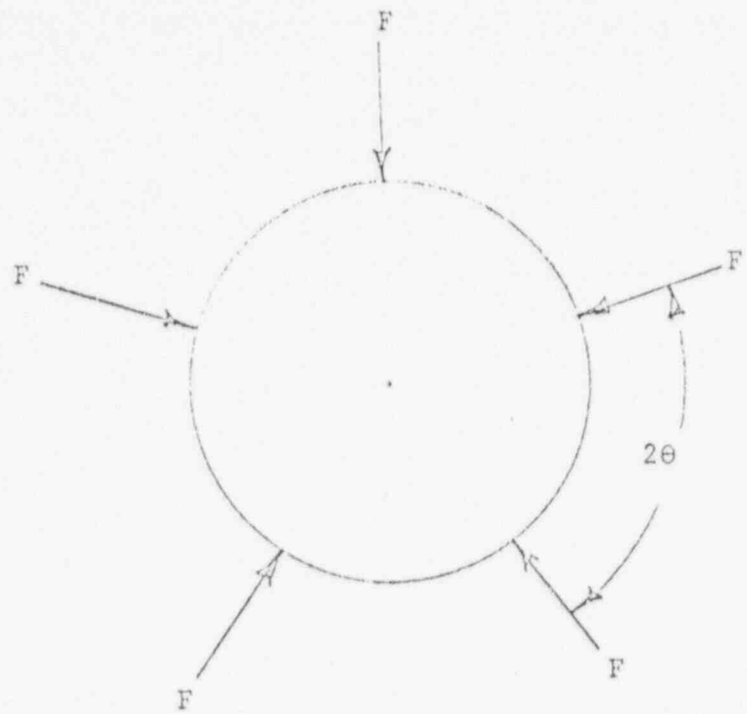

1162 lb per in. acting downward on the tube is balanced by an equal resultant force acting upward, the value of each individual line load, F, shown in the above sketch can be determined by assuming that half of the "F force" act downward and the other half act upward. Thus, the total load is

$$L = \frac{5F}{2}$$

or

$$F = \frac{2}{5} L = \frac{(2)(1162)}{5} = 465 \text{ lb/in.}$$

From Roark[1], it is seen that the maximum bending moments and the shear force in the tube can be expressed as follows:

$$+M: \quad M_{+max} = \frac{WR}{2} \left(\frac{1}{\sin\theta} - \frac{1}{\theta}\right)$$

---

(1) Roark, R.J., Formulas for Stress and Strain, 4th edition, McGraw-Hill Book Co, 1965, page 174, Case 9.

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-M: $M_{-max} = \frac{WR}{2} (\frac{1}{\theta} - \cot \theta)$

T: $T = \frac{W}{2 \sin \theta}$

The value of $M_{\underline{+}}$ at which the tube will yield can be found from

$$M = \frac{F_{ty} I}{C}$$

where

F_{ty} = tensile yield for 6061-T6 aluminum = 37,000 psi

$I = \frac{bh^3}{12}$

b = unit length of tube = 1.0 in.

h = tube wall thickness = .125 in.

c = 1/2 h

Then

$$I = \frac{(1.0)(.125)^3}{12} = (1.63)(10^{-4}) \text{ in}^4/\text{in.}$$

$$c = \frac{.125}{2} = .0625 \text{ in.}$$

and

$$M_{\underline{+}} = \frac{(37,000)(1.63)(10^{-4})}{.0625} = 96.5 \text{ in-lb/in.}$$

Then solving for W in the above equations yield

$$W_{+max} = \frac{2M_{+max}}{R} \quad \frac{1}{(\frac{1}{\sin \theta} - \frac{1}{\theta})}$$

and

$$W_{-max} = \frac{2M_{-max}}{R} \quad \frac{1}{(\frac{1}{\theta} - \cot \theta)}$$

where

$M_{+max} = M_{-max} = M_{\underline{+}}$ = 96.5 in-lb/in.

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R = average tube radius = 2.56 in.

$2\theta = \frac{360}{5}$ = 72 degrees

θ = 36 degrees = .628 radius

$$\sin \theta = .588$$

$$\cot \theta = 1.376$$

Then

$$W_{+max} = 705 \text{ lb/in.}$$

$$W_{-max} = 352 \text{ lb/in.}$$

The tube will begin to yield plasticly at the lesser of these two values or at $W_{-} = 352$ lb per in. The shear is

$$T = \frac{352}{(2)(.588)} = 300 \text{ lb/in.}$$

The shear stress is

$$\sigma_{sh} = \frac{T}{A} = \frac{T}{bh} = \frac{300}{(1)(.125)} = 2400 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1$$

where

F_{su} = the shear strength of 6061-T6 aluminum = 28,000 psi

then

$$MS = \frac{28,000}{2,400} - 1 = \text{large}$$

Thus, the tube will collapse plastically before it will fail due to shear.

It is assumed that as the tube collapses down on the failed fuel can (a radial distance of about 1/8 in.), the tube configuration is sufficiently circular so that the collapsing force remains a constant 352 lb. Then the force which will act upon the failed fuel can is the difference between the applied load and the collapsing force, or

$$W_{ffc} = F\text{-}W = 465\text{-}352$$

$$= 113 \text{ lb/in.}$$

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The failed fuel can consists of a .062-in. thick aluminum tube with a close fitting .062 steel liner. To determine the force required to initiate plastic yielding of the aluminum outer shell, the same procedure is followed as for the analysis of the basket tube.

Thus

$$M_{-max} = \frac{\sigma I}{c} = \frac{F_{ty} I}{c}$$

$$F_{ty} = 37{,}000 \text{ psi}$$

$$I = \frac{bh^3}{12}$$

$$b = 1.0 \text{ in.}$$

$$h = .062 \text{ in.}$$

$$c = \frac{h}{2}$$

Then

$$I = \frac{(1)(.062)^3}{12} = (1.99)(10^{-5}) \text{ in}^4/\text{in.}$$

$$c = \frac{.062}{2} = .031 \text{ in.}$$

$$M_{-max} = \frac{(37{,}000)(1.99)(10^{-5})}{.037} = 23.8 \text{ in.-lb/in.}$$

$$W_{Al} = \frac{2M_{-max}}{R} \quad \frac{1}{\frac{1}{\theta} - \cot\theta}$$

In this case R = 2.344 in. and θ is 36 degrees as above.

Then

$$W_{Al} = 95 \text{ lb/in.}$$

The load which the steel liner must withstand then is

$$W_{Fe} = W_{fcc} - W_{Al} = 113 - 95 = 18 \text{ lb/in.}$$

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The stress in the steel liner is

$$\sigma_{Fe} = \frac{Mc}{I}$$

where

$$M = M_{-max} = -\frac{1}{2} W_{Fc} R \left(\frac{1}{\theta} - \cot \theta\right)$$

$R = 2.281$ in.

$\theta = 36$ degrees

$$I = \frac{bh^3}{12}$$

$b = 1.0$ in.

$h = .062$ in.

$$c = \frac{h}{2} = .031 \text{ in.}$$

Then

$M = 4.39$ in.-lb/in.

$I = (1.99)(10^{-5}) in^4/in.$

and

$$\sigma_{Fe} = \frac{(4.39)(.031)}{(1.99)(10^{-5})} = 6850 \text{ psi}$$

The margin of safety is

$$MS = \frac{F_{ty}}{\sigma_{Fc}} - 1 = \frac{34,500}{6,850} - 1 = 4.0$$

Thus, although some of the basket tubes will yield plastically, the failed fuel can will adequately protect the fuel elements.

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2.10 Appendix

POOR ORIGINAL

2.10.1

REFERENCES

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(10) McFarland, R.K., Jr., "The Development of Metal Honeycomb Energy-Absorbing Elements", Technical Report No. 32-639, Jet Propulsion Laboratory, Pasadena, California (July 24, 1964).

(11) Roark, Raymond J., Formulas for Stress and Strain, Fourth Edition, McGraw-Hill Book Company, New York (1965).

(12) Ibid., page 216.

(13) Ibid., Chapter 12, page 248.

(14) Letter and Data Package from D. Guggisberg, Head of Hot Cell Operations, Gulf General Atomic, Inc., San Diego, California, to Mr. George H. Bidinger, Irradiated Fuels Branch, Division of Materials Licensing, USAEC, Washington, D.C., Docket 70-72 (March 23, 1969).

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2.10 Appendix

2.10.1

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(2) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 2", Philadelphia Electric Company, Docket 50171-3 (March 3, 1964).

(3) "Peach Bottom Atomic Power Station No. 1 Final Hazards Summary Report, Part C., Vol. 3", Philadelphia Electric Company, Docket 50171-4 (March 3, 1964).

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(6) "Packaging of Radioactive Material for Transport", Code of Federal Regulations, Title 10, Part 71 (December 31, 1968).

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2.10.2

APPENDIX B

COMPUTER PROGRAM FLOW CHART FOR ANALYSIS OF STRESSES IN SHELL AND TRUNNION

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POOR ORIGINAL

COMPUTER PROGRAM FLOW CHART FOR ANALYSIS OF STRESSES IN SHELL AND TRUNNION

The equations for stresses in the shell of the cask as defined by Roark* for a trunnion attached to a flat plate are as follows:

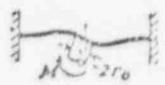
Equation 1:

Edges supported
9. Central couple (trunnion loading)

$$(\text{At } r = r_0)\ \text{Max } s_r = \frac{3M}{4\pi t^2 r_0}\left[1 + \left(\frac{m+1}{m}\right)\log\frac{2(a-r_0)}{Ka}\right] \quad \text{where } K = \frac{0.1a^3}{(r_0+0.7a)^3}$$

Equation 2:

Edges fixed
10. Central couple (trunnion loading)



$$(\text{At } r = r_0)\ \text{Max } s_r = \frac{3M}{4\pi t^2 r_0}\left[1 + \left(\frac{m+1}{m}\right)\log\frac{2(0.45a-r_0)}{0.45ka}\right]$$

$$\text{where} \quad k = \frac{0.1a^3}{(r_0+0.25a)^3}$$

Equation 3:

Outer edge fixed and supported
18. Uniform load along inner edge

$$(\text{At outer edge})\ \text{Max } s_r = \frac{3W}{2\pi t^2}\left[1 - \frac{2mb^2 - 2b^2(m+1)\log\frac{a}{b}}{a^2(m-1)+b^2(m+1)}\right] = \text{Max } s \text{ when } \frac{a}{b} < 2.4$$

$$(\text{At inner edge})\ \text{Max } s_t = \frac{3W}{2\pi m t^2}\left[1 + \frac{ma^2(m-1) - mb^2(m+1) - 2(m^2-1)a^2\log\frac{a}{b}}{a^2(m-1)+b^2(m+1)}\right] = \text{Max } s \text{ when } \frac{a}{b} > 2.4$$

$$\text{Max } y = -\frac{3W(m^2-1)}{4\pi m^2 E t^3}\left\{a^2 - b^2 + \frac{2mb^2(a^2-b^2) - 8ma^2b^2\log\frac{a}{b} + 4a^2b^2(m+1)\left(\log\frac{a}{b}\right)^2}{a^2(m-1)+b^2(m+1)}\right\}$$

Equation 4:

Outer edge fixed and supported. Inner edge fixed
20. Uniform load along inner edge

$$(\text{At outer edge})\ s_r = \frac{3W}{2\pi t^2}\left[1 - \frac{2b^2}{a^2-b^2}\left(\log\frac{a}{b}\right)\right]$$

$$(\text{At inner edge})\ \text{Max } s_r = \frac{3W}{2\pi t^2}\left[1 - \frac{2a^2}{a^2-b^2}\left(\log\frac{a}{b}\right)\right] \qquad \text{Max } y = -\frac{3W(m^2-1)}{4\pi m^2 E t^3}\left[a^2 - b^2 - \frac{4a^2b^2}{a^2-b^2}\left(\log\frac{a}{b}\right)^2\right]$$

where

- M = Pe
- P = Bending force on the trunnion
- e = Moment arm = 1/2 (STK + PP + TL)
- STK = Shell thickness
- PP = Patch plate thickness
- TL = Trunnion length
- t = STK + PP
- r_o = Outside radius of the trunnion
- m = 1/poissons ratio
- a = Patch plate radius
- W = Pull out force
- B (equations 3 and 4) = r_o

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* Roack, R.J., Formulas for Stress and Strain, 4th edition, McGraw-Hill Book Company, New York, Chapter 10, Table X.

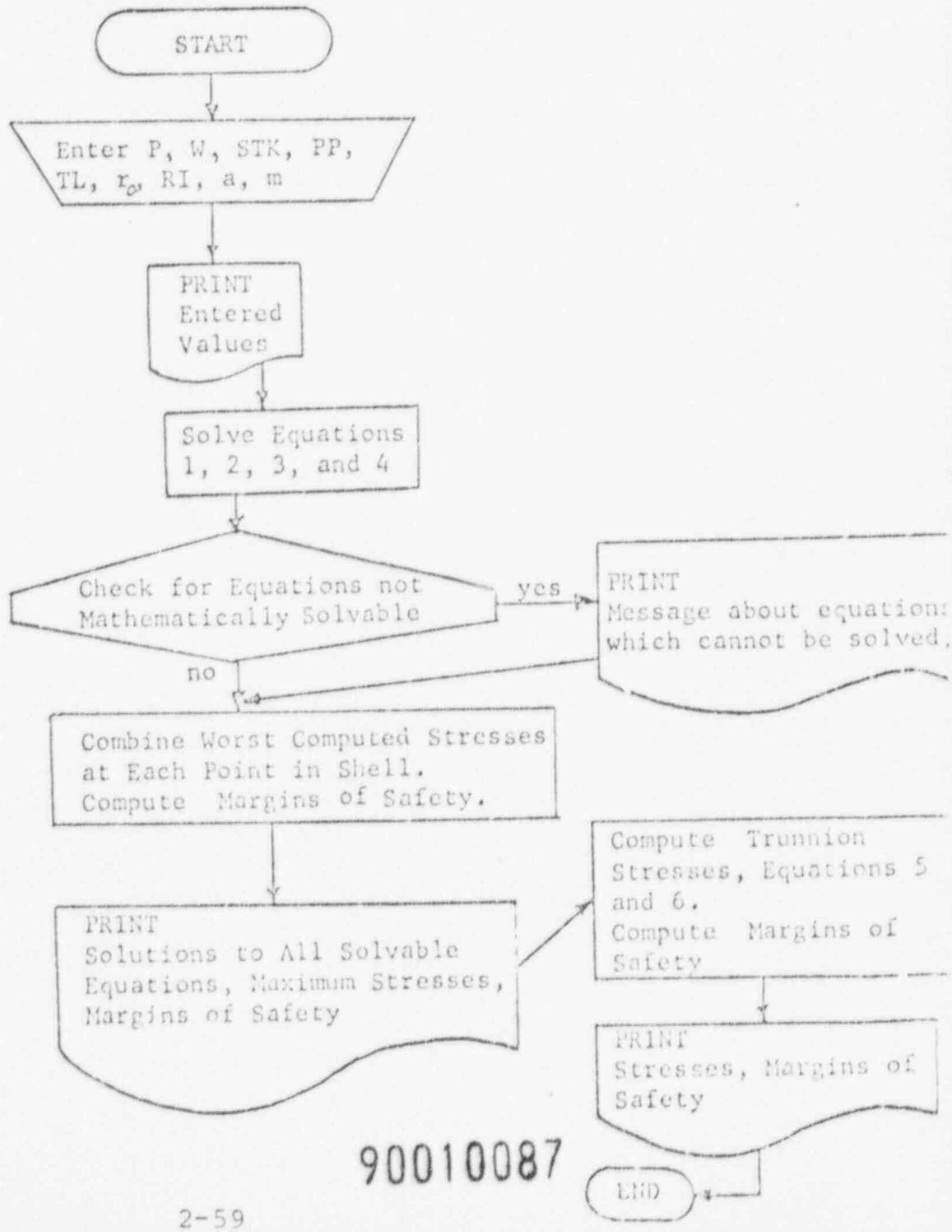
The equations for stress in the trunnion are as follows:

Equation 5: $$\sigma_f = \frac{MC}{I} + \frac{W}{A} = \frac{4M\,r_o}{\pi\,(r_o^4 - RI^4)} + \frac{W}{\pi\,(r_o^2 - RI^2)}$$

Equation 6: $$\sigma_{sh} = \frac{P}{A} = \frac{P}{\pi\,(r_o^2 - RI^2)}$$

where RI = the inside radius of the trunnion and the other terms are as above.

The flow chart of the computer program is presented below.



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2.10.3

APPENDIX C

DESIGN DATA FOR METALLIC TUBE IMPACT LIMITERS

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DESIGN DATA FOR METALLIC TUBE IMPACT LIMITERS

McFarland* investigated the energy absorption properties of all metallic devices under static loading and dynamic loading conditions up to impact velocities of about 50 fps. He was able to show that over this range of impact velocities the structures responded almost identically as under static loading. He investigated two materials, aluminum and maraging steel, and three device configurations, close-packed tubes, loose-packed tubes and hexagonal-cell honeycomb. Figure C-1 illustrates the three configurations.

The specific energy absorption of the impact limiters is defined as

$$E_{sp} = \frac{\sigma_{mc}\ \eta}{\rho_u} \qquad \text{(C-1)}$$

where

E_{sp} = specific energy, in.-lb. per lb.

σ_{mc} = mean crushing stress, psi

η = thickness efficiency (also called stroke efficiency)

ρ_u = unit weight, lb. per cu. in.

The specific energy is a measure of the degree to which the mass of the impact absorber is utilized in absorbing the kinetic energy of the impacting body. The mean crushing stress is the average stress at which the absorber structure will begin to deform. Ideally, the collapse of the impact absorber structure will continue at this same stress level until all the kinetic energy is absorbed, or until the structure is completely collapsed. The ratio of the maximum distance the absorber will collapse until "bottoming" occurs to the original height of the structure is the thickness efficiency (stroke efficiency) of the structure. The unit weight is the weight per unit volume occupied by the composite structure, Figure C-1. The unit weight is a geometrical relationship of tube or honeycomb cell configurations and, as shown in Figure C-1, it is only a function of the wall thickness, tube diameter (or cell size) and specific weight of the material of construction. The weight of the end plates or other attachments is not included.

The typical collapse response of the tubes and honeycomb cell structures under axial loading is to form multiple convolutions as shown in the sketch in Figure C-2. The energy is absorbed during collapse in one of three different ways, rigid-plastic, elastic, or elastic-plastic. The stress pattern for the three ways is shown schematically in Figure C-3. McFarland presents experimental data for steel hexagonal cell honeycomb structures which correlate very well with relationships obtained by other investigators for the rigid-plastic mode of response, Figure C-3. These results show that the mean crushing stress can be expressed by the equation,

$$\sigma_{mc} = 40.53\ \sigma_y \left(\frac{t}{s}\right)^2 \qquad \text{(C-2)}$$

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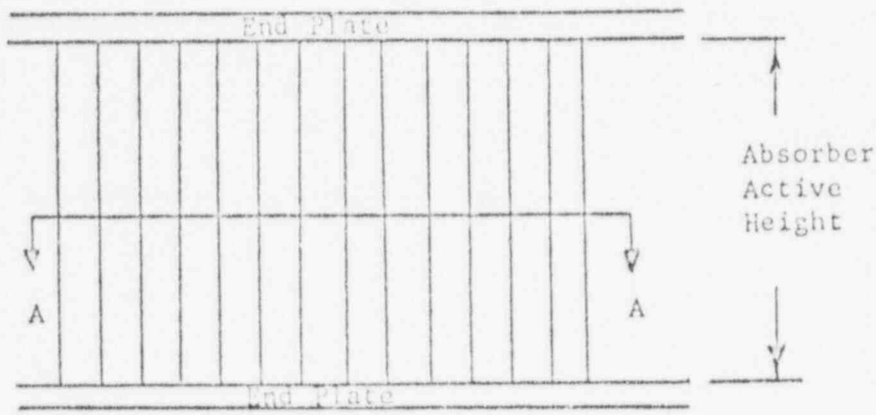
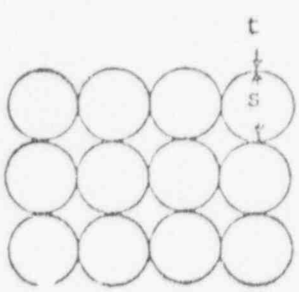
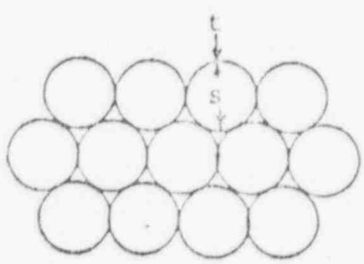
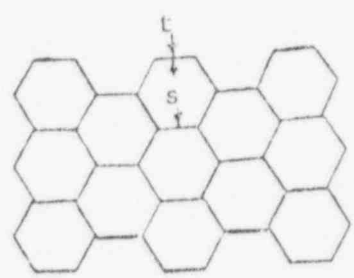
* McFarland, R.K., Jr., The Development of Metal Honeycomb Energy - Absorbing Elements, Jet Propulsion Laboratory, Pasadena, California, Technical Report No. 32-639, July 24, 1964.



Loose Packed Tubes	Close Packed Tubes	Hexagonal Cell Honeycomb







$\rho_u = \pi\rho \frac{t}{s}$	$\rho_u = \frac{2\pi}{3} \rho \frac{t}{s}$	$\rho_u = \frac{8}{3} \rho \frac{t}{s}$
rho	rho	rho

ρ_u = unit weight

ρ = material specific weight

t = wall thickness

s = mean diameter or cell size

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FIGURE C-1. THREE IMPACT LIMITER CONFIGURATIONS INVESTIGATED BY McFARLAND AND DEFINITION OF THEIR UNIT WEIGHTS

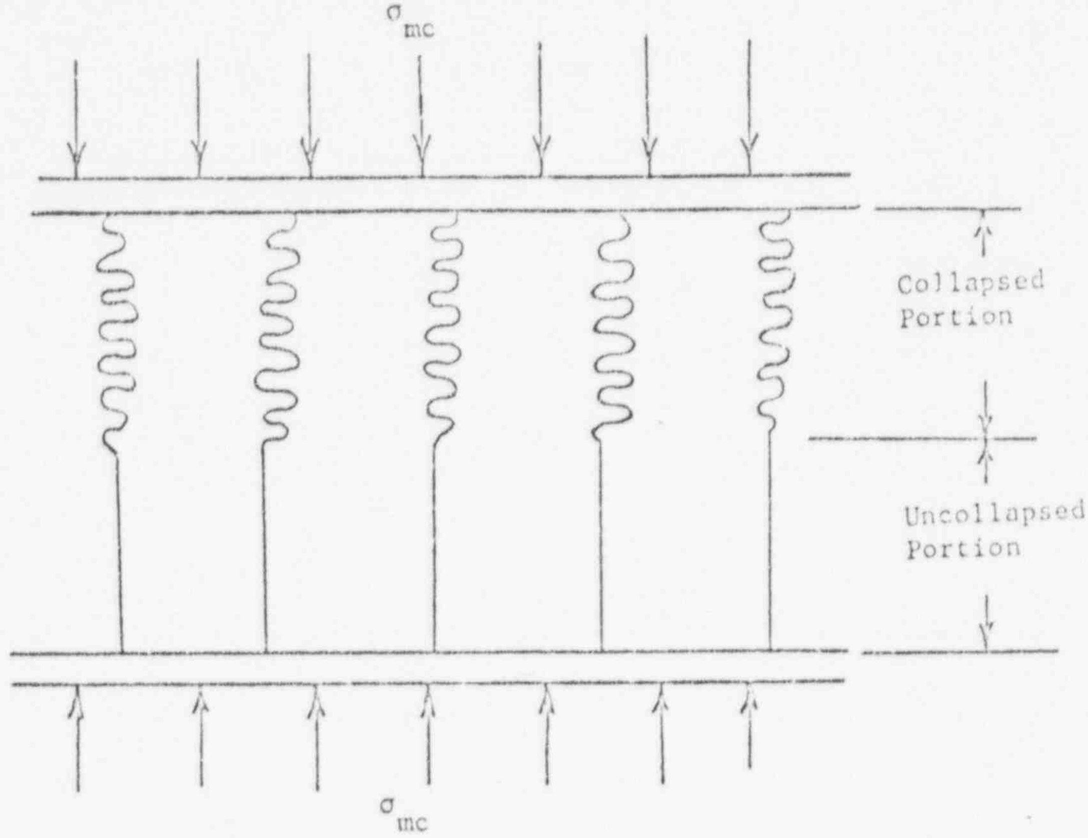

FIGURE C-2. TYPICAL COLLAPSE MODE OF TUBE OR HEXAGONAL CELL HONEYCOMB IMPACT ABSORBER STRUCTURE

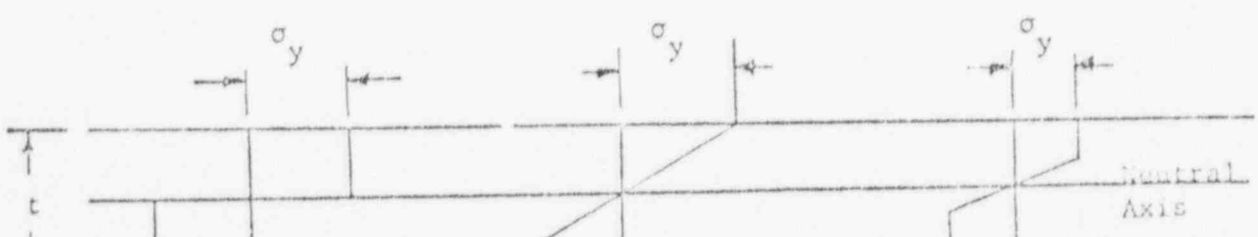

FIGURE C-3. STRESS PATTERN FOR THE THREE MODES OF ABSORBER RESPONSE

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McFarland subsequently concludes that the specific energy of the tubular structures can be closely approximated by using computed data for the hexagonal cell honeycomb. Thus, Equation C-1 can be written for the case of a hexagonal cell and a tubular structure and the two equated.

$$E_{sp_{hex}} = \left(\frac{\sigma_{mc}\,\eta}{\rho_u}\right)_{hex} = E_{sp_{tube}} = \left(\frac{\sigma_{mc}\,\eta}{\rho_u}\right)_{tube} \qquad \text{(C-3)}$$

Data is also presented by McFarland which shows that the thickness efficiencies for the three types of structures illustrated in Figure C-1 differ by only about 5 percent. Thus, in Equation C-3, if it is assumed that $\eta_{hex} = \eta_{tube}$, the equation can be rewritten as

$$\left(\frac{\sigma_{mc}}{\rho_u}\right)_{hex} = \left(\frac{\sigma_{mc}}{\rho_u}\right)_{tube} \qquad \text{(C-4a)}$$

or

$$\sigma_{mc_{tube}} = \sigma_{mc_{hex}}\left(\frac{\rho_{u_{tube}}}{\rho_{u_{hex}}}\right) \qquad \text{(C-4b)}$$

Substituting the values of ρ_u from Figure C-1 in the above equations yields

<u>close pack tubes</u>

$$\sigma_{mc_{cp}} = \frac{3\pi}{4}\,\sigma_{mc_{hex}}$$

$$\sigma_{m_{cp}} = 55.13\,\sigma_y\left(\frac{t}{s}\right)^2 \qquad \text{(C-5)}$$

and

<u>loose pack tubes</u>

$$\sigma_{mc_{LP}} = \frac{3\pi}{8}\,\sigma_{mc_{hex}}$$

$$\sigma_{mc_{LP}} = 47.74\,\sigma_y\left(\frac{t}{s}\right)^2 \qquad \text{(C-6)}$$

The curves in Figure C-4 are equations C-2, C-5, and C-6 plotted for the case where σ_y = 60,000 psi. This is the yield strength quoted by vendors for carbon

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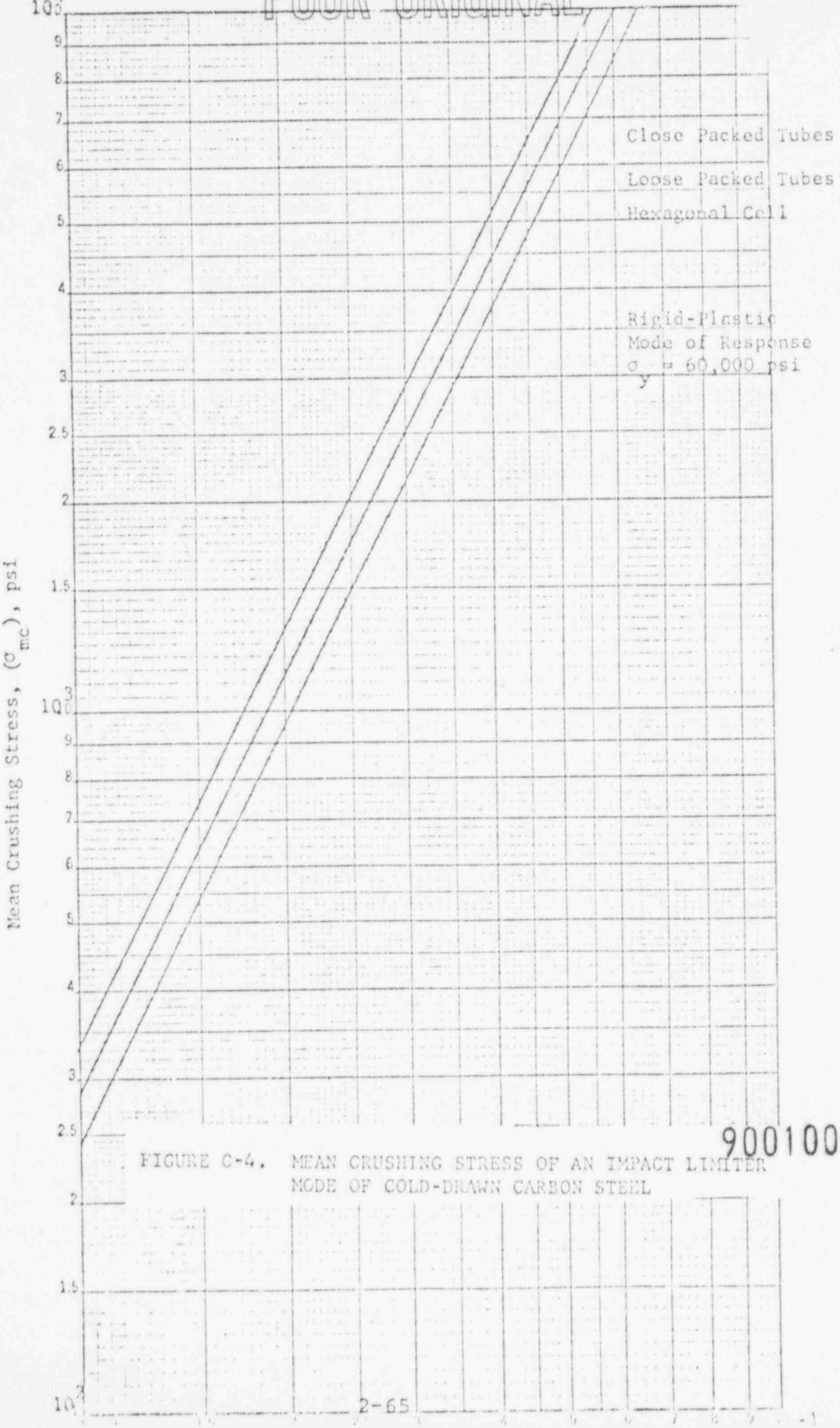

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FIGURE C-4. MEAN CRUSHING STRESS OF AN IMPACT LIMITER MODE OF COLD-DRAWN CARBON STEEL

steel (.10 to .25 percent carbon), cold drawn mechanical tubing. These curves, the data presented in Figure C-1, and the equation given by McFarland for the thickness efficiency of steel hexagonal cell honeycomb structures,

$$\eta = 88.13 - 329 \frac{t}{s}$$

were used to design the impact limiter.

2.10.4

APPENDIX D

COMPUTER PROGRAM FLOW CHART FOR THE ANALYSIS OF A CORNER IMPACT

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COMPUTER PROGRAM FLOW CHART FOR THE ANALYSIS OF A CORNER IMPACT

The computer program for the analysis of the forces acting on a cask during impact on a corner was written for the worst case, that in which the line of action of the resultant force passes through the "corner" of the cask and the center of mass. The program includes the case where the end of the cask is protected by an energy absorbing device (impact limiter). Figure D-1 is a sketch of the cask when the impact limiter has been partly deformed.

The decelerating force, F, is the product of the area in contact with the impacting surface and the average pressure of that area on the impacting surface. The impact limiter is designed to primarily absorb energy by collapse in the axial direction only, i.e., the line of action of the axial collapsing force F_c in Figure D-1c. The energy absorbed by collapse in the radial direction, line of action of F_s in Figure D-1c, is minimal since the impact limiter is designed so that the shear stresses produced by the force, F_s, remain below the shear yield strength of the impact limiter. Then from Figure D-1, the decelrating force is

$$F = (F_c)(\cos \alpha)$$

$$= (\sigma_{mc})(A)(\cos \alpha) \qquad \text{(D-1)}$$

where

$F_c = \sigma_{mc} A$

σ_{mc} = mean axial collapsing stress of the impact limiter

A = the contact area

α = the angle of impact of the cask.

Since the contact area, A, increases as the impact limiter continues to deform, distance d in Figure D-1, the deceleration force continues to increase. In order to solve the problem, the computer code was written to calculate F at any instant during the impact of the cask. From Figure D-2, the contact area for any deformation d, is for $a < r$

$$A_d = [\pi r^2 (\frac{2\theta}{2\pi}) - (r_{\sin}\theta)(r_{\cos}\theta)] \frac{1}{\cos \alpha} \qquad \text{(D-2a)}$$

$$A_d = \frac{r^2}{\cos \alpha} (\theta - \sin \theta \cos \theta)$$

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Similarly for $a > r$

$$A_d = \frac{r^2}{\cos \alpha} (\theta + \sin \theta \cos \theta) \qquad \text{(D-2b)}$$

After continued deformation through the additional distance, Δd, the area for $a < r$ is

$$A_{d + \Delta d} = \frac{r^2}{\cos \alpha} [(\theta + \Delta\alpha) - \sin (\theta + \Delta\theta) \cos (\theta + \Delta\theta)] \qquad \text{(D-3a)}$$

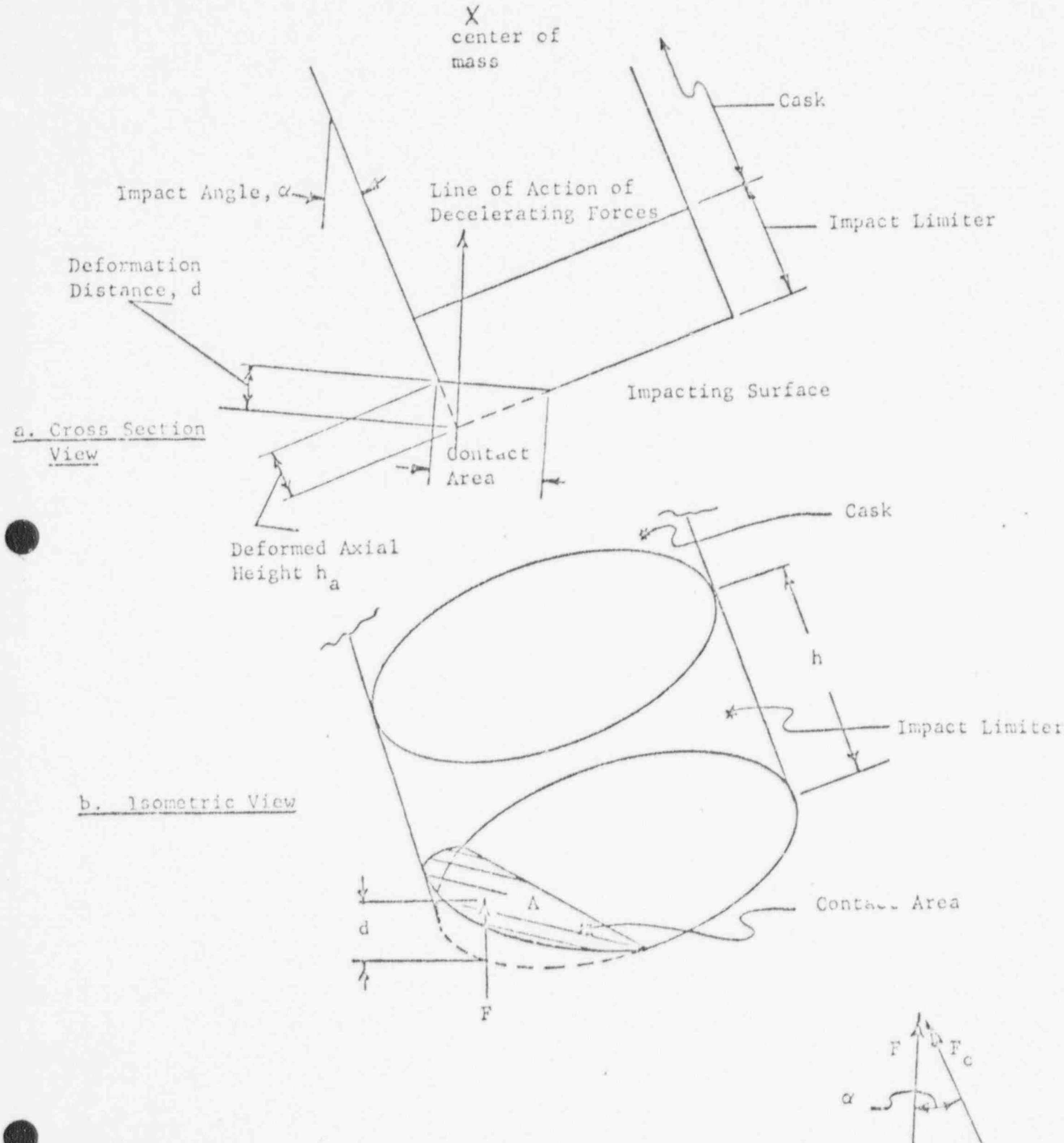

FIGURE D-1. SKETCH OF CASK DURING IMPACT AT POINT WHEN IMPACT LIMITER IS PARTLY DEFORMED

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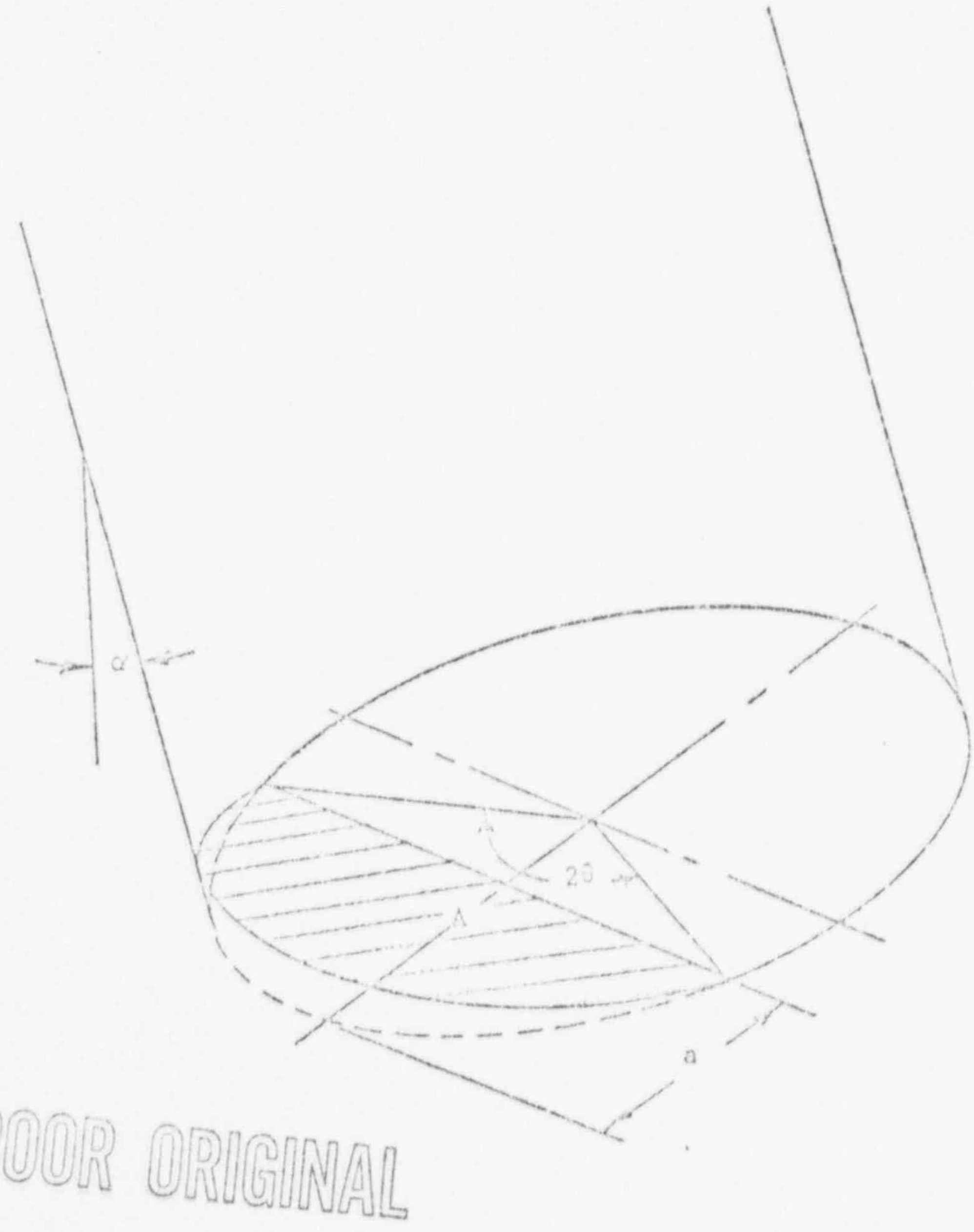

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FIGURE D-2. CONTACT AREA FOR a < r.

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and for $a > r$

$$A_{d + \Delta d} = \frac{r^2}{\cos \alpha} [(\theta + \Delta\theta) + \sin (\theta + \Delta\theta) \cos (\theta + \Delta\theta)] \qquad \text{(D-3b)}$$

The average force acting through the deformation distance, Δd, was taken as the product of the contact pressure and the average of the two areas at d and at $(d + \Delta d)$. Thus

$$F = F_c(\cos \alpha) \left(\frac{A_d + A_{d + \Delta d}}{2}\right) \qquad \text{(D-4)}$$

Then if V_d is the velocity of the cask at deformation d, the velocity at $d + \Delta d$ is

$$V_{d + \Delta d} = [(V_d)^2 - \frac{64.4\ F}{W} (\Delta d)]^{1/2} \qquad \text{(D-5)}$$

where

W = weight of the cask

and the other terms are as defined above. The program then continued to increase the deformation, d, in increments of Δd until the velocity of the cask was reduced to zero.

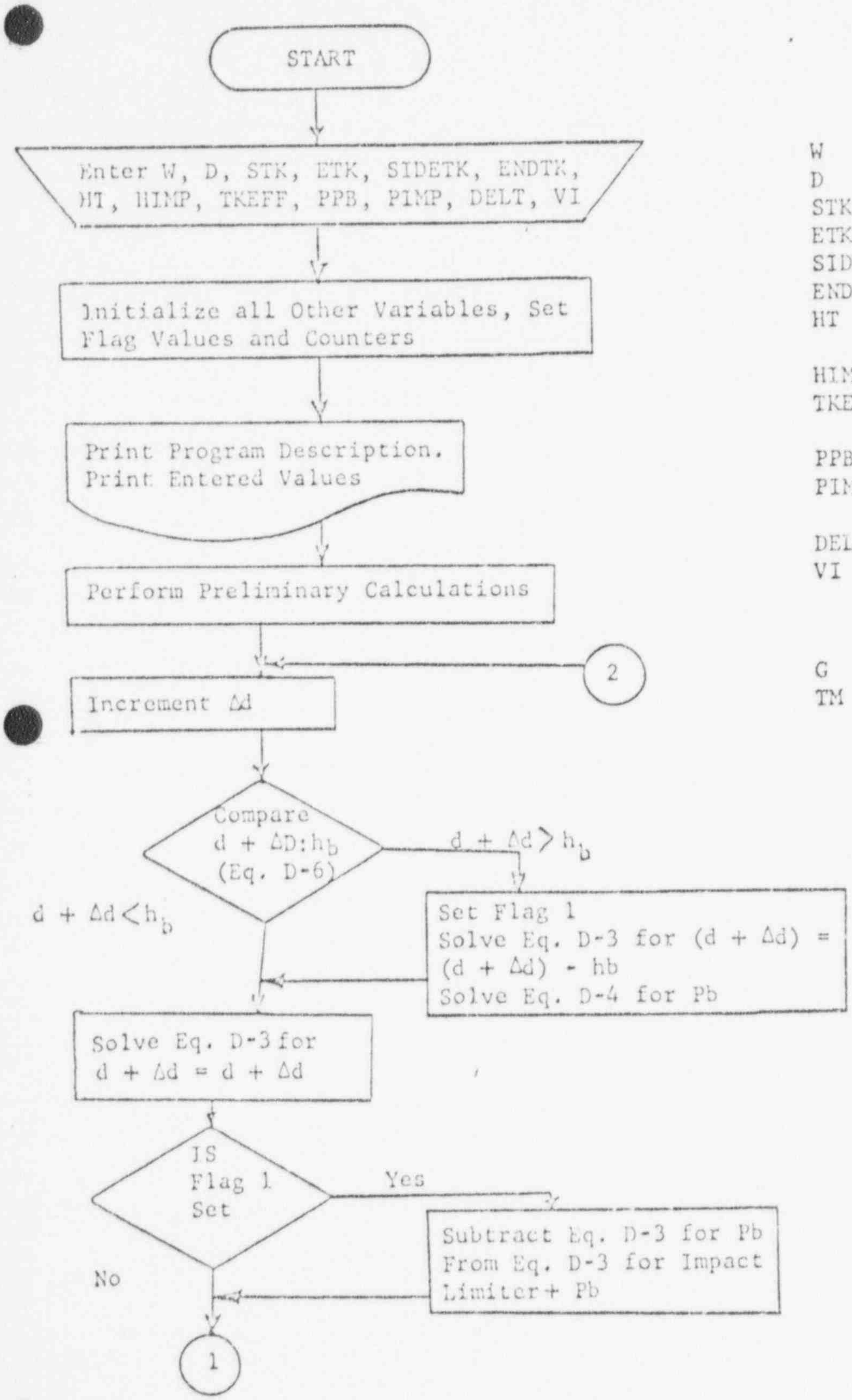
The calculation of the decelerating force was modified when, during the execution of the program, the deformed axial height of the impact limiter, h_a in Figure D-1a equaled the stroke distance defined as

$$h_b = h\eta \qquad \text{(D-6)}$$

where

h = impact limiter active height (Figure D-1a)
η = thickness (or stoke) efficiency of the impact limiter.

At this point, it was assumed that no more energy could be absorbed by those portions of the impact limiter which had "bottomed". In addition, no credit is taken for energy absorbed by deformation of the shell of the cask. Therefore, for continued deformation, energy was assumed to be absorbed in the lead portions of the cask as well as in those portions of the impact limiter not yet bottomed. The contribution of the lead to the decelerating force was evaluated according to Equations D-1 and D-4 as for the impact limiter except that for the lead, the term, $\cos \alpha$, was omitted since energy absorption by deformation of the lead is not directional. The lead flow pressure, commonly accepted as 10,000 psi, was used for the term F_c in these equations. A flow chart of the program is presented in Figure D-3.



Variable Names

Input

W	cask weight
D	cask diameter
STK	side shell thickness
ETK	end shell thickness
SIDETK	side lead thickness
ENDTK	end lead thickness
HT	cask height (without impact limiter)
HIMP	impact limiter height
TKEFF	thickness efficiency of impact limiter
PPB	lead flow pressure
PIMP	mean crushing stress of impact limiter
DELT	deformation increment
VI	initial velocity

Other

G	deceleration
TM	time

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FIGURE D-3. FLOW CHART OF COMPUTER PROGRAM TO CALCULATE DECELERATION OF CASK IMPACTING ON A CORNER

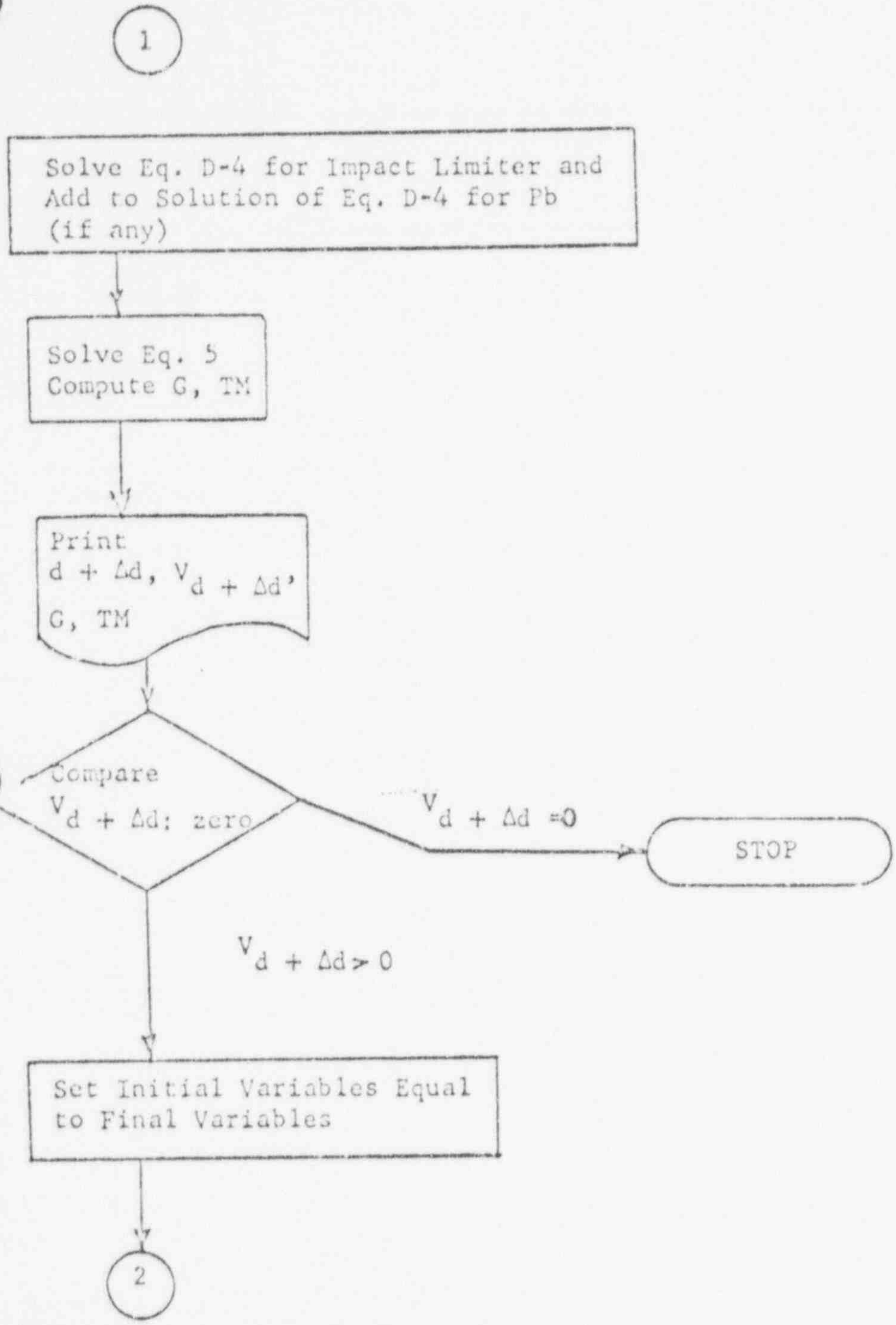

FIGURE D-3. (Continued)

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2.10.5

APPENDIX E

COMPUTER PROGRAM FLOW CHART FOR THE ANALYSIS OF A SIDE IMPACT

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COMPUTER PROGRAM FLOW CHART FOR THE ANALYSIS OF A SIDE IMPACT

The computer program for a side impact of a cask on a flat, unyielding surface was written to accommodate a cask with stepped sides. It neglects energy absorption by yielding of the cask shell and assumes that all energy is absorbed in deformation of the lead. The decelerating force at any instant during the impact is the product of the area of lead in contact with the unyielding surface and the flow pressure of lead (commonly accepted as 10,000 psi). From Figure E-1 it is seen that the area in contact with the unyielding surface varies as the deformation, d, increases.

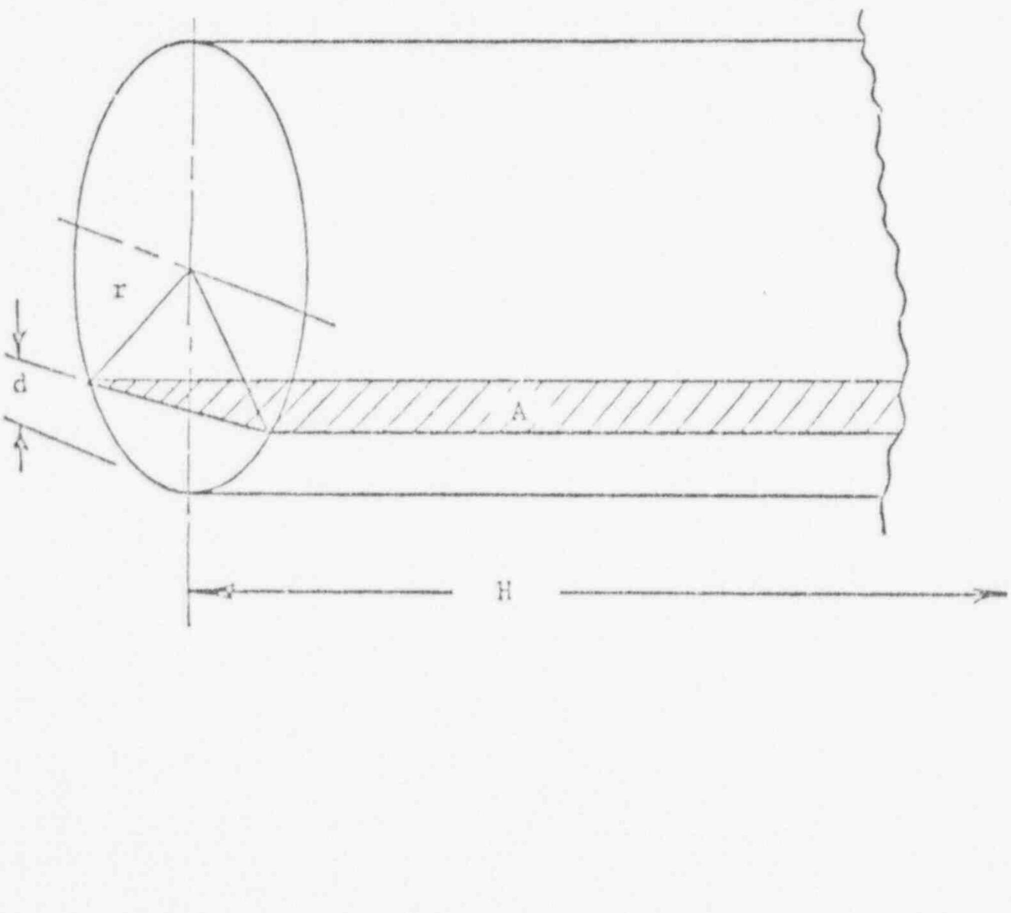

FIGURE E-1. CONTACT AREA FOR CASK UNDER SIDE IMPACT

90010103

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Thus,

$$A_d = 2\ [r^2 - (r-d)^2]^{1/2}\ H$$

$$A_d = 2\ (2rd - d^2)^{1/2}\ H \quad \text{(E-1)}$$

Similarly after additional deformation through a distance Δd, the area is

$$A_{d + \Delta d} = 2\ [2r\ (d + \Delta d) - (d + \Delta d)^2]^{1/2}\ H \quad \text{(E-2)}$$

The average deceleration force acting through the distance Δd is

$$F = P\ \left(\frac{A_d + A_{d + \Delta d}}{2}\right) \quad \text{(E-3)}$$

where

P = the lead flow pressure.

The velocity at the end of the deformation increment is

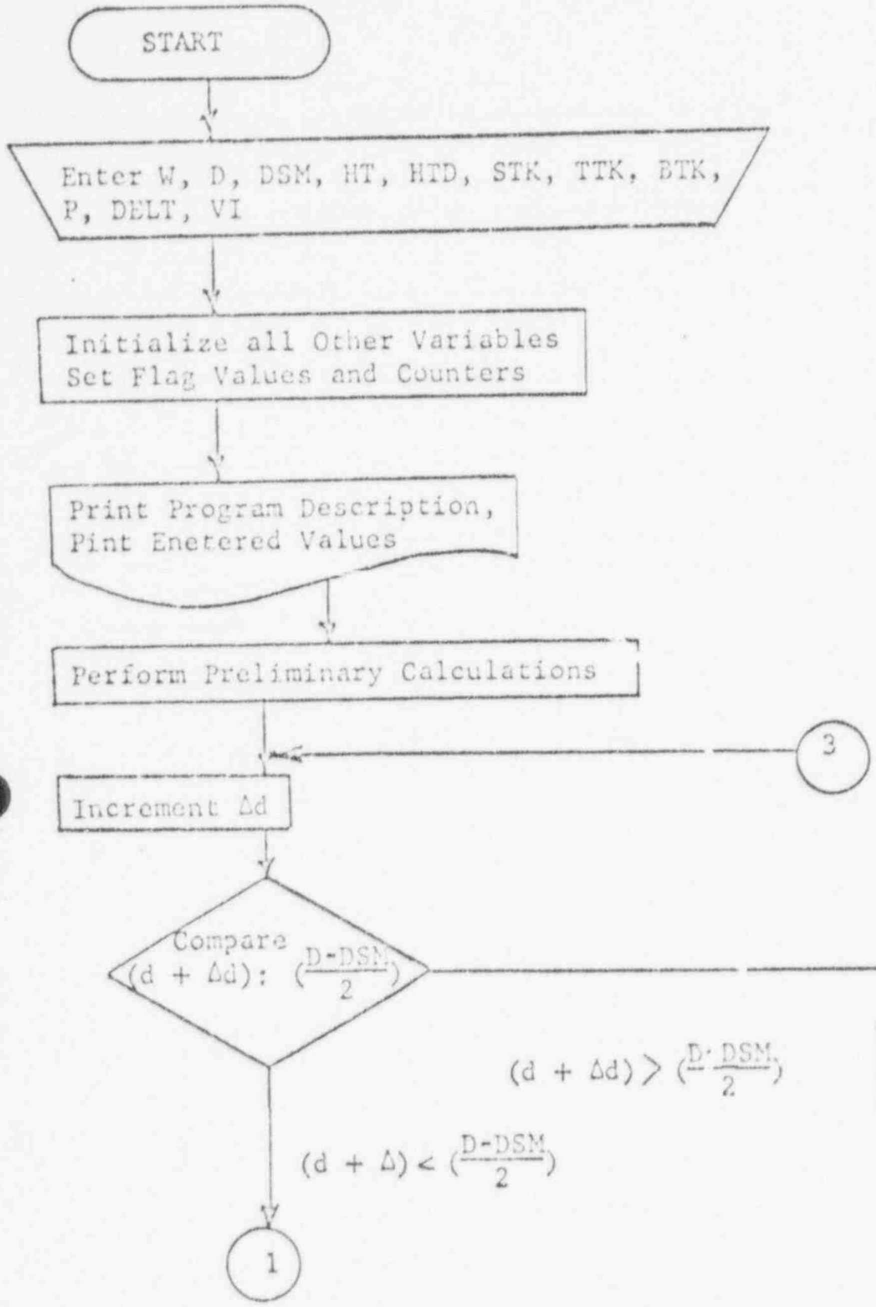
$$V_{d + \Delta d} = [(V_d)^2 - \frac{64.4\ F}{W}\ (\Delta d)]^{1/2} \quad \text{(E-4)}$$

where

W = weight of the cask
V_d = velocity at the beginning of the deformation increment.

The program increases the deformation in increments of Δd until the velocity of the cask is reduced to zero. The length of lead undergoing deformation, H, is initially taken as the length of lead in the larger diameter section of the stepped cask. When the deformation has proceeded until the lead in the smaller diameter section also comes into contact with the impacting surface, the above calculations are repeated for the geometry of this portion of the cask. The total decelerating force then is the sum of the contributions from each portion of the cask. A flow chart of the program is presented in Figure E-2.

90010104



Variable Names

Impact

W	cask weight
D	cask diameter, large step
DSM	cask diameter, small step
HT	cask weight
HTD	length of large diameter s
STK	shell side thickness
TTK	shell thickness, top end
BTK	shell thickness, bottom e:
P	lead flow pressure
DELT	deformation increment
VI	initial velocity

FIGURE E-2. FLOW CHART OF COMPUTER PROGRAM TO CALCULATE DECELERATION OF CASK IMPACTING ON A SIDE

90010105

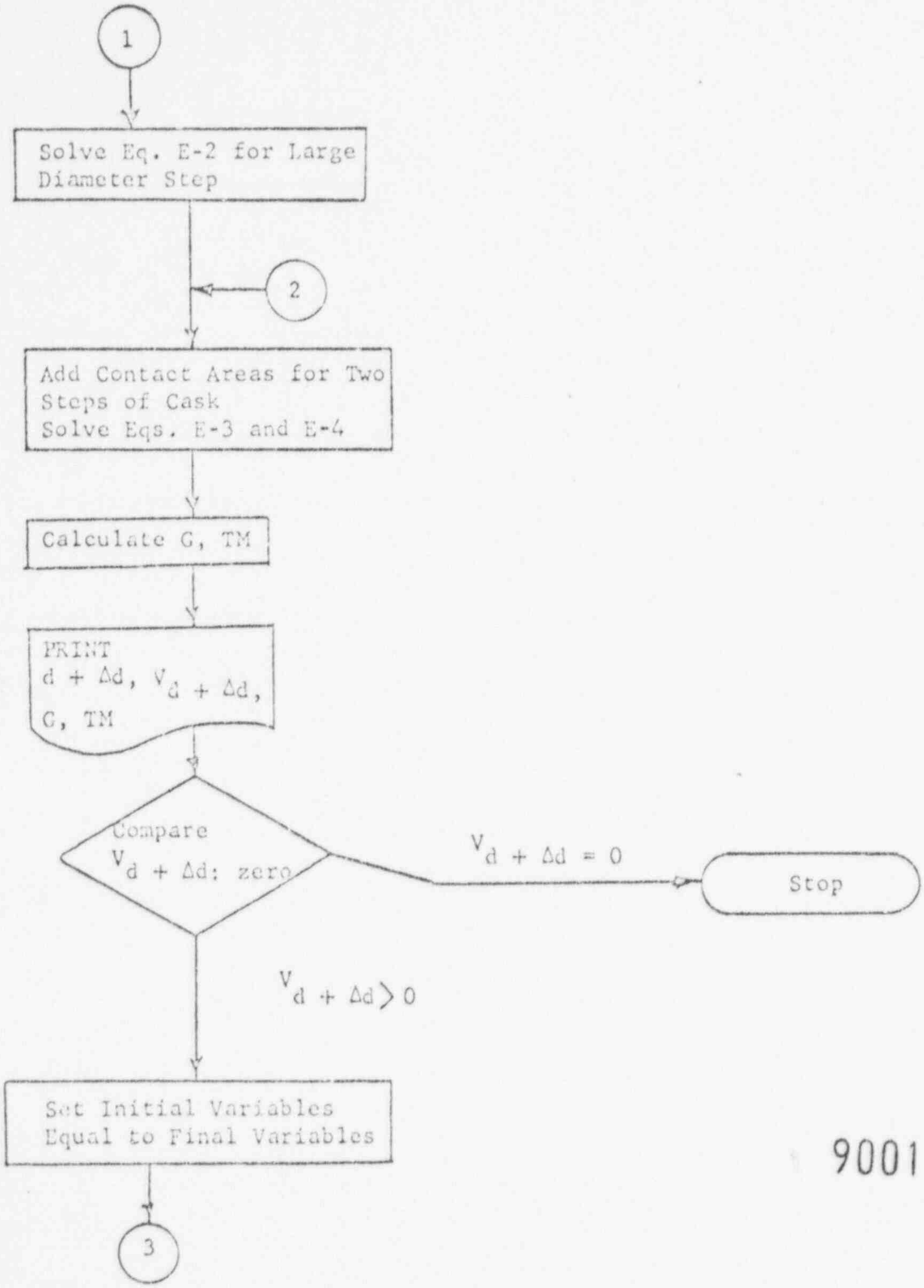


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FIGURE E-2. (Continued)

III

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3.0 THERMAL EVALUATION

3.1 Discussion

The thermal analysis presented in this section examines the thermal condition of the W&K Model No. PB-1 cask when subjected to the normal conditions of transport outlined in Appendix A of 10-CFR-Part 71. This analysis section also examines the thermal response, and associated effects, of the W&K Model No. PB-1 cask when subjected to the hypothetical accident fire condition outlined in Appendix B of 10-CFR-Part 71. The normal conditions of transport as they apply to this analysis section are defined as (1) cask exposed to direct sunlight on 130 F day in still air, and (2) cask exposed to -40 F day in still air and shade. The hypothetical accident condition as it applies to this analysis section is defined as an environmental fire radiant thermal source having a temperature of 1475 F lasting for 30 minutes. In addition, the "standard fire" is defined to have an effective source emissivity of 0.9, and the thermal absorptivity of the exposed cask surface is defined to be 0.8.

Summary

A midplane cylindrical region of the W&K Model No. PB-1 cask was analyzed in detail to assess the potential for lead melt during a postulated hypothetical fire and to determine the normal thermal condition of the cask and its contents. This analysis considers heat transfer through the cylindrical wall of the cask. This is the most severe thermal condition which could exist since the top and bottom covers of the cask have sufficient thermal protection in the form of thick structural plates (i.e., 1.50-in. thick stainless steel cover inner plate + 1.50-in. thick stainless steel cover outer plates) and steel impact limiters. These structures provide a significant thermal capacitance and/or resistance.

The results of the thermal transient analysis indicate that the cask inner liner temperature reaches a maximum value of 416 F, 60 minutes after the hypothetical accident fire begins (30 minutes after the end of the hypothetical accident fire) and that the maximum lead temperature at any time during or after the fire is 426 F. The analysis assumed temperatures at commencement of the fire correspond to normal operation on a 100 F day with a 14,250 Btu/hr internal heat load. Since no lead melts during or after the fire, no lead is lost from the shield region. The temperature of the hottest aluminum fuel can 3 hours after the end of the hypothetical fire accident is 442 F which is safely below the limiting 500 F for the aluminum fuel cans set in the structural analysis section of this safety analysis report.

3.2 Thermal Model

3.2.1 Analytic Model

The thermal transient analysis was carried out using the THT-D[12] heat-transfer computer program. A cylindrical section representative of the midplane of the W&K Model No. PB-1 cask was analyzed. Figure 21 and Figure 22 illustrate the thermal models analyzed by the THT-D computer program.

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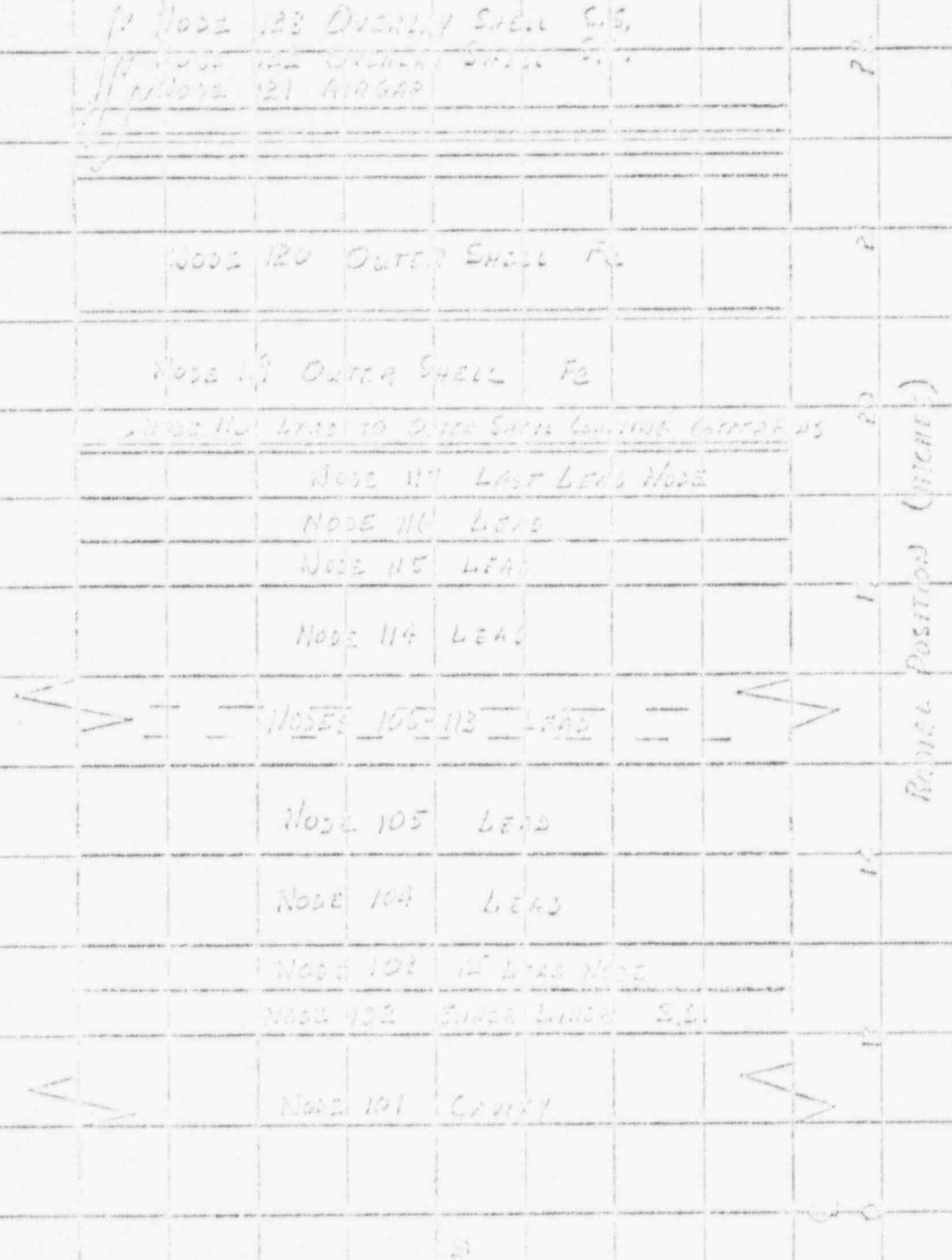
NODE 123 OVERLAY SHELL S.S.
NODE 121 AIRGAP
NODE 120 OUTER SHELL FE
OUTER SHELL FE
NODE 117 LAST LEAD NODE
NODE 116 LEAD
NODE 115 LEAD
NODE 114 LEAD
NODES 106-113 LEAD
NODE 105 LEAD
NODE 104 LEAD
NODE 101 CAVITY
RADIAL POSITION (INCHES)

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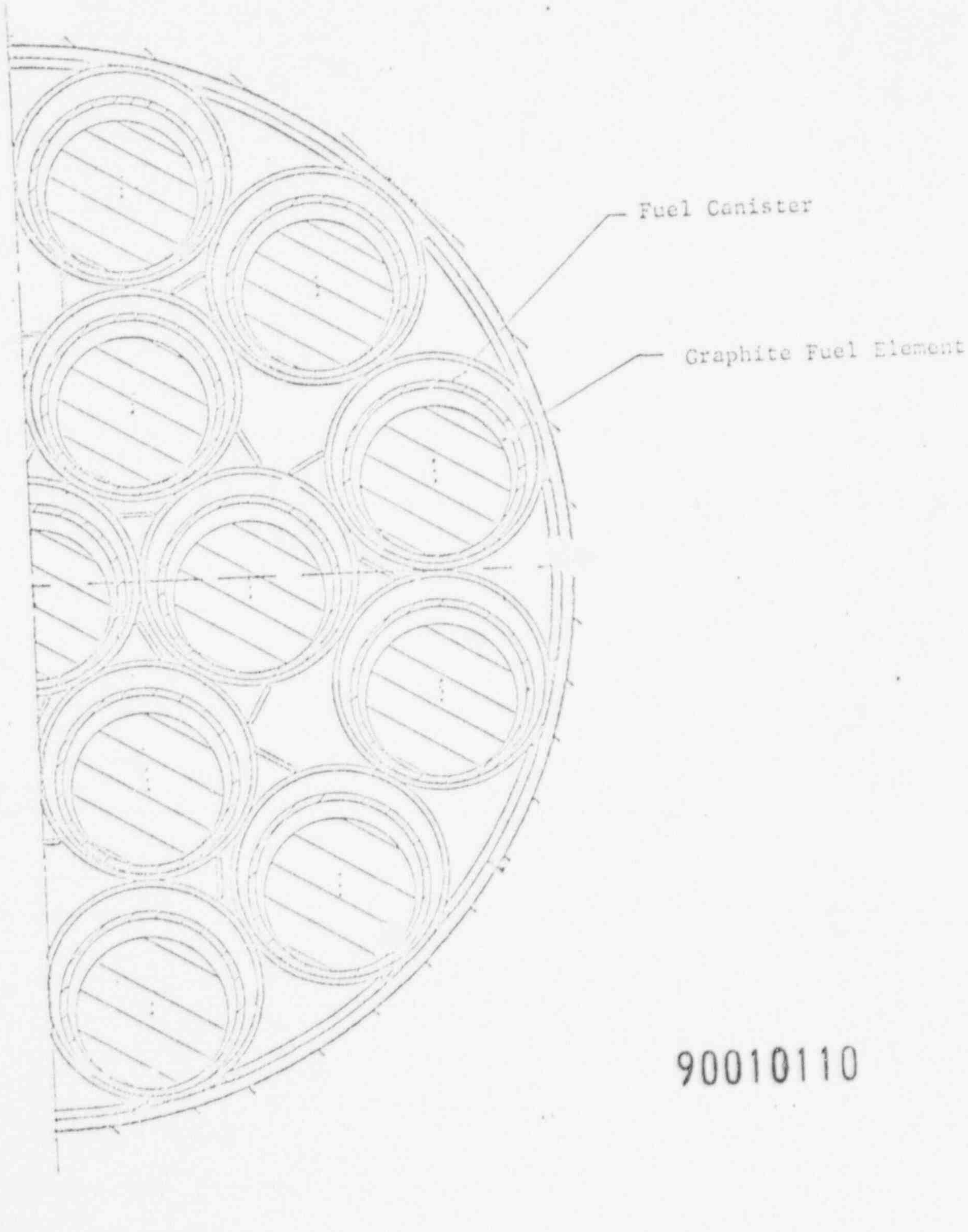

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FIGURE 22. THERMAL MODEL FOR BASKET REGION

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The design concept most significant to the thermal analysis of the W&K Model No. PB-1 shipping cask is that of a 0.25-inch thick stainless steel overlay shell (a thermal buffer shell) which encapsulates the cask body. The planned use of evenly spaced spot-welded spacers, 1/16-in. high, will assure an air gap between the overlay shell and the 1.50-in. thick steel outer shell. This air gap will impede the thermal pulse resulting from the hypothetical fire. A constant 0.125-in. air gap was used in the transient heat transfer analysis of the W&K Model No. PB-1 cask exposed to the hypothetical fire although it can be shown that as much as a 1/4-in. air gap would exist due to differences in thermal expansions during the fire period.

3.3 Hypothetical Accident Thermal Evaluation

The starting temperatures (at start of the 30-minute fire) of the cask system, shown in Figure 23, were calculated for conditions corresponding to a 100 F day and a cask thermal load of 14,250 Btu/hr. Normal condition operating temperatures for the cask system (130 F day, cask exposed to direct sunlight in still air and -40 F day, cask setting in the shade in still air are illustrated in Figure 24.

Since the cask system has a high thermal capacity, a 24-hour average solar load on a clear day at the summer solstice for 42 N latitude was used (see Figure 25). This solar load was computed for a horizontal surface having a cross-sectional area equivalent to the rectangular cross-section area of the W&K Model No. PB-1 cask (i.e., 42.5 in. x 173.12 in.) and having an average absorptivity of 0.55. The average solar load was computed to be

$$[51.5\ ft^2] \times [.55] \times [125\ Btu/hr\ ft^2] = 3540\ Btu/hr$$

where

$51.5\ ft^2$ = rectangular cross-sectional area of W&K Model No. PB-1 cask

.55 = surface absorptivity of cask

$125\ Btu/hr\text{-}ft^2$ = 24-hour average solar load

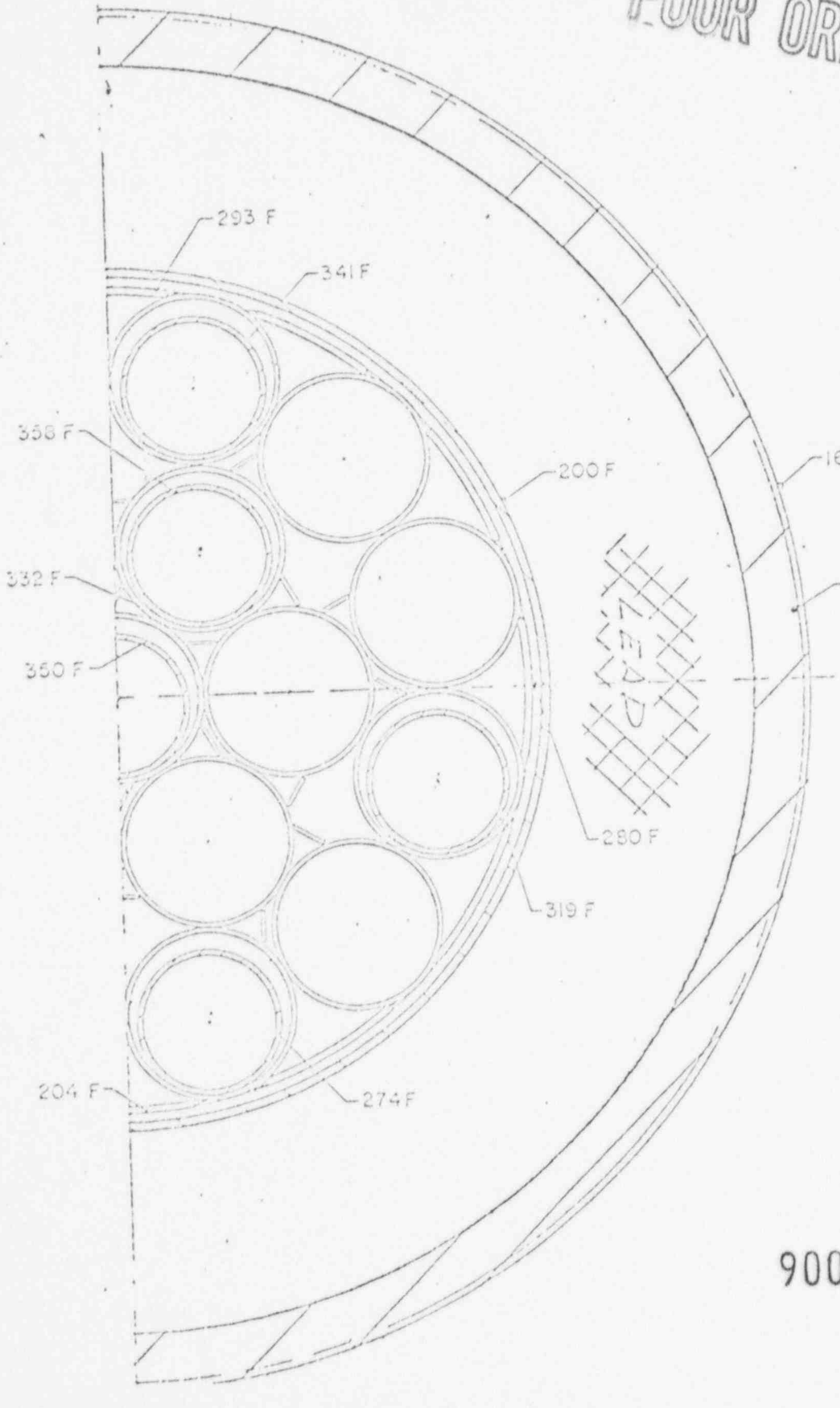
computed by the following equation

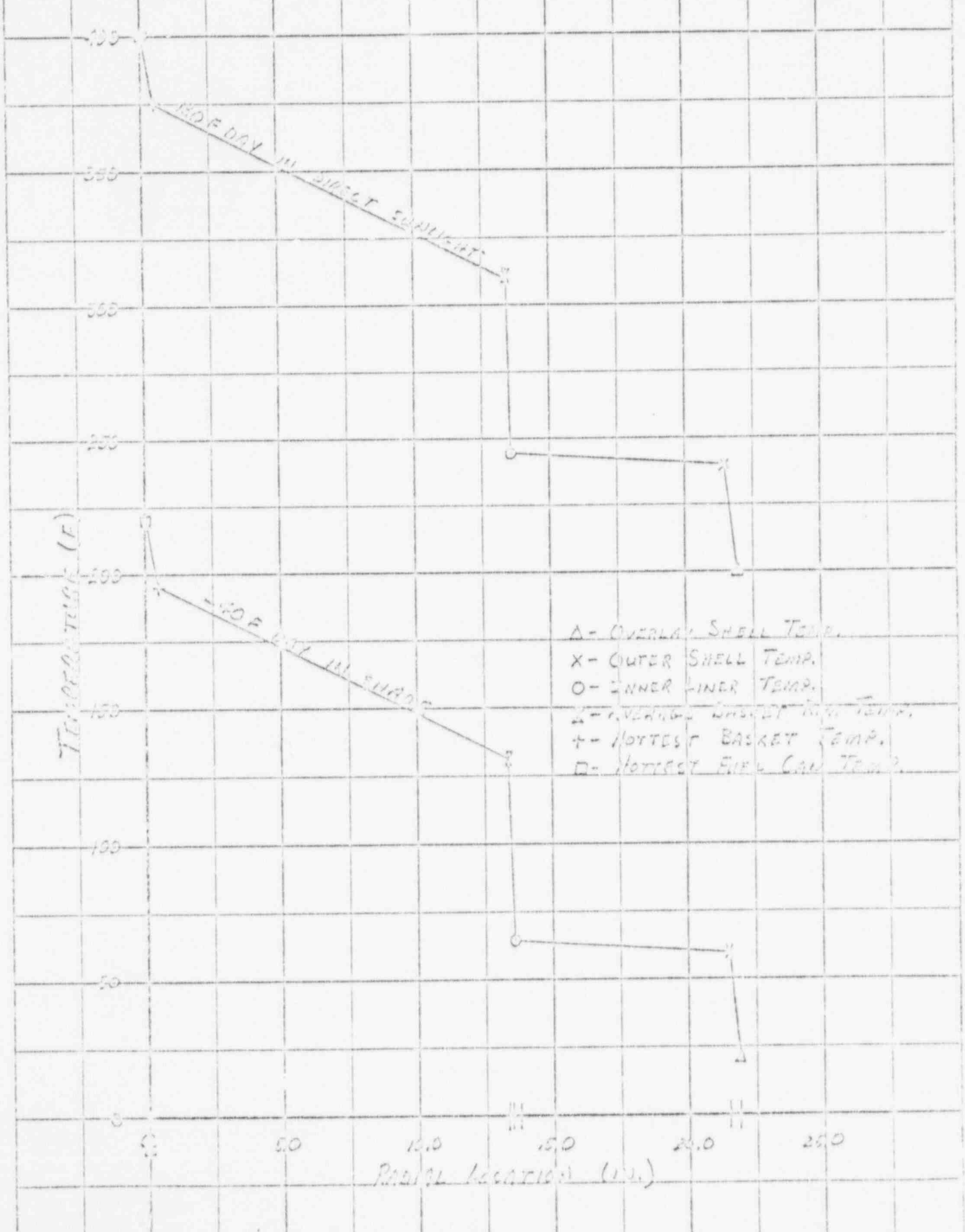
$$\frac{\int_{4.30\ a.m.}^{7.30\ p.m.} S(t)dt}{24\ hours} = \text{24-hour average solar load}$$

90010111

where S(t) = solar incidence for horizontal surface at summer solstice for 42 N lattitude as a function of time. See Figure 25. For analysis purposes $S(t) = 310 \cos\left(\frac{\pi t}{15}\right)$

The total heat which must be rejected from the surface of the W&K Model No. PB-1 cask for analysis purposes is therefore 17,790 Btu/hr.


293 F
341 F
358 F
200 F
160 F
332 F
196 F
350 F
LEAD
280 F
319 F
204 F
274 F


TEMPERATURE (F)
RADIAL LOCATION (IN.)
5.0
10.0
15.0
20.0
25.0
X- OUTER SHELL TEMP.
O- INNER LINER TEMP.
+- HOTTEST BASKET TEMP.

90010113

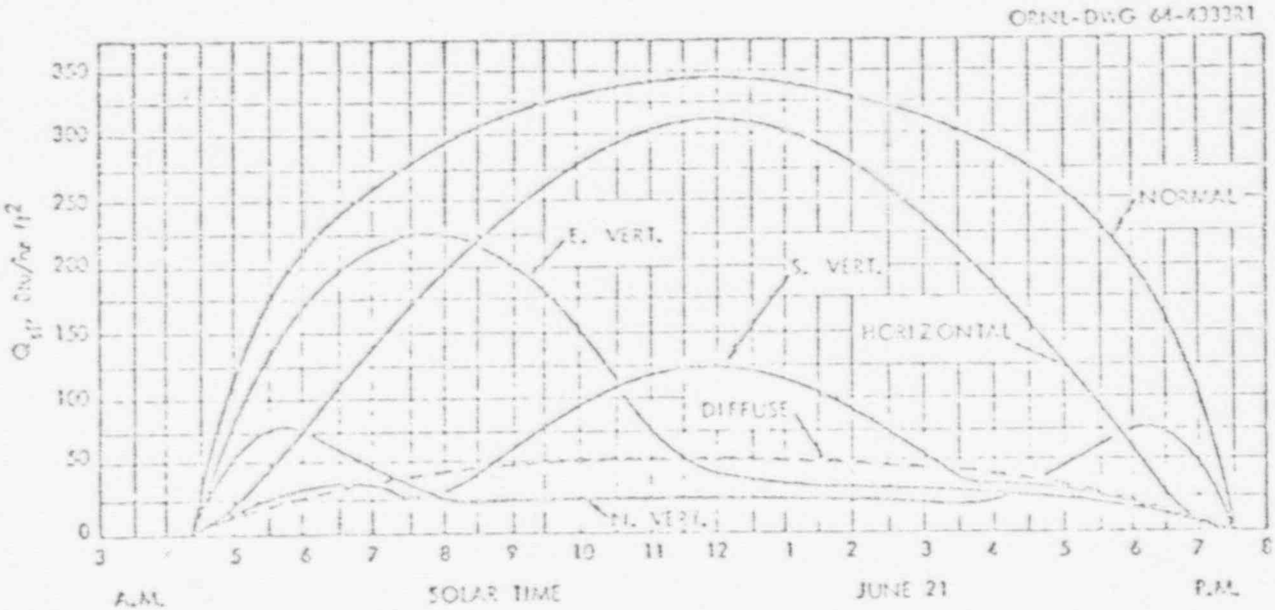


FIGURE 25. INCIDENT SOLAR ENERGY ON CLEAR DAYS, LATITUDE 42 N.

90010114

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For conservatism the thermal capacitance of the graphite fuel elements and their encapsulating aluminum fuel cans contained in the cask cavity, was neglected for the thermal transient calculations of cask shield temperatures. The materials thermophysical properties which were employed are shown in Tables 8, 9, and 10. The anodized outer surface of the aluminum fuel-element basket was assumed to have an effective emissivity of 0.8. The normal operating condition temperatures of cask contents (fuel element cans and basket), assuming a maximum thermal load of 17,790 Btu/hr (14,250 Btu/hr decay heat, 3,540 Btu/hr solar load) for the cask system, are illustrated in Figure 24. Since it is extremely unlikely that the cask would be engulfed by the hypothetical fire accident while in any position other than the horizontal position (i.e., normal shipping position is horizontal), the starting temperatures for the fire transient calculations are those illustrated in Figure 25. Figure 26 illustrates the thermal history of selected regions of the cask contents during the fire and up to 3 hours after the hypothetical fire accident at which time artificial cooling may be used. Although the cask system was analyzed for a total internal heat load of 14,250 Btu/hr, the total heat transferred by conduction, thermal radiation, and convection from the aluminum basket to the inner liner of the cask (wall of the cask cavity) is only 12,700 Btu/hr. The remaining source thermal power (1,550 Btu/hr) escapes the fuel element and basket region of the cask cavity in the form of gamma radiation incident on the cask cavity wall. The basket and fuel element region temperatures illustrated in Figure 24 and Figure 26 are therefore calculated for a heat transfer of 12,700 Btu/hr. of thermal power from the aluminum basket to the cask cavity wall.

To properly account for the axial spreading of the heat generated in the central 90-in. fueled region of the fuel element, an axial section consisting of (1) the graphite fuel element, (2) the aluminum and iron fuel can, and (3) an enclosing aluminum tube from the fuel element basket was analyzed assuming the thermal heat source distribution illustrated in Figure 27. The distribution was determined by fitting the equation

$$S(x) = A + B \cos \left[\frac{\pi x}{90}\right] \quad \text{(x in inches)}$$

to empirical data.

The empirical data used are listed below:

(1) Maximum reactor fuel element operating power = 174 kwth

(2) Average reactor fuel element operating power = 140 kwth

(3) Maximum local - to-core average specific power ratio = 1.59

(4) Maximum fuel element decay power = 750 Btu/hr

(5) Total fuel element fueled region volume = .5 ft^3
(assumes 90-in. long x 3.5-in dia. fueled region)

Using the above data

$$S(x) = (763.5 + 1156.5 \cos \left[\frac{\pi x}{90}\right]) \text{ Btu/hr-ft}^3$$

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TABLE 8. THERMOPHYSICAL PROPERTIES EMPLOYED FOR LEAD AND STEEL

Lead

Density = 705 lb/ft^3
Melting Temperature = 621 F
Latent Heat = 10.5 Btu/lb

Temperature, F	Thermal Conductivity, Btu/hr-ft-F	Specific Heat, Btu/lb	Emissivity
32	20.1	0.0303	1.0
212	19.6	0.0315	1.0
572	18.0	0.0338	1.0
621	8.8	0.0337	1.0
900	8.9	0.0326	1.0

Steel

Density = 488 lb/ft^3
Latent Heat = 120 Btu/lb
Melting Temperature = 1800 F

Temperature, F	Thermal Conductivity, Btu/hr-ft-F	Specific Heat, Btu/lb	Emissivity
32	8.0	0.11	0.8[a], 1.0[b]
212	9.4	0.11	0.8, 1.0
572	10.9	0.11	0.8, 1.0
932	12.4	0.11	0.8, 1.0
1800	15.0	0.11	0.8, 1.0

(a) For steel surface exposed to flame, ϵ = 0.8.

(b) For steel surfaces viewing each other across internal air gaps, ϵ = 1.0.

TABLE 9. THERMOPHYSICAL PROPERTIES EMPLOYED FOR IRON AND ALUMINUM

Iron

Density =488 lb/ft^3

Melting temperature = 2,750 F

Latent heat = 117 Btu/lb

Temperature, F	Thermal Conductivity Btu/hr-ft-F	Specific Heat Btu/lb	Emissivity
32	8.0	.11	.8
212	9.4	.11	.8
572	10.9	.11	.8
932	12.4	.11	.8

Aluminum 6061

Density = 170 lb/ft^3

Melt temperature = 1,100 F

Latent heat = 170 Btu/lb

Temperature, F	Thermal Conductivity Btu/hr-ft-F	Specific Heat Btu/lb	Emissivity(18) Hard Anodized
68	90	.23	.84
200	92.5	.23	.84
300	95	.23	.84
500	100	.23	.84

TABLE 10. THERMOPHYSICAL PROPERTIES EMPLOYED FOR GRAPHITE

Graphite

Density = 118 lb/ft^3

Temperature, F	Thermal Conductivity(2) Btu/hr-ft-F	Specific Heat Btu/lb	Emissivity
100	15	.18	1.0
300	15	.235	1.0
400	15	.26	1.0
500	15	.29	1.0

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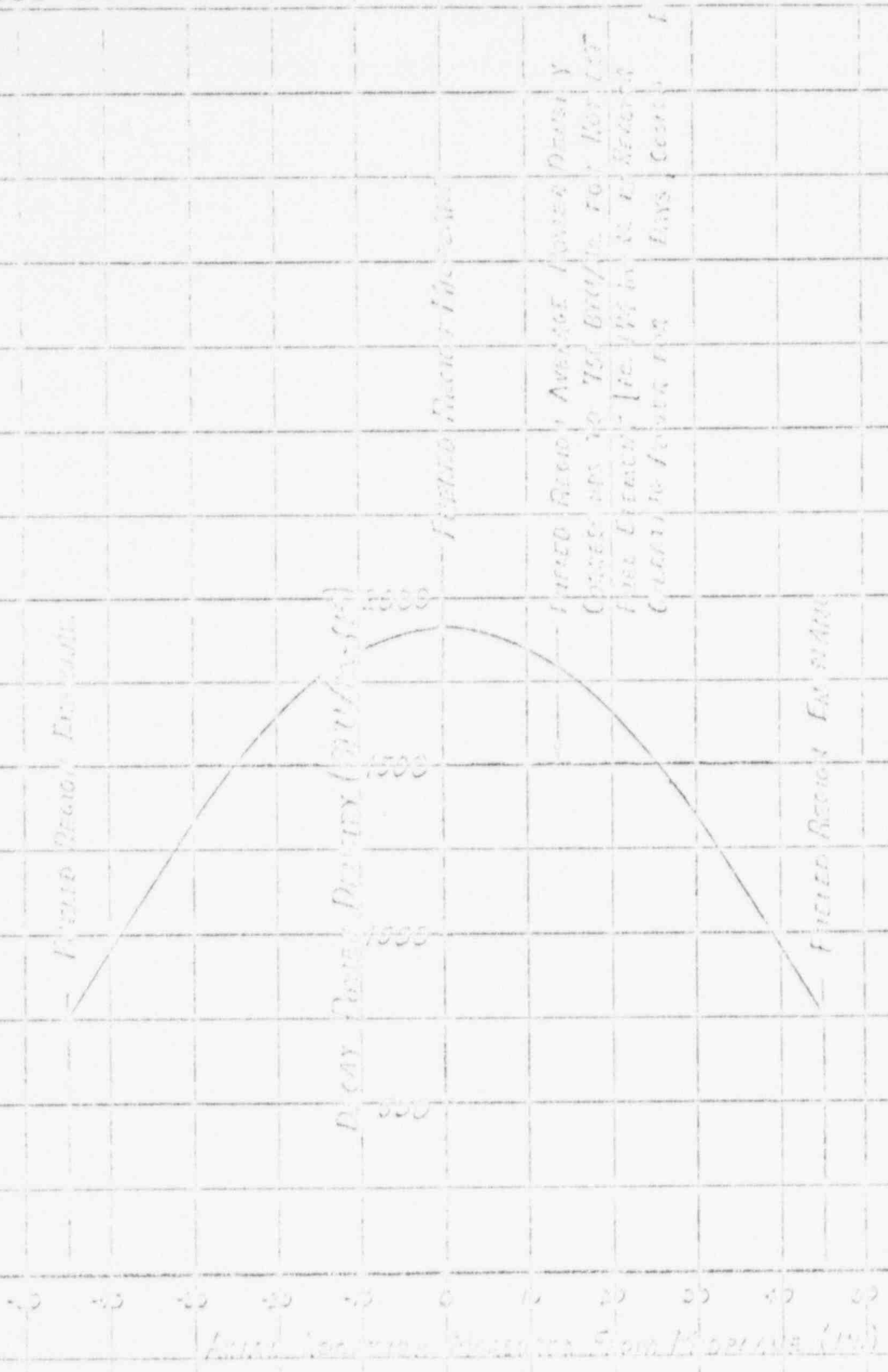


It was determined that of the 222 Btu/hr generated in the center 2 ft. section of the fueled region of the fuel element, 39.8 Btu/hr or 17.9 percent was conducted axially. The thermal analysis of the basket region assumes that the remaining 82.1 percent of the available heat load is conducted and/or radiated from the central 2 feet of the fuel and basket in the radial direction only.

The top and bottom covers of the cask were not analyzed specifically since the analysis presented above contains sufficient conservatism to permit extrapolation to those cask regions. Furthermore, the end covers are protected from the fire by the steel impact limiters.

3.4 Appendix

3.4.1 Computer Codes Description

THT-D - Transient Heat-Transfer Program - Version D
(Originator - The General Electric Company)

The THT-D computer program computes transient and steady state temperature solutions for three-dimensional heat transfer problems. Over 1,200 temperature nodes have been handled in a single problem, but the actual number possible depends on the available computer memory and the amount of non-geometrical data. Problems can include:

Node-to-node heat transfer by conduction, convection, and radiation.

Node-to-boundary heat transfer by convection and radiation.

Latent heat for an isothermal phase change for any material.

User supplied input includes:

(1) Geometrical dimensions, connections, and material reference for temperature nodes which can have up to six faces. (Dimensional data can be detailed or, if applicable, approximated by three mutually orthogonal dimensions for rectangular parallelepipeds.)

(2) Flow geometry and convection data references for nodes through which fluid flows.

(3) Radiation linkages between nodes or between nodes and external boundaries without limit to the number of linkages for a node face.

(4) Initial rates for fluid flow, surface flux, and internal heating.

(5) Convective heat transfer coefficient data. These take the form of tables of Nusselt Number as a function of Reynolds Number for which linear interpolation is done between the natural logarithms, or the form of correlation equations of the Dittus-Boelter type for Nusselt Number.

(6) Thermal resistance coefficients which can be assigned between faces of neighboring nodes.

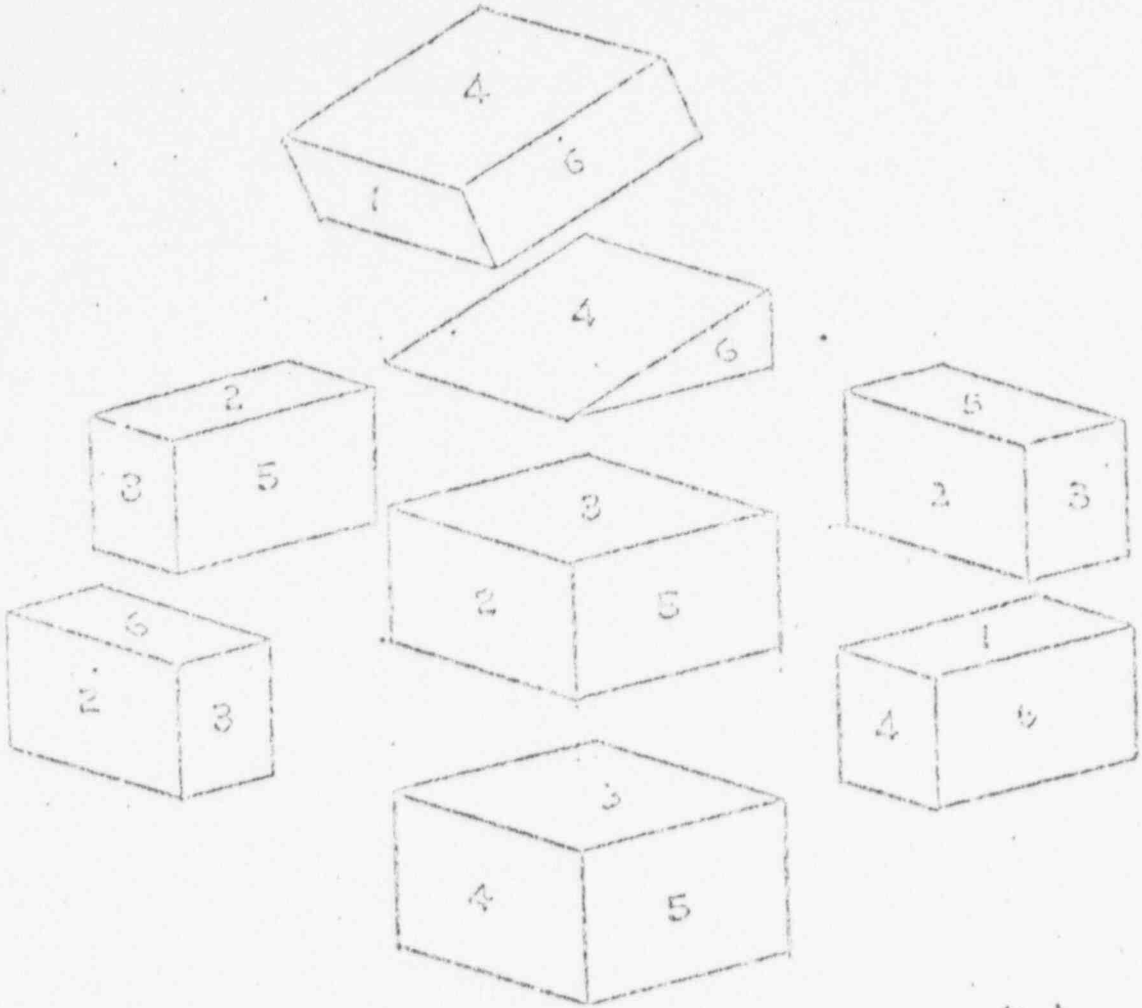
(7) Temperature-dependent tables for material properties, including emissivities for boundary radiation. Material property tables can also indicate the isothermal energy absorption (assuming heating) which is to take place during phase change.

(8) Time-dependent tables which can include fluid inlet temperature or boundary fluid temperature, convective heat transfer coefficients, fluid flow, surface flux, internal heating, and temperature for radiation boundaries.

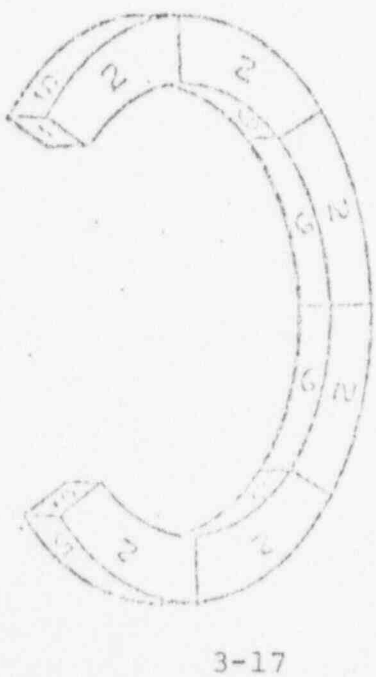
Considerable data checking is done to assure consistent, complete problem input and thus avoid wasted computer time. Edited output in the form of tables of physically connected nodes and tables of temperatures as functions of time can be obtained to enhance readability of output and to facilitate data plotting.

Temperature solutions are obtained by iterative solution of simultaneous algebraic equations for node temperatures derived from finite-difference analysis. The use of simultaneous equations (the implicit method of formulating nodal heat balances) precludes any stability limitations on time-increments and permits a direct steady-state solution at any stage of a computer run, including solutions to serve as initial conditions for a transient. Convergence of a temperature solution is recognized and controlled by tolerances on the residual heat balances which provide a measure of the "imperfection" of a solution as well as by the conventional maximum change in any node temperature during an iteration sweep.

Figure F-1 illustrates typical nodal geometries which can be constructed, and examples of the face-to-face connections (face 1 to face 3; face 2 to face 4; face 5 to face 6). Since only face connections of arbitrary node-to-node arrangements are required, 1-, 2-, or 3-dimensional heat transfer networks can be readily constructed.



(1a)



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(1b)

FIGURE F.1. EXAMPLES OF NODES AND NODE FACE CONVECTION CONVENTION FOR THE [illegible]-D COMPUTER PROGRAM

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IV

4.0 CONTAINMENT

All items in this section are covered in other sections.

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5.0 SHIELDING EVALUATION

5.1 Discussion

The nuclear radiation analyses described in this section were performed to determine the lead shield thicknesses required to limit external dose rates to NRC and DOT constraints, to predict dose rates for the design shown on Drawing [illegible]-0001, and to predict nuclear heating rates for input to thermal analyses. The results show that the shielding provided in the W&K Model No. [illegible] shipping cask complies with the NRC and DOT regulations (1,2) pertaining to radiation shielding standards for shipping containers for a transport vehicle assigned for sole use under both normal and hypothetical fire and free drop accident conditions.

Radiation Criteria

DOT regulations pertaining to radiation shielding requirements for shipping containers state (§ 173.393(i) of 49 CFR) that the container shall be so designed and constructed and its contents so limited that the radiation dose rate originating from the container will not exceed at any time during normal conditions incident to transportation either of the following limits:

(1) 200 millirem per hour at any point on the external surface of the shipping container; or

(2) 10 millirem per hour at a distance of 3 feet from any point on the external surface of the shipping container.

Containers for which the radiation dose rate exceeds the above limits, but does not exceed at any time during transportation any of the following limits, may be transported in a transport vehicle (except aircraft) assigned for the sole use of that consignor, and unloaded by the consignee from the transport vehicle in which originally loaded (§ 173.393(j) of 49 CFR):

(1) 1,000 millirem per hour 3 feet from the external surface of the package (closed transport vehicle only)

(2) 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only)

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(3) 10 millirem per hour 6 feet from the external surface of the car or vehicle

(4) 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

In addition, the cask upon subjection to the specified hypothetical conditions of free drop, puncture, and fire (thermal) will meet the following requirement from § 71.36(a)(1) of 10-CFR 71:

(1) The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1,000 millirem per hour 3 feet from the external surface of the package.

5.2 Source Specification

The following beta and gamma release rates due to the beta decay of U-235 fission products were computed using computer program PHOEBE(3) * for 120 days following reactor operation for 900 equivalent full power days:

Beta activity = 9.64×10^4 curies/kg U^{235}

Beta release rate = 3.57×10^{15} particles/sec-kg U^{235}

Beta energy release rate = 1.27×10^{15} Mev/sec-kg U^{235}

Average beta energy = 0.355 Mev

Gamma activity = 3.64×10^4 curies/kg U^{235}

Gamma release rate = 1.35×10^{15} photons/sec-kg U^{235}

Gamma energy release rate = 8.71×10^{14} Mev/sec-kg U^{235}

Average gamma energy = 0.647 Mev

Beta + gamma energy release rate = 2.14×10^{15} Mev/sec-kg U^{235}

Gamma release rates in 12 energy groups are presented in Table 11. These release rates are based on a conversion factor of 3.38×10^{10} fissions/sec-watt. Release rates for 450 days operation are essentially the same since fission product production and decay are nearly in equilibrium at 450 days.

Since the Peach Bottom No. 1 reactor employes the U^{235}-Th fuel cycle to achieve higher fuel burnup and lower fuel costs, protactinium-233 is also a source of considerably beta and gamma energy in the Peach Bottom fuel. Protactinium-233 is formed in the reactor by the following series of processes:

$$_{90}Th^{232} + {_0n^1} \longrightarrow {_{90}Th^{233}} + \gamma$$

$$_{90}Th^{233} \longrightarrow {_{-1}\beta^0} + {_{91}Pa^{233}}$$

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* See Appendix for brief description.

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The protactinium-233 then decays by beta emission

$$_{91}Pa^{233} \longrightarrow {}_{-1}\beta^{0} + {}_{92}U^{233}$$

with a half-life of 27.4 days and a total energy release of 0.568 Mev/disintegration. The beta particle energies are 0.26^{58}, 0.15^{37}, and 0.57^{5}; and the associated photon energies are 0.31^{80}, 0.016 - 0.42 Mev.

The equilibrium quantity of protactinium-233 present in the Peach Bottom reactor is 2,300 grams for full power operation at 115.5 Mw(t). After 120 day delay, the total energy released by this much protactinium-233 is 1.38×10^{21} Mev/hr or 2.1×10^{5} Btu/hr. The average in each of the 804 elements (neglecting the difference in the 162 Type-4, heavy-thorium elements) is 261 Btu/hr-element. The gamma energy release rate (0.31 Mev/photon) due to protactinium-233 decay is 7.6×10^{14} Mev/sec-kg U^{235}. This compares with 1.06×10^{14} Mev/sec-kg U^{235} in the 0.1 - 0.4-Mev group due to fission product decay. The source for group 1 in Table 11 includes both contributions.

Each of the Type -1, -2, or -3 fuel elements contains 0.291 kg uranium-235. The average energy release rate after 120 days delay is

Pa^{233}	-	261 Btu/hr-element
Fission products	-	341.5 Btu/hr-element
Pa^{233} + fission products	-	602.5 Btu/hr-element

The power generated during full power operation in an average fuel element is 140 kw(t), and the peak power generated in a hottest fuel element is approximately 174 kw(t) at 900 days. Therefore, the maximum fuel element energy release rate after 120 days delay is

$$\frac{174}{140} \times 602.5 = 750 \text{ Btu/hr-element}$$

All fuel elements were conservatively assumed to be maximum power elements. Thus each element contains 3.7×10^{4} curies of gamma ray emitter, and a load of 19 elements contains 7.05×10^{5} curies. These gamma ray sources emit 5.90×10^{14} Mev/sec-element or 1.12×10^{16} Mev/sec-19 elements. The total energy source in 19 elements is 1.425×10^{4} Btu/hr.

The radial source distribution in the fuel compacts was assumed flat in all calculations. All shielding calculations assumed the relative axial distribution shown in Figure 27. This symmetrical distribution approximates the distribution with the maximum peak-to-average ratio from the end-of-life distribution shown in Figure 5.

5.3 Model Specification

Point Kernel Analysis

Point-kernel program QAD-P5A [4]* was used to compute gamma heating rates in the shipping cask and gamma dose rates external to the cask. The point-kernel

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* See Appendix for brief description.

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TABLE 11. PEACH BOTTOM NO. 1 FUEL DECAY GAMMA SOURCES

Group	Energy Range Mev	Average Energy Mev	Source Photons/sec-kg U^{235}	Source Mev/sec-kg U^{235}
1	0.1 - 0.4	0.3	.280 E + 16*	.866 E + 15
2	0.4 - 0.9	0.63	.727 E + 15	.458 E + 15
3	0.9 - 1.35	1.10	.246 E + 15	.270 E + 15
4	1.35 - 1.8	1.55	.151 E + 14	.234 E + 14
5	1.8 - 2.2	1.99	.167 E + 13	.332 E + 13
6	2.2 - 2.6	2.38	.336 E + 13	.800 E + 13
7	2.6 - 3.0	2.75	.575 E + 12	.158 E + 13
8	3.0 - 3.5	3.25	.934 E + 11	.303 E + 12
9	3.5 - 4.0	3.70	.410 E + 11	.152 E + 12
10	4.0 - 4.5	4.22	0	0
11	4.5 - 5.0	4.70	0	0
12	5.0 - 5.5	5.25	0	0
			3.794 E + 15	1.631 E + 15

* Read .280 E + 16 as .280 x 10^{16}.

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method used in QAD-P5A combines the use of point-to-point attenuation functions with summation over source regions. It is assumed that the point-to-point attenuation function (point kernel) depends only on the quantity of each material encountered by the primary ray proceeding from the source point directly to the receiver point. This assumption is valid for any source-shield configuration if the significant radiation is collimated along the primary ray. It is valid for infinite homogeneous systems, and it is a good approximation for many symmetrical homogeneous systems, even where it is important to consider radiation which is scattered through large angles.

Point kernel calculations for paths through regions of high attenuation bordered by regions of low attenuation are likely to yield low answers because of scattering around (short-circuiting) the regions of high attenuation. This effect is observed behind shadow shields and in regions adjacent to large voids in the shield.

Calculations for paths through regions of low attenuation bordered by regions of high attenuation are likely to yield high answers because calculated scattered contributions from the adjacent regions may be much greater than actual contributions. This effect is observed along source-receiver paths that penetrate large voids or weak shield regions adjacent to shadow shields.

A point-to-point attenuation function can be expressed as a function of the source receiver path length, ρ, the path length, ρ_m, in each of the M materials, the source energy, E_j, the detector energy, E, and the macroscopic cross section, $\Sigma_m (E_j)$.

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This function,

$$\phi = \phi[\Sigma_m (E_j), \rho_m, \rho, E_j, E]$$

equals the flux of particles of energy E at the receiver due to particles of energy E_j emitted by a point source of unit strength.

Assuming that the point source emits isotropically, the point kernel can be written as the product of a material attenuation function

$$\psi[\Sigma_m (E_j), \rho_m, E_j, E]$$

and a geometrical attenuation function $1/4 \pi\rho^2$

$$\phi[\Sigma_m(E_j), \rho_m, \rho, E_j, E] = \frac{\psi[\Sigma_m (E_j), \rho_m, E_j, E]}{\pi\rho^2}$$

Material attenuation functions can be established by fitting attenuation data obtained by either theoretical or experimental methods. The functions may be either purely mathematical or based on some physical analysis.

The material attenuation function used for computing gamma ray flux and dose and energy absorption rates is:

$$V_{\gamma}\,[\Sigma_m(E_j),\ \rho_m] = B[\Sigma_m(E_j),\ \rho_m]\ \exp-\left[\sum_{m=1}^{M} \rho_m\,\Sigma_m\,(E_j)\right]$$

where $B[\Sigma_m(E_j),\ \rho_m]$ is a buildup factor used to determine empirically the scattered contribution to the computer detector response. Uncollided contributions of each discrete energy source are determined correctly by the exponential function. Buildup factors[21] obtained by a moments method solution of the Boltzmann transport equation have been fitted by the following cubic polynomials with excellent results:

$$B(x) = \beta_o(E_j) + \beta_1(E_j)x + \beta_2(E_j)x^2 + \beta_3(E_j)x^3$$

x is the number of relaxation lengths encountered and is given by

$$x(E_j) = \sum_{M=1}^{M} \rho_m \Sigma_m(E_j)$$

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The buildup coefficients are computed in QAD-P5A from bivariant polynomial expressions and coefficients reported in APEX-510 (5). The bivariant polynomial coefficients and mass gamma ray total absorption coefficients are incorporated in the program.

QAD was used to compute gamma dose rates external to the cask for varying uniform thicknesses of lead in the cask body and end covers. A nuclear model of the cask conceptual design was prepared that contained 9 elements, 19 compositions, 38 regions, and 26 region boundaries. The central fuel element was described in detail with a gamma source only in the fuel compacts. As indicated in Table 6, average graphite densities in the region were computed from the fuel-element total weight and the specifications of the fuel compacts, spine, sleeve and lower reflector. The other 18 fuel elements and the basket were homogenized around the central element and treated as a second source with an appropriately averaged uniform radial distribution.

External gamma dose rates were computed along radial traverses at the midplane of the fueled section, and at the top of the cask cavity. Dose rates were also computed along an axial traverse above the top cover. A single calculation below the bottom cover gave a 13 percent lower dose rate than through the top cover the same thickness. Results of these calculations were used in selecting the design lead thicknesses shown on Drawing 9123-0001.

5.4 Shielding Evaluation

Subsequently, the nuclear model was revised to describe the cask of Drawing 9123-0001 and confirming dose rate calculations were completed. The external dose rates are presented in Table 12. Dose rates at the ends were multiplied by the following axial streaming convection factors:

Surface	- 2.47
3 feet	- 1.035

These factors were estimated by computing dose rates at positions 11.72 cm. off the axis from the central element with the surrounding fuel-basket assembly deleted and forming the ratio of the dose rate without the fuel-basket assembly to that with the assembly in place. This, in effect, corrects for gamma ray streaming between the basket tubes.

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TABLE 12. EXTERNAL DOSE RATES

Receiver Coordinates Radial, in.	Axial, in.	Dose Rate mrem/hr
Cask surface	Bottom of cavity	.0388
72 from truck surface	Bottom of cavity	1.86
Cask surface	Fuel midplane	70.6
36 from cask surface	Fuel midplane	242.*
72 from truck surface	Fuel midplane	9.23
Cask surface	Top of fuel	17.1
72 from truck surface	Top of fuel	5.15
Cask surface	Top of cavity	.00336
72 from truck surface	Top of cavity	1.17
Axis	Top surface	12.0
Axis	36 above top surface	2.16
Axis	Bottom surface	7.45
Axis	36 below bottom surface	1.50
20.12	36 below bottom surface	.778**

* After 30-ft. side drop.
** After 30-ft. corner drop.

Table 12 also includes the dose rate predicted through the bottom corner and through the side after the drop test. The lead after the drop test was calculated to be a minimum of 2.95-in. thick along a line from the cask center-of-gravity through the corner of the inner steel plate of the cover. The side lead was crushed to a thickness of 4.55 in. at the midplane.

The results show that the predicted maximum dose rates at the side of the cask during transportation are 70.6 mrem/hr at the external surface and 9.2 mrem/hr 6 ft. from the external surface of the motor vehicle. Thus, the dose rates at the side of the cask are below the limits specified in subparagraphs (1), (2), and (3) of Paragraph 173.393(j) in the DOT Rules and Regulations for a transport vehicle assigned for sole use.

The calculated maximum dose rates at the ends of the cask are 12.0 mrem/hr at the top surface and 2.2 mrem/hr 3 ft. from the top surface. The surface dose rate is below the limit of 200 mrem/hr at the external surface specified in Paragraph 173.393(i) of the DOT Rules and Regulations, and the equivalent transport index of 3 is below the limit of 10.

The calculated maximum dose rate 3 ft. from the end surface of the cask is 6.1 mrem/hr after successive hypothetical free drop and fire accidents. The corresponding dose rate 3 ft. from the side surface is 24.2 mrem/hr. Hence, the limit of 1,000 mrem/hr specified for hypothetical accident conditions in Paragraph 71.36 of the Code of Federal Regulations, Title 10, Part 71 is easily satisfied.

In order to correct for gamma ray leakage from the fuel-basket assembly, an estimate of the self-absorption by the fuel elements and basket was obtained by integrating the gamma energy flux density over the fueled length of the cavity inner surface. The calculated maximum energy flux density was 4.358×10^{10} Mev/cm^2-sec. Assuming the same axial distribution as for the source gave an average energy flux density of 3.8×10^{10} Mev/cm^2-sec. Thus, the total gamma energy escaping radially from the fueled length of the fuel-basket assembly is 1.76×10^{15} Mev/sec. Since the total gamma source in 19 fuel elements is $19 \times 0.287 \times 1.651 \times 10^{15} = 9.02 \times 10^{15}$ Mev/sec, 19.5 percent escapes in the radial direction. The sum of the beta and gamma energy sources is 1.608×10^{16} Mev/sec. Therefore, 10.9 percent of the total energy source escapes radially. Consequently, the effective maximum fuel element heating rate is 666 Btu/hr-element.

5.5 Appendix

(1) "Packaging of Radioactive Material for Transport", Code of Federal Regulations, Title 10, Part 71 (December 31, 1968).

(2) "Radioactive Materials and Other Miscellaneous Amendments", Code of Federal Regulations, Title 49, Parts 171-179 (October 4, 1968).

(3) Arnold, E. D., "PHOEBE - A Code for Calculating Beta and Gamma Activity and Spectra for ^{235}U Fission Products", ORNL-3931 (July, 1966).

(4) Solomito, E., and Stockton, J., "Modifications of the Point-Kernel Code QAD-P5A: Conversion to the IBM-360 Computer and Incorporation of Additional Geometry Routines", ORNL-4181 (July, 1968).

(5) Capo, M.A., "Polynominal Approximation of Gamma Ray Buildup Factors for a Point Isotropic Source", APEX-510 (November, 1958).

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VI

6.0 CRITICALITY EVALUATION

6.1 Discussion

Regulatory Criteria

Regulatory criteria pertaining to criticality which are applicable to Fissile Class II shipments such as in the W&K Model No. PB-1 Cask are delineated in § 71.37 and § 71.29 of 10CFR71. These sections of the regulations are summarized as follows:

§ 71.37 Evaluation of an array of packages of fissile material.

(a) An array of packages shall be evaluated by subjecting a sample package to the conditions specified in 71.38, 71.39 or 71.40.

(b) In determining whether the standards of the Class I, II and III sections are met it will be assumed that consistent with the condition of the package:

(1) The fissile material is in the most reactive credible configuration.

(2) Water moderation occurs to the most reactive extent.

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6.2 Package Fuel Loading

Determination of Allowable Number of Packages

The number of allowable packages that can be shipped was calculated from the equation:

$$\frac{50}{N} = I_t$$

where N is the allowable number of packages and I_t is the transport index or minimum number of radiation units. For the case of sole use of vehicle shipments, § 173.396(f) or 49CFR states that for nuclear criticality control purposes, the transport index must not exceed 10. Thus, using this transport index,

§ 71.39 Specific standards for Fissile Class II package.

(a) For a Fissile Class II package; design, constructed, loaded, and number limited so that:

(1) Five times the number of undamged packages would be subcritical in any arrangement with close water reflection.

(2) Two times the number of packages damaged by the Appendix "B" tests would be subcritical in any arrangement with close water reflection and optimum interspersed moderation or built-in moderation if it is greater.

(b) The number of radiation units to be fifty divided by the allowable number of packages, rounded up to next higher tenth.

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the number of casks that could be shipped was calculated from the above equation and found to be 5.

On the basis of the allowable number of packages determined above, § 71.39 of 10-CFR-Part 71 specifies that 5N or 25 packages remain subcritical under normal conditions and that 2N or 10 packages remain subcritical under accident conditions.

The container is shown to undergo little dimensional change in the accident conditions; thus, shipment of 25 packages will be the most reactive case.

6.3 Model Specification

Calculational Procedure

The criticality evaluation of the W&K Model No. PB-1 shipping container was made using the KENO computer code. A modified 16-group Hansen and Roach* cross-section set was used for all calculations.

The fuel for all calculations was assumed to be compact Type A (see Table 1 and Figure 1). This fuel type is the most reactive of the fuels to be shipp

TABLE 1. FUEL COMPACT LOADINGS FOR PEACH BOTTOM FUEL
(loading per 3 inch of compact [gm])

Compact Type	A	B	C	D
Description	Standard	Heavy Rhodium	Light Rhodium	Heavy Thorium
Th-232	52.10	52.10	52.10	115.36
U-234 (max)	0.156	0.156	0.156	0.082
U-235	9.70	9.70	9.70	5.14
U-236 (max)	0.052	0.052	0.052	0.028
U-238	0.505	0.505	0.505	0.268
Rh-103	0.	1.028	0.342	0.
Carbon	285.00	285.00	285.00	273.00

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* Bell, R.I., Devaney, J.J., Hansen, G.E., Mills, C.B., and Roach, W.H., "Los Alamos Group-Average Cross Sections", LASM-2441 (1963).

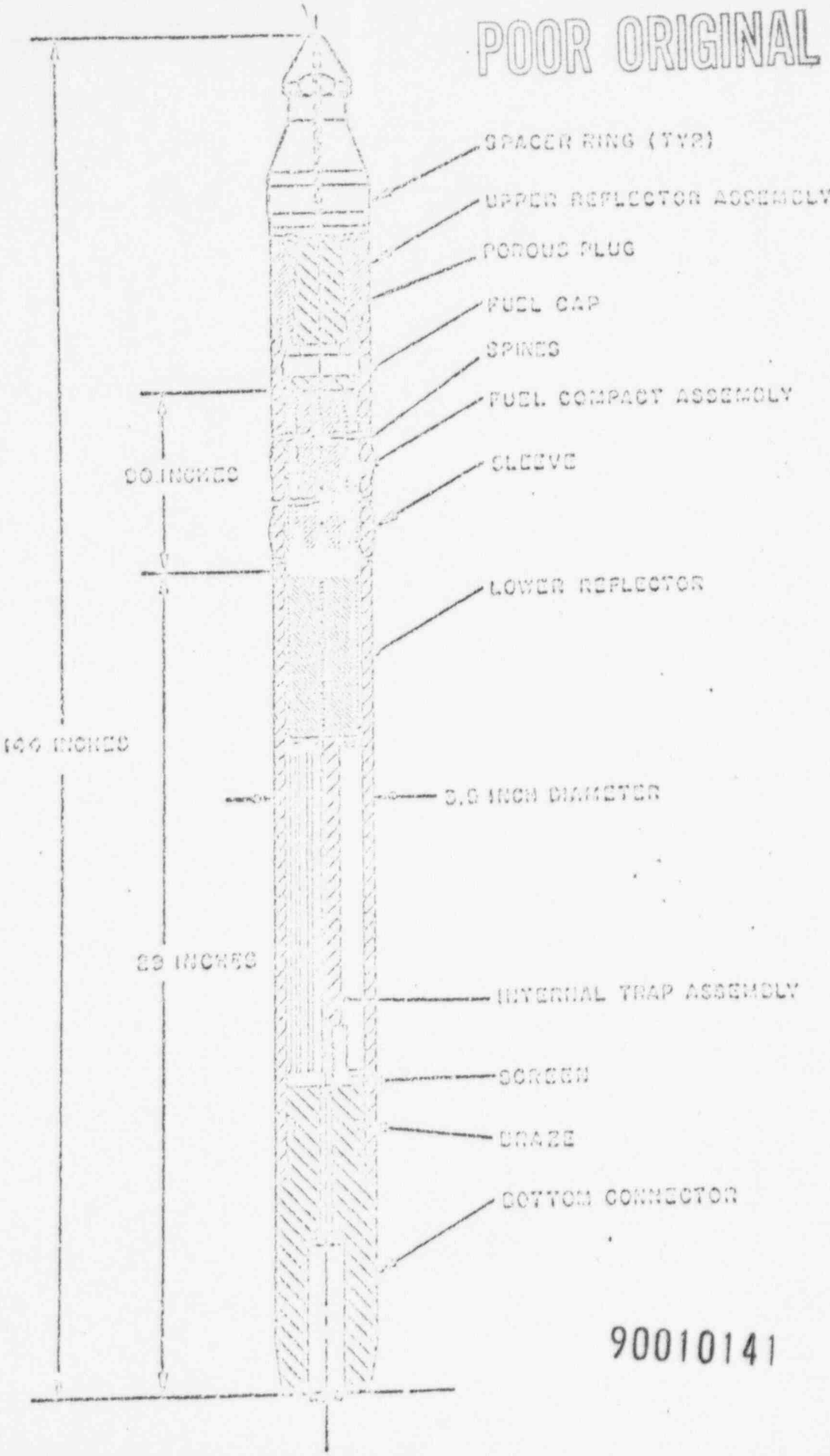


FIGURE 1. PEACH BOTTOM REACTOR FUEL ELEMENT

Calculations were made for a 5 x 5 x 1 array of PB-1 containers surrounded by a water reflector. It was assumed that there was no water between the units of this array. This represents the most reactive configuration for 25 PB-1 containers.

The analytical model for the PB-1 container is shown in Figure 2 and the number densities for each region are shown in Table 2. The active fuel region of the inner cavity of the shipping container was homogenized assuming water filled the inner cavity.

6.4 Criticality Calculation

Using this analytical model, the calculated value of K_{eff} for a 5 x 5 x 1 array of Peach Bottom I containers was 0.72 ± 0.02.

Additional calculations were made to determine the effect of homogenization of the inner cavity material on the calculated value of K_{eff}. Comparison was made between a detailed analytical model of a 2 x 2 x 1 array of Peach Bottom fue surrounded by a lead reflector and one where the fuel and basket were homogenized.

The detailed analytical model for the 2 x 2 x 1 array of Peach Bottom fuel is shown in Figure 3 and the number densities for each region are given in Table 3. For this calculation there is no homogenization of the fuel. Only the 90-in. active length of the Peach Bottom fuel is considered and each fuel element is placed in an aluminum basket identical to those used in the PB-1 shipping container. The calculated K_{eff} for this model was found to be $.31 \pm .015$.

A second calculation was made for which the fuel region (containing four Peach Bottom fuel elements), was homogenized. Figure 4 shows the analytical model used for this calculation and Table 4 gives the number densities for each region of the model. The calculated K_{eff} for this model was $.33 \pm .015$.

90010142

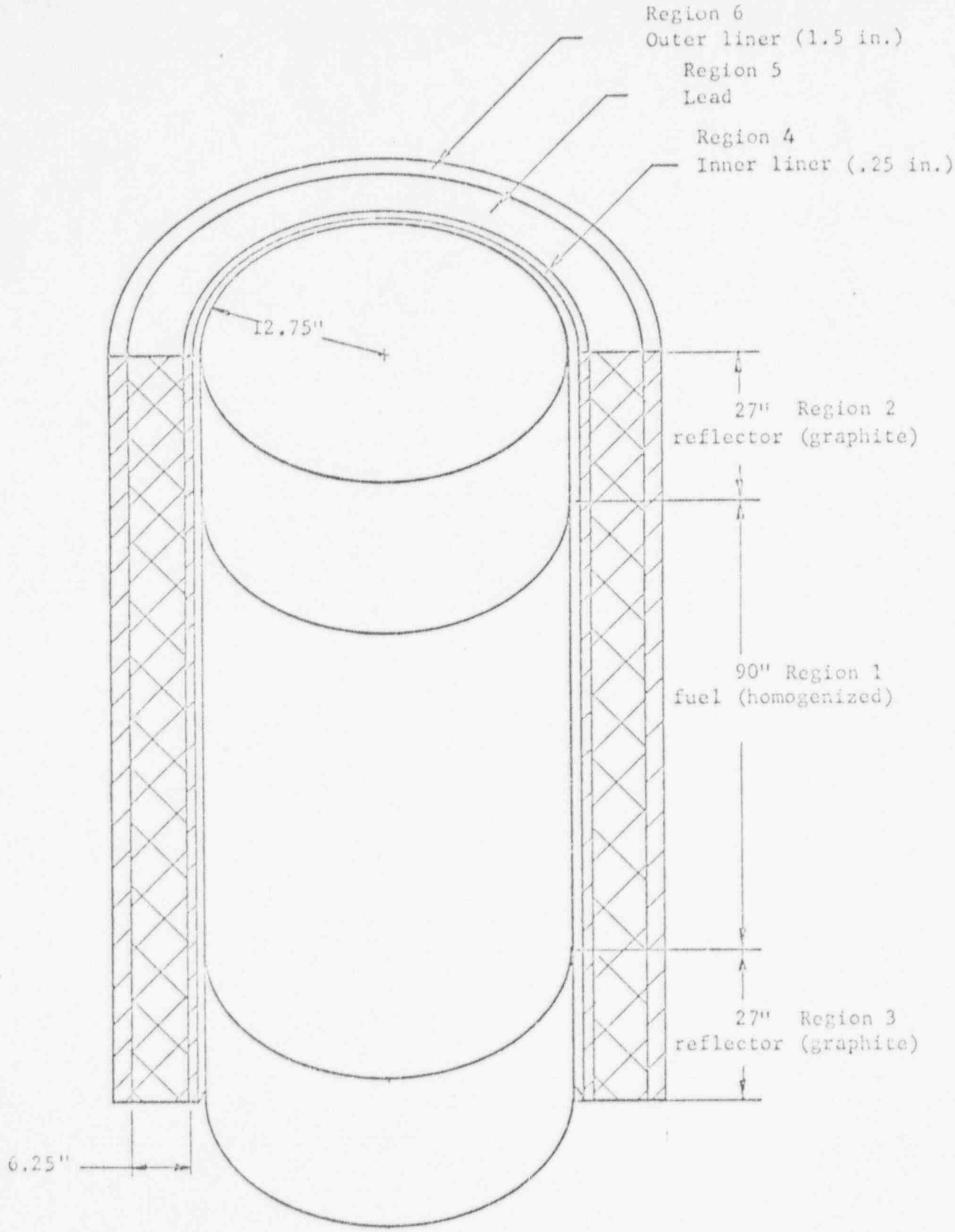


FIGURE 2. PEACH BOTTOM CONTAINER ANALYTICAL MODEL

90010143

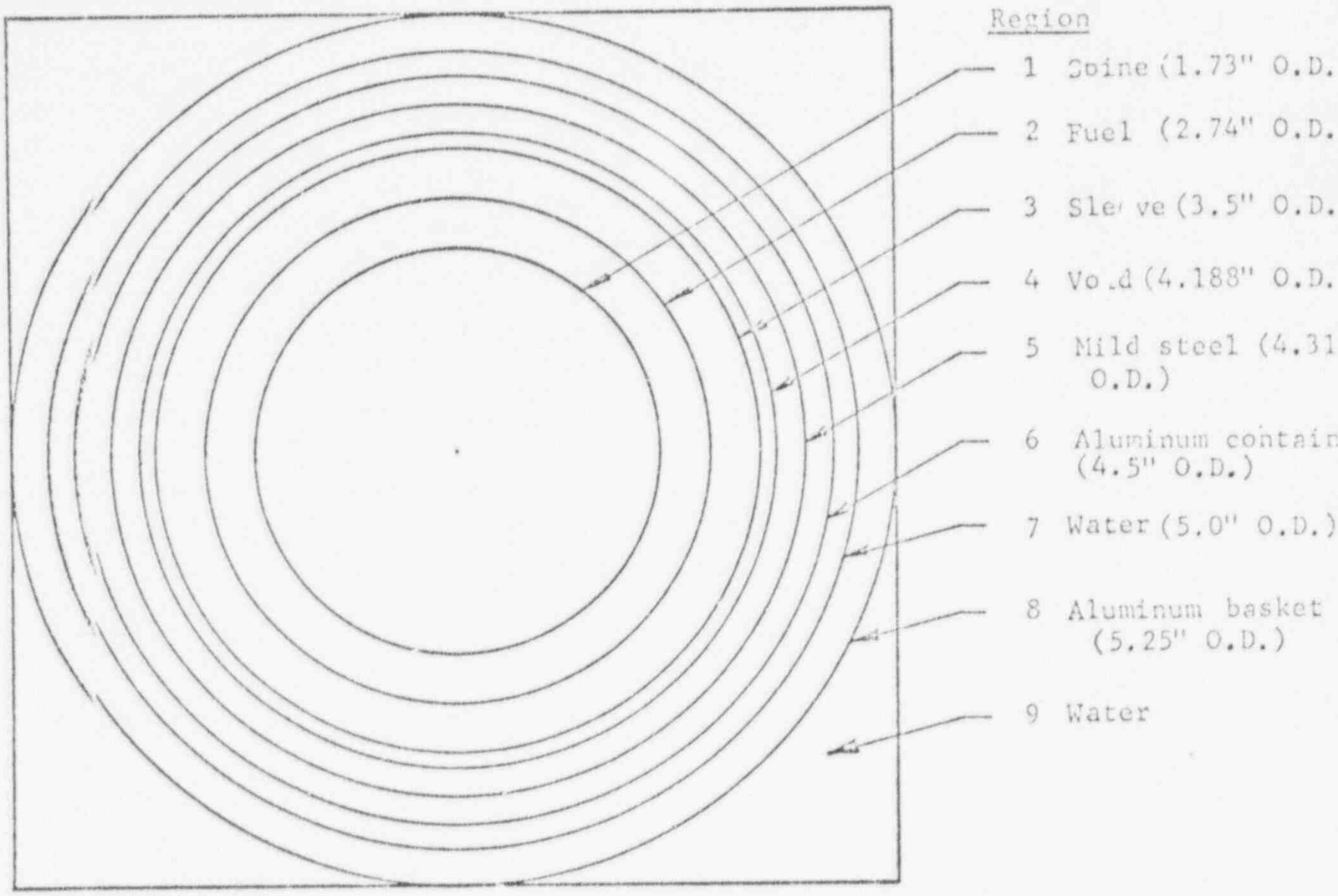
TABLE 4. NUMBER DENSITIES FOR ANALYTICAL MODEL OF THE PEACH BOTTOM NO. 1 CONTAINER

Region*	Material	Number Density x 10^{24}
1	Carbon (spine)	.00811
	Carbon (sleeve)	.01304
	Carbon (fuel)	.01081
	U^{235}	.0000188
	U^{238}	.000000966
	Th^{232}	.0001023
	Al	.004172
	Fe	.002609
	H	.02487
	O	.01244
2 and 3	Carbon	.03469
	Al	.004172
	Fe	.002609
	H	.02487
	O	.01244
4	Fe	.08487
5	Pb	.0329
6	Fe	.08487

* See Figure 2 for region descriptions.

90010144

Unit Description



Cross Section of Fuel Array Geometry

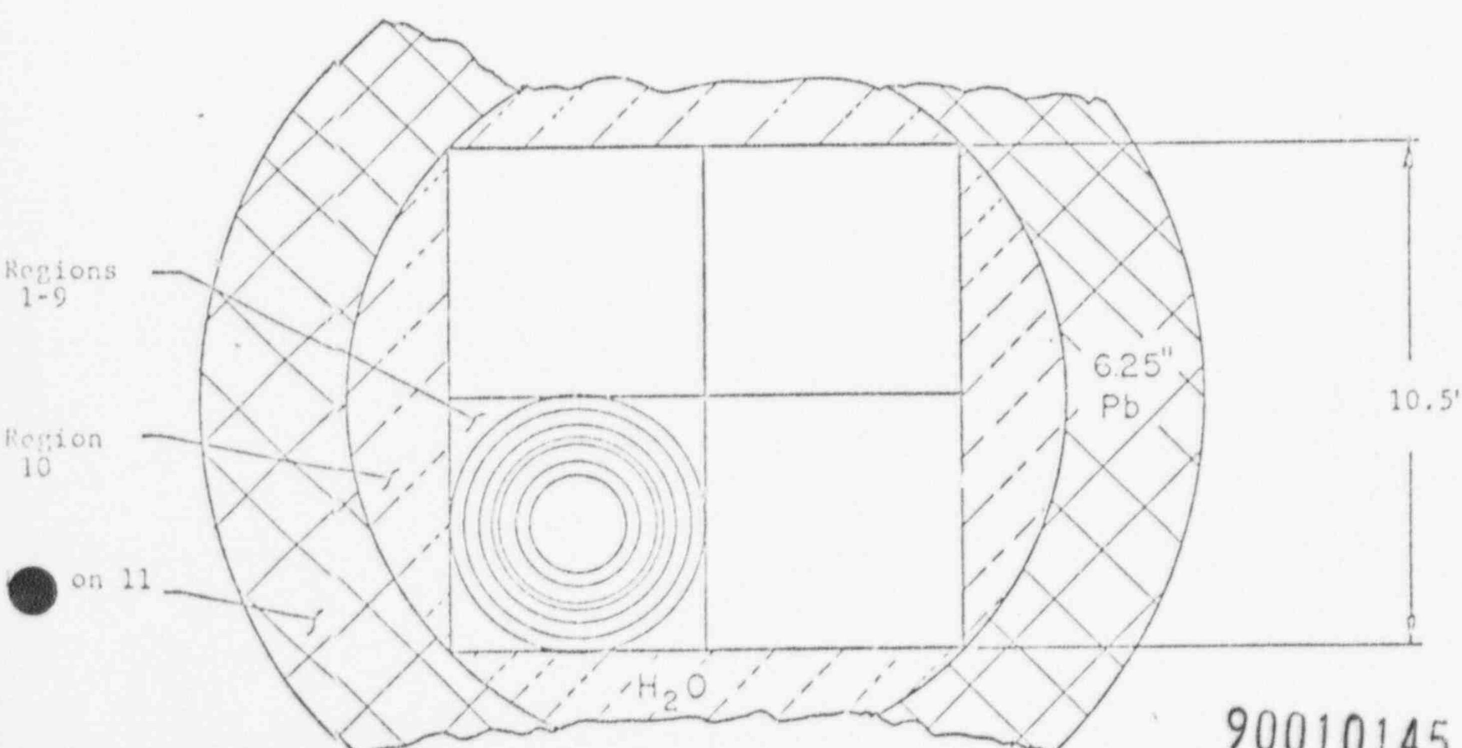


FIGURE 3. GEOMETRY MODEL FOR DETAILED FUEL CALCULATION

TABLE 3. NUMBER DENSITIES FOR DETAILED MODEL*

Region Number	Material	O.D., inches	Number Density x 10^{24}
	Fuel Unit		
1	Graphite (spine)	1.73	.0928
2	Fuel	2.74	--
	U^{235}		.001428
	U^{238}		.00000536
	Th^{232}		.000776
	C_{12}		.0822
3	Graphite (sleeve)	3.5	.0953
4	Void	4.188	.0000
5	Mild steel	4.312	.08487
6	Aluminum	4.5	.0603
7	Water (H,O)	5.0	.067, .0335
8	Aluminum	5.25	.0603
9	Water (H,O)	--	.067, .0335
	Reflector		
10	Water (H,O)		.067, .0335
11	Lead		.0329

* See Figure 3 for region descriptions.

90010146

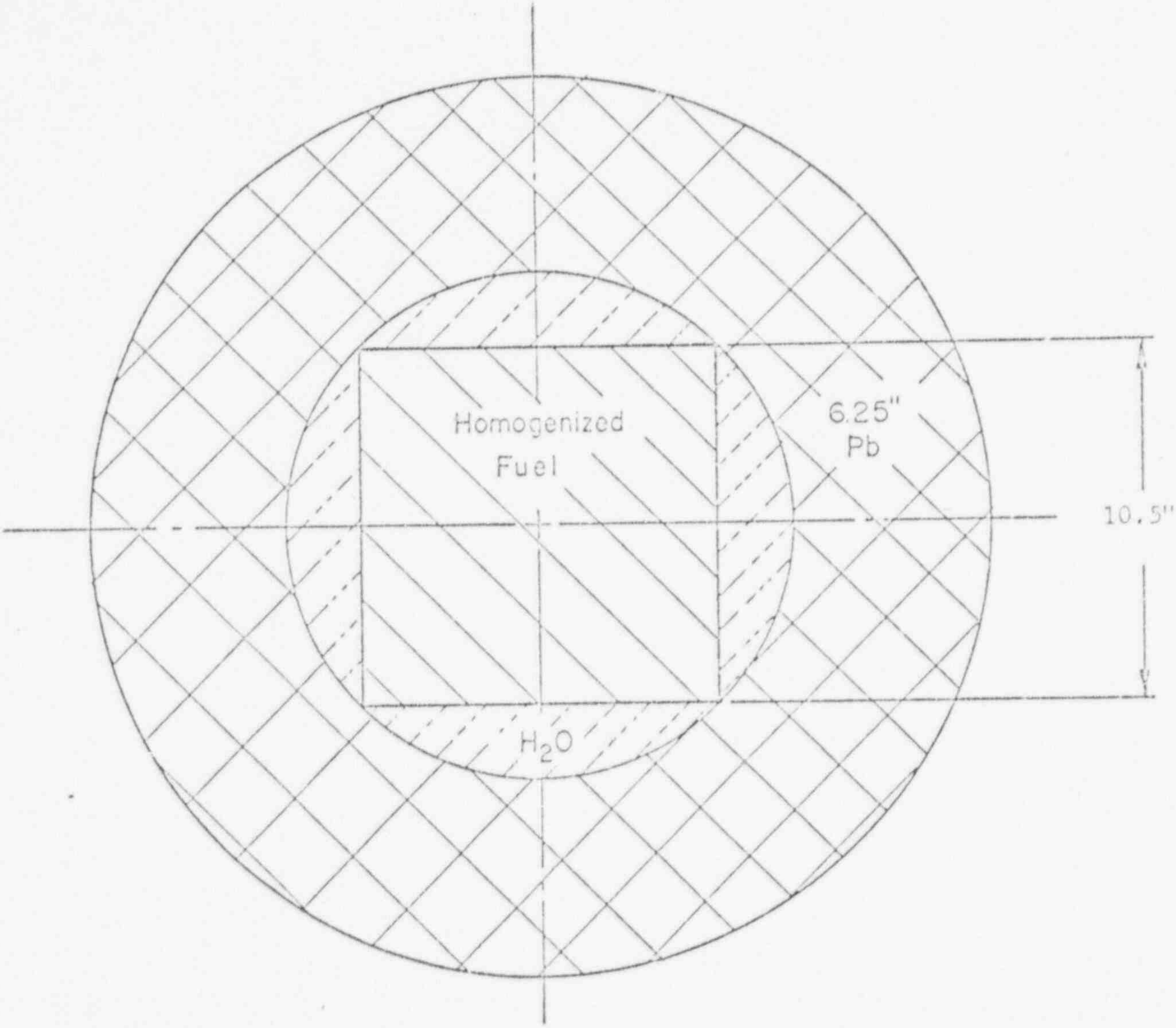


FIGURE 4. GEOMETRY MODEL FOR HOMOGENIZED FUEL CALCULATION

90010147

TABLE 4. NUMBER DENSITIES FOR HOMOGENIZED MODEL OF 2 x 2 x 1 FUEL ARRAY

Material	Number Density $\times 10^{24}$
Homogenized Fuel	
Carbon (fuel)	.0167
Graphite (spine)	.01253
Graphite (sleeve)	.02016
U^{235}	.00002906
U^{238}	.00000149
Th^{232}	.0001581
Al	.006443
Fe	.004033
Water (H_2O)	.01431, .007155
Reflector	
Water (H_2O)	.067, .0335
Pb	.03348

90010148

6.4.1 Criticality Results

The results of these two calculations show that the homogenized fuel model compares favorably with the detailed fuel model for calculation of K_{eff} and yields slightly conservative values of K_{eff}. These results substantiate the validity of the fuel homogenization for the PB-1 K_{eff} calculations, since this same fuel homogenization scheme was used for the calculation of the 5 x 5 x 1 array of PB-1 containers.

6.5 Appendix

6.5.1 Computer Codes Description

KENO (Originator - Oak Ridge National Laboratory)

KENO is a three-dimensional multigroup Monte Carlo criticality code written in FORTRAN IV for the IBM-360 computer. The Battelle-Columbus version of this code has been converted to the CDC-6400 computer. A salient feature of the code is its special geometry package (GEM) which allows three-dimensional descriptions of systems which are made up of cylinders, spheroids, and cuboids. For more complex systems, the code can use the generalized geometry package (GEOM) developed for the O5R Monte Carlo code. With this package, any system can be handled which can be described by a collection of plans and/or quadratic surfaces, arbitrarily oriented and intersecting in arbitrary fashion.

Multigroup cross sections such as the Hansen and Roach 16-group set are used. Up to 30-group cross sections can be used with the Battelle-Columbus version of KENO. In the code, neutron scattering is assumed to be isotropic in the laboratory system for all elements except hydrogen. The anisotropic scattering of hydrogen is found from the randomly determined energy change associated with the neutron-hydrogen collision.

Energy and spacially dependent biasing can be used to reduce the variance in systems with regions of widely ranging neutron importance.

The computer time required to solve a given problem is quite short as compared to similar Monte Carlo codes. Also, KENO generally has shorter computing times than the two-dimensional transport code, DOT, for the same problem.

POOR ORIGINAL

90010151

VII

7.0 OPERATING PROCEDURES

7.1 Procedures for Loading and Unloading the Package

Detailed loading and unloading procedures are given Appendix 7.2, Procedure No. TR-OP-002, "Handling Procedure for Chem-Nuclear Systems, Inc. (CNSI) Transport Cask CNS 4-45, C of C No. USA/6375/B (F).

90010152

REV.	DESCRIPTION	DATE	APPROVED

CNSI SAFETY REVIEW BOARD APPROVAL
BY Bruce Johnson
DATE 11/14/79

90010153

REVISION STATUS

SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REV.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SHEET	18	19															
REV.	-	-															

PREPARED M C Terry	DATE 11/12/79	CHEM – NUCLEAR SYSTEMS, INC.
CHECKED D. E. Corbett	11-12-79	TITLE HANDLING PROCEDURE FOR CHEM-NUCLEAR SYSTEMS, INC. (CNSI) TRANSPORT CASK C " 4-45, MODEL NUMBER PB-1 CERTIFICATE OF COMPLIANCE NUMBER 6375
ENGINEER W. D. Hidgs	11/14/79	UNCONTROLLED COPY
QUALITY B. Smiris	11/14/79	

APPROVED	CONTRACT NO.	DOCUMENT NO.	REV.	SHEET
K.H. Kinkade 11/14/79		TR-OP-002	-	1

CNSQ 1001/8-78

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LIST OF FIGURES

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1.0 SCOPE

1.1 Purpose

This document establishes procedures for the routine handling, loading, and unloading of CNSI Transport Cask CNS 4-45 Model Number PB-1.

1.2 Applicability

This procedure applies to CNSI Transport Cask CNS 4-45, Model Number PB-1.

2.0 CASK DESCRIPTION

The CNS 4-45 (Model No. PB-1) is a mild steel encased shipping cask designed for transporting low-level radioactive material (see Figure 1). The cylindrical cask is 173 1/8 inches long and 42 1/2 inches in diameter except for 31-5/8 inches at the end which is 40 1/2 inches in diameter. The principal shielding consists of 6 1/4 inches of lead. The cask cavity is 26 inches in diameter and 159 inches long.

Each end of the cask has a cover and an impact limiter. Each impact limiter is bolted to the lid and the cask by four (4) of the twelve (12) 1 1/4-inch cover bolts. There are twenty-four (24) cover bolts in all. Each lid consists of two (2) 1 1/2-inch stainless steel plates with 4 inches of lead shielding. Each impact limiter consists of a bundle of 2 1/4-inch, 13-gauge tubing welded between 1/4-inch stainless steel plates. The cask also has two (2) drain valves and a vent.

CASK WEIGHTS (APPROXIMATE):

CASK LID WEIGHT	3,000	pounds
IMPACT LIMITERS (EACH)	630	pounds
CASK WEIGHT (EMPTY, WITH LIDS INSTALLED)	57,050	pounds
MAXIMUM CASK PAYLOAD (INCLUDING SHORING)	10,000	pounds
MAXIMUM CASK WEIGHT (LOADED)	67,050	pounds
MAXIMUM DECAY HEAT	3,715	Watts

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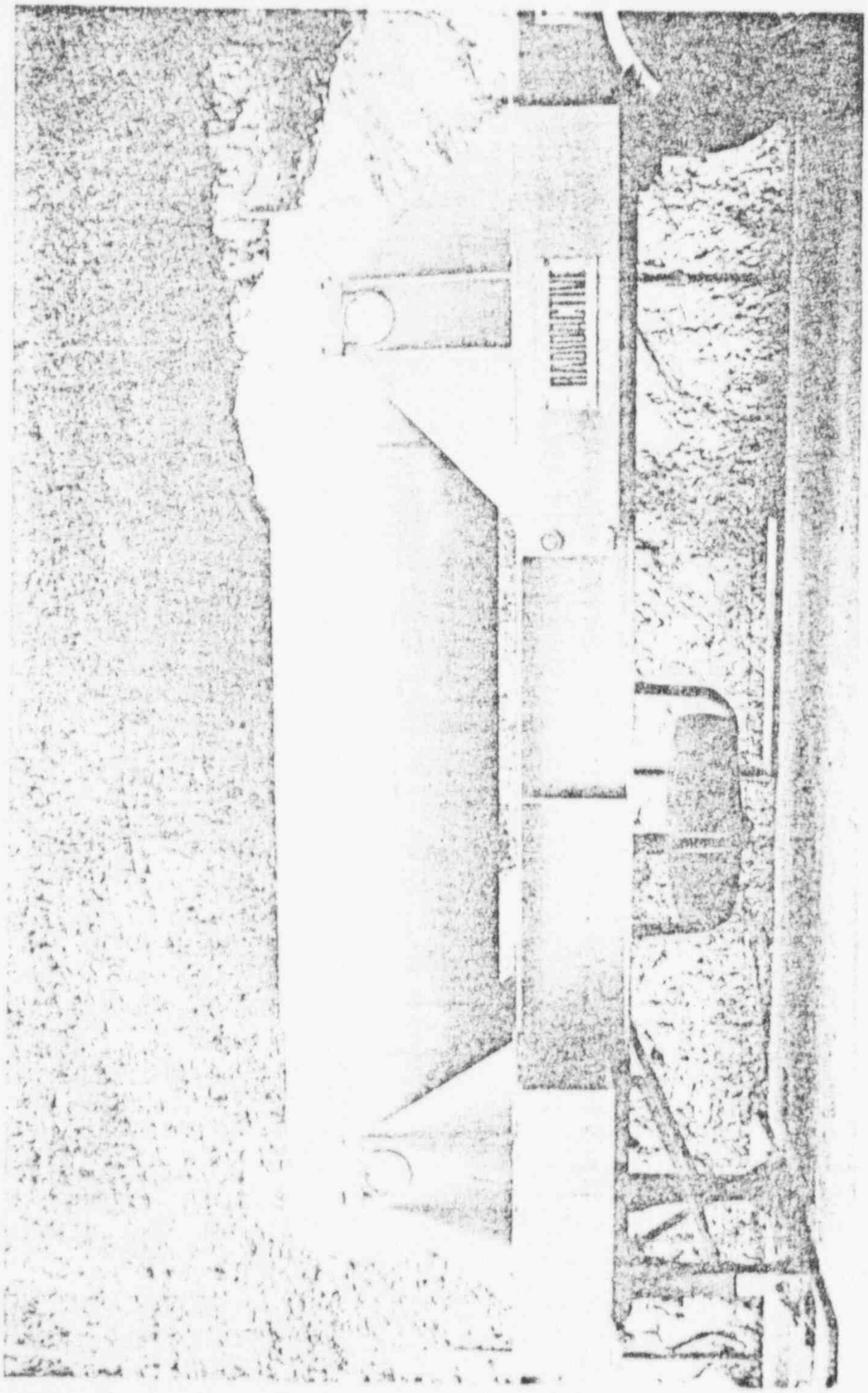


CHEM NUCLEAR SYSTEMS, INC.
CNS 4-45

Rev. 1

Figure 1. CNSI Transport Cask CNS 4-45, Model Number PB-1

CHEM NUCLEAR SYSTEMS, INC.

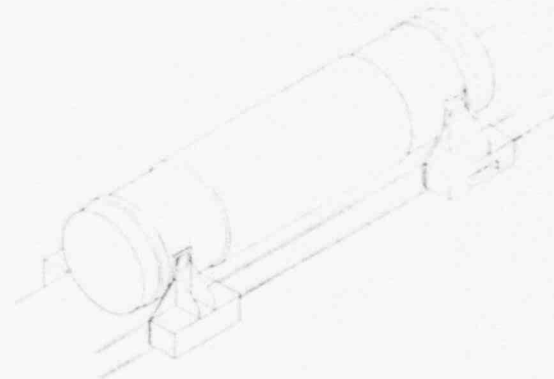
CNS 4-45
SHIELDING: 6.5 IN.–7.5 IN. LEAD EQUIV.
U.S.N.R.C. PACKAGE IDENT NO. USA/6375/B( )F

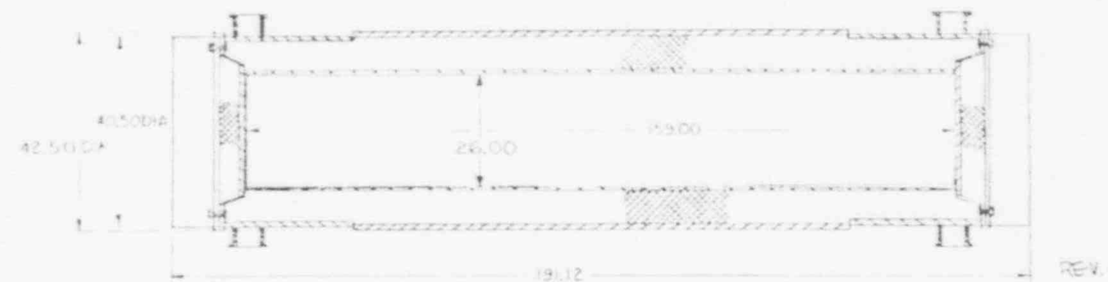
CAPACITY
(6) 55 GAL. DRUMS
OR (1) 45 CU. FT. CONTAINER

WEIGHT
GROSS WEIGHT: 57,050 LBS. (EMPTY)
CASK BODY WEIGHT: 51800 LBS

IMPACT LIMITERS: 630 LBS (EA)

MODE OF TRANSPORTATION
TRUCK/TRAILER





POOR ORIGINAL

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DOCUMENT	REV.	SHEET
TR-OP-002	-	5

CNSQ 1002/8-78

USER CHECKOFF SHEET

Date__________ Shipment Number__________ Waste Identification __________

Operator(s)__________________________ HP Technician(s)__________________________

__________________________ __________________________

__________________________ __________________________

Shipper __________________________ Driver__________________________

Time of arrival at Site __________ Time of departure from site __________

==

Please initial when item completed: Operator (O), Supervisor (S)

1. Disposable Liner Closure Devices Replaced __________(O) __________(S)
2. Gaskets Inspected __________(O) __________(S)
3. Lid bolts torqued __________(O) __________(S)
4. Cask sealed __________(O) __________(S)
5. Cask tiedowns inspected __________(O) __________(S)
6. Vehicle Placarded __________(O) __________(S)

Please fill in blank and initial: Operator (O), Health Physist (HP), Supervisor (S)

7. Cask Payload (including shoring) Max. __________ Actual __________ __________(O) __________(S)
8. Decay heat-watts (if applicable) Max. __________ Actual __________ __________(O) __________(S)
9. GAMMA = __________ at 6 ft. from tailer __________(HP) __________(S)
10. GAMMA = __________ at cask surface __________(HP) __________(S)
11. Smearable ($d/m/100\ cm^2$) = __________, __________(HP) __________(S)

==

Health & Safety (H & S) - Please fill in blanks and initial.

GAMMA = __________ at 6 ft. from tailer __________(H&S)

GAMMA = __________ at cask surface __________(H&S)

12. Smearable ($d/m/100\ cm^2$) = ____________________(H&S)

==

I hereby certify that the above statement is correct and the cask has been loaded and tested in accordance with approved procedures.

Operator(s) __________________________

____

H & S Tech(s) __________________________

____

Supervisor(s) __________________________

____

____

Figure 2. User Check-off Sheet

90010158

DOCUMENT	REV.	SHEET
TR-OP-002	-	6

CNSQ 1002/8-78

3.0 REFERENCES

Code of Federal Regulations (CFR)	Title 10, Part 71	
	Title 49, Part 172	
		Parts 173.389-173.398
		Part 391
Federal Motor Carrier Safety Regulations		Part 393.100
CNSI Transport Cask CNS 4-45, Model No. PB-1		Certificate of Compliance No. 6375

Battelle Memorial Institute Drawings No. 9123-6PB-0001, Rev. E (Whitehead & Kales PF-1 Shipping Container) and 000-000-552, Rev. A (Fuel Basket Container Assembly PRDC)

4.0 REQUIREMENTS

4.1 Tools, Materials, and Equipment--At Shipper's Location

4.1.1 CNSI-furnished Items

(a) CNS 4-45 (PB-1) cask and trailer

(b) CNS 4-45 (PB-1) cask license and documentation

(c) CNS 4-45 (PB-1) cask lid gaskets and spare parts

(d) CNS 4-45 (PB-1) fuel basket container or liner, as required

(e) CNS 4-45 (PB-1) cask lifting yoke

(f) CNS 4-45 (PB-1) lid lifting device

(g) CNS 4-45 (PB-1) cask pressurization test equipment

(h) CNS 4-45 (PB-1) redundant lifting yoke, if required

(i) Pressure relief valve

4.1.2 Shipper-furnished Items

(a) Crane compatible with loaded cask, filled fuel basket, and cask lids

(b) Auxiliary mobile crane compatible with cask lids and impact limiters

(c) Cask and lid lifting yokes

(d) Lifting sling compatible with filled fuel basket and loaded cask

(e) Lifting tools compatible with cask lid lifting devices

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(f) Tools

(1) 0-150 ft lb and 150-600 ft lb torque wrenches

(2) Proper size sockets

(3) Ratchet and breaker bar with drive

(g) Acceptable bolt lubricant (Moly-Z, Neolube, or Anti-Seize)

(h) Health physics (HP) instrumentation and support materials

4.2 <u>Tools, Materials, and Equipment--At Unloading Site</u>

(a) Crane compatible with loaded cask, filled fuel basket or liner, and cask lids

(b) Auxiliary mobile crane compatible with cask lids and impact limiters

(c) Lifting and unloading hardware

(d) Horizontal lid lifting yoke

(e) Front-end loader or equivalent equipment

(f) One throw-away hook assembly with approximately 30 feet of cable attached

(g) Wood blocks

(h) Lifting sling compatible with loaded cask, filled fuel basket or liner, and cask lid

(i) Tools

(1) 0-150 ft lb and 150-600 ft lb torque wrenches

(2) Proper size sockets

(3) Ratchet and breaker bar with drive

(j) Acceptable bolt lubricant (Moly-Z, Neolube, or Anti-Seize)

(k) Health physics (HP) instrumentation and support materials

4.3 <u>Prerequisites</u>

Not applicable.

4.4 <u>Acceptance Criteria</u>

Not applicable

5.0 HANDLING PRECAUTIONS

5.1 Treat the inside of the cask, the bottom of the cask lids, and any material removed as contaminated.

5.2 When lifting the cask, keep crane cables vertical <u>at all times</u> to avoid lateral movement of the cask.

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5.3 When unloading the cask, remain clear of the cask as the lid is removed. Radiation will stream from the cask.

5.4 Survey the cask cavity for radiation and contamination levels after the cask contents have been removed. Decontaminate as required by the health physics technician after the contents have been removed.

5.5 Remove any liquid from the cask cavity. Treat this liquid as radioactive waste.

5.6 Visually inspect the cask for damage to the cask lids, gasket, gasket seating surfaces, lifting trunnions, lifting yokes, impact limiters, or tie-downs.

5.7 To prevent personal injury and cask damage, ensure that free-standing ladders are secured and attended by personnel. Do this before climbing onto the cask.

5.8 Before the cask leaves the facility, the following shall be confirmed:

(a) That any external lifting lugs or trunnions are properly covered for transport.

(b) That the cask is secured to the trailer in accordance with Section 393.100 of the Federal Motor Carrier Safety Regulations and the Certificate of Compliance.

(c) That trailer placarding and cask labelling meet DOT Specifications (CFR Title 49, Part 172).

(d) That exterior radiation levels do not exceed 10 mR/hr at 6 feet and 2 mR/hr in the tractor cab, in accordance with 49 CFR 173.393 (j).

(e) That the outer package is sealed with anti-tamper seals.

(f) That all drain plugs are securely installed and sealed with anti-tamper seals.

6.0 <u>LOADING PROCEDURE</u>

NOTE: KEEP CRANE CABLES VERTICAL <u>AT ALL TIMES</u> TO AVOID LATERAL MOVEMENT OF THE CASK.

THE CASK SHALL BE REPLACED ON THE TRAILER IN THE EXACT ORIENTATION AS IT WAS RECEIVED UNLESS SPECIFIC APPROVAL AND/OR INSTRUCTIONS TO THE CONTRARY ARE RECEIVED FROM CNSI.

IDENTIFY THE "TOP" OF THE CASK BY THE REMOVABLE PORT IN THE CENTER OF THE "TOP" LID.

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6.1 Position the trailer under the overhead crane (35-ton capacity).

6.2 Prepare to remove the impact limiters.

CAUTION: EACH IMPACT LIMITER WEIGHS 630 POUNDS.

(a) Attach the crane hook on the mobile crane to the lifting lug on each impact limiter.

(b) Remove the four (4) 1 1/4-inch bolts on each impact limiter using a two-inch socket.

(c) Slowly remove each impact limiter.

(d) Move each impact limiter to a convenient position on the trailer or in a clean set-down area.

(e) Detach the crane hook.

6.3 Prepare to attach the cask lifting yoke.

(a) Using a 1 1/2-inch socket, remove the two (2) 1 1/2-inch bolts that attach each tie-down plate to the cask cradle in four places. Remove a total of eight (8) bolts and retain them for re-installation.

(b) Remove the four (4) cask tie-down plates and retain them for re-installation.

(c) Attach the crane hook to the lifting yoke.

(d) Remove the two (2) keepers by removing two (2) bolts each.

(e) Attach the lifting yoke to the two (2) lifting trunnions on the "top" of the cask.

(f) Raise the cask about six inches and attach the two (2) keepers to the lifting yoke with two (2) bolts each. Use a 1 1/8-inch socket to attach the bolts.

6.4 Prepare to upright the cask on the trailer.

NOTE: DO NOT PLACE ANYTHING UNDER THE CASK UNTIL THE CASK IS IN A COMPLETELY UPRIGHT POSITION.

(a) Slowly lift the cask to a vertical position, keeping the crane cables vertical at all times to avoid lateral movement of the cask. Slowly advance the crane bridge, or the trailer, if necessary, while lifting the cask.

(b) Inspect the cask for damage. If necessary, rinse road dirt from the cask exterior.

(c) Place clean plywood or equivalent material under the bottom of the cask to prevent foreign material (contamination) from embedding

into the surface of the cask. Plywood should be secured to the lower trunnions and retained to protect the bottom of the cask when it is lowered into the pool.

6.5 Prepare to open the cask vents.

CAUTION: TREAT ALL PLUGS REMOVED AS CONTAMINATED.

(a) Expose the valve and test ports by removing the four (4) covers at the center of each trunnion, four (4) cover bolts each.

(b) Remove the pipe plugs from the two (2) drain valves on the bottom of the cask and the vent valve on the top of the cask. Retain the plugs for re-installation.

(c) Open the two (2) drain valves on the cask bottom.

(d) Open the vent valve at the top of the cask.

(e) Ensure that all valves are in the full open position.

6.6 Prepare the cask for lowering into the pool.

NOTE: THE CASK LID IS NORMALLY REMOVED UNDERWATER. IF THE LID IS TO BE REMOVED BEFORE THE CASK IS IMMERSED, CONTACT THE HEALTH PHYSICS DEPARTMENT BEFORE REMOVING THE LID.

(a) Attach the lid lifting device to the cask lid.

(b) Move the cask to the pool.

(c) Remove the cask lid bolts.

(d) Lower the cask to the bottom of the pool. Allow time for the cask to fill with water before removing the lid. This step will prevent inrushing water from dislodging the O-ring from the lid.

NOTE: WHEN THE AIR BUBBLES STOP COMING FROM THE TOP VENT, THE CASK IS FULL OF WATER.

(e) Allow the cask lifting yoke to swing down and clear the lid.

(f) Remove the crane hook, if necessary.

6.7 Prepare to remove the cask lid.

CAUTION: TREAT THE UNDERSIDE OF THE LID, THE INSIDE SURFACES OF THE CASK, AND ANY BOLTS OR SEALS REMOVED AS CONTAMINATED.

(a) Confirm that the cask is filled with water.

(b) Attach the crane hook or a suitable extension tool to the lid lifting device.

(c) Slowly remove the cask lid.

NOTE: CAREFULLY OBSERVE THIS OPERATION TO CONFIRM THAT THE O-RING DOES NOT FALL FROM ITS RETAINING GROOVE. IF THE O-RING

DOES FALL, REMOVE THE LID FROM THE POOL AND RE-INSERT THE O-RING OR REPLACE IT WITH A NEW O-RING.

(d) Move the lid to a convenient position (in the pool, on the deck, or suspended from the crane or extension tool).

(e) Remove the crane hook, if necessary.

6.8 Load the cask, exercising caution not to damage the gasket seating surfaces.

NOTE: ADD VERTICAL OR LATERAL SPACERS TO THE CONTENTS OF THE CASK, IF NECESSARY, TO PREVENT SIGNIFICANT MOVEMENT DURING NORMAL TRANSPORT CONDITIONS.

6.9 Prepare to replace the cask lid.

(a) Attach the crane hook to the cask lid lifting device, if necessary, and lift the lid onto the cask.

(b) Carefully lower and position the lid on the cask using the alignment pins.

NOTE: TWO (2) ALIGNMENT PINS MUST BE ENGAGED BEFORE THE LID IS PROPERLY ALIGNED.

6.10 Prepare to raise the cask to the surface of the pool.

CAUTION: TREAT THE CABLES, THE CASK, THE CRANE HOOK, AND THE LIFTING YOKE AS CONTAMINATED. RINSE THEM WITH CLEAN WATER.

(a) Attach the crane hook to the lifting yoke, if necessary.

(b) Slowly lift the cask to the surface of the pool and insert the lid bolts, hand-tight.

(c) While raising the cask, rinse the cables, cask, crane hook, and lifting yoke with clean water.

(d) Suspend the cask over the pool and allow all of the water to drain out of the cask.

(e) Estimate if an appropriate amount of water has drained out of the cask, an amount consistent with the cask contents. If it appears that drain blockage has occurred, check clearance with a hand pump or slight (5-10 psi) pressurization.

(f) Rinse the valve ports with clean water.

CAUTION: DO NOT MOVE THE CASK FROM THE POOL SURFACE WHILE IT IS STILL DRIPPING WATER.

(g) Monitor the cask (as required by the health physics technician) for neutron and gamma radiation.

(h) Allow the cask to drain completely.

NOTE: PROVIDE ANTI-FREEZE INSIDE THE CASK TO PREVENT FREEZING, IF APPROPRIATE.

6.11 Prepare to check the pressure relief valve.

(a) Unscrew the relief valve from the trunnion and place it on test stand.

(b) Increase the pressure until it relieves at 85 psi.

(c) Replace the valve if it is faulty or re-install the valve if it is operable.

6.12 Prepare to move the cask to the decontamination area.

(a) Remove the keepers from the cask yoke, if necessary.

(b) Remove the lifting device from the cask lid.

(c) Close the top vent.

(d) Close one (1) of the two (2) drain valves on the bottom of the cask.

(e) Replace the plug in the closed drain valve and in the top vent.

(f) Tighten the eight (8) 1 1/4-inch lid bolts using an alternating pattern. Torque them to 100 ± 10 ft lb (90 ± 9 ft lb if lubricated).

(g) Re-torque the eight (8) lid bolts to 300 ± 30 ft lb (270 ± 27 ft lb if lubricated), using an alternating pattern.

6.13 Prepare to perform the cask pressurization test.

(a) Attach the cask pressurization test equipment to the open drain valve on the bottom of the cask.

(b) Pressurize the cask to a minimum of 30 psi or a maximum of 60 psi.

(c) Hold the pressure for five (5) minutes while checking for pressure leakdown with the test equipment gauge. If the cask does not hold pressure, check for leakage in the O-rings in the top and bottom lids, the two (2) drain valves, the cask vent, and the pressure gauge connections at the four (4) trunnion locations.

(d) Vent the cask to the plant ventilation system, the fuel pool, or other acceptable contamination containment area.

(e) Correct any leakage and repeat the pressure test, if necessary, until the leakage is controlled.

(f) Close the drain valve and repeat the pressure test for 30 seconds to assure a sealed drain valve.

90010165

(g) Remove the pressure test equipment and replace the pipe plug in the drain valve.

6.14 Decontaminate the cask and yoke surfaces. Obtain a health physics survey to confirm that the cask is free of contamination.

6.15 Prepare to replace the cask on the trailer.

CAUTION: KEEP CRANE CABLES VERTICAL AT ALL TIMES TO AVOID LATERAL MOVEMENT OF THE CASK.

NOTE: REPLACE THE CASK ON THE TRAILER IN THE EXACT ORIENTATION AS RECEIVED.

(a) Attach the lifting yoke and keepers to the cask lifting trunnions, if necessary.

(b) Lift the cask in a vertical position.

(c) Back the trailer under the cask.

(d) Lower the cask onto the trailer by carefully lowering the bottom trunnions into the tie-down saddles at the appropriate end of the trailer. Move the crane bridge or back the trailer SLOWLY to keep crane cables vertical. Note the offset of the bottom trunnions to tilt the cask in the proper direction.

(e) Remove the keepers from the lifting yoke while the cask is at a convenient height and before the trunnions enter the lower saddles.

(f) Remove the lifting yoke and decontaminate all parts.

(g) Reload the yoke, the lid lifting device, the pressure tester, and all spare parts onto the trailer.

(h) Place the cask tie-down plates on the cask cradle and replace the two (2) 1 1/2-inch bolts that attach the plates to the cask cradle in four (4) places. Replace a total of eight (8) bolts in all. Torque to 100 ± 10 ft lb (90 ± 9 ft lb if lubricated).

(i) Move the cask and trailer outside the loading facility, if necessary.

6.16 Prepare to replace the impact limiters

(a) Attach the crane hook to the lifting lugs on each impact limiter.

(b) Position each impact limiter on the cask.

(c) Replace the four (4) 1 1/4-inch bolts on the impact limiters using a 2-inch socket. Torque to 70 ± 7 ft lb (63 ± 7 ft lb if lubricated).

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(d) Attach lead wire seals to the lifting shackles on the impact limiters and secure them to the trunnions. Seal both impact limiters.

6.17 Before the cask leaves the facility, the following shall be confirmed:

(a) That any external lifting lugs or trunnions are properly covered for transport.

(b) That the cask is secured to the trailer in accordance with Section 393.100 of the Federal Motor Carrier Safety Regulations and the Certificate of Compliance.

(c) That trailer placarding and cask labelling meet DOT Specifications (CFR Title 49, Part 172).

(d) That exterior radiation levels do not exceed 10 mR/hr at 6 feet and 2 mR/hr in the tractor cab, in accordance with 49 CFR 173.393 (j).

(e) That the outer package is sealed with anti-tamper seals.

(f) That all drain plugs are securely installed and sealed with anti-tamper seals.

6.18 Complete the USER CHECK-OFF SHEET and send a copy along with the shipment.

7.0 UNLOADING PROCEDURE

NOTE: ALL PERSONNEL HANDLING THE FILLED FUEL BASKET SHALL OBSERVE ESTABLISHED SITE RADIATION PROTECTION PROCEDURES.

KEEP CRANE CABLES VERTICAL AT ALL TIMES TO AVOID LATERAL MOVEMENT OF THE CASK.

THE CASK SHALL BE REPLACED ON THE TRAILER IN THE EXACT ORIENTATION AS IT WAS RECEIVED UNLESS SPECIFIC APPROVAL AND/OR INSTRUCTIONS TO THE CONTRARY ARE RECEIVED FROM CNSI.

IDENTIFY THE "TOP" OF THE CASK BY THE REMOVABLE PORT IN THE CENTER OF THE "TOP" LID.

7.1 Position the unloading crane at an optimum distance to facilitate off-loading and to minimize operator exposure.

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7.2 Prepare to remove the impact limiters.

CAUTION: EACH IMPACT LIMITER WEIGHS 630 POUNDS.

(a) Attach the crane hook on the mobile crane to the lifting lug on each impact limiter.

(b) Remove the four (4) 1 1/4-inch bolts on each impact limiter using a two-inch socket.

(c) Slowly remove each impact limiter.

(d) Move each impact limiter to a convenient position on the trailer or in a clean set-down area.

(e) Detach the crane hook.

7.3 Prepare to remove the cask tie-down plates.

(a) Using a 1 1/2-inch socket, remove the two (2) 1 1/2-inch bolts that attach the tie-down plates to the cask cradle in four (4) places. Remove a total of eight (8) bolts and retain them for re-installation.

(b) Remove the four (4) cask tie-down plates and retain them for re-installation.

7.4 Prepare to lift the cask horizontally.

(a) Attach the cask lifting slings to the crane hook and position the sling around the four (4) cask lifting trunnions.

(b) Lift the cask horizontally.

(c) Position the cask (on plastic sheeting) near the disposal trench and block the "top" end of the cask with wood blocks to allow lid removal.

7.5 Prepare to remove the cask lid.

CAUTION: REMAIN CLEAR OF THE CASK AS THE LID IS REMOVED. RADIATION WILL STREAM FROM THE CASK.

(a) Position the mobile crane to remove the lid from the cask.

(b) Attach the horizontal lid lifting yoke to the "top" lid of the cask.

(c) Attach the mobile crane to the lifting yoke.

(d) Remove the remaining eight (8) 1 1/4-inch bolts from the cask lid. Retain for re-installation.

(e) Remove the cask lid. Swing it clear of the cask and wrap it in plastic. Leave it suspended from the mobile crane or position as required.

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7.6 The health physics technician shall conduct a radiation and contamination survey to determine offloading precautions.

7.7 Prepare to remove the contents of the cask.

(a) Attach the hook/cable assembly to the liner.

CAUTION: DO THIS AS QUICKLY AS POSSIBLE TO MINIMIZE EXPOSURE.

(b) Reposition the cask over the edge of the trench and allow the cask to rest on the ground. The open end of the cask should be over the disposal area of the trench.

(c) Lead the throw-away cable assembly from the cask to the front-end loader.

(d) As directed by the HP technician, vacate all persons from the immediate area except for the crane operator and a rigger. The rigger shall stand in clear view of the crane operator.

CAUTION: THE NEXT STEP MUST BE DONE CAUTIOUSLY TO AVOID BREAKING THE CABLE. DO NOT ALLOW THE CABLE TO GO SLACK. DO NOT PERFORM ANY MOVEMENTS IN A JERKING MANNER.

(e) Slowly move the front-end loader so that the attached cable will pull the liner out of the cask. Continue movement until the liner clears the cask and is in burial position in the trench.

(f) Detach the throw-away cable from the front-end loader. Allow the cable to fall into the trench.

7.8 Reposition the cask to its earlier position on wood blocks.

7.9 The health physics technician shall survey the interior of the cask for radiation and contamination levels. Decontaminate if acceptable levels are exceeded.

CAUTION: TREAT ANY LIQUID IN THE CASK OR USED IN THE DECONTAMINATION PROCESS AS CONTAMINATED.

7.10 Visually inspect the inside of the cask for damage or for liquid accumulation. If the inside surfaces of the cask are damaged, remove the cask from service.

7.11 As the health physics technician directs, clean the inside of the cask lid, the O-ring, and the seating surfaces. Replace the O-ring if it is damaged.

7.12 Prepare to replace the cask lid.

(a) Visually check to confirm that the O-ring is in place in its retaining groove.

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(b) Attach the crane hook to the lifting yoke on the cask lid and lift the lid onto the cask.

(c) Position the lid on the cask using the alignment pins.

NOTE: TWO (2) ALIGNMENT PINS MUST BE ENGAGED BEFORE THE LID IS PROPERLY ALIGNED.

(d) Replace the eight (8) 1 1/4-inch lid bolts, using an alternating pattern. Torque them to 100 ± 30 ft lb (90 ± 9 ft lb if lubricated).

(e) Retorque the eight (8) lid bolts to 300 ± 30 ft lb (270 ± 27 ft lb if lubricated), using an alternating pattern.

(f) Remove the lid lifting yoke and the crane hook.

7.13 Decontaminate the cask and yoke surfaces. Obtain a health physics survey to confirm that the cask is free of contamination.

7.14 Prepare to replace the cask on the trailer.

CAUTION: KEEP THE CRANE CABLES VERTICAL AT ALL TIMES TO AVOID LATERAL MOVEMENT OF THE CASK.

(a) Attach the lifting sling to the cask lifting trunnions, if necessary.

(b) Lift the cask in a horizontal position, keeping crane cables vertical at all times to avoid cask swing.

(c) Lower the cask onto the trailer by carefully lowering the cask into trunnions into the tie-down saddles on the cask cradle.

NOTE: REPLACE THE CASK IN THE EXACT ORIENTATION AS RECEIVED. THE DESIGNATED "TOP" OF THE CASK IS IDENTIFIABLE BY THE REMOVABLE PORT IN THE "TOP" LID.

(d) Remove the lifting slings.

(e) Reload the lid lifting device and all spare parts onto the trailer.

(f) Place the cask tie-down plates on the cask cradle and replace the two (2) 1 1/2-inch bolts that attach the plates to the cask cradle in four (4) places. Replace a total of eight (8) bolts in all. Torque to 100 ± 10 ft lb (90 ± 9 ft lb if lubricated).

7.15 Prepare to replace the impact limiters.

(a) Attach the crane hook to the lifting trunnion on each impact limiter.

(b) Position each impact limiter on the cask.

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(c) Replace the four (4) 1 1/4-inch bolts on the impact limiter using a 2-inch socket. Torque to 70 ± 7 ft lb (63 ± 6 ft lb if lubricated.

(d) Attach lead wire seals to both impact limiters.

7.16 The health physics technician shall survey all exterior surfaces of the cask for contamination and radiation levels. Decontaminate, as required, to meet the limits set forth in Section 173.397 of CFR 49.

7.17 Before the cask leaves the facility, the following shall be confirmed:

(a) That any external lifting lugs or trunnions are properly covered for transport.

(b) That the cask is secured to the trailer in accordance with Section 393.100 of the Federal Motor Carrier Safety Regulations and the Certificate of Compliance.

(c) That trailer placarding and cask labelling meet DOT Specifications (CFR Title 49, Part 172).

(d) That exterior radiation levels do not exceed 10 mR/hr at 6 feet and 2 mR/hr in the tractor cab, in accordance with 49 CFR 173.393 (j).

(e) That the outer package is sealed with anti-tamper seals.

(f) That all drain plugs are securely installed and sealed with anti-tamper seals.

8.0 REPORTS AND RECORDS

The following reports shall acc[illegible] all loaded shipments:

(a) Radioactive Shipping Record (RSR)--prepared by the shipper's health physics department.

(b) Vehicle Radiation Survey--prepared by the shipper's health physics department.

(c) Bill of Lading--prepared and certified by the shipper.

(d) User Check-off Sheet--prepared and signed by the shipper.

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VIII

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

8.1.1 Fabrication Inspection

In addition to the standard testing procedures described in Construction Specifications and Procedures and Appendix 7.2, the following inspections will be performed by the fabricator to the satisfaction of Battelle personnel prior to shipping the cask to the Peach Bottom Atomic Power Station:

(1) Check the mechanical fit and operability of all parts, including the cask lifting yoke and tilting device.

(2) Pressurize the internal cavity of the cask with water and air to 150 psig and hold for one hour.

(3) Check the operability of the relief and drain valves.

8.1.2 Preliminary Inspection

The following inspection and tests will be completed at the Peach Bottom Atomic Power Station before the initial use of the cask:

(1) Check all tiedown mechanisms for appropriate tightness after receipt of cask.

(2) Check all steps of loading procedure for fuel and salvage canisters.

(3) Verify handling capability during all steps.

(4) Check mechanical fits and clearances of all components, including fuel and salvage canisters.

(5) Check cask for complete water drainage.

(6) Check cask decontamination using Peach Bottom Atomic Power Station decontamination procedure.

(7) Verify shielding effectiveness by measuring radiation levels in air at all cask exterior surfaces with cask fully loaded with irradiated fuel elements.

(8) Verify cask thermal capacity by monitoring mid-plane outer surface temperature of fully loaded cask until equilibrium is achieved.

8.1.3 Routine Inspection

Prior to each use, the cask will be given a routine inspection to ascertain that the cask and its contents satisfy the applicable requirements in Subpart C of 10CFR71 and 49CFR171-179, including the following:

(1) Visual inspection of cask for damage.

(2) Visual inspection to assure that the cask cover is in place and properly sealed.

(3) Placement of lock wires and seals on drain valves.

(4) Monitor external radiation levels to assure that radiation constraints are not exceeded.

(5) Monitor the cask outer surface temperature to assure that the equilibrium temperature will not exceed the maximum design operating temperature during transport.

8.2 Appendix

STANDARD CONSTRUCTION SPECIFICATIONS AND PROCEDURES

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STANDARD CONSTRUCTION SPECIFICATIONS AND PROCEDURES

Cask Surface Finish
748-SF-801

Acceptable surface finish to be used in cask construction where machined and/or polished surface components are joined or assembled are listed below:

(1) The material surface should be machined or polished in the same direction where at all possible

(2) The surface finish of the components should be comparable

(3) Acceptable equivalent surface finishes

(A) Number 3 ground surface

(B) Microfinish No. 63 on machined surfaces

(C) Cold rolled finished surface

(D) Polished surface using 150 grit

Welding Procedure for Cask Construction
748-WP-101 Revised 8/1968

General

This specification covers the welding of austentic stainless steel and clad stainless steel by the Metallic Arc Process and the TIG Process. The following provisions are essentially those of the American Society of Mechanical Engineers Boilers and Pressure Vessel Code Section VIII Unfired Pressure Vessels 162 Edition and Section IX Welding Qualifications 1962 Edition.

Operator Qualification

All welders shall be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

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Base Metal

This procedure is applicable when welding involves joining the following materials:

(1) Plate	- ASTM	A-167 TP 304
(2) Pipe	- ASTM	A-312 TP 304
(3) Bars	- ASTM	A-276 TP 304
(4) Plate	- ASTM	A-240 TP 304

Filler Metal

Electrode materials shall comply with the following:

(1) ASTM - A - 298	E-308-15 lime coated
(2) ASTM - A - 298	E-310-15 lime coated
(3) ASTM - A - 371	GR-308 (TIG Process)
(4) ASTM - A - 276-65	E-308-L

Process

(A) Welding of all passes shall be done by the shielded metal arc process or the tungsten inert gas process.

(B) Tungsten electrodes shall conform to ASTM B-297 and shall be classification EWth-2. Shielding gas shall be welding-grade argon of 99.9 minimum purity.

(C) Inert gas shielded tungsten arc welders must be equipped with starting amperage adjustment control and built in high frequency to permit easy starting, continuous operation and to produce crater free welds.

Preparation of Base Metal

(A) No welding is to be done on edges or surfaces which have been arc or flame cut. Where arc or flame cutting is employed, not less than the following amount of material shall be removed from the cut edge.

Thickness of Material	Cleanup Allowance
Up to 1 in.	1/4 in.
1 in. to 2 in.	1/2 in.
2 in. to 3 in.	3/4 in.
All (plasma cut)	3/32 in. min.

(B) All paint, oxides, and scale on any surface involved in and for a distance of 2 in. adjacent to a weld joint shall be removed by grinding prior to any welding.

(C) The surface of the base metal shall be free of oil, grease, cutting fluids and other impurities for at least 1 in. on each side of the joint.

(D) Linear defects on the surface of the weld joint end preparation shall be repaired for a minimum of 3/4 in. from both edges of the weld joint if the defects:

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(1) Are not approximately parallel to the surface of the base material

(2) Are approximately parallel to the surface of the base material and are in excess of the limits specified below from various base material thicknesses:

Base Material Thickness	Maximum Total Defect Length in 3 in.
1/4 in. or below	1/16 in.
Above 1/4 in. to and including 1/2 in.	1/8 in.
Above 1/2 in. to and including 2 in.	1/4 in.
Above 2 in.	3/4 in.

(E) Defective material such as linear defects, cracks, craters, slag occlusion or porous welds will be removed by grinding. Grinding shall be done using rubber or resin bonded aluminum oxide or silicon carbide wheels. If burrs are required, carbide burrs will be used, none of which have been previously used on ferrous type material.

(F) On all ground out cavities no less than a 1/16-in. radius per 1/4-in. of depth will be permitted.

Preheat and Interpass Temperature

Preheat shall not be employed except when the base metal is below 60 F. Preheating shall be performed to raise the temperature of the base metal to within the range of 60 to 85 F. The interpass temperature shall not exceed 200 F for seal welds and 350 F for other welds.

Equipment

(A) Wire Brushes - wire brushing shall be done when using stainless steel wire burshes which have not previously been employed on any other type material.

(B) Grinding Wheels - grinding shall be done using rubber or resin-bonded aluminum oxide or silicon carbide wheels not previously used on any other type material.

(C) Deburring - filing or deburring operation shall be carried out only with carbide files or deburring tools not previously used on any other type material.

Joint Preparation and Assembly

(A) The edges or surfaces of all parts to be joined by welding will be prepared by machining or grinding, and will conform to dimensions outlined on production drawings.

(B) All joints will be cleaned and free of all scale, dirt, grease, oil, paint, or other foreign matter.

Welding Technique

(1) Welding technique using electrode weaving shall not exceed three times the diameter of the electrode core wire being employed.

(2) There will be no undercutting valleys, grooves, or other irregularities along the edges or at the center of the weld reinforcement.

(3) All slag or flux remaining on any layer will be removed before the next successive layer is deposited. All craters shall be ground out. Liquid penetrant inspect first layer (root pass) of all welds. Visual inspection only will be used between successive beads except liquid penetrant inspection of final pass. The final pass will not contain any unfilled craters or cracks.

(4) All gas holes, cracks, trapped slag, and undercutting shall be removed from any pass before the succeeding layer is applied. The final pass will not contain any cracks or unfilled craters.

(5) Defective material removal see 748-WP-101 Preparation of Base Metal, Section A, B, C, D, E, F.

(6) Water soluble EUTECTO mask, Protecto Metal No. 2 or an equivalent liquid mask or anti-spatter compound will be used to protect polished surfaces and to facilitate weld spatter removal.

(7) Upon completion of the weld, all flux and weld spatter will be removed and the weld finished by abrasive methods or by mechanical finishing to a finish suitable for dye penetrant examination. (See Liquid Penetrant Inspection Procedure No. 748 DP1).

(8) Final finish of all welded areas will comply with notations on drawing. All finishing will be accomplished by brushing, grinding, buffing or machining of surfaces where necessary.

Inspection

(A) Visual - All welds shall be visually inspected for compliance with the drawings and requirements of the welding procedure at the following stages:

(a) Prior to welding for compliance with the drawing including:

(1) Weld end preparation dimensions and shape

(2) Clearance dimensions of backing strip

(3) Alignments and fit-up of the pieces being welded.

(b) After welding for compliance with the drawings, and surface finish requirements including:

(1) Size of legs and throat of fillet welds

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(2) Contour and surface condition of outside surface of welds

(3) Degree of undercutting

(4) Evidence of mishandling, tool marking, or excessive grinding.

(c) All welds shall be inspected for soundness of liquid penetrant or examination as per attached Specification No. 748 DP1.

Liquid Penetrant Inspection 748-PT-201
Revised 12/1/67

Surface Preparation

The surface being examined shall be free from scale, slag and adhering or imbedded contamination. As welded surfaces, following the removal of slag, shall be considered suitable for liquid penetrant inspection without grinding if this does not interfere with interpretation of the test results and if the weld contour blends into the base material without undercutting.

(A) Pre-cleaner used shall be Acetone or Trichloroethylene.

(B) Liquid Penetrant Test Material - Magnaflux Penetrant - Type SKL-HF having the trade name--Spotcheck--manufactured by Magnaflux Corporati n or any equivalent sulfur and chlori... free material may be used.

(C) Developer - Magnaflux Type SKD-NF, nonflammable (sulfur free). Trade name--Spotcheck--manfuactured by Magnaflux Corporation or equivalent.

(D) Cleaner - Magnaflux Penetrant Clearner, Type SKC-NF or equi alent.

Application and Procedure

The temperature of the surface to be tested shall be between 50 F and 100 F. Cleaner shall be used on the surfaces in the weld areas and allowed to thoroughly dry for 5 minutes. The complete surface shall be thoroughly and uniformly coated with penetrant by spraying or bushing and shall be kept completely wetted for a minimum of 10 minutes and a maximum of 20 minutes. Any complete drying of penetrant during this time shall require recleaning and repeating the test.

After the alloted application time has expired, the dye penetrant shall be removed by wiping the surface with a lint-free cloth. This operation will continue until most of the penetrant has been removed. The remaining penetrant shall be removed by wiping the surface with a clean cloth dampened with penetrant cleaner. Flushing of the surface with any liquid following application of the penetrant and prior to developing is prohibited.

Surface drying - The drying of test surfaces after the removal of excess penetrant shall be accomplished only by normal evaporation, or by blotting with absorbent paper or clean, lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used.

Developing - A nonaqueous wet developer recommended by the penetrant manufacturer shall be used. Immediately prior to application, the developing liquid should be kept agitated in order to prevent settling of solid particles dispersed in the liquid. The developer shall be uniformly applied in a thin coating to the test surfaces by spraying unless otherwise specified for specific cases in the approved inspection procedure. Pools of wet developer in cavities on the inspection surfaced shall not be permitted since these pools will dry to an excessively heavy coating in such areas resulting in the masking of indications. Inspection should be made a minimum of 5 minutes and no later than 30 minutes after the developer is applied.

Lighting in test area - The test area shall be adequately illuminated for proper evaluation of indications revealed on the test surface.

Final cleaning - When the inspection is concluded the penetrant materials shall be removed as soon as possible by means of suitable solvents in accordance with the grade of cleaning required by system or component specifications.

Acceptance Standards for Liquid Penetrant Inspection

If indications are believed to be nonrelevant, at least 10 percent of each type of indication shall be explored by removing the surface roughness believed to have caused the type of indication to determine if defects are present. The absence of indications upon reinspection by liquid penetrant inspection after removal of the surface roughness shall be considered to prove that the indications were nonrelevant with respect to actual defects. If reinspection reveals any indications, these indications and all of the original indications in the same area shall shall be considered to be defects. Defects shall be evaluated to the acceptance standards below:

(A) All surfaces shall be free of all cracks, laps, fissures, and other linear defects, and free of linearly disposed rounded defects when there are four or less such rounded defects in a line and each is separated from the adjacent defects by less than 1/16 inch. Rounded defects are any defects that preduce liquid penetrant indications which are circular or elliptical with the long axis less more than twice as long as the other axis and with no sharp corners.

(B) Liquid penetrant inspection shall be used to evaluate rounded defects which are not linearly disposed. All surfaces shall be free of linear and linearly disposed defects as specified in (A) above and shall also be free of rounded defects in excess of the limits specified in Table A-1.

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TABLE A-1. ROUNDED DEFECT LIMITS

Maximum dimension of rounded defect	Number of indicated rounded defects allowed per square inch or per 6-inch length of weld, whichever is less.
1/32" and less	The total number of indicated defects shall not exceed 20 and shall be randomly distributed.
Greater than 1/32" to and including 1/16"	The total number of defects shall not exceed 10 and shall be randomly distributed.
Greater than 1/16"	None allowed.

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Hydrostatic Testing Procedure
738-HT601

Pressure leak testing will be employed to chec[illegible] the cavity for leaks.

The first of two such tests will be performed after the cavity subassembly construction has been completed.

Temporary plugs can be used in cavity openings to complete this test. The test consists of closing the necessary openings in the cavity and completely filling with water. The cavity will then be pressurized with air to a maximum pressure of 150 psig. This pressure must be held for a period of one hour with no detectable leakage.

A final leak test will be performed after the cask is completed. The same procedure will be followed as for the first test with all permanent fittings in place, and with the relief valve opening sealed.

Pouring Procedure for Lead Shielding 748-LP-1001
Revised 5/3/68

This specification covers the standard practice followed in providing void-free lead shielding.

1. Cleaning of Lead Containers

1.1 Interior cavities and surfaces of container shells which are to be in contact with lead shielding will be cleansed of loose mill scale, weld slag, and all carbonaceous materials.

1.2 Containers will be filled with water for the purpose of cleaning, checking for leak tightness.

1.3 Units required to dissipate large quantities of heat and which do not incorporate the Edward Lead Company's patented heat removal fins will be cleaned by sandblasting before assembly.

1.4 Surfaces to which lead is to be bonded will be tinned prior to fabrication where practical. Weld areas to be tin [illegible] 1" from each weld surface.

1.5 Individual procedures will be established for bonding lead to the surfaces of fabricated containers.

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2. Material Selection

2.1 Lead of a grade qualifying as Federal Specification QQ-L-171c-Grade C or B29-55 or equivalent will be used in shipping containers unless otherwise specified.

2.2 Special lead types will be selected and tested for low background shielding systems where this requirement is specified.

3. Description of Equipment

3.1 Sufficient melting capacity must be provided to allow for continuous pouring of the lead.

3.2 All kettles must be provided with facilities for pouring lead from the bottom of the kettle.

3.3 Pumps will be utilized to fill extra long or high containers.

3.4 Equipment for dross-free pouring will be used where required.

4. Opening for Lead Filling

4.1 Containers will be provided (where possible with large pour openings in order to allow for easy dross removal and proper agitation of the molten lead. (A 4-in. diameter opening is the minimum size for adequate lead pouring and dross removal).

4.2 All areas which could possibly trap air will be vented with seal-off plugs.

5. Preheating of Containers

5.1 Normally the lead containment will be uniformly heated to 450-500 F (± 25 F) over the entire surface prior to lead pouring. The above temperature will be checked by a contact pyrometer.

5.2 Air drafts must be limited so as not to vary the heating and cooling temperatures of the container surface by more than 50 F.

6. Filling of Containers

6.1 The temperature of the lead at the time of filling must normally range from 750 F to 800 F. The lead temperature, when poured, must not exceed 850 F because of excess dross formation. If copper, brass, or aluminum alloys are present in the lead

cavity, the maximum lead-pouring temperature must not exceed 750 F and remain molten for not more than 24 hours.*

6.2 A lead fill pipe will be located to minimize splashing as the molten lead enters the container.

6.3 The lead fill pipe will be located to prevent the m[illegible]en lead from impinging upon the container walls, there[illegible] resulting in hot-spot distortion of the container.

6.4 The lead fill pipe must be located so that the molten lead does not impinge upon any copper or brass parts in the container.

6.5 The lead-flow rate should be adjusted for continuous flow in order to fill the container as rapidly as possible.

6.6 At the completion of the fill, the temperature of all lead in the containment must be above 625 F as checked by a chromel-alumel thermocouple sheathed in stainless steel.

6.7 The molten lead in the filled container must be mechanically agitated for the purpose of freeing any entrapped solid particles, dross, or gas bubbles.

7. Lead Cooling

7.1 The molten lead in the container must be cooled from the bottom up in increments small enough to insure that only one solidifying front exists in the container. A normal cooling profile in a cylindrical container above the solidification front should show increment of 10 F to 20 F per foot of height.

7.2 The molten lead in the container must be thoroughly probed and agitated to facilitate the release of entrapped gas and particulate matter.

7.3 All foreign matter and dross must be removed from the surface of the lead.

8. Filling Lead Shrinkage Void

8.1 Molten lead at a minimum temperature of 750 F will be added in small increments from ladles to fill the normal shrinkage void.

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* The temperature of the molten lead resting in the container awaiting solidification should not exceed 700 F. The temperature of this lead shall be continuously monitored.

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8.2 A record will be kept of the weight of all lead added to fill the shrinkage void when a volumetric check is made in place of gamma probing.

8.3 Direct heat may be carefully applied to the lead surface last in the solidification process to insure that the fill area is free of voids.

8.4 The fill opening will be filled to the proper level, dross removed, and the lead surface fire-polished to finish the pouring procedure.

9. Closure of Lead Fill Openings

9.1 All openings must be cleansed of lead splatter and lead oxide before welding the closure plug.

9.2 Closure-plug welds must not penetrate into the lead.

Shielding Integrity Testing Procedure
748-GP-401 Revised 5/3/68

1. Scope

This procedure covers the limits and methods for testing the integrity of the lead shielding in radioactive material shipping containers by means of a gamma ray source.

2. Equipment

(a) The gamma ray source shall be encapsulated and the external surface free of loose contamination.

(b) The gamma ray source and detection equipment shall be capable of detecting a void, at any place in the lead shielding, equivalent to the thickness of the penetrameter in the table below. This sensitivity capability shall be checked with the lead penetrameter attached directly to the outer surface of the container.

(c) Shielding components to be tested should be located so as to be remote from any shielded or unshielded source of radiation which might otherwise interfere with reliable test results.

(d) The equipment for positioning the source shall be capable of physically locating the source on or near the container bottom at the center near the top just below the cover and at all intermediate positions inside the cask.

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TABLE A-2. GAMMA PROBE SENSITIVITY CHART

Thickness of Lead, inches	Dimensions of Penetrameter inches	Indication
2	.062 x 1 x 2	clear definition
4	.093 x 2 x 4	clear definition
6	.125 x 3 x 4	clear definition
8	.187 x 4 x 4	clear definition
9	.250 x 5 x 5	definite indication
10	.30 x 6 x 6	definite indication
11	.500 x 6 x 6	definite indication

3. Gamma Probe Inspection

(a) The entire surface of the container shall be gamma probe inspected on a grid as given below.

Lead Thickness, inches	Vertical Distance, inches	Horizontal Distance, inches
2	2	2
4	3	3
6	3	3
8	4	4
9	4	4
10	4	4

(b) All significant deviations in shielding integrity shall be recorded on an appropriate drawing and be made available to the inspector.

(c) Questionable areas shall be mapped and outlined on the side of the container with chalk.

(d) Any area showing a shielding deficiency of 10 percent below the normal average shall be repaired. The repair shall be accomplished by a procedure acceptable to the owner and reprobed as in (c) above.

4. Inspection Reports

Final inspection reports containing actual measured radiation values shall be prepared. All questionable and repaired areas and their final measured radiation values shall be shown on an appropriate map of the exterior of the container.

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