This document was too large to scan as a whole document, therefore it required breaking into smaller sections.

Document number: SD-TP-SARP-017

Section 1 **of** 2

Title: Safety Analysis Report for Packaging (Onsite) Multicanister Overpack Cask

Date: 7/14/97 **Revision:** A000

Originator: Edwards, WS
Co: WMNW

Recipient:
Co:

References: EDT-618195

JUL 14 1997 Sta. 37 (20)

ENGINEERING DATA TRANSMITTAL

1. EDT 618195

2. To: (Receiving Organization) Packaging Engineering	3. From: (Originating Organization) Packaging Engineering	4. Related EDT No.: 618188
5. Proj./Prog./Dept./Div.: 03E00	6. Design Authority/ Design Agent/Cog. Engr.: W. S. Edwards	7. Purchase Order No.: NA
8. Originator Remarks: The attached safety analysis report for packaging is being submitted for approval and release.		9. Equip./Component No.: NA
		10. System/Bldg./Facility: NA
11. Receiver Remarks: 11A. Design Baseline Document? [] Yes [X] No		12. Major Assm. Dwg. No.: NA
		13. Permit/Permit Application No.: NA
		14. Required Response Date: January 28, 1997

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	HNF-SD-TP-SARP-017	NA	0	Safety Analysis Report for Packaging (Onsite) Multi-canister Overpack Cask	SQD	1,2	1	

16. KEY

Approval Designator (F)	Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
(See Approval Designator for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
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1	1	Cog. Mgr. JG Field	[signature]	1/21/97	G1-11						
1	1	QA CR Hoover	[signature]	1/21/97	G1-11						
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3		RL Clawson			G1-13						
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18.	19.	20.	21. DOE APPROVAL (if required)
W. S. Edwards [signature] 1/21/97 Signature of EDT Originator Date	Authorized Representative for Receiving Organization Date	J. G. Field [signature] 1/21/97 Design Authority/ Cognizant Manager Date	Ctrl. No. 97-WPD-055 [X] Approved [] Approved w/comments [] Disapproved w/comments

Safety Analysis Report for Packaging (Onsite) Multicanister Overpack Cask

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Waste Management Federal Services, Inc., Northwest Operations
Richland, Washington 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: EDT 618195 UC: 513
Org Code: 03E00 Charge Code: E23595
B&R Code: 35EW31354 Total Pages: ~~735~~ 756

Key Words: Canister Storage Building, CSB, Cold Vacuum Drying Facility, CVDF, K Basins, cold vacuum drying, CVD, irradiated fuel, Type B, highway route controlled quantity, transfer

Abstract: This safety analysis report for packaging (SARP) documents the safety of shipments of irradiated fuel elements in the Multicanister Overpack (MCO) and MCO Cask for a highway route controlled quantity, Type B fissile package. This SARP evaluates the package during transfers of (1) water-filled MCOs from the K Basins to the Cold Vacuum Drying Facility (CVDF) and (2) sealed and cold vacuum dried MCOs from the CVDF in the 100 K Area to the Canister Storage Building in the 200 East Area.

Janis Bishop 7-14-97
Release Approval Date

JUL 14 1997
DATE: HANFORD RELEASE
STA: 37 ID: 20
Release Stamp

Approved for Public Release

LIST OF EFFECTIVE PAGES

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	0	EDT
	0	SD
	0	LOEP
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LIST OF TERMS

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
B&PV	Boiler and Pressure Vessel
Btu/h-ft^2	British thermal units per hour foot squared
cm	centimeter
std cc/s	standard cubic centimeters per second
CSB	Canister Storage Building
CVD	cold vacuum drying
CVDF	Cold Vacuum Drying Facility
dpm/cm^2	disintegrations per minute per square centimeter
FDH	Fluor Daniel Hanford, Inc.
FEA	finite-element analysis
F.T.	failure threshold
ft·lb	foot pound
gpm	gallons per minute
HEPA	high-efficiency particulate air
H/U	hydrogen to uranium (ratio)
Hz	hertz
in.	inch
in/s	inches per second
ISS	Information and Scientific Systems
kg	kilogram
km	kilometer
kPa	kilopascal
ksi	1000-lb per square inch
L	liter
lb	pound
LEU	low-enriched uranium
L/min	liters per minute
m	meter
m/s	meters per second
μCi/cm^2	microcuries per square centimeter
ms	millisecond
MCNP	Monte Carlo N-Particle (code)
MCO	Multicanister Overpack
mi	mile
MPa	megapascal
mrem/h	millirem per hour
mSv/h	millisievert per hour
MTU	metric ton of uranium
N	newton
NCT	normal conditions of transport
NDE	nondestructive examination
N·m	newton meter
PE	Packaging Engineering
PFF	probability of fire failure
PIF	probability of impact failure
p/M	parts per million

LIST OF TERMS (cont.)

PO	purchase order
PPF	probability of puncture failure
PR	purchase requisition
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
QA	quality assurance
QC	Quality Control
SARP	safety analysis report for packaging
SI	stress intensity
SNF	Spent Nuclear Fuel
SS	stainless steel
3-D	three-dimensional
TN	Transnuclear, Inc.
W	watt

SAFETY ANALYSIS REPORT FOR PACKAGING (ONSITE) MULTICANISTER OVERPACK CASK

PART A: DESCRIPTION AND OPERATIONS

1.0 INTRODUCTION

1.1 GENERAL INFORMATION

The Multicanister Overpack (MCO) and the MCO Cask are used to transport irradiated fuel from the storage basins in the 100 K Area to the Canister Storage Building (CSB) in the 200 East Area of the Hanford Site. Individual fuel elements are removed from their canister storage containers in the K Basins, cleaned, and placed in baskets. The baskets are then top loaded into the MCO. The MCO and MCO Cask are then closed with the MCO vented to the cask interior through a high-efficiency particulate air (HEPA) filter. The package is transferred to the Cold Vacuum Drying Facility (CVDF) with the MCO and MCO Cask filled with water. The MCO Cask provides containment for the spent fuel during transfer to the CVDF. Cold vacuum drying (CVD), which involves water circulation and vacuum drying of the fuel elements, is performed at a CVDF in the 100 K Area. After CVD is complete, the MCO Cask is transported to the CSB, where hot conditioning of the fuel and long-term storage of the MCO occurs. The MCO Cask provides containment for the spent fuel during transport to the CSB.

This safety analysis report for packaging (SARP) provides the analyses and evaluation necessary to demonstrate that the design of the MCO Cask shown in Part A, Section 10.0 (Transnuclear, Inc. [TN], drawings, dated October 21, 1996) meets the requirements and acceptance criteria for both Hanford Site normal transport conditions and accident condition events for a highway route controlled quantity Type B fissile package. These criteria were documented and approved in HNF-SD-TP-PDC-030 (Edwards 1997). This SARP evaluates the package during transfer of water-filled MCOs from the K Basins to the CVDF and sealed and cold vacuum dried MCOs from the CVDF in the 100 K Area to the CSB. The packaging meets all WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, requirements for the Hanford Site. Evaluation by analysis and initial leak testing per American National Standards Institute (ANSI) N14.5 (ANSI 1987) demonstrate packaging performance and safety. Hanford Site packaging safety acceptance criteria (Mercado 1994) are satisfied.

The scope of this SARP includes evaluating the cask design and demonstrating that it meets the onsite transportation safety requirements. This SARP also establishes operational, acceptance, maintenance, and quality assurance (QA) guidelines to ensure that the transportation of the MCO Cask is performed safely in accordance with WHC-CM-2-14.

1.2 SYSTEM DESCRIPTION

The MCO Cask is an onsite, interarea packaging for transferring highway route controlled quantity, Type B, fissile, radioactive material on the Hanford Site in accordance with WHC-CM-2-14. The analyses and evaluations performed in this SARP demonstrate that this packaging complies with the onsite transportation safety criteria and the safety-related requirements of the packaging design criteria (Edwards 1997).

TN designed the MCO Cask to meet the design criteria of the MCO Cask specification (WHC 1996). This SARP was prepared by Rust Federal Services Inc., Northwest Operations, completely independent of all analyses performed by TN.

The MCO Cask is a vertical, cylindrical steel transport cask that contains one MCO. The MCO Cask consists of a body fabricated from stainless steel forgings and a bolted stainless steel lid with a lifting device. The MCO Cask, not including lifting trunnions, is 101.12 cm (39.81 in.) in diameter and 432.44 cm (170.25 in.) tall. The overall dimensions of the packaging assembly, including the lifting device, are 111.33 cm (43.83 in.) in diameter and 483.24 cm (190.25 in.) in height. The cask cavity is 63.98 cm (25.19 in.) in diameter and 407.67 cm (160.50 in.) tall. The gross weight of the system is less than 27,000 kg (60,000 lb). The package is transported vertically on a trailer designed specifically for shipment of the MCO Cask. The gross weight of the package, tractor, and trailer is approximately 47,000 kg (104,000 lb).

The SARP is based on the MCO prototype design (August 1996). The MCO is a stainless steel cylinder which is top loaded into the MCO Cask cavity. The MCO body consists of a 1.27-cm- (0.50-in.-) thick stainless steel cylinder with an outside diameter of 60.96 cm (24.00 in.) and a length of 406.40 cm (160.00 in.). A 30.48-cm- (12.00-in.-) thick shield plug is retained inside the top end of the MCO by a mechanical closure system. Five baskets containing 54 Mark IV fuel elements each, or six baskets containing 48 Mark IA fuel elements each, are placed in each MCO. One fuel scrap basket may be substituted for one fuel basket in each MCO.

1.3 REVIEW AND UPDATE CYCLES

This SARP is subject to periodic reviews and updates. The reviews shall be performed every five years to ensure that all SARP evaluations and other included information meet new or revised regulatory and/or company requirements. The first complete review and update of the MCO Cask SARP will be as soon as the MCO and fuel basket designs are finalized. Development of the fuel parameters is still ongoing. Any revisions to the fuel source term will be evaluated to ensure that the fuel parameters within the SARP remain conservative. If not, the revised source term will be incorporated into the SARP. Single Pass Reactor fuel will be addressed by a future revision of the SARP. The review shall be conducted in accordance with the formal process per Part A, Section 7.6.

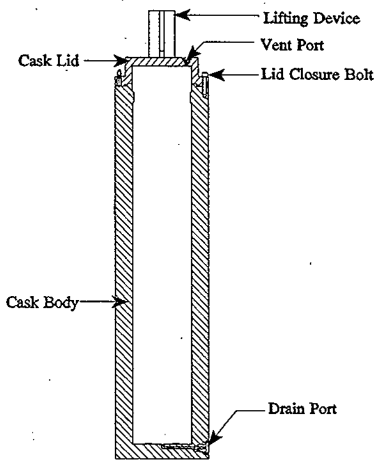
2.0 PACKAGING SYSTEM

2.1 CONFIGURATION AND DIMENSIONS

2.1.1 MCO Cask

The MCO Cask (Figure A2-1) is a vertical, cylindrical, stainless steel transport cask. The MCO Cask is 101.1 cm (39.81 in.) in diameter and 432.4 cm (170.3 in.) tall. The overall dimensions of the packaging assembly, including the lifting device, are 111.3 cm (43.83 in.) in diameter and 483.2 cm (190.3 in.) in height. The cask cavity is 63.98 cm (25.19 in.) in diameter and 407.7 cm (160.5 in.) tall. The cask consists of a forged, 18.6-cm- (7.31-in.-) thick, 432.4-cm- (170.3-in.-) long, stainless steel cylinder with an integrally welded stainless steel bottom head that is 15.6 cm (6.13 in.) thick.

Figure A2-1. Multicanister Overpack Cask.



The lid is a stainless steel forging with a 8.89-cm- (3.50-in.-) thick top and 7.62-cm (3.00-in.) sides, an outer diameter of 80.01 cm (31.50 in.), an inner diameter of 64.77 cm (25.50 in.), and a height of 27.94 cm (11.00 in.). The lid has a 10.2-cm- (4.00-in.-) tall, 10.6-cm- (4.16-in.-) wide flange at its base, which makes the diameter of the lid 101.1 cm (39.81 in.) at the flange. The base of the lid has an O-ring groove that has an inner diameter of 80.19 cm (31.57 in.). The interior of the base of the lid also has a 5.49-cm- (2.16-in.-) wide, 2.77-cm- (1.09-in.-) tall notch that mates with a similar-sized extension in the cask shell. The lid is bolted to the cask body with 12, 1.50-in.-diameter bolts, which are arranged on a circle with a 92.56-cm (36.44-in.) diameter. A single Butyl[1] rubber O-ring seal will form the containment boundary between the cask body and lid. The lid is guided by two alignment pins that are integral to the cask body.

Two lifting brackets are welded to the cask lid for lifting of the cask and the lid. A 10.2-cm- (4.00-in.-) diameter trunnion is welded to each lifting bracket. The brackets protrude 50.8 cm (20.0 in.) from the lid surface.

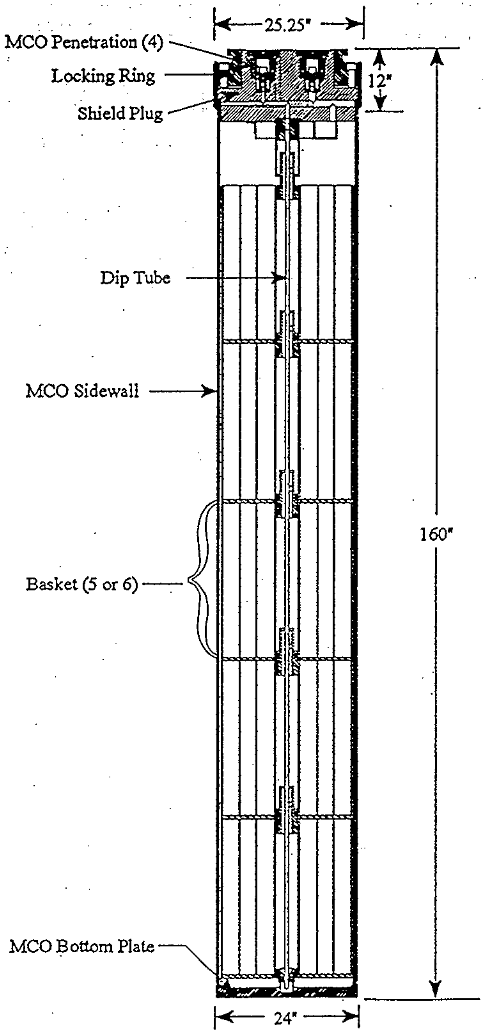
The cask also has one vent port and one drain port. The center of the vent port is located 12.7 cm (5.00 in.) from the exterior of the cask lid, while the drain port is positioned in the side of the cask body, 12.2 cm (4.79 in.) from the bottom. The drain port is closed with quick-disconnect couplings 1.60 cm (0.63 in.) in diameter. The drain port is covered by a 15.2-cm- (6.00-in.-) diameter, 1.91-cm- (0.75-in.-) thick cover that is bolted onto the cask with four 0.50-in. bolts. The vent port is also closed with a quick-disconnect coupling, 1.12 cm (0.44 in.) in diameter. The vent port is covered by a 15.2-cm- (6.00-in.-) diameter, 1.91-cm- (0.75-in.-) thick cover that is bolted onto the lid with four 0.50-in. bolts. Both cover plates utilize butyl rubber O-ring seals as the containment boundary.

2.1.2 MCO

The MCO (Figure A2-2) is a vertical, cylindrical stainless steel container that retains the spent fuel. The overall dimensions of the MCO, without the canister cover, are 60.96 cm (24.00 in.) in diameter by 406.4 cm (160.0 in.) tall. The wall thickness is 1.30 cm (0.50 in.). The shell is welded to a stainless steel bottom forging 60.96 cm (24.00 in.) in diameter. The bottom forging is 4.47 cm (1.76 in.) thick with a center area 2.20 cm (0.88 in.) thick. A 30.48-cm- (12.00-in.-) thick shield plug is inserted into the top of the MCO. The shield plug has a 10.4-cm- (4.09-in.-) wide, 15.9-cm- (6.25-in.-) tall annular section cut out of the top, where the MCO locking and lifting ring is placed. The locking and lifting ring is threaded on the outside, which mates with threads on the interior of the MCO. Eight 1.00-in. screws penetrate the locking and lifting ring to further compress the MCO seal. The top of the shield plug has four penetrations, which connect to two quick-disconnect couplings that are used for conditioning the fuel inside the MCO (dip tube and short draw tube), a rupture disk, and a relief valve downstream from a HEPA filter. For shielding purposes, all four penetrations have double bends as they penetrate the shield plug.

[1]Butyl is a trademark of Dewitt Products.

Figure A2-2. Multicanister Overpack Body.



2.2 MATERIALS OF CONSTRUCTION

The structural materials for the MCO Cask are as follows:

- **Cask Shell:** American Society of Mechanical Engineers (ASME) SA-336, Type 304 stainless steel
- **Bottom Head:** ASME SA-336, Type 304 stainless steel
- **Lid:** ASME SA-336, Type 304 stainless steel
- **Closure Bolts:** ASME SA-479-XM19
- **Trunnions:** Type 304 stainless steel.

The following are other materials of construction used in the MCO Cask:

- Butyl rubber O-ring seals
- Vent and drain ports quick-disconnect couplings, Type 303 stainless steel
- Vent and drain port covers, Type 304 stainless steel.

The structural materials for the MCO are as follows:

- **MCO Shell:** ASME SA-312, Type 304L stainless steel
- **Bottom Forging Assembly:** ASME SA-182, Type 304L stainless steel
- **Shield Plug:** American Society for Testing and Materials (ASTM) A108 carbon steel
- **Locking and Lifting Ring:** 4140 carbon steel
- **Locking and Lifting Ring Bolts:** ASTM A574 carbon steel.

2.3 MECHANICAL PROPERTIES OF MATERIALS

The mechanical material properties for the MCO Cask and MCO are presented in Part B, Section 7.1.2. These properties are taken from ASME Boiler and Pressure Vessel (B&PV) Code, Section II, Part D (ASME 1995a).

2.4 DESIGN AND FABRICATION METHODS

The MCO Cask is a Category I package (as defined in Regulatory Guide 7.11, Table 1 [NRC 1991]). Therefore, NUREG/CR-3854 (Fischer 1985) indicates that design, fabrication, and testing of the MCO Cask containment boundary is performed to the intent of the requirements of the ASME B&PV Code, Section III, Subsection NB, Class 1 (ASME 1995b). The containment boundary design follows the criteria from Section III. The structural analyses criteria meet Section III requirements. However, the MCO Cask is not code stamped.

Fabrication of the MCO Cask was in accordance with the guidelines of NUREG/CR-3854 (Fischer and Lai 1985). All welds and weld joints meet criteria in NUREG/CR-3019 (Monroe et al. 1984) and were examined in accordance with ASME B&PV Code, Section III, Subsection NB, by inspectors qualified per American Society of Nondestructive Testing SNT-TC-1A (ASNT 1993). All containment welds were radiographed per ASME B&PV Code, Section III, Subsection NB-5000 (ASME 1995b). During fabrication, welds were made sufficiently smooth to enable easy decontamination. Consideration was given in the design, to the greatest extent practicable, to avoid potential contamination traps.

During fabrication, inspections and containment leak testing of the MCO Cask were performed per ASME B&PV Code, Section III (ASME 1995b), and ANSI N14.5, respectively.

The MCO was designed, fabricated, inspected, and examined to the requirements of the ASME B&PV Code, Section III, Subsection NB, for all components except for plate and shell supports, which meet the requirements of Subsection NF, and the spent fuel basket assembly, which meets the requirements of Subsection NG. All MCO welds were completed and examined in accordance with ASME B&PV Code, Section III, Subsection NB, and Section IX. Consideration was given in the design, to the greatest extent practicable, to avoid potential contamination traps.

2.5 WEIGHTS AND CENTER OF GRAVITY

The expected weights of the MCO, MCO Cask, contents, and ancillary equipment are shown in Table A2-1. The total weight of the MCO Cask with a 9,164-kg (20,160-lb) water-filled MCO is 26,872 kg (59,120 lb), while the total weight of the MCO Cask with an 8,612-kg (18,946-lb) cold-vacuum-dried MCO is 26,320 kg (57,903 lb). The MCO Cask has the center of gravity located on the vertical centerline of the cask, regardless of whether the MCO is water filled or dry. Because the cask is nearly symmetrical, the center of gravity of the cask is near the geometrical center.

Table A2-1. Multicanister Overpack (MCO) Cask and MCO Weights.

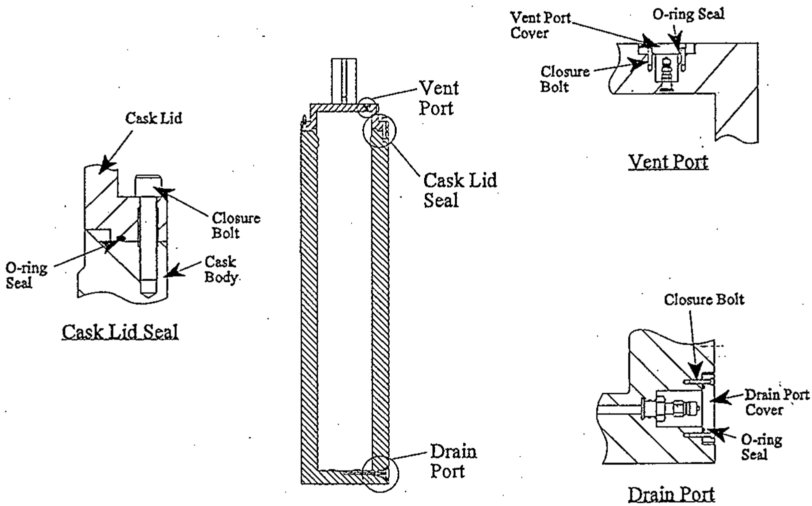
Component	Weight kg (lb)
MCO empty, no shield plug	864 (1,900)
MCO shield plug	618 (1,360)
Five fuel baskets with 54 Mark IV elements per basket	7,130 (15,685)
Water inside MCO (K Basins to Cold Vacuum Drying Facility transfer)	552 (1,215)
Cask shell	15,590 (34,300)
Cask bottom	1,032 (2,270)
Cask lid	859 (1,890)
Lifting attachment	227 (500)
Total (dry MCO)	26,320 (57,903)
Total (water-filled MCO)	26,872 (59,120)

2.6 CONTAINMENT BOUNDARY

The MCO Cask provides the containment boundary under normal transfer and accident conditions specified in this SARP, while the MCO retains the package contents during transfer from the CVDF to the CSB. The MCO relief valve is removed and the MCO vented to the MCO Cask cavity through the HEPA filter for the transfer from the K Basins to the CVDF. The MCO Cask containment boundary consists of the following items as shown in Figure A2-3:

- Cask lid
- Cask shell
- Cask bottom
- Weld of cask shell to cask bottom
- Cask lid O-ring seal
- Vent and drain port covers
- Vent and drain port covers O-ring seals.

Figure A2-3. Multicanister Overpack Cask Containment Boundary.



The MCO Cask closure lid uses a butyl rubber O-ring face seal to maintain a leaktight (10^{-7} std cc/s) seal as defined in ANSI Standard N14.5 (ANSI 1987). The seal is located on the interface surface between the flange on the closure lid and the MCO Cask shell. This seal is placed in an O-ring groove in the closure lid flange. The O-ring is compressed by tightening 12, 1.50-in. bolts on the lid. The face seal is required to meet leaktight requirements upon initial loading of the cask and will maintain containment as shown in Part B, Section 4.0, through Hanford Site normal transfer conditions and all accident conditions.

There is one containment weld located on the MCO Cask. The weld is used to seal the cask shell to the cask bottom head. These welds are required to be radiographically or ultrasonically examined in accordance with ASME B&PV Code, Section III, Subsection NB-5300 (ASME 1995b). The weld procedures are qualified to ASME B&PV Code, Section IX (ASME 1995b).

There are two penetrations into the MCO Cask. One penetration is through the cask lid for the vent port, while the other is through the side of the cask for the drain port. Both the vent and drain ports are quick-disconnect couplings attached to coupling adapters, which are recessed from the exterior of the cask. No credit is taken for the containment provided by those couplings. Leaktight containment for those ports is provided by cover plates and butyl rubber O-ring face seals. An O-ring groove is cut into each cover plate, and the cover is attached by four 0.50-in. bolts.

An additional boundary for the spent fuel, which this SARP does not take credit for, is established by the MCO during transfer from the CVDF to the CSB. The primary purpose for the MCO is to be the long-term storage container for the spent fuel. Therefore, the MCO was designed to meet 10 CFR 72 criteria for long-term storage of spent fuel.

The MCO boundary consists of the following items:

- Shield plug
- MCO shell
- MCO bottom
- Welds of shell to bottom
- Mechanical closure of shell-to-shield plug
- Four shield plug penetrations.

A weld joins the MCO shell to the MCO bottom forging assembly. This weld was made in conformance with ASME B&PV Code, Sections III and IX. The weld was radiographically or ultrasonically examined in accordance with ASME B&PV Code, Section III, Subsection NB-5300 (ASME 1995b). The MCO shield plug is connected to the MCO shell via a metallic seal, which is compressed by the locking and lifting ring and eight locking ring bolts to maintain a confinement seal.

There are four penetrations through the MCO shield plug. Two penetrations are fitted with quick disconnects, which are used for conditioning the spent fuel; one is a relief valve downstream of a HEPA filter; and the last penetration is for a rupture disk. For the first leg of transport between the K Basins and the CVDF, the relief valve on the MCO is removed and the MCO is vented to the cask cavity through the HEPA filter.

2.7 CAVITY SIZE

The MCO Cask cavity is 63.98 cm (25.19 in.) in diameter and 407.7 cm (160.5 in.) high. The MCO cavity, without considering the filter that protrudes from the bottom of the shield plug, is 58.42 cm (23.00 in.) in diameter and 371.9 cm (146.4 in.) high.

2.8 HEAT DISSIPATION

The MCO has a maximum total allowable decay heat load of 835 W. Heat is also produced by the chemical reaction of exposed uranium metal from the fuel and water. Heat is dissipated passively.

2.9 SHIELDING

The stainless steel cask and carbon steel shield plug on the MCO provide at least 18 cm (7.0 in.) of radiation shielding for the spent fuel. The drain port penetration on the cask is 1.60 cm (0.63 in.) in diameter, and the vent port penetration on the cask lid is 1.12 cm (0.44 in.) in diameter. All penetrations through the MCO shield plug are 2.54 cm (1.00 in.) in diameter and have double bends to preclude radiation streaming.

2.10 LIFTING DEVICES

The lifting device for the cask consists of two lifting brackets with a trunnion welded to each bracket. Two existing Hanford "J" hooks attach to the trunnions. A lift arm actuating device is used to place the lifting arms over the trunnions on the cask lid. The brackets, 50.8 cm (20.00 in.) tall and 27.9 cm (11.00 in.) wide, are welded to the cask lid. Each bracket is supported by a gusset, which is also welded to the cask lid.

2.11 TIEDOWN DEVICES

The MCO Cask is transported on a semi-trailer that is procured as a commercial-grade item with no nuclear QA. The tiedown configuration is shown in Figure B10-1.

3.0 PACKAGE CONTENTS

3.1 GENERAL DESCRIPTION

The authorized contents for the MCO Cask consist of the MCO loaded with irradiated uranium metal fuel elements. The authorized payload also includes fuel fragments and corrosion products. The fuel is loaded into the MCO in the K East and K West Basins located in the 100 K Area and transferred to the CVDF while full of water. Once at the CVDF, the MCO is drained of water and cold vacuum dried before transfer from the 100 K Area. The MCO is described in Part A, Section 2.1.2.

3.1.1 N Reactor Fuel

N Reactor fuel assemblies consist of two concentric tubes of uranium metal coextruded in Zircaloy-2 cladding. During the fabrication process, each uranium tube was encased in an inner and outer sleeve of Zircaloy-2 with an outer sheath of copper. The tube ends were closed by placing a braze ring, made of Zircaloy-2 and 5% beryllium, and a Zircaloy-2 end cap in the recess in each end of the fuel. A detailed physical description of these fuel assemblies is provided in Table A3-1.

There are several configurations of the fuel elements. A Mark IV fuel assembly is shown schematically in Figure A3-1. Mark IA fuel assemblies are similar. There is a small amount of fuel with 0.71% ^{235}U content, which was designated as Mark IVB fuel and has the same dimensions and weights as the 66.3-cm (26.1-in.) Mark IV fuel.

The newest fuel stored in the K Basins is from the N Reactor, which was shut down in April 1987. Some corrosion products will still be adherent to the fuel, including uranium oxides and hydrides.

3.2 CONTENT RESTRICTIONS

3.2.1 Content Matrix

Maximum weight of the package, including the weight of the MCO Cask and a water-filled MCO, is 26,872 kg (59,120 lb). The maximum weight of the package after CVD will not exceed 26,320 kg (57,905 lb). The maximum weight of the MCO is 9,164 kg (20,160 lb) when water-filled and 8,612 kg (18,945 lb) when dry. No more than one scrap basket can be loaded into each MCO.

3.2.2 Radioactive Materials

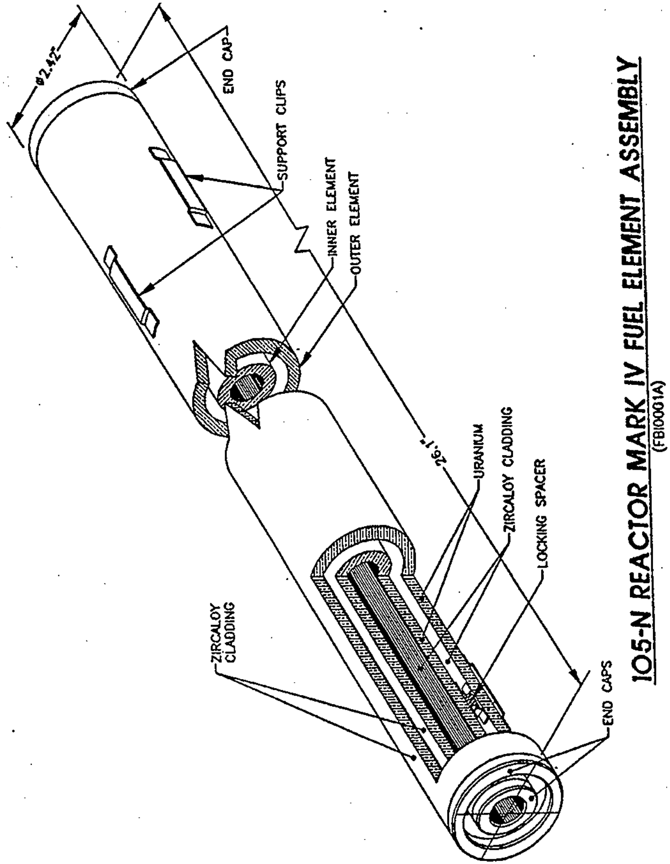
The MCO Cask can contain one MCO loaded with no more than 270 irradiated Mark IV fuel elements or 288 irradiated Mark IA fuel elements from the N Reactor. Single Pass Reactor fuel was not evaluated, so it is not authorized for shipment. The total decay heat load of the cask shall not exceed 1000 W.

Table A3-1. N Reactor Fuel Assembly Description.

	Mark IV				Mark IA		
Preirradiation ^{235}U enrichment	0.947%				1.25%-0.947%		
Type-length code*	E	S	A	C	M	T	F
Length (cm)	66.3	62.5	58.9	44.2	53.1	49.8	37.8
Element diameter (cm)							
1. Outer of outer	6.15				6.10		
2. Inner of outer	4.32				4.50		
3. Outer of inner	3.25				3.18		
4. Inner of inner	1.22				1.11		
Cladding mass (kg)							
1. Outer element	1.09	1.04	0.99	0.79	0.88	0.83	0.66
2. Inner element	0.55	0.52	0.50	0.40	0.54	0.51	0.40
Mass of uranium in outer (kg)							
1. (0.947% ^{235}U)	16.0	15.0	14.1	10.5			
2. (1.25% ^{235}U)					11.1	10.4	7.85
Mass of uranium in inner (kg) 0.947% ^{235}U	7.48	7.03	6.62	4.94	5.49	5.12	3.90
Weighted average of uranium in element (kg)	22.7				16.3		
Ratio of Zircaloy-2 to uranium (kg/MTU)	70.0	70.8	71.6	77.1	85.5	86.3	90.4
Weighted average for Zircaloy-2 (kg/MTU)	70.3				85.7		
Percentage of total elements	63				37		
Percentage of length type of each fuel	78	10	7	5	87	10	3
Displacement volume (L/MTU)	67				67		

MTU = Metric ton of uranium.
*Letter code differentiates the different lengths of the Mark IV or Mark IA fuel elements; i.e., a type "E" element is 66.3 cm long.

Figure A3-1. N Reactor Fuel Assembly.



Additional heat will be generated from the reaction of exposed uranium metal with water in the MCO. No other radioactive materials may be placed in the MCO.

3.2.3 Nonradioactive Materials

Nonradioactive materials shipped in the MCO cask consist of the MCO and the fuel baskets. The MCO is described in Part A, Section 2.1.2. The fuel baskets, which are stacked five (Mark IV) or six (Mark IA) high inside the MCO, are stainless steel, cylindrical baskets with circular sockets in the bottom to retain the fuel elements. The bottom of the basket is supported by a grating that permits effective water and gas flow. Each basket has a center tube that provides handling capability and dip tube access.

The Mark IA baskets are 57.468 cm (22.625 in.) in diameter and 60.419 cm (23.787 in.) high with a center tube 15 cm (6 in.) in diameter. The Mark IA basket holds 48 fuel elements, and the center tube also provides criticality control. The Mark IV fuel basket is similar except the height is 68.20 cm (26.85 in.), the center tube is 6.985 cm (2.75 in.) in diameter, and the basket holds 54 elements.

The MCO is filled with 552 kg (1,215 lb) of water during the transfer from the K Basins to the CVDF. This quantity of water fills the MCO to within 10 cm (4 in.) of the bottom of the shield plug. During the transfer from the CVDF to the CSB, water inside the MCO is limited to the amount that causes a pressure rise of 1.4 kPa (0.2 psi) per hour at 75 °C. That amount is monitored via pressure rise measurements at the CVDF (see Part A, Section 6.2.2). Because hydrogen is produced by the reaction of water with exposed uranium from damaged fuel, the MCO is backfilled with 20.7 kPa (3.0 psig) of nitrogen during the transfer from the K Basins to the CVDF and 20.7 kPa (3.0 psig) of helium during transfer from the CVDF to the CSB to prevent production of an explosive gas mixture inside the MCO. The cavity between the MCO Cask and the MCO is also backfilled with 20.7 kPa (3.0 psig) of helium. No other materials are authorized to be placed inside the MCO Cask or MCO.

4.0 TRANSPORT SYSTEM

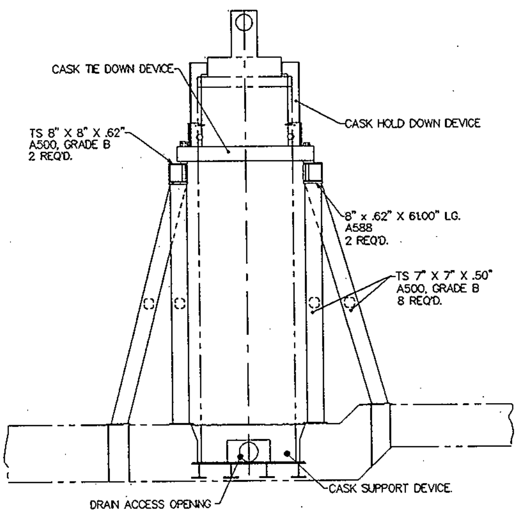
4.1 TRANSPORTER

The transporter consists of the three axle trailer provided by TN and Nelson Manufacturing Company attached to a standard Hanford Site three-axle jeep (wheeled trailer-like platform between the tractor and the trailer that spreads the weight distribution on the tires) and tractor. The trailer is procured as a commercial grade item.

4.2 TIEDOWN SYSTEM

The tiedown system (see Figure A4-1), as designed by TN in conjunction with Nelson Manufacturing Company (TN 1996), is a fixed system, which is an integral part of the conveyance system. The conveyance system is based on a custom double-drop semi-trailer designed specifically for securement and transport of the MCO Cask. The cask is transported in the vertical position and fits into the cask support device, which is a 39.47-cm- (15.54-in.-) deep well located beneath the deck of the trailer. Approximately 300 cm (118 in.) above the deck of the trailer, the cask is secured by a cask tiedown device mounted onto a fixed frame constructed of structural tube members, braced to the trailer deck with four structural tube members. The tiedown system is constructed of a rectangular, structural steel tubing (ASTM A500, Grade B

Figure A4-1. Multicanister Overpack Cask Tiedown.



[ASTM 1989]) frame, which is welded to the transport trailer bed. The cask tiedown device is designed as a hinged clam-shell ring where each half section pivots about a fixed 3.81-cm (1.50-in.) hinge pin and is secured with three 1.50-in. hex head bolts. The inside diameter of the clamping ring is constructed of 6061-T6 aluminum and equipped with a neoprene abrasion pad which forms a tight fit with the cask. Attached to the clamping ring are four cask hold-down brackets, equally spaced around the circumference, which restrain vertical movement of the cask.

4.3 SPECIAL TRANSFER REQUIREMENTS

4.3.1 Routing and Access Control

The cask is authorized for onsite exclusive-use transport only. The first transport leg consists of less than 0.8 km (0.5 mi) between either the K East or K West Basin and the CVDF. The second leg consists of an 12.9-km (8.0-mi) route following Route 1 out of the 100 K Area, followed by Routes 4N and 7 to the CSB.

4.3.2 Radiological Limitations

Dose rate limitations are as follows.

- The general surface dose rate on the accessible surface of the package must be below 200 mrem/h (2 mSv/h).
- The maximum surface dose rate at any radiation hot spot on the package does not exceed 1000 mrem/h (10 mSv/h), is less than 10 mrem/h (0.1 mSv/h) at 2 m (78.74 in.) from the package, and is less than 2 mrem/h (0.02 mSv/h) in the cab of the transporter (49 CFR 173.441).
- Areas that are only accessible with long-reach tools may have contact dose rates up to 1000 mrem/h (10 mSv/h).

External contamination limits are as shown in Table A4-1 for the exterior of the cask. Internal contamination limits are 100 times the limits shown in Table A4-1 for the cask cavity.

Table A4-1. External Container Contamination Limits.

Contaminant	Maximum permissible limits	
	$\mu Ci/cm^2$	dpm/cm^2
Beta-gamma-emitting radionuclides; all radionuclides with half-lives less than ten days; natural uranium; natural thorium; uranium-235; uranium-238; thorium-232; thorium-228 and thorium-230 when contained in ores or physical concentrates	10^{-5}	22
All other alpha-emitting radionuclides	10^{-6}	2.2

Source: 49 CFR 173.443, 1996, "Shippers--General Requirements for Shipments and Packagings," Code of Federal Regulations, as amended

4.3.3 Speed Limitations

The transport vehicle shall follow all speed limits along the route of transportation.

4.3.4 Environmental Conditions

If extreme fog, ice, or adverse snow conditions exist, the package shall not be transported. If the ambient air temperature is 4 °C (40 °F) or less, personnel shall drive the shipping route to ensure there is no ice or snow on the road immediately prior to shipment. If there is ice or snow on the road, the shipment shall not be made. If visibility is less than 400 m (0.25 mi) due to fog,the shipment shall not be made.

4.3.5 Frequency of Use and Milage Limitations

The frequency of use is limited by the radiological risk evaluation (Part B, Section 3.0), which limits the number of transfers from the 100 K Area to the 200 Area to fewer than 225 trips per year.

4.3.6 Escort and Emergency Response

Escorts are not required for the transport of the MCO Cask. An emergency response plan shall be in place before a shipment occurs. That emergency response plan will provide detailed procedures for responding to accidents, including beyond-shipping-window conditions (Part A, Section 6.4).

4.3.7 Driver Training Requirements

The driver of the vehicle shall meet the Site requirements for a heavy-duty driver, be qualified as a radiation worker, and have specific training for transporting highway route controlled quantities of radioactive material.

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5.0 ACCEPTANCE OF PACKAGING FOR USAGE

5.1 NEW PACKAGE ACCEPTANCE TESTING

Acceptance testing and inspections are performed to evaluate the performance of the MCO Cask per the requirements of this SARP. The acceptance inspections and tests are categorized as fabrication, performance, and prior to first use.

During fabrication of all MCO Cask components, the QA plan or equivalent described in Part A, Section 7.0, will be implemented.

The following are requirements for the inspection and testing of the packaging. Specific procedures with appropriate Quality Control (QC) hold points, shall be written by the fabricator or user, prior to use, to ensure the packaging is not damaged during inspection and testing operations.

5.1.1 Acceptance Requirements

Acceptance criteria for the pressure testing are found in ASME B&PV Code, Section III, Subsection NB (ASME 1995b). Nondestructive examination (NDE) acceptance criteria for welds are found on the drawings and in ASME B&PV Code, Section III, Subsection NB. The fabrication leakage rate tests require a leak rate equal to or less than leaktight, as defined in ANSI N14.5 (1.0×10^{-7} atm std cc/s, air). Acceptance criteria for the dimensions are stated on the drawings found in Part A, Section 10.0.

5.1.2 Inspection and Testing

5.1.2.1 Fabrication Inspection and Testing.

5.1.2.1.1 Fabrication Inspection. The cask components shall be inspected after final assembly to verify compliance with the drawing dimensions given in Part A, Section 10.0. Visual, liquid penetrant, radiography, or ultrasonic NDE shall be performed on the applicable welds per the drawing requirements.

5.1.2.1.2 Pressure Test. Each MCO Cask containment barrier will be pressure tested. Pressure tests will be performed at ambient temperature on each fully assembled MCO Cask with the butyl rubber O-ring seals installed.

The pressure test will be performed at 150% of design pressure if hydrostatically tested, or 125% of design pressure if tested pneumatically. The design pressure of the MCO Cask is 1,034 kPa (150 psig). The pressure test will be conducted in accordance with Section III, Subsection NB, of the ASME B&PV Code (ASME 1995b).

5.1.2.1.3 Leakage Rate Testing. Each complete MCO Cask containment boundary shall be leakage rate tested upon completion of fabrication. The tests will be performed at ambient temperature after final assembly of the pressure boundary is completed. The leakage rate tests will be performed in accordance with ANSI N14.5 (ANSI 1987).

5.1.2.1.4 Proof Load Test. A proof load test of the lifting point will be performed on each cask. The proof load will be 150% of the maximum loaded MCO Cask weight of 27,273 kg (60,000 lb). This load is held for 10 minutes, then released. A pre-test and post-test evaluation of each trunnion, consisting of a visual inspection and liquid penetrant examination, shall be performed and documented.

5.1.2.2 First Article Testing. The following operational tests will be performed on the first MCO Cask to verify its performance. These tests will be performed upon arrival at Hanford.

5.1.2.2.1 Handling, Loading, and Unloading Operational Tests. The test will use the cask lifting assembly to move the MCO Cask onto and off of the transport trailer. The tiedown system, which is a integral part of the trailer, will be used to secure the cask to the trailer. This test shall verify that the cask and tiedowns perform as designed.

5.1.2.2.2 Cask Seal Assembly Tests. Consistent proper assembly of the main closure seal on the MCO Cask shall be verified. The cask lid shall be installed by following approved procedures for cask closure that are based on the requirements of Part A, Section 6.0. Upon completion of lid installation, a leakage rate test shall be performed on the MCO Cask to confirm that the seal is leaktight as defined in ANSI N14.5 (ANSI 1987). This test shall be repeated five times to demonstrate the cask closure procedures are adequate to ensure formation of a leaktight containment boundary.

5.1.2.3 Prior to First-Use Inspections. Prior to first use, inspections shall be performed to ensure the cask meets the SARP requirements and can be assembled to meet the leaktight acceptance criteria. Also, before first use, the packaging shall be labeled with its gross weight, tare weight, and drawing number. Each MCO Cask shall be inspected prior to first use as described below. Each inspection shall be documented as stated in Part A, Section 5.1.3. The inspections shall be performed to ensure that the packaging has maintained the original fabricated configuration, including dimensional verification.

Each MCO Cask shall be leakage rate tested per Part A, Section 5.1.2.1.3, following fabrication and prior to shipment from the fabricator. The first-use inspections shall consist of the following steps.

1. Visually examine the MCO Cask and lifting and tiedown equipment for damage due to storage or transport from the fabricator.

2. Visually inspect all seals for damage.

3. Visually examine all bolts to ensure that none exhibit headmarks that match those on the U.S. Department of Energy "Suspect Fastener Headmark List" and that none exhibit any degradation or dinged, damaged, or deformed threads.

4. Visually examine cask for cleanliness; ensure the packaging is cleaned of any dirt or dust.

5.1.3 Documentation

Acceptance testing and inspection verification (including results therefrom) shall be documented with QC verification and maintained for the life of the package or five years, whichever is longer.

5.2 PACKAGING FOR REUSE

The following applies to MCO Casks that have already been used to transport loaded MCOs.

5.2.1 Acceptance Requirements

The visual acceptance criteria shall be no container material degradation that could affect the containment of the package. The cask shall be cleaned to nonfixed external contamination levels (Table A4-1). Transport requirements, appropriate at time of transport, shall be followed.

The inspections shall consist of the following steps.

1. Visually examine the MCO Cask and lifting and tiedown equipment for damage due to storage.

2. Visually inspect all seals for damage.

3. Visually examine all bolts to ensure that none exhibit headmarks that match those on the U.S. Department of Energy "Suspect Fastener Headmark List" and that none exhibit any degradation or dinged, damaged, or deformed threads.

4. Visually examine cask for cleanliness; ensure the packaging is cleaned of any dirt or dust.

5.2.2 Inspection

For MCO Cask shipment after extended storage, the MCO Cask shall have:

- The closure lid inspected to ensure no degradation has occurred
- The closure lid, drain port, and vent port butyl rubber O-rings inspected to ensure no degradation has occurred and that the service life of the O-rings has not been exceeded
- The tiedown equipment and trailer inspected for damage due to storage.

5.2.3 Documentation

All inspections shall be documented in procedures and/or inspection checklists and verified by QC. The documentation shall be maintained for the life of the package or five years, whichever is longer.

6.0 OPERATING REQUIREMENTS

6.1 GENERAL REQUIREMENTS

The following are requirements for the use of the MCO Cask. Each facility shall prepare operating procedures based on the following requirements; K Basin fuel characteristics; and Fluor Daniel Hanford, Inc. (FDH), safety requirements. Prior to use, the specific operating procedures with appropriate Quality Assurance/QC hold points, shall be written by the user and approved in accordance with WHC-CM-2-14.

For loading/unloading operations, the following shall be performed.

1. Visually inspect seals and sealing surfaces for damage.
2. Visually inspect MCO and MCO Cask for cracks or damage. Visually examine cask for cleanliness; ensure the cask is cleaned of dust or dirt.
3. Visually inspect lifting attachments for cracks or damage.
4. Verify loading and closure of the MCO and MCO Cask are performed in accordance with procedural requirements.
5. Verify shipping time window is not exceeded.
6. Verify dose rates are acceptable prior to shipment.
7. Verify MCO Cask external contamination limits per Table A4-1 are met prior to transport.
8. Verify tiedown of MCO Cask to transporter.
9. Verify appropriate shipping paperwork is prepared and signed by a certified shipper.
10. Verify proper removal from transporter.

Prior to initial loading, the cask shall be helium leakage rate tested during fabrication per Part A, Section 5.1.2.1.3. Also, an annual leakage rate test shall be performed per Part A, Section 8.2.2.

6.2 LOADING AND UNLOADING PACKAGE

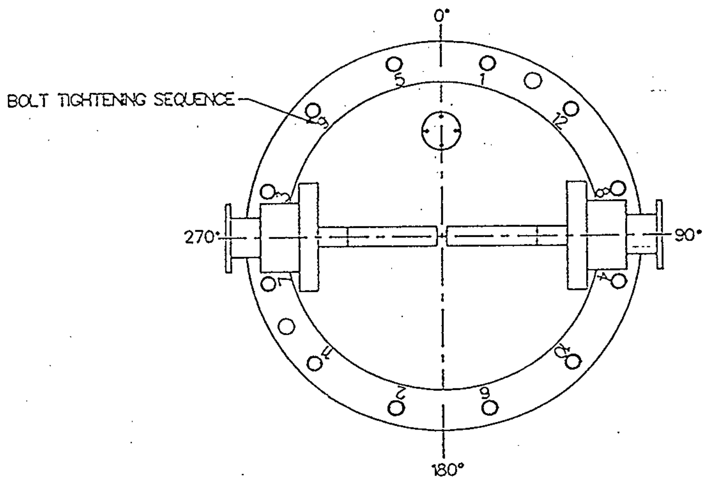
The MCO and MCO Cask operational requirements shall be included in detailed plant operating procedures. The following are items required for the safe transport of the MCO and MCO cask.

6.2.1 Operations at K Basins

The MCO is loaded with fuel baskets at the K Basins and prepared for transport to the CVDF. The following safety items are required in the plant operating procedures for the safe transport of the MCO and MCO Cask.

1. The MCO Cask shall be decontaminated when appropriate and surveyed before release for conveyance.
2. Visually inspect MCO Cask seals and sealing surfaces for damage.
3. The MCO shield plug shall be installed, and the bolts shall be torqued to 759 N·m (560 ft·lb) and verified.
4. The MCO cask lid shall be installed, and the bolts shall be torqued to 407 N·m (300 ft·lb) ± 14 N·m (10 ft·lb) and verified (Figure A6-1).
5. The tiedowns shall be secured and verified before transport.
6. Mark IV fuel baskets shall only be filled with Mark IV fuel elements and scrap baskets shall only be loaded into the top or bottom position within the MCO, but only one scrap basket can be loaded into each MCO.
7. The package must be backfilled with 21 kPa (3.0 psig) of helium gas.
8. The shipping time window (see Part A, Section 6.3.1) is 24 hours for transfer from the K Basins to the CVDF.

Figure A6-1. Multicanister Overpack Cask Lid Torque Sequence.



6.2.2 Operations at CVDF

The CVDF receives the fuel from the K Basins, processes it, and then prepares the package for transport to the CSB. The following safety items are required in the plant operating procedures for the safe transport of the MCO and MCO Cask.

1. The seals and surfaces of the MCO Cask shall be inspected for degradation.
2. The MCO Cask lid shall be installed, and the bolts shall be torqued to 407 N·m (300 ft·lb) ± 14 N·m (10 ft·lb) and verified (Figure A6-2).
3. Prior to transport the bulk temperature of the package must be less than 15 °C (see Part B, Section 8.0).
4. The gas generation rate inside the MCO at 75 °C shall be measured, and it shall not exceed 1.4 kPa (0.2 psi) per hour (see Part B, Section 8.0).
5. The shipping time window (see Part A, Section 6.3.2) is 36 hours for transfer from the CVDF to the CSB.
6. The MCO must be backfilled with 21 kPa (3.0 psig) of helium gas.
7. The tiedowns shall be secured and verified before transport.
8. The MCO Cask shall be decontaminated when appropriate and surveyed before release for conveyance.
9. The MCO pressure relief devices shall be verified for nonblockage.

6.3 SHIPPING-TIME WINDOW

Included in the detailed operating procedures written for each facility shall be a maximum shipping-time window. If the shipping-time window is exceeded, then the transport becomes an off-normal condition (Section 6.4).

6.3.1 K Basins to CVDF

The shipping-time window between the K Basins and the CVDF must be less than 24 hours. The time clock starts at the K Basins when the air space within the MCO is purged with helium. The time clock runs continuously to the CVDF and is stopped when the cask is vented at the CVDF. The average time estimated for this shipping-time window is 8 hours.

6.3.2 CVDF to CSB

The shipping-time window between the CVDF and the CSB must be less than 36 hours. After cooling to 15 °C, the time clock starts at the CVDF immediately after the cask/MCO annular space is drained, dried, and purged with helium. The time clock runs continuously to the CSB and is stopped when the venting package is installed and venting of the MCO begins. The average time estimated for this shipping time window is 14 hours.

6.4 BEYOND SHIPPING WINDOW

A beyond-shipping-window condition exists when the time exceeds the normal shipping window. Detailed procedures for responding to these beyond-shipping-window conditions and accidents shall be provided in the emergency response plan discussed in Part A, Section 4.3.6. That emergency response plan shall include detailed procedures implementing the requirements of the following two sections. Part B, Section 8.6, demonstrates that these procedures prevent both overpressurization of the package and a runaway uranium-water reaction.

6.4.1 K Basins to CVDF Transport

The recovery procedure, for the time when the package has left the K Basins, but has not arrived at the CVDF within 24 hours, is as follows.

1. Vent the cask using a venting device that connects to the vent port quick disconnect, but prevents air from flowing back into the cask.

2. The venting system can be either continuous into a closed volume or opened periodically. If a periodic system is used, vent the cask every 12 hours to prevent an overpressurization.

6.4.2 CVDF to CSB Transport

The recovery procedure, if the package has not arrived at the CSB within 36 hours, is as follows.

1. Connect water hoses to the vent and drain ports for cooling the cask and MCO.

2. Pump 29 °C (85 °F) or cooler water at least 76 L/min (20 gpm) through the cask annulus. This operation must occur continuously until the cask is moved into the CSB and can only be stopped for actual movement of the transport sytem.

6.5 EMPTY PACKAGE (PACKAGING)

When empty MCO packages are transported, the following steps must be performed.

Empty packages shall be prepared for transport per 49 CFR 173.428 under the conditions that the smearable internal contamination levels and the smearable external contamination levels are acceptable per 49 CFR 173.443 (see Table A4-1). Otherwise, the package shall be reassembled and transported per

Part A, Section 6.2, except that temperature limits and shipping windows do not apply. Shipment of an empty package does not count towards the Part A, Section 4.3.5, limit of 300 trips per year.

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7.0 QA REQUIREMENTS

7.1 INTRODUCTION

This section describes the QA requirements for the design, procurement, fabrication, and maintenance of the MCO Cask. The format and requirements are taken from WHC-CM-4-2, *Quality Assurance Manual*; Regulatory Guide 7.10, *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material* (NRC 1986); WHC-IP-0705, *Quality Assurance Program Plan for the Hazardous Materials Transportation and Packaging Program* (WHC 1995); 49 CFR 173; and 10 CFR 71, Subpart H.

7.2 GENERAL REQUIREMENTS

These requirements apply to activities which could affect the safety basis or quality of the MCO Cask and associated hardware. The overall MCO Cask assembly is classified per WHC-CM-4-46, *Nonreactor Facility Safety Analysis Manual*, Section 9.0, as "Safety Class."

Specific components of the MCO are assigned quality categories based upon Regulatory Guide 7.10 (NRC 1986) and are used to show that each individual component meets the requirements of the overall MCO Cask safety classification.

7.3 ORGANIZATION

The organizational structure and the assignment of responsibility shall be such that quality is achieved and maintained by those who have been assigned responsibility for performing work. Quality achievement is to be verified by persons or organizations not directly responsible for performing the work.

Packaging Engineering and cognizant Spent Nuclear Fuel (SNF) project managers are responsible for the quality of the work performed by their respective organizations and for performing the following activities:

- Follow current requirements of this SARP, WHC-CM-4-2, and WHC-IP-0705 (WHC 1995).
- Provide instructions for implementing QA requirements.

The Director, Quality Assurance, is responsible for establishing and administering the FDH QA program as stated in HNF-CM-4-2.

7.4 QA PLAN AND ACTIVITIES

Each cognizant engineer involved with design, procurement, fabrication, use, or maintenance of the MCO Cask is responsible for ensuring that the assigned tasks are performed in accordance with controlling plans and procedures, which must, in turn, conform to the requirements of these QA requirements. QA requirements for tasks are determined and documented in the plans and procedures used by the involved organizations.

Quality Categories 1, 2 or 3, as defined below, establish a graded approach for determining applicable quality assurance requirements for MCO Cask components. The Quality Categories are based upon Regulatory Guide 7.10 (NRC 1986).

The QA requirements applicable to design, procurement, and fabrication of each MCO Cask component is based upon the quality categories below.

Quality Category 1--Critical: Includes items and activities that could directly impact public radiological health and safety. This classification includes items and activities for which omission, error, or failure could directly result in consequences exceeding the requirements specified in or based upon applicable federal regulations. These items and activities are critical to safety. An unsafe condition could result from the single failure of one of these items.

Quality Category 2--Major: Includes items and activities for which failure could indirectly affect public radiological health and safety. This classification encompasses items and activities whose failure would indirectly adversely impact performance of critical items or occupational radiological health and safety. An unsafe condition could result only if failure of this item or system occurred in conjunction with the failure of another item or system in this category.

Quality Category 3--Minor: Includes items and activities for which failure is unlikely to result in a predictable, significant, adverse impact on public health and safety regardless of other failures in this category.

The extent of the QA requirements application to a given activity is controlled by the quality category assigned and its attendant QA requirements. The QA requirements for each quality category are listed below.

Quality Category 1--Critical: All documentation for these items and activities require S,Q (Safety, Quality Assurance) and possibly D (U.S. Department of Energy, Richland Operations Office) review and approval. Design and fabrication shall meet the QA requirements of the ASME B&PV Code, Section III (ASME 1995b), as required by NUREG/CR-3854 (Fischer and Lai 1985).

Quality Category 2--Major: All documentation for these items and activities require Q and designated S review and approval. Design and fabrication shall meet the quality assurance requirements of the ASME B&PV Code, Section III (ASME 1995b), as required by NUREG/CR-3854 (Fischer and Lai 1985).

Quality Category 3--Minor: All documentation for these items and activities require only review and approval of the cognizant engineer and manager. these items shall be fabricated using ASTM, ANSI, American Institute of Steel Construction, Association of American Railroads, or other recognized national standard.

Requirements are imposed on organizations by direct reference in plans and procedures. Table A7-1, "Functional Responsibility Matrix," shows documentation review requirements. This matrix assigned responsibility for review and approval to the appropriate organization either designing or using the MCO Cask. U.S. Department of Energy, Richland Operations Office, approval is required for all changes to the SARP.

Table A7-1. Functional Responsibility Matrix.

Document	PE	SNF Engineering	Quality Assurance	Safety	SNF Operations
MCO Cask Safety Analysis Report for Packaging	P,R,A	R,A	R,A	R,A	R,A
MCO Cask drawings	R	P,R,A	R,A	R,A	R,A
MCO Cask purchase order	R	P,R,A	R,A	R,A	R,A
Operating procedures	R	R,A	R,A	R,A	P,R,A
Maintenance procedures	R	R,A	R,A	R,A	P,R,A
MCO Cask fabrication/nonconformance reports	R,A	P,R,A	R,A	R	R
Leakage rate test procedures	R,A	R,A	R,A	R,A	P,R,A

A = Approval.
MCO = Multicanister Overpack.
P = Primary responsibility (organization responsible for developing the document).
PE = Packaging Engineering.
R = Review.
SNF = Spent Nuclear Fuel.

7.5 QUALITY REQUIREMENTS

7.5.1 Design Control

Quality categories for design control of MCO Cask components are shown in Table A7-2. Classification of components into these quality categories ensures that critical parameters of a given component are reviewed in a manner consistent with their importance. The design and analysis shall correspond to the QA requirements of the assigned quality category.

Table A7-2. Design Quality Categories.

Component	Quality category
Closure bolts	1
Trunnions	3
Multicanister Overpack Cask body	1
Multicanister Overpack Cask lid	1
O-ring seal	1
Vent and drain ports	2
Vent and drain port covers	2
Vent and drain port seals	2

7.5.1.1 Design Inputs. Design inputs for the MCO Cask are taken from the component drawings as presented in this SARP. Any changes to these drawings shall be identified, documented, approved, and controlled in the same manner in which the drawings were released. For those components designed by offsite fabricators, a design review shall be conducted to ensure that the submitted design meets the requirements of this SARP.

7.5.1.2 Design Process. The MCO Cask was designed by TN. Cognizant SNF personnel shall ensure that the MCO Cask components meet the design requirements of the governing design specification.

7.5.1.3 Design Verification. Design adequacy of the MCO Cask is demonstrated by this SARP. Any changes to the final design of the MCO Cask may require revision of this SARP.

Design adequacy of the MCO Cask shall be verified. SNF Engineering shall conduct a design review in accordance with HNF-CM-6-1, *Standard Engineering Practices*, EP 4.1, as required by WHC-CM-4-2, QR 3.0. The final design of the MCO Cask shall meet all requirements of this SARP; otherwise, a SARP revision will be required.

7.5.1.4 Documentation and Records. Design documentation and records providing evidence that the design verification processes were performed in accordance with the requirements of this SARP shall be collected, stored, and maintained for the life of the package.

7.5.2 Procurement and Fabrication Control

7.5.2.1 Procurement Document Control. Procurement documentation for MCO Cask items is initiated by the SNF engineer responsible for the MCO Cask design. The standard FDH purchase requisition (PR) contains both the technical and QA requirements. Specifications shall be written for complicated or critical component procurement items. The PR information is converted to a purchase order (PO) by the FDH Purchasing organization. The cognizant Quality Assurance engineer or Quality Assurance manager reviews and approves all PRs and specifications per WHC-CM-4-2.

Changes to the PR, or subsequent PO, are subject to the same review and approval requirements as the original PR. QA requirements are imposed by FDH specifications, engineering drawings, or other QA documents. The quality categories for procurement of MCO Cask components are shown in Table A7-2.

7.5.2.2 Control of Purchased Items and Services. The procurement of MCO Cask items and services shall be documented and controlled to ensure conformance to specified requirements of WHC-CM-4-2.

7.5.2.3 Identification and Control of Items. The identification of purchased items shall be at initial receipt and maintained through installation and use. The identification of items fabricated or assembled onsite shall be established at the earliest practical time in the fabrication or assembly sequence.

The identification of items shall relate each to an applicable design or other pertinent specifying document, such as the governing PO, specification, test plan, procedure, or drawing(s).

Physical identification markings, such as stamping and etching, shall be used to the maximum extent possible on the MCO Cask components to ensure that the markings remain durable as long as possible.

Where required, items and material having limited calendar or operating lives or cycles are identified and controlled to preclude use of items with expired shelf life or insufficient operating life.

Provisions shall be made for the preservation of identification marking consistent with the planned use of the MCO Cask. Such provisions shall include criteria for the maintenance and replacement of markings damaged during use of the MCO Cask and/or aging.

7.5.2.4 Control of Operations/Processes. Processes affecting the safety basis or quality of MCO Cask items shall be controlled by instructions, procedures, drawings, checklists, or other appropriate means. These means shall ensure that process parameters are controlled within defined limits and that specified controls will be applied as defined in WHC-CM-4-2.

Special processes performed onsite and by suppliers that control or verify quality, such as those used in welding, heat treating, and NDE of containment boundary items, shall be performed by qualified personnel using applicable qualified procedures.

Records shall be maintained in accordance with 10 CFR 71, Subpart H, for currently qualified personnel, processes, and equipment for each special process (if a procured item) or by the shop performing the process, per HNF-CM-4-2 (if onsite).

7.5.3 Control of Inspection and Testing

In-process and final inspections shall be performed in accordance with the following guidelines.

7.5.3.1 Inspection/Test Personnel. Inspection for acceptance shall be performed by SNF Quality Assurance personnel.

7.5.3.2 Fabrication Inspection/Testing. Fabrication inspections for the MCO Cask include the following, which are performed in accordance with HNF-CM-4-2:

- Welding and NDE personnel qualifications
- Material certifications/marking
- NDEs
- Proper assembly of the MCO Cask
- Proper torquing of bolts
- Welding certification records
- Testing of the assembly.

7.5.3.3 In-Service Inspection/Testing. Loading/unloading procedures shall be written by SNF Operations with appropriate reference to maintenance procedures and shall be used to ensure adequate loading, operation, and maintenance of the MCO Cask. The maintenance procedures identify the items to be maintained, criteria for acceptability or replacement, and the frequency and type of inspection assigned to the item. All procedures shall require that the "Master Safety Rules" are met as required by WHC-CM-1-10, *Safety Manual*.

QA inspection planning is established to ensure that final inspection, prior to use, verifies compliance with the following items.

- The MCO Cask is properly assembled.
- All acceptance criteria are met for its use.
- All shipping papers are properly completed.
- The MCO Cask is conspicuously and durably marked as required by HNF-CM-2-14 and 49 CFR 173.
- Measures are established to ensure that an individual trained and certified as an onsite shipper, designated by the user of the MCO Cask, signs the shipping papers before authorization for shipping.
- Operational and maintenance procedures are properly completed.

7.5.3.5 Acceptance and Records. Acceptance of an item shall be documented and approved by authorized facility Quality Assurance/QC personnel per HNF-CM-4-2. Inspection documentation shall be maintained for the life of the MCO Cask.

7.5.4 Test Control

These requirements apply to activities associated with the testing of the MCO Cask and associated hardware involving Quality Category 1, 2, or designated 3 items.

Tests required to verify conformance of MCO Cask components to this SARP's requirements and to demonstrate satisfactory performance for service shall be planned, performed, and documented. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented, and their conformance with acceptance criteria shall be evaluated.

Test procedures for activities classified as Quality Category 1, 2, or designated 3 are subject to review and approval. Logbooks for activities classified as Quality Category 1, 2, or designated 3 items shall be maintained and controlled in accordance with WHC-CM-4-2.

7.5.4.1 Test Requirements. Test requirements and acceptance criteria for the MCO Cask are identified, documented, and approved within this SARP. Test requirements and acceptance criteria for the MCO Cask are per the ASME B&PV Code and 10 CFR 71. Required procedures for design analysis tests, fabrication tests, operations tests, and maintenance tests shall be controlled.

7.5.4.2 Test Procedures. Test procedures shall incorporate and be traceable to these SARP requirements and include the minimum information required by HNF-CM-4-2.

7.5.4.3 Test Results. Test results shall be documented and evaluated by the engineering group not directly involved in the performance of the test to ensure that test requirements have been satisfied and that appropriate Quality Assurance acceptance was obtained.

7.5.4.4 Test Records. Test records shall be written and maintained as QA records, following the requirements of WHC-CM-4-2 and Part A, Section 7.5.9.

7.5.5 Control of Measuring and Test Equipment

The requirements for measuring and test equipment apply to the tools used for testing the MCO Cask and torquing of closure bolts. Accuracy, standards, recall system, and calibration shall meet the requirements of WHC-CM-4-2.

7.5.6 Checks and Controls

The maintenance procedures establish, as appropriate, criteria for maintenance tests to be conducted by the user to ensure the MCO Cask maintains containment and is free of excessive contamination. The maintenance procedures also establish qualification criteria for responsible personnel who document and evaluate test results.

7.5.7 Control of Nonconforming Items

These QA requirements shall apply when the nonconformance will affect new or existing Quality Category 1, 2, or designated 3 items.

All items procured or fabricated for, or in use with, the MCO Cask shall be inspected prior to use for compliance with the governing PO, specification, or fabrication drawing. The cognizant engineer, with Quality Assurance assistance, shall define the acceptance and nonconformance criteria.

7.5.7.1 Identification. Identification of nonconforming items shall be by marking or tagging or by other suitable methods that do not adversely affect the end use of the item per WHC-CM-4-2.

7.5.7.2 Evaluation and Disposition. Nonconforming characteristics shall be reviewed, and recommended dispositions of nonconforming items shall be proposed and approved in accordance with WHC-CM-4-2.

7.5.8 Corrective Action

Nonconformances or conditions adverse to quality are evaluated as described in Part A, Section 7.5.7.2, and the need for corrective action is determined in accordance with WHC-CM-4-2. For Quality Category 3 items, cognizant engineers are responsible for implementing and monitoring the effectiveness of any corrective action taken. For Quality Category 1, 2, and designated 3 items, appropriate action shall be taken by Quality Assurance to ensure prompt implementation by follow-up reviews and submission of a report to the upper management level(s) documenting the nonconformance, its causes, and the corrective action taken.

7.5.9 QA Records and Document Control

Records that furnish documentary evidence of quality shall be specified, prepared, and maintained per WHC-CM-4-2. All documents used tp perform and/or verify quality-related activities shall be controlled. Controlled documents include (but are not limited to) the following:

- Drawings
- Specifications
- POs
- Inspection and test plans and procedures
- Reports
- Verification data
- Nonconformance reports
- Corrective action reports
- This SARP
- Operational and maintenance procedures.

The document control system embodies the following features.

- Document changes are controlled in the same manner as the original issue.
- Interfacing documents are properly coordinated and controlled.
- A reference system is in use that provides access to the current issues of project documents.

The cognizant engineer is responsible for ensuring accessibility to the latest issue of all such documents. Use or maintenance of the MCO Cask shall not start until all required documents are readily available.

All records associated with hazardous material packaging and transportation shall be retained for the life of the packaging. All lifetime storage QA records required for the MCO Cask shall be appropriately stored by Packaging Engineering or the responsible user organization, depending upon the purpose of the document (see Table A7-3).

7.5.10 Audits

The FDH internal and external audit processes are guided by and shall be in accordance with WHC-CM-4-2.

Table A7-3. Retention and Location Matrix.

Document	Retention period	Location
Packaging design criteria/safety analysis report for packaging	Lifetime	Packaging Engineering
Maintenance procedures	Lifetime	User facility
Leakage rate test procedures	Lifetime	User facility
Inspection plans/procedures	Lifetime	User facility
Operating procedures	Lifetime	User facility
Quality Assurance/Quality Control inspection reports	Lifetime	Quality Assurance/ISS
Nonconformance reports	Lifetime	Quality Assurance/ISS
MCO Cask specification and drawings	Lifetime	SNF/ISS
Purchase orders	Lifetime	Procurement/ISS
MCO Cask data acquisition report	Lifetime	SNF/ISS
Data packages	Lifetime	SNF/ISS
Corrective action reports	Lifetime	SNF/ISS

ISS = Information and Scientific Systems.
MCO = Multicanister Overpack.
SNF = Spent Nuclear Fuel.

7.5.11 Handling, Storage, and Shipping

QA requirements, specified in WHC-CM-4-2, apply to activities involved in handling, storage, and shipping of Quality Category 1, 2, and designated 3 items.

Transportation Logistics will oversee the use of the MCO Cask, including marking/labeling and proper shipment records, to ensure compliance with HNF-CM-2-14.

7.6 SARP CONTROL SYSTEM

This SARP is a copy controlled supporting document to ensure that only up-to-date approved versions are used. Any changes made to this SARP will be by engineering change notices, which are distributed to users through the Copy Control System and incorporated into the SARP.

Any review comment records produced during the initial release or subsequent changes will be on file with Packaging Engineering.

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8.0 MAINTENANCE

8.1 GENERAL REQUIREMENTS

The MCO Cask is a passive system designed to require minimal maintenance during its use. Maintenance of the MCO Cask during use is limited to a visual inspection. No hands-on changing of parts is necessary between uses unless a degradation is noticed or component service lives are exceeded. The MCO Cask is considered a contact-handled system.

8.2 INSPECTION AND VERIFICATION SCHEDULES

These inspections are only required as maintenance of the MCO Cask. They are to be performed at the CSB or prior to use at the K Basins. If operations require, inspections may be performed during use.

8.2.1 Regular Inspections

The following are regular maintenance inspections to be performed at the CSB before transport back to the K Basins.

1. Determine cask external contamination levels and document.
2. Determine cask external dose rates and document.
3. Visually inspect package markings for deterioration.
4. Visually inspect lid bolts for deterioration (such as stripping).
5. Visually inspect O-rings for deterioration (such as cracking, extrusion, shrinkage, overstretching, or foreign particles).
6. Inspect lifting attachment area for indications of damage.

8.2.2 Scheduled Maintenance

1. Replace the butyl O-ring of the cask annually with a Parker 3-912 B612-70 or equivalent gasket.
2. Replace the vent port cover O-ring annually with a Parker 2-328 B612-70 or equivalent gasket.
3. Replace the drain port cover O-ring annually with a Parker 2-341 B612-70 or equivalent gasket.
4. After replacement of the O-rings, perform a leakage rate test in accordance with ANSI N14.5 (ANSI 1987) to confirm the leaktightness of the containment boundary.

8.2.3 Lifting/Tiedown Inspections

These maintenance visual inspections shall be performed on the tiedown system prior to each use.

1. Inspect the tiedown lifting points prior to each use for plastic deformation or cracking. Any indication of cracking or distortion shall be repaired prior to further use of the lifting or tiedown device.

2. Inspect the tiedown turnbuckle attachment plates and the bearing pad surfaces. Any indication of cracking or distortion shall be repaired prior to further use.

Annual load testing of the lifting devices in accordance with ANSI Standard N14.6 (ANSI 1993) is required.

8.2.4 Subsystems Maintenance

8.2.4.1 Fasteners. All threaded parts, including the closure bolts for the cask and tiedown system bolts, will be inspected prior to use for deformed or stripped threads and heads. Any damaged parts shall be replaced prior to further use. Bolts which are found to exhibit headmarks matching those on the DOE-HQ "Suspect Fastener Headmark List" shall be segregated and processed in accordance with WHC-CM-4-2. Bolts shall be lubricated with Neolube,[2] or other appropriate lubricant, as necessary.

8.3 RECORDS AND DOCUMENTATION

Visual inspections shall be documented, including QC verification and maintained for the life of the article or five years, whichever is longer.

8.4 SPARE PARTS

The following spare parts are recommended for the MCO, MCO cask and tiedown system. Complete descriptions of the recommended spare parts are listed on the drawings in Part A, Section 10.0.

- O-ring, butyl--Parker 3-912 B612-70 or equivalent (10), Parker 2-341 B612-70 or equivalent (10), Parker 2-328 B612-70 or equivalent (10)
- ASME SA-540, Grade B24, Class 1, 1.50-in.--6UNC x 3.00-in. bolts (5)
- ASME SA-193-B8 or equivalent, 0.50-in.--13UNC x 0.50-in. bolts (4)
- ASME SA-193-B8 or equivalent, 0.25-in.--20UNC x 1.00-in. bolts (4).

[2] Neolube is a trademark of Huron Industries Inc.

9.0 REFERENCES

10 CFR 71, 1996, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

10 CFR 72, 1996, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," *Code of Federal Regulations*, as amended.

49 CFR 173, 1996, "Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

ANSI, 1993, *American National Standard for Radioactive Materials--Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More*, ANSI Standard N14.6, American National Standards Institute, New York, New York.

ANSI, 1987, *American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment*, ANSI Standard N14.5-1987, American National Standards Institute, New York, New York.

ASME, 1995a, Section II, Part D, *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.

ASME, 1995b, Section III, Subsection NB, *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.

ASNT, 1993, *Recommended Practice No. SNT-TC-1A, 1992 edition*, SNT-TC-1A, American Society for Nondestructive Testing, Columbus, Ohio.

Edwards, W. S., 1997, *Packaging Design Criteria for the MCO Cask*, HNF-SD-TP-PDC-030, Rev. 4, Rust Federal Services Inc., Northwest Operations, Richland, Washington.

Fischer, L. E., and W. Lai, 1985, *Fabrication Criteria for Shipping Containers*, NUREG/CR-3854 (under Lawrence Livermore National Laboratory contract to the U.S. Nuclear Regulatory Commission), U.S. Nuclear Regulatory Commission, Washington, D.C.

Mercado, J. E., 1994, *Report on Equivalent Safety for Transportation and Packaging of Radioactive Materials*, WHC-SD-TP-RPT-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Monroe, R. E., H. H. Woo, and R. G. Sears, 1984, *Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials*, NUREG/CR-3019 (under Lawrence Livermore National Laboratory contract to the U.S. Nuclear Regulatory Commission), U.S. Nuclear Regulatory Commission, Washington, D.C.

NRC, 1991, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches*, Regulatory Guide 7.11, U.S. Nuclear Regulatory Commission, Washington, D.C.

NRC, 1986, *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material*, Regulatory Guide 7.10, U.S. Nuclear Regulatory Commission, Washington, D.C.

Pajunen, A. L., 1996, *Bounding Particulate Contents of a Multi-Canister Overpack*, WHC-SD-SNF-TI-023, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Parsons, 1996, *MCO Assembly*, drawing H-2-826303, Rev. 0, Parsons Engineering Science, Inc., Richland, Washington.

RL, 1995, *Hanford Site Hoisting and Rigging Manual* DOE/RL-92-36, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

WHC-CM-1-10, *Safety Manual*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-4-2, *Quality Assurance Manual*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-4-46, *Nonreactor Facility Safety Analysis Manual*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-6-1, *Standard Engineering Practices*, Westinghouse Hanford Company, Richland, Washington.

WHC, 1996, *Specification for SNF Path Forward Cask and Transportation System*, WHC-S-0396, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

WHC, 1995, *Quality Assurance Program Plan for the Hazardous Materials Transportation and Packaging Program*, WHC-IP-0705, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

10.0 APPENDIX: DRAWINGS

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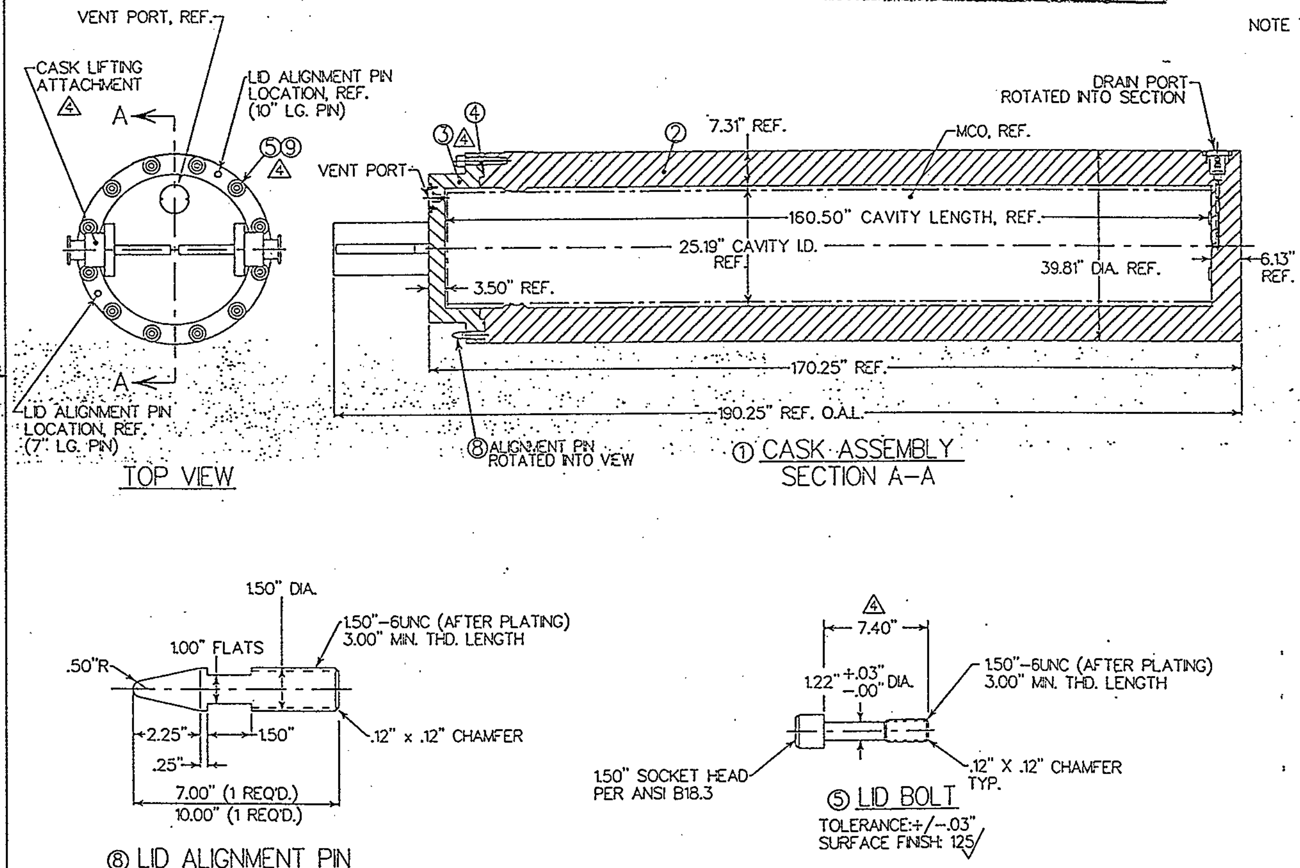
			PARTS LIST	
	ITEM NO.	NO. REQ'D	NOMENCLATURE	DESCRIPTION
	1	–	CASK ASSEMBLY	
	2	1	CASK BODY	SEE DWG. 3035-3 SHEET 2
	3	1	LID	SEE DWG. 3035-3 SHEET 4
	4	1	O-RING SEAL	PARKER .275"DIA. XSECT. X 31.31"I.D. BUTYL # B612 70 OR EQUIV.
NOTE 7	5	12	LID BOLT	SA-479-XM19 ROT ROLLED OR EQUIV.
	6		DELETED	
	7		DELETED	
NOTE 7, NOTE 4 *	8	2	LID ALIGNMENT PIN	SA-193-B8 OR EQUIV.
△4	9	12	WASHER	1.50" DIA. FLAT, SST



NOTES:

1. DELETED
2. DELETED
3. DELETED
4. * INDICATES NON SAFETY RELATED ITEM.
5. THIS PARTS LIST IS FOR SHEET 1 ONLY.
6. △4 TORQUE REQUIREMENTS:
   LID BOLTS: 300 FT. LBS. ± 10 FT. LBS.
   VENT & DRAIN PORT COVER SCREWS: 15 FT. LBS. ± 3 FT. LBS.
   ALIGNMENT PINS: 40 FT. LBS. ± 5 FT. LBS.
7. LID BOLTS & ALIGNMENT PINS TO BE CHROMIUM PLATED (THREADS ONLY) PER QQ-C-320-B, CLASS 2, TYPE 1 (.0002" MIN. THK.) BOLT TO BE INSPECTED TO NB-2580 OF ASME B & PV CODE, SECTION II, INCLUDING VT (VISUAL EXAMINATION) & LP (LIQUID PENETRANT EXAMINATION), BEFORE PLATING.
8. LUBRICATE BOLTS WITH NEOLUBE AS NEEDED.

ITEM NO. 7
WHC SPECIFICATION NO. WHC-S-0396
WHC PURCHASE ORDER NO. MJK-SPX-452727

NO.	DATE	REVISIONS	DWN.	CHKD	M.D.	Q/A	PROJ.
4	11/7/96	SEE DCN 3035-14	GTD	PS	PS	ED	GG
3	1/9/96	SEE DCN 3035-11	J.T.G.	P.S.	P.S.	E.D.	G.G.
2	9/30/95	SEE DCN 3035-6	J.T.G.	P.S.	P.S.	E.D.	G.G.
1	8/1/95	SEE DCN 3035-1	J.T.G.	P.S.	P.S.	E.D.	G.G.

APPROVALS	DATE
G.G. PROJ.	21 JUNE 95
E.D. Q/A	21 JUNE 95
P.S. MECH. DES.	21 JUNE 95
P.S. CHK'D. BY	21 JUNE 95
J.T.G. DWN. BY	21 JUNE 95

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

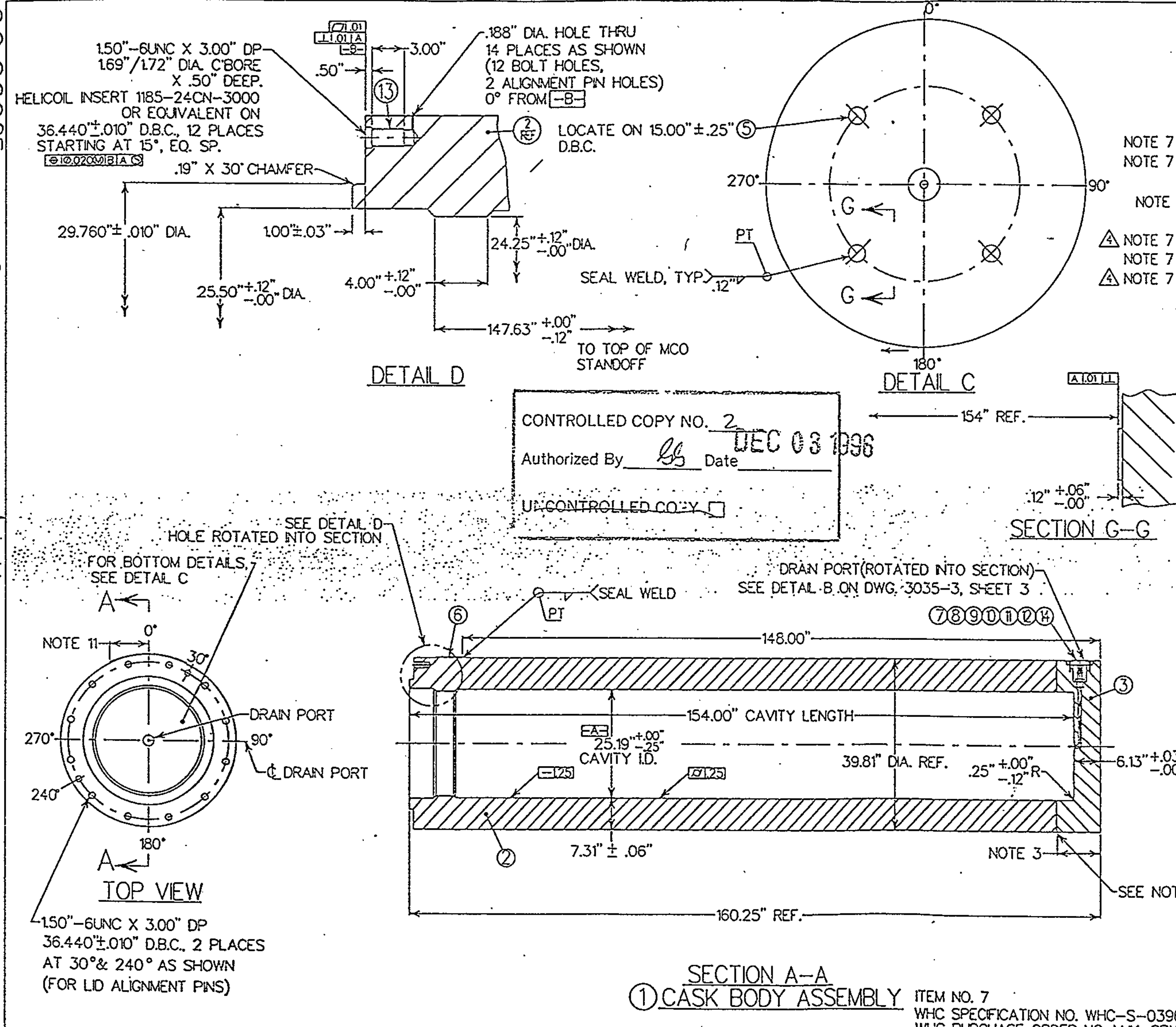
TN–WHC CASK
TRANSPORTATION SYSTEM
ASSEMBLY & PARTS LIST
WHC DWG. NO. H-1-81535

SCALE	SIZE	DWG. NO.	REV.
NONE	B	3035–3	4

SHEET 1 OF 5

STATE OF NEW YORK ★ LICENSED PROFESSIONAL ENGINEER — GLENN VICTOR GUERRA — 056070
[signature] 12/3/96

S.O. 96025



ITEM NO. 7
WHC SPECIFICATION NO. WHC-S-0396
WHC PURCHASE ORDER NO. MJK-SPX-452727

PARTS LIST

	ITEM NO.	NO. REQ'D	NOMENCLATURE	DESCRIPTION	MATERIAL
	1	–	CASK BODY ASSEMBLY	———	———
	2	1	CASK SHELL	SEE FIELD	SA-336 TYPE F304 OR EQUIV.
	3	1	BOTTOM	SEE FIELD	SA-336 TYPE F304 OR EQUIV.
	4		DELETED		
NOTE 7✻	5	4	MCO STANDOFF	.12" THK. X 2.00" DIA.	SST
NOTE 7✻	6	1	NAME PLATE	SEE DWG. 3035-4	SST
	7	1	COVER	SEE DWG. 3035-3 SHEET 3	304 SST
NOTE 9	8	4	SOC HD CAP SCREW	SEE DWG. 3035-3 SHEET 3	SA-193-B8 OR EQUIV.
	9	1	O-RING	PARKER 2-341 B612-70 OR EQUIVALENT	BUTYL
⚠4 NOTE 7✻	10	1	QDISC COUPLING	HANSEN LL6-KP-12 OR EQUIV.	303 SST
NOTE 7✻	11	1	COUPLING ADAPTER	SEE DWG. 3035-3 SHEET 3	304 SST
⚠4 NOTE 7✻	12	2	O-RING	PARKER 3-912 B612-70 OR EQUIVALENT	BUTYL
	13	12	THREADED INSERT	HELICOIL 1185-24CN-3000 OR EQUIVALENT	SST
	14	4	THREADED INSERT	HELICOIL 1185-6CN-0500 OR EQUIVALENT	SST

NOTES:

1. FOR CASK ASSEMBLY SEE DWG. 3035-3, SHEET 1.
2. TOLERANCE, UNLESS OTHERWISE SPECIFIED:+/-.12" ANGLES: +/-1°
3. NUMBER & LOCATION OF FULL PENETRATION WELDS TO BE SPECIFIED BY FABRICATOR, RT & PT REQUIRED.
4. REMOVE ALL BURRS & WELD SPLATTER AND BREAK ALL SHARP EDGES.
5. SURFACE FINISH, UNLESS OTHERWISE SPECIFIED: 125√
6. DELETED
7. ✻ INDICATES NON SAFETY RELATED ITEM.
8. THIS PARTS LIST IS FOR SHEETS 2 AND 3 ONLY.
9. BOLTS TO BE CHROMIUM PLATED (THREADS ONLY), PER QQ-C-320-B, CLASS 2, TYPE 1 (.0002" MIN. THK.)
10. LUBRICATE BOLTS WITH NEOLUBE AS NEEDED.

⚠4 11. NAMEPLATE TO BE CENTERED ABOUT 0°AXIS.

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	O/A	PROJ.
4	11/21/96	SEE DCN 3035-15	JTD	PS	PS	ED	GG
3	1/29/96	SEE DCN 3035-12	J.T.G.	P.S.	P.S.	E.D.	G.G.
2	9/25/95	SEE DCN 3035-7	J.T.G.	P.S.	P.S.	E.D.	G.G.
1	8/16/95	SEE DCN 3035-2	J.T.G.	P.S.	P.S.	E.D.	G.G.

APPROVALS	DATE
PROJ. G.G.	24 JUNE 95
O/A E.D.	24 JUNE 95
MECH. DES. P.S.	21 JUNE 95
CHK'D. BY P.S.	21 JUNE 95
DWN. BY J.T.G.	21 JUNE 95

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

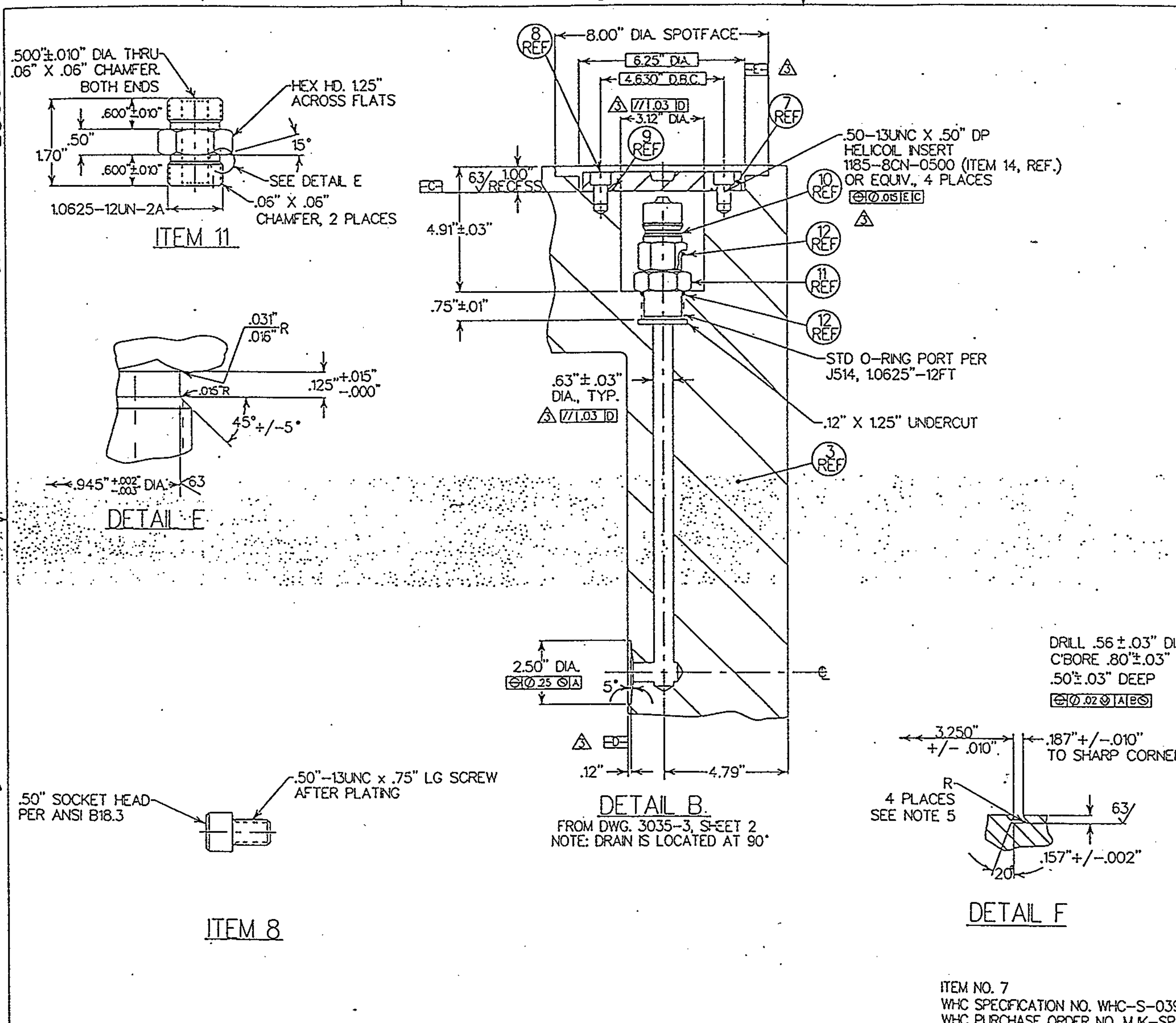
TN-WHC CASK
TRANSPORTATION SYSTEM
CASK BODY & PARTS LIST
WHC DWG. NO. H-1-81535

SCALE: NONE | SIZE: B | DWG. NO. 3035-3 | REV. 4

SHEET 2 OF 5

S.O. 96025

STATE OF NEW YORK ✻ LICENSED PROFESSIONAL ENGINEER — GLENN VICTOR GUERRA 056070
Glenn Guerra 12/3/96



NOTES:

1. FOR CASK ASSEMBLY SEE DWG. 3035-3, SHEET 1
2. TOLERANCE, UNLESS OTHERWISE SPECIFIED: +/-.12"
3. REMOVE ALL BURRS & WELD SPLATTER AND BREAK ALL SHARP EDGES.
4. SURFACE FINISH, UNLESS OTHERWISE SPECIFIED: 125
5. RADIUS TO BE SPECIFIED BY FABRICATOR.

ITEM NO. 7
WHC SPECIFICATION NO. WHC-S-0396
WHC PURCHASE ORDER NO. MJK-SPX-452727

NO.	DATE	REVISIONS	DWN.	CHKD	M.D.	Q/A	PROJ.
3	11/13/96	SEE DCN 3035-16	[illegible]	P.S.	P.S.	E.D.	G.G.
2	9/30/96	SEE DCN 3035-8	J.T.G.	P.S.	P.S.	E.D.	G.G.
1	8/6/96	SEE DCN 3035-3	J.T.G.	P.S.	P.S.	E.D.	G.G.

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-WHC CASK
TRANSPORTATION SYSTEM
CASK BODY DETAILS
WHC DWG. H-1-81535

APPROVALS	DATE
G.G. PROJ.	24 JUNE 96
E.D. Q/A	24 JUNE 96
P.S. MECH. DES.	21 JUNE 96
P.S. CHK'D. BY	21 JUNE 96
J.T.G. DWN. BY	21 JUNE 96

SCALE: NONE | SIZE: B | DWG. NO.: 3035-3 | REV.: 3

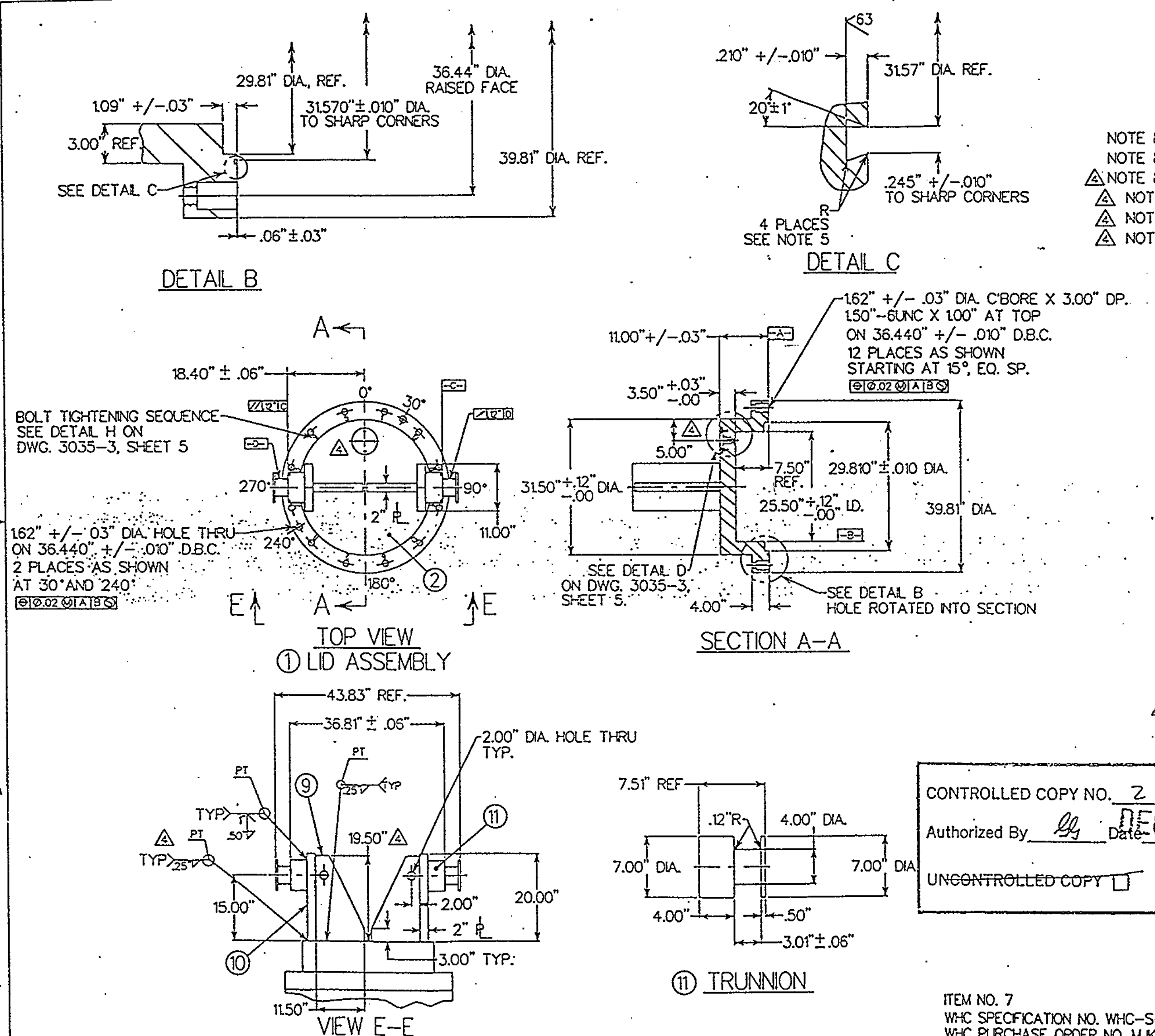
SHEET 3 OF 5

S.O. 96025

CONTROLLED COPY NO. 2
Authorized By [signature] Date DEC 03 1[illegible]
~~UNCONTROLLED COPY~~ ☐

STATE OF NEW YORK * LICENSED PROFESSIONAL ENGINEER
GLENN VICTOR GUENIA
066070

Glenn Guenia
12/3/96



PARTS LIST

ITEM NO.	NO. REQ'D.	NOMENCLATURE	DESCRIPTION	MATERIAL
1	–	LID ASSEMBLY	———	———
2	1	LID	SEE FIELD	SA-336 TP F304 OR EQUIV NOTE 7
3		DELETED		
4	1	PORT COVER	SEE DWG. 3035-3, SHEET 5	304 SST
NOTE 8 * 5	1	QDISC. COUPLING	HANSEN 1-HK-LL1-K-4	303 SST
NOTE 8 * 6	1	COUPLING ADAPTER	SEE DWG. 3035-3, SHEET 5	304 SST
△ NOTE 8 * 7	2	O-RING (ADAPTER)	PARKER 3-904	BUTYL / E692 70 OR EQUIV.
△ NOTE 10 8	4	SOC HD CAP SCREW	SEE DWG. 3035-3, SHEET 5	SA-193-B8 OR EQUIV.
△ NOTE 11 9	2	GUSSET	SEE FIELD	304 SST
△ NOTE 11 10	2	LIFTING BRACKET	SEE FIELD	304 SST
11	2	TRUNNION	SEE FIELD	304 SST
△ 12	4	HELICOIL THREADED INSERT	# 1185-8CN-0500	SST
△ 13	1	PORT COVER O-RING	PARKER 2-341	BUTYL / E692 70 OR EQUIV.

NOTES:

1. FOR CASK ASSEMBLY SEE DWG. 3035-3, SHEET 1
2. TOLERANCE, UNLESS OTHERWISE SPECIFIED:
   2 PLACE DECIMALS: +/- .12"
   3 PLACE DECIMALS: +/- .010"
   ANGLES: +/- 1°
3. REMOVE ALL BURRS & WELD SPLATTER AND BREAK ALL SHARP EDGES.
4. SURFACE FINISH, UNLESS OTHERWISE SPECIFIED: 125/
5. RADIUS TO BE SPECIFIED BY FABRICATOR.
6. DELETED
7. FABRICATOR HAS OPTION TO USE SA-240, TYPE 304 PLATE, WELDED TOGETHER, RT & PT REQUIRED.
8. * INDICATES NON SAFETY RELATED ITEM.
9. THIS PARTS LIST IS FOR SHEETS 4 AND 5 ONLY.
10. BOLTS TO BE CHROMIUM PLATED (THREADS ONLY) PER QQ-C-320-B, CLASS 2, TYPE 1 (.0002" MIN. THK.).
11. △ TOLERANCE THICKNESS PER PLATE MANUFACTURER SPECIFICATION, DURING FABRICATION, LOCALIZED SURFACE IRREGULARITIES, ETC. PER TOLERANCE FROM NOTE 2.

CONTROLLED COPY NO. 2
Authorized By [signature] Date DEC 03 1996
UNCONTROLLED COPY ☐

ITEM NO. 7
WHC SPECIFICATION NO. WHC-S-0396
WHC PURCHASE ORDER NO. MJK-SPX-452727

NO.	DATE	REVISIONS	DWN.	CH'KD	M.D.	Q/A	PROJ.
4	11/1/96	SEE DCN 3035-17	JTC	PS	PS	ED	GG
3	9/9/96	SEE DCN 3035-14	J.T.C.	P.S.	P.S.	E.D.	G.G.
2	8/29/96	SEE DCN 3035-9	J.T.C.	P.S.	P.S.	E.D.	G.G.
1	8/6/96	SEE DCN 3035-4	J.T.C.	P.S.	P.S.	E.D.	G.G.

APPROVALS		DATE
PROJ.	G.G.	24 JUNE 96
Q/A	E.D.	24 JUNE 96
MECH. DES.	P.S.	21 JUNE 96
CHK'D. BY	P.S.	21 JUNE 96
DWN. BY.	J.T.C.	21 JUNE 96

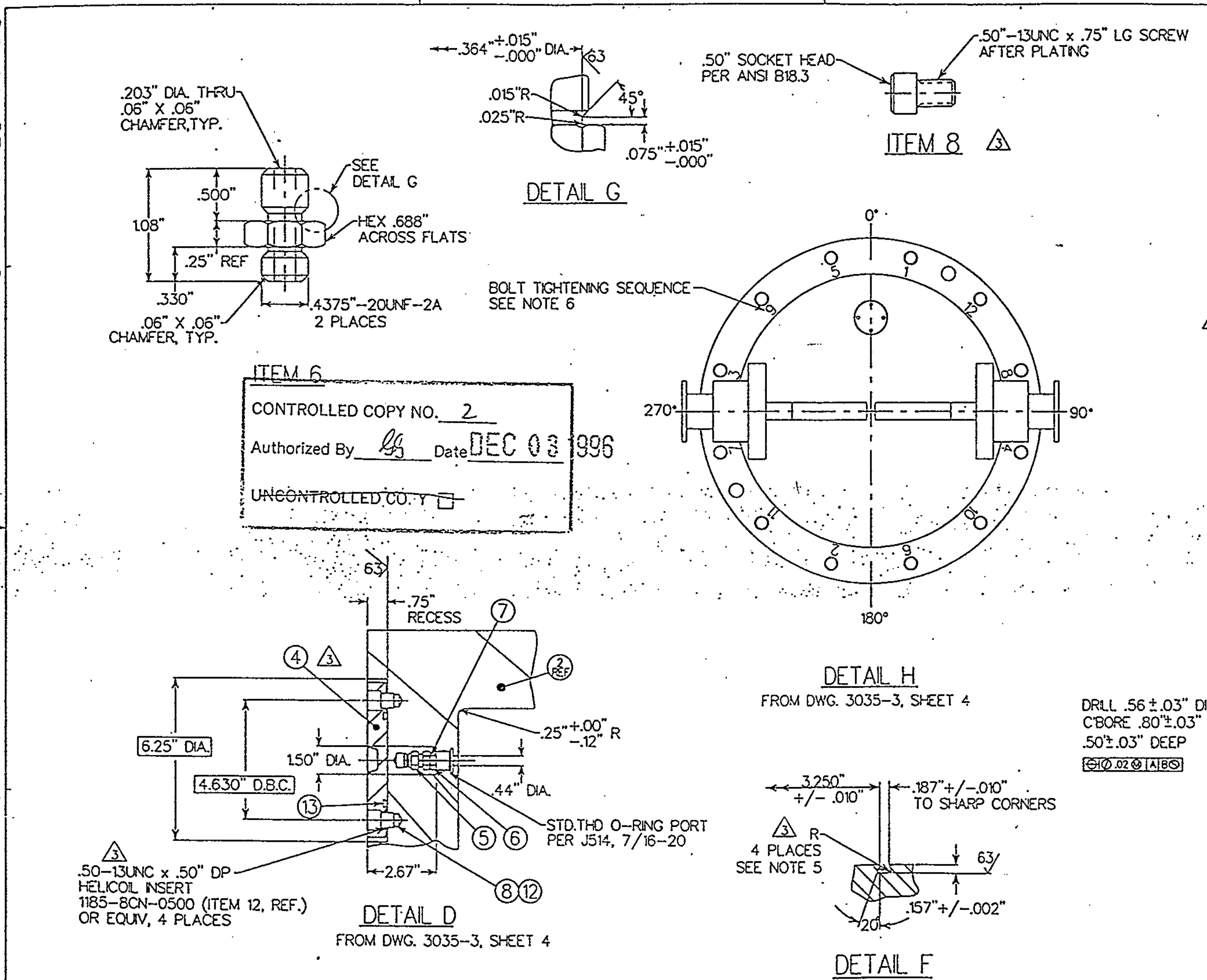
TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-WHC CASK
TRANSPORTATION SYSTEM
LID
WHC DWG. NO. H-1-81535

NONE SCALE | B SIZE | 3035-3 DWG. NO. | 4 REV
SHEET 4 OF 5

S.O. 96025

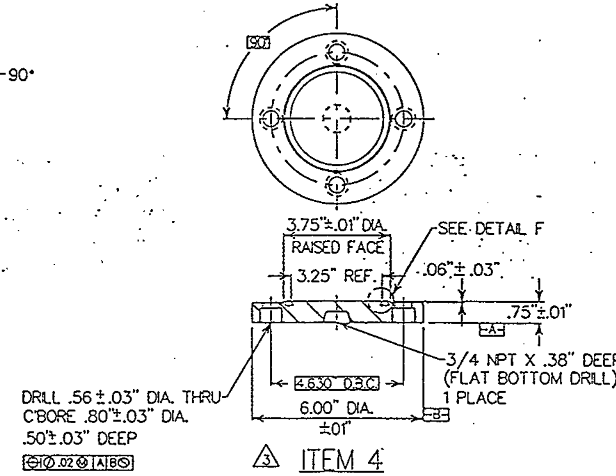
STATE OF NEW YORK ★ LICENSED PROFESSIONAL ENGINEER GLENN VICTOR GUENZ... 066070
[signature] 12/3/96



ITEM NO. 7
WHC SPECIFICATION NO. WHC-S-0396
WHC PURCHASE ORDER NO. MJK-SPX-452727

NOTES:

1. FOR CASK ASSEMBLY SEE DWG. 3035-3, SHEET 1
2. TOLERANCE, UNLESS OTHERWISE SPECIFIED:
   2 PLACE DECIMALS: +/- .12"
   3 PLACE DECIMALS: +/- .010"
   ANGLES: +/- .5°
3. REMOVE ALL BURRS & WELD SPLATTER AND BREAK ALL SHARP EDGES.
4. SURFACE FINISH, UNLESS OTHERWISE SPECIFIED: 125/
5. RADIUS TO BE SPECIFIED BY FABRICATOR.
6. TEXT SIZE .50" HIGH, METHOD TO BE PERMANENT IDENTIFICATION MARKING.
7. LUBRICATE BOLTS WITH NEOLUBE AS NEEDED.



NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	Q/A	PROJ.
3	11/3/96	SEE DCN 3035-18		PS	PS		
2	9/3/96	SEE DCN 3035-10	J.T.G.	P.S.	P.S.	E.D.	G.G.
1	8/5/96	SEE DCN 3035-5	J.T.G.	P.S.	P.S.	E.D.	G.G.

APPROVALS	DATE
PROJ. G.G.	24 JUNE 96
Q/A E.D.	24 JUNE 96
MECH. DES. P.S.	21 JUNE 96
CHK'D. BY P.S.	21 JUNE 96
DWN. BY J.T.G.	21 JUNE 96

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

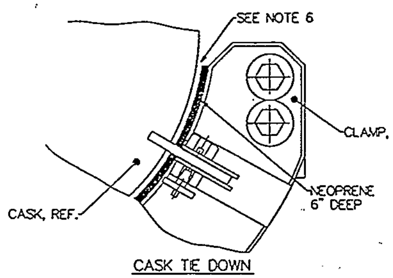
TN-WHC CASK TRANSPORTATION SYSTEM
LID
WHC DWG. NO. H-1-81535

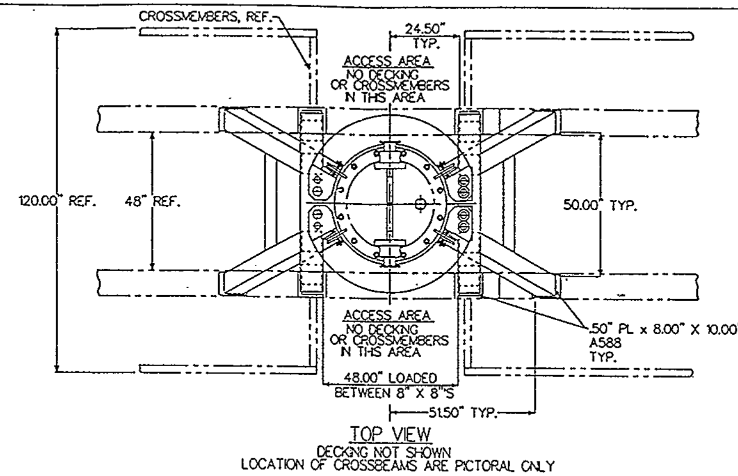
SCALE	SIZE	DWG. NO.	REV
NONE	B	3035-3	3

SHEET 5 OF 5

S.O. 96025

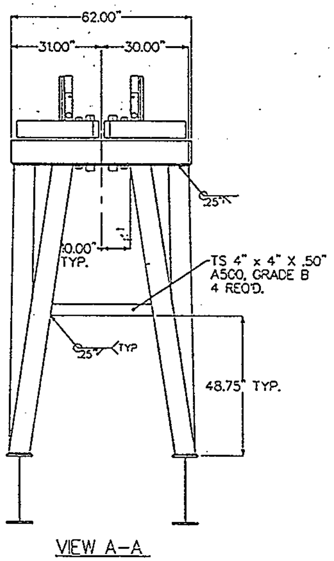
STATE OF NEW YORK ★ GLENN VICTOR GUERRA 056070 LICENSED PROFESSIONAL ENGINEER
12/3/96

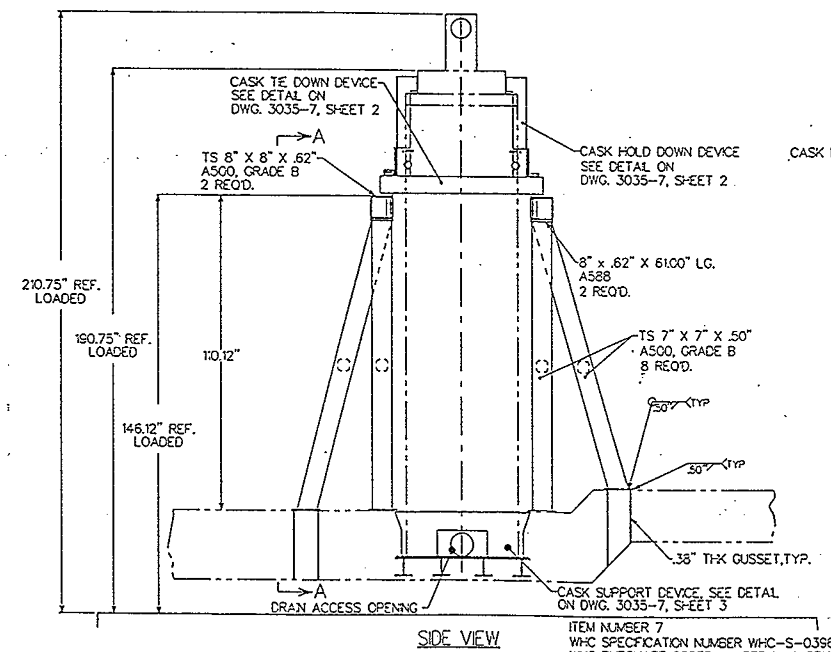




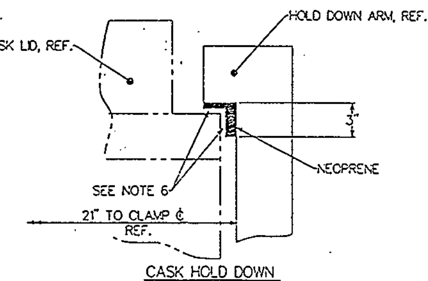
NOTES:

1. FOR DETAILS SEE DWG. 3035-7, SHEETS 2 & 3.
2. TOLERANCE, UNLESS OTHERWISE SPECIFIED: +/- .12"
3. STEEL COMPONENTS SHALL BE PAINTED WITH AMERON AMERLOCK 400 PRIMER, AMERON AMERCOAT 450HS FINISH COAT, RT-8304 WHITE.
4. REMOVE ALL BURRS, BREAK ALL SHARP EDGES AND REMOVE WELD SPLATTER FROM AREAS WHICH CASK WILL CONTACT AND INTERFERE WITH OPERATING OF THE TIEDOWN SYSTEM.
5. SURFACE FINISH, UNLESS OTHERWISE SPECIFIED: 250/
6. TRAILER MANUFACTURER TO INSTALL NEOPRENE AS REQUIRED TO MAINTAIN A MAXIMUM .12" GAP, AT FINAL FIT UP WITH CASK AS SHOWN. ADHESIVE PER MANUFACTURE RECOMENDATION.
7. NON-SAFETY RELATED.
8. LUBRICATE BOLTS WITH NEOLUBE AS REQUIRED.
9. TORQUE CLAMP BOLTS TO 200 FT. LBS.
10. ALL MATERIAL PROPERTIES (INCLUDING NEOPRENE) USED FOR DESIGN OF THE TIEDOWN SYSTEM SHOULD BE TAKEN AT 150°F.





ITEM NUMBER 7
WHC SPECIFICATION NUMBER WHC-S-0396
WHC PURCHASE ORDER NUMBER MJX-SPX-452727



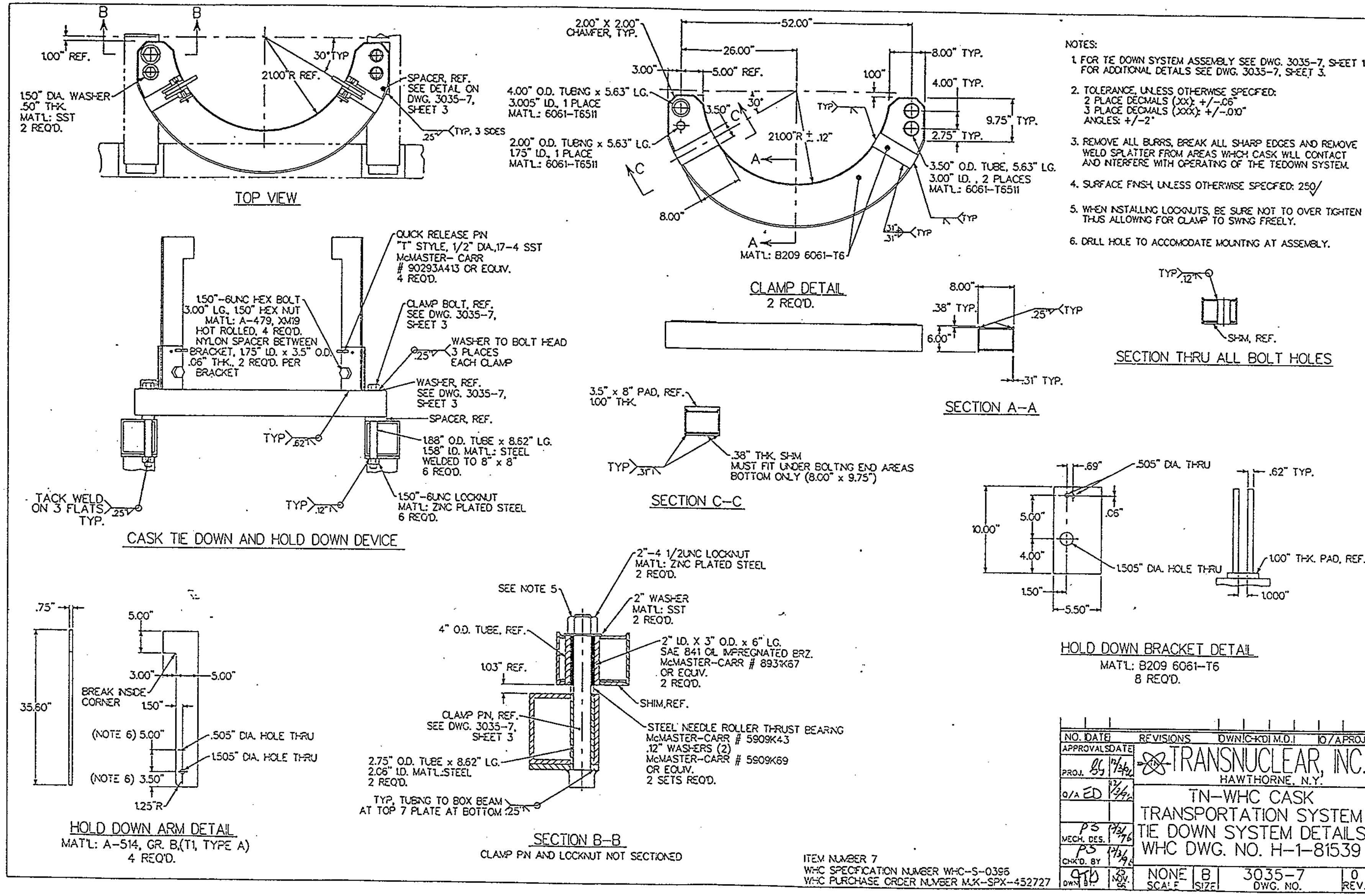
NO.	DATE	REVISIONS	DWN	CHKD	M.D.	I.O.	APROJ.

APPROVALS	DATE	
PROJ. GG	12/3/96	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
Q/A ED	12/3/96	TN-WHC CASK TRANSPORTATION SYSTEM TIE DOWN SYSTEM WHC DWG. NO. H-1-81539
MECH. DES. PS	12/3/96	
CHK'D. BY PS	12/3/96	
DWN. BY STD	NOV. 96	SCALE: NONE; SIZE: B; DWG. NO.: 3035-7; REV.: 0

SHEET 1 OF 3

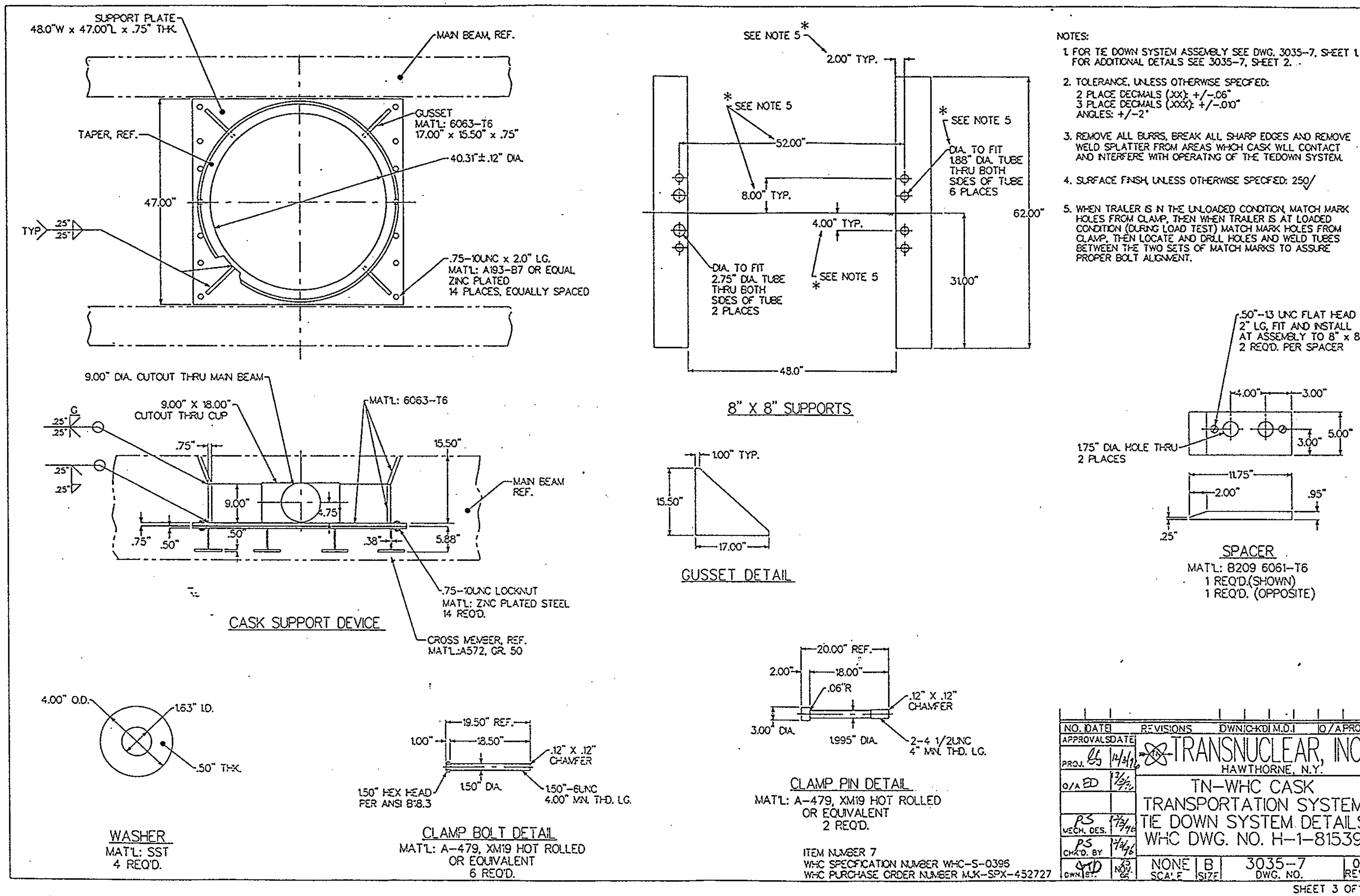
STATE OF NEW YORK ★ LICENSED PROFESSIONAL ENGINEER ★ GLENN VICTOR GUERRA 066070

Glenn Guerra
12/3/96



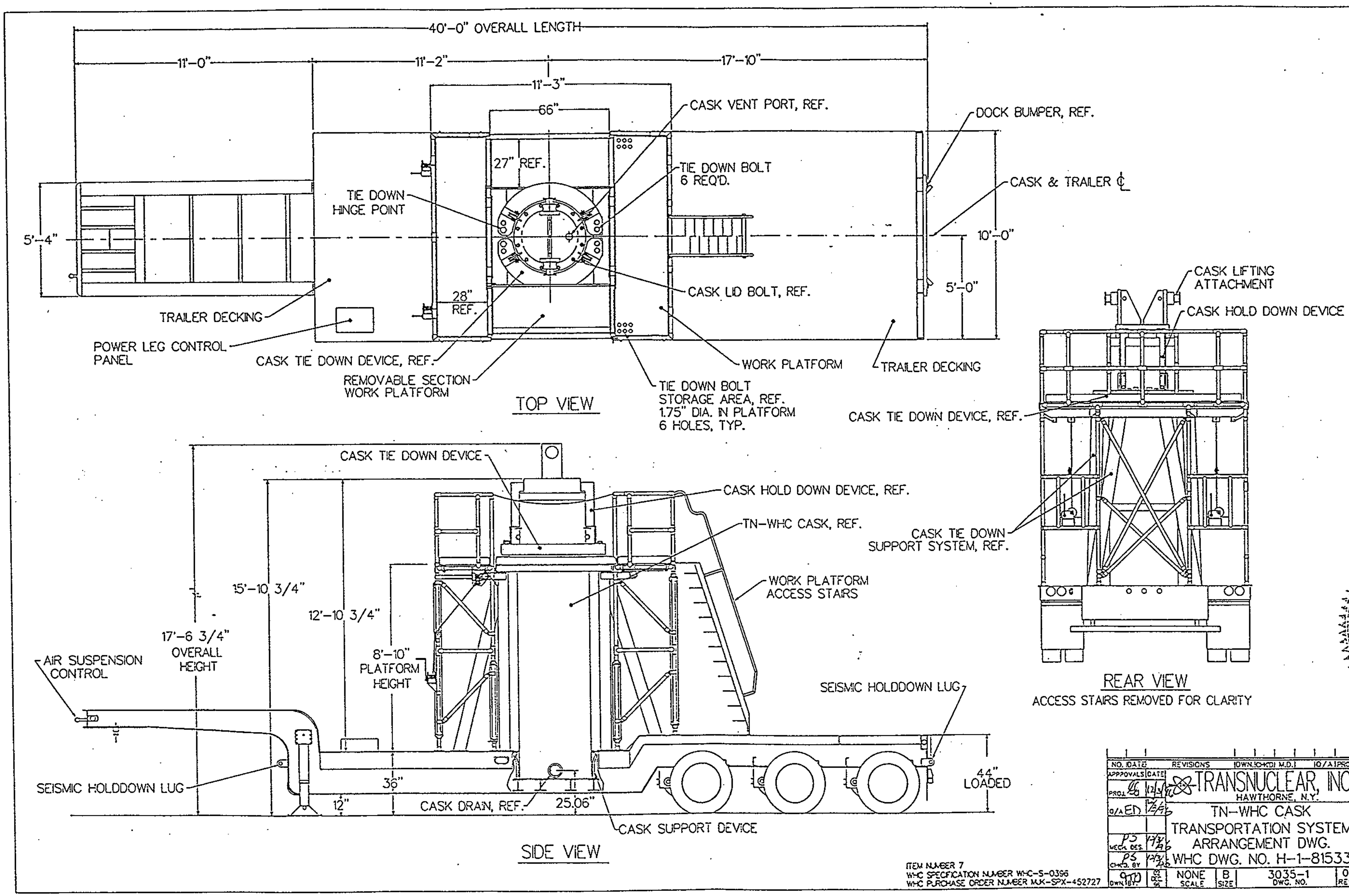
STATE OF NEW YORK LICENSED PROFESSIONAL ENGINEER GLENN VICTOR GUERRA 056070

Glenn Guerra 12/3/96



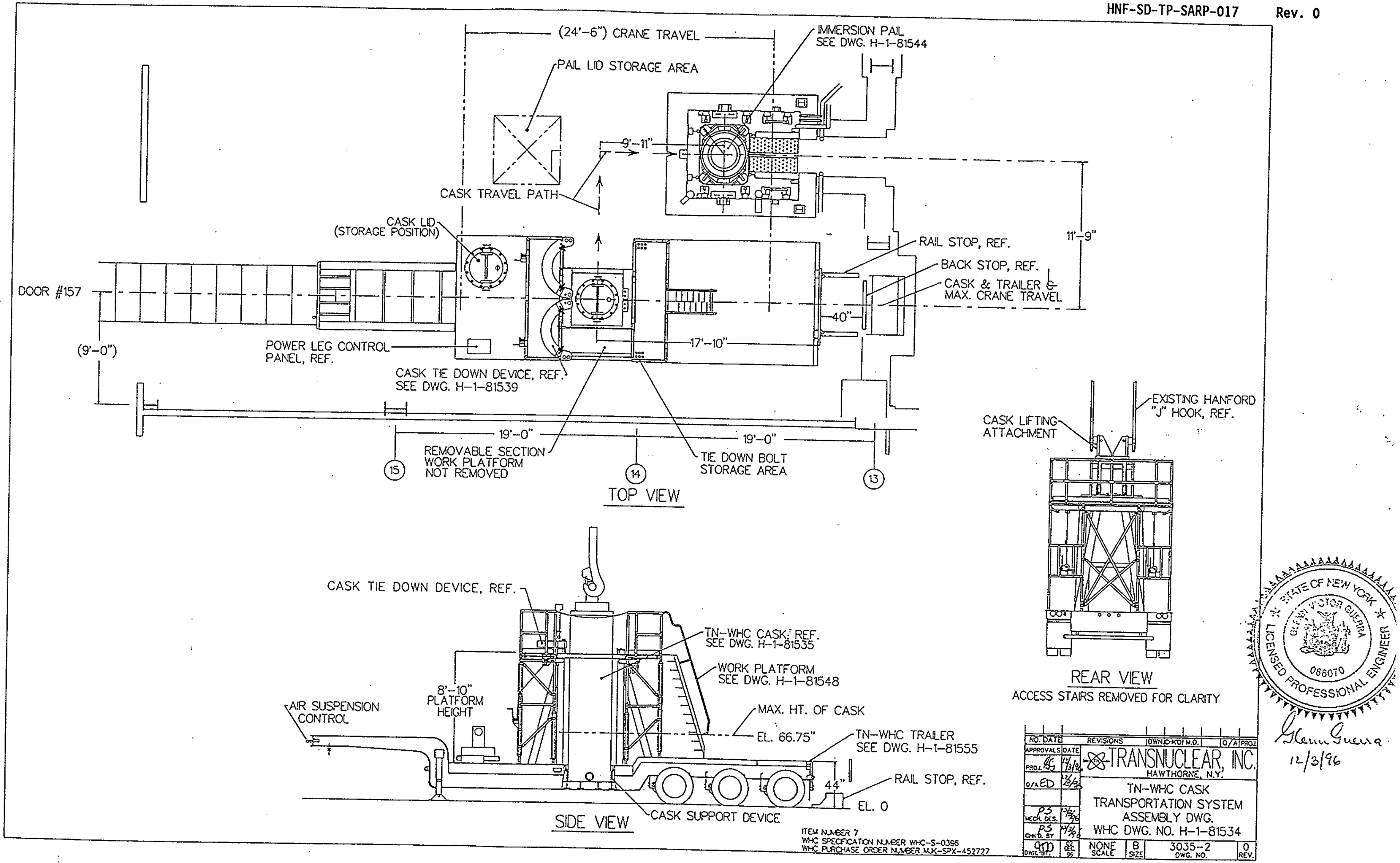
STATE OF NEW YORK — GLENN VICTOR GUERRA — 066070 — LICENSED PROFESSIONAL ENGINEER

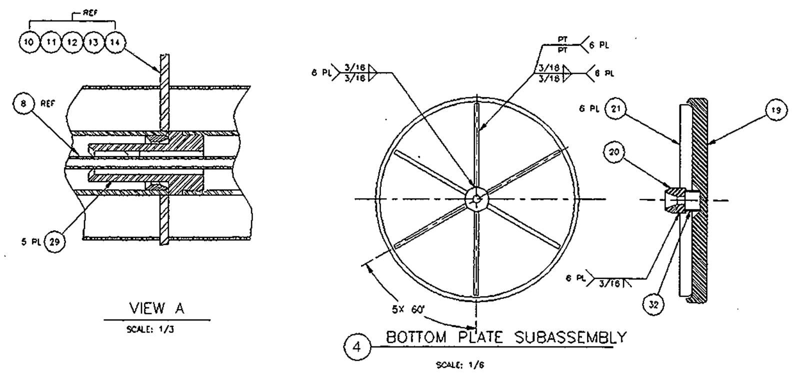
Glenn Guerra 12/3/96



LICENSED PROFESSIONAL ENGINEER, STATE OF NEW YORK, CLENT VICTOR GUERRA, 066070

Glenn Guerra
12/3/96


(24'-6") CRANE TRAVEL
IMMERSION PAIL
SEE DWG. H-1-81544
PAIL LID STORAGE AREA
9'-11"
CASK TRAVEL PATH
CASK LID
(STORAGE POSITION)
RAIL STOP, REF.
11'-9"
BACK STOP, REF.
CASK & TRAILER ℄
MAX. CRANE TRAVEL
DOOR #157
40"
17'-10"
(9'-0")
POWER LEG CONTROL
PANEL, REF.
CASK TIE DOWN DEVICE, REF.
SEE DWG. H-1-81539
19'-0"
19'-0"
REMOVABLE SECTION
WORK PLATFORM
NOT REMOVED
TIE DOWN BOLT
STORAGE AREA
15
14
13
TOP VIEW
EXISTING HANFORD
"J" HOOK, REF.
CASK LIFTING
ATTACHMENT
REAR VIEW
ACCESS STAIRS REMOVED FOR CLARITY
CASK TIE DOWN DEVICE, REF.
TN-WHC CASK, REF.
SEE DWG. H-1-81535
WORK PLATFORM
SEE DWG. H-1-81548
8'-10"
PLATFORM
HEIGHT
AIR SUSPENSION
CONTROL
MAX. HT. OF CASK
EL. 66.75"
TN-WHC TRAILER
SEE DWG. H-1-81555
44"
RAIL STOP, REF.
EL. 0
SIDE VIEW
CASK SUPPORT DEVICE
ITEM NUMBER 7
WHC SPECIFICATION NUMBER WHC-S-0396
WHC PURCHASE ORDER NUMBER MJK-SPX-452727
TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.
TN-WHC CASK
TRANSPORTATION SYSTEM
ASSEMBLY DWG.
WHC DWG. NO. H-1-81534
NONE SCALE
B SIZE
3035-2 DWG. NO.
0 REV.
STATE OF NEW YORK
GLENN VICTOR GUERRA
066070
LICENSED PROFESSIONAL ENGINEER
12/3/96



GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

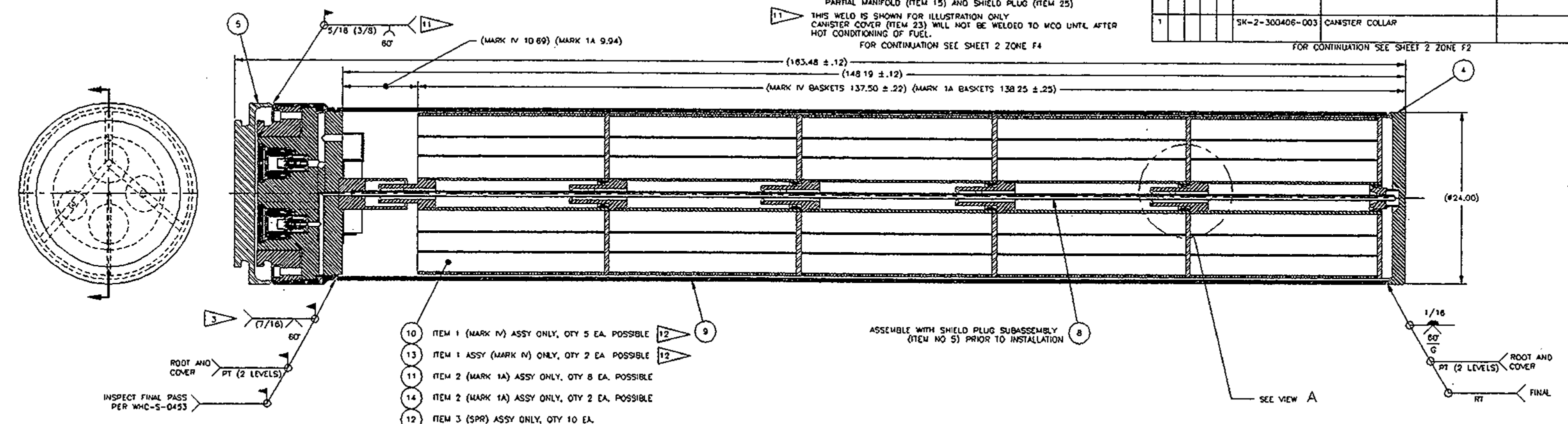
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. DIMENSIONS ARE IN INCHES. TOLERANCES: ANGULAR ±1°
2. SHIELD PLUG SUBASSEMBLY (ITEM 5) AND DIP TUBE (ITEM 8) ARE FIELD INSTALLED.
3. AVOID EXCESS FILLER METAL DEPOSITION TO LIMIT DISTORTION OF THE SHELL. THE CROWN OF THE WELD SHALL BE MINIMIZED TO NOT INTERFERE WITH THE TRANSFER CASK. GRINDING IS TO BE AVOIDED WHEN POSSIBLE AND MINIMIZED WHERE REQUIRED
4. WELDING AND NDE SHALL BE IN ACCORDANCE WITH ASME B & PV CODE, 1995 EDITION, SECTION III, DIVISION 1, SUBSECTION NB FOR CLASS 1 COMPONENTS. SPECIFICATION: WHC-S-0453
5. MARK IV ASSY -010 (ITEM 1) CAN HAVE A TOTAL OF 5 MARK IV BASKET ASSEMBLIES (ITEM 10) OR 3 ITEM 10 BASKET ASSEMBLIES WITH UP TO 2 ITEM 13 MARK IV SCRAP BASKET ASSEMBLIES. WHEN THE SCRAP BASKET ASSEMBLIES ARE USED, THEY SHALL BE PLACED AT THE TOP AND/OR BOTTOM OF THE WELDED CLOSURE ASSEMBLY.
6. MARK 1A ASSY -020 (ITEM 2), CAN HAVE A TOTAL OF 6 MARK IA BASKET ASSEMBLIES (ITEM 11) OR 4 ITEM 11 BASKET ASSEMBLIES WITH UP TO 2 ITEM 14 MARK IA SCRAP BASKET ASSEMBLIES. WHEN THE SCRAP BASKET ASSEMBLIES ARE USED, THEY SHALL BE PLACED AT THE TOP AND/OR BOTTOM OF THE WELDED CLOSURE ASSEMBLY.
7. THERMAFOIL® SELF ADHESIVE TAPE, GTF NUCLEAR GRADE, .005 TK., MANUFACTURED BY EGC ENTERPRISES INCORP., SHALL BE USED FOR INSTALLATION OF ALL THREADED FITTINGS (ITEMS 36 & 37).
8. SEAL RETAINING SCREWS SUPPLIED WITH SEAL (ITEM #40).
9. WELD & INSPECT PER SECTION III, DIV. 1, OF THE ASME BOILER AND PRESSURE VESSEL CODE. FABRICATOR MAY USE DOWEL OR THREADED PLUG TO FACILITATE WELD. MATERIAL SHALL BE WELDABLE STAINLESS STEEL, WHICH IS COMPATIBLE WITH THE BASE MATERIAL, ASME SA-182, TYPE 304L.
10. WELDS MUST BE COMPLETED IN THE FOLLOWING ORDER.
    1) BASKET STABILIZER (ITEM 26) WELDED TO SHIELD PLUG (ITEM 25)
    2) PARTIAL MANIFOLD (ITEM 15) WELDED TO SHIELD PLUG (ITEM 25)
    3) ANGLE (ITEM 27) AND END PLATES (ITEM 28) WELDED TO PARTIAL MANIFOLD (ITEM 15) AND SHIELD PLUG (ITEM 25)
11. THIS WELD IS SHOWN FOR ILLUSTRATION ONLY CANISTER COVER (ITEM 23) WILL NOT BE WELDED TO MCO UNTIL AFTER HOT CONDITIONING OF FUEL.

FOR CONTINUATION SEE SHEET 2 ZONE F4

PARTS/MATERIAL LIST

QTY -050	QTY -040	QTY -030	QTY -020	QTY -010	PART/DASH NUMBER	NOMENCLATURE / DESCRIPTION	MATERIAL / REFERENCE	SHEET	ITEM NO.
				X	-010	ASSEMBLY, MECHANICAL CLOSURE (MARK IV FUEL)		1	1
			X		-020	ASSEMBLY, MECHANICAL CLOSURE (MARK 1A FUEL)		1	2
		X			-030	ASSEMBLY, MECHANICAL CLOSURE (SPR FUEL)		1	3
	X	1	1	1	-040	SUBASSEMBLY, BOTTOM PLATE		1	4
X		1	1	1	-050	SUBASSEMBLY, SHIELD PLUG		2	5
									6
									7
		1	1	1	SK-2-300462-001	DIP TUBE			8
		1	1	1	SK-2-300398-001	SHELL			9
				AR	SK-2-300375-010	MARK IV SNF RERACK BASKET ASSEMBLY			10
			AR		SK-1-80208-010	MARK 1A SNF STORAGE BASKET ASSY			11
		10			SK-2-300376-010	SPR SNF RERACK BASKET ASSEMBLY			12
				AR	SK-1-80209-010	SCRAP MARK IV SNF BASKET ASSEMBLY			13
			AR		SK-1-80210-010	SCRAP MARK IA SNF BASKET ASSEMBLY			14
1					SK-2-300402-010	INTERNAL FILTER, PARTIAL MANIFOLD			15
2					SK-2-300407-010	ASSEMBLY, 5 1/2" CAP			16
1					SK-2-300407-020	ASSEMBLY, 4" CAP			17
1					SK-2-300407-030	ASSEMBLY, 5" CAP			18
	1				SK-2-300378-001	SHELL BOTTOM MACHINED FORGING			19
	1				SK-2-300383-001	DIP TUBE GUIDE CONE			20
	6				SK-2-300381-001	BASKET SUPPORT PLATE			21
1					SK-2-300406-001	LOCKING & LIFTING RING			22
1					SK-2-300406-002	CANISTER COVER			23
1					SK-2-300406-003	CANISTER COLLAR			24

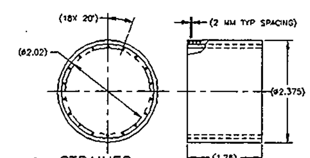
FOR CONTINUATION SEE SHEET 2 ZONE F2



1 MECHANICAL CLOSURE ASSEMBLY
SCALE: 1/6
MARK IV BASKETS SHOWN 5

2 MECHANICAL CLOSURE ASSEMBLY
MARK 1A BASKETS SIMILAR 6

3 MECHANICAL CLOSURE ASSEMBLY
SPR BASKETS SIMILAR



32 STRAINER
SCALE: 1/1
NOTE: THIS PART IS A VENDOR SUPPLIED ITEM AND IS SHOWN FOR REFERENCE INFORMATION ONLY.

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

REF NUMBER	SK-2-300408
TITLE	MULTI CANISTER OVERPACK ASSEMBLY & PARTS LIST
NEXT USED ON	END ITEM
CADFILE	X300461A
CADCODE	WIN95 AC02 12 0.5S
	BA MESSINGER 9/18/96
	LJ ROBINSON 9/18/96
	BL NIELSEN 9/18/96
	SR CROW
	LH GOLDMANN
	KE SMITH
	ES RUFF
	PARSONS ENG. INC.
	U.S. DEPARTMENT OF ENERGY, DOE Field Office, Richland
TITLE	MCO PROTOTYPE MECHANICAL CLOSURE ASSEMBLY
SIZE	F
DWG NO	SK-2-300461
REV	0
SCALE	1/6
	613656
SHEET	1 of 3

SK-2-300461

54-6000-027(3/89)

(CONTINUED FROM SHEET 1 ZONE D4)

12. AFTER PROTOTYPE FABRICATION OF THIS MCO, MARK IV FUEL BASKET DESIGN WAS CHANGED. REFER TO DRAWING SK-2-80211. NEW BASKET DESIGN DELETES CENTERING SPACER (SK-2-300382), AND GRAPPLE (SK-2-300377) HAS BEEN REDESIGNED PER DRAWING SK-1-80215.

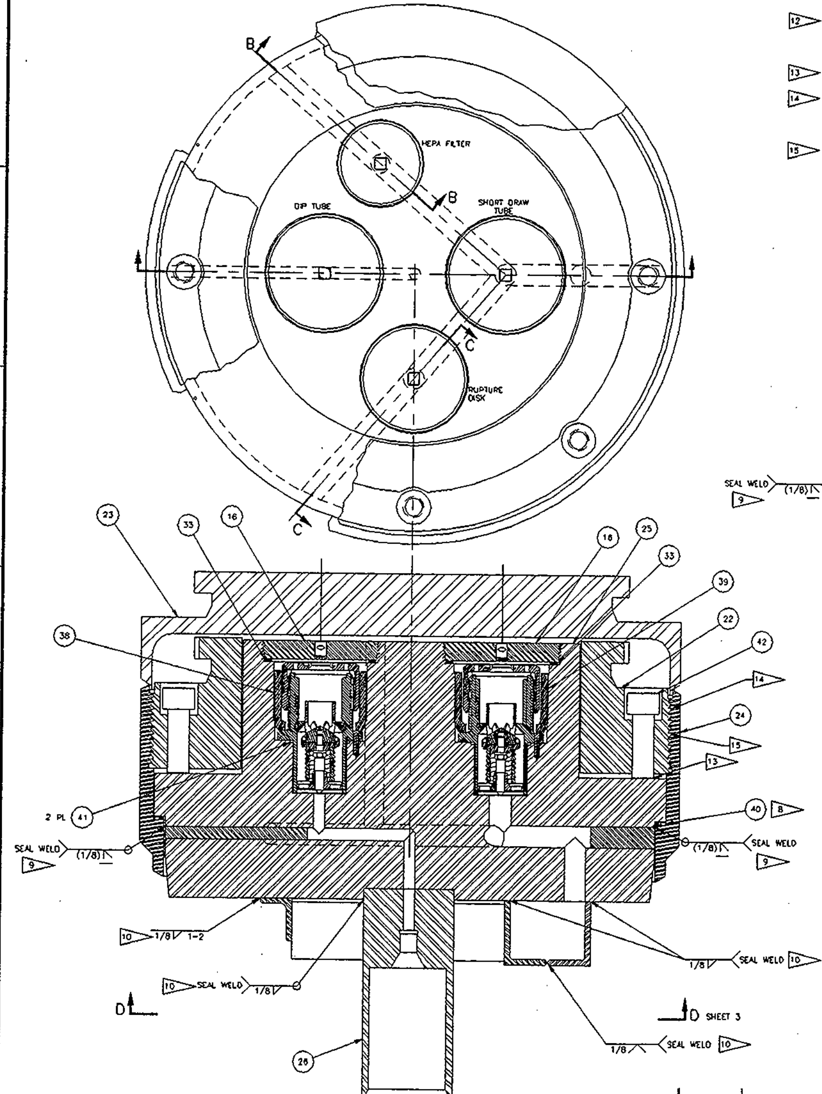
13. SMOOTH ENDS OR THE CAP SCREW (i.e. ELIMINATE CUP AND SHARP EDGES) TO AVOID GOUGING THE LOCKING RING WHEN ASSEMBLING.

14. TAKE SPECIAL CARE TO ENSURE THAT THREADS ON LOCKING RING AND COLLAR ARE SCRUPULOUSLY CLEAN AND FREE OF BURRS. COAT BOTH THREADS WITH NEOLUBE (GRAPHITE/ALCOHOL) BEFORE ASSEMBLY. WHEN THREADING LOCKING RING INTO COLLAR, USE A LOAD CELL ON HOISTING DEVICE. THIS WILL ASSIST IN KEEPING WEIGHT OFF OF THREADS.

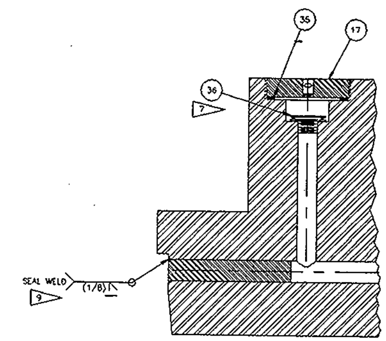
15. LOCKING RING THREADS MUST BE HARDENED TO AVOID GALLING WITH THE COLLAR THREADS.

PARTS/MATERIAL LIST (CONTINUED FROM SHEET 1 ZONE D1)

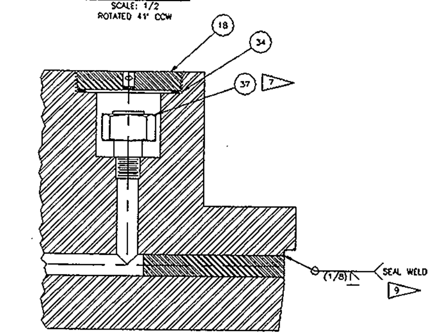
QTY REQ'D -050	-040	-030	-020	-010	PART/DASH NUMBER	NOMENCLATURE / DESCRIPTION	MATERIAL / REFERENCE	SHEET	ITEM NO.
1					SK-2-300404-001	SHIELD PLUG			25
1					SK-2-300403-001	BASKET STABILIZER EXTENSION			26
1					SK-2-300399-001	ANGLE 3 x 2 x 1/4	304L SST, ASTM A276		27
2					SK-2-300399-002	END PLATE 1/8 THICK	304L SST, ASTM A240		28
				AR	SK-2-300377	SNF RERACK BASKET GRAPPLE ADAPTER			29
									30
									31
	1					STRAINER, #63 WIRE AND #63 VERTICAL ROD W/2.0 MM SLOTS	JOHNSON SCREENS, INC. 304L SST	1	32
2					GRAFOIL	RING GASKET, 5.25 OD X 4.5 ID X .125 THICK	UCAR CARBON COMPANY INC.		33
1					GRAFOIL	RING GASKET, 4.75 OD X 4.00 ID X .125 THICK	UCAR CARBON COMPANY INC.		34
1					GRAFOIL	RING GASKET, 3.75 OD X 3.00 ID X .125 THICK	UCAR CARBON COMPANY INC.		35
1						LOW FLOW HEPA FILTER, ø .75 MODEL NUCFIL 013 DRUM VENTING FILTER ASSEMBLY	NUCLEAR FILTER TECHNOLOGY, INC. 304L STAINLESS STEEL		36
1					MODEL NO. 0198-042	RUPTURE DISK, ø1.00 SPECIAL WELDED, SCORED, REVERSE ACTING DISK ASSEMBLY	CONTINENTAL DISC CORPORATION ASME SA-182 OR SA-312, TYPE 316L		37
1					1-SH-032-0-XX001 Y05-R1	QUICK DISCONNECT COUPLING, ø32MM.	WALTHER PRAZISION, CARL KURT WALTHER GMBH & CO. KG 304L STAINLESS STEEL		38
1					1-SH-032-0-XX002 Y05-R1	QUICK DISCONNECT COUPLING, ø32MM.	WALTHER PRAZISION, CARL KURT WALTHER GMBH & CO. KG 304L STAINLESS STEEL		39
1					H-304888	SEAL	HELICOFLEX		40
2					614U51-0041-2	C-SEAL, FACE TYPE, INTERNAL PRESSURE, CLASS II QUALITY GRADE. SEAL OD: 2.802" +.000", -.008" SEAL FREE HEIGHT: 1/8"	SILVER-COATED INCONEL EG&G PRESSURE SCIENCES		41
8						SCREW, SOC HD CAP, 1"-8UNC-2A X 3" LG	CSTL ASTM A574		42



5 SUBASSEMBLY, SHIELD PLUG
SCALE: 1/2



SECTION B-B
SCALE: 1/2
ROTATED 41° CCW



SECTION C-C
SCALE: 1/2
ROTATED 131° CCW

FOR GENERAL NOTES AND PARTS LIST SEE SH 1.

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

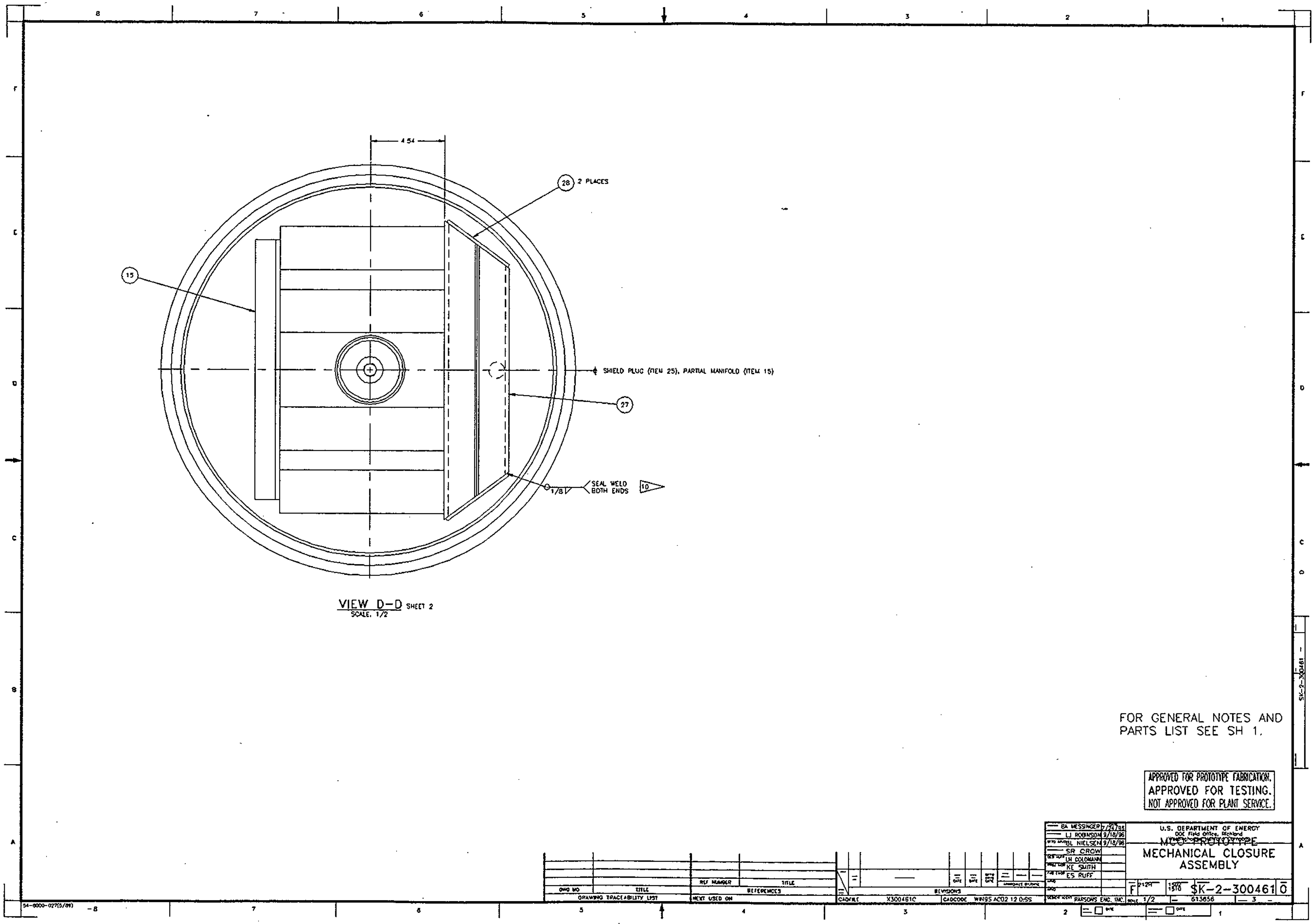
BA MESSINGER 9/18/96
LJ ROBINSON 9/18/96
BL NIELSEN 9/18/96
SR CROW
LH COLDMANN
KE SMITH
ES RUFF
PARSONS ENG. INC.

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland

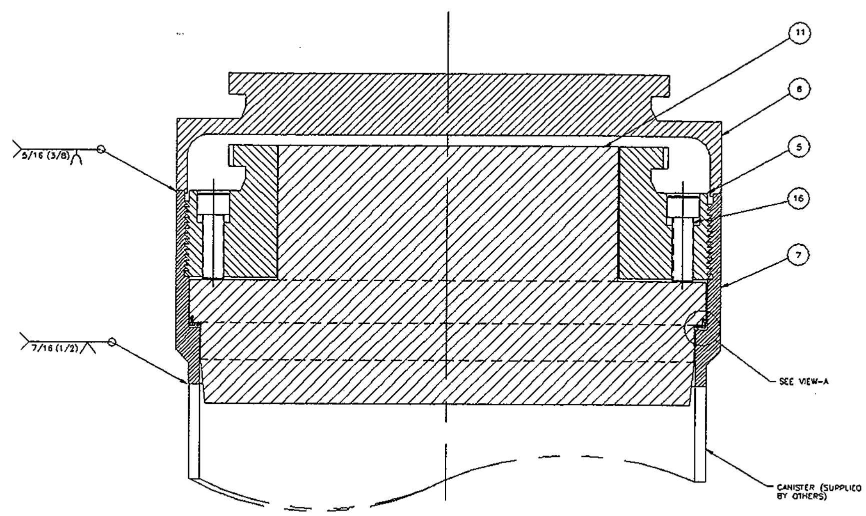
~~MCO PROTOTYPE~~
MECHANICAL CLOSURE ASSEMBLY

F 212A 1506 1516 SK-2-300461 0
SCALE 1/2 613656 2

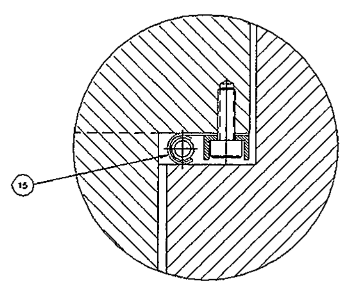
DRAWING TRACEABILITY LIST | NEXT USED ON | REFERENCES | REVISIONS
CADFILE X3004618 CADCODE WIN95 ACO2 12 0:55



4.54
28 2 PLACES
15
SHIELD PLUG (ITEM 25), PARTIAL MANIFOLD (ITEM 15)
27
1/8
SEAL WELD BOTH ENDS
10
VIEW D-D SHEET 2
SCALE: 1/2
FOR GENERAL NOTES AND PARTS LIST SEE SH 1.
APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.
BA MESSINGER
LJ ROBINSON 9/18/96
BL NIELSEN 9/18/96
SR CROW
LH COLDMANN
KE SMITH
ES RUFF
U.S. DEPARTMENT OF ENERGY
MCO PROTOTYPE
MECHANICAL CLOSURE
ASSEMBLY
SK-2-300461 0
PARSONS ENG. INC.
1/2
613656
3
X300461C
WIN95 AC02 12.0-55
DRAWING TRACEABILITY LIST
REFERENCES
REVISIONS
NEXT USED ON



1 ASSEMBLY
SCALE: 1/2



VIEW-A

PARTS/MATERIAL LIST

QTY RQD -020 -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO.
X	-010	ASSEMBLY		1	1
					2
					3
					4
1	-001	LOCKING & LIFTING RING	CSTL 4140	2	5
1	-002	CANISTER COVER	SST SA 182 F304L	3	6
1	-003	CANISTER COLLAR	SST SA 182 F304L	4	7
					8
					9
					10
1	SK-2-300404 -001	SHIELDING PLUG			11
					12
					13
					14
1	H-304868	SEAL	HELICOFLEX		15
8		SCREW, SOC HD CAP, 1"-8UNC-2A x 3" LG	CSTL ASTM A574		16

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-82. DIMENSIONS ARE IN INCHES.
2. TOLERANCES: DECIMAL: .XX= ±.03, .XXX = ±.005 FRACTIONS: ± 1/16 ANGULAR: ± 1°
3. ALL MACHINED SURFACES SHALL BE 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1.
4. BREAK ALL SHARP EDGES & REMOVE ALL BURRS.
5. MACHINED FILLET RADII SHALL BE .03 MAX.
6. SEAL RETAINING SCREWS SUPPLIED WITH SEAL (ITEM #12).

PROTOTYPE

DWG NO	TITLE
DRAWING TRACEABILITY LIST	
REF NUMBER	TITLE
NEXT USED ON	REFERENCES END ITEM

CADFILE X300406A — REVISIONS — CADCODE DOS 6.00:ACD2.12:SS

D. WEBB 5-96
R. ATWOOD 5-96
L. WATSON 5-96
S. CROW

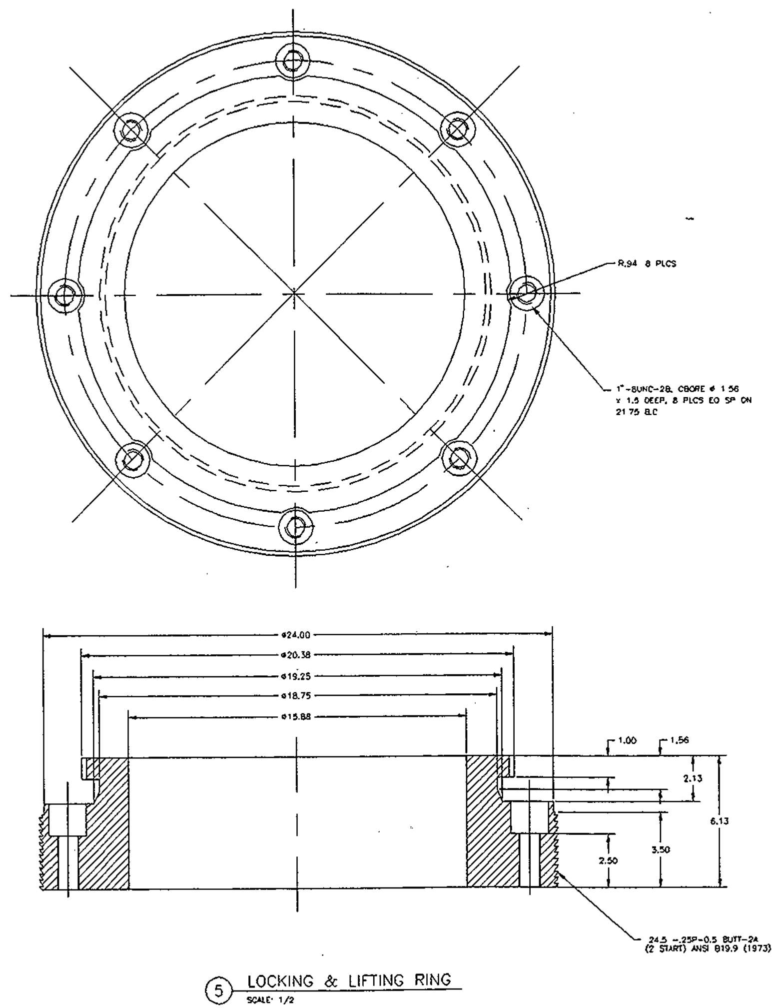
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MULTI CANISTER OVERPACK ASSEMBLY & PARTS LIST

F 212-H 2450 SK-2-300406 0
SCALE SHOWN 615811 1 - 4

SK-2-300406 1 - 4 0

54-6000-027(5/89)



FOR GENERAL NOTES & PARTS LIST SEE SH-1

PROTOTYPE

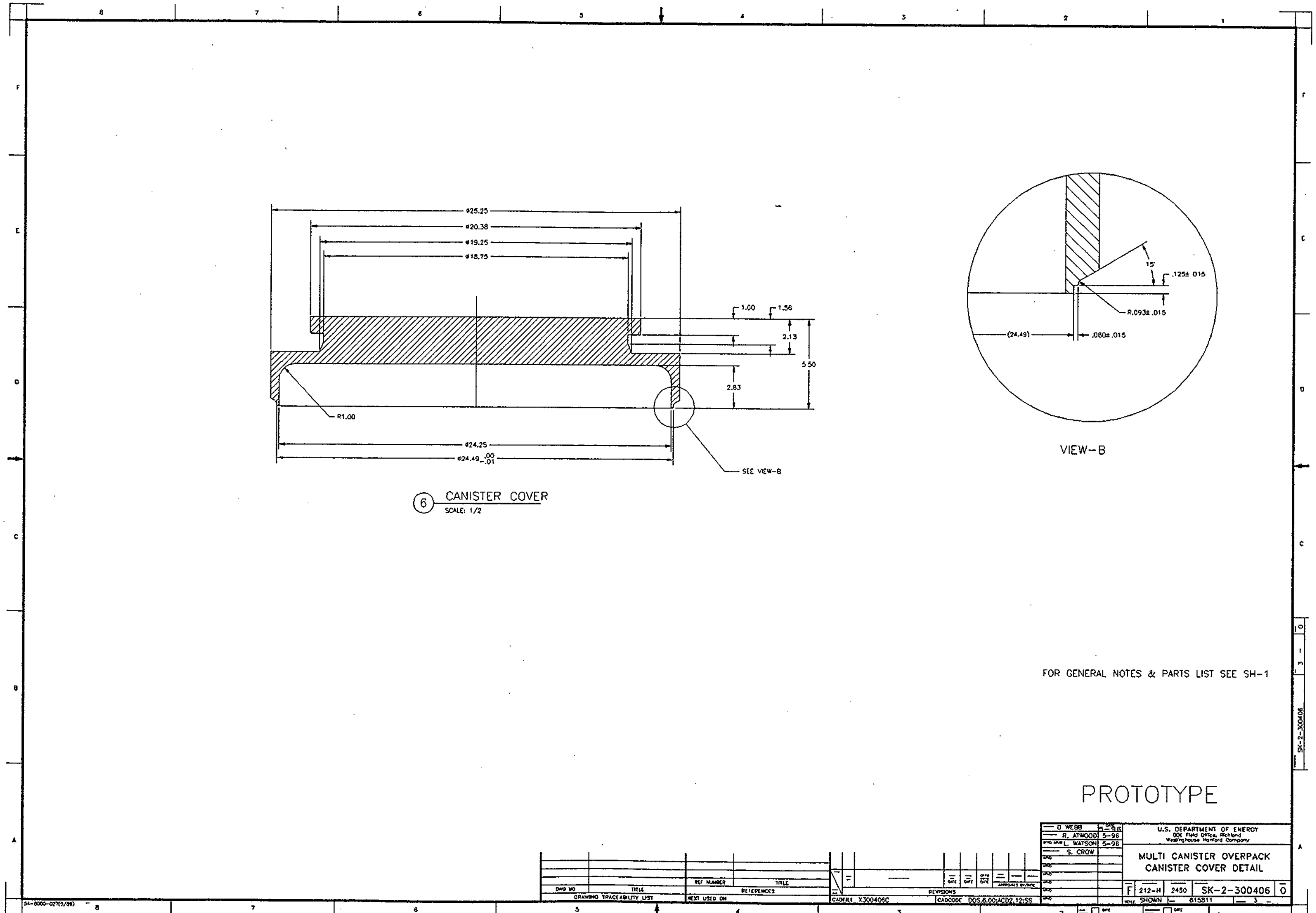
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MULTI CANISTER OVERPACK
LOCKING & LIFTING RING DETAIL

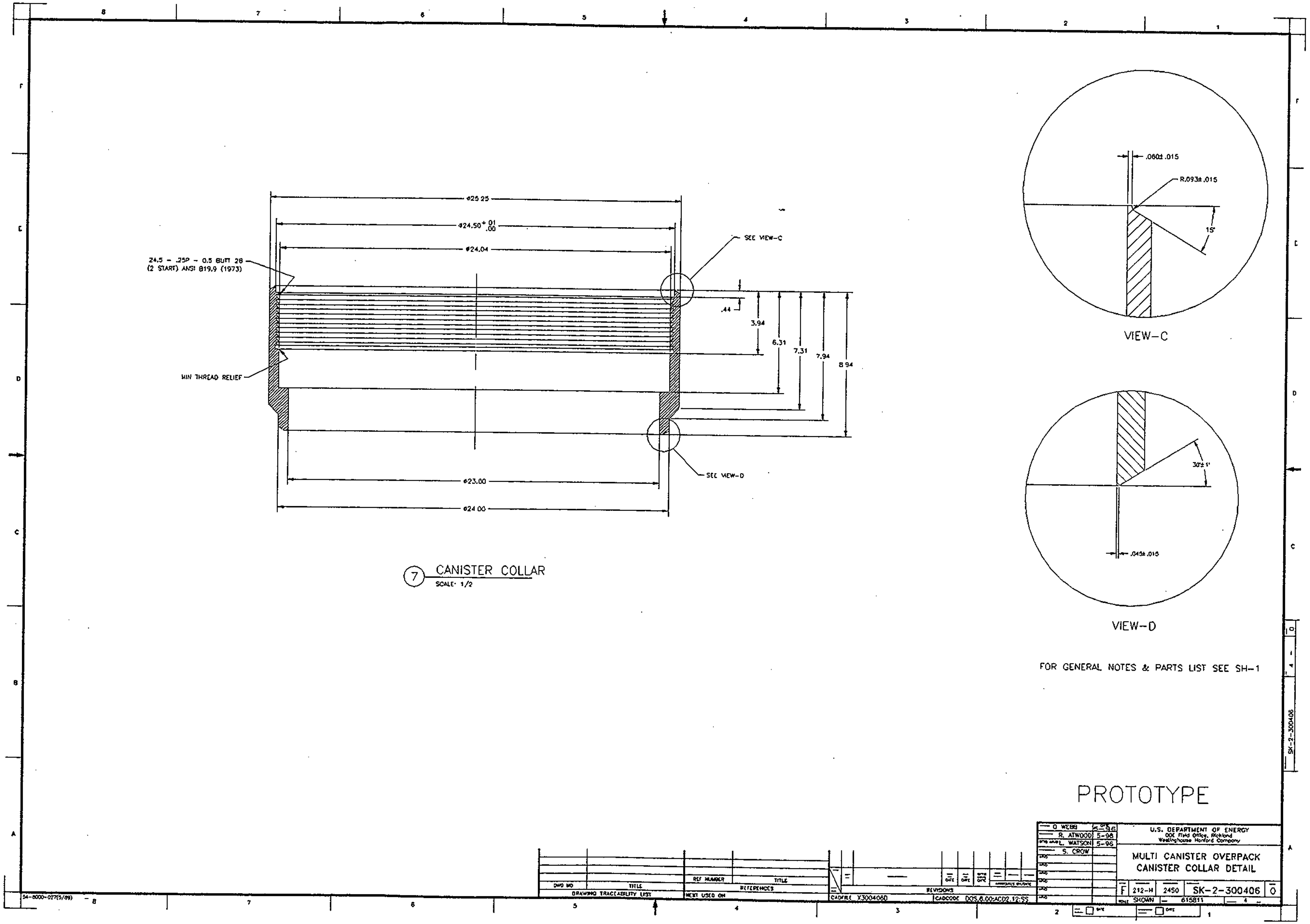
D. WEBB; R. ATWOOD 5-96; L. WATSON 5-96; S. CROW

F 212-H 2450 SK-2-300406 0
SCALE SHOWN 615811 2

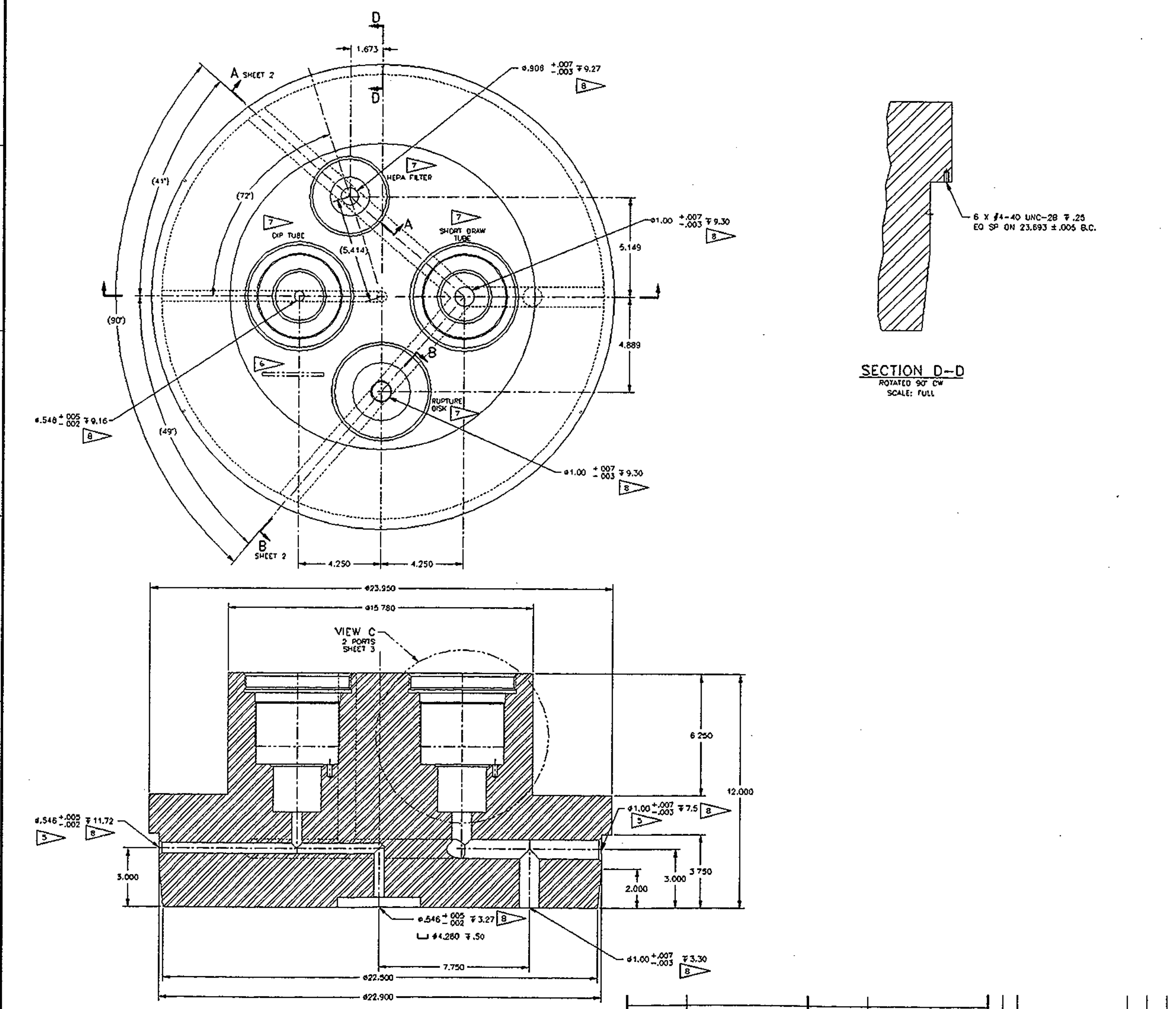
CADFILE X300406B
CADCODE DOS.6.00:ACD2.12:SS



ø25.25
ø20.38
ø19.25
ø18.75
1.00
1.56
2.13
5.50
2.83
R1.00
ø24.25
ø24.49 +.00 -.01
SEE VIEW-B
6 CANISTER COVER
SCALE: 1/2
15°
.125± .015
R.093± .015
(24.49)
.080± .015
VIEW-B
FOR GENERAL NOTES & PARTS LIST SEE SH-1
PROTOTYPE
D. WEBB
R. ATWOOD 5-96
L. WATSON 5-96
S. CROW
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company
MULTI CANISTER OVERPACK
CANISTER COVER DETAIL
F 212-H 2450 SK-2-300406 0
SHOWN 615811 3
DRAWING TRACEABILITY LIST
REFERENCES
NEXT USED ON
REVISIONS
CADFILE X300406C
SK-2-300406



Ø25.25
Ø24.50 +.01 .00
Ø24.04
24.5 - .25P - 0.5 BUTT 28 (2 START) ANSI B19.9 (1973)
MIN THREAD RELIEF
SEE VIEW-C
SEE VIEW-D
.44
3.94
6.31
7.31
7.94
8.94
Ø23.00
Ø24.00
7 CANISTER COLLAR
SCALE: 1/2
.060±.015
R.093±.015
15°
VIEW-C
30°±1°
.045±.015
VIEW-D
FOR GENERAL NOTES & PARTS LIST SEE SH-1
PROTOTYPE
O. WEBB
R. ATWOOD 5-96
L. WATSON 5-96
S. CROW
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company
MULTI CANISTER OVERPACK
CANISTER COLLAR DETAIL
F 212-H 2450 SK-2-300406 0
SHOWN 615811
DWG NO
TITLE
DRAWING TRACEABILITY LIST
REF NUMBER
REFERENCES
NEXT USED ON
REVISIONS
CADFILE X300406D
CADCODE DOS,6.00;ACD2.12;SS
SK-2-300406



1 SHIELD PLUG
SCALE: 1/2

SECTION D–D
ROTATED 90° CW
SCALE: FULL

PARTS/MATERIAL LIST

PART/DASH NUMBER	NOMENCLATURE / DESCRIPTION	MATERIAL / REFERENCE	SHEET	ITEM NO.
-001	SHIELD PLUG	CARBON STEEL ASTM A108 GRADE TYPE 1018	1	1

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. DIMENSIONS ARE IN INCHES.
2. TOLERANCES: DECIMALS: .X = ±.1 .XX = ±.03, .XXX = ±.015 ANGULAR: ± 1/2°
3. ALL MACHINED SURFACES 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1.
4. BREAK ALL SHARP EDGES & REMOVE ALL BURRS.

5. COUNTERSINK AS REQUIRED FOR .125 MIN WELD PREP.
6. IDENTIFY PER HS-BS-0015, TYPE 5 (ELECTROCHEMICAL ETCH), WITH DRAWING NUMBER AND DRAWING REVISION NUMBER, IN APPROXIMATE LOCATION SHOWN, USING .12 MINIMUM HIGH CHARACTERS.
7. IDENTIFY PER HS-BS-0015, TYPE 5 (ELECTROCHEMICAL ETCH), AS SHOWN, USING .12 MINIMUM HIGH CHARACTERS.
8. HOLE DEPTH SPECIFIED IS TO POINT OF DRILL BIT
9. FOR PRODUCTION VERSION, INCREASE THIS TO ø.265 (17/64), +.005, -.001 .
10. FOR PRODUCTION VERSION, INCREASE THIS TO ø2.530 +.005, -.001 .

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

DWG NO	TITLE
DRAWING TRACEABILITY LIST	

REF NUMBER	TITLE
SK-2-300406	MCO CANISTER OVERPACK ASSEMBLY & PARTS LIST
REFERENCES	
NEXT USED ON	SK-2-300461

CADFILE X300404A — REVISIONS — CADCODE WIN95:ACD2:12.0:SS

BA MESSINGER 9/17/96
LJ ROBINSON 9/18/96
BL NIELSEN 9/18/96
LH GOLDMANN
KE SMITH
ED S. RUFF

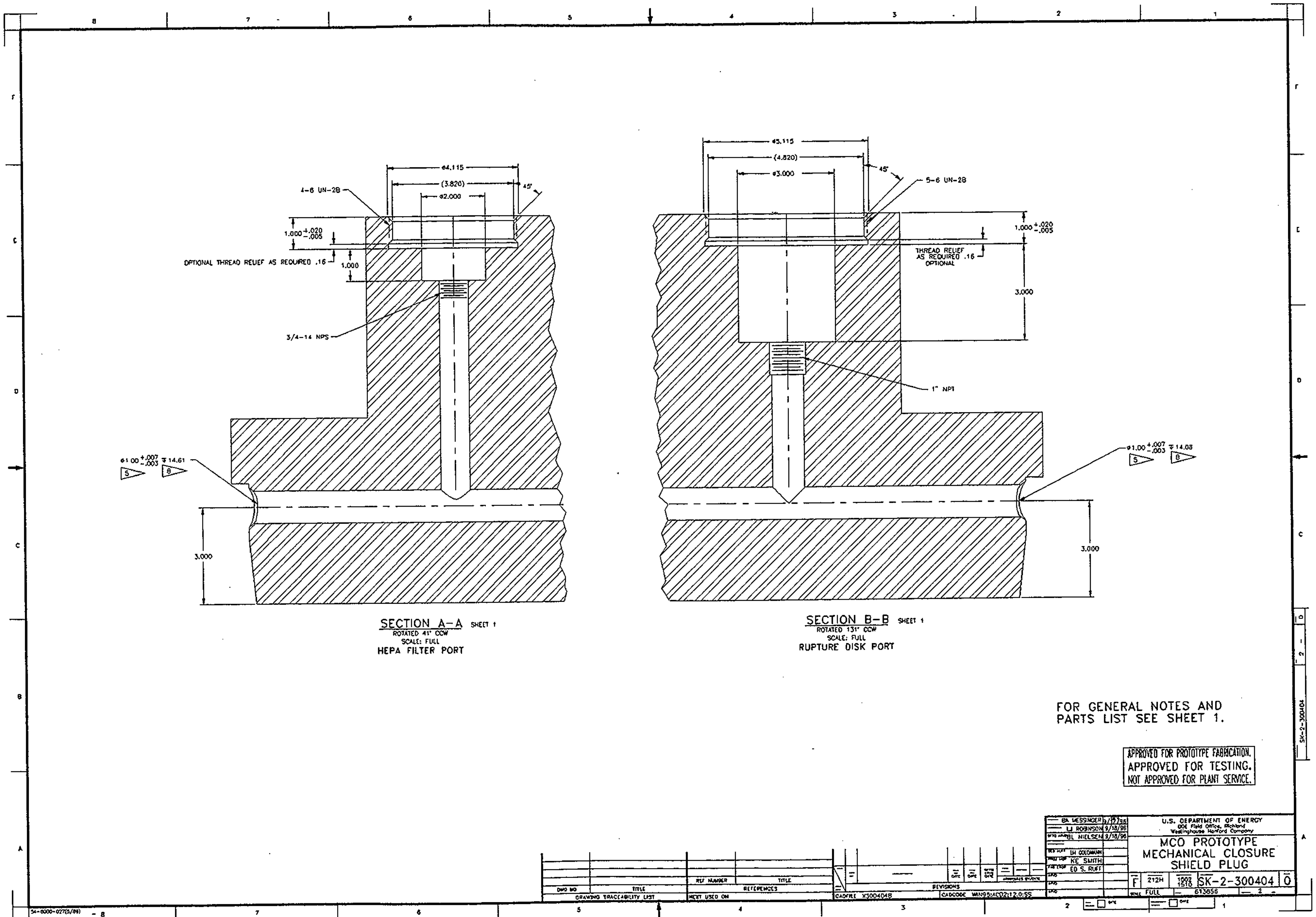
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE
MECHANICAL CLOSURE
SHIELD PLUG

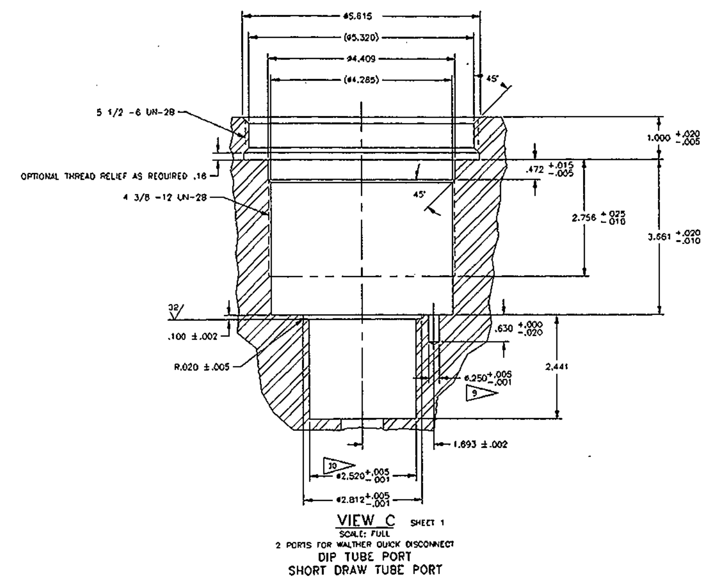
F 212H 1502 1510 SK-2-300404 0
SCALE 1/2 — 613656 — 1 — 3

SK-2-300404 1 – 3 0

54-6000-027(5/89)



4-6 UN-2B
ø4.115
(3.820)
ø2.000
45°
1.000 +.020 -.005
OPTIONAL THREAD RELIEF AS REQUIRED .16
1.000
3/4-14 NPS
ø1.00 +.007 -.003 ⌵14.61
3.000
SECTION A-A SHEET 1
ROTATED 41° CCW
SCALE: FULL
HEPA FILTER PORT
ø5.115
(4.820)
ø3.000
5-6 UN-2B
1.000 +.020 -.005
THREAD RELIEF AS REQUIRED .16 OPTIONAL
3.000
1" NPT
ø1.00 +.007 -.003 ⌵14.08
3.000
SECTION B-B SHEET 1
ROTATED 131° CCW
SCALE: FULL
RUPTURE DISK PORT
FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.
APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.
BA MESSINGER
LJ ROBINSON 9/18/96
BL NIELSEN 9/18/96
LH GOLDMANN
KE SMITH
ED S. RUFF
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company
MCO PROTOTYPE
MECHANICAL CLOSURE
SHIELD PLUG
F
212H
SK-2-300404
0
FULL
613656
2
DRAWING TRACEABILITY LIST
DWG NO
TITLE
REF NUMBER
TITLE
REFERENCES
NEXT USED ON
CADFILE X3004048
REVISIONS
SK-2-300404



FOR GENERAL NOTES AND PARTS LIST SEE SHEET 1.

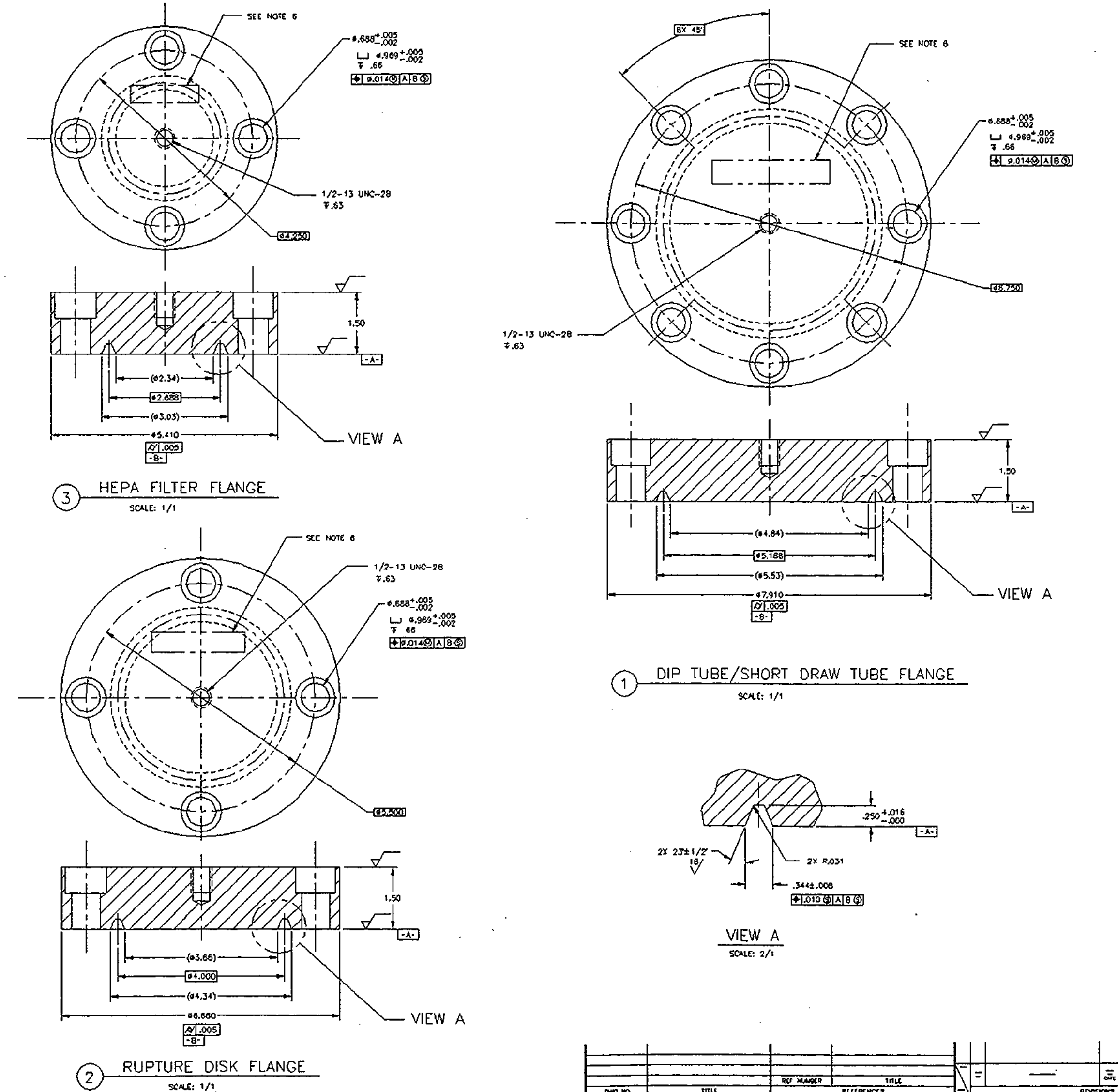
APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

BA MESSINGER 9/17/98	U.S. DEPARTMENT OF ENERGY
LJ ROBINSON 9/18/98	DOE Field Office, Richland
BL NIELSEN 9/18/98	Westinghouse Hanford Company
LH GOLDMANN	MCO PROTOTYPE MECHANICAL CLOSURE SHIELD PLUG
KE SMITH	
ED S. RUFF	F 212H 1510 SK-2-300404 0
	SCALE FULL 613656 SHEET 3

DRAWING TRACEABILITY LIST — NEXT USED ON — REFERENCES — REVISIONS

CADFILE X300404C — CADCODE WIN95(AC02:12.0:SS

SK-2-300404 3 0



PARTS/MATERIAL LIST

PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
-001	DIP TUBE/SHORT DRAW TUBE FLANGE, PLATE	ANY 300 SERIES SST	1	1
-002	RUPTURE DISK FLANGE, PLATE	ANY 300 SERIES SST	1	2
-003	HEPA FILTER FLANGE, PLATE	ANY 300 SERIES SST	1	3

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. TOLERANCES: DECIMAL .XX = ±.03
   .XXX = ±.005
   ANGULAR ±1°
4. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
5. ALL MACHINED SURFACES SHALL BE 125/√ OR BETTER IN ACCORDANCE WITH ANSI B46.1.
6. MARK ITEM WITH DRAWING NUMBER, PART NUMBER AND LATEST REVISION NUMBER IN APPROXIMATE AREA SHOWN. VIBRA-ETCH, STAMP, OR ELECTRO-CHEMICAL ETCH ARE ALL ACCEPTABLE MARKING MEANS.

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON SK-2-300399	REFERENCES

CADFILE X300386A — REVISIONS — CADCODE D05.6.22:ACD2.12.0:S5

LJ ROBINSON 4-11-96
LH GOLDMAN
KE SMITH
ES RUFF
PARSONS ENG. INC.

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE
WELDED CLOSURE
FLANGES

F 212H 1502 1510 SK-2-300386 0
SCALE 1/1 613654 1 — 1

SK-2-300386 1 - 1 0

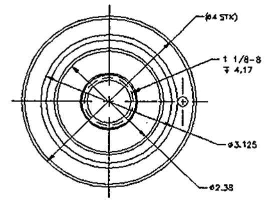
54-6000-027(5/89)

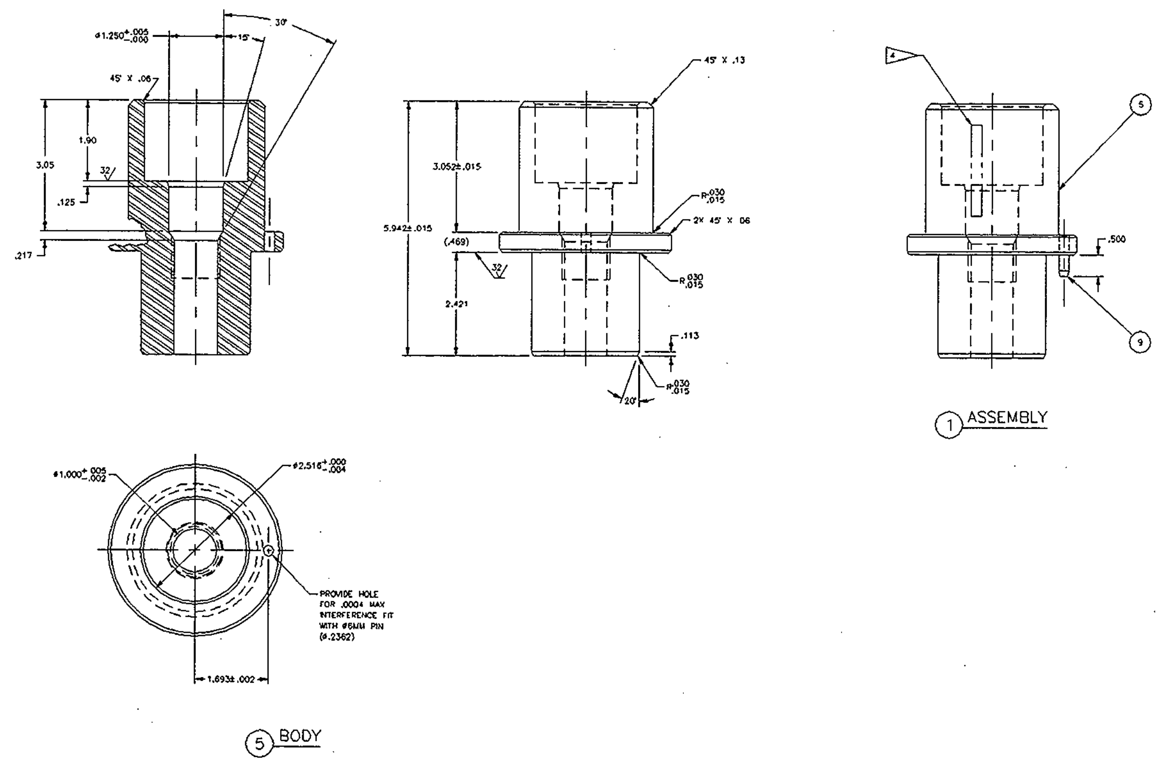
PARTS/MATERIAL LIST

QTY REQD -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
X	-010	ASSEMBLY			1
					2
					3
					4
1	-001	BODY, BAR, ø4 X 5.95 LONG	ANY 300 SERIES SST		5
					6
					7
					8
1	MDP18-5	PIN, DOWEL, ø6MM X 24MM LONG, HARDENED TO 36-42 ROCKWELL C	PIC DESIGN TYPE 416 SST		9

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982
   TOLERANCES:
   DECIMALS: .XX= ±.03 .XXX= ±.005
   ANGLES: ±1°
2. REMOVE ALL BURRS. BREAK SHARP EDGES.
3. ALL MACHINED SURFACES SHALL BE 125/ PER ANSI B46.1. ALL MACHINED RADII SHALL BE .030 MAX.
4. IDENTIFY WITH THE DRAWING NUMBER, PART NUMBER, AND LATEST REV IN THE AREA INDICATED WITH 1/8 HIGH CHARACTERS PER HS-BS-0015, TYPE 2.





APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
MCO PROTOTYPE
SHIELD PLUG
PROCESS PORT ADAPTER

AJ PALOMBI
SK-2-300408 0
F 613656
SCALE 1/1

DRAWING TRACEABILITY LIST | REFERENCES: SK-2-300399 | REVISIONS
CADFILE X300408A | CADCODE DOS 6.22:ACD2:12:SS
PARSONS ENG. INC.

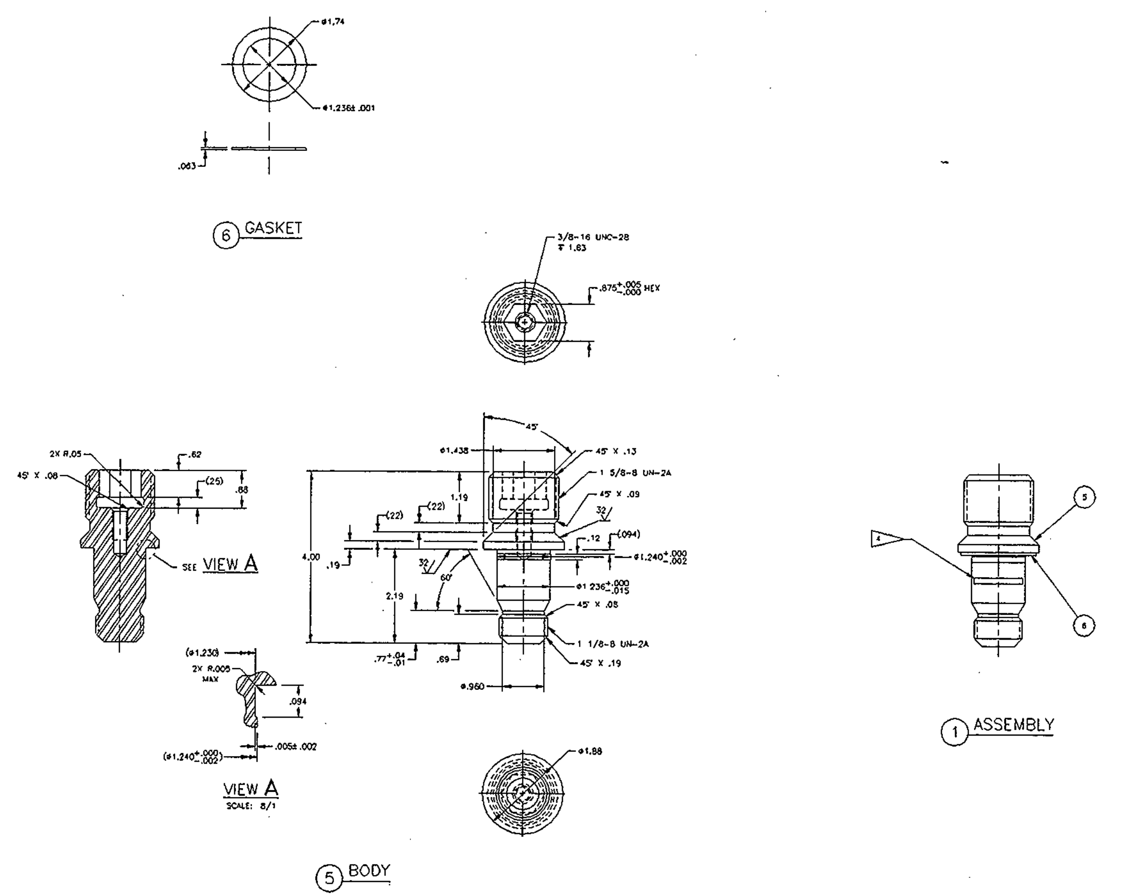
54-6000-027(3/89)

PARTS/MATERIAL LIST

QTY REQD -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
X	-010	ASSEMBLY			1
					2
					3
					4
1	-001	BODY, BAR, ø2 X 4.00 LONG	ANY 300 SERIES SST		5
1	-002	GASKET, SHEET, 16 GA (.065 THK), HOT ROLLED, (SOFT)	COPPER ALLOY 110 ASTM B 152		6

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED).

1. ALL DIMENSIONS ARE IN INCHES. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. TOLERANCES: DECIMALS: .XX= ±.03 .XXX= ±.005 ANGLES: ±1°
2. REMOVE ALL BURRS. BREAK SHARP EDGES
3. ALL MACHINED SURFACES SHALL BE 125 PER ANSI B46.1. ALL MACHINED RADII SHALL BE .030 MAX.
4. IDENTIFY WITH THE DRAWING NUMBER, PART NUMBER, AND LATEST REV IN THE AREA INDICATED WITH 1/8 HIGH CHARACTERS PER HS-BS-0015, TYPE 2.



APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
MCO PROTOTYPE
SHIELD PLUG
PROCESS ADAPTER PLUG

AJ PALOMBI
SK-2-300409 0
NOTED
613656
PARSONS ENG. INC.

DWG NO	TITLE	RSF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON	SK-2-300399

CADFILE X300409A CADCODE 005 6.22;AC02:12:55

SK-2-300409

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES AND DEGREES.
2. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
3. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M -1982.
   TOLERANCES: .XX = ± .03
   .XXX = ± .005
4. ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125√ OR BETTER.
5. ALL DIMENSIONS ARE APPLICABLE AT 68° F AND ALL TOLERANCING APPLIES AFTER WELDING AND FINAL MACHINING.

6 ▷ PIPE MAY BE EITHER SEAMLESS AS INDICATED IN PARTS LIST OR FABRICATED FROM PLATE 75.40 W X 146.67 L X .50 THK, ASTM A240, TYPE 304L WITH ONE LONGITUDINAL WELD.

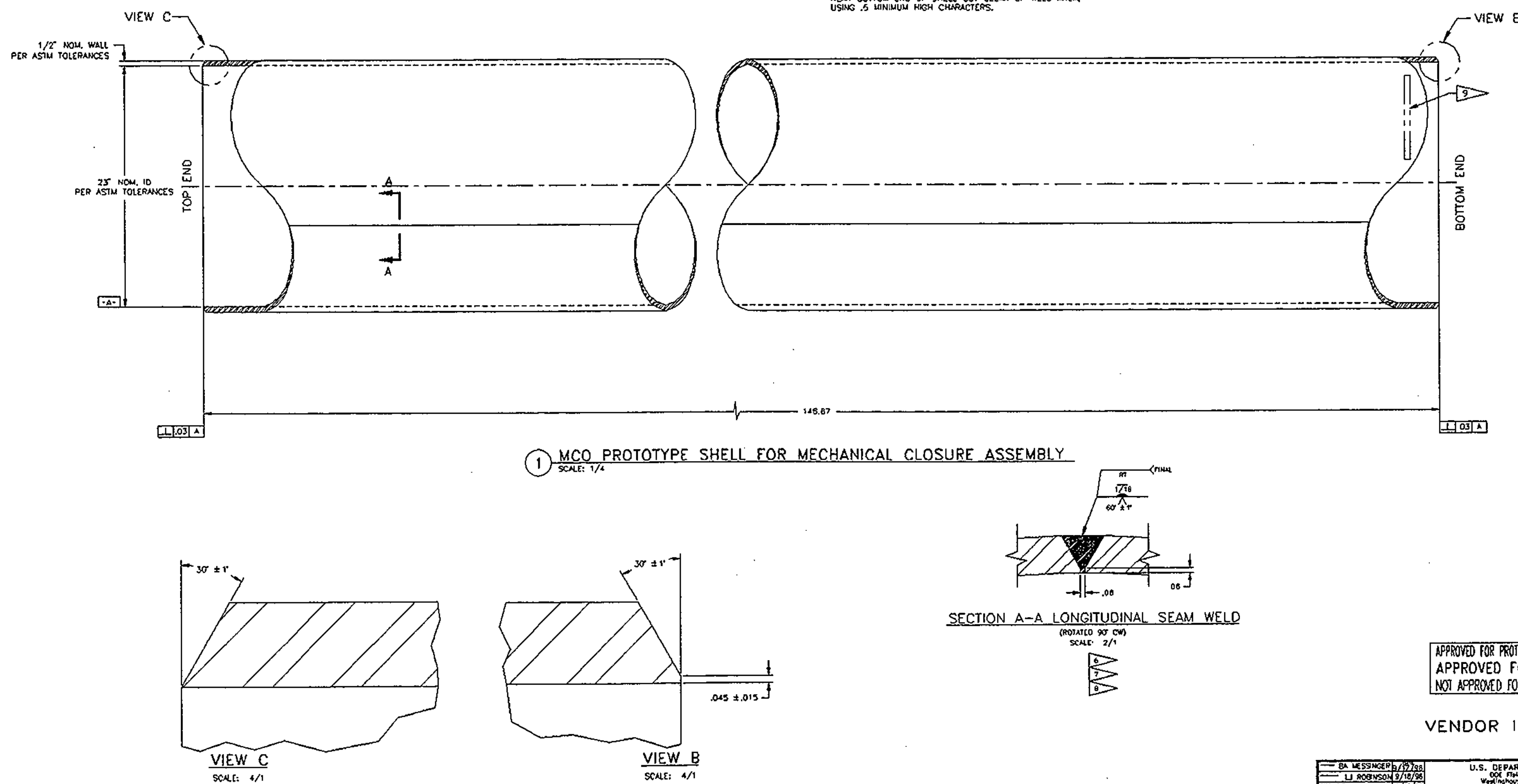
7 ▷ IF LONGITUDINAL WELD IS USED, IT SHALL BE MADE ACCORDING TO LONGITUDINAL SEAM WELD DETAIL SHOWN IN SECTION A-A. EQUIVALENT FULL PENETRATION DETAIL MAY BE SUBMITTED FOR APPROVAL. ALL EXTERIOR SURFACES SHALL BE GROUND FLUSH WITH FINISH AS NOTED. WELD MAY NOT PROTRUDE INSIDE SHELL. MINIMUM WALL THICKNESS SHALL NOT BE VIOLATED.

8 ▷ IF LONGITUDINAL WELD IS USED, THE WELD SHALL BE RADIOGRAPHICALLY EXAMINED (X-RAYED).

9 ▷ IDENTIFY PER HS-85-0015, TYPE 5 (ELECTROCHEMICAL ETCH), WITH DRAWING NUMBER, PART NUMBER AND DRAWING REVISION NUMBER, NEAR BOTTOM END OF SHELL BUT CLEAR OF WELD AREA, USING .5 MINIMUM HIGH CHARACTERS.

PARTS/MATERIAL LIST

QTY REQD -001	-010	PART/DASH NUMBER	NOMENCLATURE / DESCRIPTION	MATERIAL / REFERENCE	SHEET	ITEM NO.
6 ▷		-001	MCO PROTOTYPE SHELL FOR MECHANICAL CLOSURE ASSEMBLY	PIPE, 24" NOMINAL O.D. SCHEDULE 80S, 304L S.S.	1	1



APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

VENDOR INFORMATION

DWG NO	TITLE	DRAWING TRACEABILITY LIST
SK-2-300406	MULTI CANISTER OVERPACK ASSEMBLY & PARTS LIST	REFERENCES
SK-2-300378	SHELL BOTTOM MACHINED FORGING	
NEXT USED ON SK-2-300461		

CADFILE X300398A — CADCODE WIN95:ACD2:12.0:SS

BA MESSINGER 9/17/98; LJ ROBINSON 9/18/98; BL NIELSEN 9/18/98; LH COLEMAN; KE SMITH; ED S. RUFF

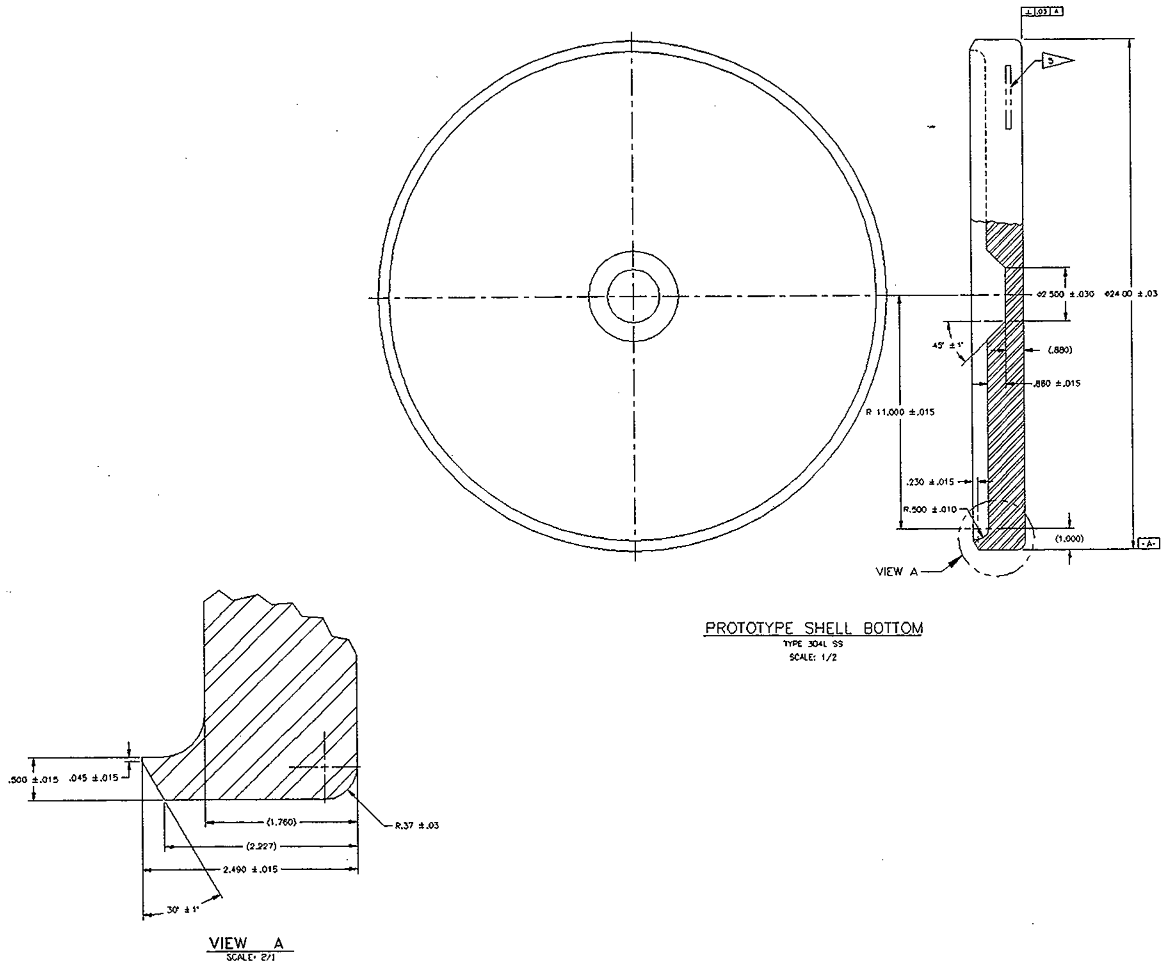
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE SHELL FOR MECHANICAL CLOSURE ASSEMBLY

F 212H 1502 1510 SK-2-300398 0
SCALE 1/4 — 613656 — 1 — 1

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. DIMENSIONS ARE IN INCHES.
2. TOLERANCES ARE SPECIFIED.
3. ALL MACHINED SURFACES 125 √ OR BETTER IN ACCORDANCE WITH ANSI B46.1.
4. BREAK ALL SHARP EDGES & REMOVE ALL BURRS.
5. IDENTIFY PER HS-BS-0015 TYPE 5 (ELECTROCHEMICAL ETCH) WITH DRAWING NUMBER, PART NUMBER AND DRAWING REVISION NUMBER IN LOCATION INDICATED USING .5 MINIMUM HIGH CHARACTERS.



PROTOTYPE SHELL BOTTOM
TYPE 304L SS
SCALE: 1/2

VIEW A
SCALE: 2/1

DWG NO	TITLE	REF NUMBER	TITLE
SK-2-300379	MCO PROTOTYPE SHELL	WHC-S-0453	MULTI-CANISTER OVERPACK SPECIFICATION
SK-2-300381	MCO PROTOTYPE BASKET SUPPORT PLATE	H-2-826303	MULTI-CANISTER OVERPACK ASSEMBLY

DRAWING TRACEABILITY LIST — REFERENCES — NEXT USED ON: END ITEM

CADFILE X300378A — CADCODE DOS.6.22:ACD2.12.0:SS

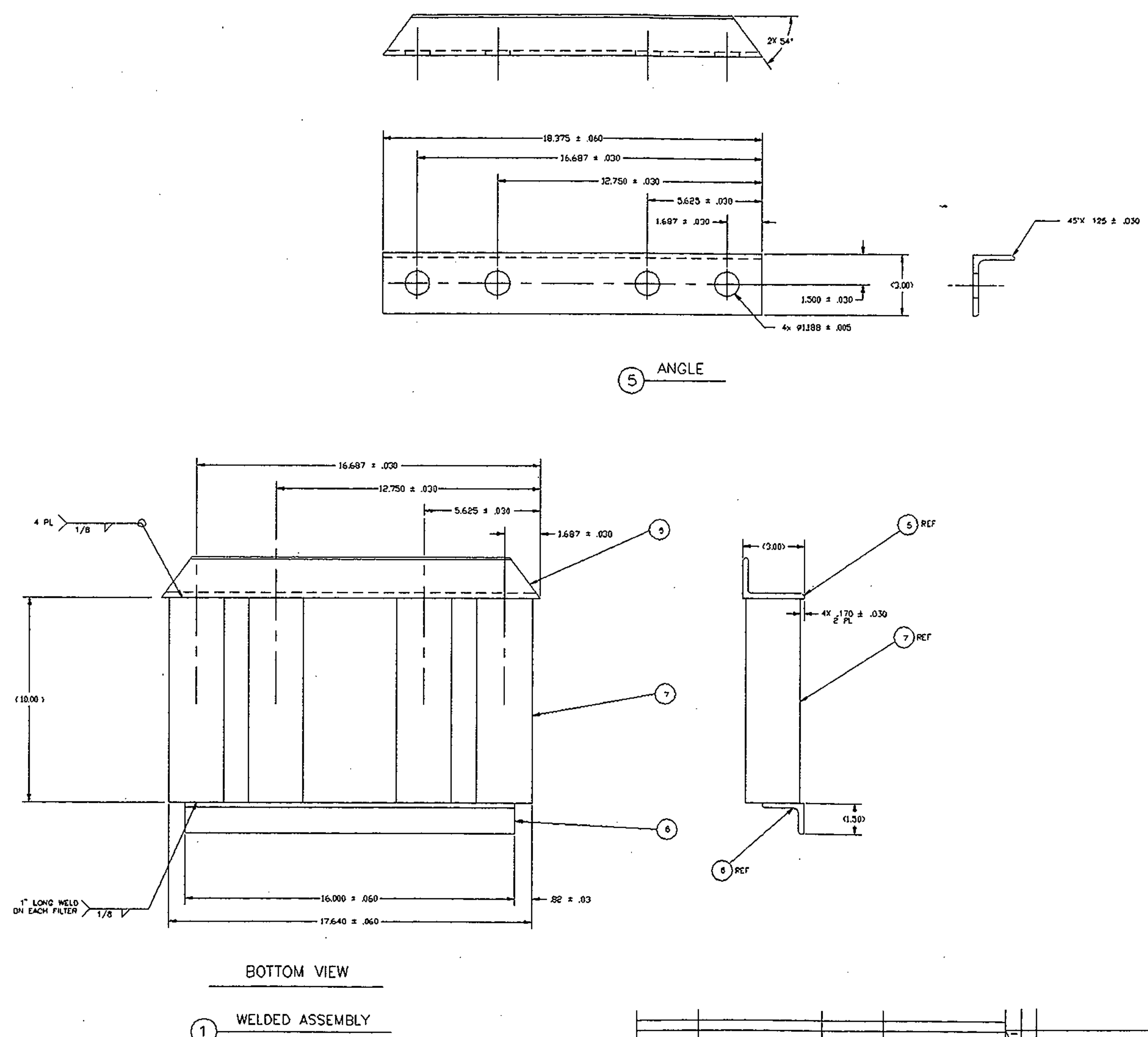
BA MESSINGER	3/18/96	
LJ ROBINSON	3/19/96	
JW JACKSON	3/19/96	
ED S. RUFF		

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE SHELL BOTTOM MACHINED FORGING

F | 212H | 1502 1510 | SK-2-300378 | 0

SCALE 1/2 | 607585 | 1 | 1



PARTS/MATERIAL LIST

QTY REQD -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
X	-010	WELDED ASSEMBLY		1	1
					2
					3
					4
1	-001	ANGLE 3 x 2 x 1/4 THICK	304L SST, ASTM A276		5
1		ANGLE 2 x 1 1/2 x 1/4 THICK	304L SST, ASTM A276		6
4		PALL FILTER	(316 SST)		7
					8
					9
					10
					11
					12

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. ALL DIMENSIONS ARE IN INCHES TOLERANCES: ANGLES: ± 1°
2. ALL MACHINED SURFACES 125 √ IN ACCORDANCE WITH ANSI B46.1 (LATEST REVISION)
3. BREAK ALL SHARP EDGES. REMOVE ALL BURRS.

VENDOR INFORMATION

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO INTERNAL FILTER PARTIAL MANIFOLD

F 212H 8504 SK-2-300402 0

1/2 815124

DWG NO | TITLE | REF NUMBER | REFERENCES | TITLE

DRAWING TRACEABILITY LIST | NEXT USED ON SK-2-300399

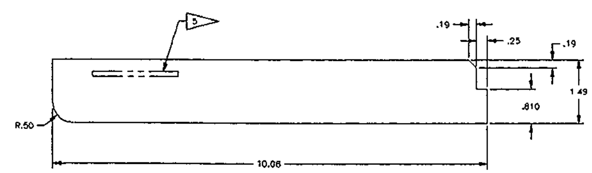
CADFILE Y300402A | REVISIONS | CADCODE D0S:8.22:ACD2:12.0:SS

SK-2-300402 1-1 0

54-6000-027(5/81)

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. DIMENSIONS ARE IN INCHES.
2. TOLERANCES. DECIMALS: .XX = ±.03, .XXX = ±.015 ANGULAR: ± 1°.
3. ALL MACHINED SURFACES 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1.
4. BREAK ALL SHARP EDGES & REMOVE ALL BURRS.
5. IDENTIFY PER HS-BS-0015, TYPE 5 (ELECTROCHEMICAL ETCH), WITH DRAWING NUMBER AND DRAWING REVISION NUMBER, IN APPROXIMATE LOCATION SHOWN, USING .12 MINIMUM HIGH CHARACTERS.
6. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.



BASKET SUPPORT PLATE
1/2" BAR, ASME SA-240, TYPE 304L
SCALE: FULL

REF NUMBER	TITLE
WHC-S-0453	MULTI-CANISTER OVERPACK SPECIFICATION
H-2-826303	MULTI-CANISTER OVERPACK ASSEMBLY
SK-2-300383	MCO PROTOTYPE DIP TUBE GUIDE CONE
SK-2-300378	SHELL BOTTOM MACHINED FORGING

REFERENCES

NEXT USED ON END ITEM

DWG NO | TITLE — DRAWING TRACEABILITY LIST

REVISIONS: 1 REV PER ECN #630787 CK 9/96

CADFILE X300381A CADCODE DOS.6.22:ACD2.12.0:SS

BA MESSINGER 3/19/96
LJ ROBINSON 3/19/96
JM JACKSON 3/19/96
LK GOLDMAN
R.E. SMITH
ED S. RUFF

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE BASKET SUPPORT PLATE

F 212H 1502 1510 SK-2-300381 1

SCALE FULL 607585 1 - 1

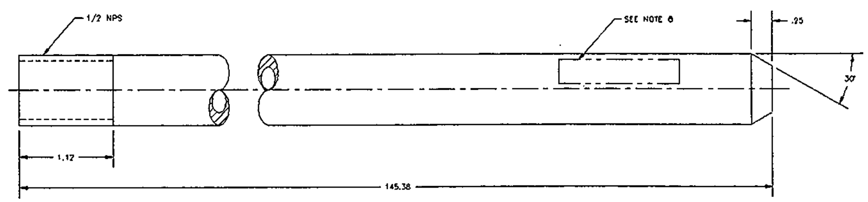
SK-2-300381

PARTS/MATERIAL LIST

PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
-001	DIP TUBE, PIPE, 1/2 SCHED 80 SMLS	ASTM A312, GR TP 304L SST		1

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. TOLERANCES: DECIMAL .XX = ±.03
   ANGULAR ± 5°
4. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
5. ALL MACHINED SURFACES SHALL BE 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1
6. MARK ITEM WITH DRAWING NUMBER, PART NUMBER AND LATEST REVISION NUMBER IN APPROXIMATE AREA SHOWN. VIBRA-ETCH, STAMP, OR ELECTRO-CHEMICAL ETCH ARE ALL ACCEPTABLE MARKING MEANS.



① DIP TUBE

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

BA MESSINGER 7/24/96
LJ ROBINSON 9/18/96
BL NIELSEN 9/18/96
LH GOLDMANN
KE SMITH
ES RUFF
PARSONS ENG. INC.

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO MECHANICAL CLOSURE PROTOTYPE DIP TUBE

F 212H 1502 1510 SK-2-300462 0

2/1 — 613656

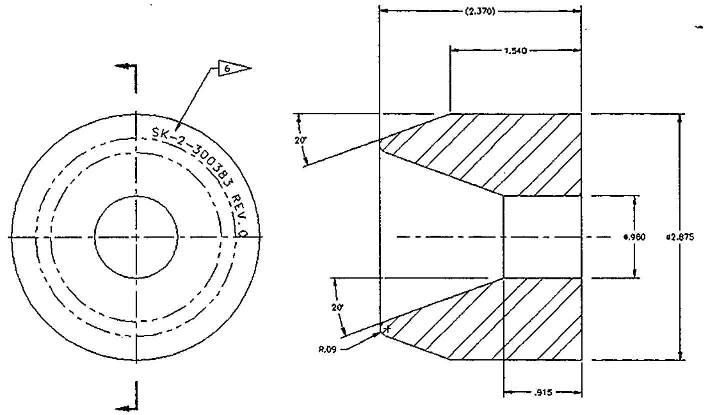
DRAWING TRACEABILITY LIST — DWG NO — TITLE
REFERENCES — REF NUMBER — TITLE
NEXT USED ON H-2-300481
CADFILE X300462A
REVISIONS
CADCODE WIN95:AC02 12.0 SS

SK-2-300462 1 - 1 0

54-6000-027(3/89)

GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. DIMENSIONS ARE IN INCHES
2. TOLERANCES: DECIMALS: .XX = ±.03, .XXX = ±.010 ANGULAR: ± 1°.
3. ALL MACHINED SURFACES 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1.
4. BREAK ALL SHARP EDGES & REMOVE ALL BURRS
5. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
6. IDENTIFY PER HS-BS-0015, TYPE 5 (ELECTROCHEMICAL ETCH), WITH DRAWING NUMBER AND DRAWING REVISION NUMBER, IN APPROXIMATE LOCATION SHOWN, USING .09 MINIMUM HIGH CHARACTERS



DIP TUBE GUIDE CONE
MATL: ASTM A-479 TYPE 304L
SCALE: 2/1

REF NUMBER	TITLE
SK-2-300378	SHELL BOTTOM MACHINED FORGING
WHC-S-0453	MULTI-CANISTER OVERPACK SPECIFICATION
H-2-826303	MULTI-CANISTER OVERPACK ASSEMBLY

REFERENCES

DWG NO | TITLE — DRAWING TRACEABILITY LIST

NEXT USED ON END ITEM

CADFILE X300383A — REVISIONS — CADCODE DOS.6.22:ACD2.12.0:S5

BA MESSINGER 1/18/96
LJ ROBINSON 3/19/96
JW JACKSON 3/19/96
ED S. RUFF

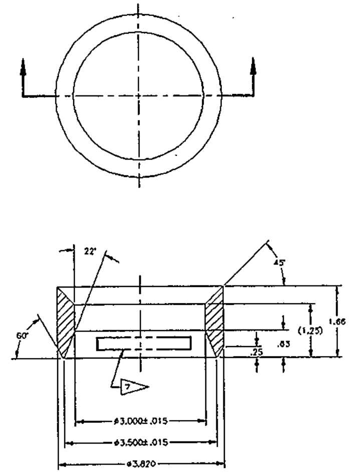
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE
DIP TUBE GUIDE CONE

F 212H 1502 1510 SK-2-300383 0
SCALE 2/1 — 607585 — 1 — 1

54-6000-027(5/89)

SK-2-300383



GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. TOLERANCES: DECIMAL X = ±.1
   .XX = ±.03
   XXX = ±.005
   ANGULAR ±1°
4. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
5. ALL MACHINED SURFACES SHALL BE 125√ OR BETTER IN ACCORDANCE WITH ANSI B46.1.
6. MATERIAL SHALL BE ASTM A-450, TYPE 304L
7. MARK WITH DRAWING NUMBER AND LATEST REVISION NUMBER IN 3/32 INCH HIGH CHARACTORS. VIBRA-ETCH, STAMP, OR ELECTRO-CHEMICAL ETCH ARE ALL ACCEPTABLE MARKING MEANS.
8. THIS PART REPLACES ITEM NO. 32 ON PARSONS ENGINEERING DRAWING H-2-826303, SHEET 9.

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

DWG NO	TITLE	REF NUMBER	TITLE
		WHC-S-0453	MULTI-CANISTER OVERPACK SPECIFICATION
DRAWING TRACEABILITY LIST		NEXT USED ON H-2-826303	

REV	REVISIONS	
1	REVISED PER ECN 606261	LJR 9/98

CADFILE X300382A CADCODE DOS.6.22:ACD2.12.0:SS

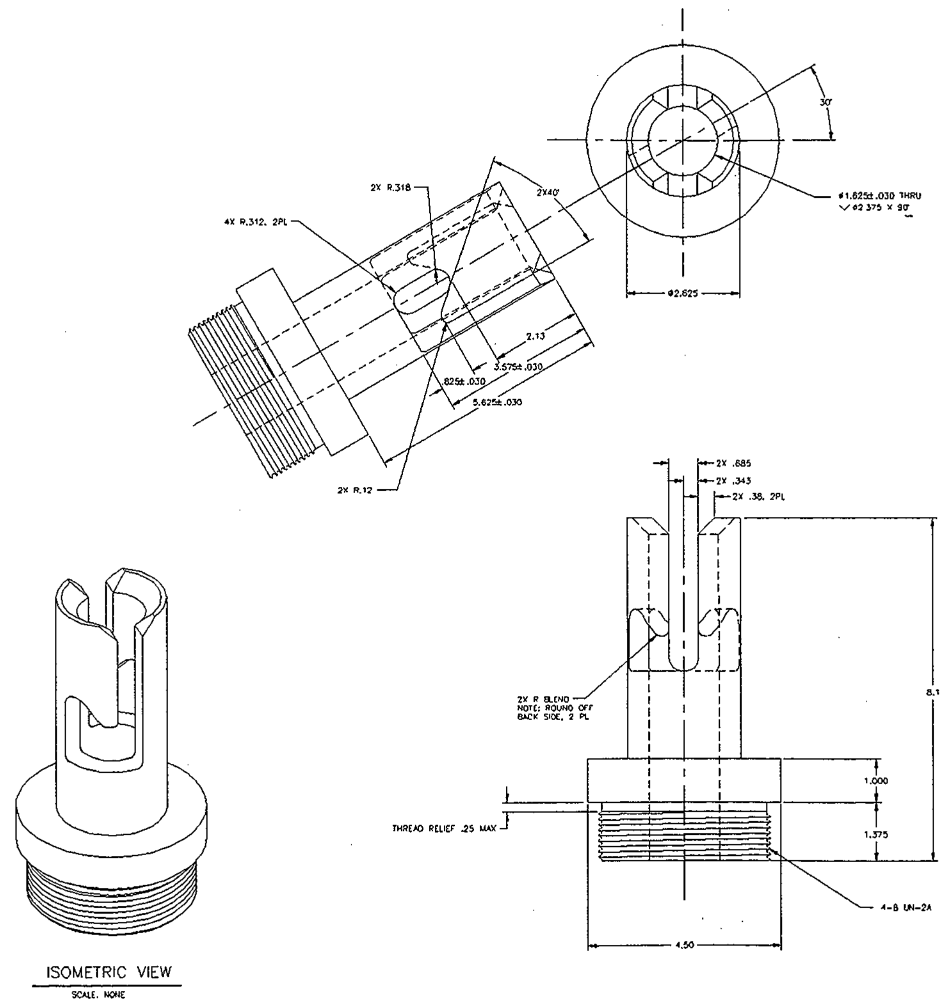
LJ ROBINSON 4-?-98
P ROMERO 4-13-98
BL NIELSEN 4-13-98
ES RUFF
H GOLDMAN
KE SMITH
ES RUFF
PARSONS ENG INC

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE
SNF RERACK BASKET
BOTTOM RING

F 212H 1502 1510 SK-2-300382 1
SCALE 1/1 607589 1 - 1

54-6000-077(5/89)



GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. TOLERANCES: DECIMAL X = ±.1, .XX = ±.03, .XXX = ±.005; ANGULAR ±1°
4. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
5. ALL MACHINED SURFACES SHALL BE 125 OR BETTER IN ACCORDANCE WITH ANSI B46.1.
6. ALL MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
7. ACCEPTABLE ALLOYS ARE :

MATERIAL	YIELD STRENGTH (KSI)	ULTIMATE STRENGTH (KSI)
SA540-B24	130-150	145-165
SA540-B22	105	120
SA540-B21	130-150	145-165
SA437-B4B	105	145
SA437-B4C	85	115
SA564-630	107	135
ASTM A434 BC (ALLOY 4142)	85	110

8. MARK WITH DRAWING NUMBER AND LATEST REVISION NUMBER VIBRA-ETCH, STAMP, OR ELECTROCHEMICAL ETCH ARE ALL ACCEPTABLE MARKING MEANS.
9. IF ALLOY SUBSTITUTIONS ARE REQUIRED DUE TO UNAVAILABILITY OF SPECIFIED MATERIAL, STRENGTH PROPERTIES OF THE SUBSTITUTE ALLOY MUST BE EQUAL TO OR LARGER THAN THE FOLLOWING:
   YIELD STRENGTH=61,500 PSI
   ULTIMATE TENSILE STRENGTH=102,500 PSI
   TO ASSURE ADEQUATE RESISTANCE TO SHOCK LOADING, CRACK INITIATION, OR BRITTLE FRACTURE, THE SUBSTITUTE ALLOY MUST ALSO HAVE PROPERTIES EQUAL TO OR LARGER THAN THE FOLLOWING:
   ELONGATION: 20%
   REDUCTION OF AREA: 30%
   CHARPY V-NOTCH IMPACT RESISTANCE: 15 FT-LBS MIN. (20 FT-LBS PREFERRED)

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

MCO PROTOTYPE
SNF RERACK BASKET
GRAPPLE ADAPTER

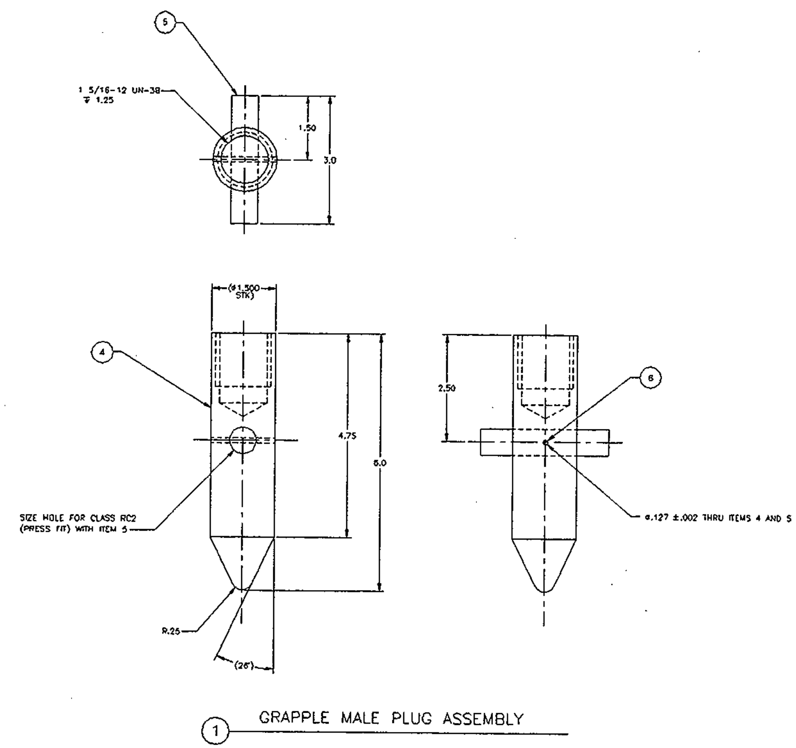
SK-2-300377 2

2 REVISED PER ECN 606261

PARSONS ENG INC

PARTS/MATERIAL LIST

QTY REQD -020	QTY REQD -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
	X	-010	ASSEMBLY, GRAPPLE MALE PLUG			1
						2
						3
	1	-001	BAR, ø1 1/2	SEE NOTE 6		4
	1	-002	BAR, ø5/8	SEE NOTE 6		5
	1	79-028-125-1500	ROLLPIN, ø1/8 X 1.50 L	ALL-STAINLESS INC.		6



GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
3. TOLERANCES: DECIMAL .X = ±.1, .XX = ±.03, .XXX = ±.005; ANGULAR ±1°
4. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
5. ALL MACHINED SURFACES SHALL BE 125√ OR BETTER IN ACCORDANCE WITH ANSI B46.1.
6. ACCEPTABLE ALLOYS ARE :

MATERIAL	YIELD STRENGTH (KSI)	ULTIMATE STRENGTH (KSI)
SA540-B24	130-150	145-165
SA540-B22	105	120
SA540-B21	130-150	145-165
SA437-B4B	105	145
SA437-B4C	85	115
SA564-630	107	135

7. MARK WITH DRAWING NUMBER, PART NUMBER AND LATEST REVISION NUMBER. VIBRA-ETCH, STAMP, OR ELECTROCHEMICAL ETCH ARE ALL ACCEPTABLE MARKING MEANS.

APPROVED FOR PROTOTYPE FABRICATION.
APPROVED FOR TESTING.
NOT APPROVED FOR PLANT SERVICE.

REF NUMBER	TITLE
SK-2-300380	MCO PROTOTYPE SHIELD PLUG
SK-2-300378	SHELL BOTTOM MACHINED FORGING
WHC-S-0453	MULTI-CANISTER OVERPACK SPECIFICATION
SK-2-300377	GRAPPLE ADAPTER

REFERENCES — NEXT USED ON H-2-828303

DRAWING TRACEABILITY LIST

REVISIONS: 1 REVISED PER ECN 608261

CADFILE X300384A — CADCODE DOS.6.22:ACD2.12.0:SS

LJ ROBINSON — P ROMERO 4-15-96 — BL MELSEN 4-15-96 — ES RUFF — LH GOLDMAN — KE SMITH — ES RUFF — PARSONS ENG INC

U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
Westinghouse Hanford Company

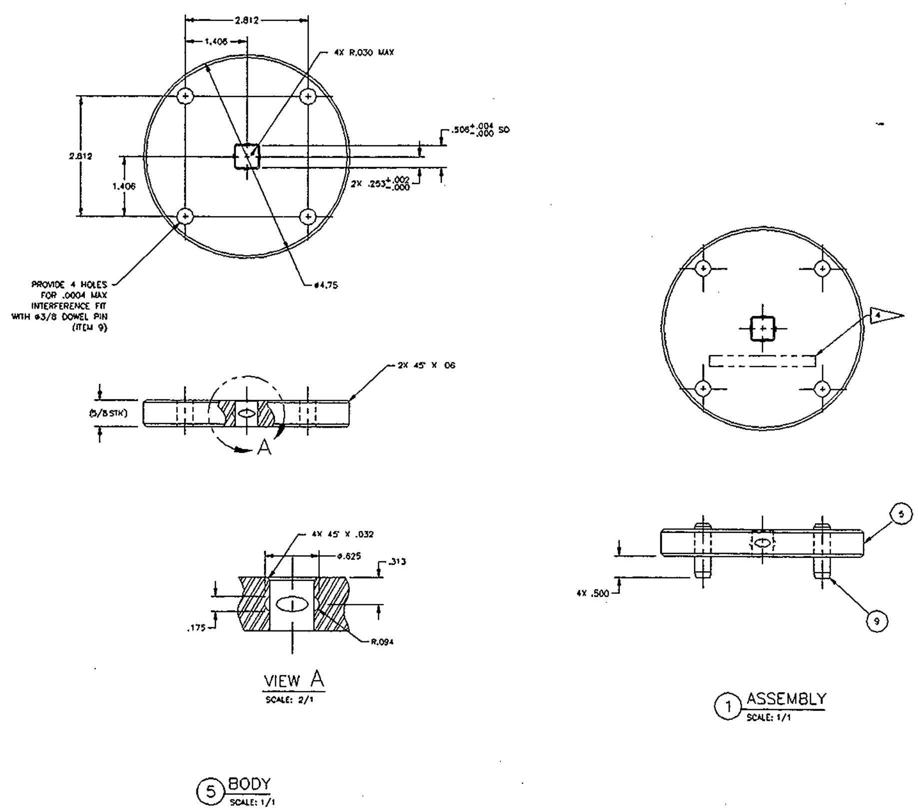
MCO PROTOTYPE
SNF RERACK BASKET
GRAPPLE MALE PLUG

F 212H 1502 1510 SK-2-300384 1 — SCALE FULL — 007589 — SHEET 1 of 1

54-6000-027(5/94)

PARTS/MATERIAL LIST

QTY	REQD -010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO
	X	-010	ASSEMBLY			1
						2
						3
						4
	1	-001	BODY, PLATE, 5/8 THICK	ANY 300 SERIES SST		5
						6
						7
						8
	4	022-1250	PIN, DOWEL, ø3/8 X 1 1/4 LONG HARDENED TO 36-42 ROCKWELL C	PIC DESIGN TYPE 416 SST		9



GENERAL NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS ARE IN INCHES. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982. TOLERANCES:
   DECIMALS: .X= ±.1 .XX= ±.03 .XXX= ±.005
   ANGLES: ±3°
2. REMOVE ALL BURRS. BREAK SHARP EDGES
3. ALL MACHINED SURFACES SHALL BE 125/ PER ANSI B46.1.
4. IDENTIFY WITH THE DRAWING NUMBER, PART NUMBER, AND LATEST REV IN THE AREA INDICATED WITH 1/4 HIGH CHARACTERS PER HS-BS-0015, TYPE 2.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

DWG NO	TITLE	REF NUMBER	TITLE
		SK-2-300399	MCO SHIELD PLUG ASSY
DRAWING TRACEABILITY LIST		NEXT USED ON	END ITEM

CADFILE X300460A CADCODE DOS 6.22:ACD2:12:SS

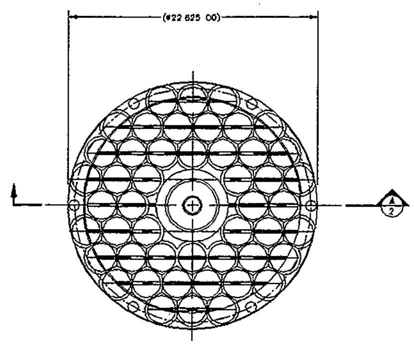
AJ PALOMBI
NC SCHENEWERK
LH GOLDMANN
RC SMITH
ES RUFF
PARSONS ENG. INC.

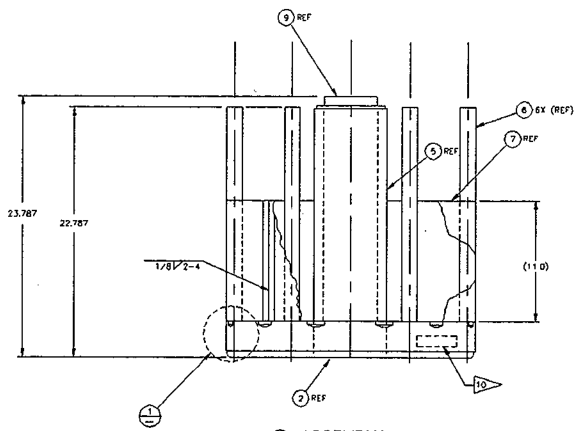
U.S. DEPARTMENT OF ENERGY
DOE Field Office, Richland
MCO PROTOTYPE
SHIELD PLUG
COLLAR SPANNER WRENCH

F SK-2-300460 0
SCALE NOTED 613658 SHEET 1 OF 1

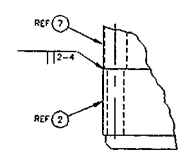
54-6000-027(5/89)

PART/MATERIAL LIST						
-020	-010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO.
	X	-010	ASSEMBLY		1	1
X	1	-020	BASE PLATE		2	2
						3
						4
	AR		PIPE, ⌀ 6" SCHED XXS (.864 WALL) SMLS	ASTM A-312 GR TP 304 OR 304L SST	3	5
	6		BAR, ROUND ⌀1 3/8"	ASTM A-276 TP 304 OR 304L SST	3	6
	1		SHEET METAL, 18 (.05 THK) GA X 11" X 71" L	ASTM A-240 TP 304 OR 304L SST	1	7
	1		BUSHING, BAR ROUND ⌀ 5" X 10" L	ASTM A-276 TP 304 OR 304L SST	3	8
	1		COUPLING, BAR ROUND ⌀ 6 1/4" X 3" L	ASTM A-276 TP 304 OR 304L SST	4	9
1			PLATE, 3" THK	ASTM A-240 TP 304 OR 304L SST	2	10
AR			PLATE 1 3/8" X 5/8"	ASTM A-240 TP 304 OR 304L SST	3	11
						12
AR			BAR, FLAT 1/4" X 1/2"	ASTM A-240 TP 304 OR 304L SST	3	13





1 ASSEMBLY
SCALE: 1/4



1 DETAIL
SCALE: 1/2

GENERAL NOTES:

1. ALL PARTS AND MATERIAL AS SPECIFIED OR ENGINEERING APPROVED EQUAL.
2. ABBREVIATIONS ARE IN ACCORDANCE WITH ASME Y1.1.
3. WELDING SYMBOLS ARE IN ACCORDANCE WITH AWS A2.4.
4. SURFACE TEXTURE SYMBOLS ARE IN ACCORDANCE WITH ANSI/ASME Y14.36. SURFACE TEXTURE VALUES ARE IN MICROINCHES AND ARE IN ACCORDANCE WITH ANSI/ASME B46.1
5. ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125√ OR BETTER
6. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO .06 MAXIMUM.
7. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
8. WELDED SURFACES SHALL BE SMOOTH AND UNIFORM IN APPEARANCE WITHOUT ABRUPT CHANGES IN CONTOUR.
9. SCREW THREADS SHALL BE IN ACCORDANCE WITH ANSI B1.1. ALL THREADED HOLES SHALL HAVE A LEAD-IN CHAMFER OF 90° TO 105° INCLUDED ANGLE EQUAL TO OR SLIGHTLY LARGER THAN THE MAJOR THREAD DIAMETER.
10. MARK WITH "DWG NUMBER H-2-827589", "EMPTY APPROX WEIGHT -XXX LB", AND "NOT FOR USE" PER HS-BS-0015 TYPE 1 (VIBRATORY) OR TYPE 2 (DIE STAMP) OVER PAINT USING 1/4"(MIN) HIGH CHARACTERS.
11. CALCULATED WEIGHT = XXX LB.
12. WELD AND INSPECT PER HS-V-S-0013 PT FINAL PASS.
13. PAINT ALL NON STAINLESS PARTS WITH INORGANIC ZINC-RICH PRIMER PRIOR TO NOTE 10. (CARBOLINE CARBO ZINC 11 OR EQUAL)
14. MATE PARTS IN ACCORDANCE WITH, SHRINK FIT PER FN2 PER ANSI B4.1-1967, R1979.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

DIMENSIONING AND TOLERANCING SHALL BE INTERPRETED PER ANSI Y14.5M-1982
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED

UNSPECIFIED TOLERANCES SHALL BE.

DECIMAL .X ± .1 .XX ± .03 .XXX ± .010

ANGULAR ± 2°

ALL IMPLIED 90° ANGLES SHALL BE PERPENDICULAR WITHIN THE GREATEST TOLERANCE OF THE LINEAR DIMENSIONS

ALL COAXIAL FEATURES SHALL BE CONCENTRIC WITHIN .032 DIAMETER, UNLESS OTHERWISE SPECIFIED.

DWG NO | TITLE — DRAWING TRACEABILITY LIST

REF NUMBER | TITLE — REFERENCES

NEXT USED ON AS ALLOCATED

CADFILE B8275989A | CADCODE WIN95:ACD2:12.4:SS | REVISIONS

B SHEPPARD
DES APR LC COLEMAN
STRESS DM CHENAULT
FAB ENG ES RUFF
PROJ MGR KE SMITH
DES ENG RC CORBIN
STRUCT ENG LL HYDE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.

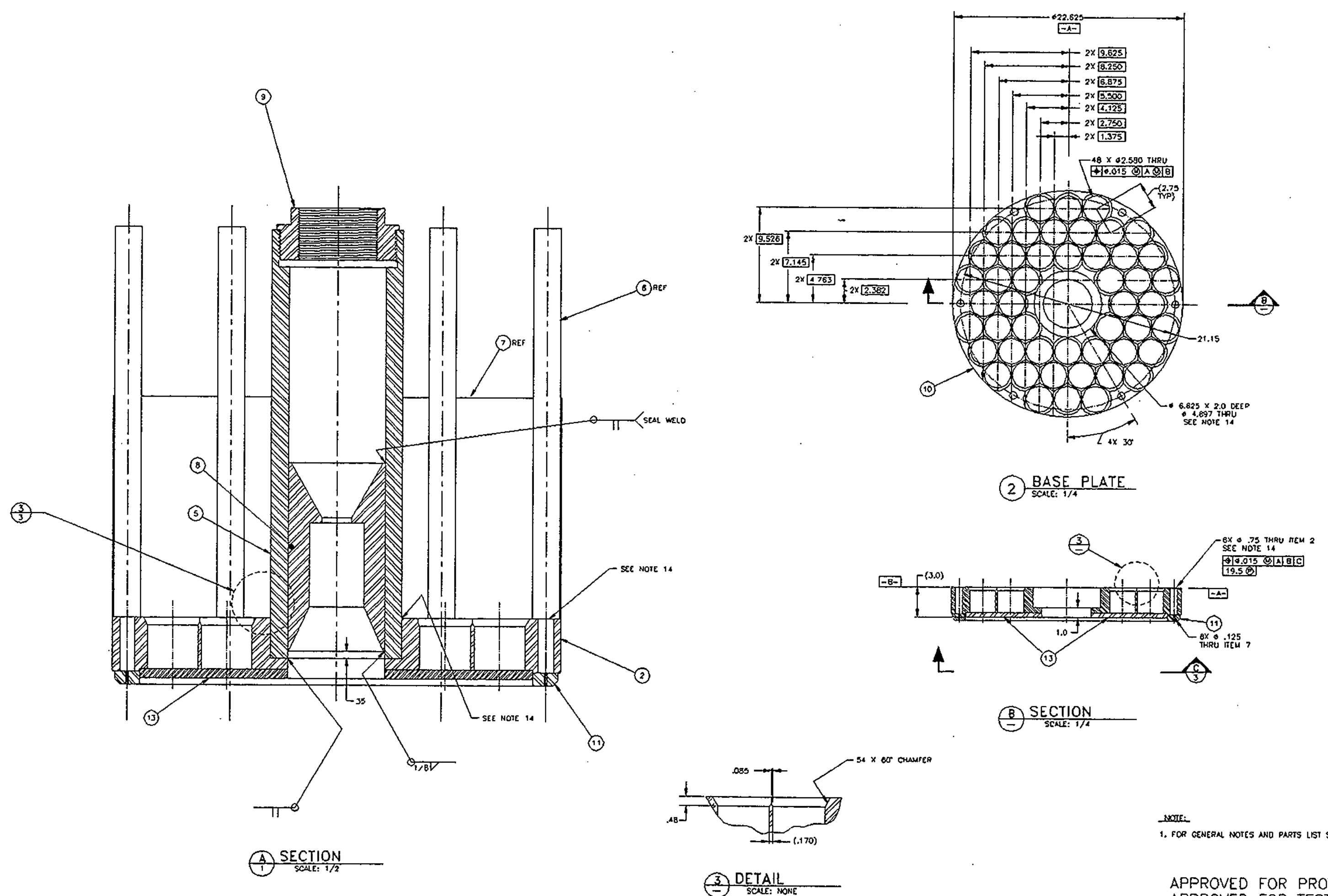
K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK 1A

105K | 2452 | H-2-827589 | B

SHOWN | 1 - 4

2 PLOT SCALE: 1=4 | 1 CTITLE.DWG (10/98)

DWG NO H-2-827589 | SH 1 OF 4 | REV A



NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.
K-BASIN SNF STORAGE BASKET MOCK-UP MARK 1A

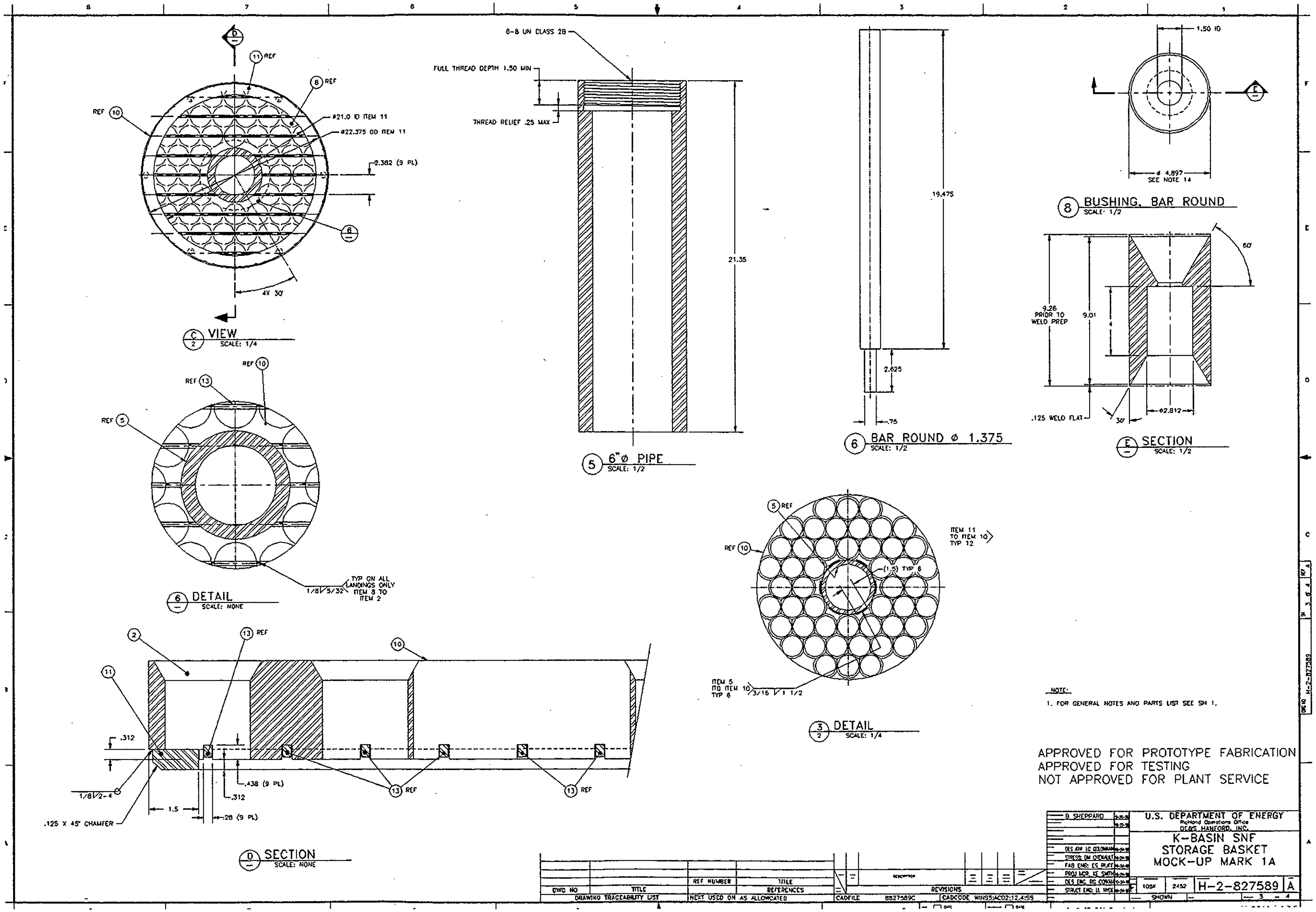
B SHEPPARD
DES AUTH: TC COLDMAN
STRESS: DM CHENAULT
FAB ENG: ES RUFF
PROJ MGR: KE SMITH
DES ENG: RS CONAN
STRUCT ENG: LL HOOE

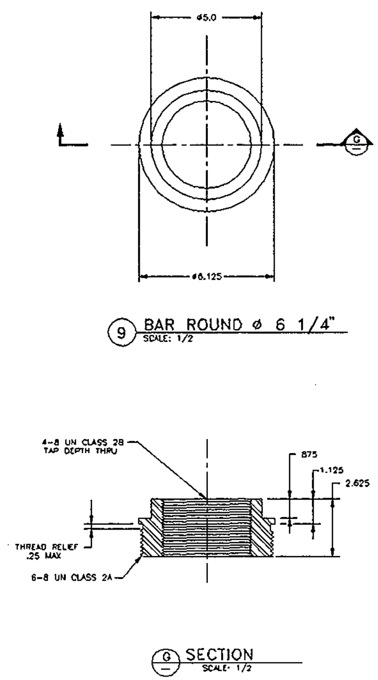
F 105K 2452 H-2-827589 B

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON AS ALLOWCATED	REFERENCES

CADFILE B8275898 REVISIONS CADCODE WIN95:ACO2:12.4:SS

DWG NO H-2-827589 SH 2 OF 4 REV A


C VIEW
SCALE: 1/4
ø21.0 ID ITEM 11
ø22.375 OD ITEM 11
2.382 (9 PL)
4X 30°
6 DETAIL
SCALE: NONE
TYP ON ALL LANDINGS ONLY ITEM 8 TO ITEM 2
D SECTION
SCALE: NONE
.125 X 45° CHAMFER
.438 (9 PL)
.28 (9 PL)
.312
1.5
6-8 UN CLASS 2B
FULL THREAD DEPTH 1.50 MIN
THREAD RELIEF .25 MAX
21.35
5 6"ø PIPE
SCALE: 1/2
19.475
2.625
.75
6 BAR ROUND ø 1.375
SCALE: 1/2
3 DETAIL
SCALE: 1/4
ITEM 11 TO ITEM 10 TYP 12
ITEM 5 TO ITEM 10 TYP 6
(1.5) TYP 6
1.50 ID
ø 4.897 SEE NOTE 14
8 BUSHING, BAR ROUND
SCALE: 1/2
9.26 PRIOR TO WELD PREP
9.01
60°
30°
.125 WELD FLAT
ø2.812
E SECTION
SCALE: 1/2
NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.
APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE
U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.
K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK 1A
B SHEPPARD
H-2-827589
A
DRAWING TRACEABILITY LIST
NEXT USED ON AS ALLOCATED
REVISIONS
CADFILE 8827589C



NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.

K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK 1A

B SHEPPARD

H-2-827589 A

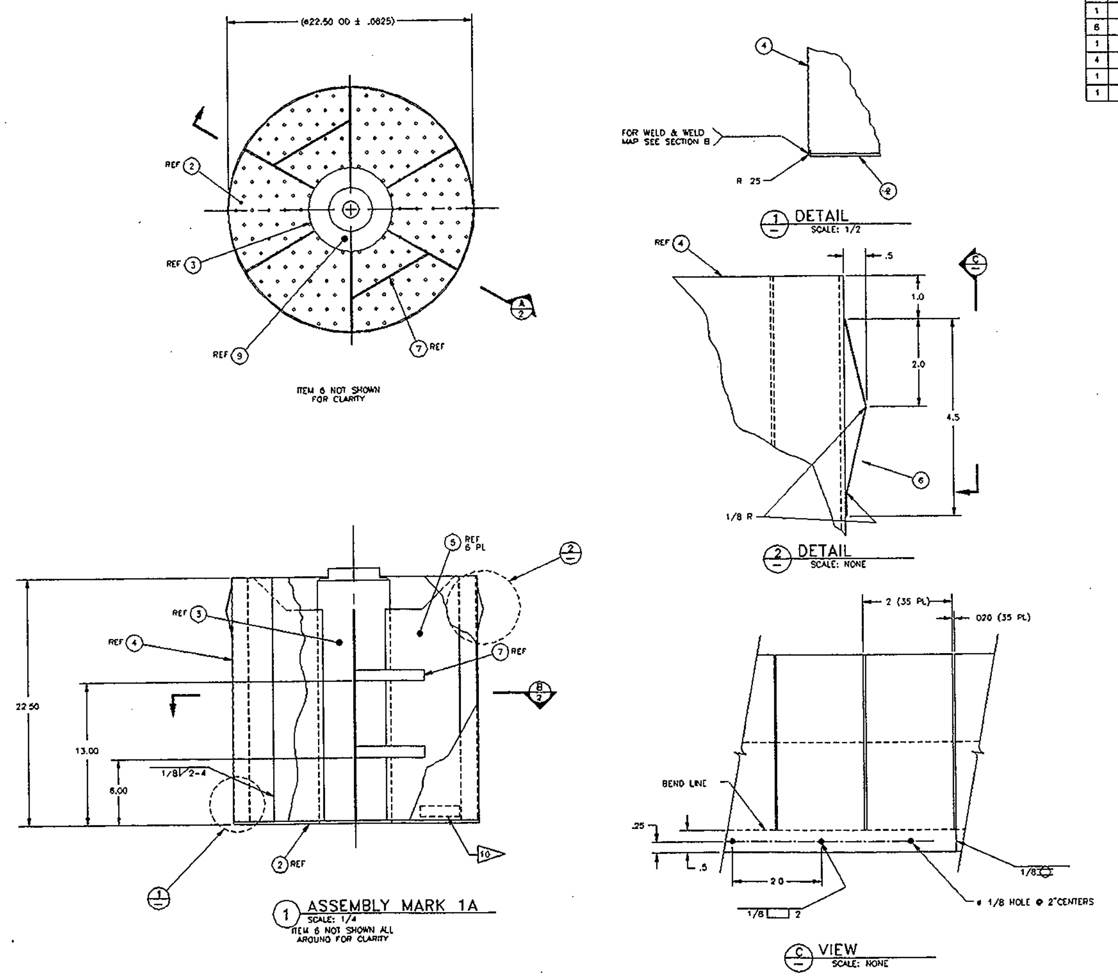
DRAWING TRACEABILITY LIST | NEXT USED ON AS ALLOWCATED | REVISIONS

CADFILE 882759890 CADCODE WN95:ACD2:12.4:55

PLOT SCALE: 1=2

PART/MATERIAL LIST

-010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO.
X	-010	ASSEMBLY		1	1
1		BASE PLATE	SEE NOTE 13	2	2
1	-001	PIPE, ø 6" SCHED XXS (.864 WALL) SMLS	ASTM A-312 GR TP 304 OR 304L SST	3	3
1		PLATE 1/4" THK X 22.25" W X 71"±1/16L	ASTM A-240 TP 304 OR 304L SST	1	4
6	-002	SHEET METAL, 12 GA (.109 THK)	ASTM A-240 TP 304 OR 304L SST	2	5
1		SHEET METAL, 30 GA (.0125 THK) 4 5/8"W X 71"±1/16L	ASTM A-240 TP 304 OR 304L SST	1	6
4		SHEET METAL, 12 GA (.109 THK) 1 "W X L AS REQD	ASTM A-240 TP 304 OR 304L SST	2	7
1	-003	BAR, ROUND ø 6 1/4" X 3" L	ASTM A-276 TP 304 OR 304L SST	3	8
1		BUSHING, BAR ROUND ø 5" X 10" L	ASTM A-276 TP 304 OR 304L SST	3	9



GENERAL NOTES:

1. ALL PARTS AND MATERIAL AS SPECIFIED OR ENGINEERING APPROVED EQUAL.
2. ABBREVIATIONS ARE IN ACCORDANCE WITH ASME Y1.1.
3. WELDING SYMBOLS ARE IN ACCORDANCE WITH AWS A2.4.
4. SURFACE TEXTURE SYMBOLS ARE IN ACCORDANCE WITH ANSI/ASME Y14.36. SURFACE TEXTURE VALUES ARE IN MICROINCHES AND ARE IN ACCORDANCE WITH ANSI/ASME B46.1.
5. ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125/√ OR BETTER.
6. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO .06 MAXIMUM.
7. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
8. WELDED SURFACES SHALL BE SMOOTH AND UNIFORM IN APPEARANCE WITHOUT ABRUPT CHANGES IN CONTOUR.
9. SCREW THREADS SHALL BE IN ACCORDANCE WITH ANSI B1.1. ALL THREADED HOLES SHALL HAVE A LEAD-IN CHAMFER OF 90° TO 108° INCLUDED ANGLE EQUAL TO OR SLIGHTLY LARGER THAN THE MAJOR THREAD DIAMETER.
10. MARK WITH "DWG NUMBER H-2-827590", "EMPTY APPROX WEIGHT =230 LB", AND "NOT FOR USE" PER HS-BS-0015 TYPE 1 (VIBRATORY) OR TYPE 2 (DIE STAMP) USING 1/4"(MIN) HIGH CHARACTERS
11. CALCULATED WEIGHT = 230 LB.
12. WELD AND INSPECT PER HS-V-S-0013 PT FINAL PASS.
13. PERFORATED PLATE 1/4" THK, W/ø 1/4" X 1 1/2" CENTER STAGGERED PATTERN SST 304. (McNICHOLS CO.)
14. MATE PARTS IN ACCORDANCE WITH, SHRINK FIT PER FN2 PER ANSI B4.1-1967, R1979.

DIMENSIONING AND TOLERANCING SHALL BE INTERPRETED PER ANSI Y14.5M-1982
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
UNSPECIFIED TOLERANCES SHALL BE:
DECIMAL .X ±.1 .XX ±.03 .XXX ±.010
ANGULAR ± 2°
ALL IMPLIED 90° ANGLES SHALL BE PERPENDICULAR WITHIN THE GREATEST TOLERANCE OF THE LINEAR DIMENSIONS
ALL COAXIAL FEATURES SHALL BE CONCENTRIC WITHIN .032 DIAMETER, UNLESS OTHERWISE SPECIFIED.

DWG NO | TITLE — DRAWING TRACEABILITY LIST
REF NUMBER | TITLE — REFERENCES — NEXT USED ON AS ALLOCATED
REVISIONS — CADFILE B827590A — CADCODE WN95:ACD2:12 4:SS

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

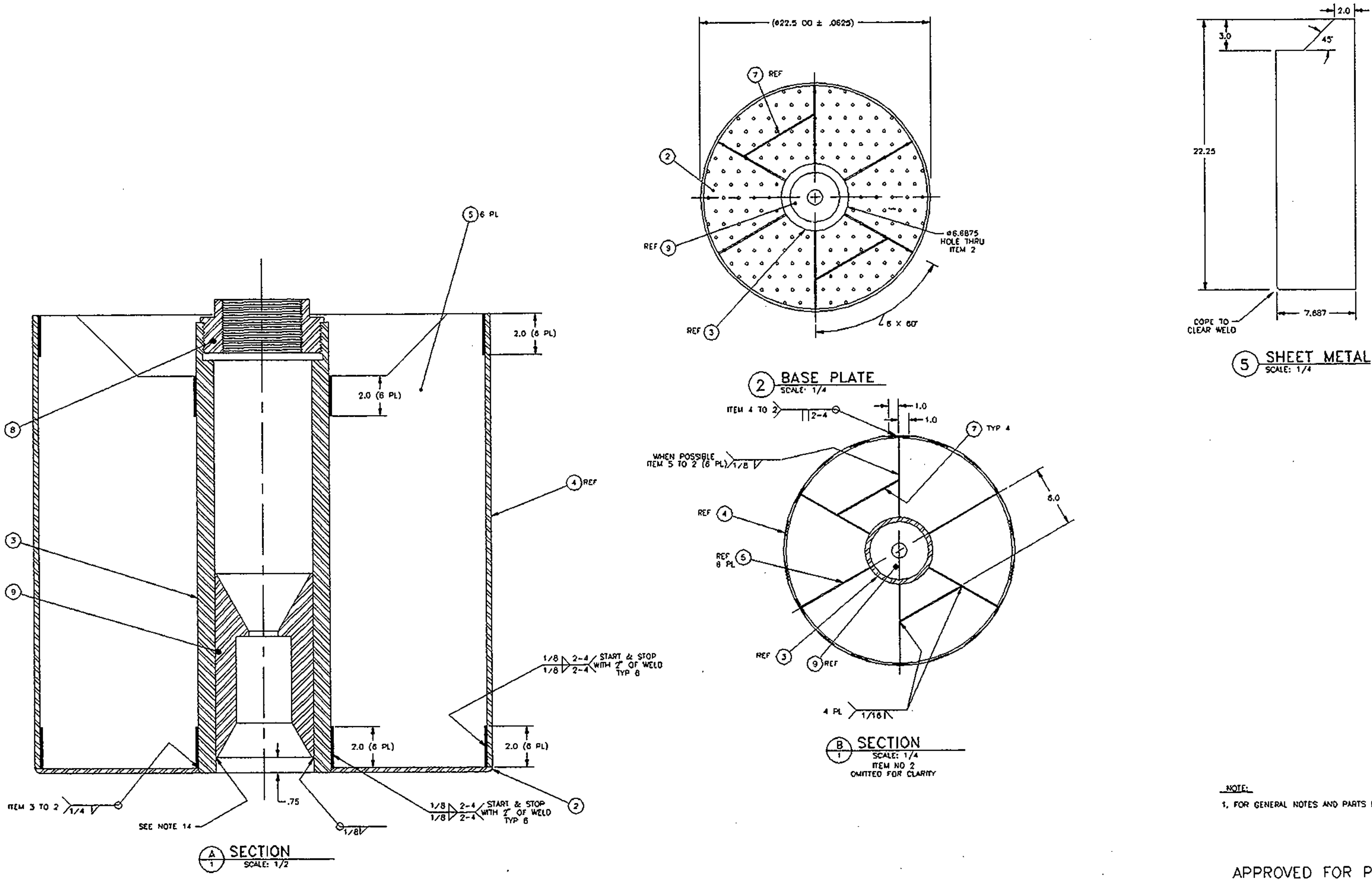
B SHEPPARD
DES AUTH: LG GOLDMANN
STRESS: DM CHENAULT
FAB ENG: ES RUFF
PROJ MGR: KE SMITH
DES ENG: RG COMAN
STRUCR ENG: LL HYDE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.

K-BASIN SNF
STORAGE SCRAP BASKET
MOCK-UP MARK 1A

105K | 2452 | H-2-827590 | B
SHOWN — 1 — 3

PLOT SCALE: 1=4 GTITLE.DWG (10/96)



NOTE:

1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.

K-BASIN SNF
STORAGE SCRAP BASKET
MOCK-UP MARK 1A

B SHEPPARD

105K | 2452 | H-2-827590 | B

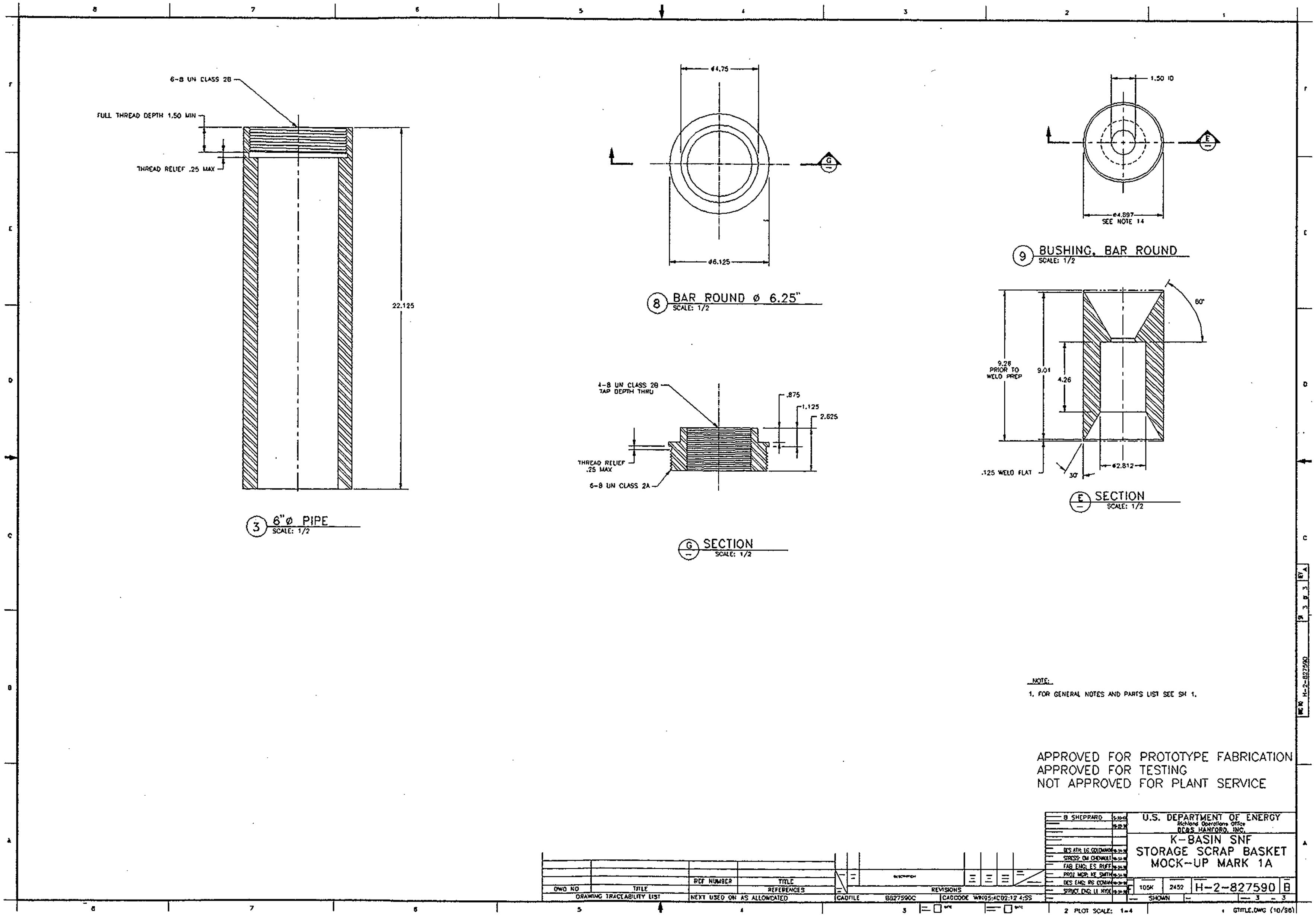
SHOWN | 2 | 3

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON AS ALLOWCATED	REFERENCES

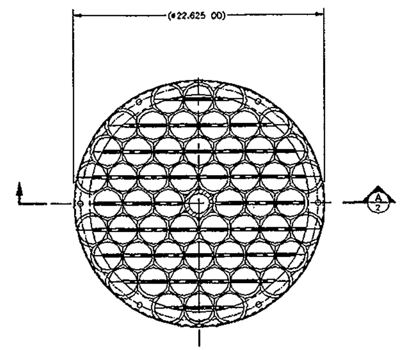
REVISIONS

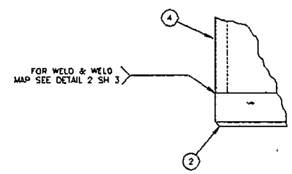
CADFILE B8275908 CADCODE WIN95:ACD2:12 4:SS

2 PLOT SCALE: 1=4 GTITLE.DWG (10/98)

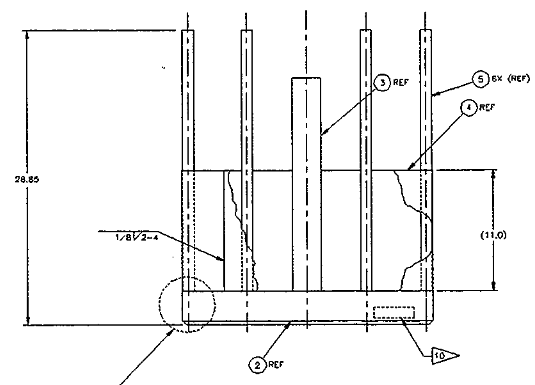

6-8 UN CLASS 2B
FULL THREAD DEPTH 1.50 MIN
THREAD RELIEF .25 MAX
22.125
3 6"ø PIPE
SCALE: 1/2
ø4.75
ø6.125
8 BAR ROUND ø 6.25"
SCALE: 1/2
4-8 UN CLASS 2B
TAP DEPTH THRU
.875
1.125
2.625
THREAD RELIEF
.25 MAX
6-8 UN CLASS 2A
G SECTION
SCALE: 1/2
1.50 ID
ø4.897
SEE NOTE 14
9 BUSHING, BAR ROUND
SCALE: 1/2
60°
9.26
PRIOR TO
WELD PREP
9.01
4.26
.125 WELD FLAT
30°
ø2.812
E SECTION
SCALE: 1/2
NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.
APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE
B SHEPPARD
U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.
K-BASIN SNF
STORAGE SCRAP BASKET
MOCK-UP MARK 1A
H-2-827590 B
DWG NO
TITLE
DRAWING TRACEABILITY LIST
REF NUMBER
TITLE
REFERENCES
NEXT USED ON AS ALLOCATED
REVISIONS
CADFILE 8827590C
PLOT SCALE: 1=4
SHOWN

PART/MATERIAL LIST						
-020	-010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO.
	X	-010	ASSEMBLY		1	1
X	1	-020	BASE PLATE		2	2
	AR	-001	TUBING, ⌀ 2.75" OD X .500 WALL	ASTM A-269 GR TP 304 OR 304L SST	3	3
	1		SHEET METAL 18 GA (.05 THK)11 X 71" L	ASTM A-240 TP 304 OR 304L SST	1	4
	6	-002	BAR, ROUND ⌀1 1/4"	ASTM A-276 TP 304 OR 304L SST	3	5
1			PLATE, 3" THK	ASTM A-240 TP 304 OR 304L SST	2	6
AR			PLATE 3/8" X 1 1/4"	ASTM A-240 TP 304 OR 304L SST	3	7
AR			BAR, FLAT 1/4" X 3/8"	ASTM A-240 TP 304 OR 304L SST	3	8





DETAIL 1
SCALE: 1/4



ASSEMBLY 1
SCALE: 1/4

GENERAL NOTES:

1. ALL PARTS AND MATERIAL AS SPECIFIED OR ENGINEERING APPROVED EQUAL.
2. ABBREVIATIONS ARE IN ACCORDANCE WITH ASME Y1.1.
3. WELDING SYMBOLS ARE IN ACCORDANCE WITH AWS A2.4.
4. SURFACE TEXTURE SYMBOLS ARE IN ACCORDANCE WITH ANSI/ASME Y14.36. SURFACE TEXTURE VALUES ARE IN MICROINCHES AND ARE IN ACCORDANCE WITH ANSI/ASME B46.1.
5. ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125/√ OR BETTER.
6. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO .06 MAXIMUM.
7. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
8. WELDED SURFACES SHALL BE SMOOTH AND UNIFORM IN APPEARANCE WITHOUT ABRUPT CHANGES IN CONTOUR.
9. SCREW THREADS SHALL BE IN ACCORDANCE WITH ANSI B1.1. ALL THREADED HOLES SHALL HAVE A LEAD-IN CHAMFER OF 90° TO 108° INCLUDED ANGLE EQUAL TO OR SLIGHTLY LARGER THAN THE MAJOR THREAD DIAMETER.
10. MARK WITH "DWG NUMBER H-2-827591", "EMPTY APPROX WEIGHT -160 LB", AND "NOT FOR USE" PER HS-BS-0015 TYPE 1 (VIBRATORY) OR TYPE 2 (DIE STAMP) OVER PAINT USING 1/4"(MIN) HIGH CHARACTERS
11. CALCULATED WEIGHT = 160 LB.
12. WELD AND INSPECT PER HS-V-S-0013 PT FINAL PASS.
13. PAINT ALL NON STAINLESS PARTS WITH INORGANIC ZINC-RICH PRIMER PRIOR TO NOTE 10. (CARBOLINE CARBO ZINC 11 OR EQUAL)
14. MATE PARTS IN ACCORDANCE WITH, SHRINK FIT PER FN2 PER ANSI B4.1-1967, R1979.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

DIMENSIONING AND TOLERANCING SHALL BE INTERPRETED PER ANSI Y14.5M-1982
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
UNSPECIFIED TOLERANCES SHALL BE:
DECIMAL .X ± .1 .XX ± .03 .XXX ± .010
ANGULAR ± 2°
ALL IMPLIED 90° ANGLES SHALL BE PERPENDICULAR WITHIN THE GREATEST TOLERANCE OF THE LINEAR DIMENSIONS
ALL COAXIAL FEATURES SHALL BE CONCENTRIC WITHIN .032 DIAMETER, UNLESS OTHERWISE SPECIFIED.

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON AS ALLOWCATED	REFERENCES

REVISIONS
CADFILE B827591A CADCODE WN95:AC02:12 4:55

B SHEPPARD
DES APR: LG COLEMAN
STRESS: DM CHENAULT
FAB ENG: ES RUFF
PROJ MGR: KE SMITH
DES ENG: RG COWAN
STRUCT ENG: LL HYDE

U.S. DEPARTMENT OF ENERGY
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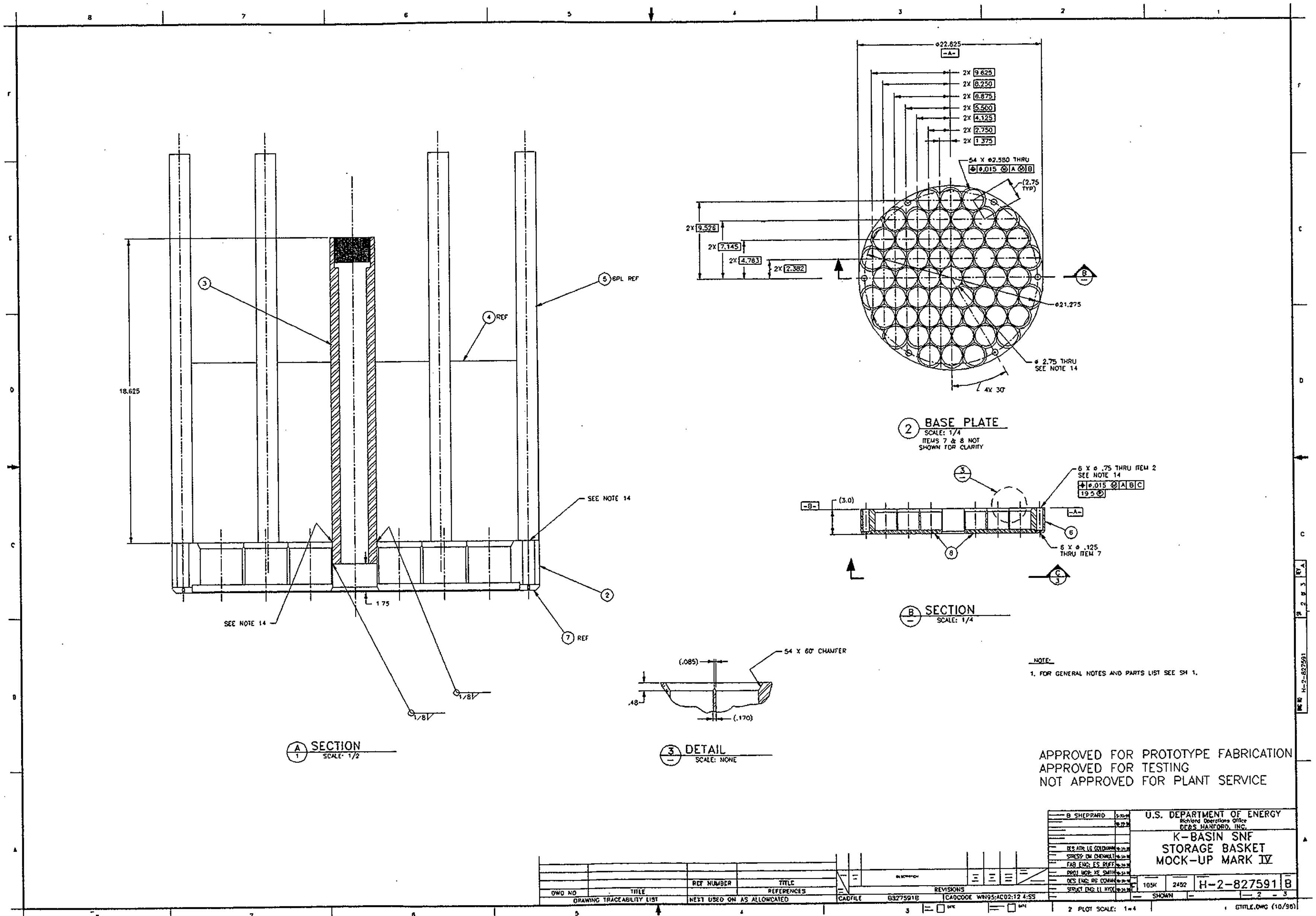
DE&S HANFORD, INC.

K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK IV

F 105K 2452 H-2-827591 B
SHOWN 1 3

2 PLOT SCALE: 1=4 GTITLE.DWG (10/96)

DWG NO H-2-827591 SH 1 of 3 REV A



18.625
SEE NOTE 14
1.75
1/8
SECTION A
SCALE: 1/2
BASE PLATE
SCALE: 1/4
ITEMS 7 & 8 NOT SHOWN FOR CLARITY
SECTION B
SCALE: 1/4
DETAIL 3
SCALE: NONE
54 X 60° CHAMFER
(.085)
(.170)
.48
⌀22.625
⌀21.275
54 X ⌀2.580 THRU
⌀ 2.75 THRU SEE NOTE 14
4X 30°
(2.75 TYP)
2X 9.625
2X 8.250
2X 6.875
2X 5.500
2X 4.125
2X 2.750
2X 1.375
2X 9.526
2X 7.145
2X 4.763
2X 2.382
6 X ⌀ .75 THRU ITEM 2 SEE NOTE 14
6 X ⌀ .125 THRU ITEM 7
(3.0)
REF
SPL REF
NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.
APPROVED FOR PROTOTYPE FABRICATION
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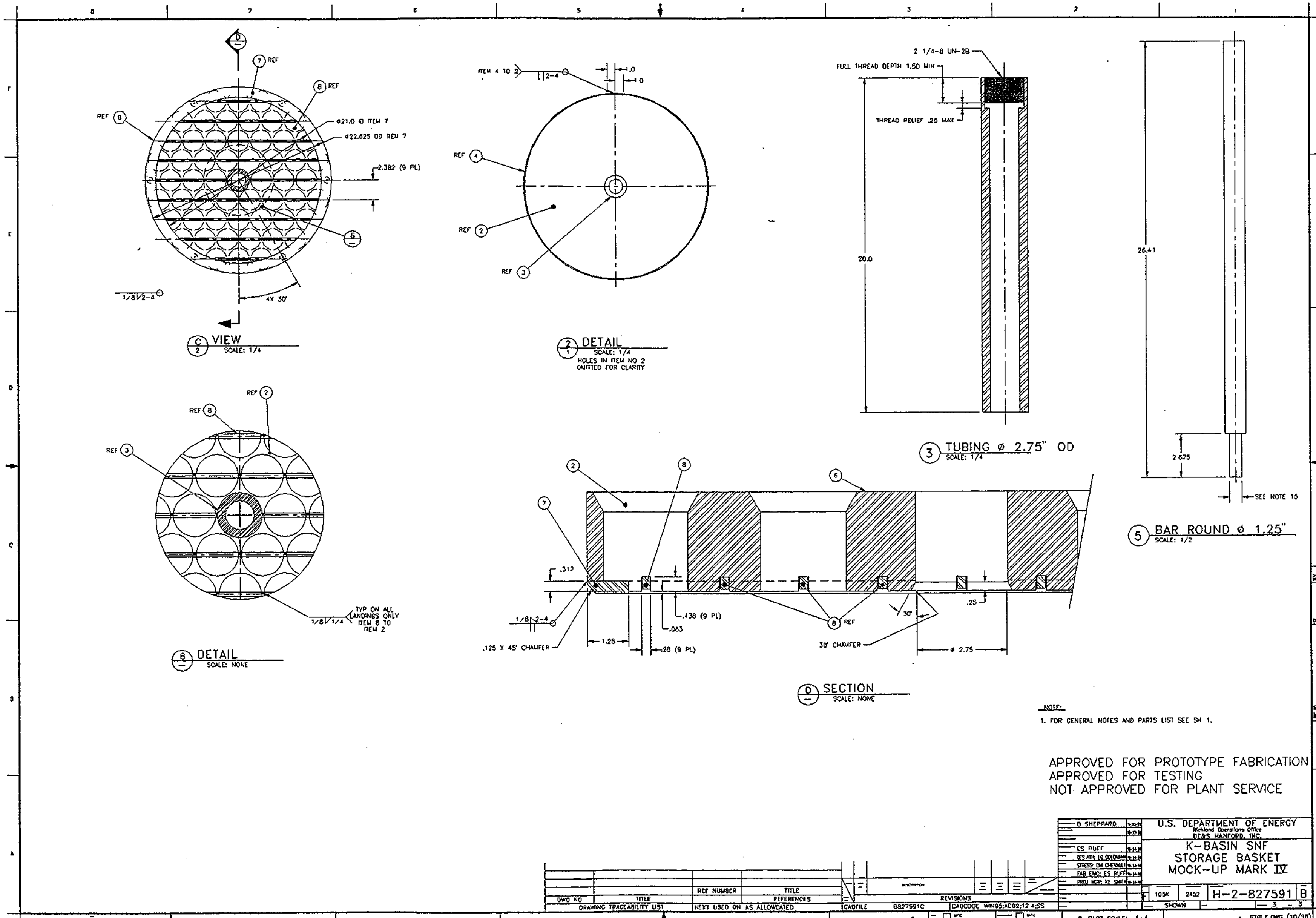
K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK IV
B SHEPPARD
H-2-827591 B
DRAWING TRACEABILITY LIST
NEXT USED ON AS ALLOWCATED
REVISIONS
PLOT SCALE: 1=4



NOTE:
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APPROVED FOR TESTING
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U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.
K-BASIN SNF
STORAGE BASKET
MOCK-UP MARK IV

B SHEPPARD
ES RUFF
FAB ENG ES RUFF

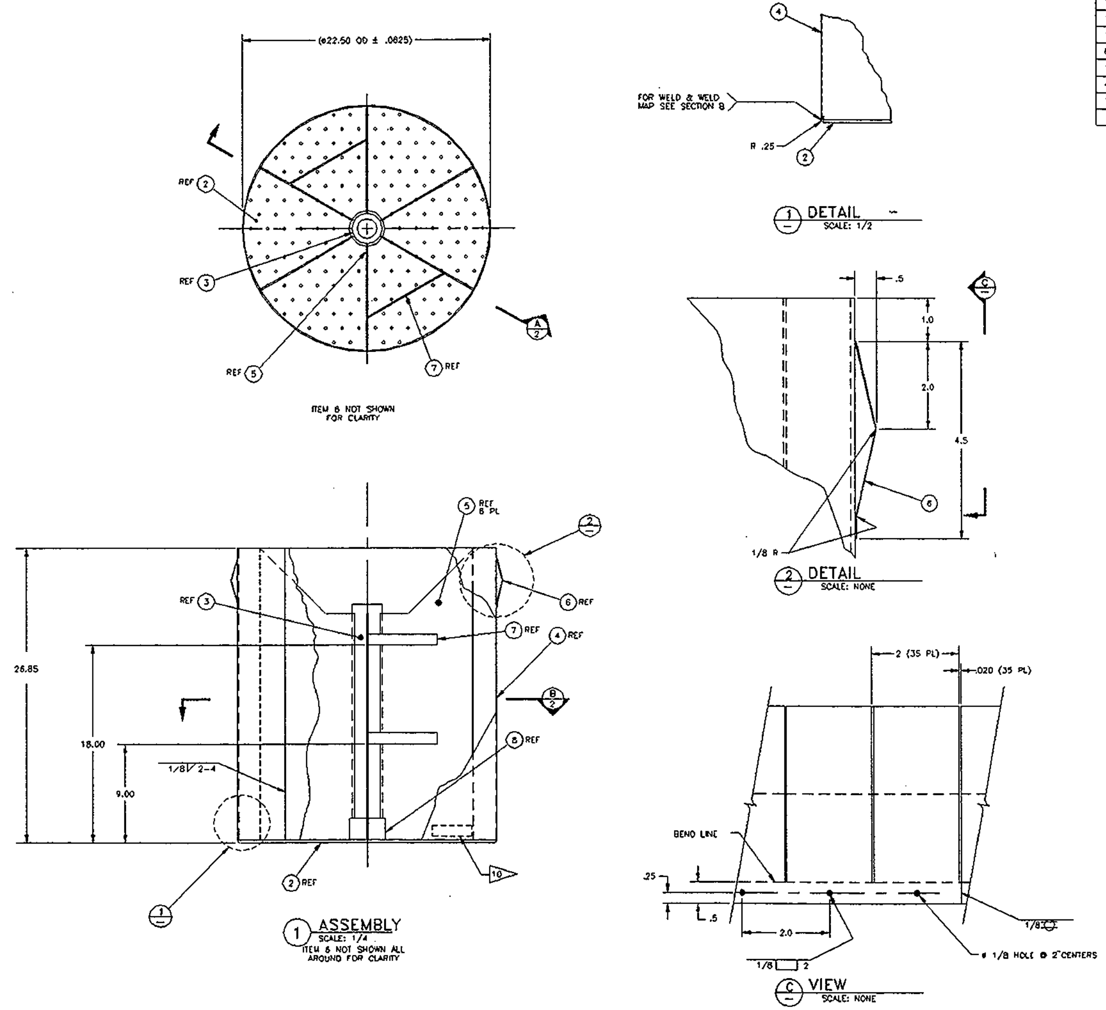
105K | 2452 | H-2-827591 | B
SHOWN | 3 of 3

DWG NO | TITLE | REF NUMBER | TITLE
DRAWING TRACEABILITY LIST | NEXT USED ON AS ALLOCATED | REFERENCES

REVISIONS
CADFILE B827591C | CADCODE WIN95:ACD2:12 4:SS
PLOT SCALE: 1=4
GTITLE.DWG (10/96)

H-2-827591 SH 3 OF 3 REV A

PART/MATERIAL LIST					
-010	PART/DASH NUMBER	NOMENCLATURE/DESCRIPTION	MATERIAL/REFERENCE	SHEET	ITEM NO.
X	-010	ASSEMBLY		1	1
1		BASE PLATE	SEE NOTE 13	2	2
1	-001	TUBING, ø 2.75" OD X .500 WALL	ASTM A-269 GR TP 304 OR 304L SST	2	3
1		SHEET METAL, 12 GA (.109 THK)26.6"W X 71"±1/16L	ASTM A-240 TP 304 OR 304L SST	1	4
6	-002	SHEET METAL, 12 GA (.109 THK)	ASTM A-240 TP 304 OR 304L SST	2	5
1		SHEET METAL, 30 GA (.0125 THK) 4 5/8"W X 71"±1/16L	ASTM A-240 TP 304 OR 304L SST	1	6
4		SHEET METAL, 12 GA (.109 THK) 1 "W X L AS REQD	ASTM A-240 TP 304 OR 304L SST	2	7
1	-003	TUBING, ø 3.25" OD X .500 WALL X 2.25 L	ASTM A-269 GR TP 304 OR 304L SST	2	8



GENERAL NOTES:

1. ALL PARTS AND MATERIAL AS SPECIFIED OR ENGINEERING APPROVED EQUAL.
2. ABBREVIATIONS ARE IN ACCORDANCE WITH ASME Y1.1.
3. WELDING SYMBOLS ARE IN ACCORDANCE WITH AWS A2.4.
4. SURFACE TEXTURE SYMBOLS ARE IN ACCORDANCE WITH ANSI/ASME Y14.36. SURFACE TEXTURE VALUES ARE IN MICROINCHES AND ARE IN ACCORDANCE WITH ANSI/ASME B46.1.
5. ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125√ OR BETTER.
6. REMOVE ALL BURRS AND BREAK ALL SHARP EDGES TO .06 MAXIMUM.
7. ALL UNSPECIFIED MACHINE TOOL RADII SHALL BE .03 MAXIMUM.
8. WELDED SURFACES SHALL BE SMOOTH AND UNIFORM IN APPEARANCE WITHOUT ABRUPT CHANGES IN CONTOUR.
9. SCREW THREADS SHALL BE IN ACCORDANCE WITH ANSI B1.1. ALL THREADED HOLES SHALL HAVE A LEAD-IN CHAMFER OF 90° TO 108° INCLUDED ANGLE EQUAL TO OR SLIGHTLY LARGER THAN THE MAJOR THREAD DIAMETER.
10. MARK WITH "DWG NUMBER H-2-827592", "EMPTY APPROX WEIGHT -150 LB", AND "NOT FOR USE" PER HS-BS-0015 TYPE 1 (VIBRATORY) OR TYPE 2 (DIE STAMP) USING 1/4"(MIN) HIGH CHARACTERS
11. CALCULATED WEIGHT = 150 LB.
12. WELD AND INSPECT PER HS-V-S-0013 PT FINAL PASS.
13. PERFORATED PLATE 1/4" THK, W/ø 1/4" X 1 1/2" CENTER STAGGERED PATTERN SST 304. (McNICHOLS CO.)

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
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DIMENSIONING AND TOLERANCING SHALL BE INTERPRETED PER ANSI Y14.5M-1982
DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED
UNSPECIFIED TOLERANCES SHALL BE:
DECIMAL .X ± .1 .XX ± .03 .XXX ± .010
ANGULAR ± 2°
ALL IMPLIED 90° ANGLES SHALL BE PERPENDICULAR WITHIN THE GREATEST TOLERANCE OF THE LINEAR DIMENSIONS
ALL COAXIAL FEATURES SHALL BE CONCENTRIC WITHIN .032 DIAMETER, UNLESS OTHERWISE SPECIFIED.

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON AS ALLOWCATED	REFERENCES

REVISIONS
CADFILE B827592A CADCODE WN95:AC02:12 4:55

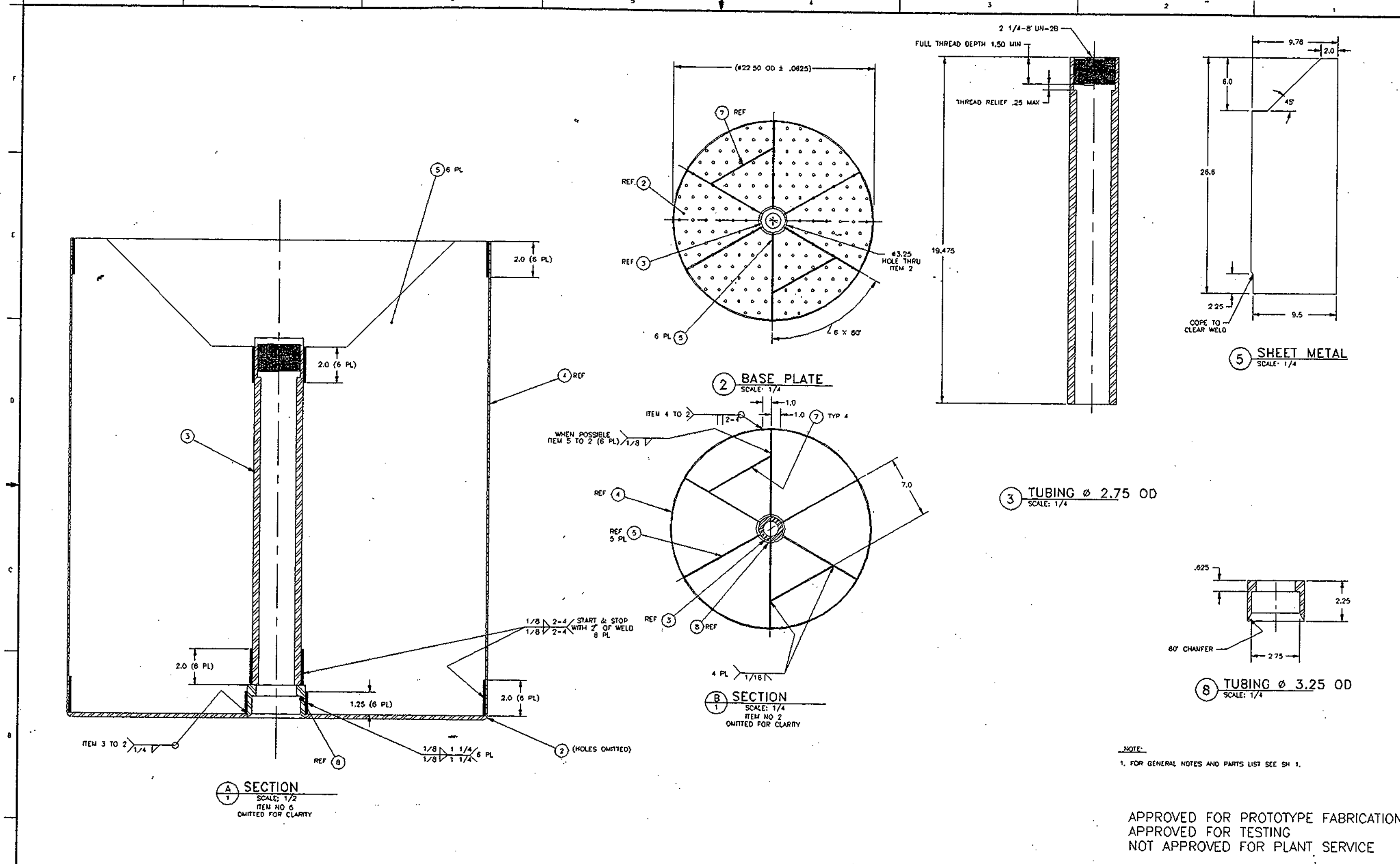
B SHEPPARD
DES ATH: LG COLDMAN
STRESS: DB CHENAULT
FAB ENG: ES RUFF
PROJ MGR: KE SMITH
DES ENG: RG COWAN
STRUCT ENG: LL HYDE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.

K-BASIN SNF
STORAGE SCRAP BASKET
MOCK-UP MARK IV

F 105K 2452 H-2-827592 B
SHOWN 1 2

2 PLOT SCALE: 1=4 GTITLE.DWG (10/96)



NOTE:
1. FOR GENERAL NOTES AND PARTS LIST SEE SH 1.

APPROVED FOR PROTOTYPE FABRICATION
APPROVED FOR TESTING
NOT APPROVED FOR PLANT SERVICE

U.S. DEPARTMENT OF ENERGY
Richland Operations Office
DE&S HANFORD, INC.
K-BASIN SNF STORAGE SCRAP BASKET MOCK-UP MARK IV
B SHEPPARD
H-2-827592 B
105K 2452
SHOWN 2 of 2
PLOT SCALE: 1=4
CADFILE B8275928 CADCODE WN95:AC02:12 4:55

DWG NO	TITLE	REF NUMBER	TITLE
DRAWING TRACEABILITY LIST		NEXT USED ON AS ALLOWCATED	REFERENCES

PART B: PACKAGE EVALUATION

1.0 INTRODUCTION

1.1 SAFETY EVALUATION METHODOLOGY

The Multicanister Overpack (MCO) Cask has been analyzed to meet the requirements of WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, for the onsite transport of Type B, fissile material and the MCO Cask specific requirements of the packaging design criteria (Edwards 1997). The onsite normal transport conditions and accident conditions were analyzed as demonstrated in this part. The MCO Cask meets the criteria for those conditions.

The MCO Cask was designed by Transnuclear, Inc. (TN) under contract with Westinghouse Hanford Company. The design has been formally reviewed at Hanford in accordance with the requirements of WHC-CM-6-1, *Standard Engineering Practices*.

The analyses detailed in this part for normal transport conditions include a 0.3-m (1.0-ft) drop onto a concrete surface in an orientation to cause the most damage, elevated and reduced external pressure, increased internal pressure, hot and cold conditions, penetration, vibration normally incident to transportation, lifting, and tiedown loadings. Accident conditions evaluated include a 9.1-m (30-ft) drop onto a concrete surface when the MCO is dry; a 6.4-m (21-ft) drop onto a concrete surface when the MCO is water-filled; and a 6-minute, fully engulfing, 800 °C (1475 °F) fire followed by a quench. The analyses show that the MCO Cask maintains leaktight containment of the spent fuel through all normal transport and accident conditions. Therefore, the MCO Cask system meets onsite transportation safety criteria (Mercado 1994) based on MCO Cask system design and operational control.

Fabrication leakage rate testing and assembly leakage rate testing are performed per American National Standards Institute (ANSI) Standard N14.5 (ANSI 1987). That leak testing will demonstrate that the MCO Cask was fabricated and assembled in a manner in which leaktightness (per ANSI N14.5) is ensured. Part B, Sections 4.0 and 7.0, demonstrate that leaktight containment boundary is maintained for the postulated onsite accidents.

1.2 EVALUATION CONCLUSIONS

The MCO Cask is safe for the onsite transfer of MCOs loaded with fuel elements from the N Reactor as demonstrated by this safety analysis report for packaging (SARP). All operations and acceptance requirements and tests shall be conducted and documented as stated in Part A of this SARP.

1.2.1 Contents

The contents evaluated in Part B, Section 2.0, of this SARP are the MCO filled with 270 Mark IV or 288 Mark IA fuel elements from the N Reactor.

1.2.2 Radiological Risk

The radiological risk evaluation in Part B, Section 3.0, demonstrates that the system design meets the onsite transportation safety criteria (Mercado 1994) as required by WHC-CM-2-14.

1.2.3 Containment

Part B, Section 4.0, together with the structural analyses in Part B, Section 7.0, demonstrates that the MCO Cask leaktight containment boundary is maintained throughout all normal transport conditions and onsite accident conditions. Part B, Section 4.7.2, demonstrates that the leakage rate testing of the containment boundary will result in a higher dose to test personnel than a leaking MCO Cask. Therefore, leakage rate testing of the containment boundary will not be performed prior to each shipment.

1.2.4 Shielding

As shown by Part B, Section 5.0, the general surface dose rate on the accessible surface of the package is maintained below 200 mrem/h on contact, and the maximum surface dose rate at any radiation hot spot on the package does not exceed 1000 mrem/h. The package shielding is maintained below 10 mrem/h at 2 m during normal transport conditions, and below 1000 mrem/h at 1 m for accident conditions. Therefore, the package meets transportation criteria.

1.2.5 Criticality

Subcriticality of the package is demonstrated in Part B, Section 6.0, which shows that k_{eff} is less than 0.95 for all conditions when the fuel is dry. In order to show subcriticality when the MCO is fully flooded with water, any baskets of fuel scrap loaded into the MCO must be at the top or bottom of the MCO, not in the center.

1.2.6 Structural

The structural analysis (Part B, Section 7.0) shows that the MCO Cask package meets criteria identified in the packaging design criteria (Edwards 1997) for all onsite normal transport and accident conditions. The structural analysis shows there are sufficient safety factors for the MCO Cask, which is demonstrated by stress levels observed in the package remaining below Service Level A stress allowables specified in American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Subsection NB (ASME 1995), during normal conditions of transfer and below Service Level D Stress allowables specified in ASME B&PV Code, Section III, Subsection NB (ASME 1995), during accident conditions. The MCO center criticality control tube for Mark IA fuel is demonstrated to remain intact and within 5 cm (2 in.) of the center of the MCO during all accident conditions.

1.2.7 Thermal

The package contents have a maximum decay heat of 835 W per cask. As shown in Part B, Section 8.4.4.2, the gas generation rate in the MCO at 75 °C must be less than 1.4 kPa (0.2 psi) per hour after completion of the cold vacuum drying (CVD) process in order to prevent a runaway uranium-water corrosion reaction during the transfer from the Cold Vacuum Drying Facility (CVDF) to the Canister Storage Building (CSB). If that runaway corrosion reaction was to occur, venting the package or cooling the cask with water would not be able to stop the reaction. The shipping window for the package is 24 hours from the K Basins to the CVDF and 36 hours from the CVDF to the CSB. If those shipping windows are exceeded, the actions described in Part A, Section 6.4, must be taken.

1.2.8 Gas Generation

As shown in Part B, Section 9.0, the package contents can produce hydrogen through the reaction of uranium and residual water in the MCO. Backfilling both the MCO Cask and the MCO with helium will prevent flammable or explosive mixtures of gas from forming within the package. The total pressure inside the MCO Cask or the MCO will not exceed their 1034-kPa (150-psig) design pressures within the applicable shipping windows.

1.2.9 Tiedown System

The MCO Cask tiedown system was designed specifically for the MCO Cask. Part B, Section 10.0, shows that the tiedown system keeps the cask on the transport trailer under all transfer conditions.

1.3 REFERENCES

ANSI, 1987, *American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment*, ANSI Standard N14.5-1987, American National Standards Institute, New York, New York.

ASME, 1995, Section III, Subsection NB, *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.

Edwards, W. S., 1997, *Packaging Design Criteria for the MCO Cask*, HNF-SD-TP-PDC-030, Rev. 4, Rust Federal Services Inc., Northwest Operations, Richland, Washington.

Mercado, J. E., 1994, *Report on Equivalent Safety for Transportation and Packaging of Radioactive Materials*, WHC-SD-TP-RPT-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

WHC-CM-6-1, *Standard Engineering Practices*, Westinghouse Hanford Company, Richland, Washington.

2.0 CONTENTS EVALUATION

2.1 CHARACTERIZATION

Spent nuclear reactor fuel has been stored in water from the beginning of operations at the Hanford Site. Fuels in the K Basins have been in storage for up to about 23 years, and even the youngest fuels have been in the basins for at least 7.5 years.

A detailed description of the source terms used in evaluating K Basin fuel is provided in Willis (1995). Separate source terms were developed in Willis (1995) to represent the worst-case shielding, dose consequence, heating, and criticality. Source terms were evaluated according to the length of time the fuel has been in the reactor and the decay time between discharge and expected shipment. The length of time an assembly has been irradiated is proportional to the amount of ^{240}Pu in the discharged fuel and will be used as a reference for the amount of burnup, or exposure time in the reactor, throughout this document.

Development of the source terms emphasized providing a best estimate of the actual bounds of material compositions with a minimum of conservatism. The decay date selected for presenting radionuclide inventories and bounds was December 31, 1997.

Accountability records were used as a basis for the quantity, exposure variation, and decay time variation of stored fuel. Radionuclide estimates were derived using the RADNUC computer code (Schwarz 1995), which generates radionuclide inventories by interpolating ORIGEN2 data (Schmittroth 1994) using the exposure and decay time information from the accountability database.

The ^{85}Kr data provided in these tables assumes there has been no release of this gaseous isotope from the fuel. Single Pass Reactor fuel is not included in this evaluation.

As more characterization data become available, these source terms may be revised. Changes to the source term will be evaluated by Packaging Engineering, and those evaluations will be maintained in Packaging Engineering files. If those evaluations determine that the existing SARP source term is conservative, this section may not be updated. If the new source term is conservative, this section will be updated.

2.1.1 Shielding Source Term

The shielding source term was selected on the basis of the fuel having the highest ^{137}Cs content, because ^{137}Cs is the major contributor to the gamma-ray source term. The fuel with the highest ^{137}Cs content is Mark IV fuel with a ^{240}Pu content of 15.74% when discharged from the reactor. For conservatism, the shielding source term is defined as Mark IV fuel with 16% ^{240}Pu that has been aged 13 years to December 31, 1997. Table B2-1 lists the curie inventories per MTU and per MCO, where one MCO full of Mark IV fuel contains 6.34 MTU for the shielding source term as reproduced from the Willis (1995) document. The neutron and photon source terms are both derived from the values shown in Table B2-1.

Table B2-1. Shielding and Heat Generation Source for a Multicanister Overpack (MCO).

Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)	Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)
^{3}H	4.11 E+01	2.6 E+02	^{127m}Te	3.10 E-10	2.0 E-09
^{14}C	5.27 E-01	3.3 E+00	^{129}I	4.88 E-03	3.1 E-02
^{55}Fe	5.85 E+00	3.7 E+01	^{134}Cs	1.23 E+02	7.8 E+02
^{60}Co	6.62 E+00	4.2 E+01	^{135}Cs	5.77 E-02	3.7 E-01
^{59}Ni	3.03 E-02	1.9 E-01	^{137}Cs	1.14 E+04	7.2 E+04
^{63}Ni	3.55 E+00	2.3 E+01	^{137m}Ba	1.08 E+04	6.8 E+04
^{79}Se	6.23 E-02	3.9 E-01	^{144}Ce	2.53 E+00	1.6 E+01
^{85}Kr	6.38 E+02	4.0 E+03	^{144}Pr	2.50 E+00	1.6 E+01
^{90}Sr	8.27 E+03	5.2 E+04	^{144m}Pr	3.03 E-02	1.9 E-01
^{90}Y	8.27 E+03	5.2 E+04	^{147}Pm	1.18 E+03	7.5 E+03
^{93}Zr	2.83 E-01	1.8 E+00	^{151}Sm	1.08 E+02	6.8 E+02
^{95}Zr	2.16 E-17	1.4 E-16	^{152}Eu	1.24 E+00	7.9 E+00
^{93m}Nb	1.35 E-01	8.6 E-01	^{154}Eu	2.08 E+02	1.3 E+03
^{95}Nb	4.78 E-17	3.0 E-16	^{155}Eu	3.63 E+01	2.3 E+02
^{95m}Nb	1.60 E-19	1.0 E-18	^{153}Gd	6.04 E-06	3.8 E-05
^{99}Tc	2.08 E+00	1.3 E+01	^{160}Tb	9.46 E-19	6.0 E-18
^{106}Ru	1.25 E+01	7.9 E+01	^{234}U	3.92 E-01	2.5 E+00
^{106}Rh	1.25 E+01	7.9 E+01	^{235}U	1.31 E-02	8.3 E-02
^{107}Pd	1.44 E-02	9.1 E-02	^{236}U	7.12 E-02	4.5 E-01
^{110}Ag	6.31 E-06	4.0 E-05	^{238}U	3.35 E-01	2.1 E+00
^{110m}Ag	4.73 E-04	3.0 E-03	^{237}Np	4.42 E-02	2.8 E-01
^{113m}Cd	4.04 E+00	2.6 E+01	^{238}Pu	1.28 E+02	8.1 E+02
^{113m}In	6.42 E-11	4.1 E-10	^{239}Pu	1.68 E+02	1.1 E+03
^{113}Sn	6.42 E-11	4.1 E-10	^{240}Pu	1.28 E+02	8.1 E+02
^{119m}Sn	7.14 E-04	4.5 E-03	^{241}Pu	9.62 E+03	6.1 E+04
^{121m}Sn	6.74 E-02	4.3 E-01	^{242}Pu	7.46 E-02	4.7 E-01
^{123}Sn	9.12 E-09	5.8 E-08	^{241}Am	2.85 E+02	1.8 E+03
^{126}Sn	1.22 E-01	7.7 E-01	^{242}Am	3.20 E-01	2.0 E+00
^{125}Sb	1.09 E+02	6.9 E+02	^{242m}Am	3.22 E-01	2.0 E+00
^{126}Sb	1.71 E-02	1.1 E-01	^{243}Am	2.22 E-01	1.4 E+00
^{126m}Sb	1.22 E-01	7.7 E-01	^{242}Cm	2.65 E-01	1.7 E+00
^{123m}Te	2.85 E-13	1.8 E-12	^{244}Cm	4.69 E+00	3.0 E+01
^{125m}Te	2.66 E+01	1.7 E+02	Total	5.15 E+04	3.3 E+05
^{127}Te	3.04 E-10	1.9 E-09			

MTU = Metric ton of uranium.

2.1.2 Dose Consequence Source Term

The dose consequence source term was selected by determining which fuel would result in the highest estimated dose to people if exposed to a unit of material. Americium, plutonium, strontium, and cesium are estimated to be the major contributors to the dose consequence source. The dose consequence source term is from N Reactor Mark IV fuel with 16.72% ^{240}Pu when discharged from the reactor on February 20, 1979, and decayed to December 31, 1997. Table B2-2 shows the curie inventories for the dose consequence source term.

2.1.3 Heat Generation Source Term

The heat generation source term was selected by determining the fuel with the greatest heat generation. A comparison was made of the decay heat produced by different source terms, including the most recently discharged fuel (29 W/MTU), the shielding source term (137 W/MTU), the dose consequence source term (121 W/MTU), and a 13.4% ^{240}Pu fuel that was decayed for 8.5 years after discharge (113 W/MTU). As shown by the heat generation numbers presented above, the shielding source term will also generate the most heat. This source term is shown in Table B2-1.

2.1.4 Criticality Source Term

Unirradiated Mark IV fuel was used as the basis for the criticality source term. Table B2-3 shows the isotopic inventory for Mark IV fuel in an MCO that consists of a total of 6.34 MTU with a ^{235}U enrichment of 0.947% (Willis 1995). Mark IV fuel also contains 70 ppm of ^{234}U and 400 ppm of ^{236}U.

2.2 RESTRICTIONS

The MCO Cask can contain one MCO loaded with no more than either 270 Mark IV fuel elements or 288 Mark IA fuel elements from the N Reactor. The design of the fuel baskets that hold the fuel elements placed into the MCO will prevent overloading the MCO. Additional fuel elements are beyond the scope of the criticality analysis in Part B, Section 6.0, and are not authorized.

No more than one scrap basket can be placed into an MCO, and that scrap basket must be positioned as the top or bottom basket within the MCO. The source terms presented in Section 2.1 include one scrap basket per MCO. Scrap is defined as pieces of fuel elements that have at least one dimension greater than 0.64 cm (0.25 in.). The restriction on number of scrap baskets results from assumptions made about the surface area of exposed uranium metal within the MCO. The worst-case surface area with one scrap basket is 1,200,000 cm^2, which is based on WHC-SD-SNF-TI-026 (Cooper 1996). Additional surface area would cause the gas generation rate and temperature and pressure buildup resulting from uranium corrosion to exceed the values calculated in the thermal and gas generation analyses in Part B, Sections 8.0 and 9.0. Part A, Section 6.0, precludes loading an MCO with more than one scrap basket. The worst-case amount of corrosion products in an MCO after loading in the

K Basins is 142 kg (Pajunen 1996). By the time hot conditioning is completed, there will be up to 300 kg of corrosion products in an MCO (Pajunen 1996).

Table B2-2. Dose Consequence Source for a Multicanister Overpack (MCO).

Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)	Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)
^{3}H	2.67 E+01	1.7 E+02	^{129}I	5.16 E-03	3.3 E-02
^{14}C	5.53 E-01	3.5 E+00	^{134}Cs	7.42 E+00	4.7 E+01
^{55}Fe	6.05 E-01	3.8 E+00	^{135}Cs	6.04 E-02	3.8 E-01
^{60}Co	2.21 E+00	1.4 E+01	^{137}Cs	9.74 E+03	6.2 E+04
^{59}Ni	3.18 E-02	2.0 E-01	^{137m}Ba	9.22 E+03	5.8 E+04
^{63}Ni	3.48 E+00	2.2 E+01	^{144}Ce	1.15 E-03	7.3 E-03
^{79}Se	6.54 E-02	4.1 E-01	^{144}Pr	1.13 E-03	7.2 E-03
^{85}Kr	3.80 E+02	2.4 E+03	^{144m}Pr	1.37 E-05	8.7 E-05
^{90}Sr	7.00 E+03	4.4 E+04	^{147}Pm	1.22 E+02	7.7 E+02
^{90}Y	7.00 E+03	4.4 E+04	^{151}Sm	1.02 E+02	6.5 E+02
^{93}Zr	2.95 E-01	1.9 E+00	^{152}Eu	8.62 E-01	5.5 E+00
^{93m}Nb	1.91 E-01	1.2 E+00	^{154}Eu	1.16 E+02	7.4 E+02
^{99}Tc	2.19 E+00	1.4 E+01	^{155}Eu	1.12 E+01	7.1 E+01
^{106}Ru	3.41 E-02	2.2 E-01	^{153}Gd	8.00 E-10	5.1 E-09
^{106}Rh	3.41 E-02	2.2 E-01	^{234}U	3.84 E-01	2.4 E+00
^{107}Pd	1.56 E-02	9.9 E-02	^{235}U	1.27 E-02	8.1 E-02
^{110}Ag	1.09 E-09	6.9 E-09	^{236}U	7.16 E-02	4.5 E-01
^{110m}Ag	8.20 E-08	5.2 E-07	^{238}U	3.31 E-01	2.1 E+00
^{113m}Cd	2.83 E+00	1.8 E+01	^{237}Np	4.66 E-02	3.0 E-01
^{113m}In	3.38 E-19	2.1 E-18	^{238}Pu	1.34 E+02	8.5 E+02
^{113}Sn	3.37 E-19	2.1 E-18	^{239}Pu	1.73 E+02	1.1 E+03
^{119m}Sn	9.42 E-08	6.0 E-07	^{240}Pu	1.37 E+02	8.7 E+02
^{121m}Sn	6.31 E-02	4.0 E-01	^{241}Pu	6.96 E+03	4.4 E+04
^{123}Sn	3.85 E-16	2.4 E-15	^{242}Pu	8.71 E-02	5.5 E-01
^{126}Sn	1.29 E-01	8.2 E-01	^{241}Am	4.29 E+02	2.7 E+03
^{125}Sb	1.31 E+01	8.3 E+01	^{242}Am	3.72 E-01	2.4 E+00
^{126}Sb	1.81 E-02	1.1 E-01	^{242m}Am	3.73 E-01	2.4 E+00
^{126m}Sb	1.29 E-01	8.2 E-01	^{243}Am	2.78 E-01	1.8 E+00
^{123m}Te	3.60 E-21	2.3 E-20	^{242}Cm	3.08 E-01	2.0 E+00
^{125m}Te	3.20 E+00	2.0 E+01	^{244}Cm	4.54 E+00	2.9 E+01
^{127}Te	5.54 E-19	3.5 E-18	Total	4.16 E+04	2.6 E+05
^{127m}Te	5.66 E-19	3.6 E-18			

MTU = Metric ton of uranium.

Table B2-3. Criticality Source for a Multicanister Overpack.*

Isotope	Mass (g/MCO)	Activity (Ci/MCO)
^{234}U	4.44 E+02	2.77 E-01
^{235}U	6.00 E+04	1.30 E-01
^{236}U	2.54 E+03	1.64 E-02
^{238}U	6.28 E+06	2.11 E+00
Total	6.34 E+06	2.53 E+00

*Mark IV fuel initial composition.

The total decay heat load of the payload does not exceed 835 W. Heat will also be produced by the chemical reaction between water in the MCO and exposed uranium metal. Higher thermal loads are not authorized because they would increase the temperature of the MCO faster than the predictions from the thermal analysis in Part B, Section 8.0. Higher thermal loads would also increase the hydrogen generation rate from the reaction among the residual water and exposed uranium metal in the MCO.

The MCO and the cavity between the MCO and the MCO Cask are filled with water during transportation from the K Basins to the CVDF in the 100 K Area. The water in the MCO is slightly contaminated water directly from the K Basins, while the water in the cask cavity is demineralized water. The water level in the MCO is approximately 10 cm (4 in.) below the bottom of the shield plug, while the water level in the cask cavity is at the same level, which is 41.4 cm (16.3 in.) below the top of the cavity. The MCO is vented through a high-efficiency particulate air (HEPA) filter to the cask cavity during this transfer to provide a larger volume for the gas generated from corrosion.

The gas generation rate within the MCO after the CVD process is measured. If more than 1.4 kPa (0.2 psi) per hour of gas is produced in the MCO during the measurement, then the CVD process must be repeated until the criterion is met. During this transfer from the CVDF to the CSB, the MCO is sealed.

Both the MCO and the annulus between the MCO Cask and the MCO must be backfilled with 21 kPa (3 psig) of helium. As shown in Part B, Section 9.0, the hydrogen gas concentration inside the MCO may exceed 5% under some conditions, so the only way to prevent an explosive mixture from forming within the MCO cavity is to backfill that cavity with an inert gas. The annulus between the MCO Cask and the MCO is also backfilled with helium to provide a buffer between the outside air and the MCO cavity.

2.3 SIZE AND WEIGHT

The MCO Cask is a vertical, cylindrical, stainless steel transport cask. The overall dimensions of the MCO Cask are 101.12 cm (39.81 in.) in diameter by 432.44 cm (170.25 in.) in height. The cask cavity is 63.98 cm (25.19 in.) in diameter by 407.67 cm (160.50 in.) in height. The MCO (WHC 1996) is a vertical, cylindrical, stainless steel container that will retain the spent fuel. The overall dimensions of the MCO are 60.96 cm (24.00 in.) in diameter by 406.40 cm (160.00 in.) in height. The MCO cavity is 58.42 cm (23.00 in.) in diameter and 371.93 cm (146.43 in.) long. Weights for the MCO package components are shown in Table B2-4. The maximum weight of the MCO package cannot exceed 27,270 kg (60,000 lb).

Table B2-4. Multicanister Overpack (MCO) Cask and MCO Weights.

Component	Weight kg (lb)
MCO empty, no shield plug	864 (1,900)
MCO shield plug	618 (1,360)
Five fuel baskets with 54 Mark IV elements per basket	7,130 (15,685)
Water inside MCO (K Basin to Cold Vacuum Drying Facility transfer)	552 (1,215)
Cask shell	15,590 (34,300)
Cask bottom	1,032 (2,270)
Cask lid	859 (1,890)
Lifting attachment	227 (500)
Total (dry MCO)	26,320 (57,905)
Total (water-filled MCO)	26,872 (59,120)

2.4 CONCLUSIONS

270 Mark IV fuel elements or 288 Mark IA fuel elements from the N Reactor are authorized for transport in the MCO Cask package. MCOs that exceed the source term descriptions shown in Tables B2-1 through B2-3 and MCO packages that exceed the weights shown in Table B2-4 are not authorized and would require additional evaluation to demonstrate that the package evaluation provided by this SARP is met.

2.5 REFERENCES

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3.0 RADIOLOGICAL RISK EVALUATION

3.1 INTRODUCTION

The MCO Cask is used to transport unprocessed, irradiated nuclear fuel from storage in the K Basins. The MCO Cask provides containment and shielding during transportation. The first part of each shipment takes place between the K Basins and a nearby CVDF. After processing at the CVDF the loaded MCO Cask travels by highway to the CSB in the 200 East Area. Radiological risks are evaluated to determine compliance with onsite safety requirements for each leg of the shipment campaign. The risk evaluation addresses only the transportation portion of the MCO Cask operation; handling of the package at the facilities is addressed separately in the appropriate documents.

The K Basin campaign is scheduled to extend over a period of two years. The CVDF transport leg covers a distance of less than 0.8 km (0.5 mi), and the CSB leg covers approximately 12.9 km (8.0 mi). The assumptions for the radiological risk evaluation are the following:

- Highway shipment mode
- One cask per shipment
- 400 total shipments
- 225 shipments per year maximum.

The cask and cask contents are assumed to weigh 26,872 kg (59,120 lb) when water filled and 26,320 kg (57,903 lb) post-cold vacuum dried. The tractor and trailer with the tiedown system are assumed to weigh 20,682 kg (45,500 lb). These parameters are used in determining conditional probabilities for the highway mode. They produce conservative values for shipments of greater weight.

The MCO Cask is designed to withstand normal transportation conditions. For accident environments, the cask must meet onsite transportation safety requirements as outlined in WHC-CM-2-14 and Mercado (1994). The requisite safety is determined by a radiological risk evaluation, which uses risk acceptance criteria, MCO Cask failure threshold values, and Washington State truck accident frequencies. For the evaluation, all accidents are binned to fall into four groups: impact, crush, puncture, and fire. Immersion as an accident scenario is ignored, because the transport route is not adjacent to water.

Risk acceptance criteria are outlined in Section 3.2. Dose consequence are discussed in Section 3.3. Failure thresholds are given in Section 3.4 and the analysis of accident release frequencies in Section 3.5. For MCO Cask shipments, the accident frequencies provide the necessary input to evaluate risk acceptance.

The MCO Cask shipments originate at the K Basins, a remote location on the Hanford Site. Due to the isolation of the originating facility, vehicle traffic is minimal. Routine public access to this area is prohibited. The first leg of the shipment is less than 0.8 km (0.5 mi) and takes place entirely within the 100 K Area. During the first shipment leg, the MCO is vented to the interior of the MCO Cask. The MCO is mechanically sealed prior to the second transport leg between the CVDF and the CSB, a distance of 12.9 km (8 mi).

The MCO Cask packaging system, including the MCO, is a system of multiple barriers designed to contain the contents in the event of an accident. These barriers include the cask wall, lid, and bottom, which are solid steel forgings, and the MCO. The accident evaluations presented in this chapter, however, take credit for the MCO Cask alone in order to simplify the analysis while ensuring conservatism in the results. This approach also maximizes the flexibility of the design as the MCO and MCO Cask design efforts proceed in parallel.

The accident evaluation addresses all primary functions of the MCO Cask, including subcriticality, shielding, and containment.

3.2 RISK ACCEPTANCE CRITERIA

Graded dose limitations for probable, credible, and incredible accident frequencies ensure safety in radioactive material packaging and transportation (Mercado 1994). The dose limitations to the offsite and onsite individual for probable, credible, and incredible accident frequencies are shown in Table B3-1.

Table B3-1. Risk Acceptance Criteria Limits.

Description	Annual frequency	Onsite dose limit* Sv (rem)	Offsite dose limit* Sv (rem)
Incredible	$< 10^{-7}$	None	None
Incredible	10^{-7} to $< 10^{-6}$	None	.25 (25)
Credible	10^{-6} to 10^{-3}	.05 (5)	.005 (.5)
Probable	10^{-3} to 1	.002 (.2)	.0001 (.01)

*Effective dose equivalent.

The analysis of the MCO Cask shipments initially focuses on determining whether the total annual accident frequency is less than 10^{-7}. If so, the necessity of determining the potential dose consequence resulting from the release of the payload is eliminated. If not, dose consequence calculations would be performed to allow comparisons to be made to risk acceptance criteria.

3.3 DOSE CONSEQUENCE ANALYSIS

The dose consequence of a failure of the MCO Cask is not calculated for the purposes of the risk analysis because the magnitude of the annual accident frequencies is minimal, placing the probability of cask failure well in the incredible range. This approach is justified by requiring that the accident scenarios evaluated encompass any event that would result in a loss of effectiveness of the MCO Cask.

3.4 PACKAGE FAILURE THRESHOLD ANALYSIS

Accident performance of a package is determined by the probability given an accident that a package is subjected to a force more severe than the package failure threshold level for that force. Failure threshold values for the package are accordingly necessary input parameters for determining the subsequent probability of cask failure and material release. Failure thresholds were determined for the MCO Cask for impact, puncture, crush, and fire:

- Impact: Survives a 40.3-km/h (25.0-mi/h) velocity change for CVDF leg and a 48.3-km/h (30.0-mi/h) velocity change for CSB leg with no containment boundary failure (Part B, Sections 3.4.1 and 7.0)
- Puncture: Minimum thickness of 8.9-cm (3.5-in.) equivalent steel (H&R 1995)
- Crush: Survives a 7,257-kg (16,000-lb) crush force with no containment boundary failure (see discussion in Section 3.4.3)
- Fire: Survives a 6-minute fully engulfing fire with no containment boundary failure (Part B, Sections 3.4.4 and 8.5).

3.4.1 Impact

The structural analysis of the post-cold vacuum dried MCO Cask (Part B, Section 7.0) determined that the cask containment boundary is maintained, including welds and seals, when subjected to the forces corresponding to a 48.3-km/h (30.0-mi/h) change in velocity for the CSB leg. A 40.3 km/h (25.0 mi/h) change in velocity for the water-filled cask during the CVD leg is also analyzed and shows that the cask containment boundary is maintained. Shifting of the contents of the cask is bounded by the shielding analysis (Part B, Section 5.5). The criticality analysis (Part B, Section 6.4.3) shows that subcriticality is maintained under impact conditions. The criticality analysis relies on the structural analysis, which shows that the Mark IA basket center tube does not buckle or shift farther than 5.08 cm (2 in.) under impact conditions.

3.4.2 Puncture

The threat of puncture to the cask body is considered negligible due to the thickness of the steel shell and cask lid, a minimum of 8.9 cm (3.5 in.).

However, the puncture accident mode is also considered to include the scenario where the cask vent or drain port cover strikes a puncture bar or similar structure. If this event occurs, the port cover is assumed to lose its seal. This approach is conservative because impact to a port cover will not always result in a loss of the seal.

3.4.3 Crush

The forces potentially generated by an inertial crush accident where the 7,300-kg (16,000-lb) trailer hits the MCO Cask are bounded by the forces evaluated for the impact event. The worst-case *g*-loads that the cask experiences during the impact event, as determined in Part B, Section 7.3, are on the order of 25*g*. The magnitude of these forces greatly exceeds the weight of the trailer. Because the cask containment is maintained when subjected to the worst-case *g*-loads, the cask is considered to survive a static crush event, which would have much smaller *g*-loads, with no loss of containment shielding, or criticality control.

3.4.4 Fire

The thermal evaluation (Part B, Section 8.5) shows that the failure threshold of the port cover seals is slightly more than six minutes in an all-engulfing fire. As shown in Table B3-3, fires with durations longer than six minutes are not credible and do not need to be analyzed further to show that onsite transportation safety criteria (Mercado 1994) are satisfied.

For information, Part B, Section 8.5, also evaluates the 10 CFR 71-specified fully engulfing fire duration of 30 minutes during transfer from the CVDF to the CSB. That evaluation, along with Part B, Section 7.4, shows that the cask retains the MCO during a 30-minute fire and that a runaway chemical reaction does not occur within the MCO.

3.5 ACCIDENT RELEASE FREQUENCY ASSESSMENT

3.5.1 Approach

The accident release frequency assessment is based on the assumption that a single failure mode is appropriate for each of the different forces described as impact, puncture, crush, and fire. Packages on the Hanford Site do not encounter immersion accident environments. The union of the package conditional release probabilities corresponding to different scenarios with similar consequences is multiplied by the frequency of truck accidents to arrive at a total release frequency.

The annual frequency (F) of a truck accident is the product of the annual number of trips, the number of miles per trip, and the accident rate per mile.

$$F = \frac{225\ trips}{year} \times \frac{miles}{trip} \times \frac{accidents}{mile}$$

The truck accident rate is the Saricks and Kvitek (1994) value for the Washington State accident rate for secondary (rural) state highways. This rate is 1.17×10^{-7} accidents per mile. For the Hanford site, this rate is reduced by a factor of 40 as recommended in Appendix B of *Recommended Onsite Transportation Risk Management Methodology* (H&R 1995). Appendix B of the H&R report summarizes statistics from the U.S. Department of Transportation and the studies conducted by Sandia National Laboratory on accident responses of small and large packages. The report recommends reducing truck accident rates by 10 for "safe" truck drivers, a factor of two for travel north of the Wye barricade and another factor of two for shipment of radioactive material. These reduction factors are based on the following logic:

- Safe truck drivers: Hanford Site truck drivers have special training. Drivers must complete several driver's education courses, have a valid commercial driver's license with hazardous endorsement, complete specific training for highway route controlled quantities of radioactive material, and complete radiation worker and hazardous materials training. References show that drivers that participate in special safety programs reduce single-vehicle accident rates by up to a factor of 100. The H&R report (H&R 1995) recommends using an overall accident reduction factor of 10.

- Travel north of the Wye Barricade: The general population is excluded north of the Wye barricade. The roads are straight and generally flat. These conditions eliminate conditions caused by after-work activities, such as alcohol consumption and travel during limited visibility. Statistics show that the difference between travel during day and night leads to an accident reduction of 2.67. Therefore, although the MCO is not limited to travel during daylight hours, because there is a constraint on traveling during adverse weather conditions, which may affect visibility, and because no alcohol consumption is permitted on the Hanford Site during the day or at night, a conservative factor of two reduction is recommended for travel north of the Wye Barricade.

- Radioactive material: An additional factor of two is recommended based on the higher level of training required for drivers of vehicles carrying radioactive material and the higher level of caution that would be expected from drivers of cargos consisting of radioactive material.

K Basin to CVDF:

$$\frac{225\ trips}{yr} \times \frac{0.5\ mi}{trip} \times \frac{1.17 \times 10^{-7}\ \frac{accidents}{mi}}{40\ (reduction\ factor)}$$

$$F = 3.3 \times 10^{-7}\ \frac{accidents}{yr}$$

CVDF to CSB:

$$\frac{225\ trips}{yr} \times \frac{8\ mi}{trip} \times \frac{1.17 \times 10^{-7}\ \frac{accidents}{mi}}{40\ (reduction\ factor)}$$

$$F = 5.3 \times 10^{-6}\ \frac{accidents}{yr}$$

The frequency of accidents is multiplied by the union of the conditional release probabilities determined in Section 3.5.2 to arrive at an annual accident release frequency. The annual release frequency is then compared to the risk acceptance criteria of 10^{-7}.

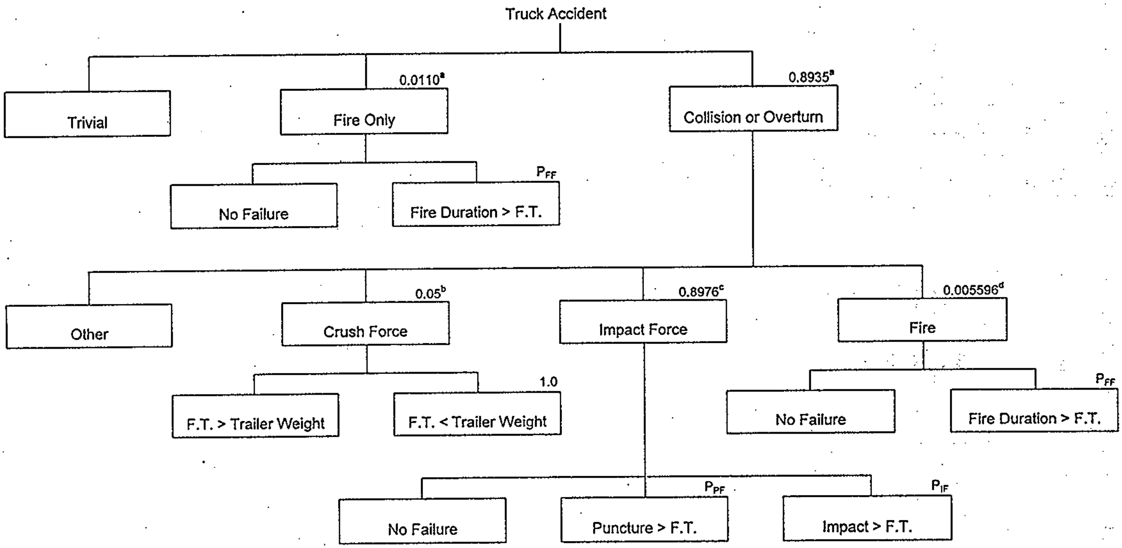
3.5.2 Accident Release Frequency Analysis

Information for the probability of occurrence and conditional probabilities of failure is taken from *Severities of Transportation Accidents Involving Large Packages* (Dennis et al. 1978), *Severities of Transportation Accidents Volume III--Motor Carriers* (Clarke et al. 1976), and H&R (1995). A simplified generic flow chart, shown in Figure B3-1, has been developed using statistics presented in Clarke et al. (1976) and Dennis et al. (1978). It visually depicts events that may occur as a result of a truck accident on the Hanford Site. Scenarios that are not pertinent to the shipment of radioactive material on the Hanford Site are not included. These include accidents such as immersion and fires not involving the cargo. Package failure and material release may occur from fire, impact, crush, and puncture, which, for purposes of the joint probability calculations, are assumed to be independent events. The crush force in the flow chart represents static crush. For large packages such as the MCO, inertial crush falls under the category of an impact force. Impact failure thresholds are accordingly evaluated for either impact or inertial crush failure, whichever is the limiting value.

The probability of an event in the flow chart given a preceding event is determined from the studies presented with large and small packages in Clarke et al. (1976) and Dennis et al. (1978). Thus, as can be seen in Figure B3-1, the probability of a fire only given a truck accident is 0.0110, and the probability of an accident resulting in collision or overturn is 0.8935 (Clarke et al. [1976], p. 13). Trivial accidents are defined as those that do not affect the payload. These accidents may not result in trivial damage to other vehicles or the transport vehicle.

The probability of static crush given a collision or overturn accident is found in Dennis et al. (1978 [p. II-25]) as 0.05. This means that 1 in 20 collision or overturn accidents results in static crush to the package. Use of the 0.05 value is recommended in Dennis et al. (1978) even though the study states that accident statistics indicate a lower rate would be more representative of accident conditions. Conditional release probabilities for crush are either 1.0 for failure or 0 for no failure. Failure occurs if the static crush failure threshold for the package is less than the weight of the truck trailer. The MCO Cask will survive the crush force from a 7,300-kg

Figure B3-1. Flow Chart for Hanford Site Truck Accidents With Large Packages.



F.T. = Failure Threshold
PFF = Probability of Fire Failure
PPF = Probability of Puncture Failure
PIF = Probability of Impact Failure

a) Clarke, 13
b) Dennis, II-25
c) P(collision given an accident) = 0.8976 x 0.8935 = 0.8020 from Dennis, II-28 and B-8
d) Fire Frequency/accident = 1.6% (Dennis II-15); [0.0110 + 0.8935(0.005596)] = 0.016

(16,000-lb) truck trailer, as discussed in Section 3.4.3, and therefore the conditional probability of failure due to crush is essentially equal to zero.

The impact environment may result in puncture or impact failure. Dennis et al. (1978) cites a value of 0.8020 for the probability of an impact environment given an accident. Accordingly, the probability of an impact force, as shown in Figure B3-1, occurring given a collision or overturn is calculated to be 0.8976 (0.8020/0.8935). The conditional probability of release from impact forces given an impact event (PIF) represents the probability that the package will be subjected to an impact resulting in a velocity change greater than that which could fail the package. As previously stated, inertial crush is included in this category.

The values for the impact conditional release probabilities are found in Dennis et al. (1978 [p. II-23]). They are based on the expected system velocity change resulting from the collision or overturn event. The impact failure threshold for the cask was determined to be a 40-km/h (25-mi/h) change in velocity onto a typical Hanford Site surface for the CVDF leg and a 48-km/h (30-mi/h) change for the CSB leg. The conditional probability of failures for the respective legs are 0.0072 and 0.005 (Dennis et al. [1978]).

The conditional probability of release from puncture given an impact event (PPF) represents the probability that an impact event will result in a puncture force large enough to penetrate and fail the equivalent steel thickness of the package. The PPF values are found in Dennis et al.(1978 [p. II-35]) and are tabulated as the probability that given an accident with an impact force, a package of an equivalent steel thickness will undergo puncture failure. The MCO Cask has an equivalent steel thickness of at least 8.9 cm (3.5 in.), which has a conditional probability of failure of approximately zero. However, an impact event may result in a puncture threat to the port covers. The port covers are 1.9 cm (0.75 in.) thick, and although the port covers are less than 1% of the total surface area of the cask, the puncture failure conditional probability is based on a cask thickness of 1.9 cm (0.75 in.). The PPF value for an equivalent steel thickness of 1.9 cm (0.75 in.) is 2.04×10^{-3}.

In a similar manner, the conditional probability of fire given a collision or overturn is calculated from a fire frequency per accident of 1.6% (Dennis et al. [1978], p. II-15) and the value for the fire-only scenario of 0.0110. The conditional probability of release from failure from fire (PFF) is determined from an H&R report (H&R 1995), which incorporates Hanford Site information for emergency response time and fire duration. The value represents the probability that the fire duration is greater than the length of time determined to be the failure point for the package. Although the structural elements of the massive MCO Cask will not respond negatively to a 6-minute fire, the thermal section (Part B, Section 8.5.5) shows that a fire longer than 6 minutes will result in failure of the cask drain port seal. Therefore, because containment has been breached, a 6-minute fire failure threshold is assumed, and a PFF value of 0.72 is used.

Conditional release probabilities and failure thresholds are summarized in Table B3-2. The joint probability is calculated by taking the union of events (McCormick 1981). The equation represents the sum of the probabilities of independent events while the subtracted terms eliminate double counting arising from the overlap caused by the intersection of the events. The general equation is given as:

$$P(A_1+A_2+\ldots+A_N)=\sum_{n=1}^{N}P(A_n)-\sum_{n=1}^{N-1}\sum_{m=n+1}^{N}P(A_nA_m)+-\ldots+(-1)^{N-1}P(A_1A_2\ldots A_N).$$

where

P(f¦a) = the probability of fire given that an accident has occurred

P(fc¦a) = the probability of fire and crush given that an accident has occurred

and

P(FTE f¦f) = the probability that the failure threshold is exceeded by fire given that a fire has occurred, etc.

Likewise, I = impact and p = puncture. Then the above equation can be expanded and written as:

P = P(f¦a) P(FTE f¦f) + P(c¦a) P(FTE c¦c) + P(I¦a) P(FTE I¦I) + P(p¦a) P(FTE p¦p) - P(fc¦a) P(FTE f¦f) P(FTE c¦c) - P(fi¦a) P(FTE f¦f) P(FTE I¦I) - . . .

Thus the values from the flow chart in Figure B3-1 and the conditional probabilities from Table B3-2 yield a total conditional release probability of 0.019 for the CVDF leg and 0.017 for the CSB leg.

Table B3-2. Failure Thresholds and Conditional Release Probabilities.

Force type	Failure threshold	Conditional release probability
Crush	16,000 lb	Does not fail (~0)
Puncture	0.75 in.	2.04×10^{-5}
Fire	6 minutes to loss of seal	0.72
Impact--Cold Vacuum Drying Facility leg	25 mi/h	0.0072
Impact--Canister Storage Building leg	30 mi/h	0.005

3.6 EVALUATION AND CONCLUSION

Table B3-3 shows the risk evaluation summary. The table summarizes the accident frequency per year, the union of the conditional release probabilities, and the resulting annual accident release frequency. As can be seen in the table, the accident release frequencies for both the CVDF and CSB legs are less than the risk acceptance criteria of 10^{-7}.

Table B3-3. Summary of the Radiological Risk Evaluation.

Leg	Frequency (accidents/year)	Union of conditional release probabilities	Annual accident release frequency
Cold Vacuum Drying Facility	3.3×10^{-7}	1.9×10^{-2}	6.2×10^{-9}
Canister Storage Building	5.3×10^{-6}	1.71×10^{-2}	9.0×10^{-8}

3.7 REFERENCES

Clarke, R. K., J. T. Foley, W. F. Hartman, and D. W. Larson, 1976, *Severities of Transportation Accidents, Volume III--Motor Carriers*, SLA-74-0001, Sandia National Laboratory, Albuquerque, New Mexico.

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Saricks, C., and T. Kvitek, 1994, *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight*, Center for Transportation Research, Argonne National Laboratory, Illinois.

WHC-CM-2-14, *Hazardous Material Packaging and Shipping*, Westinghouse Hanford Company, Richland, Washington.

4.0 CONTAINMENT EVALUATION

4.1 INTRODUCTION

The MCO Cask is designed and fabricated to meet the leaktight criteria of ANSI N14.5 (ANSI 1987) and maintains containment of the spent fuel through normal transport conditions and accident conditions on the Hanford Site. The MCO will retain the spent fuel during normal transfer and accident conditions, but no credit is taken for that boundary.

The MCO Cask closure lid uses a Butyl[1] rubber O-ring face seal to maintain a leaktight (10^{-7} std cc/s) seal. The seal is located on the interface surface between the flange on the closure lid and the MCO Cask shell. This seal is placed in an O-ring groove in the closure lid flange. The O-ring is compressed by tightening 12 1.5-in. bolts on the lid. There are two penetrations into the MCO cask for the vent port and the drain port. Both of these ports are quick-disconnect couplings attached to coupling adapters, which are recessed from the exterior of the cask. These couplings are not considered to be containment boundaries. Leaktight containment for these ports is provided by cover plates and Butyl rubber O-ring face seals. An O-ring groove is cut into each cover plate. At the drain port, the O-ring is compressed by four 0.5-in. bolts. At the vent port, the O-ring is compressed by four 0.5-in. bolts.

The primary purpose for the MCO is to be the long-term storage container for the spent fuel, so the MCO meets criteria for long-term storage of spent fuel. The MCO retains the spent fuel under all normal and accident conditions. During the transfer from the K Basins to the CVDF, the MCO is vented via a HEPA filter to the cask interior. The MCO lid/shield plug assembly is mechanically secured to the MCO shell by a threaded locking ring. A Helicoflex[2] seal serves as the primary seal between the shield plug and the MCO. Eight 1.0-in. screws penetrate the locking ring to further compress the seal. There are four penetrations through the MCO lid/shield plug assembly. The two process penetrations will be covered by a blind flange and a flexible graphite gasket that maintains a seal, while the penetrations for the rupture disk and relief valve are uncovered. The covers for the two process penetrations are closed by eight 0.625-in. bolts, while the other two covers are closed by four 0.625-in. bolts.

4.2 CONTAINMENT SOURCE SPECIFICATION

The authorized contents for the MCO Cask is the MCO filled with 270 Mark IV fuel elements or 288 Mark IA fuel elements from the N Reactor. The dose consequence source term described in Part B, Section 2.1.2 (see Table B4-1), was used as the basis for all containment calculations, because that source term would result in the highest estimated dose to receptors exposed to the material.

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[1] Butyl is a trademark of Dewitt Products.

[2] Helicoflex is a trademark of Helicoflex Corporation.

Table B4-1. Dose Consequence Source for a Multicanister Overpack (MCO).

Isotope	Activity (curies/MCO)	Isotope	Activity (curies/MCO)
^{3}H	1.7 E+02	^{127m}Te	3.6 E-18
^{14}C	3.5 E+00	^{129}I	3.3 E-02
^{55}Fe	3.8 E+00	^{134}Cs	4.7 E+01
^{60}Co	1.4 E+01	^{135}Cs	3.8 E-01
^{59}Ni	2.0 E-01	^{137}Cs	6.2 E+04
^{63}Ni	2.2 E+01	^{137m}Ba	5.8 E+04
^{79}Se	4.1 E-01	^{144}Ce	7.3 E-03
^{85}Kr	2.4 E+03	^{144}Pr	7.2 E-03
^{90}Sr	4.4 E+04	^{144m}Pr	8.7 E-05
^{90}Y	4.4 E+04	^{147}Pm	7.7 E+02
^{93}Zr	1.9 E+00	^{151}Sm	6.5 E+02
^{93m}Nb	1.2 E+00	^{152}Eu	5.5 E+00
^{99}Tc	1.4 E+01	^{154}Eu	7.4 E+02
^{106}Ru	2.2 E-01	^{155}Eu	7.1 E+01
^{106}Rh	2.2 E-01	^{153}Gd	5.1 E-09
^{107}Pd	9.9 E-02	^{234}U	2.4 E+00
^{110}Ag	6.9 E-09	^{235}U	8.1 E-02
^{110m}Ag	5.2 E-07	^{236}U	4.5 E-01
^{113m}Cd	1.8 E+01	^{238}U	2.1 E+00
^{113m}In	2.1 E-18	^{237}Np	3.0 E-01
^{113}Sn	2.1 E-18	^{238}Pu	8.5 E+02
^{119m}Sn	6.0 E-07	^{239}Pu	1.1 E+03
^{121m}Sn	4.0 E-01	^{240}Pu	8.7 E+02
^{123}Sn	2.4 E-15	^{241}Pu	4.4 E+04
^{126}Sn	8.2 E-01	^{242}Pu	5.5 E-01
^{125}Sb	8.3 E+01	^{241}Am	2.7 E+03
^{126}Sb	1.1 E-01	^{242}Am	2.4 E+00
^{126m}Sb	8.2 E-01	^{242m}Am	2.4 E+00
^{123m}Te	2.3 E-20	^{243}Am	1.8 E+00
^{125m}Te	2.0 E+01	^{242}Cm	2.0 E+00
^{127}Te	3.5 E-18	^{244}Cm	2.9 E+01
Total 2.6 E+05			

A fabrication verification leak test of the MCO Cask containment boundary will be performed at the manufacturer. That leak test will demonstrate that the MCO Cask can meet the 10^{-7} std cc/s leak rate defined as leaktight by ANSI N14.5 (ANSI 1987).

4.3 NORMAL TRANSFER CONDITIONS

4.3.1 Conditions To Be Evaluated

The conditions to be evaluated for normal transfer are pressurization of the MCO and MCO Cask, seal temperature range, and seal integrity. The MCO Cask must remain leaktight, and the MCO must provide containment under all normal transfer conditions.

The normal transfer conditions involve exposure to temperatures as low as -33 °C (-27 °F) and as high as 46 °C (115 °F) while exposed to maximum solar insolation. The containment boundary must survive external pressure fluctuations as low as 24.5 kPa (3.5 psi) and as high as 140 kPa (20 psi) as well as a maximum internal pressure of 1034 kPa (150 psi). The containment boundaries also must survive a water spray; vibration normally incident to transport; impact of a 3.2-cm- (1.25-in.-) diameter, 6-kg (12-lb), vertical steel cylinder dropped from a height of 1 m; a 0.3-m (1-ft) free drop onto a Hanford Site concrete surface when the MCO is dry; and a 5*g* impact onto the flat bottom of the cask when the MCO is water-filled.

4.3.2 Containment Acceptance Criteria

The MCO Cask design must meet external release rate requirements with a containment system that satisfies the ANSI N14.5 (ANSI 1987) leaktight criterion (leakage rate less than 10^{-7} std cc/s). Leaktightness is proven when the MCO Cask containment boundary is shown to meet ASME B&PV Code, Section III (ASME 1995), Service Level A stress allowables during all normal transfer conditions.

As stated in Section 4.2, the MCO Cask will undergo a fabrication leak test to demonstrate a leaktight design. The MCO will undergo a fabrication leak test to demonstrate that containment requirements for long-term storage are met. Since there is a significant dose associated with performing an assembly leak test, an analysis was done comparing the dose to a worker performing the leak test to the dose received from an improperly sealed cask. The supporting analysis, given in Part B, Section 4.7.2, shows the dose received from an improperly sealed cask to be less than the dose received from performing a leak test. Therefore, an assembly leak test is not required prior to every shipment.

4.3.3 Containment Model

The structural analyses of the MCO Cask are provided in Part B, Section 7.0. The results of the normal conditions of transfer analyses are presented in Part B, Section 7.3.4.3. These structural analyses demonstrate that the MCO Cask maintains a leaktight containment boundary during normal transfer conditions.

4.3.4 Containment Calculations

The structural analyses summarized in Part B, Section 7.3.4.3, demonstrate that the MCO Cask satisfies ASME B&PV Code, Section III (ASME 1995), Service Level A stress allowables during normal transfer conditions. Since the Service Level A stress allowables are met, the cask remains leaktight during normal transfer conditions.

4.4 ACCIDENT CONDITIONS

4.4.1 Conditions To Be Evaluated

The conditions to be evaluated for accident scenarios are pressurization of the MCO Cask and MCO and performance of the MCO Cask and MCO Cask seal during the drop, puncture, and fire.

The accident conditions listed are evaluated at an ambient temperature between -32 °C (-27 °F) and 46 °C (115 °F), whichever is more severe for the individual accident. The impact accident is simulated by a free drop of 9.0 m (30 ft) of the dry package or a free drop of 6.4 m (21 ft) of the water-filled package onto a typical Hanford Site concrete surface. The puncture is a 1-m free drop of the package onto a 15-cm- (6.-in.-) diameter mild steel bar. The thermal accident is simulated by exposure of the package to a 6-minute, 800 °C (1475 °F) engulfing fire during transfer from the CVDF to the CSB, which is followed by a quench.

4.4.2 Containment Acceptance Criteria

The package must satisfy external release rate requirements for defined accident conditions. The MCO Cask containment boundary remains leaktight during defined accident scenarios. The containment boundary must be shown to satisfy ASME B&PV Code, Section III (ASME 1995), Service Level D stress allowables during the accident conditions. Proper squeeze must also be maintained on the MCO Cask lid seal. Squeeze is defined as the percent reduction in the cross-sectional diameter of the O-ring due to compression.

4.4.3 Containment Model

The structural analyses of the MCO Cask and the MCO are provided in Part B, Section 7.0. The results of the accident condition analyses are presented in Part B, Section 7.4.4.3., and the thermal evaluation is presented in Section 7.4.4.2. These analyses demonstrate that the MCO Cask maintains a leaktight containment boundary and the MCO Cask provides containment during all accident conditions.

4.4.4 Containment Calculations

The structural analyses summarized in Part B, Section 7.4.4.3, demonstrate both the MCO Cask and the MCO satisfy ASME B&PV Code, Section III (ASME 1995), Service Level D stress allowables during all accident conditions. Since the Service Level D stress allowables are met and proper squeeze is maintained on all MCO Cask seals (as shown in Part B, Section 4.7.1), the cask meets containment criteria.

4.5 CONTAINMENT EVALUATION AND CONCLUSIONS

Structural analyses show that leaktightness of the MCO Cask packaging system containment is maintained for onsite normal transfer conditions and for defined accident conditions. The MCO also retains the spent fuel during all conditions.

4.6 REFERENCES

ANSI, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, ANSI Standard N14.5-1987, American National Standards Institute, New York, New York.

ASME, 1995, *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.

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4.7 APPENDIX

4.7.1 Squeeze Calculation

This calculation shows that proper squeeze is maintained on the MCO Cask lid seal after the defined accident condition drop test.

Given:

Inside diameter (ID) of O-ring = 31.31 in.
ID of O-ring groove = 31.57 in +/- .01 in.
Cross-sectional diameter of o-ring = 0.275 in.
Groove depth = 0.210 in +/- 0.01 in.

Find normal transfer conditions

max o-ring stretch = (31.58 - 31.31)/31.31 = 0.86%

% reduction in cross-sectional diameter (from Parker)

$\% \text{ red} = -0.005 + 1.19(.86) - 0.19(.86)^2 - 0.001(.86)^3 + 0.008(.86)^4$
% red = 0.88%

installed cross-sectional diameter of o-ring = (1 - 0.88%)(0.275) = 0.2726 in

maximum squeeze = (0.2726 - 0.20)/0.2726 = 27%
minimum squeeze = (0.2726 - 0.22)/0.2726 = 19%

Accident conditions

Parker recommends a minimum squeeze of 0.007 in. for static seals. To obtain this amount of squeeze, the groove depth would be (0.2726 - 0.007) = 0.2656

The minimum recommended squeeze, in %, is 0.007/0.2726 = 2.57%

The groove depth for accident conditions will take into account the bolt strain.

$$d_{AC} = d_{NTC} + (l_b)(\epsilon)$$

where:
- d_{AC} = groove depth for accident conditions (in.)
- d_{NTC} = groove depth for normal transfer conditions (0.22 in. max.)
- l_b = bolt length, unthreaded (4.25 in. max.)
- ϵ = bolt strain, from Part B, Table B7-23, the worst-case drop scenario (0.006)

d_{AC} = 0.2455 in.

squeeze = (0.2726 - 0.2455)/0.2726 = 9.94%

Adequate squeeze is maintained for accident conditions.

4.7.2 Dose Comparison Analysis

ENGINEERING SAFETY EVALUATION

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I. Objectives:

Spent fuel from the K Basins is to be shipped in the MCO cask assembly. The MCO cask design is such that the cask will remain leaktight under normal conditions of transport (NCT). In order to keep dose rates ALARA, it is desired to transport each MCO cask assembly without performing a leak test after the cask lid has been assembled. This evaluation compares the dose to the worker performing a leak test to the dose received should the cask lid fail to seal properly.

II. References:

ANSI N14.5, 1987, *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment*, American National Standards Institute, New York, New York.

ASME, 1995, *ASME Boiler and Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.

Chemical Rubber Publishing Company, 1961, *Handbook of Chemistry and Physics*, The Chemical Rubber Publishing Company, Cleveland, Ohio.

III. Results and Conclusions:

The following table summarizes the results calculated using the methods described in Section IV of this report.

Table 1. Dose Comparison

	15 min. exposure time	30 min. exposure time
K Basins to CVD - MCO is vented/filtered, Cask leaking	1.1 mrem	2.2 mrem
CVD to CSB - MCO confines spent fuel, Cask leaking	6.1×10^{-4} mrem	1.2×10^{-3} rem
CVD to CSB - MCO is leaking while Cask is leaking	0.61 mrem	1.2 mrem
Dose to worker performing leak test (worker standing at side of cask, 1m away)	3.5 mrem	6.9 mrem

Results from the shielding analysis, Section 5.0, state that the dose rate from the side of the MCO Cask at a distance of 2 m is 6.9 mrem/hr. Because the diameter of the MCO Cask is small compared to its length, the dose rate at 1 m falls off as 1/r. Therefore, at a distance of

1 m, the dose rate is doubled, or 13.8 mrem/hr. It is important to note that the dose from the leak test is received each time a leak test is performed. For the remaining cases, the dose is received only if the MCO and/or MCO Cask were improperly sealed. Since an approved procedure will be used to assemble the cask lid, the probability of receiving these doses is reduced. This is especially true for the case where both the MCO and MCO Cask are leaking, since both conditions would have to exist simultaneously. The actual time spent 1 m away from the cask during the leak test is estimated to be approximately 20 minutes.

IV. Engineering Evaluation:

Table 2 shows the dose consequence source term used in this evaluation. The activity per MCO is based on 270 Mark IV fuel elements per MCO. Following the table is a description of each transport scenario. All supporting calculations are found in the Appendix of this evaluation.

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Table 2: MCO Source Term

Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)	Isotope	Activity (Ci/MTU)	Activity (Ci/MCO)
Fission and Activation Products					
H-3	2.67e+01	1.7e+02	Sn-123	3.85e-16	2.4e-15
C-14	5.53e-01	3.5e+00	Sn-126	1.29e-01	8.2e-01
Fe-55	6.05e-01	3.8e+00	Sb-124	0.00e+00	0.00e+00
Co-60	2.21e+00	1.4e+01	Sb-125	1.31e+01	8.3e+01
Ni-59	3.18e-02	2.0e-01	Sb-126	1.81e-02	1.1e-01
Ni-63	3.48e+00	2.2e+01	Sb-126m	1.29e-01	8.2e-01
Se-79	6.54e-02	4.1e-01	Te-123m	3.60e-21	2.3e-20
Kr-85	3.80e+02	2.4e+03	Te-125m	3.20e+00	2.0e+01
Sr-90	7.00e+03	4.4e+04	Te-127	5.54e-19	3.5e-18
Y-90	7.00e+03	4.4e+04	Te-127m	5.66e-19	3.6e-18
Zr-93	2.95e-01	1.9e+00	I-129	5.16e-03	3.3e-02
Nb-93m	1.91e-01	1.2e+00	Cs-134	7.42e+00	4.7e+01
Tc-99	2.19e+00	1.4e+01	Cs-135	6.04e-02	3.8e-01
Ru-106	3.41e-02	2.2e-01	Cs-137	9.74e+03	6.2e+04
Rh-106	3.41e-02	2.2e-01	Ba-137m	9.22e+03	5.8e+04
Pd-107	1.56e-02	9.9e-02	Ce-144	1.15e-03	7.3e-03
Ag-110	1.09e-09	6.9e-09	Pr-144	1.13e-03	7.2e-03
Ag-110m	8.20e-08	5.2e-07	Pr-144m	1.37e-05	8.7e-05
Cd-113m	2.83e+00	1.8e+01	Pm-147	1.22e+02	7.7e+02
In-113m	3.38e-19	2.1e-18	Sm-151	1.02e+02	6.5e+02
Sn-113	3.37e-19	2.1e-18	Eu-152	8.62e-01	5.5e+00
Sn-119m	9.42e-08	6.0e-07	Eu-154	1.16e+02	7.4e+02
Sn-121m	6.31e-02	4.0e-01	Eu-155	1.12e+01	7.1e+01
			Gd-153	8.00e-10	5.1e-09
Fission and Activation Product Totals				3.38e+04	2.14e+05

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Actinides					
U-234	3.84e-01	2.4e+00	Pu-241	6.96e+03	4.4e+04
U-235	1.27e-02	8.1e-02	Pu-242	8.71e-02	5.5e-01
U-236	7.16e-02	4.5e-01	Am-241	4.29e+02	2.7e+03
U-238	3.31e-01	2.1e+00	Am-242	3.72e-01	2.4e+00
Np-237	4.66e-02	3.0e-01	Am-242m	3.73e-01	2.4e+00
Pu-238	1.34e+02	8.5e+02	Am-243	2.78e-01	1.8e+00
Pu-239	1.73e+02	1.1e+03	Cm-242	3.08e-01	2.0e+00
Pu-240	1.37e+02	8.7e+02	Cm-244	4.54e+00	2.9e+01
Actinide Totals				7.84e+03	4.98e+04

K Basins to CVD

MCO is Vented, Cask is Leaking

During this leg of the shipment, the MCO is vented to the MCO Cask cavity. The vent port is equipped with a particulate filter, such that only the tritium and Kr-85 are vented. The MCO Cask is also leaking. The shipping time is 24 hours. Since the MCO is open to the MCO cask, the void spaces for each are modeled as a single void space. A theoretical hole diameter of 2.54×10^{-3} cm is assumed as the leak path through the MCO Cask. This value is based on what an inspector can reasonably detect during a visual inspection. The dose from inhalation and submersion is found for both a 15 and 30 minute exposure starting at the end of the 24 hour shipping time.

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CVD to CSB

MCO Provides Containment, Cask is Leaking

In this scenario, the MCO provides containment of the spent fuel, which limits the leak rate from the MCO into the cask cavity to no greater than 1 x 10^{-4} std cc/s. The MCO cask is assumed to be leaking. All of the gases are able to escape through this leak path. Also, it is assumed that a certain portion of the solid activity will aerosolize and become part of the gaseous mixture. The shipping time is 36 hours. It is conservatively assumed that all radioactive material released into the MCO Cask during this time is there throughout the shipping time. A theoretical hole diameter of 2.54 x 10^{-3} cm is assumed as the leak path through the MCO Cask. This value is based on what an inspector can reasonably detect during a visual inspection. The dose from inhalation and submersion is found for both a 15 and 30 minute exposure starting at the end of the 36 hour shipping time.

MCO and MCO Cask are Leaking

This scenario assumes that both the MCO and MCO Cask are leaking. Again, all of the gases are able to escape through this leak path, and a certain portion of the solid activity will aerosolize and become part of the gaseous mixture. The shipping time is 36 hours. It is conservatively assumed that all radioactive material released into the MCO Cask during this time is in the cask cavity throughout the shipping time. A theoretical hole diameter of 2.54 x 10^{-3} cm is assumed as the leak path through both the MCO and the MCO Cask. This value is based on what an inspector can reasonably detect during a visual inspection. The dose from inhalation and submersion is found for both a 15 and 30 minute exposure starting at the end of the 36 hour shipping time.

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V. Appendix

Leak Rate Calculations

Note: All solubility and viscosity values were taken from the *Handbook of Chemistry and Physics*, 43rd. edition.

Release Scenarios:

i) From K Basins to CVD: MCO is vented, MCO Cask is leaking

Given: Shipping window from K Basins to CVD = 24 hours
Void Volume of MCO = 27 L
Void Volume of Cask cavity = 15 L
^{3}H activity = 170 Ci
^{85}Kr activity = 2400 Ci

Assume: - Vent filter prevents all particulates from escaping MCO. Therefore, only gaseous isotopes are considered.

1. Since MCO is open to cask for this leg of the transfer, consider MCO and MCO Cask void volumes as a single void volume.

2. Determine volume of ^{3}H and ^{85}Kr in source term.

M_{H-3} = 6 g/mol
M_{Kr-85} = 85 g/mol

Specific activity of ^{3}H = 9700 Ci/g
Specific activity of ^{85}Kr = 390 Ci/g

From the Ideal Gas Law, at 25°C, the volume of a gas per mole is 24.5 L/mol.

For ^{3}H, the volume is: (170 Ci)(24.5 L/mol)/(6 g/mol)(9700 Ci/g) = 0.0716 L = 71.6 cc
Similarly, the volume of ^{85}Kr in the source term is 1770 cc.

3. ^{3}H and ^{85}Kr are soluble in water. Determine equilibrium conditions to find volume of radioactive gases in vapor space.

$$s_{x2} = (s_{x1})\left(\frac{V_x}{V_v}\right)(v_w)$$

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Where:

s_{x1} = solubility of nuclide "x" in water, 25°C (H3: 19.1 cc/L, Kr85: 60 cc/L)
v_x = volume of nuclide "x" in vapor space (cc)
v_w = volume of water in MCO and MCO cask (635 L)
v_v = void volume in MCO and MCO cask (42000 cc)
s_{x2} = volume of nuclide "x" in solution at 25°C (cc)

Also, $v_x + s_{x2} = v_t$, where v_t is the total volume of nuclide "x" in the source term. For H_3, v_t = 71.6 cc, and for Kr_{85}, v_t = 1770 cc.

Solving these two equations for v_x gives:

$$v_x = \frac{v_t}{1 + \frac{7.35(s_{x1})(v_w)}{(v_v)}}$$

The factor of 7.35 is due to the increased solubility due to the internal MCO pressure of 7.347 atm (108 psia), from Fig B8-8.

^3H: v_x = 22.9 cc
^{85}Kr: v_x = 231 cc

Converting back to Ci, this gives:

^3H: 54.4 Ci
^{85}Kr: 313 Ci

The total activity concentration, A_c, is (313 + 54.4 Ci)/42000 cc = 2.44 x 10^{-3} Ci/cc

4. Find leak rate from MCO Cask, L_c, assuming a 2.54 x 10^{-3} cm diameter hole. This represents the diameter of an unobservable crack.

Given:	P_u	= upstream pressure	= 7.347 atm (108 psia), from Fig B8-8, MCO internal pressure
	P_d	= downstream pressure	= 0.95 atm
	P_a	= $(P_u+P_d)/2$	= 4.149 atm
	a	= leak path length	= 0.6223 cm (o-ring width)

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T	= Temp of fill gas (He)	= 311 K (avg. SNF temp)
R_o	= Gas constant	= 8.31×10^7 erg/gmol K
k	= Ratio of specific heats	= 1.66 for He (ANSI N14.5, Table B1
M	= Molecular weight of He	= 4.0 g/mol
D	= Leakage hole diameter	= 2.54×10^{-3} cm

The pressure ratio $P_d/P_u = 0.129$. Since this ratio is less than the critical pressure ratio for helium, 0.487 (ANSI N14.5, Table B1), the flow is choked and equation B7 of ANSI N14.5 can be used.

$$L = \frac{\pi D^2}{4}\sqrt{\frac{2kR_o\,T}{M(k+1)}}\left(\frac{2}{k+1}\right)^{\frac{1}{(k-1)}}$$

Solving for L_c gives 2.95×10^{-1} cc/s.

5. Find release rate, R_c, from cask.

$L_c = 2.95 \times 10^{-1}$ cc/s (step 4)
$A_c = 2.44 \times 10^{-3}$ Ci/cc (step 3)

$R_c = (L_c)(A_c)(3600 \text{ s/hr}) = 2.59$ Ci/hr total

6. Using the ratio of ^3H to ^{85}Kr in the vapor space, the release rates are:

3.83×10^{-1} Ci/hr of ^3H
2.21 Ci/hr of ^{85}Kr

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ii) From CVD to CSB: MCO provides containment, MCO Cask is leaking

1. Find: Reference air hole diameter, D, for leak rate of 1×10^{-4} cc/s from the MCO.

Given:

P_u	= upstream pressure	= 1.0 atm (ref. condition)
P_d	= downstream pressure	= 0.01 atm (ref. condition)
P_a	= $(P_u+P_d)/2$	= 0.505 atm
R_o	= gas constant	= 8.31×10^7 erg/gmol K
k	= specific heat ratio	= 1.4 for air
T	= Temp of fill gas (air)	= 298 K (ref. condition)
M	= Molecular weight of air	= 29.0 g/mol
L	= Allowable leak rate for for MCO containment	= 1×10^{-4} std cc/s

The pressure ratio is 0.01, which is less than the critical pressure ratio for air, 0.528. Therefore, the flow is choked, and equation B7 of ANSI N14.5 will be used.

$$L = \frac{\pi D^2}{4}\sqrt{\frac{2kR_o\,T}{M(k+1)}}\left(\frac{2}{k+1}\right)^{\frac{1}{(k-1)}}$$

Substituting and solving for D gives D = 7.99×10^{-5} cm. This represents the maximum hole diameter that can exist to remain within the requirements for containment.

2. Determine actual leakage conditions, L_a, based on maximum allowable hole size.

Find: Actual leakage rate from MCO based on 7.99×10^{-5} cm hole.

Given:

P_u	= upstream pressure	= 11.2 atm (150 psig MCO design pressure)
P_d	= downstream pressure	= 1.204 atm (3 psig He fill gas)
P_a	= $(P_u+P_d)/2$	= 6.204 atm
R_o	= gas constant	= 8.31×10^7 erg/gmol K
T	= Temp of fill gas. (He)	= 353 K (max SNF temp after 36 hours, Fig B8-13, Thermal Section)
k	= specific heat ratio	= 1.66
M	= Molecular weight of He	= 4.0 g/mol
D	= Leakage hole diameter	= 7.99×10^{-5} cm

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Again, the pressure ratio is less than the critical pressure ratio, so the flow is choked and equation B7 is used.

Solving for L_a gives 3.12×10^{-4} cc/s,

3. Find release rate, R_m, from MCO to cask cavity based on 3.12×10^{-4} cc/s leak rate.

a) Find activity concentration, A_{c1}, of mixture in Ci/cc.

Total activity from solids present in the MCO (See Table 1 in this report) = 2.61×10^5 Ci
Total grams of solids = 6.26×10^6 g (See Table 1)
Aerosol Density = 9.0×10^{-6} g/cc (see Example 31 in ANSI N14.5)

A_{c1} for solids = $(9.0 \times 10^{-6}$ g/cc$)(2.61 \times 10^5$ Ci$)/(6.26 \times 10^6$ g$) = 3.75 \times 10^{-7}$ Ci/cc.

Total activity from gases = 2570 Ci
MCO void volume = 560 L = 560000 cc

A_{c1} for gases = 2570 Ci/560000 cc = 4.59×10^{-3} Ci/cc.

A_{c1} for solid is $<<$ A_{c1} for gases, so total $A_{c1} = 4.59 \times 10^{-3}$ Ci/cc.

b) Multiplying the leak rate by the concentration and converting to Ci/hr gives R_m = 5.15×10^{-3} Ci/hr.

In 36 hours, which is the shipping window for the transfer from CVD to CSB, the MCO will leak 1.85×10^{-1} Ci.

4. Find activity concentration, A_{c2}, in cask cavity after 36 hours.

Activity = 1.85×10^{-1} Ci
Volume of cask cavity = 122 L = 122,000 cc

$A_{c2} = 1.85 \times 10^{-1}$ Ci/122,000 cc = 1.52×10^{-6} Ci/cc.

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5\. Find leak rate from cask, L_c, assuming a 2.54×10^{-3} cm diameter hole. This represents the diameter of an unobservable crack.

Given:	P_u	= upstream pressure	= 1.463 atm (conservative)
	P_d	= downstream pressure	= 0.95 atm
	P_a	= $(P_u+P_d)/2$	= 1.207 atm
	a	= leak path length	= 0.6223 cm (o-ring width)
	T	= Temp of fill gas (He)	= 313 K (40°C avg. cask wall temp after 36 hours)
	u	= He viscosity at T	= 0.0203 cP
	M	= Molecular weight of He	= 4.0 g/mol
	D	= Leakage hole diameter	= 2.54×10^{-3} cm

The pressure ratio is 0.649, so the flow is unchoked and Equation B2 of ANSI 14.5 is used.

$$L_T = (F_c+F_m)(P_u-P_d)$$

where

$$F_c = 2.49 \times 10^6 \, D^4/(au) \ cm^3/s$$

$$F_m = 3.81 \times 10^3 \, D^3 \sqrt{T/M}\,/(aP_a) \ cm^3/s$$

Solving for L_c, gives $L_c = 4.59 \times 10^{-3}$ cc/s

6\. Find release rate, R_c, from cask.

$L_c = 4.59 \times 10^{-3}$ cc/s (step 5)
$A_c = 1.52 \times 10^{-6}$ Ci/cc (step 4)

$R_c = (L_c)(A_c)(3600 \text{ s/hr}) = 2.51 \times 10^{-5}$ Ci/hr

7\. Determine release rate of each radionuclide.

Given: Source term in PDC

From step 4a, the release fraction attributed to the gases is 0.99992 and the release fraction attributed to the solids is 0.00008.

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Example: R_{Fe55} = Activity of Fe_{55} released (Ci/hr)
A_{Fe55} = Activity of Fe_{55} in source term (3.8 Ci)
A_s = Activity of all solids in source term (2.61×10^5 Ci)
P_s = Fraction of released activity that is a solid (0.00008)
R_c = Release rate from cask (2.51×10^{-5} Ci/hr)

$$R_{Fe55} = (A_{Fe55})(P_s)(R_c)/(A_s)$$

$$R_{Fe55} = 2.93 \times 10^{-14} \text{ Ci/hr}$$

The release for each radionuclide is given in the dose consequence section at the end of this evaluation.

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iii) From CVD to CSB: MCO is leaking, MCO Cask is leaking

1. Find: Leakage rate, L_{mco}, from MCO to cask cavity.

Given:

P_u = upstream pressure	= 11.2 atm (150 psig MCO design pressure)
P_d = downstream pressure	= 1.204 atm (3 psig He fill gas)
$P_a = (P_u+P_d)/2$	= 6.204 atm
R_o = gas constant	= 8.31 x 10^7 erg/gmol K
T = Temp of fill gas (He)	= 353 K (max SNF temp after 36 hours, Fig. B8-13, Thermal Section)
k = specific heat ratio	= 1.66 (ANSI N14.5, Table 1)
M = Molecular weight of He	= 4.0 g/mol
D = Leakage hole diameter	= 2.54 x 10^{-3} cm

Solving for L_a, similar to Part ii, step 2, gives L_a = 3.16 x 10^{-1} cc/s.

2. Find release rate, R_m, from MCO to cask cavity based on 3.16 x 10^{-1} cc/s leak rate.

a) Find activity concentration, A_{c1}, of mixture in Ci/cc.

A_{c1} for solids = 3.75 x 10^{-7} Ci/cc. (Same as in Part ii, step 3)
A_{c1} for gases = 4.59 x 10^{-3} Ci/cc. (Same as in Part ii, step 3)

A_{c1} for solid is << A_{c1} for gases, so total A_{c1} = 4.59 x 10^{-3} Ci/cc.

b) Multiplying the leak rate by the concentration and converting to Ci/hr gives R_m = 5.22 Ci/hr.

In 36 hours, the MCO will leak 188 Ci.

3. Find activity concentration, A_{c2}, in cask cavity after 36 hours.

Activity = 188 Ci
Volume of cask cavity = 122 L = 122,000 cc

A_{c2} = 188 Ci/122,000 cc = 1.54 x 10^{-3} Ci/cc.

4. Find leak rate from cask, L_c, assuming a 2.54 x 10^{-3} cm diameter hole.

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The solution is identical to that in part ii), step 5.

$L_c = 4.59 \times 10^{-3}$ cc/s

5. Find release rate, R_c, from cask.

$L_c = 4.59 \times 10^{-3}$ cc/s (step 4)
$A_c = 1.54 \times 10^{-3}$ Ci/cc (step 3)

$R_c = (L_c)(A_c)(3600 \text{ s/hr}) = 2.55 \times 10^{-2}$ Ci/hr

6. Determine release rate of each radionuclide.

Given: Source term in PDC

From step 2a, the release fraction attributed to the gases is 0.99992 and the release fraction attributed to the solids is 0.00008.

Example:
R_{Fe55} = Activity of Fe_{55} released (Ci/hr)
A_{Fe55} = Activity of Fe_{55} in source term (3.8 Ci)
A_s = Activity of all solids in source term (2.61×10^5 Ci)
P_s = Fraction of released activity that is a solid (0.00008)
R_c = Release rate from cask (2.55×10^{-2} Ci/hr)

$R_{Fe55} = (A_{Fe55})(P_s)(R_c)/(A_s)$

$R_{Fe55} = 2.97 \times 10^{-11}$ Ci/hr

The release for each radionuclide is given in the dose consequence section at the end of this evaluation.

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Table 1: MCO Solid Source Term

		Specific	
	Activity	Activity	Quantity
Nuclide	Ci	Ci/g	g
---------	--------	--------	--------
C 14	3.50e+00	4.50e+00	7.78e-01
FE55	3.80e+00	2.40e+03	1.58e-03
CO60	1.40e+01	1.10e+03	1.27e-02
NI59	2.00e-01	8.00e-02	2.50e+00
NI63	2.20e+01	5.70e+01	3.86e-01
SE79	4.10e-01	7.00e-02	5.86e+00
SR90	4.40e+04	1.40e+02	3.14e+02
Y 90	4.40e+04	5.40e+05	8.15e-02
ZR93	1.90e+00	2.50e-03	7.60e+02
NB93M	1.20e+00	2.40e+02	5.00e-03
TC99	1.40e+01	1.70e-02	8.24e+02
RU106	2.20e-01	3.30e+03	6.67e-05
RH106	2.20e-01	3.46e+09	6.36e-11
PD107	9.90e-02	1.90e-05	5.21e+03
AG110	6.90e-09	4.17e+09	1.65e-18
AG110M	5.20e-07	4.70e+03	1.11e-10
CD113M	1.80e+01	2.20e+02	8.18e-02
IN113M	2.10e-18	1.67e+07	1.26e-25
SN113	2.10e-18	1.00e+04	2.10e-22
SN119M	6.00e-07	3.70e+03	1.62e-10
SN121M	4.00e-01	5.40e+01	7.41e-03
SN123	2.40e-15	8.20e+03	2.93e-19
SN126	8.20e-01	2.80e-02	2.93e+01
SB125	8.30e+01	1.00e+03	8.30e-02
SB126	1.10e-01	8.40e+04	1.31e-06
SB126M	8.20e-01	7.85e+07	1.04e-08

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TE123M	2.30e-20	8.90e+03	2.58e-24
TE125M	2.00e+01	1.80e+04	1.11e-03
TE127	3.50e-18	2.60e+06	1.35e-24
TE127M	3.60e-18	9.40e+03	3.83e-22
I 129	3.30e-02	1.80e-04	1.83e+02
CS134	4.70e+01	1.30e+03	3.62e-02
CS135	3.80e-01	1.20e-03	3.17e+02
CS137	6.20e+04	8.70e+01	7.13e+02
BA137M	5.80e+04	5.38e+08	1.08e-04
CE144	7.30e-03	3.20e+03	2.28e-06
PR144	7.20e-03	7.56e+07	9.52e-11
PR144M	8.70e-05	1.81e+08	4.81e-13
PM147	7.70e+02	9.30e+02	8.28e-01
SM151	6.50e+02	2.60e+01	2.50e+01
EU152	5.50e+00	1.80e+02	3.06e-02
EU154	7.40e+02	2.60e+02	2.85e+00
EU155	7.10e+02	4.90e+03	1.45e-01
GD153	5.10e-09	3.50e+03	1.46e-12
U 234	2.40e+00	6.20e-03	3.87e+02
U 235	8.10e-02	2.20e-06	3.68e+04
U 236	4.50e-01	6.50e-05	6.92e+03
U 238	2.10e+00	3.40e-07	6.18e+06
NP237	3.00e-01	7.10e-04	4.23e+02
PU238	8.50e+02	1.70e+01	5.00e+01
PU239	1.10e+03	6.20e-02	1.77e+04
PU240	8.70e+02	2.30e-01	3.78e+03
PU241	4.40e+04	1.00e+02	4.40e+02
PU242	5.50e-01	3.90e-03	1.41e+02
AM241	2.70e+03	3.40e+00	7.94e+02
AM242	2.40e+00	8.08e+05	2.97e-06
AM242M	2.40e+00	9.70e+05	2.47e-06

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AM243	1.80e+00	2.00e-01	9.00e+00
CM242	2.00e+00	3.30e+03	6.06e-04
CM244	2.90e+01	8.10e+05	3.58e-05
Total	2.61e+05		6.26e+06

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MCO Leak Rate Worker Dose Calculations

Worker inhalation and submersion doses were calculated for three different source terms and two exposure times. The first two source terms address particulate leakage from the MCO cask, and the third addresses leakage of the gases present in the MCO. The first case, which will be labeled "Particulate Case 1," applies to conditions where the MCO and MCO cask both have leakage paths corresponding to a 1 mil thick crack. The second case, called "Particulate Case 2," applies to conditions where the MCO maintains confinement to a level of 1×10^{-4} cc/s, and the MCO cask has a 1 mil leakage path. The third source term assumes that the MCO HEPA filter remains functional, therefore, only gases are released.

For each of the three source terms it is assumed that the worker is located inside the Canister Storage Building (CSB) for a 15 min and 30 min exposure period. The calculations were made assuming the radioactivity in the MCO had been leaking into the CSB and had reached an equilibrium activity concentration (C_{eq}, Ci/m^3). The worker was assumed to breath at a rate of 3.3×10^{-4} m^3/s (ICRP 1975), which is the breathing rate associated with light activity. Doses were computed using the GENII dose conversion factors for a 50 year dose commitment period. The leakage rates (Ci/h) for the particulate cases are listed Table 1. The leakage rates for the gas case are 3.83×10^{-1} Ci/h of H-3, and 2.21 Ci/h of Kr-85.

The equilibrium concentration (C_{eq}, Ci/m^3) is equal to the activity leakage rates (L_r, Ci/h) divided by the CSB ventilation flow rate (F, 6250 cfm = 10619 m^3/h). The equilibrium concentrations for the particulate cases are listed Table 1. Note that no credit is taken for removal of the particulates from the air inside the CSB as a result of the HEPA filtration system. This will result in very conservative equilibrium activity concentrations.

The following equation is used to calculate the inhalation and submersion Committed Effective Dose Equivalent (CEDE) for a single involved worker.

$$D(rem) = C_{eq}(Ci/m^3) \;\; x \;\; t_{exp}(s) \;\; x \;\; BR(m^3/s) \;\; x \;\; DCF(rem/Ci)$$

where,

C_{eq} = equilibrium activity concentration, Ci/m^3 = L_r/F,
where, L_r = activity leakage rates, Ci/h
F = CSB ventilation flow rate, 10619 m^3/h

t_{exp} = Duration of worker exposure = 15 min (900 s) or 30 min (1800 s)
BR = Typical acute breathing rate, 3.3×10^{-4} m^3/s (light activity)
DCF = dose conversion factor for each radionuclide, rem/Ci

The GENII computer code (Napier 1988) was used to calculate the CEDE for each case for a 15 min exposure duration. As evident from the equation above, the dose for a 30 min exposure duration is simply two times that for a 15 min duration.

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The CEDE from GENII is 0.6 mrem for a 15 min exposure duration and 1.2 mrem for a 30 min duration using the equilibrium activity concentrations in Table 1 for Particulate Case 1. The CEDE for Particulate Case 2 is 6 x 10^{-4} mrem for a 15 min exposure duration and 1.2 x 10^{-3} mrem for a 30 min duration.

The CEDE is 1.1 mrem for a 15 min exposure duration for an equilibrium activity concentration of 3.6 x 10^{-5} Ci/m³ (0.383 Ci/h /10619 m³/h) of H-3, and 2.1 x 10^{-4} Ci/m³ (2.2 Ci/h /10619 m³/h) of Kr-85. The CEDE is 2.2 mrem for a 30 min exposure duration.

The results for each case are summarized below.

Case	Exposure Duration min	Dose mrem
Particulate Case 1	15	0.61
Particulate Case 1	30	1.2
Particulate Case 2	15	6.1E-4
Particulate Case 2	30	1.2E-3
Gas Case 1	15	1.1
Gas Case 2	30	2.2

An example GENII input is included below. The GENII libraries used were as follows:

GENII Default Parameter Values (28-Mar-90 RAP)
Radionuclide Library - Times < 100 years (23-July-93 PDR)
External Dose Factors for GENII in person Sv/yr per Bq/n (8-May-90
Worst-Case Solubilities, Yearly Dose Increments (23-Jul-93 PDR)

References:

ICRP, 1975, *Report of the Task Group on Reference Man*, International Commission on Radiological Protection Report No. 23, Elmsford, New York.

Napier, B. A., et al., December 1988, *GENII - The Hanford Environmental Radiation Dosimetry Software System*, Pacific Northwest Laboratory, Richland, Washington, PNL-6584 Vol. 1, UC-600.

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Table 1 - Releases from the MCO Cask Due to Leakage

Nuclide	Particulate Case 1		Particulate Case 2	
	Leakage Rate Ci/h	Equil. Conc. (Ci/m³)	Leakage Rate Ci/h	Equil. Conc. (Ci/m³)
H 3	1.7E-03	1.6E-07	1.7E-06	1.6E-10
C 14	2.7E-11	2.5E-15	2.7E-14	2.5E-18
FE55	3.0E-11	2.8E-15	2.9E-14	2.7E-18
CO60	1.1E-10	1.0E-14	1.1E-13	1.0E-17
NI59	1.6E-12	1.5E-16	1.5E-15	1.4E-19
NI63	1.7E-10	1.6E-14	1.7E-13	1.6E-17
SE79	3.2E-12	3.0E-16	3.2E-15	3.0E-19
KR85	2.4E-02	2.3E-06	2.3E-05	2.2E-09
SR90	3.4E-07	3.2E-11	3.4E-10	3.2E-14
Y 90	3.4E-07	3.2E-11	3.4E-10	3.2E-14
ZR93	1.5E-11	1.4E-15	1.5E-14	1.4E-18
NB93M	9.4E-12	8.9E-16	9.2E-15	8.7E-19
TC99	1.1E-10	1.0E-14	1.1E-13	1.0E-17
RU106	1.7E-12	1.6E-16	1.7E-15	1.6E-19
RH106	1.7E-12	1.6E-16	1.7E-15	1.6E-19
PD107	7.7E-13	7.3E-17	7.6E-16	7.2E-20
AG110	5.4E-20	5.1E-24	5.3E-23	5.0E-27
AG110M	4.1E-18	3.9E-22	4.0E-21	3.8E-25
CD113M	1.4E-10	1.3E-14	1.4E-13	1.3E-17
IN113M	1.6E-29	1.5E-33	1.6E-32	1.5E-36
SN113	1.6E-29	1.5E-33	1.6E-32	1.5E-36
SN119M	4.7E-18	4.4E-22	4.6E-21	4.3E-25
SN121M	3.1E-12	2.9E-16	3.1E-15	2.9E-19
SN123	1.9E-26	1.8E-30	1.8E-29	1.7E-33
SN126	6.4E-12	6.0E-16	6.3E-15	5.9E-19
SB125	6.5E-10	6.1E-14	6.4E-13	6.0E-17

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SB126	8.6E-13	8.1E-17	8.5E-16	8.0E-20
SB126M	6.4E-12	6.0E-16	6.3E-15	5.9E-19
TE123M	1.8E-31	1.7E-35	1.8E-34	1.7E-38
TE125M	1.6E-10	1.5E-14	1.5E-13	1.4E-17
TE127	2.7E-29	2.5E-33	2.7E-32	2.5E-36
TE127M	2.8E-29	2.6E-33	2.8E-32	2.6E-36
I 129	2.6E-13	2.4E-17	2.5E-16	2.4E-20
CS134	3.7E-10	3.5E-14	3.6E-13	3.4E-17
CS135	3.0E-12	2.8E-16	2.9E-15	2.7E-19
CS137	4.9E-07	4.6E-11	4.8E-10	4.5E-14
BA137M	4.5E-07	4.2E-11	4.5E-10	4.2E-14
CE144	5.7E-14	5.4E-18	5.6E-17	5.3E-21
PR144	5.6E-14	5.3E-18	5.5E-17	5.2E-21
PR144M	6.8E-16	6.4E-20	6.7E-19	6.3E-23
PM147	6.0E-09	5.7E-13	5.9E-12	5.6E-16
SM151	5.1E-09	4.8E-13	5.0E-12	4.7E-16
EU152	4.3E-11	4.0E-15	4.2E-14	4.0E-18
EU154	5.8E-09	5.5E-13	5.7E-12	5.4E-16
EU155	5.6E-09	5.3E-13	5.5E-12	5.2E-16
GD153	4.0E-20	3.8E-24	3.9E-23	3.7E-27
U 234	1.9E-11	1.8E-15	1.8E-14	1.7E-18
U 235	6.3E-13	5.9E-17	6.2E-16	5.8E-20
U 236	3.5E-12	3.3E-16	3.5E-15	3.3E-19
U 238	1.6E-11	1.5E-15	1.6E-14	1.5E-18
NP237	2.3E-12	2.2E-16	2.3E-15	2.2E-19
PU238	6.7E-09	6.3E-13	6.5E-12	6.1E-16
PU239	8.60E-09	8.1E-13	8.50E-12	8.0E-16
PU240	6.80E-09	6.4E-13	6.70E-12	6.3E-16
PU241	3.40E-07	3.2E-11	3.40E-10	3.2E-14
PU242	4.30E-12	4.0E-16	4.20E-15	4.0E-19

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AM241	2.10E-08	2.0E-12	2.10E-11	2.0E-15
AM242	1.90E-11	1.8E-15	1.80E-14	1.7E-18
AM242M	1.90E-11	1.8E-15	1.80E-14	1.7E-18
AM243	1.40E-11	1.3E-15	1.40E-14	1.3E-18
CM242	1.60E-11	1.5E-15	1.50E-14	1.4E-18
CM244	2.30E-10	2.2E-14	2.20E-13	2.1E-17
TOTALS	2.6E-02		2.5E-05	

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Example GENII input for Particulate Case 1

```
######################### Program GENII Input File ############ 8 Jul 88 ####
Title: MCO Worker Inh/Sub Dose - Particulate Case 1 - 15 min
    \SAMPL\G-AIR.AC                    Created on 01-22-1990 at 07:30
OPTIONS===========================Default
======================================
F   Near-field scenario?    (Far-field)   NEAR-FIELD: narrowly-focused
F   Population dose?        (Individual)        release, single site
T   Acute release?          (Chronic)     FAR-FIELD: wide-scale release,
   Maximum Individual data set used              multiple sites
                      Complete                      Complete
TRANSPORT OPTIONS============= Section  EXPOSURE PATHWAY
OPTIONS===== Section
T  Air Transport              1   F  Finite plume, external      5
F  Surface Water Transport     2    T  Infinite plume, external    5
F  Biotic Transport (near-field) 3,4  F  Ground, external          5
F  Waste Form Degradation (near) 3,4  F  Recreation, external        5
                          T  Inhalation uptake      5,6
REPORT OPTIONS======================== F  Drinking water ingestion
7,8
T  Report AEDE only              F  Aquatic foods ingestion     7,8
F  Report by radionuclide       F  Terrestrial foods ingestion  7,9
F  Report by exposure pathway     F  Animal product ingestion   7,10
F  Debug report on screen        F  Inadvertent soil ingestion

INVENTORY ##############################################################

 4  Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0  Surface soil source units (1- m2  2- m3  3- kg)
    Equilibrium question goes here

    --------|----Release Terms------|----------Basic Concentrations---------|
    Use when|  transport selected   |  near-field scenario, optionally      |
    --------|-----------------------|---------------------------------------|
    Release |       Surface Buried  |    Surface Deep    Ground  Surface|
    Radio-  |Air     Water  Waste  |Air     Soil   Soil    Water   Water  |
    nuclide |/yr     /yr    /m3    |/m3     /unit  /m3     /L      /L     |
    --------|------- ------- -------|------- ------- ------- ------- -------|
    H 3     1.6E-07
    C 14    2.5E-15
    FE55    2.8E-15
    CO60    1.0E-14
    NI59    1.5E-16
    NI63    1.6E-14
    SE79    3.0E-16
```

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KR85	2.3E-06
SR90	3.2E-11
Y 90	3.2E-11
ZR93	1.4E-15
NB93M	8.9E-16
TC99	1.0E-14
RU106	1.6E-16
PD107	7.3E-17
AG110M	3.9E-22
CD113M	1.3E-14
IN113M	1.5E-33
SN113	1.5E-33
SN119M	4.4E-22
SN121M	2.9E-16
SN123	1.8E-30
SN126	6.0E-16
SB125	6.1E-14
SB126	8.1E-17
SB126M	6.0E-16
TE123M	1.7E-35
TE125M	1.5E-14
TE127	2.5E-33
TE127M	2.6E-33
I 129	2.4E-17
CS134	3.5E-14
CS135	2.8E-16
CS137	4.6E-11
CE144	5.4E-18
PR144	5.3E-18
PR144M	6.4E-20
PM147	5.7E-13
SM151	4.8E-13
EU152	4.0E-15
EU154	5.5E-13
EU155	5.3E-13
GD153	3.8E-24
U 234	1.8E-15
U 235	5.9E-17
U 236	3.3E-16
U 238	1.5E-15
NP237	2.2E-16
PU238	6.3E-13
PU239	8.1E-13
PU240	6.4E-13
PU241	3.2E-11
PU242	4.0E-16

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```
AM241   2.0E-12
AM242   1.8E-15
AM242M  1.8E-15
AM243   1.3E-15
CM242   1.5E-15
CM244   2.2E-14
--------|----Derived Concentrations-----|
Use when|  measured values are known   |
--------|-------------------------------|
Release |Terres. Animal  Drink   Aquatic|
Radio-  |Plant   Product Water   Food   |
nuclide |/kg     /kg     /L      /kg    |
--------|------- ------- ------- -------|
```

TIME ##

1 Intake ends after (yr)
50 Dose calc. ends after (yr)
1 Release ends after (yr)
0 No. of years of air deposition prior to the intake period
0 No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ######################################

0 Definition option: 1-Use population grid in file POP.IN
0 2-Use total entered on this line

NEAR-FIELD SCENARIOS ###

Prior to the beginning of the intake period: (yr)
0 When was the inventory disposed? (Package degradation starts)
0 When was LOIC? (Biotic transport starts)
0 Fraction of roots in upper soil (top 15 cm)
0 Fraction of roots in deep soil
0 Manual redistribution: deep soil/surface soil dilution factor
0 Source area for external dose modification factor (m2)
TRANSPORT ##
====AIR
TRANSPORT======================================SECTION
1=====

```
             0-Calculate PM           |0    Release type (0-3)
1      Option: 1-Use chi/Q or PM value |F    Stack release (T/F)
             2-Select MI dist & dir   |0    Stack height (m)
             3-Specify MI dist & dir  |0    Stack flow (m3/sec)
900.   Chi/Q or PM value              |0    Stack radius (m)
9      MI sector index (1=S)          |0    Effluent temp. (C)
```

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100.0 MI distance from release point (m)|0 Building x-section (m2)
T Use jf data, (T/F) else chi/Q grid|0 Building height (m)

====SURFACE WATER
TRANSPORT==============================SECTION2=====
0 Mixing ratio model: 0-use value, 1-river, 2-lake
0 Mixing ratio, dimensionless
0 Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0 Transit time to irrigation withdrawl location (hr)
If mixing ratio model > 0:
0 Rate of effluent discharge to receiving water body (m3/s)
0 Longshore distance from release point to usage location (m)
0 Offshore distance to the water intake (m)
0 Average water depth in surface water body (m)
0 Average river width (m), MIXFLG=1 only
0 Depth of effluent discharge point to surface water (m), lake only

====WASTE FORM
AVAILABILITY===========================SECTION3=====
0 Waste form/package half life, (yr)
0 Waste thickness, (m)
0 Depth of soil overburden, m

====BIOTIC TRANSPORT OF BURIED
SOURCE=================SECTION4=====
T Consider during inventory decay/buildup period (T/F)?
T Consider during intake period (T/F)? | 1-Arid non agricultural
0 Pre-Intake site condition.............| 2-Humid non agricultural
| 3-Agricultural

EXPOSURE ##

====EXTERNAL
EXPOSURE=================================SECTION
5=====
Exposure time: | Residential irrigation:
0 Plume (hr) | T Consider: (T/F)
0 Soil contamination (hr) | 0 Source: 1-ground water
0 Swimming (hr) | 2-surface water
0 Boating (hr) | 0 Application rate (in/yr)
0 Shoreline activities (hr) | 0 Duration (mo/yr)
0 Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0 Transit time for release to reach aquatic recreation (hr)
1.0 Average fraction of time submersed in acute cloud (hr/person hr)

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====INHALATION==
===SECTION 6=====
8766.0 Hours of exposure to contamination per year
0 0-No resus- 1-Use Mass Loading 2-Use Anspaugh model
0 pension Mass loading factor (g/m3) Top soil available (cm)

====INGESTION
POPULATION==============================SECTION7=====
0 Atmospheric production definition (select option):
0 0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
1-Use population-weighted chi/Q
2-Use uniform production
3-Use chi/Q and production grids (PRODUCTION will be overridden)
0 Population ingesting aquatic foods, 0 defaults to total (person)
0 Population ingesting drinking water, 0 defaults to total (person)
F Consider dose from food exported out of region (default=F)

Note below: S* or Source: 0-none, 1-ground water, 2-surface water
3-Derived concentration entered above
==== AQUATIC FOODS / DRINKING WATER
INGESTION=========SECTION 8====

F Salt water? (default is fresh)

USE ? T/F	FOOD TYPE	TRAN-SIT hr	PROD-UCTION kg/yr	-CONSUMPTION- HOLDUP da	RATE kg/yr	DRINKING WATER	
F	FISH	0.00	0.0E+00	0.00	0.0	0	Source (see above)
F	MOLLUS	0.00	0.0E+00	0.00	0.0	T	Treatment? T/F
F	CRUSTA	0.00	0.0E+00	0.00	0.0	0	Holdup/transit(da)
F	PLANTS	0.00	0.0E+00	0.00	0.0	0	Consumption (L/yr)

====TERRESTRIAL FOOD
INGESTION========================SECTION9=====

USE ? T/F	FOOD TYPE	GROW TIME da	--IRRIGATION-- S *	RATE in/yr	TIME mo/yr	YIELD kg/m2	PROD-UCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr
F	LEAF V	0.00	0	0.0	0.0	0.0	0.0E+00	0.0	0.0
F	ROOT V	0.00	0	0.0	0.0	0.0	0.0E+00	0.0	0.0
F	FRUIT	0.00	0	0.0	0.0	0.0	0.0E+00	0.0	0.0
F	GRAIN	0.00	0	0.0	0.0	0.0	0.0E+00	0.0	0.0

ENGINEERING SAFETY EVALUATION

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Originator J. S. Boettger/A. V. Savino *[signature]* Date 01/09/96
Checker *See Peer Review Checklist* Date 01/09/96

====ANIMAL PRODUCTION
CONSUMPTION====================SECTION 10====

USE ? T/F	FOOD TYPE	HUMAN CONSUMPTION RATE kg/yr	HUMAN HOLDUP da	TOTAL PRODUCTION kg/yr	DRINK WATER CONTAM FRACT.	STORED FEED DIET FRACTION	STORED FEED GROW TIME da	IRRIGATION S *	IRRIGATION RATE in/yr	IRRIGATION TIME mo/yr	YIELD kg/m3	STORAGE da
F	BEEF	0.0	0.0	0.00	0.00	0.00	0.0	0	0.0	0.00	0.00	0.0
F	POULTR	0.0	0.0	0.00	0.00	0.00	0.0	0	0.0	0.00	0.00	0.0
F	MILK	0.0	0.0	0.00	0.00	0.00	0.0	0	0.0	0.00	0.00	0.0
F	EGG	0.0	0.0	0.00	0.00	0.00	0.0	0	0.0	0.00	0.00	0.0
						FRESH FORAGE						
	BEEF					0.00	0.0	0	0.0	0.00	0.00	0.0
	MILK					0.00	0.0	0	0.0	0.00	0.00	0.0

##

CHECKLIST FOR PEER REVIEW

Document Reviewed: MCO Leakrate Worker Dose Calculations, by A. V. Savino, dated 1/4/97.

Scope of Review: Entire Document

Yes	No	NA	
[X]	[ ]	[ ] *	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[X]	[ ]	[ ]	Accident scenarios developed in a clear and logical manner.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[X]	[ ]	[ ]	Software input correct and consistent with document reviewed.
[X]	[ ]	[ ]	Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[X]	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[X]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[ ]	[ ]	[X]	Format consistent with appropriate NRC Regulatory Guide or other standards
[ ]		[X] *	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]	Document approved.

Paul Rittmann *Paul Rittmann* 1-7-97

Reviewer (Printed Name and Signature) Date

* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

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5.0 SHIELDING EVALUATION

5.1 INTRODUCTION

This shielding evaluation supports the transport of N Reactor fuel from K Basin to the CSB in an MCO Cask. The MCO Cask shielding consists of a cask body, cask lid, and the shield plug on the MCO. A bounding source term consisting of 6.34 MTU of Mark IV fuel was used for shielding calculations as shown in Part B, Table B2-1.

The dose limits for this package are 200 mrem/h at any accessible point on the exterior surface of the package, 1000 mrem/h at any point on the surface of the package that is only accessible by long-reach tools, 10 mrem/h at a distance of 2 m from the package, and less than 2 mrem/h in any normally occupied space in the transport vehicle (6 m). After the cask is subjected to accident conditions, the limit is 1 rem/h at 1 m.

Both normal transport conditions and accident conditions are analyzed. The normal transport condition considers both a water-flooded and a dry MCO with the cask lid in place. The dry MCO was found to be the bounding case. Dose rates for the cask containing a dry MCO are given in Table B5-1.

Table B5-1. Dose Rates for a Dry Multicanister Overpack (MCO) for Normal Conditions.

Location relative to cask	Total dose rates in mrem/h (MCNP uncertainty[a])		
	Contact	2 m	6 m
Side	49 (1%)	6.9 (1%)	1.5 (1%)
Top[b,c]	0.60 (2%)	N/A[d]	N/A[d]
Bottom[b]	43 (2%)	N/A[e]	N/A[e]
Bottom, center[f]	63 (9%)	N/A[e]	N/A[e]
Streaming through shield plug ports[c] Dip tube port Short draw tube port	 1.2 (7%) 2.4 (6%)	 N/A[d] N/A[d]	 N/A[d] N/A[g]
Vent port	0.55 (3%)	N/A[d]	N/A[d]
Drain port[h]	310 (7%)	3.6 (3%)	1.1 (3%)
Maximum dose rate above radial side of cask[i]	1.9 (3%)	N/A[d]	N/A[d]

MCNP = Monte Carlo N-Particle (computer code).

[a]The one standard deviation statistical uncertainty (relative) in MCNP calculation.

[b]Average over 30 cm (12 in.) radius, corresponding to the radius of the MCO.

[c]Photon dose rates were calculated using top 4 in. of source, and have been scaled by a 1.05 correction factor (see Section 5.2.1).

[d]Contact dose rate meets the criteria for 2 m and 6 m.

[e]Dose rates at 2 m and 6 m from bottom are beneath ground level in this condition.

[f]There is a small recess in the center of the bottom plate of the MCO.

[g]Calculation of neutron dose shows total dose will drop below the 2 mrem/h limit.

[h]Dose rates along axis of drain port.

[i]Dose rate "D" on Figure B5-1.

The bounding accident condition is defined as a vertical drop in which the fuel is condensed in the bottom of the MCO. This configuration increases dose rates at the side and bottom of the cask. The ratio of the height of the source region to its diameter under normal conditions is more than five. Consequently, for a given percentage of compaction, vertical compaction of the source due to a vertical cask drop will have a much more dramatic effect on the spatial distribution of the source region than will compaction of the source if the cask is dropped on its side. As the height of the source region approaches the diameter, dose rates near the surface will increase. A side drop would result in horizontal compaction and possibly vertical expansion of the source. Therefore, maximum vertical compaction of the source is considered the worst case, and the effects of a side drop on the dose rates are not analyzed in this section.

The maximum contact dose rates at the side and bottom of the cask are 54 mrem/h and 110 mrem/h, respectively (Table B5-2). Compaction of the fuel at the bottom of the cask will decrease dose rates at the top of the cask.

Table B5-2. Contact Dose Rates for a Dry Multicanister Overpack (MCO) Under Accident Conditions.

Location	Dose type	Dose rates in mrem/h (MCNP uncertainty[a])	Output file
Side	Photon	46 (2%)	oacc
	Neutron	7.6 (1%)	onacc
	Total	54 (1%)	
Bottom, average[b]	Photon	47 (1%)	oacc
	Neutron	7.3 (2%)	onacc
	Total	54 (1%)	
Bottom, center[c]	Photon	100 (11%)	oac
	Neutron	11 (7%)	onacc
	Total	110 (10%)	
Drain port	Photon	180 (11%)	oacc
	Neutron	2.4 (1%)	onacc
	Total	190 (11%)	

MCNP = Monte Carlo N-Particle (code).
[a]The one standard deviation statistical uncertainty (relative) in MCNP calculation.
[b]Average over 30 cm (12 in.) radius, corresponding to the radius of the MCO.
[c]There is a small recess in the center of the bottom plate of the MCO.

5.2 DIRECT RADIATION SOURCE SPECIFICATION

The source used for these evaluations represents a worst-case source loading for shielding analysis. All shipments are bounded by this evaluation. The source consists of 6.34 MTU of Mark IV fuel irradiated to 16% ^{240}Pu as given in Part B, Table B2-1.

The source geometry for normal conditions consists of five tiers (baskets) placed one on top of the other inside the MCO. The baskets were modeled as 68.2 cm (26.9 in.) tall with each containing 54 Mark IV series E fuel assemblies. The total length of each assembly is 66.3 cm (26.1 in.) including end-caps (Short 1995). The end-caps are up to 0.635 cm (0.25 in.) long (WHC 1979). Rather than modeling the end-caps, the source material was extended to include the full 66.3-cm length. This 2% increase in length will have a negligible effect on dose rates. Scrap baskets have approximately the same internal volume as fuel baskets and should be bounded by the worst-case fuel basket loading used in this analysis.

For the accident condition, it was assumed that there is a vertical drop that causes all the fuel to be condensed in the bottom of the MCO. For shielding purposes, maximum compaction of the source volume will give the most conservative dose rates. Therefore, the accident condition source is a cylinder 129.0 cm (51.0 in.) tall with a radius of 58.4 cm (23.0 in.), consisting of uranium metal fuel with a density of 18.77 g/cm^3.

5.2.1 Gamma Source

The ORIGEN2 (Schmittroth 1994) computer code was used to calculate the gamma-ray source based on the shielding source term shown in Part B, Table B2-1. Table B5-3 shows the photon source per MCO. The total photon strength is 5.71 E+15 photons/s/MCO.

For photon dose rates above the cask, only the top 10 cm (4 in.) of the top tier were included as the source for calculational efficiency. A calculation of photon dose rates at the bottom of the MCO shield plug indicates that the top 10 cm (4 in.) of source contribute 96% of the total photon dose (Table B5-4) above the MCO shield plug. All results above the MCO shield plug using only the top 10 cm (4 in.) of source will be scaled by this factor (multiplication by 1.04). Similarly, a calculation of dose rates at the top of the gap between the MCO and the cask indicates that the top 10 cm (4 in.) of source contribute 95% of the total photon dose (Table B5-4) above the gap. All results above the gap using the top 10 cm (4 in.) of the source will be multiplied by 1.05.

Table B5-5 shows the flux-to-dose rate conversion factors used to calculate the gamma-ray dose rates. These conversion factors are the ANSI/ANS-6.1.1-1991 (ANSI/ANS 1991) conversion factors and conservatively assume the radiation exposure is from an anterior-posterior exposure.

Table B5-3. Photon Source Term for the Multiple Canister Overpack (MCO).

Energy (MeV)	Mark IV fuel 16.0% ^{240}Pu (photons/s/MCO)
1.50 E-02	1.65 E+15
2.50 E-02	3.52 E+14
3.75 E-02	3.97 E+14
5.75 E-02	3.33 E+14
8.50 E-02	1.84 E+14
1.25 E-01	1.37 E+14
2.25 E-01	1.55 E+14
3.75 E-01	7.35 E+13
6.62 E-01*	2.33 E+15**
8.50 E-01	5.87 E+13
1.25 E+00	3.37 E+13
1.75 E+00	1.04 E+12
2.25 E+00	8.85 E+09
2.75 E+00	6.34 E+08
3.50 E+00	8.31 E+07
5.00 E+00	3.95 E+05
7.00 E+00	4.51 E+04
1.10 E+01	5.16 E+03
Total	5.71 E+15

*Changed from 0.575 MeV to 0.662 Mev to accurately reflect ^{137m}Ba gamma ray.
**Scaled to conserve energy as a result of changing energy bin from 0.575 MeV to 0.662 MeV.

Table B5-4. Calculations Showing Contribution to Photon Dose Rates by Top Four Inches of Source.

	Photon dose rates (mrem/h)	
	Top of gap between Multi-canister Overpack and cask	Bottom of shield plug
Top 10 cm (4 in.) of source	500 (1%) Output file = onormt2	6.27 E+5 Output file = onormt
Full source	520 (10%) Output file = onorm2	6.53 E+5 Output file = onorm
Ratio (top 10 cm [4 in.] full source)	1.05	1.04

Table B5-5. Photon Dose Conversion Factors.

Energy (MeV)	Fluence to dose 1E-12 Sv-cm^2/photon	Flux-to-dose rate (mrem/h)/(photon/cm^2/s)
1.00 E-02	0.0620	2.232 E-5
1.50 E-02	0.1570	5.625 E-5
2.00 E-02	0.2380	8.568 E-5
3.00 E-02	0.3290	1.184 E-4
4.00 E-02	0.3650	1.314 E-4
5.00 E-02	0.3840	1.382 E-4
6.00 E-02	0.4000	1.440 E-4
8.00 E-02	0.4510	1.624 E-4
1.00 E-01	0.5330	1.919 E-4
1.50 E-01	0.7770	2.797 E-4
2.00 E-01	1.0300	3.708 E-4
3.00 E-01	1.5600	5.616 E-4
4.00 E-01	2.0600	7.416 E-4
5.00 E-01	2.5400	9.144 E-4
6.00 E-01	2.9900	1.076 E-3
8.00 E-01	3.8300	1.379 E-3
1.00 E+00	4.6000	1.656 E-3
1.50 E+00	6.2400	2.246 E-3
2.00 E+00	7.6600	2.758 E-3
3.00 E+00	10.2000	3.672 E-3
4.00 E+00	12.5000	4.500 E-3
5.00 E+00	14.7000	5.292 E-3
6.00 E+00	16.7000	6.012 E-3
8.00 E+00	20.8000	7.488 E-3
1.00 E+01	24.7000	8.892 E-3
1.20 E+01	28.9000	1.040 E-2

5.2.2 Beta Source

The direct contribution of the beta source to the dose outside the cask will be prevented because of the attenuation provided by the self shielding of the fuel elements as well as the steel shielding of the cask, cask lid, and MCO shield plug. Bremsstrahlung photons within the source region are included in the ORIGEN2 (Schmittroth 1994) calculation of the photon source.

5.2.3 Neutron Source

The neutron source term was generated using the ORIGEN2 (Schmittroth 1994) computer code and the shielding source term shown in Part B, Table B2-1, of this SARP. The source includes both spontaneous fission and (alpha,n) reactions as shown in Table B5-6. The (alpha,n) contribution was calculated assuming an oxide fuel. Because N Reactor fuel is not an oxide fuel (Short 1995), the (alpha,n) contribution conservatively bounds oxidation of the fuel and the presence of any light trace elements or impurities. With 6.34 MTU per MCO, this results in a total neutron source strength of 1.17 E+7 neutrons/s/MCO.

Table B5-6. Neutron Source Term for the Multicanister Overpack (MCO).

Component of source	Source strength (neutrons/s/MCO)
(α,n)	3.95×10^6
Spontaneous fission	7.79×10^6
Total	1.17×10^7

There is a small difference among the energy shapes of the spontaneous fission spectra of the different isotopes. The watt spectrum used is given by:

$$f(E) = C \exp(-E/.906) \sinh([3.848E]^{0.5}),$$

where E is the neutron energy in MeV and C is a normalization constant so that the integral over f(E) is unity--this fission spectrum is for ^{244}Cm and has an average neutron energy of 2.15 MeV (Breismeister 1993). A tabulation of this spectrum is shown in Table B5-7. The energy distribution of the (α,n) neutrons is shown in Table B5-8, where the average neutron energy of this distribution is 2.01 MeV (Jobs and Liskien 1990). Induced fission neutrons are generated by the Monte Carlo N-Particle (MCNP) calculation.

Table B5-7. Energy Distribution of Neutrons from Spontaneous Fission Events.

Upper energy (MeV)	Cumulative probability	Probability of bin
0.00	0.00000	0.00000
0.10	0.01194	0.01194
0.20	0.03167	0.01972
0.30	0.05590	0.02424
0.40	0.08316	0.02726
0.50	0.11250	0.02934
0.60	0.14326	0.03076
0.70	0.17493	0.03167
0.80	0.20711	0.03218
0.90	0.23950	0.03238
1.00	0.27182	0.03232
1.20	0.33550	0.06368
1.40	0.39690	0.06140
1.60	0.45523	0.05832
1.80	0.50997	0.05475
2.00	0.56087	0.05090
2.20	0.60782	0.04695
2.40	0.65083	0.04301
2.60	0.69001	0.03917
2.80	0.72550	0.03549
3.00	0.75752	0.03202
3.20	0.78628	0.02876
3.40	0.81202	0.02574
3.60	0.83499	0.02297
3.80	0.85542	0.02043
4.00	0.87353	0.01812
4.20	0.88956	0.01603
4.40	0.90371	0.01415
4.60	0.91616	0.01246
4.80	0.92711	0.01095
5.00	0.93671	0.00960
5.50	0.95578	0.01907
6.00	0.96931	0.01354
6.50	0.97884	0.00953
7.00	0.98550	0.00665
7.50	0.99011	0.00461
8.00	0.99329	0.00318
9.00	0.99695	0.00366
10.00	0.99863	0.00169
11.00	0.99940	0.00076
12.00	0.99974	0.00034
13.00	0.99989	0.00015
14.00	0.99995	0.00007
15.00	9.99998	0.00003

Table B5-8. Energy Distribution of Neutrons from (α,n) Events.

Upper energy (MeV)	Cumulative probability	Probability of bin
0.00	0.00000	0.00000
0.10	0.01059	0.01059
0.20	0.02243	0.01184
0.30	0.03396	0.01153
0.40	0.04766	0.01371
0.50	0.06636	0.01869
0.60	0.08738	0.02103
0.70	0.11044	0.02305
0.80	0.13567	0.02523
0.90	0.15981	0.02414
1.00	0.17975	0.01994
1.10	0.20062	0.02087
1.20	0.22321	0.02259
1.30	0.24860	0.02539
1.40	0.27601	0.02741
1.50	0.30405	0.02804
1.60	0.33349	0.02944
1.70	0.36542	0.03193
1.80	0.40093	0.03551
1.90	0.43785	0.03692
2.00	0.47664	0.03879
2.10	0.51558	0.03894
2.20	0.55623	0.04065
2.30	0.59751	0.04128
2.40	0.63707	0.03956
2.50	0.67492	0.03785
2.60	0.71137	0.03645
2.70	0.74611	0.03474
2.80	0.77819	0.03209
2.90	0.80935	0.03115
3.00	0.83863	0.02928
3.10	0.86449	0.02586
3.20	0.88879	0.02430
3.30	0.90966	0.02087
3.40	0.92664	0.01698
3.50	0.94097	0.01433
3.60	0.95327	0.01231
3.70	0.96324	0.00997
3.80	0.97181	0.00857
3.90	0.97928	0.00748
4.00	0.98536	0.00607
4.10	0.99081	0.00545
4.20	9.99439	0.00358
4.30	0.99720	0.00280
4.40	0.99891	0.00171
4.50	1.00000	0.00109

Table B5-9 shows the flux-to-dose rate conversion factors used to calculate the neutron dose rates.

Table B5-9. Neutron Flux-to-Dose Rate Conversion Factors.*

Energy (MeV)	Fluence to dose 1E-12 Sv-cm^2	Flux-to-dose rate (mrem/hr)/(n/cm^2/s)
2.50 E-08	10.2	3.68 E-3
1.00 E-07	10.2	3.68 E-3
1.00 E-06	12.4	4.46 E-3
1.00 E-05	12.4	4.46 E-3
1.00 E-04	12.0	4.31 E-3
1.00 E-03	10.2	3.68 E-3
1.00 E-02	9.92	3.57 E-3
1.00 E-01	60.3	2.17 E-2
5.00 E-01	257	9.26 E-2
1.00 E+00	367	1.32 E-1
5.00 E+00	433	1.56 E-1
7.00 E+00	408	1.47 E-1
1.00 E+01	408	1.47 E-1
1.40 E+01	578	2.08 E-1

*Source: Phillips, J. D., Sr., 1996, Spent Nuclear Fuel Project Canister Storage Building - Neutron Quality Factors (external letter 9650748 to E. R. Jacobs, Fluor Daniel, Inc., February 15), Westinghouse Hanford Company, Richland, Washington.

5.3. SUMMARY OF SHIELDING PROPERTIES OF MATERIAL

Shielding consists of the MCO Cask, cask lid, MCO, and MCO shield plug. The transport cask, lid, and MCO are made from 304 stainless steel. Table B5-10 shows material properties. The shielding attenuation properties are obtained from the data library for the MCNP computer code (Breismeister 1993 and Carter 1996).

Table B5-10. Materials and Densities Used for Shielding.

Material	Density (g/cm^3)	Remarks
304 stainless steel	8.0	Used in the cask, cask lid, Multicanister Overpack (MCO), and MCO plug (ORNL 1976)
Air	0.00123	Air outside cask (Lide 1992)
Uranium	18.77	Fuel elements are modeled as ^{238}U with 0.947% ^{235}U (Short 1995)
Zircaloy	6.55	Fuel cladding (Short 1995)
Soil	1.67	Hanford Waste Vitrification Plant dirt (Brown 1992)
Concrete	2.26	Hanford ordinary concrete (Carter 1983)

Brown, R. C., 1992, "Soil Density and Mass Attenuation Coefficients for Use in Shielding Calculations at the Hanford Waste Vitrification Plant", Proceedings of New Horizons in Radiation Protection and Shielding Topical Meeting, American Nuclear Society, Inc., La Grange Park, Illinois.

Carter, L. L., 1983, "Bulk Shield Design for Neutron Energies Below 50 MeV", Nuclear Technology/Fusion, vol. 3, pp. 165-168.

Lide, D. R., Editor-In-Chief, 1992, Handbook of Chemistry and Physics, 72nd Edition, 1991-1992, Student Edition, CRC Press, Inc.,

ORNL (Oak Ridge National Laboratory), 1976, Nuclear Systems Materials Handbook, Volume 1, Design Data, TID 26666 Volume 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Short, S. M., 1995, Spent Nuclear Fuel Project Technical Databook, WHC-SD-SNF-TI-015, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

5.4 NORMAL TRANSPORT CONDITIONS

This section addresses the shielding analysis for the package for the normal transport condition. For this analysis, the presence of the trailer is ignored, and the exterior surface of the package is assumed to be the outside surface of the MCO Cask.

5.4.1 Conditions To Be Evaluated

The normal transport condition is defined as a water-flooded or dry MCO with the cask lid in place. Dose rates are calculated at the surface and 2 m and 6 m from the radial side and top of the cask. Only the contact dose is calculated for the bottom of the cask because the bottom of the MCO is less than 2 m from the ground during transport. Additionally, the dose rates due to streaming through the ports in the MCO shield plug, the drain port, the vent port, and through the gap between the MCO Cask and the MCO are calculated. The effects of reflection of radiation off the ground are also included.

5.4.2 Acceptance Criteria

The dose rate at the surface of the cask, including dose rates from streaming, must be less than 200 mrem/h on accessible surfaces and less than 1000 mrem/h on surfaces only accessible by long-reach tools. The dose rate at 2 m must be less than 10 mrem/h. The dose rate in any normally occupied space in the transport vehicle (here assumed to be 6 m) must be less than 2 mrem/h.

5.4.3 Shielding Model

The cask, cask lid, MCO, and MCO shield plug are made from stainless steel. The inside diameter of the MCO is 58.42 cm (23 in.), and the inside height is 372 cm (146 in.) to the bottom of the MCO plug. The MCO plug is 30.48 cm (12 in.) thick, and the cask lid is 8.89 cm (3.5 in.) thick for a total top shield thickness of 39.4 cm (15.5 in.). The MCO sidewall is 1.27 cm (0.5 in.) thick, and the cask sidewall is 18.6 cm (7.31 in.) thick for a total thickness of 19.8 cm (7.81 in.). The bottom of the MCO is 4.47 cm (1.76 in.) thick. The bottom of the cask is 15.6 cm (6.13 in.) thick for a total bottom shield thickness of 20.0 cm (7.89 in.). Figure B5-1 shows a cross section of the top of the MCO Cask and MCO shield plug.

5.4.4 Shielding Calculations

The MCNP computer code (Breismeister 1993 and Carter 1996) was used to perform the dose rate calculations. MCNP has powerful geometry routines and uses Evaluated Nuclear Data Files (ENDF/B) for cross sections (BNL 1991). The ENDF/B system is maintained by the National Nuclear Data Center at Brookhaven National Laboratory under contract from DOE. The quality assurance documentation of MCNP for use at the Hanford Site is given in Carter (1996).

The dose rate was calculated at the surface and 2 m and 6 m from the side of the cask for the normal transport condition. Only the contact dose was calculated for the bottom of the cask because the bottom of the MCO is less than 2 m from the ground during transport. Contact doses at the top of the cask were also calculated. With the exception of some dose rates through the drain port, all dose rates were calculated using MCNP surface tallies. A summary of dose rates is shown in Table B5-1.

Contact dose rates will bound dose rates at distances further from the cask. As photons get further from the source, they will generally disperse over a larger area. Because the dose rate is proportional to the number of photons per unit area, dose rates decrease as the distance from the source to the dose location is increased (thus, the "inverse square law" for point sources). Dose rates also decrease due to attenuation in air. In instances where the dose at contact is low enough to meet dose rate limits at all other distances, no further effort was made to calculate dose rates at further distances.

The water in a flooded MCO will provide additional self shielding; therefore, the dry MCO will give higher dose rates for photons. Filling the interior of the MCO with water will increase neutron multiplication due to fission, thus providing a mechanism for increasing neutron dose rates. However, this moderation process will also decrease neutron energies, and the water will act as self-shielding, thus introducing a reduction in dose rates. Calculations of neutron dose rates for both flooded and dry MCOs were made to find the bounding case. The highest radial neutron contact doses for the dry and flooded cases, as shown in Table B5-11, were 5.7 mrem/h and 2.8 mrem/h, respectively, indicating that neutron dose rates are highest when the cask is dry. Since the dry MCO gives higher dose rates for both photons and neutrons, the remainder of the analysis considers a dry MCO only.

Table B5-11. Comparison of Dry Versus Flooded Multicanister Overpack Neutron Dose Rates.

	Dose rates in mrem/h (MCNP uncertainty*)	Output file
Flooded	2.8 (6%)	owet
Dry	5.7 (1%)	odry

MCNP = Monte Carlo N-Particle (code).
*The one standard deviation statistical uncertainty (relative) in MCNP calculation.

For shielding analysis, the MCO was assumed to contain fuel baskets only. Since scrap baskets are more reactive than fuel, a comparison of nominal k_{eff} for the MCO containing scrap baskets (.86, case plan_150) and a case with fuel only (.87, case CSBI) given in Miller (1996) shows that there is very little increase in neutron production using scrap baskets in normal, flooded conditions.

The bottom of the cask was modeled to be 51.4 cm (20.3 in.) above the ground. Ground was modeled as Hanford soil (Brown 1992) throughout this analysis. However, additional calculations were made to compare the effect of using concrete instead of soil for ground material. Dose rates below the cask, where reflection from the ground is most pronounced, are shown in Table B5-12. The results of these calculations show that the difference in ground reflection when using concrete rather than soil is negligible.

Table B5-12. Comparison of Soil and Concrete Reflection.

Reflective material	Dose type	Dose Rates in mrem/h (MCNP uncertainty*)		Output file
		Bottom surface of cask	Ground level	
Soil	Photon	39 (2%)	15 (3%)	onorm
	Neutron	4.4 (1%)	1.5 (2%)	odry
	Total	43 (2%)	17 (2%)	
Concrete	Photon	40 (3%)	16 (4%)	onormc
	Neutron	4.2 (6%)	1.3 (12%)	odryc
	Total	44 (3%)	17 (4%)	

MCNP = Monte Carlo N-Particle (code).
*The one standard deviation statistical uncertainty (relative) in MCNP calculation.

There is a 2.2-cm (0.88-in.) recess in the bottom plate of the MCO. Table B5-13 shows an average dose rate at the bottom of the cask and a dose rate at the center, just below this recess.

Table B5-13. Dose Rates at Bottom of Multicanister Overpack Cask.

Dose area	Dose type	Contact dose rates in mrem/h (MCNP uncertainty[a])	Output file
Bottom, average[b]	Photon	39 (2%)	onorm
	Neutron	4.4 (1%)	odry
	Total	43 (2%)	
Bottom, center[c]	Photon	58 (9%)	onorm
	Neutron	5 (9%)	odry
	Total	63 (9%)	

MCNP = Monte Carlo N-Particle (code).
[a]The one standard deviation statistical uncertainty (relative) in MCNP calculation.
[b]Average over 30-cm (12-in.) radius, corresponding to the radius of the MCO.
[c]There is a small recess in the center of the bottom plate of the MCO.

The maximum total dose rates for the radial side of the cask were found to be 49 mrem/h, 6.9 mrem/h, and 1.5 mrem/h at contact, 2 m, and 6 m, respectively. Dose rates were calculated from 1.05 m below to 1.05 m above the center of the fuel region in 30-cm increments. The highest dose rate at each radial distance is reported. Table B5-14 shows neutron, photon, and total dose rates.

Table B5-14. Side (Radial) Dose Rates.

Dose type	Dose rates in mrem/h (MCNP uncertainty*)			Output file
	Contact	2 m	6 m	
Photon	43 (2%)	6.3 (1%)	1.3 (1%)	onorm
Neutron	5.6 (1%)	0.63 (1%)	0.12 (1%)	odry
Total	49 (1%)	6.9 (1%)	1.5 (1%)	

MCNP = Monte Carlo N-Particle (code).
*The one standard deviation statistical uncertainty (relative) in MCNP calculation.

There is a drain port in the side of the cask near the bottom. The total dose rate at contact was found to be 310 mrem/h. Details are shown in Table B5-15. In terms of shielding, the presence of this port represents a displacement of shielding material, contributing to an increase in dose rates in its vicinity. It is worth noting that the space between the bottom of the MCO and the bottom of the fuel (3.8 cm or 1.5 in.) provides a streaming path from the bottom of the fuel toward the drain port.

Table B5-15. Drain Port Contact Dose.

Dose type	Dose rates in mrem/h (MCNP uncertainty*)	Output file
Photon	310 (7%)	odrainc
Neutron	3.0 (16%)	odry
Total	310 (7%)	

MCNP = Monte Carlo N-Particle (code).
*The one standard deviation statistical uncertainty (relative) in MCNP calculation.

Table B5-16 shows photon dose rates for various distances from the cask due to potential streaming through the drain port. Because of the orientation of the port relative to the source, any streaming through the port could potentially be directed toward some angle below the axis of the port. The results shown in Table B5-16 indicate that either the dose rate due to streaming through the port drops off quite rapidly with distance or the dose stream is angled such that it reaches the ground before a 2-m radial distance is reached. In any case, the photon dose rates are less than those listed for the side (radial) dose rates given above.

Table B5-16. Photon Dose Rates Due to Streaming Through the Drain Port.

Up angle (°)	Photon dose rates[a] in mrem/h (MCNP uncertainty[b])		Output file
	2 m	6 m	
0	3.6 (3%)	1.1 (3%)	odrain
-5	3.2 (3%)	NA	odrain
-10	2.8 (4%)	NA	odrain
Ground level[c]	2.7 (4%)	0.96 (3%)	odrain

MCNP = Monte Carlo N-Particle (code).
[a]Dose rates calculated with point detectors.
[b]The one standard deviation statistical uncertainty (relative) in MCNP calculation.
[c]Ground level for 2 m is at an up angle of -12.9°. Ground level for 6 m is at an up angle of -4.3°.

Dose rates above the top of the cask and the short draw tube and dip tube ports in the MCO shield plug are shown in Table B5-17. The dip tube and short draw tube ports are the deepest and widest cavities in the MCO shield plug. As with the drain port discussed previously, the presence of each port represents a displacement of shielding material, contributing to an increase in dose rates. There are two other ports in the MCO: one used for a relief valve downstream of a HEPA filter, the other for a rupture disk. Because the displacement of shielding material for these two ports is less, they are considered less problematic in terms of compromising shielding effectiveness and are not analyzed.

Table B5-17. Dose Rates at the Top of the Cask for Normal Conditions.

Location	Dose type	Dose rates in mrem/h at contact (MCNP uncertainty[a])	Output file
Top[b]	Photon[c]	0.14 (4%)	onormt
	Neutron	0.47 (1%)	odryt
	Total	0.6 (2%)	
Dip tube port	Photon[c]	0.58 (8%)	onormt
	Neutron	0.60 (10%)	odry
	Total	1.2 (7%)	
Short draw tube port	Photon[c]	1.7 (8%)	onormt
	Neutron	0.67 (9%)	odry
	Total	2.4 (6%)	
Vent port	Photon[c]	0.13 (13%)	onormt
	Neutron[d]	0.42 (2%)	odry
	Total	0.55 (3%)	

MCNP = Monte Carlo N-Particle (code).
[a]The one standard deviation statistical uncertainty (relative) in MCNP calculation.
[b]Average over 30 cm (12 in) radius, corresponding to the radius of the MCO
[c]Photon dose rates were calculated using top 4 in. of source, and have been scaled by a 1.04 correction factor (see Section 5.2.1).
[d]Neutron dose rate is based on average over annulus at top of lid with an inner radius of 23.81 cm (9.375 in.) and an outer radius of 32.05 cm (12.62 in.).

There is a 3.81-cm (1.50-in.) vent port in the cask lid. The vent port is 27.31 cm (10.75 in.) from the cask centerline, which is outside the radius of the ports in the MCO shield plug. Because of the vent port's small diameter and its relatively large offset from the centerline, it does not present a problem in terms of dose rate streaming.

The calculated dose rate at contact above the short draw tube port is 2.4 mrem/h. To demonstrate that the dose rate will drop to less than 2 mrem/h at 6 m, the neutron dose rate at 2 m was calculated using an MCNP point detector (output file odrytp). The neutron dose rate at 2 m was calculated to be 0.049 mrem/h, with an MCNP one standard deviation statistical uncertainty (relative) of 1%.

Dose rates above the radial side of the cask, as shown in Figure B5-1, are given in Table B5-18. Table B5-18 shows dose rates only at contact. All dose rates due to penetration of the shielding in this vicinity will be bounded by the contact dose rates shown in Table B5-18.

Figure B5-1. Monte Carlo N-Particle Model for Multicanister Overpack and Transport Cask.

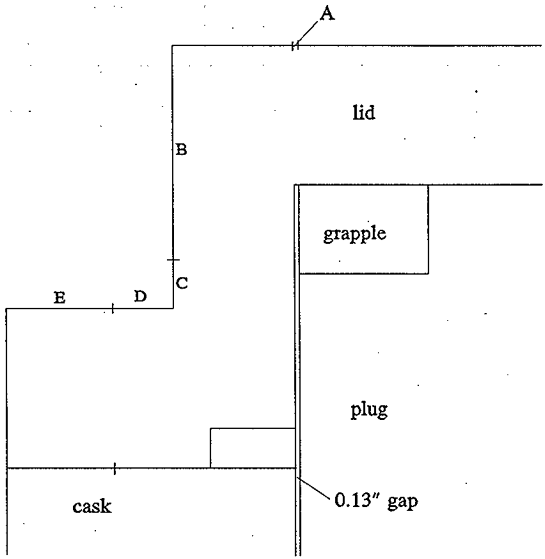

Table B5-18. Dose Rates Above the Radial Side of Cask for Normal Conditions.

Location	Dose Type	Dose rates in mrem/h at contact (MCNP uncertainty[a])	Output file
Position "A" in Figure B5-1	Photon[b]	0.10 (9%)	onormt
	Neutron	0.36 (7%)	odry
	Total	0.47 (6%)	
Position "B" in Figure B5-1	Photon	0.15 (9%)	onorm
	Neutron	0.52 (2%)	odry
	Total	0.67 (2%)	
Position "C" in Figure B5-1	Photon	0.77 (9%)	onorm
	Neutron	1.1 (2%)	odry
	Total	1.9 (4%)	
Position "D" in Figure B5-1	Photon	0.80 (7%)	onorm
	Neutron	1.1 (2%)	odry
	Total	1.9 (3%)	
Position "E" in Figure B5-1	Photon	0.21 (8%)	onorm
	Neutron	0.57 (2%)	odry
	Total	0.78 (3%)	

MCNP = Monte Carlo N-Particle (code).
[a]The one standard deviation statistical uncertainty (relative) in MCNP calculation.
[b]Photon dose rates were calculated using top 4 in. of source, and have been scaled by a 1.05 correction factor (see Section 5.2.1).

Except for the drain port, maximum dose rates for normal conditions are at the radial side of the cask. Dose rates at the side of the cask are 49 mrem/h, 6.9 mrem/h, and 1.5 mrem/h at contact, 2 m, and 6 m, respectively. The contact dose for the drain port is 310 mrem/h.

5.5 ACCIDENT CONDITIONS

This section addresses the shielding analysis for the package for accident conditions. For this analysis, the presence of the trailer is ignored, and the exterior surface of the package is assumed to be the outside surface of the MCO Cask.

5.5.1 Conditions To Be Evaluated

For this analysis, it is assumed that the worst-case credible accident would involve a vertical drop, resulting in a compaction of the fuel in the bottom of the cask. This will cause not only an increase in dose rates at the side and bottom but also a decrease in dose rates at the top of the cask.

5.5.2 Acceptance Criteria

The dose rate 1 m from the surface of the cask must be less than 1 rem/h.

5.5.3 Shielding Model

Shielding includes the cask, MCO, and MCO shield plug as described previously in Section 5.4.3.

5.5.4 Shielding Calculations

Again, the MCNP computer code (Breismeister 1993 and Carter 1996) was used to perform the dose rate calculations. All dose rates calculated are contact dose rates. This should prove sufficient in showing that the criteria of 1 rem/h at 1 m is met.

For the accident condition, it was assumed that there is a vertical drop that causes all the fuel to be condensed in the bottom of the MCO. For shielding purposes, maximum compaction of the source volume will give the most conservative dose rates. Therefore, the accident condition source is a cylinder 129.0 cm (51.0 in.) tall with a radius of 58.4 cm (23.0 in.), consisting of uranium metal fuel with a density of 18.77 g/cm^3.

As shown in Section 5.4.4, the dry MCO gives higher dose rates than a flooded MCO. For this reason, analysis in this section is for a dry MCO only. The bottom of the cask was modeled to be 51.4 cm (20.3 in.) above the ground as it was for normal conditions. However, since the dose rates reported are contact dose rates, the effects of ground shine are negligible. Dose rates at the bottom and side of the cask are shown in Table B5-2.

The highest dose rate is the drain port contact dose (190 mrem/h). This is lower than for normal conditions because of the elimination of the gap between the bottom of the fuel and the bottom of the MCO. The side and bottom dose rates, on the other hand, have increased as expected.

5.6 SHIELDING EVALUATION AND CONCLUSIONS

The shielding calculations have shown that for normal and accident transport conditions, the dose rates calculated meet the acceptance criteria. The contact dose rate at the cask drain port is 310 mrem/h, which exceeds 200 mrem/h, but the drain port will only be accessible with long-reach tools when the cask is loaded onto the trailer. Close access to the drain port will be controlled, and facility ALARA procedures will be followed during loading and unloading to guarantee worker safety.

A number of uncertainties affect the accuracy of the results presented. Included are uncertainties in material compositions and densities and in data in the MCNP library. Conservatism in the source term will result in conservative dose rate calculations.

5.7 REFERENCES

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5.8 APPENDICES

5.8.1 MCNP Tally Results

With the exception of side dose rates and the "top radial" contact dose rate, all dose rates calculated are based on averages constructed from radial splits using the following:

Dose in region 1 = D1
Area in region 1 = A1
Uncertainty in region 1 = U1
Total area = A = A1 + A2 + ...
Average dose = D = (D1*A1 + D2*A2 +...)/A
Average uncertainty = sqrt((D1*A1*U1)^2 + (D2*A2*U2)^2 + ...))/(D*A)

The addition of photon and neutron dose, which used the same areas, was calculated from:

Photon dose = DP
Photon dose uncertainty = UP
Neutron dose = DN
Neutron dose uncertainty = UN
Total Dose = T = DP + DN
Uncertainty = sqrt($(DP*UP)^2 + (DN*UN)^2$)/T

5.8.2 MCNP Input and Output Files

The files are currently stored in CFS file /home/w80395/MCO/sarp/final.tar.Z in compressed, tarred format. Included in this section is a listing of one MCNP input file, called "inorm," and the ORIGIN input file used to create the source strength and energy spectrum, called "sarp." Rather than reprinting the remainder of the MCNP input files, they are related to inorm by the use of the UNIX command "diff." The "diff" command indicates with a "<" changed lines as they appear in the first file, and a ">" indicates lines as they appear in the second file.

ORIGIN INPUT FILE (osarp)

Library files orig21, orig60, and orig61 used

```
-1
-1
-1
TIT     1 MTU OF 16% Pu240 MARK IV FUEL FROM RADNUC, DECAYED 13 YEARS
LIP     0 0 0
LIB     0 1 2 3 381 382 383 9 3 0 1 43
PHO     101  102  103  10
RDA     1 Liter
INP     -1  1  -1  -1  1  1
MOV     -1   1 0   1.0
BUP
DEC       1.0            1  2  4  1
DEC       5.0            2  3  4  0
DEC      10.0            3  4  4  0
DEC      50.0            4  5  4  0
DEC     100.0            5  6  4  0
DEC     200.0            6  7  4  0
DEC       1.0            7  8  5  0
DEC       2.0            8  9  5  0
DEC       5.0            9 10  5  0
DEC      10.0           10 11  5  0
DEC      20.0           11 12  5  0
BUP
CUT     5  1.E-20  7  1.E-20  9  1.E-20  -1
RDA     ACTIVATION PRODUCTS OUTPUT TABLE OPTIONS
OPTL     8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
RDA     FISSION PRODUCTS OUTPUT TABLE OPTIONS
OPTF     8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
RDA     ACTINIDE AND DAUGHTER OUTPUT TABLE OPTIONS
OPTA     8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT      12 1 -1  0
STP 4
3   10030  2.694E-02 60140  7.404E-01 340790 5.599E+00 360850 1.020E+01
3   380890 0.000E+00 380900 3.812E+02 390900 9.558E-02 390910 0.000E+00
3   400930 0.716E+03 410931 3.043E-03 400950 6.517E-21 410950 7.672E-21
3   410951 2.626E-24 430990 0.767E+03 441030 0.000E+00 451031 0.000E+00
3   441060 2.361E-02 451060 2.219E-08 461070 1.769E+02 471100 9.595E-15
3   471101 6.315E-07 481131 1.199E-01 481151 0.000E+00 501191 1.005E-06
3   501211 7.273E-03 501230 7.057E-12 521231 2.029E-16 511240 0.000E+00
3   511250 6.683E-01 521251 9.439E-03 501260 2.714E+01 511260 1.316E-06
3   511261 9.804E-09 521270 7.200E-16 521271 2.120E-13 521290 0.000E+00
3   521291 0.000E+00 531290 1.756E+02 551340 6.029E-01 551350 3.214E+02
3   551370 0.828E+03 561371 1.264E-04 581410 0.000E+00 591430 0.000E+00
3   581440 5.016E-03 591440 2.118E-07 591441 1.048E-09 611470 8.091E+00
3   611480 0.000E+00 611481 0.000E+00 621510 2.585E+01 631520 4.568E-02
3   641530 1.078E-08 631540 4.816E+00 631550 4.945E-01 651600 5.316E-22
1   10030  0.000E+00 60140  0.000E+00 260550 1.480E-02 280590 2.509E+00
1   270600 3.715E-02 280630 3.729E-01 400930 0.000E+00 410931 0.000E+00
1   400950 0.000E+00 410950 0.000E+00 410951 0.000E+00 491131 2.451E-17
1   501130 4.084E-14 501191 0.000E+00 501211 0.000E+00 511250 0.000E+00
2   521251 0.000E+00 000000 0.000E+00 000000 0.000E+00 000000 0.000E+00
2   922340 4.001E+02 922350 3.840E+04 922360 6.956E+03 000000 0.000E+00
2   922380 6.247E+06 932370 3.972E+02 942380 4.732E+01 942390 1.769E+04
2   942400 3.555E+03 942410 0.592E+03 942420 1.231E+02 952410 0.524E+03
2   952421 2.058E-01 952420 2.474E-06 952430 7.023E+00 962420 5.142E-04
2   962440 3.708E-01 000000 0.000E+00 000000 0.000E+00 000000 0.000E+00
0
END
```

MCNP INPUT FILE inorm

```
MCO Final SARP, photon model, lid-on
    1    0   -20   31  -52           fill=1
c      main lattice along cask length
    2      0    -1   2  -3   4  -5   6  -54   55   u=1   lat=2
                 fill=-5:5  -5:5   0:4
            2    2    2    2    2    2    2    2    2    2    2     $  1
            2    2    2    2    2    2    3    3    3    2    2     $  2
            2    2    2    2    3    3    3    3    3    3    2     $  3
            2    2    2    3    3    3    3    3    3    3    2     $  4
            2    2    3    3    3    3    3    3    3    3    2     $  5
            2    2    3    3    3    2    3    3    3    2    2     $  6   level 1
            2    3    3    3    3    3    3    3    3    2    2     $  7
            2    3    3    3    3    3    3    3    2    2    2     $  8
            2    3    3    3    3    3    3    2    2    2    2     $  9
            2    2    3    3    3    2    2    2    2    2    2     $ 10
            2    2    2    2    2    2    2    2    2    2    2     $ 11
c          -5   -4   -3   -2   -1    0    1    2    3    4    5
            2    2    2    2    2    2    2    2    2    2    2     $  1
            2    2    2    2    2    2    3    3    3    2    2     $  2
            2    2    2    2    3    3    3    3    3    3    2     $  3
            2    2    2    3    3    3    3    3    3    3    2     $  4
            2    2    3    3    3    3    3    3    3    3    2     $  5
            2    2    3    3    3    2    3    3    3    2    2     $  6   level 2
            2    3    3    3    3    3    3    3    3    2    2     $  7
            2    3    3    3    3    3    3    3    2    2    2     $  8
            2    3    3    3    3    3    3    2    2    2    2     $  9
            2    2    3    3    3    2    2    2    2    2    2     $ 10
            2    2    2    2    2    2    2    2    2    2    2     $ 11
c          -5   -4   -3   -2   -1    0    1    2    3    4    5
            2    2    2    2    2    2    2    2    2    2    2     $  1
            2    2    2    2    2    2    3    3    3    2    2     $  2
            2    2    2    2    3    3    3    3    3    3    2     $  3
            2    2    2    3    3    3    3    3    3    3    2     $  4
            2    2    3    3    3    3    3    3    3    3    2     $  5
            2    2    3    3    3    2    3    3    3    2    2     $  6   level 3
            2    3    3    3    3    3    3    3    3    2    2     $  7
            2    3    3    3    3    3    3    3    2    2    2     $  8
            2    3    3    3    3    3    3    2    2    2    2     $  9
            2    2    3    3    3    2    2    2    2    2    2     $ 10
            2    2    2    2    2    2    2    2    2    2    2     $ 11
c          -5   -4   -3   -2   -1    0    1    2    3    4    5
            2    2    2    2    2    2    2    2    2    2    2     $  1
            2    2    2    2    2    2    3    3    3    2    2     $  2
            2    2    2    2    3    3    3    3    3    3    2     $  3
            2    2    2    3    3    3    3    3    3    3    2     $  4
            2    2    3    3    3    3    3    3    3    3    2     $  5
            2    2    3    3    3    2    3    3    3    2    2     $  6   level 4
            2    3    3    3    3    3    3    3    3    2    2     $  7
            2    3    3    3    3    3    3    3    2    2    2     $  8
            2    3    3    3    3    3    3    2    2    2    2     $  9
            2    2    3    3    3    2    2    2    2    2    2     $ 10
            2    2    2    2    2    2    2    2    2    2    2     $ 11
c          -5   -4   -3   -2   -1    0    1    2    3    4    5
            2    2    2    2    2    2    2    2    2    2    2     $  1
            2    2    2    2    2    2    3    3    3    2    2     $  2
            2    2    2    2    3    3    3    3    3    3    2     $  3
            2    2    2    3    3    3    3    3    3    3    2     $  4
            2    2    3    3    3    3    3    3    3    3    2     $  5
            2    2    3    3    3    2    3    3    3    2    2     $  6   level 5
            2    3    3    3    3    3    3    3    3    2    2     $  7
            2    3    3    3    3    3    3    3    2    2    2     $  8
            2    3    3    3    3    3    3    2    2    2    2     $  9
            2    2    3    3    3    2    2    2    2    2    2     $ 10
            2    2    2    2    2    2    2    2    2    2    2     $ 11
c          -5   -4   -3   -2   -1    0    1    2    3    4    5
    3   304     -8.0        (20:-31)       -207  32  -52          $ MCO pipe wall
    4     0     21    57    -22  (-214:-210)  216  $ gap
  400     0     -594 -320 -216 (217:300) 21 $ gap
    5   304     -8.0        223 -23   57 -52                      $ 1" shield side
    6   304     -8.0         23 -24   57 -52                      $ 2" shield side
    7   304     -8.0         24 -25   57 -52   (-584:582:-583)    $ 3" shield side
    8   304     -8.0         25 -26   33 -52        (582:-583)        $ 4" shield side
    9   304     -8.0         26 -27   34 -52   (-584:582:-583)        $ 5" shield side
```

```
10   304    -8.0        27 -28  35 -52   (-584:582:-583)       $ 6" shield side
11   304    -8.0        28 -29  36 -52   (-584:582:-583:585)   $ 7" shield side
12   304    -8.0  29 -30  37 -52  (-584:585:582:-583)(587:-586) $ 8" shield side
13    0    61  -578 -526 (-255:252:258)          $ outside the cask
14    0                 (578:526:-581)                    $ outside world
15    7      0.0000512          18     -53             u=3     $ between fuels
16    3     -6.55       -18     17     -53             u=3     $ Zr-2 clad
17    5    -18.77       -17     16     -53             u=3     $ 0.947% U-235
18    3     -6.55       -16     15     -53             u=3     $ Zr-2 clad
19    7      0.0000512  -15     14     -53             u=3     $ H20
20    3     -6.55       -14     13     -53             u=3     $ Zr-2 clad
21    5    -18.77       -13     12     -53             u=3     $ 0.947% U-235
22    3     -6.55       -12     11     -53             u=3     $ Zr-2 clad
23    7      0.0000512  -11            -53             u=3     $ H20
24    7      0.0000512  -51                            u=2     $ fictitious cl
25    7      0.0000512   52    -500    -20                      $ 2" gap at top
26    7      0.0000512   53                            u=3     $ gap at top of fuel
30   7 0.0000512   596 -256 -250 (30:515)        $ Air, top, up to 1m
31   7 0.0000512    38 -256 -596 (30)            $ Air, side, out to 1m
32   7 0.0000512    61 -256 -38                  $ Air, bottom, down to 1m
33   7 0.0000512   596 -257 -251 (250:256)       $ Air, top, up to 2m
34   7 0.0000512    61 -257 -596 (256)           $ Air, side, out to 2m
35   221  -1.67    254 -257 -61                  $ Air, bottom, down to 2m
36   7 0.0000512   596 -258 -252 (257:251)       $ Air, top, up to 3m
37   7 0.0000512    61 -258 -596 (257)           $ Air, side, out to 3m
38   221  -1.67    581 -578 -61 (-254:257)       $ Air, bottom, down to 3m
40   0  56 -32 -21  $ bottom of MCO, air space
41   304    -8.0  310 -56 -21 311 $ bottom of MCO, top .88"
42   304   -8.0 -310 57 -21  $ bottom of MCO, bottom .88"
43   0  310 -56 -311 $ divit at bottom of MCO
44   304    -8.0        -57 33       -25  (-584:585:582:-583)   $ 1" shield bottom
                        592
45   304    -8.0        -33 34       -26  (-584:585:582:-583)   $ 2" shield bottom
                        (-583:590:584) (-591:592) (583:591:590:592)
46   304    -8.0        -34 35       -27  (-584:585:582:-583)   $ 3" shield bottom
47   304    -8.0        -35 36       -28  (-584:585:582:-583)   $ 4" shield bottom
48   304    -8.0        -36 37       -29                     $ 5" shield bottom
49   304  -8.0  -37 38 -30 (587:-586) $ shield bottom
500    0                 19 -20 500 -509                  $ gap: plug/MCO wall
501    304   -8.0       500 -501 -19 542 546 (541:-561)   $ 1" shield top
502    304   -8.0       501 -502 -19                      $ 2" shield top
       546 (544:-564) (541:-561) 542             $(546:-420)to546, (-562:542:-561) to 542
       (551:421:-546:-544) (556:-557:-546:-544)
503    304    -8.0      502 -503 -19                      $ 3" shield top
        (546) (544:563:-564)                                    $from E1
        (542) (541:-561:560)                                    $from E2
        (556:558:-557)                                $from f1
        (-540:551:421:-541)                                       $(546:-420)to 546,
504    304    -8.0  503 -504 -19                          $ 4" shield top;
       (543:-405:-544)(544:563:-564)   $ #537 #538
       (538:-541:505:(-556 557):(-551 -421))   $ #533
       (546:420:-544)(542:-541:562)  $ #540 #536
       (541:560:-561)(556:-557:558:-546:-544)  $#535 #550
       (550:-551)(555:-556) $ #545 #549
       (551:-540:421:-541)  $ #546
505    304    -8.0      504 -505 -19                      $ 5" shield top
        543 538 555 (556:558) 550 (551:-540)  $(544:563)to(544:563:-564)
506    304    -8.0      505 -506 -19                      $ 6" shield top
       535 534 555 550
507    304    -8.0      506 -507 -19                      $ 7" shield top
       535 534 555 550 $(427:-428:425:-426:-429)
508    304    -8.0      507 -508 -19                      $ 8" shield top
       597 598 555 550 $(427:-428:425:-426:-429)
509    304    -8.0      508 -509 -19                      $ 9" shield top
       597 598 554 550 $(427:-428:425:-426:-429)
510    304  -8.0  509 -510 -300 597 598 554 550 (-305:-306)   $ 10" shield top$
511    304    -8.0      510 -511 -306 597 598 554 549     $ 11" shield top
512    304    -8.0      511 -512 -306  537 536 553 548    $ 12" shield top
c 530   0  426 -425 429 -512 428 -427                       $ grapple cutout
c          (-432:431) (-430:-434:433)
520  0  -300 305 306 -594
531   0  -534 505 -507                          $ Short Draw Port bottom
532   0  -535 505 -507                          $ Dip Tube Port bottom
533   0  -538 503 541 -505  (556:-557) (551:421)  $ Short Draw Port top pipe
535   0  -541 -560 561                          $ Short Draw Port horizontal pipe
536   0  -542 500 541 -562                      $ Short Draw Port bottom pipe
```

```
537   0  -543 405 -505 544                          $ Dip Tube Port top pipe
538   0  -544 -563 564                              $ Dip Tube Port horizontal pipe
540   0  -546 500 -420 544                          $ Dip Tube Port bottom pipe
541   304  -8.0  -536 511 -512                      $ Short Draw Port Flange
542   304  -8.0  -537 511 -512                      $ Dip Tube Port flange
543   304  -8.0  -548 511 -512                      $ HEPA Filter port flange
544   0  -549 510 -511                              $ HEPA Filter port middle
545   0  -550 503 -510 551                          $ HEPA Filter vertical pipe
546   0  -551 540 -421  541                         $ HEPA Filter horizontal pipe
547   304  -8.0  -553 511 -512                      $ Rupture Disk Flange
548   0  -554 508 -511                              $ Rupture Disk middle
549   0  -555 503 -508 556                          $ Rupture Disk vertical pipe
550   0  -556 557 -558  546 544 541                 $ Rupture Disk horizontal pipe
562   0 -582 583 584 -585                    $ drain port cavity
563   0  586 -30 -587                        $ airspace just outside of drain port cover
565   0 -584 583 -590                        $ horiz drain pipe
566   0 591 (590:-583) -592 -57              $ vert drain pipe
567   0 -591 -583 -590 -592                  $ drain pipe elbow
570   0  -598 507 -511                          $ Short Draw Port Middle
571   0  -597 507 -511                          $ Dip Tube Port middle
580   0          518 -30 519 -515                  $ above cask body
581   304 -8.0     -513 596 -28  (594:323) (-516:-506)    $ first 1" of lid
                 (215:595)
582   304 -8.0     ((-514 506 -29 (513:516) (-517:-507))  $ second 1" of lid
                :(596 -506 28 -29 ) )
583   304 -8.0     ((-515 507 -30 (514:517) (-518:-519) )  $ third 1" of lid
                :(596 -507 29 -30 ))
584   304 -8.0 596 -215 323 -595 $ lip
585   0  512 -594 -306  $ Air space above plug, under lid
c
c     MCO wall
590   304 -8.0  20 -207 52 -500          $ MCO pipe wall fuel to plug bottom
591   304 -8.0  20 (-21:-217) -303 500 -501 $ MCO pipe wall 1"+plug bottom
592   304 -8.0  20 -217 -303 501 -502      $ MCO pipe wall 2"+plug bottom
593   304 -8.0  20 -303 502 -503           $ MCO pipe wall 3"+plug bottom
594   304 -8.0  20 -303 503 -504           $ MCO pipe wall 4"+plug bottom
595   304 -8.0  20 -303 504 -505           $ MCO pipe wall 5"+plug bottom
596   304 -8.0  20 -303 505 -506           $ MCO pipe wall 6"+plug bottom
597   304 -8.0  20 -303 506 -507           $ MCO pipe wall 7"+plug bottom
598   304 -8.0  20 -303 507 -508           $ MCO pipe wall 8"+plug bottom
599   304 -8.0  20 -303 508 -509           $ MCO pipe wall 9"+plug bottom
c     side shield - top of fuel to bottom of plug
600   304 -8.0           223 -23 52 -214        $ 1" shield side
601   304 -8.0      214 22 -23  52 -500 216     $ 1" shield side
602   304 -8.0             23 -24 52 -500       $ 2" shield side
603   304 -8.0             24 -25 52 -500       $ 3" shield side
604   304 -8.0             25 -26 52 -500       $ 4" shield side
605   304 -8.0             26 -27 52 -500       $ 5" shield side
606   304 -8.0             27 -28 52 -500       $ 6" shield side
607   304 -8.0             28 -29 52 -500       $ 7" shield side
608   304 -8.0             29 -30 52 -500       $ 8" shield side
c     side shield - 1" above bottom of plug
611   304 -8.0            323 -23 500 -502 22 $ 1" shield side
612   304 -8.0             23 -24 500 -502      $ 2" shield side
613   304 -8.0             24 -25 500 -502      $ 3" shield side
614   304 -8.0             25 -26 500 -502      $ 4" shield side
615   304 -8.0             26 -27 500 -502      $ 5" shield side
616   304 -8.0             27 -28 500 -502      $ 6" shield side
617   304 -8.0             28 -29 500 -502      $ 7" shield side
618   304 -8.0             29 -30 500 -502      $ 8" shield side
c     side shield - 2" above bottom of plug
621   304 -8.0            323 -23 502 -503      $ 1" shield side
622   304 -8.0             23 -24 502 -503      $ 2" shield side
623   304 -8.0             24 -25 502 -503      $ 3" shield side
624   304 -8.0             25 -26 502 -503      $ 4" shield side
625   304 -8.0             26 -27 502 -503      $ 5" shield side
626   304 -8.0             27 -28 502 -503      $ 6" shield side
627   304 -8.0             28 -29 502 -503      $ 7" shield side
628   304 -8.0             29 -30 502 -503      $ 8" shield side
c     side shield - 3" above bottom of plug
631   304 -8.0            323 -23 503 -504      $ 1" shield side
632   304 -8.0             23 -24 503 -504      $ 2" shield side
633   304 -8.0             24 -25 503 -504      $ 3" shield side
634   304 -8.0             25 -26 503 -504      $ 4" shield side
635   304 -8.0             26 -27 503 -504      $ 5" shield side
636   304 -8.0             27 -28 503 -504      $ 6" shield side
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 637  304 -8.0        28 -29 503 -504      $ 7" shield side
 638  304 -8.0        29 -30 503 -504      $ 8" shield side
c    side shield - 4" above bottom of plug
 641  304 -8.0       323 -23 504 -596      $ 1" shield side
 642  304 -8.0        23 -24 504 -596      $ 2" shield side
 643  304 -8.0        24 -25 504 -596      $ 3" shield side
 644  304 -8.0        25 -26 504 -596      $ 4" shield side
 645  304 -8.0        26 -27 504 -596      $ 5" shield side
 646  304 -8.0        27 -28 504 -596      $ 6" shield side
 647  304 -8.0        28 -29 504 -596      $ 7" shield side
 648  304 -8.0        29 -30 504 -596      $ 8" shield side
c    MCO wall
 650  304 -8.0  207 -208 32 -58        $ MCO pipe wall from bottom of MCO
 651  304 -8.0  207 -208 58 -59        $ MCO pipe wall from bottom of MCO
 652  304 -8.0  207 -208 59 -60        $ MCO pipe wall from bottom of MCO
 653  304 -8.0  207 -208 60 -52        $ MCO pipe wall from bottom of MCO
 654  304 -8.0  207 -208 52 -500       $ MCO pipe wall fuel to plug bottom
 657  304 -8.0  303 -302 -217 -503     $ MCO pipe wall 3"+plug bottom
 658  304 -8.0  303 -302 503 -504            $ MCO pipe wall 4"+plug bottom
 659  304 -8.0  303 -302 504 -505            $ MCO pipe wall 5"+plug bottom
 660  304 -8.0  303 -302 505 -506            $ MCO pipe wall 6"+plug bottom
 661  304 -8.0  303 -302 506 -507            $ MCO pipe wall 7"+plug bottom
 662  304 -8.0  303 -302 507 -508            $ MCO pipe wall 8"+plug bottom
 663  304 -8.0  303 -302 508 -509            $ MCO pipe wall 9"+plug bottom
c    MCO wall
 670  304 -8.0  208 -209 32 -58        $ MCO pipe wall from bottom of MCO
 671  304 -8.0  208 -209 58 -59        $ MCO pipe wall from bottom of MCO
 672  304 -8.0  208 -209 59 -60        $ MCO pipe wall from bottom of MCO
 673  304 -8.0  208 -209 60 -52        $ MCO pipe wall from bottom of MCO
 674  304 -8.0  208 -209 52 -500        $ MCO pipe wall fuel to plug bottom
 677  304 -8.0  302 -301 -217 -503           $ MCO pipe wall 3"+plug bottom
 678  304 -8.0  302 -301 503 -504            $ MCO pipe wall 4"+plug bottom
 679  304 -8.0  302 -301 504 -505            $ MCO pipe wall 5"+plug bottom
 680  304 -8.0  302 -301 505 -506            $ MCO pipe wall 6"+plug bottom
 681  304 -8.0  302 -301 506 -507            $ MCO pipe wall 7"+plug bottom
 682  304 -8.0  302 -301 507 -508            $ MCO pipe wall 8"+plug bottom
 683  304 -8.0  302 -301 508 -509            $ MCO pipe wall 9"+plug bottom
c    MCO wall
 690  304 -8.0  209 -21 32 -58        $ MCO pipe wall from bottom of MCO
 691  304 -8.0  209 -21 58 -59        $ MCO pipe wall from bottom of MCO
 692  304 -8.0  209 -21 59 -60        $ MCO pipe wall from bottom of MCO
 693  304 -8.0  209 -21 60 -52        $ MCO pipe wall from bottom of MCO
 694  304 -8.0  209 -21 52 -500        $ MCO pipe wall fuel to plug bottom
 697  304 -8.0  301 -300 -217 -503           $ MCO pipe wall 3"+plug bottom
 698  304 -8.0  301 -300 503 -504            $ MCO pipe wall 4"+plug bottom
 699  304 -8.0  301 -300 504 -505            $ MCO pipe wall 5"+plug bottom
 700  304 -8.0  301 -300 505 -506            $ MCO pipe wall 6"+plug bottom
 701  304 -8.0  301 -300 506 -507            $ MCO pipe wall 7"+plug bottom
 702  304 -8.0  301 -300 507 -508            $ MCO pipe wall 8"+plug bottom
 703  304 -8.0  301 -300 508 -509            $ MCO pipe wall 9"+plug bottom
c    cask wall
 710  304 -8.0  22 -221 57 -58     $ 1" side shield from bottom of MCO
 711  304 -8.0  22 -221 58 -59     $ 1" side shield from bottom of MCO
 712  304 -8.0  22 -221 59 -60     $ 1" side shield from bottom of MCO
 713  304 -8.0  22 -221 60 -52         $ 1" side shield from bottom of MCO
 714  304 -8.0  22 -221 52 -214     $ 1" side shield fuel to plug bottom
 715  304 -8.0  214 216 210 -22
 718  304 -8.0  (320:216) -321 500 -503      $ 1" side shield 3"+plug bottom
 719  304 -8.0  320 -321 503 -594            $ 1" side shield 4"+plug bottom
c    cask wall
 720  304 -8.0  221 -222 57 -58        $ 1" side shield from bottom of MCO
 721  304 -8.0  221 -222 58 -59        $ 1" side shield from bottom of MCO
 722  304 -8.0  221 -222 59 -60        $ 1" side shield from bottom of MCO
 723  304 -8.0  221 -222 60 -52        $ 1" side shield from bottom of MCO
 724  304 -8.0  221 -222 52 -214     $ 1" side shield fuel to plug bottom
 728  304 -8.0  321 -322 500 -503            $ 1" side shield 3"+plug bottom
 729  304 -8.0  321 -322 503 -594            $ 1" side shield 4"+plug bottom
c    cask wall
 730  304 -8.0  222 -223 57 -58        $ 1" side shield from bottom of MCO
 731  304 -8.0  222 -223 58 -59        $ 1" side shield from bottom of MCO
 732  304 -8.0  222 -223 59 -60        $ 1" side shield from bottom of MCO
 733  304 -8.0  222 -223 60 -52        $ 1" side shield from bottom of MCO
 734  304 -8.0  222 -223 52 -214     $ 1" side shield fuel to plug bottom
 738  304 -8.0  322 -323 500 -503            $ 1" side shield 3"+plug bottom
 739  304 -8.0  322 -323 503 -594            $ 1" side shield 4"+plug bottom
```

```
  1       p        0.86602540   -0.5    0.0    3.556
  2       p        0.86602540   -0.5    0.0   -3.556
  3       p        0.86602540    0.5    0.0    3.556
  4       p        0.86602540    0.5    0.0   -3.556
  5       py                                   3.556
  6       py                                  -3.556
 11       cz       0.6083             $ H2O
 12       cz       0.6591             $ Zr-2 clad
 13       cz       1.5481             $ fuel
 14       cz       1.6243             $ Zr-2 clad
 15       cz       2.1603             $ H2O
 16       cz       2.2110             $ Zr-2 clad
 17       cz       3.0163             $ fuel
 18       cz       3.0798             $ Zr-2 clad
 19       cz      29.083              $ plug radius
 20       cz      29.21               $ MCO inner wall
207  cz 29.78   $ gap region
208  cz 30.18   $ gap region
209  cz 30.38   $ gap region
 21  cz  30.480    $ MCO outer wall
210  cz  30.7975   $ cask lip inner radius
214   kz   390.8171 1 -1 $ bottom of jog in cask
215  pz 386.6896   $ top of lip
216  kz  339.3821 1 1 $ top of jog in cask
217  1 kz  -30.48 1 1
 22  cz  31.9913   $ shd inner wall
221  cz 32.0913   $ gap region
222  cz 32.2913   $ gap region
223  cz 32.6913   $ gap region
300  cz  32.0548  $ upper gap region, inner edge
301  cz  31.9548  $ upper gap region, imp region
302  cz  31.7548  $ upper gap region, imp region
303  cz  31.3548  $ upper gap region, imp region
305  1  pz  25.0698  $ bottom of plug grapple region
306  cz  23.8125  $ inside radius of plug grapple region
310  pz  2.352  $ split in bottom of MCO
311  kz  -0.9579429  0.9886686  1.0  $ MCO bottom divit cone
320  cz  32.385  $ Top of cask, inner radius
321  cz  32.485  $ top of cask, inner imp zone
322  cz  32.685  $ top of cask, inner imp zone
323  cz  33.085  $ top of cask, inner imp zone
 23       cz      33.655              $ .69" shield
 24       cz      36.195              $ 1.69" shield
 25       cz      38.735              $ 2.69" shield
 26       cz      41.275              $ 3.69" shield
 27       cz      43.815              $ 4.69" shield
 28       cz      46.355              $ 5.69" shield
 29       cz      48.895              $ 6.69" shield
 30       cz      50.5587             $ 7.31" shield
 31       pz       8.25501            $ bottom of fuel region
 32       pz       8.255              $ 1.76" + 1.49" above bottom
 33       pz      -2.540              $ 1" from bottom
 34       pz      -5.080              $ 2" from bottom
 35       pz      -7.620              $ 3" from bottom
 36       pz     -10.160              $ 4" from bottom
 37       pz     -12.7                $ 5" from bottom
 38  pz  -15.5702                     $ 6.13" from bottom
 51       cz    10000.000             $ for u=1 purpose
c   top of fuel = 4(76.4540-8.255)+8.255 +(74.5744-8.255) = 347.3704
 52       pz     347.3705              $ lattice height
 53       pz      74.5744             $ fuel height
 54       pz      76.4540             $ individual lattice height
 55       pz       8.2550             $ bottom of lattice
 56       pz       4.4704             $ 1.76" above bottom of MCO
 57       pz       0.00               $ bottom of MCO
 58       pz 88.96
 59 pz  177.93
 60  pz  266.895
 61  pz  -67.0052
250  pz   512.0896 $ 1m from top
251  pz   612.0896 $ 2m from top
252  pz   1012.0896 $ 6m from top
253  pz  -115.5702 $ 1m from bottom
254  pz  -215.5702 $ 2m from bottom
255  pz  -615.5702 $ 6m from bottom
256  cz   150.5587 $ 1m from side
```

```
  257  cz   250.5587 $ 2m from side
  258  cz   650.5587 $ 6m from side
  259  cz  3.175 $ inner rad of divit
  260  cz  15
c   bottom of fuel = 8.255
c   center of fuel: (8.255+347.3704)/2 = 177.8127
  265  pz   72.8127 $ 177.8127 -105
  266  pz  102.8127 $ 177.8127 - 75
  267  pz  132.8127 $ 177.8127 - 45
  268  pz  162.8127 $ 177.8127 - 15
  269  pz  192.8127 $ 177.8127 + 15
  270  pz  222.8127 $ 177.8127 + 45
  271  pz  252.8127 $ 177.8127 + 75
  272  pz  282.8127 $ 177.8127 +105
c 404  1  pz        5.08
  405  1  pz        7.62
  420  5  px       8.25                $changed from -19.5 to 8.25
  421  6  px       19.2257                    $21.50
c
  500  1  pz        0.000              $ top of MCO open area/bot.of plug
  501  1  pz        2.540              $ 1" shield
  502  1  pz        5.2578             $ 2" shield
  503  1  pz        7.540              $ 3" shield
  504  1  pz       10.160              $ 4" shield
  505  1  pz       12.44092            $ 5" shield
  506  1  pz       15.900              $ 6" shield
  507  1  pz       18.641              $ 7" shield
  508  1  pz       20.032              $ 8" shield
  509  1  pz       23.490              $ 9" shield
  510  1  pz       25.430              $ 10" shield
  511  1  pz       27.940              $ 11" shield
  512  1  pz       30.480              $ 12" shield
  513     pz  407.0096
  514     pz  409.5496
  515     pz  412.0896 $ top of 3" lid
  516     cz  34.5313
  517     cz  37.0713
  518     cz  40.005    $ radius of lid
  519     pz  394.3096  $ top of lid bottom
  526  1  pz 4000                   $ top of 3" lid (402.515) + 20m
c 530     cz 3.81
  534     c/z  -9.576 -6.957 3.200       $ Short Draw Port bottom radius
  535     c/z  6.957  9.576  3.200       $ Dip Tube Port bottom radius
  536     c/z  -9.576 -6.957 7.1311      $ Short Draw flange
  537     c/z  6.957  9.576 7.1311       $ Dip Tube flange radius
  538     c/z  -9.576 -6.957  1.27       $ Short Draw top pipe
  540  6  px   -1.70
  541  2  cx  1.27                       $ Short Draw horizontal pipe
  542  3  cx  1.27                       $ Short Draw bottom pipe
  543     c/z 6.957  9.576 0.635         $ Dip Tube top pipe
  544  4  cx  0.635                      $ Dip Tube horizontal pipe
  546  5  cx  0.635                      $ Dip Tube bottom pipe
  548     c/z 9.483 -9.483 5.226        $ HEPA Filter flange
  549     c/z 9.483 -9.483 2.54         $ HEPA Filter middle
  550     c/z 9.483 -9.483 0.9525       $ HEPA Filter vertical pipe
  551  6  cx  1.27                      $ HEPA Filter horizontal pipe
  553     c/z -10.633  10.633 7.112         $ Rupture Disk flange
  554     c/z -10.633  10.633 3.81          $ Rupture Disk middle
  555     c/z -10.633  10.633 1.27          $ Rupture Disk vertical pipe
  556  7  cx  1.27                          $ Rupture Disk horizontal pipe
  557  7  px  -17.61856                         $-19.55
  558  7  px  1.70
  560  2  px   3.00                 $ inside edge of E2 vent mid segment; 0.70 to 2.00
  561  2  px  -10.00                $ outer edge of E2 vent mid segment:-8.00 to -10
  562  3  px 8.25                   $ outer edge of E2 vent lower segment:3  px -24.90  to 3 px 8.25
  563  4  px   2.00               $ outer edge of E1 vent mid segment
  564  4  px -13.5                  $ inner edge of E1 vent mid segment 19.50 to -13.5
  578  cz 4000 $ 6 m is at 652
  581  pz -4000 $ 6 m is at -612
  582  c/x     0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
c 582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
  583  px 0
  584  px   38.0873 $ Outer cask wall - 4.91"
  585  px   48.0187 $ Outer cask wall - 1"
  586  px  49.9237  $ Outer cask wall - .25"
  587  c/x  0 -3.4036 0.0001
```

```
c 587  c/x  0 -3.4036 10.16
c      168.88-(24-13.5)-6.5 = 151.88
  590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
  591  pz   -3.4544
  592  cz  .0001  $ Vertical drain pipe
c 592  cz  .8001  $ Vertical drain pipe
  594     pz  403.1996 $ bottom of lid
  595  cz  37.7952 $ radius of lip
  596  pz  384.1496  $ top of cask sidewall
  597  c/z  6.957 9.576 5.599  $ Dip Tube Port middle radius
  598  c/z -9.576 -6.957 5.599  $ Short Draw Port middle radius
  601  pz -3000
  602  pz -2500
  603  pz -2000
  604  pz -1500
  605  pz -1200
  606  pz -900
  607  pz -700
  608  pz -644
  609  pz -584
  610  pz -384
  611  pz -244
  612  pz -184
  613  pz -129
  614  pz  -99
  615  pz  -69
  616  pz  -39
  617  pz  -16
  618  pz 30
  619  pz 60
  620  pz 90
  621  pz 120
  622  pz 150
  623  pz 170
  624  pz 190
  625  pz 210
  626  pz 240
  627  pz 270
  628  pz 300
  629  pz 330
  630  pz 349
  631  pz 389
  632  pz 399
  633  pz 407
  634  pz 413
  635  pz 450
  636  pz 500
  637  pz 600
  638  pz 800
  639  pz 1000
  640  pz 1200
  641  pz 1500
  642  pz 2000
  643  pz 2500
  644  pz 3000
  701  cz 5
  702  cz 12.5
  703  cz 21.5
  704  cz 30.5
  705  cz 32
  706  cz 41
  707  cz 51
  708  cz 52
  709  cz 83
  710  cz 107
  711  cz 130
  712  cz 171.2
  713  cz 197
  714  cz 230
  715  cz 272.2
  716  cz 350
  717  cz 400
  718  cz 470
  719  cz 540
  720  cz 620
```

```
 721  cz 682.5
 722  cz 800
 723  cz 900
 724  cz 1090.87
 725  cz 1200
 726  cz 1500
 727  cz 2000
 728  cz 2500
 729  cz 3000

*tr1  0 0 371.4496                $ bottom of plug
*tr2  -9.576 -6.957 379.0696         $ E2 vent mid segment;-16.46 -6.30 to -9.567 -6.957
      36.0  54.0  90.0               $ changed from 37.493 72.321 58.163
*tr3  -15.925  -11.571 371.4496      $ E2 vent bottom segment:0 0 to -15.925  -11.571
      90.0  90.0  0.00               $ changed from 24.294 69.583 102.597
*tr4  6.957  9.576 379.0696          $ E1 vent mid segment; 13.49 11.33 385.445to 6.957 9.576 384.81
      54.0 36.0 90.0                 $ test model E1 vent mid segment on xy plane 45 deg to x,y
*tr5  0.000 0.000 371.4496           $ E1 vent bottom segment move to xy at 0.000 0.000
      90.0 90.0 0.0                  $ E1 vebt bittin seg straight up // Z axis
*tr6  9.483 -9.483 379.0696             $ F2 vent mid segment
      187.550 82.45 90.00
*tr7  -10.633  10.633 379.0696          $ F1 vent mid segment
      93.439  -3.439  90.000
mode      p
c
c     2nd entry=1 of phys:p turns off brehmmstralung
c     3rd entry=1 of phys:p turns off coherent scattering
c            (procedure suggested for dxtran use)
phys:p      j 1
c           1 2  3 4  400  5  6   7   8   9   10   11   12 13
imp:p       1 1 32 1    1 32 64 128 156 512 1024 2048 4096  r
c         14 15 16 17 18 19 20 21 22 23 24 25 26
           0  1  1  1  1  1  1  1  1  1  1  1  1
c          30   31    32     33   34   35     36   37   38
     131072 4096  8192 131072 4096 4096 131072 4096 4096
c       40 41  42 43  44  45   46   47   48   49
        32 64 128  1 256 512 1024 2048 4096 8192
c       500 501 502 503 504 505  506  507  508  509   510
          1  32  64 128 256 512 1024 4096 8192 8192  8192
c       511   512   520
      8192  8192  8192
c       531 532 533 535 536 537 538
          1   1   1   1   1   1   1
c       540   541   542   543 544 545 546   547 548 549
          1 16384 16384 16384   1   1   1 16384   1   1
c       550
          1
c       562 563 565 566 567
          1   1   1   1   1
c       570 571
          1   1
c       580   581   582    583  584  585
          1 32768 65536 131072 4096    1
c       590 591 592 593  594  595  596  597  598  599
         32 256 256 512 1024 2048 4096 4096 4096 4096
c       600 601 602 603 604 605  606  607  608
        128 128  64 128 256 512 1024 1024 1024
c       611 612 613 614 615  616  617  618
        256 256 256 256 512 1024 2048 4096
c       621 622 623 624 625  626  627  628
        512 512 512 512 512 1024 2048 4096
c       631  632  633  634  635  636  637  638
       1024 1024 1024 1024 1024 1024 2048 4096
c       641  642  643  644  645  646  647  648
       2048 2048 2048 2048 2048 2048 2048 4096
c       650 651 652 653 654  657  658  659  660  661  662  663
         32  32  32  32  32  512  512  512 4196 4196 4196 4196
c       670 671 672 673 674  677  678  679  680  681  682  683
         32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
c       690 691 692 693 694  697  698  699  700  701  702  703
         32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
c       710 711 712 713 714 715  718  719
         32  32  32  32  32  64 4096 4096
c       720 721 722 723 724 728  729
         32  32  32  32  32 512 4096
c       730 731 732 733 734  738 739
```

```
         32  32  32  32  32 512 4096
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
m304  6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
      28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m3        40000.60c  -1.00000                                $ zirc cladding
m5        92235.50c  -0.00947   92238.50c  -0.99053          $ inner fuel
m7         8016.50c   0.22000    7014.50c   0.78000          $ Air
m8      1001.50c  1   8016.50c 2                             $ Water
m221    8016.50c -0.511 14000.50c -0.2782 20000.50c -0.0717  $ HWVP Dirt
        26000.55c -0.1091 13027.50c -0.08326 12000.50c -0.03142
        19000.50c -0.01155 11023.50c -0.02022 22000.50c -0.01655
        25055.50c -0.001781 15031.50c -0.0024
c
sdef    cel=d1         pos=0 0 0    axs=0 0 1 ext=d3
        rad fcel d4    erg=d7       wgt=5.71e15
sc7    Energy spectrum from Willis ccmail
#      si7          sp7            sb7
       l            d              d
     1.50E-02    1.65E+15      1.65E+13
     2.50E-02    3.52E+14      5.71E+12
     3.75E-02    3.97E+14      3.97E+13
     5.75E-02    3.33E+14      3.33E+13
     8.50E-02    1.84E+14      3.67E+13
     1.25E-01    1.37E+14      2.73E+13
     2.25E-01    1.55E+14      7.77E+13
     3.75E-01    7.35E+13      3.68E+13
     6.62E-01    2.33E+15      2.33E+15
     8.50E-01    5.87E+13      5.87E+13
     1.25E+00    3.37E+13      6.74E+13
     1.75E+00    1.04E+12      5.71E+12
     2.25E+00    8.85E+09      5.71E+12
     2.75E+00    6.34E+08      5.71E+12
     3.50E+00    8.31E+07      5.71E+12
     5.00E+00    3.95E+05      5.71E+12
     7.00E+00    4.51E+04      5.71E+12
     1.10E+01    5.16E+03      5.71E+12
c          TOTAL  5.71E+15 p/s
si1      l    1:2( 1 -4  0):17   1:2( 2 -4  0):17   1:2( 3 -4  0):17
              1:2(-1 -3  0):17   1:2( 0 -3  0):17   1:2( 1 -3  0):17
              1:2( 2 -3  0):17   1:2( 3 -3  0):17   1:2( 4 -3  0):17
              1:2(-2 -2  0):17   1:2(-1 -2  0):17   1:2( 0 -2  0):17
              1:2( 1 -2  0):17   1:2( 2 -2  0):17   1:2( 3 -2  0):17
              1:2( 4 -2  0):17   1:2(-3 -1  0):17   1:2(-2 -1  0):17
              1:2(-1 -1  0):17   1:2( 0 -1  0):17   1:2( 1 -1  0):17
              1:2( 2 -1  0):17   1:2( 3 -1  0):17   1:2( 4 -1  0):17
              1:2(-3  0  0):17   1:2(-2  0  0):17   1:2(-1  0  0):17
              1:2( 1  0  0):17   1:2( 2  0  0):17   1:2( 3  0  0):17
              1:2(-4  1  0):17   1:2(-3  1  0):17   1:2(-2  1  0):17
              1:2(-1  1  0):17   1:2( 0  1  0):17   1:2( 1  1  0):17
              1:2( 2  1  0):17   1:2( 3  1  0):17   1:2(-4  2  0):17
              1:2(-3  2  0):17   1:2(-2  2  0):17   1:2(-1  2  0):17
              1:2( 0  2  0):17   1:2( 1  2  0):17   1:2( 2  2  0):17
              1:2(-4  3  0):17   1:2(-3  3  0):17   1:2(-2  3  0):17
              1:2(-1  3  0):17   1:2( 0  3  0):17   1:2( 1  3  0):17
              1:2(-3  4  0):17   1:2(-2  4  0):17   1:2(-1  4  0):17
              1:2( 1 -4  1):17   1:2( 2 -4  1):17   1:2( 3 -4  1):17
              1:2(-1 -3  1):17   1:2( 0 -3  1):17   1:2( 1 -3  1):17
              1:2( 2 -3  1):17   1:2( 3 -3  1):17   1:2( 4 -3  1):17
              1:2(-2 -2  1):17   1:2(-1 -2  1):17   1:2( 0 -2  1):17
              1:2( 1 -2  1):17   1:2( 2 -2  1):17   1:2( 3 -2  1):17
              1:2( 4 -2  1):17   1:2(-3 -1  1):17   1:2(-2 -1  1):17
              1:2(-1 -1  1):17   1:2( 0 -1  1):17   1:2( 1 -1  1):17
              1:2( 2 -1  1):17   1:2( 3 -1  1):17   1:2( 4 -1  1):17
              1:2(-3  0  1):17   1:2(-2  0  1):17   1:2(-1  0  1):17
              1:2( 1  0  1):17   1:2( 2  0  1):17   1:2( 3  0  1):17
              1:2(-4  1  1):17   1:2(-3  1  1):17   1:2(-2  1  1):17
              1:2(-1  1  1):17   1:2( 0  1  1):17   1:2( 1  1  1):17
              1:2( 2  1  1):17   1:2( 3  1  1):17   1:2(-4  2  1):17
              1:2(-3  2  1):17   1:2(-2  2  1):17   1:2(-1  2  1):17
              1:2( 0  2  1):17   1:2( 1  2  1):17   1:2( 2  2  1):17
              1:2(-4  3  1):17   1:2(-3  3  1):17   1:2(-2  3  1):17
              1:2(-1  3  1):17   1:2( 0  3  1):17   1:2( 1  3  1):17
              1:2(-3  4  1):17   1:2(-2  4  1):17   1:2(-1  4  1):17
              1:2( 1 -4  2):17   1:2( 2 -4  2):17   1:2( 3 -4  2):17
              1:2(-1 -3  2):17   1:2( 0 -3  2):17   1:2( 1 -3  2):17
              1:2( 2 -3  2):17   1:2( 3 -3  2):17   1:2( 4 -3  2):17
```

1:2(-2 -2 2):17	1:2(-1 -2 2):17	1:2(0 -2 2):17
1:2(1 -2 2):17	1:2(2 -2 2):17	1:2(3 -2 2):17
1:2(4 -2 2):17	1:2(-3 -1 2):17	1:2(-2 -1 2):17
1:2(-1 -1 2):17	1:2(0 -1 2):17	1:2(1 -1 2):17
1:2(2 -1 2):17	1:2(3 -1 2):17	1:2(4 -1 2):17
1:2(-3 0 2):17	1:2(-2 0 2):17	1:2(-1 0 2):17
1:2(1 0 2):17	1:2(2 0 2):17	1:2(3 0 2):17
1:2(-4 1 2):17	1:2(-3 1 2):17	1:2(-2 1 2):17
1:2(-1 1 2):17	1:2(0 1 2):17	1:2(1 1 2):17
1:2(2 1 2):17	1:2(3 1 2):17	1:2(-4 2 2):17
1:2(-3 2 2):17	1:2(-2 2 2):17	1:2(-1 2 2):17
1:2(0 2 2):17	1:2(1 2 2):17	1:2(2 2 2):17
1:2(-4 3 2):17	1:2(-3 3 2):17	1:2(-2 3 2):17
1:2(-1 3 2):17	1:2(0 3 2):17	1:2(1 3 2):17
1:2(-3 4 2):17	1:2(-2 4 2):17	1:2(-1 4 2):17
1:2(1 -4 3):17	1:2(2 -4 3):17	1:2(3 -4 3):17
1:2(-1 -3 3):17	1:2(0 -3 3):17	1:2(1 -3 3):17
1:2(2 -3 3):17	1:2(3 -3 3):17	1:2(4 -3 3):17
1:2(-2 -2 3):17	1:2(-1 -2 3):17	1:2(0 -2 3):17
1:2(1 -2 3):17	1:2(2 -2 3):17	1:2(3 -2 3):17
1:2(4 -2 3):17	1:2(-3 -1 3):17	1:2(-2 -1 3):17
1:2(-1 -1 3):17	1:2(0 -1 3):17	1:2(1 -1 3):17
1:2(2 -1 3):17	1:2(3 -1 3):17	1:2(4 -1 3):17
1:2(-3 0 3):17	1:2(-2 0 3):17	1:2(-1 0 3):17
1:2(1 0 3):17	1:2(2 0 3):17	1:2(3 0 3):17
1:2(-4 1 3):17	1:2(-3 1 3):17	1:2(-2 1 3):17
1:2(-1 1 3):17	1:2(0 1 3):17	1:2(1 1 3):17
1:2(2 1 3):17	1:2(3 1 3):17	1:2(-4 2 3):17
1:2(-3 2 3):17	1:2(-2 2 3):17	1:2(-1 2 3):17
1:2(0 2 3):17	1:2(1 2 3):17	1:2(2 2 3):17
1:2(-4 3 3):17	1:2(-3 3 3):17	1:2(-2 3 3):17
1:2(-1 3 3):17	1:2(0 3 3):17	1:2(1 3 3):17
1:2(-3 4 3):17	1:2(-2 4 3):17	1:2(-1 4 3):17
1:2(1 -4 4):17	1:2(2 -4 4):17	1:2(3 -4 4):17
1:2(-1 -3 4):17	1:2(0 -3 4):17	1:2(1 -3 4):17
1:2(2 -3 4):17	1:2(3 -3 4):17	1:2(4 -3 4):17
1:2(-2 -2 4):17	1:2(-1 -2 4):17	1:2(0 -2 4):17
1:2(1 -2 4):17	1:2(2 -2 4):17	1:2(3 -2 4):17
1:2(4 -2 4):17	1:2(-3 -1 4):17	1:2(-2 -1 4):17
1:2(-1 -1 4):17	1:2(0 -1 4):17	1:2(1 -1 4):17
1:2(2 -1 4):17	1:2(3 -1 4):17	1:2(4 -1 4):17
1:2(-3 0 4):17	1:2(-2 0 4):17	1:2(-1 0 4):17
1:2(1 0 4):17	1:2(2 0 4):17	1:2(3 0 4):17
1:2(-4 1 4):17	1:2(-3 1 4):17	1:2(-2 1 4):17
1:2(-1 1 4):17	1:2(0 1 4):17	1:2(1 1 4):17
1:2(2 1 4):17	1:2(3 1 4):17	1:2(-4 2 4):17
1:2(-3 2 4):17	1:2(-2 2 4):17	1:2(-1 2 4):17
1:2(0 2 4):17	1:2(1 2 4):17	1:2(2 2 4):17
1:2(-4 3 4):17	1:2(-3 3 4):17	1:2(-2 3 4):17
1:2(-1 3 4):17	1:2(0 3 4):17	1:2(1 3 4):17
1:2(-3 4 4):17	1:2(-2 4 4):17	1:2(-1 4 4):17
1:2(1 -4 0):21	1:2(2 -4 0):21	1:2(3 -4 0):21
1:2(-1 -3 0):21	1:2(0 -3 0):21	1:2(1 -3 0):21
1:2(2 -3 0):21	1:2(3 -3 0):21	1:2(4 -3 0):21
1:2(-2 -2 0):21	1:2(-1 -2 0):21	1:2(0 -2 0):21
1:2(1 -2 0):21	1:2(2 -2 0):21	1:2(3 -2 0):21
1:2(4 -2 0):21	1:2(-3 -1 0):21	1:2(-2 -1 0):21
1:2(-1 -1 0):21	1:2(0 -1 0):21	1:2(1 -1 0):21
1:2(2 -1 0):21	1:2(3 -1 0):21	1:2(4 -1 0):21
1:2(-3 0 0):21	1:2(-2 0 0):21	1:2(-1 0 0):21
1:2(1 0 0):21	1:2(2 0 0):21	1:2(3 0 0):21
1:2(-4 1 0):21	1:2(-3 1 0):21	1:2(-2 1 0):21
1:2(-1 1 0):21	1:2(0 1 0):21	1:2(1 1 0):21
1:2(2 1 0):21	1:2(3 1 0):21	1:2(-4 2 0):21
1:2(-3 2 0):21	1:2(-2 2 0):21	1:2(-1 2 0):21
1:2(0 2 0):21	1:2(1 2 0):21	1:2(2 2 0):21
1:2(-4 3 0):21	1:2(-3 3 0):21	1:2(-2 3 0):21
1:2(-1 3 0):21	1:2(0 3 0):21	1:2(1 3 0):21
1:2(-3 4 0):21	1:2(-2 4 0):21	1:2(-1 4 0):21
1:2(1 -4 1):21	1:2(2 -4 1):21	1:2(3 -4 1):21
1:2(-1 -3 1):21	1:2(0 -3 1):21	1:2(1 -3 1):21
1:2(2 -3 1):21	1:2(3 -3 1):21	1:2(4 -3 1):21
1:2(-2 -2 1):21	1:2(-1 -2 1):21	1:2(0 -2 1):21
1:2(1 -2 1):21	1:2(2 -2 1):21	1:2(3 -2 1):21
1:2(4 -2 1):21	1:2(-3 -1 1):21	1:2(-2 -1 1):21
1:2(-1 -1 1):21	1:2(0 -1 1):21	1:2(1 -1 1):21

```
        1:2( 2 -1  1):21   1:2( 3 -1  1):21   1:2( 4 -1  1):21
        1:2(-3  0  1):21   1:2(-2  0  1):21   1:2(-1  0  1):21
        1:2( 1  0  1):21   1:2( 2  0  1):21   1:2( 3  0  1):21
        1:2(-4  1  1):21   1:2(-3  1  1):21   1:2(-2  1  1):21
        1:2(-1  1  1):21   1:2( 0  1  1):21   1:2( 1  1  1):21
        1:2( 2  1  1):21   1:2( 3  1  1):21   1:2(-4  2  1):21
        1:2(-3  2  1):21   1:2(-2  2  1):21   1:2(-1  2  1):21
        1:2( 0  2  1):21   1:2( 1  2  1):21   1:2( 2  2  1):21
        1:2(-4  3  1):21   1:2(-3  3  1):21   1:2(-2  3  1):21
        1:2(-1  3  1):21   1:2( 0  3  1):21   1:2( 1  3  1):21
        1:2(-3  4  1):21   1:2(-2  4  1):21   1:2(-1  4  1):21
        1:2( 1 -4  2):21   1:2( 2 -4  2):21   1:2( 3 -4  2):21
        1:2(-1 -3  2):21   1:2( 0 -3  2):21   1:2( 1 -3  2):21
        1:2( 2 -3  2):21   1:2( 3 -3  2):21   1:2( 4 -3  2):21
        1:2(-2 -2  2):21   1:2(-1 -2  2):21   1:2( 0 -2  2):21
        1:2( 1 -2  2):21   1:2( 2 -2  2):21   1:2( 3 -2  2):21
        1:2( 4 -2  2):21   1:2(-3 -1  2):21   1:2(-2 -1  2):21
        1:2(-1 -1  2):21   1:2( 0 -1  2):21   1:2( 1 -1  2):21
        1:2( 2 -1  2):21   1:2( 3 -1  2):21   1:2( 4 -1  2):21
        1:2(-3  0  2):21   1:2(-2  0  2):21   1:2(-1  0  2):21
        1:2( 1  0  2):21   1:2( 2  0  2):21   1:2( 3  0  2):21
        1:2(-4  1  2):21   1:2(-3  1  2):21   1:2(-2  1  2):21
        1:2(-1  1  2):21   1:2( 0  1  2):21   1:2( 1  1  2):21
        1:2( 2  1  2):21   1:2( 3  1  2):21   1:2(-4  2  2):21
        1:2(-3  2  2):21   1:2(-2  2  2):21   1:2(-1  2  2):21
        1:2( 0  2  2):21   1:2( 1  2  2):21   1:2( 2  2  2):21
        1:2(-4  3  2):21   1:2(-3  3  2):21   1:2(-2  3  2):21
        1:2(-1  3  2):21   1:2( 0  3  2):21   1:2( 1  3  2):21
        1:2(-3  4  2):21   1:2(-2  4  2):21   1:2(-1  4  2):21
        1:2( 1 -4  3):21   1:2( 2 -4  3):21   1:2( 3 -4  3):21
        1:2(-1 -3  3):21   1:2( 0 -3  3):21   1:2( 1 -3  3):21
        1:2( 2 -3  3):21   1:2( 3 -3  3):21   1:2( 4 -3  3):21
        1:2(-2 -2  3):21   1:2(-1 -2  3):21   1:2( 0 -2  3):21
        1:2( 1 -2  3):21   1:2( 2 -2  3):21   1:2( 3 -2  3):21
        1:2( 4 -2  3):21   1:2(-3 -1  3):21   1:2(-2 -1  3):21
        1:2(-1 -1  3):21   1:2( 0 -1  3):21   1:2( 1 -1  3):21
        1:2( 2 -1  3):21   1:2( 3 -1  3):21   1:2( 4 -1  3):21
        1:2(-3  0  3):21   1:2(-2  0  3):21   1:2(-1  0  3):21
        1:2( 1  0  3):21   1:2( 2  0  3):21   1:2( 3  0  3):21
        1:2(-4  1  3):21   1:2(-3  1  3):21   1:2(-2  1  3):21
        1:2(-1  1  3):21   1:2( 0  1  3):21   1:2( 1  1  3):21
        1:2( 2  1  3):21   1:2( 3  1  3):21   1:2(-4  2  3):21
        1:2(-3  2  3):21   1:2(-2  2  3):21   1:2(-1  2  3):21
        1:2( 0  2  3):21   1:2( 1  2  3):21   1:2( 2  2  3):21
        1:2(-4  3  3):21   1:2(-3  3  3):21   1:2(-2  3  3):21
        1:2(-1  3  3):21   1:2( 0  3  3):21   1:2( 1  3  3):21
        1:2(-3  4  3):21   1:2(-2  4  3):21   1:2(-1  4  3):21
        1:2( 1 -4  4):21   1:2( 2 -4  4):21   1:2( 3 -4  4):21
        1:2(-1 -3  4):21   1:2( 0 -3  4):21   1:2( 1 -3  4):21
        1:2( 2 -3  4):21   1:2( 3 -3  4):21   1:2( 4 -3  4):21
        1:2(-2 -2  4):21   1:2(-1 -2  4):21   1:2( 0 -2  4):21
        1:2( 1 -2  4):21   1:2( 2 -2  4):21   1:2( 3 -2  4):21
        1:2( 4 -2  4):21   1:2(-3 -1  4):21   1:2(-2 -1  4):21
        1:2(-1 -1  4):21   1:2( 0 -1  4):21   1:2( 1 -1  4):21
        1:2( 2 -1  4):21   1:2( 3 -1  4):21   1:2( 4 -1  4):21
        1:2(-3  0  4):21   1:2(-2  0  4):21   1:2(-1  0  4):21
        1:2( 1  0  4):21   1:2( 2  0  4):21   1:2( 3  0  4):21
        1:2(-4  1  4):21   1:2(-3  1  4):21   1:2(-2  1  4):21
        1:2(-1  1  4):21   1:2( 0  1  4):21   1:2( 1  1  4):21
        1:2( 2  1  4):21   1:2( 3  1  4):21   1:2(-4  2  4):21
        1:2(-3  2  4):21   1:2(-2  2  4):21   1:2(-1  2  4):21
        1:2( 0  2  4):21   1:2( 1  2  4):21   1:2( 2  2  4):21
        1:2(-4  3  4):21   1:2(-3  3  4):21   1:2(-2  3  4):21
        1:2(-1  3  4):21   1:2( 0  3  4):21   1:2( 1  3  4):21
        1:2(-3  4  4):21   1:2(-2  4  4):21   1:2(-1  4  4):21
sp1   d 4.210  4.210  4.210  4.210  4.210  4.210
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             1.962  1.962  1.962  1.962  1.962  1.962
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             1.962  1.962  1.962  1.962  1.962  1.962
c            pi(r2*r2-r1*r1)*h  pi(r4*r4-r3*r3)*h,  pi and h cancelled
si3         8.255    74.5744
ds4     s    5    5    5    5    5    5    5    5    5
             5    5    5    5    5    5    5    5    5
             5    5    5    5    5    5    5    5    5
             5    5    5    5    5    5    5    5    5
             5    5    5    5    5    5    5    5    5
             5    5    5    5    5    5    5    5    5
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             6    6    6    6    6    6    6    6    6
             6    6    6    6    6    6    6    6    6
             6    6    6    6    6    6    6    6    6
si5         2.2110   3.0163
sp5         -21    1
si6          .6591   1.5481
sp6         -21    1
c
c        ansi/ans-6.1.1-1991 fluence-to-dose,photons(mrem/hr/(p/cm**2/s)
de0      log  .01 .015 .02 .03 .04 .05
              .06 .08 .10 .15 .20 .30
              .40 .50 .60 .80 1.0 1.5
              2.0 3.0 4.0 5.0 6.0 8.0
              10. 12.
```

```
df0    log  2.232e-5 5.652e-5 8.568e-5 1.184e-4 1.314e-4 1.382e-4
            1.440e-4 1.624e-4 1.919e-4 2.797e-4 3.708e-4 5.616e-4
            7.416e-4 9.144e-4 1.076e-3 1.379e-3 1.656e-3 2.246e-3
            2.758e-3 3.672e-3 4.500e-3 5.292e-3 6.012e-3 7.488e-3
            8.892e-3 1.040e-2
c
c       -60: dump runtpe every 60 min
prdmp     j -60  1
c
f4:p  (13 30 31 32 33 34 35 36 37 38 580)
fs4   -3000000  44 29 2
      601 602 603 604 605 606 607 608 609 610
      611 612 613 614 615 616 617 618 619 620
      621 622 623 624 625 626 627 628 629 630
      631 632 633 634 635 636 637 638 639 640
      641 642 643 644
      701 702 703 704 705 706 707 708 709 710
      711 712 713 714 715 716 717 718 719 720
      721 722 723 724 725 726 727 728 729
      583 583
fc12  Dip Tube Port contact, 1m, 2m, 6m
f12:p  515 250 251 252
fs12   -543 -535 -597 -537
c     r=0.635->1.2668 r=3.2->30.9031 r=5.599->66.3153 r=7.1311->61.2730
sd12       1.2668 30.9031 66.3153 61.2730 1e20
           1.2668 30.9031 66.3153 61.2730 1e20
           1.2668 30.9031 66.3153 61.2730 1e20
           1.2668 30.9031 66.3153 61.2730 1e20
fc22  Short Draw Port contact, 1m, 2m, 6m
f22:p 515 250 251 252
fs22   -538 -534 -598 -536
c     r=1.27->5.0671 r=3.2->27.1028 r=5.599->66.3153 r=7.1311->61.2730
sd22       5.0671 27.1028 66.3153 61.2730 1e20
           5.0671 27.1028 66.3153 61.2730 1e20
           5.0671 27.1028 66.3153 61.2730 1e20
           5.0671 27.1028 66.3153 61.2730 1e20
fc32  Top dose, contact, lid
f32:p  515
fs32   -260 -306 -300 -320 -518 -28
fc52  Top dose
f52:p  250 251 252
fs52   -260 -306 -300 -320 -518 -30 -709 -710 -711
fc62  within gap, bottom of lid top
f62:p  594
fs62  -300
fc72  Side of lid
f72:p  518
fs72  -510
fc82  Top of lid bottom
f82:p  519
fs82   -27
c     top of gap will not work for lid-on
c     fc92   Top of gap
c     f92:p  215
c     fs92  -300 -320
fc112  Next to lip
f112:p   596
fs112  -595 -27
fc122  Side of plug
f122:p  300
fs122  -596 -215 -508
fc132  Bottom
f132:p  38 61
fs132   -259 -21
e132   .01 .1 .2 .5 1 2 5 10 20
fc142  Side
f142:p  30 256 257 258
fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
e142   .01 .1 .2 .5 1 2 5 10 20
c      fc152   Dose at drain port cover
c      f152:p  586
c      fs152  -582
c      c  r=3.9624->49.3249 r=10.16->274.9679
c      sd152   49.3249 274.9679
fc162   dose at bottom of plug
f162:p   500
```

```
fs162   -20
ctme    4000
```

DIFFERENCE BETWEEN inorm AND inorm2

```
68c68,69
<   400     0     -594 -320 -216 (217:300) 21 $ gap
---
>   400     0     -215 -320 -216 (217:300) 21 $ gap
>   401     0     -594 -320 300 215
559,560c560,561
< c           1 2  3 4  400  5  6   7   8   9   10   11   12 13
< imp:p       1 1 32 1    1 32 64 128 156 512 1024 2048 4096  r
---
> c           1 2  3 4  400 401  5  6   7   8   9   10   11   12 13
> imp:p       1 1 32 1    1    1 32 64 128 156 512 1024 2048 4096  r
1063c1064,1067
< ctme    4000
---
> fc172   dose at top of lip
> f172:p   215
> fs172   -320
> ctme    900
```

DIFFERENCE BETWEEN inorm AND inormt

```
1c1
< MCO Final SARP, photon model, lid-on
---
> MCO Final SARP, photon model, lid-on, top dose
172c172
<                    (215:595)
---
>                    (215:595) (565:-567)
174c174
<                  :(596 -506 28 -29 ) )
---
>                  :(596 -506 28 -29 ) ) 565
176c176
<                  :(596 -507 29 -30 ))
---
>                  :(596 -507 29 -30 )) (565:566)
178a179
>   586  0  -565 -566 567   $ vent port
444a446,448
>   565  c/z   27.305 0 1.905
>   566  pz  410.1846
>   567  pz  405.3078
560c564
< imp:p     1 1 32 1     1 32 64 128 156 512 1024 2048 4096  r
---
> imp:p     1 1 32 1     1  1  1   1   1   1    1    1    1  r
564c568
<       131072 4096  8192 131072 4096 4096 131072 4096 4096
---
>       131072    1     1 131072    1    1 131072    1    1
566c570
<         32 64 128  1 256 512 1024 2048 4096 8192
---
>          1  1   1  1   1   1    1    1    1    1
581,582c585,586
< c       580   581    582      583  584  585
<           1 32768 65536 131072 4096    1
---
> c       580   581    582      583  584  585  586
>           1 32768 65536 131072 4096    1    1
596c600
<          32  32  32  32  32  512  512  512 4196 4196 4196 4196
---
>           1   1   1   1  32  512  512  512 4196 4196 4196 4196
598c602
<          32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
---
>           1   1   1   1  32  512 1024 4096 4096 4096 4096 4096
600c604
<          32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
---
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602c606
<          32  32  32  32  32  64 4096 4096
---
>           1   1   1   1  32  64 4096 4096
604c608
<          32  32  32  32  32 512 4096
---
>           1   1   1   1  32 512 4096
606c610
<          32  32  32  32  32 512 4096
---
>           1   1   1   1  32 512 4096
618a623
> c        5.71e15 *1/5 *10/(74.5744-8.255) =1.72e14
620c625
<          rad fcel d4   erg=d7      wgt=5.71e15
---
>          rad fcel d4   erg=d7      wgt=1.72e14
643,715c648
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<               1:2(-1 -3  0):17   1:2( 0 -3  0):17   1:2( 1 -3  0):17
```

```
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733,804d665
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832,867d692
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877,912d701
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914c703
< si3       8.255   74.5744
---
> si3       64.5744 74.5744
921,968d709
<            5      5      5      5      5      5      5      5      5
<            5      5      5      5      5      5      5      5      5
<            5      5      5      5      5      5      5      5      5
```

```
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
<              5     5     5     5     5     5     5     5     5
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<              5     5     5     5     5     5     5     5     5
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<              6     6     6     6     6     6     6     6     6
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<              6     6     6     6     6     6     6     6     6
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<              6     6     6     6     6     6     6     6     6
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<              6     6     6     6     6     6     6     6     6
<              6     6     6     6     6     6     6     6     6
<              6     6     6     6     6     6     6     6     6
<              6     6     6     6     6     6     6     6     6
993c734
< prdmp    j -60   1
---
> prdmp    j -900  1
1024c765,775
< fs32   -260 -306 -300 -320 -518 -28
---
> fs32   -565 -260 -306 -300 -320
> c                            -565     1.905^2*pi=11.400091
> c  32      515        1      -260     7.06858E+02-1.905^2*pi=695.45708
> c                     2      -306     1.07454E+03
> c                     3      -300     1.44663E+03
> c                     4      -320     6.68469E+01
> c                     5               4.73562E+03
> c     total of segment areas          8.03048E+03
> c     area   of whole surface         8.03048E+03
> sd32      11.40091 695.45708 1074.54 1446.63
>           66.8469 4735.62
1053c804
< fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
---
> fs142 -265 -266 -267 -268 -269 -270 -271 -272
1060,1063c811,823
< fc162   dose at bottom of plug
< f162:p   500
< fs162   -20
< ctme    4000
---
> fc162  Horizontal of grapple
> f162:p  305
> fs162 -19 t
```

```
> fc172  Vertical of grapple
> f172:p  306
> fs172  -511 t
> fc182  dose at bottom of lid
> f182:p  594
> fs182   -306
> fc192   dose at bottom of plug
> f192:p    500
> fs192    -20
> ctme   3600
```

DIFFERENCE BETWEEN inormt AND inormt2

```
68c68,69
<   400     0    -594 -320 -216 (217:300) 21 $ gap
---
>   400     0    -215 -320 -216 (217:300) 21 $ gap
>   401     0    -594 -320 300 215
563,564c564,565
< c           1 2  3 4  400  5  6    7    8    9    10    11    12 13
< imp:p       1 1 32 1    1  1  1    1    1    1     1     1     1  r
---
> c           1 2  3 4  400  401 5   6    7    8    9    10    11   12 13
> imp:p       1 1 32 1    1    1 1   1    1    1    1     1     1    1  r
823c824,827
< ctme   3600
---
> fc202  dose at top of lip
> f202:p   215
> fs202   -320
> ctme   900
```

DIFFERENCE BETWEEN inorm AND idrain

```
1c1
< MCO Final SARP, photon model, lid-on
---
> MCO Final SARP, photon model, lid-on, drain port analysis
69,76c69,84
<     5  304    -8.0       223 -23  57 -52                            $ 1" shield side
<     6  304    -8.0        23 -24  57 -52                            $ 2" shield side
<     7  304    -8.0        24 -25  57 -52    (-584:582:-583)  $ 3" shield side
<     8  304    -8.0        25 -26  33 -52          (582:-583)        $ 4" shield side
<     9  304    -8.0        26 -27  34 -52    (-584:582:-583)         $ 5" shield side
<    10  304    -8.0        27 -28  35 -52    (-584:582:-583)         $ 6" shield side
<    11  304    -8.0        28 -29  36 -52    (-584:582:-583:585)     $ 7" shield side
<    12  304    -8.0  29 -30  37 -52  (-584:585:582:-583)(587:-586) $ 8" shield side
---
>     5  304    -8.0  223 -23  57 -52 (-599:600:58)                 $ 1" shield side
>   105  304    -8.0  223 -23  57 -58 599 -600                      $ 1" shield side
>     6  304    -8.0   23 -24  57 -52 (-599:600:58)                 $ 2" shield side
>   106  304    -8.0   23 -24  57 -58 599 -600 (-588:589)           $ 2" shield side
>     7  304    -8.0   24 -25  57 -52  (-599:600:58) $ 3" shield side
>   107  304    -8.0   24 -25  57 -58   (-588:589) 599 -600   $ 3" shield side
>     8  304    -8.0   25 -26  33 -52  (582:-583) (-599:600:58)     $ 4" shield side
>   108  304    -8.0   25 -26  33 -58        (-588:589)  599 -600     $ 4" shield side
>     9  304    -8.0   26 -27  34 -52   (-584:582:-583) (-599:600:58)   $ 5" shield side
>   109  304    -8.0   26 -27  34 -58   (-588:589)  599 -600     $ 5" shield side
>    10  304    -8.0   27 -28  35 -52   (-584:582:-583) (-599:600:58)   $ 6" shield side
>   110  304    -8.0   27 -28  35 -58   (-588:589) 599 -600      $ 6" shield side
>    11  304    -8.0   28 -29  36 -52    (-599:600:58)  $ 7" shield side
>   111  304    -8.0   28 -29  36 -58  (-588:589) 599 -600    $ 7" shield side
>    12  304    -8.0   29 -30  37 -52  (587:-586) (-599:600:58)$ 8" shield side
>   112  304    -8.0   29 -30  37 -58  (-588:589)(587:-586) 599 -600  $ 8" shield side
92,93c100,101
<    31  7 0.0000512    38 -256 -596 (30)              $ Air, side, out to 1m
<    32, 7 0.0000512    61 -256 -38                    $ Air, bottom, down to 1m
---
>    31  7 0.0000512    58 -256 -596 (30)              $ Air, side, out to 1m
>    32  7 0.0000512    61 -258 -58 (30:-38)           $ Air, bottom, down to 1m
95c103
<    34  7 0.0000512    61 -257 -596 (256)             $ Air, side, out to 2m
---
>    34  7 0.0000512    58 -257 -596 (256)             $ Air, side, out to 2m
98c106
<    37  7 0.0000512    61 -258 -596 (257)             $ Air, side, out to 3m
---
>    37  7 0.0000512    58 -258 -596 (257)             $ Air, side, out to 3m
104c112
<    44   304    -8.0         -57 33       -25  (-584:585:582:-583)  $ 1" shield bottom
---
>    44   304    -8.0         -57 33       -25  (-588:589)  $ 1" shield bottom
106c114
<    45   304    -8.0         -33 34       -26  (-584:585:582:-583)  $ 2" shield bottom
---
>    45   304    -8.0         -33 34       -26  (-588:589)  $ 2" shield bottom
108,109c116,117
<    46   304    -8.0         -34 35       -27  (-584:585:582:-583)  $ 3" shield bottom
<    47   304    -8.0         -35 36       -28  (-584:585:582:-583)  $ 4" shield bottom
---
>    46   304    -8.0         -34 35       -27  (-588:589)  $ 3" shield bottom
>    47   304    -8.0         -35 36       -28  (-588:589)  $ 4" shield bottom
121c129
<              (-540:551:421:-541)                                $(546:-420)to 546,
---
>              (-540:551:421)                                 $(546:-420)to 546,
167a176
>   568  304  -8.0  588 -589 -586 (-584:582:585)(590:584)
238,239c247,248
<   650  304 -8.0  207 -208 32 -58        $ MCO pipe wall from bottom of MCO
<   651  304 -8.0  207 -208 58 -59        $ MCO pipe wall from bottom of MCO
---
>   650  304 -8.0  207 -208 32 -58 599 -600 $ MCO pipe wall from bottom of MCO
>   651  304 -8.0  207 -208 32 -59 (-599:600:58)$ MCO pipe wall from bottom of MCO
251,252c260,261
<   670  304 -8.0  208 -209 32 -58        $ MCO pipe wall from bottom of MCO
<   671  304 -8.0  208 -209 58 -59        $ MCO pipe wall from bottom of MCO
```

```
---
>   670  304 -8.0  208 -209 32 -58 599 -600 $ MCO pipe wall from bottom of MCO
>   671  304 -8.0  208 -209 32 -59 (-599:600:58)$ MCO pipe wall from bottom of MCO
264,265c273,274
<   690  304 -8.0  209 -21 32 -58          $ MCO pipe wall from bottom of MCO
<   691  304 -8.0  209 -21 58 -59          $ MCO pipe wall from bottom of MCO
---
>   690  304 -8.0  209 -21 32 -58 599 -600 $ MCO pipe wall from bottom of MCO
>   691  304 -8.0  209 -21 32 -59 (-599:600:58) $ MCO pipe wall from bottom of MCO
277,278c286,287
<   710  304 -8.0  22 -221 57 -58      $ 1" side shield from bottom of MCO
<   711  304 -8.0  22 -221 58 -59      $ 1" side shield from bottom of MCO
---
>   710  304 -8.0  22 -221 57 -58 599 -600 $ 1" side shield from bottom of MCO
>   711  304 -8.0  22 -221 57 -59 (-599:600:58) $ 1" side shield from bottom of MCO
286,287c295,296
<   720  304 -8.0  221 -222 57 -58         $ 1" side shield from bottom of MCO
<   721  304 -8.0  221 -222 58 -59         $ 1" side shield from bottom of MCO
---
>   720  304 -8.0  221 -222 57 -58 599 -600 $ 1" side shield from bottom of MCO
>   721  304 -8.0  221 -222 57 -59 (-599:600:58) $ 1" side shield from bottom of MCO
294,295c303,304
<   730  304 -8.0  222 -223 57 -58         $ 1" side shield from bottom of MCO
<   731  304 -8.0  222 -223 58 -59         $ 1" side shield from bottom of MCO
---
>   730  304 -8.0  222 -223 57 -58 599 -600 $ 1" side shield from bottom of MCO
>   731  304 -8.0  222 -223 57 -59 (-599:600:58) $ 1" side shield from bottom of MCO
442c451
<   562  3  px 8.25                       $ outer edge of E2 vent lower segment:3  px -24.90  to 3 px 8.25
---
>   562  3  px 8.25                  $ outer edge of E2 vent lower segment:3  px -24.90  to 3 px 8.25
447,448c456,457
<   582  c/x     0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
< c 582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
---
> c 582  c/x     0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
>   582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
453,454c462,465
<   587  c/x  0 -3.4036 0.0001
< c 587  c/x  0 -3.4036 10.16
---
> c 587  c/x  0 -3.4036 0.0001
>   587  c/x  0 -3.4036 10.16
>   588  px  35.5473  $ suface for scattering region around drain port
>   589  c/x  0 -3.4036 6.5024  $ surface for scattering region around drain port
456,457c467,468
<   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
< c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
> c 590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
>   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
459,460c470,471
<   592  cz  .0001  $ Vertical drain pipe
< c 592  cz  .8001  $ Vertical drain pipe
---
> c 592  cz  .0001  $ Vertical drain pipe
>   592  cz  .8001  $ Vertical drain pipe
465a477,478
>   599  p  1 1 0 0
>   600  p  -1 1 0 0
557,564c570,579
< c           (procedure suggested for dxtran use)
< phys:p      j 1
< c           1 2  3 4  400  5  6   7   8   9   10   11   12 13
< imp:p       1 1 32 1    1 32 64 128 156 512 1024 2048 4096  r
< c         14 15 16 17 18 19 20 21 22 23 24 25 26
<             0  1  1  1  1  1  1  1  1  1  1  1  1
< c           30   31    32     33   34   35     36   37   38
<       131072 4096  8192 131072 4096 4096 131072 4096 4096
---
> c           (procedure suggested for point detectors and dxtran use)
> phys:p      j 1  1
> c           1 2  3 4  400  5 105 6 106 7 107  8 108  9 109
> imp:p       1 1 32 1    1  2  32 4  64 8 128 16 256 32 512
> c         10  110  11  111  12  112  13
>           64 1024 128 2048 256 4096 256
```

```
> c      14 15 16 17 18 19 20 21 22 23 24
>         0  1  1  1  1  1  1  1  1  1  1
> c      25 26    30   31    32    33   34   35    36   37   38
>         1  1     1 4096  8192     1 4096 4096     1 4096 4096
567,568c582,583
< c     500 501 502 503 504 505  506  507  508  509  510
<         1  32  64 128 256 512 1024 4096 8192 8192 8192
---
> c     500 501 502 503 504 505  506  507  508  509  510
>         1   1   1   1   1   1    1    1    1    1    1
570c585
<      8192  8192  8192
---
>         1     1     1
573,574c588,589
< c     540   541   542   543 544 545 546   547 548 549
<         1 16384 16384 16384   1   1   1 16384   1   1
---
> c     540   541   542   543 544 545 546   547 548 549
>         1     1     1     1   1   1   1     1   1   1
577,578c592,593
< c     562 563 565 566 567
<         1   1   1   1   1
---
> c     562 563 565 566 567   568
>         1   1   1   1   1 16384
581,582c596,597
< c     580   581   582    583  584  585
<         1 32768 65536 131072 4096    1
---
> c     580   581   582    583  584  585
>         1     1     1      1    1    1
584c599
<         32 256 256 512 1024 2048 4096 4096 4096 4096
---
>          1   1   1   1    1    1    1    1    1    1
586c601
<       128 128  64 128 256 512 1024 1024 1024
---
>         1   1   1   1   1   1    1    1    1
588c603
<       256 256 256 256 512 1024 2048 4096
---
>         1   1   1   1   1    1    1    1
590c605
<       512 512 512 512 512 1024 2048 4096
---
>         1   1   1   1   1    1    1    1
592c607
<      1024 1024 1024 1024 1024 1024 2048 4096
---
>         1    1    1    1    1    1    1    1
594c609
<      2048 2048 2048 2048 2048 2048 2048 4096
---
>         1    1    1    1    1    1    1    1
596c611
<        32  32  32  32  32  512  512  512 4196 4196 4196 4196
---
>        32   1   1   1   1    1    1    1    1    1    1    1
598c613
<        32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
---
>        32   1   1   1   1    1    1    1    1    1    1    1
600c615
<        32  32  32  32  32  512 1024 4096 4096 4096 4096 4096
---
>        32   1   1   1   1    1    1    1    1    1    1    1
602c617
<        32  32  32  32  32   64 4096 4096
---
>        32   1   1   1   1    1    1    1
604c619
<        32  32  32  32  32  512 4096
---
>        32   1   1   1   1    1    1
```

```
606c621
<        32  32  32  32  32 512 4096
---
>        32   1   1   1   1   1   1
618d632
< c
912a927,1016
> sb1      d  4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
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>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            4.210  4.210  4.210  4.210  4.210  4.210
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            42.10  42.10  42.10  42.10  42.10  42.10
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
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>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
>            1.962  1.962  1.962  1.962  1.962  1.962
```

```
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          1.962  1.962  1.962  1.962  1.962  1.962
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
>          19.62  19.62  19.62  19.62  19.62  19.62
993c1097
< prdmp    j -60  1
---
> prdmp    j -600  1
995,1063c1099,1117
< f4:p  (13 30 31 32 33 34 35 36 37 38 580)
< fs4   -3000000  44 29 2
<       601 602 603 604 605 606 607 608 609 610
<       611 612 613 614 615 616 617 618 619 620
<       621 622 623 624 625 626 627 628 629 630
<       631 632 633 634 635 636 637 638 639 640
<       641 642 643 644
<       701 702 703 704 705 706 707 708 709 710
<       711 712 713 714 715 716 717 718 719 720
<       721 722 723 724 725 726 727 728 729
<       583 583
< fc12  Dip Tube Port contact, 1m, 2m, 6m
< f12:p  515 250 251 252
< fs12   -543 -535 -597 -537
< c    r=0.635->1.2668 r=3.2->30.9031 r=5.599->66.3153 r=7.1311->61.2730
< sd12      1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
< fc22  Short Draw Port contact, 1m, 2m, 6m
< f22:p 515 250 251 252
< fs22   -538 -534 -598 -536
< c    r=1.27->5.0671 r=3.2->27.1028 r=5.599->66.3153 r=7.1311->61.2730
< sd22     5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
< fc32  Top dose, contact, lid
< f32:p  515
< fs32   -260 -306 -300 -320 -518 -28
< fc52  Top dose
< f52:p  250 251 252
< fs52   -260 -306 -300 -320 -518 -30 -709 -710 -711
< fc62  Within gap, bottom of lid top
< f62:p  594
< fs62  -300
< fc72  Side of lid
< f72:p  518
< fs72  -510
< fc82  Top of lid bottom
< f82:p  519
< fs82   -27
< c    top of gap will not work for lid-on
< c    fc92   Top of gap
< c    f92:p  215
< c    fs92  -300 -320
< fc112  Next to lip
< f112:p   596
< fs112  -595 -27
< fc122  Side of plug
```

```
< f122:p  300
< fs122  -596 -215 -508
< fc132  Bottom
< f132:p  38 61
< fs132   -259 -21
< e132    .01 .1 .2 .5 1 2 5 10 20
< fc142  Side
< f142:p  30 256 257 258
< fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
< e142    .01 .1 .2 .5 1 2 5 10 20
< c      fc152  Dose at drain port cover
< c      f152:p  586
< c      fs152  -582
< c      c  r=3.9624->49.3249 r=10.16->274.9679
< c      sd152   49.3249 274.9679
< fc162   dose at bottom of plug
< f162:p   500
< fs162   -20
< ctme    4000
---
> fc152   Dose at drain port cover
> f152:p  586
> fs152  -582
> c  r=3.9624->49.3249 r=10.16->274.9679
> sd152   49.3249 274.9679
> fc295          200cm      up            0 degrees
> f295:p  250.5587       0  -3.4036       3
> fc305          200cm      up           -5 degrees
> f305:p  249.7976       0 -20.8347       3
> fc315          200cm      up          -10 degrees
> f315:p  247.5203       0 -38.1332       3
> fc325          200cm      up      -12.8842 degrees calculated from z pos
> f325:p  245.5232       0     -48       3      $  -50 close to ground level
> fc345          600cm      up            0 degrees
> f345:p  650.5587       0 -3.4036        3
> fc355          600cm      up      -4.26257 degrees calculated from z pos
> f355:p   648.899       0     -48       3      $  -50 close to ground level
> ctme  4000
>
```

DIFFERENCE BETWEEN idrain AND idrainc

```
1c1
< MCO Final SARP, photon model, lid-on, drain port analysis
---
> MCO Final SARP, photon model, lid-on, drain port analysis, contact
1104,1115d1103
< fc295        200cm     up            0 degrees
< f295:p  250.5587     0  -3.4036       3
< fc305        200cm     up           -5 degrees
< f305:p  249.7976     0 -20.8347       3
< fc315        200cm     up          -10 degrees
< f315:p  247.5203     0 -38.1332       3
< fc325        200cm     up       -12.8842 degrees calculated from z pos
< f325:p  245.5232     0      -48      3      $  -50 close to ground level
< fc345        600cm     up            0 degrees
< f345:p  650.5587     0 -3.4036       3
< fc355        600cm     up       -4.26257 degrees calculated from z pos
< f355:p   648.899     0      -48      3      $  -50 close to ground level
```

DIFFERENCE BETWEEN inorm AND inormc

```
1c1
< MCO Final SARP, photon model, lid-on
---
> MCO Final SARP, photon model, lid-on, concrete ground
96c96
<    35  221  -1.67     254 -257 -61                  $ Air, bottom, down to 2m
---
>    35  210  -2.258    254 -257 -61                  $ Air, bottom, down to 2m
99c99
<    38  221  -1.67     581 -578 -61 (-254:257)       $ Air, bottom, down to 3m
---
>    38  210  -2.258    581 -578 -61 (-254:257)       $ Air, bottom, down to 3m
610c610
< m3         40000.60c  -1.00000                              $ zirc cladding
---
> m3         40000.50c  -1.00000                              $ zirc cladding
614,617c614,616
< m221     8016.50c -0.511 14000.50c -0.2782 20000.50c -0.0717      $ HWVP Dirt
<          26000.55c -0.1091 13027.50c -0.08326 12000.50c -0.03142
<          19000.50c -0.01155 11023.50c -0.02022 22000.50c -0.01655
<          25055.50c -0.001781 15031.50c -0.0024
---
> c      Hanford ordinary concrete
> m210  1001.50c 0.0642  8016.50c 0.5916  14000.50c 0.2405
>       20000.50c 0.0738  26000.55c 0.0299
1063c1062
< ctme    4000
---
> ctme   1800
```

DIFFERENCE BETWEEN inorm AND iacc

```
1,66c1,4
< MCO Final SARP, photon model, lid-on
<     1    0   -20   31   -52          fill=1
< c      main lattice along cask length
<     2    0   -1   2  -3   4  -5   6  -54   55  u=1   lat=2
<                fill=-5:5  -5:5   0:4
<           2   2   2   2   2   2   2   2   2   2   2   $  1
<           2   2   2   2   2   2   3   3   3   2   2   $  2
<           2   2   2   2   3   3   3   3   3   3   2   $  3
<           2   2   2   3   3   3   3   3   3   3   2   $  4
<           2   2   3   3   3   3   3   3   3   3   2   $  5
<           2   2   3   3   3   2   3   3   3   2   2   $  6  level 1
<           2   3   3   3   3   3   3   3   3   2   2   $  7
<           2   3   3   3   3   3   3   3   2   2   2   $  8
<           2   3   3   3   3   3   3   2   2   2   2   $  9
<           2   2   3   3   3   2   2   2   2   2   2   $ 10
<           2   2   2   2   2   2   2   2   2   2   2   $ 11
< c        -5  -4  -3  -2  -1   0   1   2   3   4   5
<           2   2   2   2   2   2   2   2   2   2   2   $  1
<           2   2   2   2   2   2   3   3   3   2   2   $  2
<           2   2   2   2   3   3   3   3   3   3   2   $  3
<           2   2   2   3   3   3   3   3   3   3   2   $  4
<           2   2   3   3   3   3   3   3   3   3   2   $  5
<           2   2   3   3   3   2   3   3   3   2   2   $  6  level 2
<           2   3   3   3   3   3   3   3   3   2   2   $  7
<           2   3   3   3   3   3   3   3   2   2   2   $  8
<           2   3   3   3   3   3   3   2   2   2   2   $  9
<           2   2   3   3   3   2   2   2   2   2   2   $ 10
<           2   2   2   2   2   2   2   2   2   2   2   $ 11
< c        -5  -4  -3  -2  -1   0   1   2   3   4   5
<           2   2   2   2   2   2   2   2   2   2   2   $  1
<           2   2   2   2   2   2   3   3   3   2   2   $  2
<           2   2   2   2   3   3   3   3   3   3   2   $  3
<           2   2   2   3   3   3   3   3   3   3   2   $  4
<           2   2   3   3   3   3   3   3   3   3   2   $  5
<           2   2   3   3   3   2   3   3   3   2   2   $  6  level 3
<           2   3   3   3   3   3   3   3   3   2   2   $  7
<           2   3   3   3   3   3   3   3   2   2   2   $  8
<           2   3   3   3   3   3   3   2   2   2   2   $  9
<           2   2   3   3   3   2   2   2   2   2   2   $ 10
<           2   2   2   2   2   2   2   2   2   2   2   $ 11
< c        -5  -4  -3  -2  -1   0   1   2   3   4   5
<           2   2   2   2   2   2   2   2   2   2   2   $  1
<           2   2   2   2   2   2   3   3   3   2   2   $  2
<           2   2   2   2   3   3   3   3   3   3   2   $  3
<           2   2   2   3   3   3   3   3   3   3   2   $  4
<           2   2   3   3   3   3   3   3   3   3   2   $  5
<           2   2   3   3   3   2   3   3   3   2   2   $  6  level 4
<           2   3   3   3   3   3   3   3   3   2   2   $  7
<           2   3   3   3   3   3   3   3   2   2   2   $  8
<           2   3   3   3   3   3   3   2   2   2   2   $  9
<           2   2   3   3   3   2   2   2   2   2   2   $ 10
<           2   2   2   2   2   2   2   2   2   2   2   $ 11
< c        -5  -4  -3  -2  -1   0   1   2   3   4   5
<           2   2   2   2   2   2   2   2   2   2   2   $  1
<           2   2   2   2   2   2   3   3   3   2   2   $  2
<           2   2   2   2   3   3   3   3   3   3   2   $  3
<           2   2   2   3   3   3   3   3   3   3   2   $  4
<           2   2   3   3   3   3   3   3   3   3   2   $  5
<           2   2   3   3   3   2   3   3   3   2   2   $  6  level 5
<           2   3   3   3   3   3   3   3   3   2   2   $  7
<           2   3   3   3   3   3   3   3   2   2   2   $  8
<           2   3   3   3   3   3   3   2   2   2   2   $  9
<           2   2   3   3   3   2   2   2   2   2   2   $ 10
<           2   2   2   2   2   2   2   2   2   2   2   $ 11
< c        -5  -4  -3  -2  -1   0   1   2   3   4   5
<    3   304    -8.0      (20:-31)     -207  32  -52          $ MCO pipe wall
---
> MCO Final SARP, photon model, accident condition
>     1    0   -20   39  -52     $ air above fuel region
>     2    5  -18.77  -20  32 -39    $ fuel region
>     3   304    -8.0      (20:-32)     -207  32  -52          $ MCO pipe wall
351,352c289
```

```
<   31      pz        8.25501          $ bottom of fuel region
<   32      pz        8.255            $ 1.76" + 1.49" above bottom
---
>   32      pz        4.4705           $ squished spacer
358a296
>   39      pz      133.9246           $ top of scrunched fuel
382,391c320,328
< c   bottom of fuel = 8.255
< c   center of fuel: (8.255+347.3704)/2 = 177.8127
<   265  pz   72.8127 $ 177.8127 -105
<   266  pz  102.8127 $ 177.8127 - 75
<   267  pz  132.8127 $ 177.8127 - 45
<   268  pz  162.8127 $ 177.8127 - 15
<   269  pz  192.8127 $ 177.8127 + 15
<   270  pz  222.8127 $ 177.8127 + 45
<   271  pz  252.8127 $ 177.8127 + 75
<   272  pz  282.8127 $ 177.8127 +105
---
> c   bottom of fuel = 4.4704
> c   top of fuel = 133.9246
> c   center of fuel: (133.9246-4.4704)/2 = 64.7271
>   266  pz   24.7271 $ 64.7271  - 40
>   267  pz   44.7271 $ 64.7271  - 20
>   268  pz   59.7271 $ 64.7271  - 5
>   269  pz   69.7271 $ 64.7271  + 5
>   270  pz   84.7271 $ 64.7271  + 20
>   271  pz  104.7271 $ 64.7271  + 40
447,448c384
<   582  c/x     0 -3.4036 0.0001     $ 4.79" from bottom of cask, 3.12" dia
< c 582  c/x     0 -3.4036 3.9624     $ 4.79" from bottom of cask, 3.12" dia
---
>   582  c/x     0 -3.4036 3.9624     $ 4.79" from bottom of cask, 3.12" dia
453,454c389
<   587  c/x  0 -3.4036 0.0001
< c 587  c/x  0 -3.4036 10.16
---
>   587  c/x  0 -3.4036 10.16
456,457c391
<   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
< c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
>   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
459,460c393
<   592  cz  .0001  $ Vertical drain pipe
< c 592  cz  .8001  $ Vertical drain pipe
---
>   592  cz  .8001  $ Vertical drain pipe
559,560c492,493
< c           1 2  3 4  400  5  6   7   8   9   10   11   12 13
< imp:p       1 1 32 1     1 32 64 128 156 512 1024 2048 4096  r
---
> c           1 2   3 4  400  5  6   7   8   9   10   11   12 13
> imp:p       1 1  32 1     1 32 64 128 156 512 1024 2048 4096  r
619,620c552,553
< sdef     cel=d1        pos=0 0 0    axs=0 0 1 ext=d3
<          rad fcel d4   erg=d7       wgt=5.71e15
---
> sdef     pos=0 0 0    axs=0 0 1 ext=d3
>          rad d4    erg=d7      wgt=5.71e15
643,978c576,578
< si1      l    1:2( 1 -4  0):17   1:2( 2 -4  0):17   1:2( 3 -4  0):17
<               1:2(-1 -3  0):17   1:2( 0 -3  0):17   1:2( 1 -3  0):17
<               1:2( 2 -3  0):17   1:2( 3 -3  0):17   1:2( 4 -3  0):17
<               1:2(-2 -2  0):17   1:2(-1 -2  0):17   1:2( 0 -2  0):17
<               1:2( 1 -2  0):17   1:2( 2 -2  0):17   1:2( 3 -2  0):17
<               1:2( 4 -2  0):17   1:2(-3 -1  0):17   1:2(-2 -1  0):17
<               1:2(-1 -1  0):17   1:2( 0 -1  0):17   1:2( 1 -1  0):17
<               1:2( 2 -1  0):17   1:2( 3 -1  0):17   1:2( 4 -1  0):17
<               1:2(-3  0  0):17   1:2(-2  0  0):17   1:2(-1  0  0):17
<               1:2( 1  0  0):17   1:2( 2  0  0):17   1:2( 3  0  0):17
<               1:2(-4  1  0):17   1:2(-3  1  0):17   1:2(-2  1  0):17
<               1:2(-1  1  0):17   1:2( 0  1  0):17   1:2( 1  1  0):17
<               1:2( 2  1  0):17   1:2( 3  1  0):17   1:2(-4  2  0):17
<               1:2(-3  2  0):17   1:2(-2  2  0):17   1:2(-1  2  0):17
<               1:2( 0  2  0):17   1:2( 1  2  0):17   1:2( 2  2  0):17
<               1:2(-4  3  0):17   1:2(-3  3  0):17   1:2(-2  3  0):17
```

```
<    1:2(-1  3  0):17   1:2( 0  3  0):17   1:2( 1  3  0):17
<    1:2(-3  4  0):17   1:2(-2  4  0):17   1:2(-1  4  0):17
<    1:2( 1 -4  1):17   1:2( 2 -4  1):17   1:2( 3 -4  1):17
<    1:2(-1 -3  1):17   1:2( 0 -3  1):17   1:2( 1 -3  1):17
<    1:2( 2 -3  1):17   1:2( 3 -3  1):17   1:2( 4 -3  1):17
<    1:2(-2 -2  1):17   1:2(-1 -2  1):17   1:2( 0 -2  1):17
<    1:2( 1 -2  1):17   1:2( 2 -2  1):17   1:2( 3 -2  1):17
<    1:2( 4 -2  1):17   1:2(-3 -1  1):17   1:2(-2 -1  1):17
<    1:2(-1 -1  1):17   1:2( 0 -1  1):17   1:2( 1 -1  1):17
<    1:2( 2 -1  1):17   1:2( 3 -1  1):17   1:2( 4 -1  1):17
<    1:2(-3  0  1):17   1:2(-2  0  1):17   1:2(-1  0  1):17
<    1:2( 1  0  1):17   1:2( 2  0  1):17   1:2( 3  0  1):17
<    1:2(-4  1  1):17   1:2(-3  1  1):17   1:2(-2  1  1):17
<    1:2(-1  1  1):17   1:2( 0  1  1):17   1:2( 1  1  1):17
<    1:2( 2  1  1):17   1:2( 3  1  1):17   1:2(-4  2  1):17
<    1:2(-3  2  1):17   1:2(-2  2  1):17   1:2(-1  2  1):17
<    1:2( 0  2  1):17   1:2( 1  2  1):17   1:2( 2  2  1):17
<    1:2(-4  3  1):17   1:2(-3  3  1):17   1:2(-2  3  1):17
<    1:2(-1  3  1):17   1:2( 0  3  1):17   1:2( 1  3  1):17
<    1:2(-3  4  1):17   1:2(-2  4  1):17   1:2(-1  4  1):17
<    1:2( 1 -4  2):17   1:2( 2 -4  2):17   1:2( 3 -4  2):17
<    1:2(-1 -3  2):17   1:2( 0 -3  2):17   1:2( 1 -3  2):17
<    1:2( 2 -3  2):17   1:2( 3 -3  2):17   1:2( 4 -3  2):17
<    1:2(-2 -2  2):17   1:2(-1 -2  2):17   1:2( 0 -2  2):17
<    1:2( 1 -2  2):17   1:2( 2 -2  2):17   1:2( 3 -2  2):17
<    1:2( 4 -2  2):17   1:2(-3 -1  2):17   1:2(-2 -1  2):17
<    1:2(-1 -1  2):17   1:2( 0 -1  2):17   1:2( 1 -1  2):17
<    1:2( 2 -1  2):17   1:2( 3 -1  2):17   1:2( 4 -1  2):17
<    1:2(-3  0  2):17   1:2(-2  0  2):17   1:2(-1  0  2):17
<    1:2( 1  0  2):17   1:2( 2  0  2):17   1:2( 3  0  2):17
<    1:2(-4  1  2):17   1:2(-3  1  2):17   1:2(-2  1  2):17
<    1:2(-1  1  2):17   1:2( 0  1  2):17   1:2( 1  1  2):17
<    1:2( 2  1  2):17   1:2( 3  1  2):17   1:2(-4  2  2):17
<    1:2(-3  2  2):17   1:2(-2  2  2):17   1:2(-1  2  2):17
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<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
<             6     6     6     6     6     6     6     6     6
```

```
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
<            6     6     6     6     6     6     6     6     6
< si5       2.2110   3.0163
< sp5      -21     1
< si6        .6591   1.5481
< sp6      -21     1
---
> si3       4.4704   133.9246
> si4       0   29.21
> sp4      -21     1
992,993c592,593
< c         -60: dump runtpe every 60 min
< prdmp     j -60  1
---
> c         -600: dump runtpe every 600 min
> prdmp     j -600  1
995,1046d594
< f4:p  (13 30 31 32 33 34 35 36 37 38 580)
< fs4   -3000000  44 29 2
<       601 602 603 604 605 606 607 608 609 610
<       611 612 613 614 615 616 617 618 619 620
<       621 622 623 624 625 626 627 628 629 630
<       631 632 633 634 635 636 637 638 639 640
<       641 642 643 644
<       701 702 703 704 705 706 707 708 709 710
<       711 712 713 714 715 716 717 718 719 720
<       721 722 723 724 725 726 727 728 729
<       583 583
< fc12  Dip Tube Port contact, 1m, 2m, 6m
< f12:p  515 250 251 252
< fs12   -543 -535 -597 -537
< c    r=0.635->1.2668 r=3.2->30.9031 r=5.599->66.3153 r=7.1311->61.2730
< sd12      1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
< fc22  Short Draw Port contact, 1m, 2m, 6m
< f22:p 515 250 251 252
< fs22   -538 -534 -598 -536
< c     r=1.27->5.0671 r=3.2->27.1028 r=5.599->66.3153 r=7.1311->61.2730
< sd22     5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
< fc32  Top dose, contact, lid
< f32:p  515
< fs32   -260 -306 -300 -320 -518 -28
< fc52  Top dose
< f52:p  250 251 252
< fs52   -260 -306 -300 -320 -518 -30 -709 -710 -711
< fc62  within gap, bottom of lid top
< f62:p  594
< fs62  -300
< fc72  Side of lid
< f72:p  518
< fs72  -510
< fc82  Top of lid bottom
< f82:p  519
< fs82   -27
< c     top of gap will not work for lid-on
< c     fc92   Top of gap
< c     f92:p  215
< c     fs92  -300 -320
< fc112  Next to lip
< f112:p   596
< fs112  -595 -27
```

```
< fc122  Side of plug
< f122:p  300
< fs122  -596 -215 -508
1050d597
< e132   .01 .1 .2 .5 1 2 5 10 20
1052,1059c599,605
< f142:p  30 256 257 258
< fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
< e142   .01 .1 .2 .5 1 2 5 10 20
< c      fc152   Dose at drain port cover
< c      f152:p  586
< c      fs152  -582
< c      c  r=3.9624->49.3249 r=10.16->274.9679
< c      sd152   49.3249 274.9679
---
> f142:p  30
> fs142    -32 -266 -267 -268 -269 -270 -271 -39
> fc152   Dose at drain port cover
> f152:p  586
> fs152  -582
> c  r=3.9624->49.3249 r=10.16->274.9679
> sd152   49.3249 274.9679
1063c609
< ctme    4000
---
> ctme    900
```

DIFFERENCE BETWEEN idry AND idryc

```
1c1
< MCO Final SARP, neutron model, lid-on
---
> MCO Final SARP, neutron model, lid-on, concrete ground
96c96
<   35  221  -1.67    254 -257 -61                    $ Air, bottom, down to 2m
---
>   35  210  -2.258   254 -257 -61                    $ Air, bottom, down to 2m
99c99
<   38  221  -1.67    581 -578 -61 (-254:257)         $ Air, bottom, down to 3m
---
>   38  210  -2.258   581 -578 -61 (-254:257)         $ Air, bottom, down to 3m
447c447,448
<   582  c/x    0 -3.4036 3.9624     $ 4.79" from bottom of cask, 3.12" dia
---
>   582  c/x    0 -3.4036 0.0001     $ 4.79" from bottom of cask, 3.12" dia
> c 582  c/x    0 -3.4036 3.9624     $ 4.79" from bottom of cask, 3.12" dia
452c453,454
<   587  c/x  0 -3.4036 10.16
---
>   587  c/x  0 -3.4036 0.0001
> c 587  c/x  0 -3.4036 10.16
454c456,457
<   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
>   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
> c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
456c459,460
<   592  cz  .8001  $ Vertical drain pipe
---
>   592  cz  .0001  $ Vertical drain pipe
> c 592  cz  .8001  $ Vertical drain pipe
606,609c610,611
< m221      8016.50c -0.511 14000.50c -0.2782 20000.50c -0.0717     $ HWVP Dirt
<           26000.55c -0.1091 13027.50c -0.08326 12000.50c -0.03142
<           19000.50c -0.01155 11023.50c -0.02022 22000.50c -0.01655
<           25055.50c -0.001781 15031.50c -0.0024
---
> m210  1001.50c 0.0642  8016.50c 0.5916  14000.50c 0.2405
>       20000.50c 0.0738  26000.55c 0.0299
1040,1045c1042,1047
< fc152   Dose at drain port cover
< f152:n  586
< fs152  -582
< c  r=3.9624->49.3249 r=10.16->274.9679
< sd152   49.3249 274.9679
< ctme    2400
---
> c      fc152   Dose at drain port cover
> c      f152:p  586
> c      fs152  -582
> c      c  r=3.9624->49.3249 r=10.16->274.9679
> c      sd152   49.3249 274.9679
> ctme   360
```

DIFFERENCE BETWEEN idry AND idryt

```
1c1
< MCO Final SARP, neutron model, lid-on
---
> MCO Final SARP, neutron model, lid-on, top
447c447,448
<   582  c/x    0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
---
>   582  c/x    0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
> c 582  c/x    0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
452c453,454
<   587  c/x  0 -3.4036 10.16
---
>   587  c/x  0 -3.4036 0.0001
> c 587  c/x  0 -3.4036 10.16
454c456,457
<   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
>   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
> c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
456c459,460
<   592  cz  .8001  $ Vertical drain pipe
---
>   592  cz  .0001  $ Vertical drain pipe
> c 592  cz  .8001  $ Vertical drain pipe
551,552c555,556
< c          1 2  3 4  400  5  6   7   8   9   10   11   12 13
< imp:n      8 1  8 8    8  8  8   8   8   8    8    8    8  8
---
> c          1 2  3 4  400 5  6   7   8   9   10   11   12 13
> imp:n      1 1  1 1    1 1  1   1   1   1    1    1    1  1
554c558
<          0  8  8  8  8  8  8  8  8  8  8  8  1
---
>          0  1  1  1  1  1  1  1  1  1  1  1  1
556c560
<           8     8     8      8     8     8      8     8     8
---
>          32     1     1     32     1     1     32     1     1
558c562
<         8  8    8  8    8    8     8     8     8     8
---
>         1  1    1  1    1    1     1     1     1     1
560c564
<          8   8   8   8   8   8    8    8    8    8     8
---
>          1  32   r   r   r   r    r    r    r    r     r
562c566
<          8      8      8
---
>          r      r     32
564c568
<          8   8   8   8   8   8   8
---
>         32  32   r   r   r   r   r
566c570
<          8      8      8     8   8   8   8     8   8   8
---
>          r      r      r     r   r   r   r     r   r   r
568c572
<          8
---
>          r
570c574
<          8   8   8   8   8
---
>          r   r   r   r   r
572c576
<          8   8
---
>          r   r
574c578
<          8     8     8      8    8    8
---
```

```
>          r    r    r    r    r    r
576c580
<          8    8    8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r    r    r
578c582
<          8    8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r    r
580c584
<          8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r
582c586
<          8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r
584c588
<          8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r
586c590
<          8    8    8    8    8    8    8    8
---
>          r    r    r    r    r    r    r    r
588c592
<          8    8    8    8    8    8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r    r    r    r    r    r
590c594
<          8    8    8    8    8    8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r    r    r    r    r    r
592c596
<          8    8    8    8    8    8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r    r    r    r    r    r
594c598
<          8    8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r    r
596c600
<          8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r
598c602
<          8    8    8    8    8    8    8
---
>          1    1    1    1    32   r    r
977,978c981,982
< c          -60: dump runtpe every 60 min
< prdmp      j -60  1
---
> c          -60: dump runtpe every 600 min
> prdmp      j -600  1
1040,1045c1044,1049
< fc152   Dose at drain port cover
< f152:n  586
< fs152   -582
< c  r=3.9624->49.3249 r=10.16->274.9679
< sd152   49.3249 274.9679
< ctme    2400
---
> c      fc152   Dose at drain port cover
> c      f152:p  586
> c      fs152   -582
> c      c  r=3.9624->49.3249 r=10.16->274.9679
> c      sd152   49.3249 274.9679
> ctme   900
```

DIFFERENCE BETWEEN idryt AND idrytp

```
984,1049c984,992
< f4:n  (13 30 31 32 33 34 35 36 37 38 580)
< fs4   -3000000  44 29 2
<        601 602 603 604 605 606 607 608 609 610
<        611 612 613 614 615 616 617 618 619 620
<        621 622 623 624 625 626 627 628 629 630
<        631 632 633 634 635 636 637 638 639 640
<        641 642 643 644
<        701 702 703 704 705 706 707 708 709 710
<        711 712 713 714 715 716 717 718 719 720
<        721 722 723 724 725 726 727 728 729
<        583 583
< fc12  Dip Tube Port contact, 1m, 2m, 6m
< f12:n  515 250 251 252
< fs12   -543 -535 -597 -537
< c    r=0.635->1.2668 r=3.2->30.9031 r=5.599->66.3153 r=7.1311->61.2730
< sd12      1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
< fc22  Short Draw Port contact, 1m, 2m, 6m
< f22:n 515 250 251 252
< fs22   -538 -534 -598 -536
< c    r=1.27->5.0671 r=3.2->27.1028 r=5.599->66.3153 r=7.1311->61.2730
< sd22     5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
<          5.0671 27.1028 66.3153 61.2730 1e20
< fc32  Top dose, contact, lid
< f32:n  515
< fs32   -260 -306 -300 -320 -518 -28
< fc52  Top dose
< f52:n  250 251 252
< fs52   -260 -306 -300 -320 -518 -30 -709 -710 -711
< fc62  Within gap, bottom of lid top
< f62:n  594
< fs62  -300
< fc72  Side of lid
< f72:n  518
< fs72  -510
< fc82  Top of lid bottom
< f82:n  519
< fs82   -27
< c    top of gap will not work for lid-on
< c    fc92   Top of gap
< c    f92:p  215
< c    fs92  -300 -320
< fc112  Next to lip
< f112:n   596
< fs112  -595 -27
< fc122  Side of plug
< f122:n  300
< fs122  -596 -215 -508
< fc132  Bottom
< f132:n  38 61
< fs132   -259 -21
< e132   .01 .1 .2 .5 1 2 5 10 20
< fc142  Side
< f142:n  30 256 257 258
< fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
< e142   .01 .1 .2 .5 1 2 5 10 20
< c      fc152   Dose at drain port cover
< c      f152:p  586
< c      fs152  -582
< c      c  r=3.9624->49.3249 r=10.16->274.9679
< c      sd152   49.3249 274.9679
< ctme    900
---
> fc5      2m above Short Draw Port
> f5:n     -9.576 -6.957 612.0896 50
> fc15     6m above Short Draw Port
> f15:n    -9.576 -6.957 1012.0896 100
> fc25     2m above Dip Tube Port
```

```
> f25:n    6.957 9.576  612.0896 50
> fc35     6m above Short Draw Port
> f35:n    6.957 9.576  1012.0896 100
> ctme   1800
```

DIFFERENCE BETWEEN idry AND iwet

```
1c1
< MCO Final SARP, neutron model, lid-on
---
> MCO Final SARP, neutron model, lid-on, flooded
67,68c67,68
<     4  0  21   57   -22  (-214:-210)  216  $ gap
<   400  0  -594 -320 -216 (217:300) 21 $ gap
---
>     4  8 -1.0  21   57   -22  (-214:-210)  216  $ gap
>   400  8 -1.0  -594 -320 -216 (217:300) 21 $ gap
79c79
<    15  7  0.0000512                18    -53           u=3    $ between fuels
---
>    15  8  -1.0                     18    -53           u=3    $ between fuels
83c83
<    19  7  0.0000512        -15     14    -53           u=3    $ H20
---
>    19  8  -1.0             -15     14    -53           u=3    $ H20
87,90c87,90
<    23  7  0.0000512        -11           -53           u=3    $ H20
<    24  7  0.0000512        -51                         u=2    $ fictitious cl
<    25  7  0.0000512         52    -500    -20                  $ 2" gap at top
<    26  7  0.0000512         53                         u=3    $ gap at top of fuel
---
>    23  8  -1.0             -11           -53           u=3    $ H20
>    24  8  -1.0             -51                         u=2    $ fictitious cl
>    25  8  -1.0              52    -500    -20                  $ 2" gap at top
>    26  8  -1.0              53                         u=3    $ gap at top of fuel
447c447,448
<   582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
---
>   582  c/x     0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
> c 582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
452c453,454
<   587  c/x  0 -3.4036 10.16
---
>   587  c/x  0 -3.4036 0.0001
> c 587  c/x  0 -3.4036 10.16
454c456,457
<   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
>   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
> c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
456c459,460
<   592  cz  .8001  $ Vertical drain pipe
---
>   592  cz  .0001  $ Vertical drain pipe
> c 592  cz  .8001  $ Vertical drain pipe
605a610
> mt8     lwtr.01t
977,978c982,983
< c        -60: dump runtpe every 60 min
< prdmp     j -60  1
---
> c        -600: dump runtpe every 600 min
> prdmp     j -600  1
1040,1045c1045,1050
< fc152   Dose at drain port cover
< f152:n  586
< fs152  -582
< c  r=3.9624->49.3249 r=10.16->274.9679
< sd152   49.3249 274.9679
< ctme    2400
---
> c      fc152   Dose at drain port cover
> c      f152:p  586
> c      fs152  -582
> c      c  r=3.9624->49.3249 r=10.16->274.9679
> c      sd152   49.3249 274.9679
> ctme   360
```

DIFFERENCE BETWEEN idry AND inacc

```
1,68c1,6
< MCO Final SARP, neutron model, lid-on
<      1     0   -20   31  -52          fill=1
< c      main lattice along cask length
<      2     0   -1   2  -3   4  -5   6  -54   55   u=1   lat=2
<                fill=-5:5  -5:5   0:4
<             2    2    2    2    2    2    2    2    2    2    2    $  1
<             2    2    2    2    2    2    3    3    3    2    2    $  2
<             2    2    2    2    3    3    3    3    3    3    2    $  3
<             2    2    2    3    3    3    3    3    3    3    2    $  4
<             2    2    3    3    3    3    3    3    3    3    2    $  5
<             2    2    3    3    3    2    3    3    3    2    2    $  6   level 1
<             2    3    3    3    3    3    3    3    3    2    2    $  7
<             2    3    3    3    3    3    3    3    2    2    2    $  8
<             2    3    3    3    3    3    3    2    2    2    2    $  9
<             2    2    3    3    3    2    2    2    2    2    2    $ 10
<             2    2    2    2    2    2    2    2    2    2    2    $ 11
< c          -5   -4   -3   -2   -1    0    1    2    3    4    5
<             2    2    2    2    2    2    2    2    2    2    2    $  1
<             2    2    2    2    2    2    3    3    3    2    2    $  2
<             2    2    2    2    3    3    3    3    3    3    2    $  3
<             2    2    2    3    3    3    3    3    3    3    2    $  4
<             2    2    3    3    3    3    3    3    3    3    2    $  5
<             2    2    3    3    3    2    3    3    3    2    2    $  6   level 2
<             2    3    3    3    3    3    3    3    3    2    2    $  7
<             2    3    3    3    3    3    3    3    2    2    2    $  8
<             2    3    3    3    3    3    3    2    2    2    2    $  9
<             2    2    3    3    3    2    2    2    2    2    2    $ 10
<             2    2    2    2    2    2    2    2    2    2    2    $ 11
< c          -5   -4   -3   -2   -1    0    1    2    3    4    5
<             2    2    2    2    2    2    2    2    2    2    2    $  1
<             2    2    2    2    2    2    3    3    3    2    2    $  2
<             2    2    2    2    3    3    3    3    3    3    2    $  3
<             2    2    2    3    3    3    3    3    3    3    2    $  4
<             2    2    3    3    3    3    3    3    3    3    2    $  5
<             2    2    3    3    3    2    3    3    3    2    2    $  6   level 3
<             2    3    3    3    3    3    3    3    3    2    2    $  7
<             2    3    3    3    3    3    3    3    2    2    2    $  8
<             2    3    3    3    3    3    3    2    2    2    2    $  9
<             2    2    3    3    3    2    2    2    2    2    2    $ 10
<             2    2    2    2    2    2    2    2    2    2    2    $ 11
< c          -5   -4   -3   -2   -1    0    1    2    3    4    5
<             2    2    2    2    2    2    2    2    2    2    2    $  1
<             2    2    2    2    2    2    3    3    3    2    2    $  2
<             2    2    2    2    3    3    3    3    3    3    2    $  3
<             2    2    2    3    3    3    3    3    3    3    2    $  4
<             2    2    3    3    3    3    3    3    3    3    2    $  5
<             2    2    3    3    3    2    3    3    3    2    2    $  6   level 4
<             2    3    3    3    3    3    3    3    3    2    2    $  7
<             2    3    3    3    3    3    3    3    2    2    2    $  8
<             2    3    3    3    3    3    3    2    2    2    2    $  9
<             2    2    3    3    3    2    2    2    2    2    2    $ 10
<             2    2    2    2    2    2    2    2    2    2    2    $ 11
< c          -5   -4   -3   -2   -1    0    1    2    3    4    5
<             2    2    2    2    2    2    2    2    2    2    2    $  1
<             2    2    2    2    2    2    3    3    3    2    2    $  2
<             2    2    2    2    3    3    3    3    3    3    2    $  3
<             2    2    2    3    3    3    3    3    3    3    2    $  4
<             2    2    3    3    3    3    3    3    3    3    2    $  5
<             2    2    3    3    3    2    3    3    3    2    2    $  6   level 5
<             2    3    3    3    3    3    3    3    3    2    2    $  7
<             2    3    3    3    3    3    3    3    2    2    2    $  8
<             2    3    3    3    3    3    3    2    2    2    2    $  9
<             2    2    3    3    3    2    2    2    2    2    2    $ 10
<             2    2    2    2    2    2    2    2    2    2    2    $ 11
< c          -5   -4   -3   -2   -1    0    1    2    3    4    5
<      3   304    -8.0        (20:-31)       -207   32   -52          $ MCO pipe wall
<      4  0  21    57    -22  (-214:-210)  216  $ gap
<    400  0  -594 -320 -216 (217:300) 21 $ gap
---
> MCO Final SARP, neutron model, accident condition
>      1     0   -20   39  -52      $ air above fuel region
>      2     5  -18.77  -20  32 -39     $ fuel region
```

```
>    3   304     -8.0       (20:-32)       -207  32  -52          $ MCO pipe wall
>    4    0      21   57   -22  (-214:-210)  216  $ gap
>   400   0      -594 -320 -216 (217:300) 21 $ gap
79c17
<    15  7  0.0000512                  18     -53                 u=3    $ between fuels
---
>    15      7      0.0000512          18     -53                 u=3    $ between fuels
83c21
<    19  7  0.0000512          -15     14     -53                 u=3    $ H2O
---
>    19      7      0.0000512  -15     14     -53                 u=3    $ H2O
87,90c25,28
<    23  7  0.0000512          -11            -53                 u=3    $ H2O
<    24  7  0.0000512          -51                                u=2    $ fictitious cl
<    25  7  0.0000512           52    -500    -20                         $ 2" gap at top
<    26  7  0.0000512           53                                u=3    $ gap at top of fuel
---
>    23      7      0.0000512  -11            -53                 u=3    $ H2O
>    24      7      0.0000512  -51                                u=2    $ fictitious cl
>    25      7      0.0000512   52    -500    -20                         $ 2" gap at top
>    26      7      0.0000512   53                                u=3    $ gap at top of fuel
351,352c289
<    31      pz         8.25501            $ bottom of fuel region
<    32      pz         8.255              $ 1.76" + 1.49" above bottom
---
>    32      pz         4.4705             $ squished spacer
358a296
>    39      pz       133.9246             $ top of scrunched fuel
382,391c320,328
< c    bottom of fuel = 8.255
< c    center of fuel: (8.255+347.3704)/2 = 177.8127
<   265  pz   72.8127 $ 177.8127 -105
<   266  pz  102.8127 $ 177.8127 - 75
<   267  pz  132.8127 $ 177.8127 - 45
<   268  pz  162.8127 $ 177.8127 - 15
<   269  pz  192.8127 $ 177.8127 + 15
<   270  pz  222.8127 $ 177.8127 + 45
<   271  pz  252.8127 $ 177.8127 + 75
<   272  pz  282.8127 $ 177.8127 +105
---
> c    bottom of fuel = 4.4704
> c    top of fuel = 133.9246
> c    center of fuel: (133.9246-4.4704)/2 = 64.7271
>   266  pz   24.7271 $ 64.7271  - 40
>   267  pz   44.7271 $ 64.7271  - 20
>   268  pz   59.7271 $ 64.7271  - 5
>   269  pz   69.7271 $ 64.7271  + 5
>   270  pz   84.7271 $ 64.7271  + 20
>   271  pz  104.7271 $ 64.7271  + 40
447c384,385
<   582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
---
>   582  c/x     0 -3.4036 0.0001    $ 4.79" from bottom of cask, 3.12" dia
> c 582  c/x     0 -3.4036 3.9624    $ 4.79" from bottom of cask, 3.12" dia
452c390,391
<   587  c/x  0 -3.4036 10.16
---
>   587  c/x  0 -3.4036 0.0001
> c 587  c/x  0 -3.4036 10.16
454c393,394
<   590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
---
>   590  c/x  0 -3.4036 .0001  $ Horizontal drain pipe
> c 590  c/x  0 -3.4036 .8001  $ Horizontal drain pipe
456c396,397
<   592  cz   .8001  $ Vertical drain pipe
---
>   592  cz   .0001  $ Vertical drain pipe
> c 592  cz   .8001  $ Vertical drain pipe
549c490
< mode       n
---
> mode    n
550a492
> totnu
552c494
```

```
< imp:n     8 1  8 8    8  8  8   8   8   8    8    8    8  8
---
> imp:n     1 1  8 8    8  8  8   8   8   8    8    8    8  8
611,612c553,554
< sdef          cel=d1          pos=0 0 0        axs=0 0 1        ext d3
<               rad fcel d4     erg d7           wgt=1.174E+7 $ p/s/MCO
---
> sdef     pos=0 0 0    axs=0 0 1 ext=d3
>          rad d4    erg=d7       wgt=1.174E+7 $ p/s/MCO
632,967c574,576
< si1        l     1:2( 1 -4  0):17   1:2( 2 -4  0):17   1:2( 3 -4  0):17
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< c         pi(r2*r2-r1*r1)*h  pi(r4*r4-r3*r3)*h,  pi and h cancelled
< si3      8.255    74.5744
< ds4    s    5      5      5      5      5      5      5      5      5
<             5      5      5      5      5      5      5      5      5
<             5      5      5      5      5      5      5      5      5
<             5      5      5      5      5      5      5      5      5
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< si5      2.2110   3.0163
< sp5     -21    1
< si6      .6591   1.5481
< sp6     -21    1
---
> si3      4.4704   133.9246
> si4      0   29.21
> sp4     -21    1
977,978c586,587
< c        -60: dump runtpe every 60 min
< prdmp    j -60  1
---
> c        -600: dump runtpe every 600 min
> prdmp    j -600  1
980,1031d588
< f4:n  (13 30 31 32 33 34 35 36 37 38 580)
< fs4   -3000000  44 29 2
<       601 602 603 604 605 606 607 608 609 610
<       611 612 613 614 615 616 617 618 619 620
<       621 622 623 624 625 626 627 628 629 630
<       631 632 633 634 635 636 637 638 639 640
<       641 642 643 644
<       701 702 703 704 705 706 707 708 709 710
<       711 712 713 714 715 716 717 718 719 720
<       721 722 723 724 725 726 727 728 729
<       583 583
< fc12  Dip Tube Port contact, 1m, 2m, 6m
< f12:n  515 250 251 252
< fs12   -543 -535 -597 -537
< c    r=0.635->1.2668 r=3.2->30.9031 r=5.599->66.3153 r=7.1311->61.2730
< sd12      1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
<           1.2668 30.9031 66.3153 61.2730 1e20
< fc22  Short Draw Port contact, 1m, 2m, 6m
< f22:n 515 250 251 252
< fs22   -538 -534 -598 -536
< c    r=1.27->5.0671 r=3.2->27.1028 r=5.599->66.3153 r=7.1311->61.2730
```

```
< sd22    5.0671 27.1028 66.3153 61.2730 1e20
<         5.0671 27.1028 66.3153 61.2730 1e20
<         5.0671 27.1028 66.3153 61.2730 1e20
<         5.0671 27.1028 66.3153 61.2730 1e20
< fc32  Top dose, contact, lid
< f32:n  515
< fs32   -260 -306 -300 -320 -518 -28
< fc52  Top dose
< f52:n  250 251 252
< fs52   -260 -306 -300 -320 -518 -30 -709 -710 -711
< fc62  within gap, bottom of lid top
< f62:n  594
< fs62  -300
< fc72  Side of lid
< f72:n  518
< fs72  -510
< fc82  Top of lid bottom
< f82:n  519
< fs82   -27
< c    top of gap will not work for lid-on
< c    fc92   Top of gap
< c    f92:p  215
< c    fs92  -300 -320
< fc112  Next to lip
< f112:n   596
< fs112  -595 -27
< fc122  Side of plug
< f122:n  300
< fs122  -596 -215 -508
1035d591
< e132   .01 .1 .2 .5 1 2 5 10 20
1037,1046c593,598
< f142:n  30 256 257 258
< fs142 -265 -266 -267 -268 -269 -270 -271 -272 -519 -594
< e142   .01 .1 .2 .5 1 2 5 10 20
< fc152   Dose at drain port cover
< f152:n  586
< fs152  -582
< c  r=3.9624->49.3249 r=10.16->274.9679
< sd152   49.3249 274.9679
< ctme    2400
< totnu
---
> f142:n  30
> fs142    -32 -266 -267 -268 -269 -270 -271 -39
> fc162   dose at bottom of plug
> f162:n   500
> fs162   -20
> ctme    360
```

CHECKLIST FOR INDEPENDENT TECHNICAL REVIEW

DOCUMENT REVIEWED Chapter B5 of Multiple Cansister Overpack Transport Cask
AUTHOR(s) Karl Hillesland

I. Method(s) of Review

- (✓) Input data checked for accuracy
- (✓) Independent calculation performed
  - ( ) Hand calculation
  - (✓) Alternate computer code: ISOSHLD
- ( ) Comparison to experiment or previous results
- ( ) Alternate method (define)

II. Checklist (either check or enter NA if not applied)

- (✓) Task completely defined
- (✓) Activity consistent with task specification
- (✓) Necessary assumptions explicitly stated and supported
- (✓) Resources properly identified and referenced
- (✓) Resource documentation appropriate for this application
- (✓) Input data explicitly stated
- (✓) Input data verified to be consistent with original source
- (✓) Geometric model adequate representation of actual geometry
- (✓) Material properties appropriate and reasonable
- (NA) Mathematical derivations checked including dimensional consistency
- (NA) Hand calculations checked for errors
- (✓) Assumptions explicitly stated and justified
- (✓) Computer software appropriate for task and used within range of validity
- (NA) Use of resource outside range of established validity is justified
- ( ) Software runstreams correct and consistent with results
- (✓) Software output consistent with input
- (NA) Results consistent with applicable previous experimental or analytical findings
- (✓) Results and conclusions address all points and are consistent with task requirements and/or established limits or criteria
- (✓) Conclusions consistent with analytical results and established limits
- (✓) Uncertainty assesment appropriate and reasonable
- ( ) Other (define)

III. Comments:

IV. REVIEWER: JV Nelson DATE: 11/22/96

6.0 CRITICALITY EVALUATION

This section discusses the criticality features and analysis of the MCO Cask and its contents. The performance requirements are specified in 10 CFR 71.55 and 10 CFR 71.59 and are shown in Table B6-1. The main criticality performance requirement of the MCO Cask package is to maintain k_{eff} less than 0.95.

The irradiated fuel and fuel scraps are loaded into baskets and loaded into the MCOs and MCO Casks at the K Basins. The MCOs and shipping casks are used to ship irradiated N Reactor fuel from the K Reactor Basins to the CVDF. After emptying the water from the MCOs and casks at the CVDF, the MCO Casks are shipped from the CVDF to the CSB where the MCOs are removed from the casks, staged, hot conditioned, and placed into long-term storage. The payload is identified as irradiated Mark IA and Mark IV fuels and scraps from those fuels. Table B6-2 shows the material and material configuration, the ^{235}U wt% enrichment of the material, the configuration of fuel in the MCO in which the material will be shipped, and the quantity per MCO.

This section is divided into seven subsections. Section 6.1 gives the discussion and results, Section 6.2 is the package fuel loading, Section 6.3 discusses model specifications, and Section 6.4 presents the criticality calculations. Section 6.5 discusses the critical benchmark experiments for the computer codes used for the calculations, Section 6.6 lists the references, and Section 6.7 comprises the appendices.

6.1 DISCUSSION AND RESULTS--IRRADIATED N REACTOR MARK IA AND MARK IV FUELS

MCOs containing Mark IA and Mark IV N Reactor fuel are packaged for shipment in the MCO Cask. There is one MCO per shipping container. A weight limit of 7,682 kg (16,900 lb) is imposed on the MCO contents. This weight limit is not a criticality safety feature requirement. Shipping cask and MCO dimensions are given in Part A, Section 2.1. The design features of the MCO that affect criticality safety are the MCO inside diameter (ID) and the central insert of the Mark IA baskets.

The MCO Cask criticality analyses were performed with the MCNP code (Breismeister 1993, Carter 1995). The analyses were performed for a three-element array of undamaged containers and for two cases (vertical and side drop) of single damaged containers. The analysis models were based on conservative assumptions and demonstrated the most reactive prescribed arrangement of material. The analysis results are presented in terms of mean reactivity (k_{eff}), standard deviation (σ), and 95% confidence level reactivity including calculational bias. The 95% confidence level reactivity and calculational bias is described in Section 6.5. Table B6-3 summarizes the most limiting calculational results of shipping casks under normal and accident conditions. It shows that shipments of the Mark IA and Mark IV MCOs will remain safely subcritical for all normal transfer conditions and defined accident events.

Table B6-1. Performance Requirements.

Single package	
Criteria for subcriticality under specific moderation and reflection conditions per 10 CFR 71.55 and 10 CFR 71.59.	
General requirements	
A package must be subcritical if water were to leak into the containment system under the following conditions:	
1	Most reactive credible configuration consistent with the chemical and physical form of the material.
2	Moderation by water to the most reactive credible extent.
3	Close full reflection of the containment system by water on all sides or such greater reflection of the system as may be provided by the material of the packaging.
Normal conditions of transport	
1	The contents would be subcritical.
2	The geometric form of the package contents would not be substantially altered.
3	There would be no leakage of water into the containment system unless in the evaluation of undamaged packages it is assumed that moderation is present to cause maximum reactivity.
4	No substantial reduction in the effectiveness of the packaging: • No more than 5% reduction in total volume • No more than 5% reduction in effective spacing • No occurrence of an aperture in the outer surface of the packaging large enough to admit a 4-in. cube.
Accident conditions	
The package is subcritical under the following conditions:	
1	Most reactive credible configuration consistent with the chemical and physical form of the material
2	Moderation by water to the most reactive credible extent
3	Full reflection by water on all sides
Standards for arrays	
A package must be controlled to assure than an array remains subcritical. Derive a number N such that assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:	
1	5 times N undamaged packages with nothing between the packages would be subcritical
2	2 times N damaged packages would be subcritical with optimum interspersed hydrogenous moderation
3	N = ≥ 0.5
Transport index (TI)	
Divide 50 by N; TI = 100 if N = 0.5	

10 CFR 71, 1996, "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, as amended.

Table B6-2. Multicanister Overpack Shipping Containers.

Material	Wt% ^{235}U	Basket	Contents per container	Containers per shipment (by weight limit)
Mark IA fuel	1.15 average	Mark IA	288 pieces	4,776 kg
Mark IV fuel	0.95	Mark IV	270 pieces	6,345 kg

Table B6-3. Summary of N Reactor Shipping Cask Criticality Evaluation.

MCO type	Wt% ^{235}U	k_{eff}
Array of three undamaged shipping casks with optimum moderation and pitch		
Mark IA	1.25 and 0.95	0.8964
Mark IV	0.95	0.9029
Array of single damaged shipping cask with optimum moderation		
Mark IA	1.25 and 0.95	0.8940
Mark IV	0.95	0.9360

MCO = Multicanister Overpack.

Table B6-4 shows the criticality transport index (TI) and the value of N, a number which was used to determine the TI. TI and N are defined in Section 6.4.3.1. The value of N was 0.5 for all undamaged and damaged cases. The corresponding TI was 100 in all cases.

Table B6-4. Criticality Transport Index for Mark IA and Mark IV MCOs.

Fuel type	MCOs per cask	2 x N damaged MCOs	N	TI
Mark IA	1	1	0.5	100
Mark IV	1	1	0.5	100

MCO = Multicanister Overpack.

6.2 PACKAGE FUEL LOADING--N REACTOR MARK IA AND MARK IV FUELS

Irradiated Mark IA and Mark IV fuel and scrap will be loaded into baskets and placed into MCOs in the K Reactor basins. This section describes the N Reactor fuel and the loading of the MCO.

6.2.1 N Reactor Fuel Description

The fuel dimensions are shown in Table B6-5. This table lists the enrichments for the fresh (unirradiated) fuel before it was loaded in the N Reactor.

Table B6-5. Description of N Reactor Unirradiated Fuel Elements.

	Mark IV	Mark IA
Pre-irradiation enrichment of ^{235}U	0.947% enriched	1.25-0.947% enriched
Type-length code1*	E S A C	M T F
Length (cm)	66.3 62.5 58.9 44.2	53.1 49.8 37.8
Element diameter (cm)		
1. Outer of outer	6.15	6.10
2. Inner of outer	4.32	4.50
3. Outer of inner	3.25	3.18
4. Inner of inner	1.22	1.11
Cladding mass (kg)		
1. Outer element	1.09 1.04 0.99 0.79	0.88 0.83 0.66
2. Inner element	0.55 0.52 0.50 0.40	0.54 0.51 0.04
Mass of uranium in outer (kg)		
1. (0.947% ^{235}U)	16.0 15.0 14.1 10.5	
2. (1.25% ^{235}U)		11.1 10.4 7.85
Mass of uranium in inner (kg) 0.947% ^{235}U	7.48 7.03 6.62 4.94	5.49 5.12 3.90
Weighted average of uranium in element (kg)	22.7	16.3
Ratio of zircaloy-2 to uranium (kg/MTU)	70.0 70.8 71.6 77.1	85.5 86.3 90.4
Weighted average (kg/MTU)	70.3	85.7
% of total elements	63	37
% of length type of each fuel	78 10 7 5	87 10 3
Displacement volume (l/MTU)	67	67

*Letter code differentiates the different lengths of the Mark IV or Mark IA fuel elements (i.e., a type "E" element is 66.3 cm [26.1 in.] long).

MTU = Metric tons of uranium.

Analyses on the effects of burn up and fission products decay show that the unirradiated N Reactor fuel is more reactive (higher infinite criticality factor k_{inf}) than the spent fuel in spite of the presence of plutonium products in the spent fuel (Schwinkendorf 1997). Reduced uranium enrichment and the presence of fission products compensate for any increase in k_{inf} due to the plutonium content in the spent fuel. WHC-SD-SNF-CSER-005, *Criticality Safety Evaluation Report for Spent Nuclear Fuel Processing and Storage Facilities* (Schwinkendorf 1997) provides justification for use of the unirradiated fuel characteristics in the analyses presented in this section. As such, all the criticality analyses discussed in this section are conservatively performed with the unirradiated N Reactor fuel.

As shown in Table B6-5, there are two types of fuel assemblies, Mark IA and Mark IV, with different uranium enrichments and sets of lengths. Each fuel assembly consists of two hollow, coaxial, cylindrical elements separated by spacers. Each of the elements is clad with zircaloy; i.e., zircaloy-clad tube-in-tube metallic uranium geometry. The Mark IA fuel assembly has two uranium enrichments: the inner element has an enrichment of 0.947% (0.95%) ^{235}U, and the outer element has an enrichment of 1.25% ^{235}U, with a weighted average enrichment of 1.15% ^{235}U. The Mark IV assembly has one enrichment, 0.95% ^{235}U. Some fresh Mark IV fuel assemblies contain natural uranium (0.71% ^{235}U) and are designated Mark IVB. Those assemblies are conservatively treated as the 0.95% ^{235}U fuel in the analyses presented in this section.

The impact of the Mark IA fuel's higher enrichment on the design of the MCO and the fuel baskets is discussed below.

6.2.2 MCO Fuel Basket Description

The design parameters for the fuel baskets and fuel loadings for Mark IV and Mark IA fuels are shown schematically in Figures B6-1 and B6-2, respectively. Scrap baskets for Mark IV and Mark IA fuel scrap, are shown schematically in Figures B6-3 and B6-4, respectively. The spent fuel that is to be shipped to the CVDF and CSB is stored in the K East and K West Basins. It is estimated that about 35% of the fuel assemblies are in a highly damaged or corroded condition. The broken pieces of the fuel assemblies will be treated as scrap and packed separately in different baskets specifically designed for loading scrap into the MCOs. The Mark IA fuel and fuel scrap baskets have a centrally located hollow cylinder insert, which is a section of 6-in. schedule XXS pipe. The fuel assemblies, when loaded in the baskets, form a tight lattice with minimal separation between the neighboring fuel assemblies. Slots in the base of each basket hold the intact fuel assemblies in discrete positions. The lattice has a hexagonal center-to-center pitch of about 7.1 cm (2.8 in.) compared to about 6.1-cm (2.4-in.) OD of the fuel assemblies, as shown in Table B6-5. The fuel scrap also is tightly packed.

The Mark IA fuel, if placed in an optimum geometry, will not meet the criticality criterion of $K_{eff} \leq 0.95$. As such, the fuel baskets for the Mark IA fuel loading were designed with a standard pipe insert 16.8 cm in outside diameter (OD) installed along the central line of the fuel basket, as shown in Figure B6-2. The Mark IA fuel baskets are also shorter in height.

Figure B6-1. Loading Arrangement for Mark IV Fuel in MCO Container.

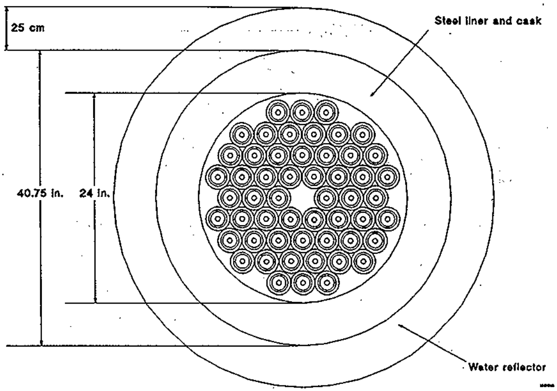


Figure B6-2. Loading Arrangement for Mark IA Fuel in MCO Container.

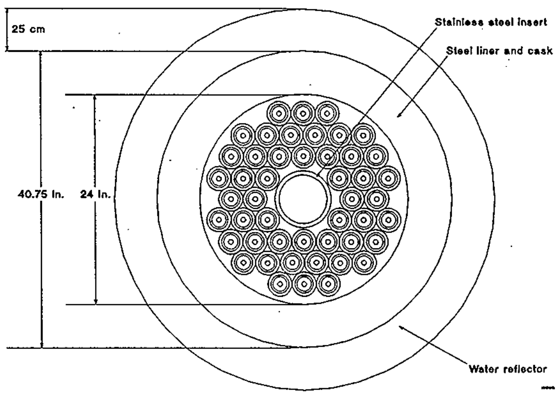


Figure B6-3. Mark IV Fuel Scrap Storage Basket.

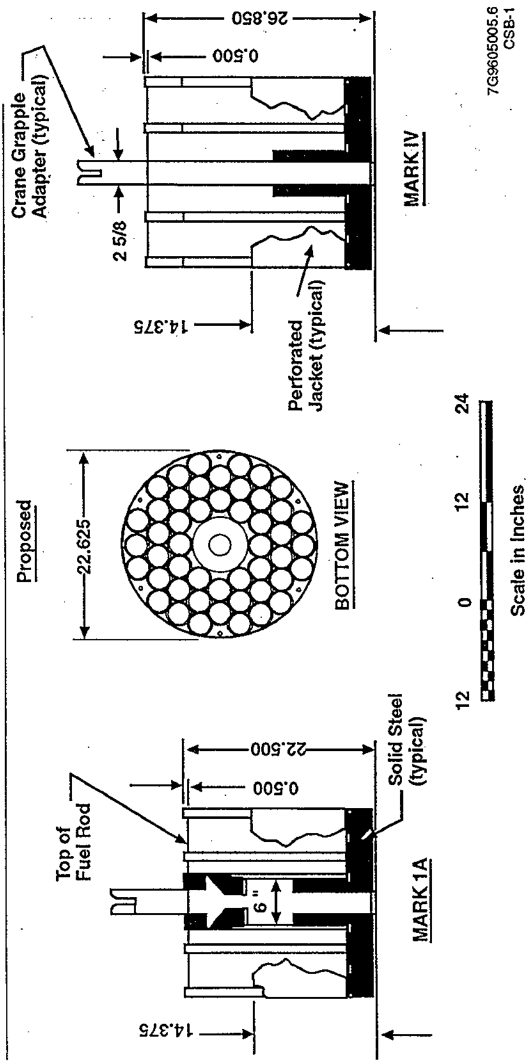
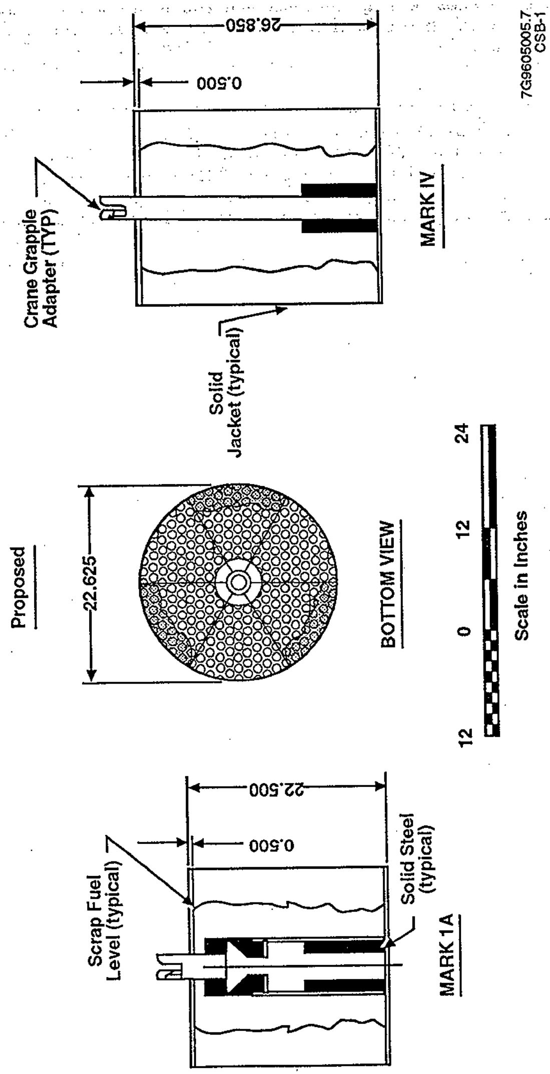


Figure B6-4. Mark IA Fuel Scrap Storage Basket.



This central insert reduces the number of Mark IA fuel assemblies or the amount of scrap that can be loaded in each basket. Most importantly, the central insert increases neutron leakage and absorption to reduce the criticality potential for the Mark IA fuel in the MCO. Part B, Section 7.5, shows that the central insert maintains integrity and orientation after the application of accident conditions.

The Mark IV fuel basket is designed to hold 54 Mark IV fuel assemblies, and the Mark IA basket is designed to hold 48 Mark IA fuel assemblies. An MCO is designed to hold a tier of five baskets, four containing Mark IV fuel assemblies and one containing scrap, or a tier of six baskets, five containing Mark IA fuel assemblies and one containing scrap. As shown in Table B6-5, the Mark IA fuel assemblies are shorter in length than the Mark IV assemblies, except for Mark IV fuel type C, thus limiting the mass of fuel per Mark IA basket while permitting six baskets of Mark IA fuel per MCO. The fuel baskets are designed for the largest fuel assemblies of Mark IA and Mark IV design.

6.2.3 MCO Description

The MCO is a steel cylinder with a removable lid on top. The MCO is 406 cm (160 in.) long with a 61-cm (24-in.) OD and a 1.30-cm (0.50-in.) wall thickness. A total of five Mark IV fuel baskets and six Mark IA fuel baskets are loaded in an MCO, respectively. The dimensions of the baskets are such that the combined active height of the fuel or fuel scrap inside the MCO is the same, irrespective of the type of fuel. Only one fuel type is allowed in an MCO. Mixing of fuel basket types in an MCO is not allowed. Also, Mark IA fuel is not allowed in a Mark IV MCO. Sketches of the MCO and normal fuel loadings with Mark IA and Mark IV fuel and scrap baskets are shown in Figure B6-5. Only one scrap basket is allowed in each MCO, as either the top or bottom basket. However, this analysis assumes the presence of a scrap basket in both the top and bottom positions within the MCO.

6.2.4 MCO Loading

The authorized contents for the MCO transportation cask is one MCO filled with 270 Mark IV fuel elements or 288 Mark IA fuel assemblies from the N Reactor. Based on the weight of these fuels, the total cask spent fuel payload is not to exceed 6,835 kg (15,070 lb). This weight limit and other weights discussed in this section are not required for criticality safety.

The fissionable material is N Reactor Mark IV and Mark IA fuel assemblies and scrap material from the same fuel. Based on the weights for the longest intact fuel assemblies, the maximum loading for a basket of Mark IV assemblies is 1,269 kg (2,798 lb). For five basket tiers, this results in 6,345 kg (13,991 lb) total Mark IV fuel per MCO-loaded cask. For the six basket tiers of Mark IA assemblies, the masses are 796 kg (1,756 lb) per basket and 4,776 kg (10,531 lb) per cask. These data for fuel baskets of the longest assemblies were assumed as the maximum loadings for criticality safety evaluations.

The scrap baskets may be loaded with fuel scrap or segments of fuel assembly components, with or without cladding. The volume of scrap will be limited to that of a full basket, with a maximum height of 67.3 cm (26.5 in.) for Mark IV and 53.3 cm (21 in.) for Mark IA baskets. If scrap has a higher packing fraction than intact fuel assemblies, a scrap basket could contain more uranium mass than a basket of whole elements. The actual mass of scrap may exceed the mass corresponding to the calculational model, which was based on optimum particle size and spacing. The scrap weight limit per basket may be determined by the basket, MCO, or cask weight limits, which will not affect this criticality evaluation.

6.3 MODEL SPECIFICATION--N REACTOR FUEL MCO

This section describes the computer models of the shipping cask and assembled MCOs containing Mark IA and Mark IV fuel and scrap baskets that were used for the analyses.

6.3.1 Description of Calculational Model

Even though thermal and gas generation considerations (Part B, Sections 8.0 and 9.0) set a limit of one scrap basket per MCO, for conservatism MCO Casks are modeled as an outer cask containing an MCO that is loaded with either four Mark IA fuel baskets and two Mark IA scrap baskets or three Mark IV fuel baskets and two Mark IV scrap baskets. The dimensions of the shipping cask, MCO, fuel and scrap baskets, and fuel used in the calculations for Mark IA and Mark IV cases are shown in Figure B6-5.

The shipping casks containing MCOs are not explicitly modeled (see Sections 6.4.2.3 and 6.4.2.4 for details of the model). The models of the package contents under normal transfer and accident conditions utilize conservative representations of design parameters. Examples of these design parameters are using longest fuel lengths, unirradiated uranium enrichments, and optimum scrap particle size and moderation. A triangular lattice of three shipping casks in contact containing MCOs conservatively represents 5 x N undamaged packages with material reflection and no moderation. For the accident events, cases of single shipping casks containing Mark IA and Mark IV fuel inside an MCO are modeled using optimum conditions of moderation, reflection, and contents damage, where applicable. These arrays represent the contents of 2 x N damaged packages. The value of N is 0.5.

6.3.2 Package Regional Densities

N Reactor Mark IA and Mark IV fuel are zircaloy-clad uranium metal tubes enriched to 0.947 ± 0.006 wt% ^{235}U and 1.25 ± 0.006 wt% ^{235}U. Material densities and atomic number densities for the constituent nuclides of all materials used in the N Reactor ingot calculations models are shown in Table B6-6. For the 1.25 wt% ^{235}U, all values in Table B6-6 apply except for the weight fraction of ^{235}U.

Figure B6-5. Monte Carlo N-Particle Input Models for Normal Mark IA and Mark IV MCOs: Axial Geometry.

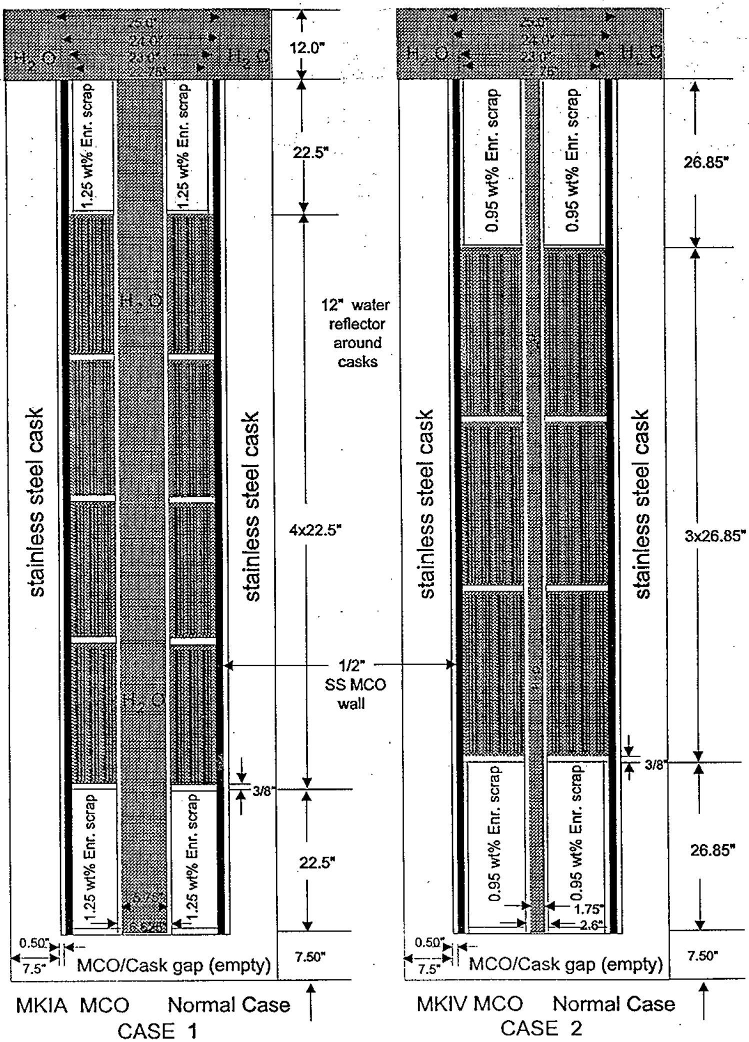


Table B6-6. Material Densities and Weight Fractions Used in Calculations.

Material	No.	Density (g/cm^3)	Isotope	Wt fraction
Mark IV inners	m1	18.58	^{235}U ^{238}U	0.009471 0.990529
Zircaloy cladding	m2	6.55	Zr (elemental)	1.000
Stainless steel 304	m3	8.03	^{12}C ^{55}Mn Si (elemental) Cr (elemental) Ni (elemental) Fe (elemental)	0.0004 0.0200 0.0100 0.1900 0.0925 0.6871
Water	m4	1.000	^{1}H ^{16}O	0.1119 0.8881

6.4 CRITICALITY CALCULATIONS--N REACTOR TRANSFER CASK AND MCO

This section describes the calculational method used for the analyses.

6.4.1 Calculational Method

The MCNP and WIMS-E computer codes were used for this criticality evaluation. MCNP was developed at the Los Alamos National Laboratory (LANL) and is now used extensively both in the United States and throughout the world. The MCNP code is a general-purpose, continuous-energy, generalized-geometry neutron and photon transport code that calculates eigenvalues for criticality evaluations.

The MCNP code uses continuous energy cross sections that are thoroughly documented in Appendix G of Breismeister. These cross sections are defined with a high-energy resolution. All the cross sections used for these analyses were generated from either Evaluated Nuclear Data Files (ENDF) or LANL evaluations.

The WIMS-E lattice transport code (Gubbins et al. 1982) was used to calculate the relationship of infinite neutron multiplication factors and rod diameter and lattice spacing representing scrap and fractured fuel. The WIMS-E code is a deterministic model, which is the most consistent and sensitive method available to represent the effects of parametric studies such as this application. The results from the parametric studies performed by the WIMS-E studies were incorporated into the MCNP model of the MCO.

6.4.2 Contents Loading Optimization

The MCO loading can be varied by the selection of fuels of various lengths, exposures, and degrees of corrosion; numbers of scrap baskets; and quantities and particle size of fuel pieces in the scrap baskets. The following section discusses the variations that can occur in the MCO loading and the conservatism or optimization that was used in the modeling to ensure that the criticality safety limit would not be exceeded.

6.4.2.1 General MCO Model. The MCO is modeled for the two cases of each spent fuel type contained in the baskets designated for that type of fuel (see Figures B6-1 and B6-2) and the baskets, in turn, stacked in an MCO. The Mark IA basket holds 48 Mark IA fuel assemblies and has a central pipe insert, 15.2-cm (6-in.) ID and 16.8-cm (6.625-in.) OD, specifically designed for criticality control. (The criticality evaluation was based on an earlier MCO design that utilized a thicker pipe for the Mark IA central pipe insert than is used in the current MCO design. However, this yields conservative results, so the analysis is acceptable as is.) The Mark IA fuel scrap basket also has a similar 15.2-cm- (6-in.) diameter central insert. The Mark IV basket holds 54 fuel assemblies and does not have the centrally located pipe insert for criticality control. Both types of baskets have a centrally located, 6.6-cm- (2.6-in.-) OD tube for installation of a dip tube for vacuum drying the fuel in the MCO.

The MCO and fuel and scrap basket loading is described in Section 6.2.3. The normal and accident loadings of the MCOs are shown in Tables B6-7 and B6-8 for Mark IA and Mark IV MCOs, respectively. For conservatism, each MCO was modeled with two scrap baskets, one at the top and the other at the bottom. As discussed in Section 6.0, only one scrap basket will actually be loaded into an MCO. One MCO is handled at a time in all transport operations. For the accident conditions model, the basket material separates the fuel material in tiers, and the tiers compact, reducing the water and air volumes.

Table B6-7. Monte Carlo N-Particle Model of Mark IA Multicanister Overpack With Normal and Accident Loading.

Basket contents by tier number (from top)						
Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Tier 6	Condition
1.25 wt% scrap	48 Mark IA	48 Mark IA	48 Mark IA	48 Mark IA	1.25 wt% scrap	Normal
1.25 wt% scrap	1.15 wt% rubble	1.15 wt% rubble	1.15 wt% rubble	1.15 wt% rubble	1.25 wt% scrap	Damaged

Table B6-8. Monte Carlo N-Particle Model of Mark IV Multicanister Overpack With Normal and Accident Loading.

Basket contents by tier number (from top)					
Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Condition
0.95 wt% scrap	54 Mark IA	54 Mark IA	54 Mark IA	0.95 wt% scrap	Normal
0.95 wt% scrap	0.95 wt% rubble	0.95 wt% rubble	0.95 wt% rubble	0.95 wt% scrap	Damaged

The MCOs and cask will be shipped from the K Reactor basins to the CVDF in the flooded condition. This is the most limiting condition as shown in Table B6-9. The MCOs will be shipped from the CVDF to the CSB emptied of water and partially dried. The concerns for potential criticality incidents are significantly reduced for the MCOs that are emptied of water and partially dried. Because the flooded MCO bounds the most limiting condition, the safety evaluation for the flooded MCO was used for both shipping from the K Reactor basins to the CVDF and shipping from the CVDF to the CSB.

Table B6-9. Undamaged Multicanister Overpack Shipping Cask Reactivities.

MCO type	MCO water density	Cask gap density moderator	k_{eff}	Standard deviation	95% C.L. plus bias	Input file
Mark IA	1.0	0.0	0.8964	0.0023	0.9074	i1.IA.10
Mark IA	0.7	0.0	0.8260	0.0020	0.8370	i1.IA.70
Mark IA	0.5	0.0	0.7480	0.0020	0.7590	i1.IA.50
Mark IA	0.3	0.0	0.6301	0.0016	0.6408	i1.IA.30
Mark IA	0.0	0.0	0.2979	0.0009	0.3084	i1.IA.00
Mark IV	1.0	0.0	0.9029	0.0014	0.9136	i1.IV.10
Mark IV	0.7	0.0	0.8379	0.0017	0.8487	i1.IV.70
Mark IV	0.5	0.0	0.7542	0.0015	0.7649	i1.IV.50
Mark IV	0.3	0.0	0.6148	0.0016	0.6256	i1.IV.30
Mark IV	0.0	0.0	0.3246	0.0010	0.3351	i1.IV.00

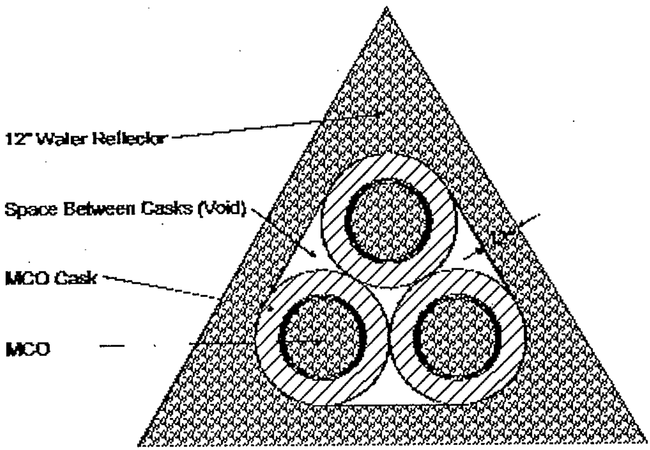
6.4.2.2 Rod Geometry Model for Scrap and Rubble. The fuel scrap and fragmented or rubblized fuel assumed to occur after a drop accident are in an uncontrolled geometry. The fuel scrap was modeled in the most optimum condition with respect to particle size and water moderation. The fuel scrap was modeled as uranium rods in triangular pitch with optimum spacing.

The rubblized fuel was modeled in optimally sized pieces that were assumed to be less optimally spaced in water due to realistic considerations that places an upper bound on the particle spacing. The forces acting on fuel from a drop accident are crushing from the weight of fuel in upper baskets. The rubblized fuel will change from a packing fraction of 0.443 for intact Mark IV fuel and 0.392 for intact Mark IA fuel, which are calculated from actual fuel array dimensions, to a nominal packing fraction of 0.4. The nominal packing fraction of 0.4 was used to be consistent with MCO accident scenarios developed for the MCO facility criticality safety evaluation report (Schwinkendorf 1997).

6.4.2.3 Shipping Cask Model. The shipping cask, shown in Figure B6-5, is modeled as a steel cylinder container surrounding the MCO. The cask model dimensions differ from actual cask measurements and are conservative. The model side thickness is 22.9 cm (9.00 in.), the floor is 22.9 cm (9.00 in.), and the top is 22.9 cm (9.00 in.). These thicknesses exceed actual cask dimensions and represent an infinite material reflector region. The infinite reflector region in the model is conservative for all shipping cask thicknesses. A gap of 1.27 cm (0.50 in.) was modeled between the MCO and inner cask side. A gap of 25.4 cm (10.0 in.) was modeled between the MCO top and lid of the shipping cask. These gap thicknesses are upper limit levels of the final cask design. The water gap thickness is conservative for all design variations.

6.4.2.4 Undamaged Shipping Cask Models. The undamaged shipping cask, shown in Figure B6-6, was modeled as three shipping casks arranged in triangular pitch. The shipping casks were modeled in contact with one another, which is the most reactive configuration. Each shipping cask contained an MCO that was filled with fuel and scrap baskets, as described in the previous section.

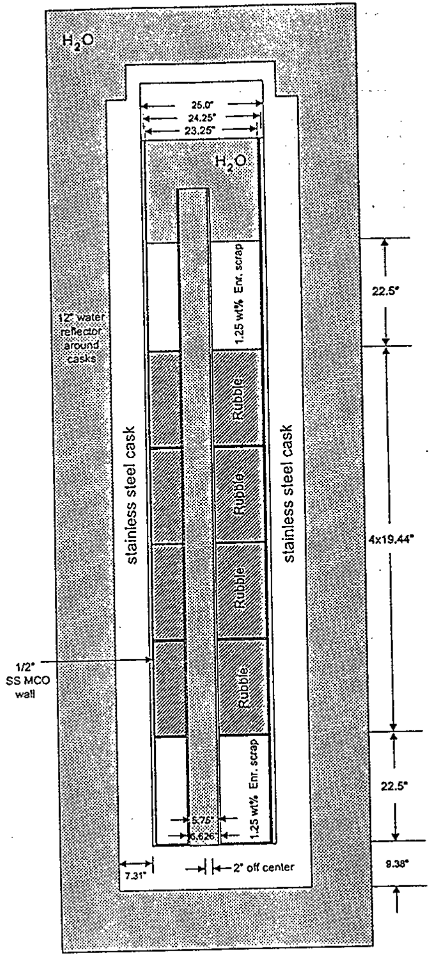
Figure B6-6. Triple Array of Undamaged Shipping Cask.



Water of various densities was modeled inside the MCO and in the regions between the shipping casks. Inside the MCO, water moderator was modeled in the fuel coolant channels and in the interstitial regions between the fuel assemblies and uranium rods used to model the scrap. The gap between the MCO and shipping cask was modeled as a void.

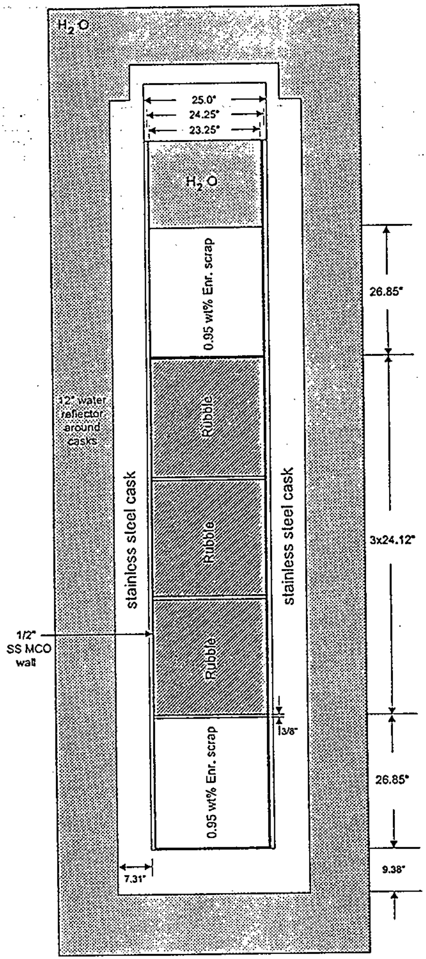
6.4.2.5 Damaged Shipping Cask Models. The single damaged shipping cask, shown in Figures B6-7 and B6-8 for Mark IA and Mark IV MCOs, respectively, was modeled in the vertical position after the postulated accident. The single damaged shipping cask, shown in Figures B6-9 and B6-10 for Mark IA and Mark IV MCOs, respectively, was modeled in the side position after the postulated accident. In the vertical case, the fuel and scrap baskets were assumed to fall to the bottom of the MCO by the forces of the drop. An upper region formed by the basket displacement was modeled as water. The fuel regions and baskets were modeled containing optimum-diameter uranium rods at a spacing

Figure B6-7. Damaged Mark IA Multicanister Overpack and Shipping Cask in Vertical Drop Position.



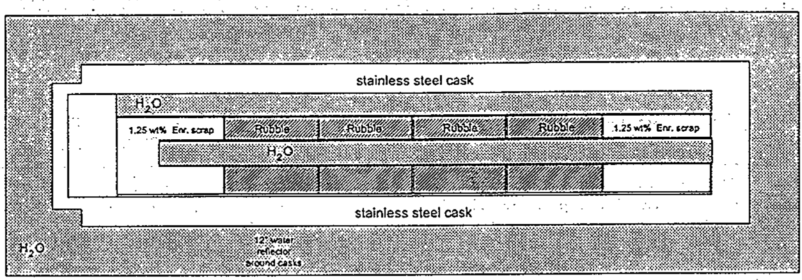
MKIA MCO Vertical Drop Case

Figure B6-8. Damaged Mark IV Multicanister Overpack and Shipping Cask in Vertical Drop Position.



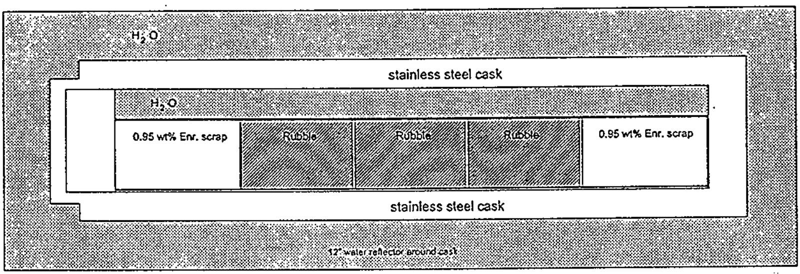
MKIV MCO Vertical Drop Case

Figure B6-9. Damaged Mark IA Multicanister Overpack and Shipping Cask in Side Drop Position.



MKIA MCO Horizontal Drop Case

Figure B6-10. Damaged Mark IV Multicanister Overpack and Shipping Cask in Side Drop Position.



MKIV MCO Horizontal Drop Case

corresponding to a packing fraction of 0.4 representing fragmented rubble. The scrap regions and baskets were modeled containing optimum-diameter uranium rods at a spacing corresponding to an optimum packing fraction. The central insert of the Mark IA MCO was assumed to be offset at its maximum deflection of 5.08 cm (2.00 in.). Mixing of fuel and scrap was not considered as 10 CFR 71 does not require the removal of all fuel barriers in accident analysis.

In the side case, the fuel and scrap baskets were assumed to remain in their original positions after the forces of the drop. An upper flat void region in each basket, formed by the crushed fuel and scrap displacement to the gap regions originally at the top of each basket, was modeled as water. The fuel baskets were modeled containing optimum-diameter uranium rods at a spacing corresponding to a packing fraction of 0.4 representing fragmented rubble. The scrap baskets were modeled containing optimum-diameter uranium rods at a spacing corresponding to an optimum packing fraction. The central insert of the Mark IA MCO was assumed to be offset at its maximum deflection of 2.00 in.

Water of various densities was modeled in the moderation and reflective regions of the damaged model. The first region was the interstitial moderating regions between the uranium rods representing scrap and fuel rubble. The second region was the gap between the MCO and shipping cask. An outer water reflector of 30.5 cm (12.0-in.) thickness, representing an infinite material region, surrounded the shipping cask.

The first set of calculations were for various water densities between the fuel elements and void in the gap between the MCO and shipping cask for Mark IA and Mark IV fuels. The second set of calculations was for full water density between the fuel elements, which is the most reactive case, and various water densities in the gap between the MCO and shipping cask for Mark IA and Mark IV fuels.

6.4.3 Criticality Results

To ensure criticality safety, the calculated k_{eff} plus code bias and uncertainties must be less than 0.95 (Section 6.5). N Reactor MCO Casks are subcritical under both normal transfer and accident conditions. Calculations show that finite arrays of the Mark IA and Mark IV MCO types are subcritical under optimum conditions of moderation, reflection, and geometry. The k_{eff} values for all undamaged cases are shown in Table B6-9. The k_{eff} values for all damaged cases are shown in Tables B6-10 and B6-11 for the vertical and side drop cases, respectively. Figure B6-11 shows the plotted data for the undamaged cases. Figures B6-12 and B6-13 show the plotted data for the damaged vertical cases with the gap between the MCO and shipping cask voided and flooded, respectively. Figures B6-14 and B6-15 show the plotted data for the damaged side cases with the gap between the MCO and shipping cask voided and flooded, respectively.

The vertical drop cases are generally more limiting than the side drop cases from a criticality safety perspective. The vertical drop cases model the fuel in a more compact and reactive form. The results of calculations characterizing the side drop accident are shown in Table 6B-11.

Figure B6-11. Undamaged MCO Reactivity Versus Fuel Region Water Density.

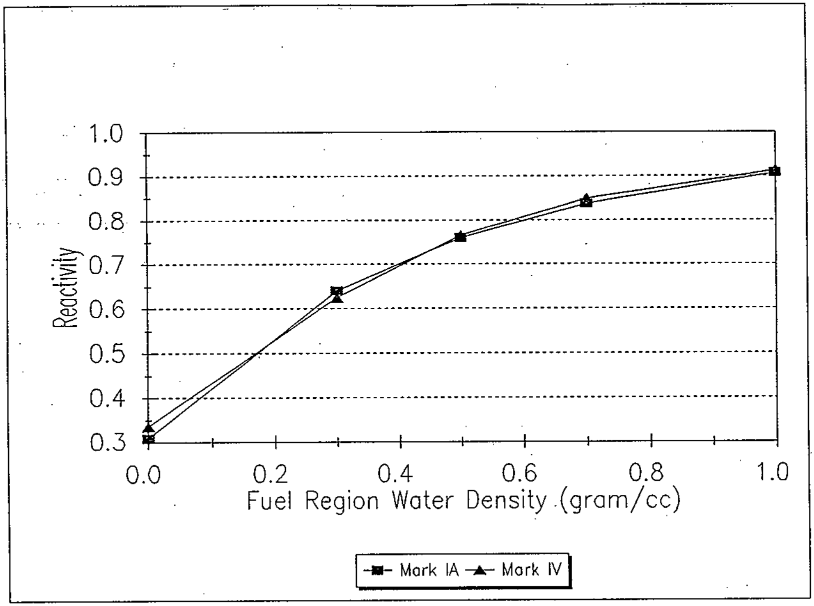


Figure B6-12. k_{eff} Values for Vertical Damaged Shipping Cask, Gap Voided.

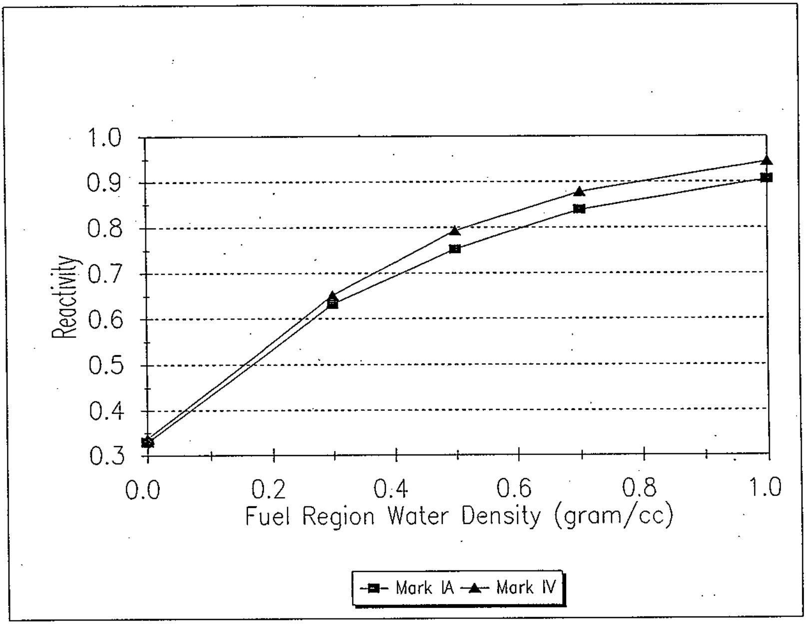


Figure B6-13. k_{eff} Values for Vertical Damaged Shipping Cask, Multicanister Overpack Flooded.

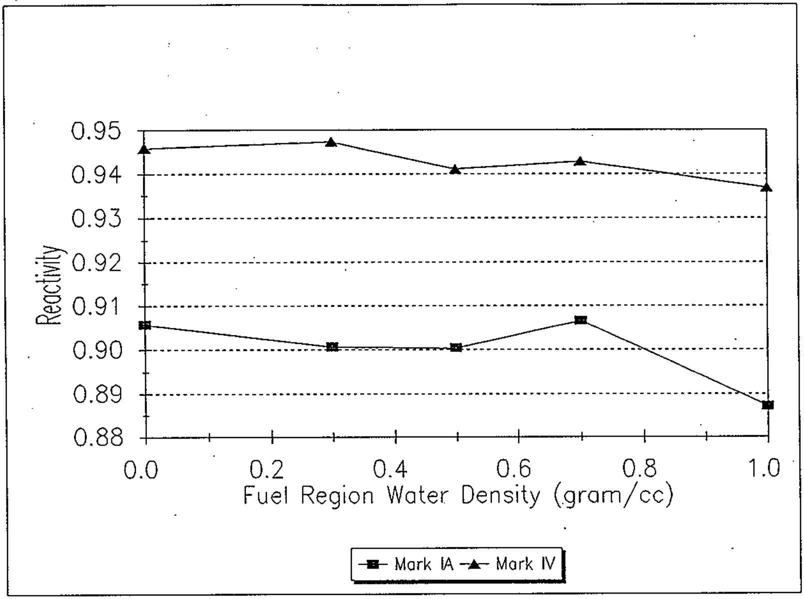


Figure B6-14. k_{eff} Values for Side-Damaged Cases, Gap Voided.

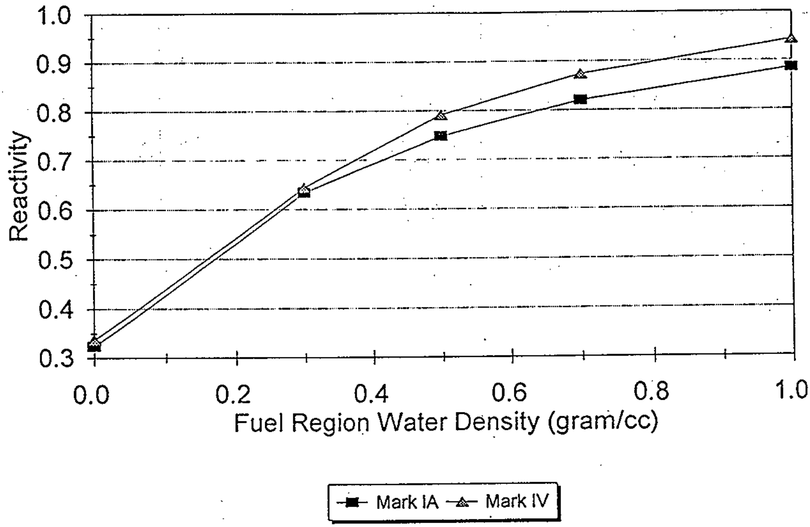


Figure B6-15. k_{eff} Values for Side-Damaged Cases, Multicanister Overpack Flooded.

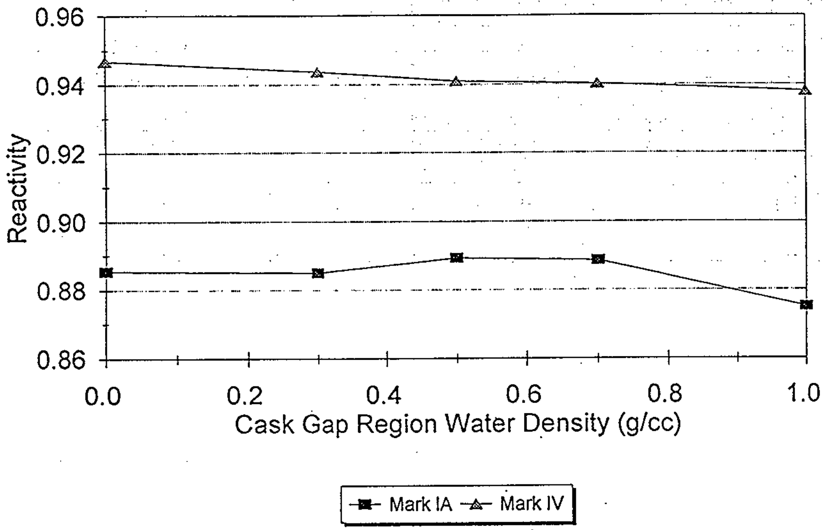


Table B6-10. Damaged Multicanister Overpack Cask in Vertical Position.

MCO type	MCO water density	Cask gap density moderator	k_{eff}	Standard deviation	95% C.L. plus bias	Input file
Mark IA	1.0	0.0	0.8940	0.0033	0.9057	i2.IA.10
Mark IA	0.7	0.0	0.8275	0.0028	0.8389	i2.IA.70
Mark IA	0.5	0.0	0.7405	0.0032	0.7521	i2.IA.50
Mark IA	0.3	0.0	0.6219	0.0022	0.6329	i2.IA.30
Mark IA	0.0	0.0	0.3193	0.0015	0.3300	i2.IA.00
Mark IA	1.0	1.0	0.8757	0.0028	0.8871	i2.IA.11
Mark IA	1.0	0.7	0.8954	0.0025	0.9066	i2.IA.17
Mark IA	1.0	0.5	0.8892	0.0025	0.9004	i2.IA.15
Mark IA	1.0	0.3	0.8890	0.0032	0.9007	i2.IA.13
Mark IA	1.0	0.0	0.8940	0.0033	0.9057	i2.IA.10
Mark IV	1.0	0.0	0.9355	0.0010	0.9460	i2.IV.10
Mark IV	0.7	0.0	0.8668	0.0032	0.8785	i2.IV.70
Mark IV	0.5	0.0	0.7814	0.0026	0.7927	i2.IV.50
Mark IV	0.3	0.0	0.6406	0.0029	0.6521	i2.IV.30
Mark IV	0.0	0.0	0.3272	0.0015	0.3378	i2.IV.00
Mark IV	1.0	1.0	0.9255	0.0028	0.9369	i2.IV.11
Mark IV	1.0	0.7	0.9316	0.0026	0.9429	i2.IV.17
Mark IV	1.0	0.5	0.9298	0.0028	0.9412	i2.IV.15
Mark IV	1.0	0.3	0.9360	0.0027	0.9474	i2.IV.13
Mark IV	1.0	0.0	0.9355	0.0010	0.9460	i2.IV.10

Table B6-11. Damaged Multicanister Overpack Cask in Side Drop Position.

MCO type	MCO water density	Cask gap density moderator	k_{eff}	Standard deviation	95% C.L. plus bias	Input file
Mark IA	1.0	0.0	0.8738	0.0032	0.8855	i2.IA.1
Mark IA	0.7	0.0	0.8089	0.0026	0.8202	i2.IA.2
Mark IA	0.5	0.0	0.7367	0.0029	0.7482	i2.IA.3
Mark IA	0.3	0.0	0.6227	0.0026	0.6340	i2.IA.4
Mark IA	0.0	0.0	0.3125	0.0018	0.3233	i2.IA.5
Mark IA	1.0	1.0	0.8640	0.0022	0.8750	i2.IA.6
Mark IA	1.0	0.7	0.8773	0.0026	0.8886	i2.IA.7
Mark IA	1.0	0.5	0.8772	0.0036	0.8892	i2.IA.8
Mark IA	1.0	0.3	0.8736	0.0029	0.8851	i2.IA.9
Mark IA	1.0	0.0	0.8738	0.0032	0.8855	i2.IA.10
Mark IV	1.0	0.0	0.9333	0.0010	0.9438	i2.IV.1
Mark IV	0.7	0.0	0.8634	0.0011	0.8740	i2.IV.2
Mark IV	0.5	0.0	0.7805	0.0010	0.7910	i2.IV.3
Mark IV	0.3	0.0	0.6337	0.0010	0.6442	i2.IV.4
Mark IV	0.0	0.0	0.3266	0.0007	0.3371	i2.IV.5
Mark IV	1.0	1.0	0.9275	0.0010	0.9380	i2.IV.6
Mark IV	1.0	0.7	0.9296	0.0012	0.9402	i2.IV.7
Mark IV	1.0	0.5	0.9304	0.0010	0.9409	i2.IV.8
Mark IV	1.0	0.3	0.9332	0.0010	0.9437	i2.IV.9
Mark IV	1.0	0.0	0.9361	0.0016	0.9468	i2.IV.10

6.4.3.1 TI. The TI is a dimensionless number placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation. For criticality control purposes the TI is the number obtained by dividing 50 by the number "N." The number "N" is based on the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:

- 5 x "N" undamaged packages with nothing between the packages would be subcritical.
- 2 x "N" damaged packages with optimum interspersed hydrogenous moderation would be subcritical.
- The value of "N" cannot be less than 0.5.

When "N" is equal to 0.5, 5 x "N" is rounded to yield a value of 3. The results shown in Table B6-12 indicate that arrays of three undamaged shipping casks, with optimum configuration and moderation, are subcritical for Mark IA and Mark IV MCOs. The calculations support the minimum value of N = 0.5 for the most limiting of the undamaged and damaged cases. Criticality TIs are shown in Tables B6-12 and B6-13.

Table B6-12. Transport Index for Undamaged N Reactor Multicanister Overpacks.

Contents	Number of casks subcritical	N	Transport index
Mark IA fuel	3	0.5	100
Mark IV fuel	3	0.5	100

Table B6-13. Transport Index for Damaged N Reactor Multicanister Overpacks.

Contents	Number of casks subcritical	N	Transport index
Mark IA fuel	1	0.5	100
Mark IV fuel	1	0.5	100

6.5 CRITICAL BENCHMARK EXPERIMENTS

The MCNP computer code (Breismeister 1993) is utilized all over the world and has been extensively tested with its ENDF/B-V-based cross sections. The code development group at LANL, where MCNP was developed, has a set of

25 calculational benchmarks that extensively test various options within the code. Additionally, MCNP has been certified for use on Hanford computer platforms (Carter 1995). This section justifies the validity of the calculational methods and neutron cross sections used by reporting the results of critical benchmark experiment analyses.

6.5.1 Benchmark Experiments and Applicability

Benchmark analyses have been performed with MCNP and the associated cross sections, as documented in Appendix G of *MCNP--A General Monte Carlo Code N-Particle Transport Code, Version 4a* (Breismeister 1993). These analyses were performed for both fast and thermalized benchmark problems (Whalen 1991). Six experiments were identified to represent various uranium critical systems similar to the MCO application. In addition to these experiments, experiments with N Reactor fuel and low-enriched uranium (LEU) were performed that are particularly applicable to the MCO models. These experiments and results are discussed below.

6.5.2 Introduction

An evaluation of K Basin criticality was made by Wittekind (1992) that included a validation of the MCNP code (Carter 1991). Comparisons were made to several criticality experiments and to other criticality codes, specifically the WIMS (versions D and E) code (WTC 1992). The comparisons provide good support for the use of MCNP in LEU systems typical of N Reactor fuel in the K Basins.

The experimental support for the validation of this study was reexamined (Schmittroth 1996) to determine a calculational bias to be used in further criticality evaluations. New validation calculations were not undertaken.

Two experiments reported by Wittekind were considered: an early report on UO_3-H_2O solutions (Neeley and Handler 1961) and a lattice experiment using actual Mark IA N Reactor fuel elements (Brown et al. 1965). A third experiment performed by Douglas United Nuclear in the 105 N Fuel Storage Basin (Neilson and Toffer 1975) reported k_{eff} values that were often well below the MCNP results. Finally, results from a benchmark experiment using 2.35% enriched fuel (Briggs et al. 1992) are included.

The experimental results, a statistical analysis, and analysis results and recommendations are discussed in detail in Schmittroth (1996). A few details are provided below from that report.

6.5.3 Experimental Results

6.5.3.1 UO_3-H_2O Solution Measurements. The homogeneous wet uranium UO_3-H_2O solution experiments consisted of 12 measured values for three different enrichments and a range of hydrogen-to-uranium ratios from 3.73 to 7.45. Table B6-14 shows numerical values for both the experiment and MCNP results.

Table B6-14. Monte Carlo N-Particle (MCNP) Calculations and Experimental Results for Homogeneous UO_3-H_2O Systems.

Enrichment	H/U	MCNP	Experiment	Experiment Uncert.
1.0059	3.772	0.9898	0.9920	0.0060
	4.999	0.9945	0.9925	0.0050
	6.614	0.9830	0.9875	0.0058
	6.881	0.9761	0.9821	0.0054
	7.449	0.9680	0.9702	0.0070
1.0704	3.728	1.0125	1.0063	0.0070
	5.778	1.0103	1.0064	0.0080
	7.075	0.9964	0.9957	0.0061
1.1586	3.728	1.0358	1.0298	0.0060
	5.926	1.0412	1.0330	0.0051
	6.838	1.0311	1.0313	0.0032
	7.449	1.0240	1.0209	0.0051

H/U = Hydrogen to uranium (ratio).

6.5.3.2 Mark IA Lattice Experiment. A set of criticality measurements was made using a lattice of actual unexposed N Reactor Mark IA fuel elements (Brown et al. 1965). The experiment consisted of three distinct types of measurements (exponential pile, neutron multiplication, and pulsed-neutron) and two fuel lattice configurations (Mark IA outers and tube-in-tube assemblies). Several different lattice pitches (2.8 in., 3.1 in., and 3.4 in.) were also included. The experiment was representative of actual N Reactor fuel configurations, with fuel elements of metallic uranium with density close to 18.64 g/cm^3. However, experimental uncertainties were not reported either in the initial report or by Wittekind (1992). Representative MCNP statistical uncertainties were determined to be 2 mk. An experimental uncertainty of ±5 Mark IA outers or tube-in-tube assemblies was determined which corresponded to an uncertainty of ±0.005 in k_{eff}.

Experimental and calculated values were compared by fitting curves to the calculated points. Ratios of the MCNP-fitted curves to the experimental values were found to be 0.9979, 0.9968, and 1.0077 for the lattice pitches 2.8 in., 3.1 in., and 3.4 in., respectively.

6.5.3.3 Benchmark Experiment for 2.35% Enriched Lattice. A set of measurements was performed at Pacific Northwest National Laboratory critical mass laboratory and designated as LEU-COMP-THERM-001 (Briggs et al. 1992). Results are given for eight water-moderated UO_2 (2.35% enriched) lattices, mostly grouped in three clusters. The reported benchmark value for k_{eff} is 0.9998 ± 0.0031. (The value less than one accounts for a small correction from acrylic lattice plates omitted from the model.) The benchmark report also includes MCNP results with statistical errors for comparison (≈1.6 mk). Resulting values are shown in Table B6-15.

Table B6-15. Monte Carlo N-Particle Calculations From Benchmark Report LEU-COMP-THERM-001.*

Case number	Number of clusters	Cluster dimensions (No. of rods, X x Y)	Monte Carlo N-Particle
1	1	20 x 18.08	0.9987 ± 0.0016
2	3	20 x 17	0.9977 ± 0.0017
3	3	20 x 16	0.9956 ± 0.0016
4	3	20 x 16 (center) 22 x 16 (two outer)	0.9992 ± 0.0014
5	3	20 x 15	0.9970 ± 0.0016
6	3	20 x 15 (center) 24 x 15 (two outer)	0.9955 ± 0.0015
7	3	20 x 14	0.9968 ± 0.0017
8	3	19 x 16	0.9921 ± 0.0015

*Source: Briggs, J. B., et al., 1992, International Handbook of Evaluated Criticality Safety Benchmark Experiments, Volume IV, Low Enriched Uranium Systems, NEA/NSC/DOC(95)03/IV, Nuclear Energy Agency, Organization for Economic Co-operation and Development OECD, Paris.

6.5.4 Statistical Analysis

The results of the above cases were used to determine a calculational bias, b, defined by

$$k_{calc}=k_{eff}+b$$

where k_{calc} represents the calculated estimate of k_{eff}.

A lower tolerance limit b_L was established such that one is 95% confident that 95% of the population is above the limit. The non-central t-distribution gives a prescription (Resnikoff and Lieberman 1956) for this limit:

$$b_L=b_{ave}-K_b s_b$$

where b_{ave} is the mean value and s_b is the corresponding sample variance. The multiplier K_b was found from statistical tables of the non-central t-distribution that depended on the number of degrees of freedom for the supporting measurements.

Table B6-16 shows the results: the average bias, b_{ave}, and the associated sample variance (expressed as a standard deviation, s_b) for each of the three individual data sets and for the pooled total set of data. The average assigned experimental uncertainty, $\sigma_{m\text{-}ave}$, is shown for comparison.

Table B6-16. Statistical Monte Carlo N-Particle Bias Results for Three Experiments and the Pooled Data.

Description	n	b_{ave}, mk	s_b, mk	$\sigma_{m\text{-}ave}$, mk	$sb/\sigma_{m\text{-}ave}$
UO_3-H_2O solution	12	1.2	4.4	5.8	0.76
Mark IA elements	3	0.8	6.0	5.0	1.20
Benchmark experiment	8	-3.2	2.2	3.5	0.64
Pooled data	23	-0.4	3.8	4.9	0.78

Based on the results in Table B6-16, the pooled bias of b_{ave} = -0.4 mk was chosen for the final result. This choice includes the lower values of the benchmark data, giving a conservative result. A standard deviation of s_b = 5.0 mk was chosen in favor of the somewhat lower value of 3.8 mk associated with pooled sample variance. The latter value assumes that all the data points are independent, while the larger value is generally consistent with the results in Table B6-16.

Finally, a value of the multiplier K_b was determined. A precise value for K_b can only be determined for a known number of degrees of freedom. Nevertheless for a 95/95 tolerance limit, standard non-central t-distribution tables show that K_b ranges from 2.4 to 1.9 as the degrees-of-freedom range from 20-100. Given that a somewhat conservative value was already chosen for s_b, a conventional and rounded value of K_b = 2.0 is a good practical choice.

The final result for the lower tolerance limit of the bias (calculated to two significant figures and rounded up to be conservative) is

$$\begin{aligned} b_L &= -0.4 - (2)(5.0) \\ &= -11 \text{ mk} \end{aligned}$$

Therefore, +11 mk should be added to MCNP criticality computed results prior to checking for other prescribed limits.

To account for MCNP statistical uncertainties, an additional value 1.645 σ_c is added in quadrature to the bias uncertainty. This means that the MCNP statistical uncertainties are not correlated to the uncertainty in the bias when compared to experiment. The value of 1.645 is the number of standard deviations in the standard normal distribution required to yield 95% confidence in the calculation. For example, a value of σ_c=2.0 mk would yield a combined limit of:

$$-0.4-[10^2+(1.645\text{x}2)^2]^{1/2} = -10.9 \text{ mk}.$$

6.5.5 Results

The results are summarized by

$$k_{calc}+0.0004+\sqrt{0.010^2+(1.645\sigma_{calc})^2} < k_{limit}$$

where k_{calc} and σ_{calc} represent the calculated value for k_{eff} and its standard deviation respectively. The limit, k_{limit}, is an established limiting value. The multiplier of 1.645 was obtained from tables of the normal distribution. This multiplier ensures that 95% of the MCNP population is bounded by the limit and assumes that there is no uncertainty in the standard deviation, σ_{calc}.

An alternative calculation can be made by assuming a value of σ_{calc} that is larger than that accepted by almost all criticality calculations done by specialists using MCNP is 0.004 k. For this value, the bias limit would be:

$$k_{calc}+0.0004+\sqrt{0.010^2+(1.645*0.004)^2} < k_{limit}$$

$$k_{calc}<k_{limit}-0.013k$$

so

$$k_{calc}+0.013k < k_{limit}$$

All resulting values are rounded up to be conservative.

Using the above calculated bias value means that the k_{calc} computed from a new MCNP run would have to be below k_{limit} - 0.013 k in meeting the allowable limit on k_{eff}. For a k_{limit} of 0.95, k_{calc} would have to be less than 0.937 to be within acceptable limits. If this particular value is used for the acceptable limit, the σ_{calc} must be less than 0.004 for each calculation.

6.6 REFERENCES

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6.7 APPENDIX: MCNP CODE INPUT LISTINGS

The following files were used in the criticality analysis. They are stored in CFS (Common File System) in /w80395/mco/sarpcrit.tar.Z.

```
i1.IA.10  A hardcopy of this file is printed below
i1.IA.30  Like i1.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.30" in all cells except cell 437
i1.IA.50  Like i1.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.50" in all cells except cell 437
i1.IA.70  Like i1.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.70" in all cells except cell 437
i1.IA.00  Like i1.IA.10, but the pattern "4  -1.00" is replaced with "0
          " in all cells except cells 437

i1.IV.10  A hardcopy of this file is printed below
i1.IV.30  Like i1.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.30" in all cells except cell 480
i1.IV.50  Like i1.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.50" in all cells except cell 480
i1.IV.70  Like i1.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.70" in all cells except cell 480
i1.IV.00  Like i1.IV.10, but the pattern "4  -1.00" is replaced with "0
          " in all cells except cell 480

i2.IA.10  A hardcopy of this file is printed below
i2.IA.30  Like i2.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.30" in all cells except cell 427
i2.IA.50  Like i2.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.50" in all cells except cell 427
i2.IA.70  Like i2.IA.10, but the pattern "4  -1.00" is replaced with "4  -
          0.70" in all cells except cell 427
i2.IA.00  Like i2.IA.10, but the pattern "4  -1.00" is replaced with "0
          " in all cells except cell 427
i2.IA.11  Like i2.IA.10, but the pattern "0        " is replaced with "4  -
          1.00" in cell 430
i2.IA.13  Like i2.IA.10, but the pattern "0        " is replaced with "4  -
          0.30" in cell 430
i2.IA.15  Like i2.IA.10, but the pattern "0        " is replaced with "4  -
          0.50" in cell 430
i2.IA.17  Like i2.IA.10, but the pattern "0        " is replaced with "4  -
          0.70" in cell 430

i2.IV.10  A hardcopy of this file is printed below
i2.IV.30  Like i2.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.30" in all cells except cell 470
i2.IV.50  Like i2.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.50" in all cells except cell 470
i2.IV.70  Like i2.IV.10, but the pattern "4  -1.00" is replaced with "4  -
          0.70" in all cells except cell 470
i2.IV.00  Like i2.IV.10, but the pattern "4  -1.00" is replaced with "0
          " in all cells except cell 470
i2.IV.11  Like i2.IV.10, but the pattern "0        " is replaced with "4  -
          1.00" in cell 473
```

i2.IV.13 Like i2.IV.10, but the pattern "0 " is replaced with "4 - 0.30" in cell 473
i2.IV.15 Like i2.IV.10, but the pattern "0 " is replaced with "4 - 0.50" in cell 473
i2.IV.17 Like i2.IV.10, but the pattern "0 " is replaced with "4 - 0.70" in cell 473

FILE i1.IA.10

```
message:

MCO SARP, Normal condition, MKIA, MCO water density 1.0, annulus 0.0
  1 4  -1.00        -1 388  -389 u=1 imp:n=1 $ inner water.....position 1
  2 2  -6.55    1   -2 388  -389 u=1 imp:n=1 $ zr clad
  3 1 -18.58    2   -3 388  -389 u=1 imp:n=1 $ inner fuel
  4 2  -6.55    3   -4 388  -389 u=1 imp:n=1 $ zr clad
  5 4  -1.00    4   -5 388  -389 u=1 imp:n=1 $ water
  6 2  -6.55    5   -6 388  -389 u=1 imp:n=1 $ zr clad
  7 6 -18.58    6   -7 388  -389 u=1 imp:n=1 $ outer fuel
  8 2  -6.55    7   -8 388  -389 u=1 imp:n=1 $ zr clad
  9 4  -1.00        -9 388  -389 u=1 imp:n=1 $ inner water.....position 2
 10 2  -6.55    9  -10 388  -389 u=1 imp:n=1 $ zr clad
 11 1 -18.58   10  -11 388  -389 u=1 imp:n=1 $ inner fuel
 12 2  -6.55   11  -12 388  -389 u=1 imp:n=1 $ zr clad
 13 4  -1.00   12  -13 388  -389 u=1 imp:n=1 $ water
 14 2  -6.55   13  -14 388  -389 u=1 imp:n=1 $ zr clad
 15 6 -18.58   14  -15 388  -389 u=1 imp:n=1 $ outer fuel
 16 2  -6.55   15  -16 388  -389 u=1 imp:n=1 $ zr clad
 17 4  -1.00       -17 388  -389 u=1 imp:n=1 $ inner water.....position 3
 18 2  -6.55   17  -18 388  -389 u=1 imp:n=1 $ zr clad
 19 1 -18.58   18  -19 388  -389 u=1 imp:n=1 $ inner fuel
 20 2  -6.55   19  -20 388  -389 u=1 imp:n=1 $ zr clad
 21 4  -1.00   20  -21 388  -389 u=1 imp:n=1 $ water
 22 2  -6.55   21  -22 388  -389 u=1 imp:n=1 $ zr clad
 23 6 -18.58   22  -23 388  -389 u=1 imp:n=1 $ outer fuel
 24 2  -6.55   23  -24 388  -389 u=1 imp:n=1 $ zr clad
 25 4  -1.00       -25 388  -389 u=1 imp:n=1 $ inner water.....position 4
 26 2  -6.55   25  -26 388  -389 u=1 imp:n=1 $ zr clad
 27 1 -18.58   26  -27 388  -389 u=1 imp:n=1 $ inner fuel
 28 2  -6.55   27  -28 388  -389 u=1 imp:n=1 $ zr clad
 29 4  -1.00   28  -29 388  -389 u=1 imp:n=1 $ water
 30 2  -6.55   29  -30 388  -389 u=1 imp:n=1 $ zr clad
 31 6 -18.58   30  -31 388  -389 u=1 imp:n=1 $ outer fuel
 32 2  -6.55   31  -32 388  -389 u=1 imp:n=1 $ zr clad
 33 4  -1.00       -33 388  -389 u=1 imp:n=1 $ inner water.....position 5
 34 2  -6.55   33  -34 388  -389 u=1 imp:n=1 $ zr clad
 35 1 -18.58   34  -35 388  -389 u=1 imp:n=1 $ inner fuel
 36 2  -6.55   35  -36 388  -389 u=1 imp:n=1 $ zr clad
 37 4  -1.00   36  -37 388  -389 u=1 imp:n=1 $ water
 38 2  -6.55   37  -38 388  -389 u=1 imp:n=1 $ zr clad
 39 6 -18.58   38  -39 388  -389 u=1 imp:n=1 $ outer fuel
 40 2  -6.55   39  -40 388  -389 u=1 imp:n=1 $ zr clad
 41 4  -1.00       -41 388  -389 u=1 imp:n=1 $ inner water.....position 6
 42 2  -6.55   41  -42 388  -389 u=1 imp:n=1 $ zr clad
 43 1 -18.58   42  -43 388  -389 u=1 imp:n=1 $ inner fuel
 44 2  -6.55   43  -44 388  -389 u=1 imp:n=1 $ zr clad
 45 4  -1.00   44  -45 388  -389 u=1 imp:n=1 $ water
 46 2  -6.55   45  -46 388  -389 u=1 imp:n=1 $ zr clad
 47 6 -18.58   46  -47 388  -389 u=1 imp:n=1 $ outer fuel
 48 2  -6.55   47  -48 388  -389 u=1 imp:n=1 $ zr clad
 49 4  -1.00       -49 388  -389 u=1 imp:n=1 $ inner water.....position 7
 50 2  -6.55   49  -50 388  -389 u=1 imp:n=1 $ zr clad
 51 1 -18.58   50  -51 388  -389 u=1 imp:n=1 $ inner fuel
 52 2  -6.55   51  -52 388  -389 u=1 imp:n=1 $ zr clad
 53 4  -1.00   52  -53 388  -389 u=1 imp:n=1 $ water
 54 2  -6.55   53  -54 388  -389 u=1 imp:n=1 $ zr clad
 55 6 -18.58   54  -55 388  -389 u=1 imp:n=1 $ outer fuel
 56 2  -6.55   55  -56 388  -389 u=1 imp:n=1 $ zr clad
 57 4  -1.00       -57 388  -389 u=1 imp:n=1 $ inner water.....position 8
 58 2  -6.55   57  -58 388  -389 u=1 imp:n=1 $ zr clad
```

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59 1 -18.58   58   -59 388   -389 u=1 imp:n=1 $ inner fuel
60 2  -6.55   59   -60 388   -389 u=1 imp:n=1 $ zr clad
61 4  -1.00   60   -61 388   -389 u=1 imp:n=1 $ water
62 2  -6.55   61   -62 388   -389 u=1 imp:n=1 $ zr clad
63 6 -18.58   62   -63 388   -389 u=1 imp:n=1 $ outer fuel
64 2  -6.55   63   -64 388   -389 u=1 imp:n=1 $ zr clad
65 4  -1.00        -65 388   -389 u=1 imp:n=1 $ inner water.....position 9
66 2  -6.55   65   -66 388   -389 u=1 imp:n=1 $ zr clad
67 1 -18.58   66   -67 388   -389 u=1 imp:n=1 $ inner fuel
68 2  -6.55   67   -68 388   -389 u=1 imp:n=1 $ zr clad
69 4  -1.00   68   -69 388   -389 u=1 imp:n=1 $ water
70 2  -6.55   69   -70 388   -389 u=1 imp:n=1 $ zr clad
71 6 -18.58   70   -71 388   -389 u=1 imp:n=1 $ outer fuel
72 2  -6.55   71   -72 388   -389 u=1 imp:n=1 $ zr clad
73 4  -1.00        -73 388   -389 u=1 imp:n=1 $ inner water.....position 10
74 2  -6.55   73   -74 388   -389 u=1 imp:n=1 $ zr clad
75 1 -18.58   74   -75 388   -389 u=1 imp:n=1 $ inner fuel
76 2  -6.55   75   -76 388   -389 u=1 imp:n=1 $ zr clad
77 4  -1.00   76   -77 388   -389 u=1 imp:n=1 $ water
78 2  -6.55   77   -78 388   -389 u=1 imp:n=1 $ zr clad
79 6 -18.58   78   -79 388   -389 u=1 imp:n=1 $ outer fuel
80 2  -6.55   79   -80 388   -389 u=1 imp:n=1 $ zr clad
81 4  -1.00        -81 388   -389 u=1 imp:n=1 $ inner water.....position 11
82 2  -6.55   81   -82 388   -389 u=1 imp:n=1 $ zr clad
83 1 -18.58   82   -83 388   -389 u=1 imp:n=1 $ inner fuel
84 2  -6.55   83   -84 388   -389 u=1 imp:n=1 $ zr clad
85 4  -1.00   84   -85 388   -389 u=1 imp:n=1 $ water
86 2  -6.55   85   -86 388   -389 u=1 imp:n=1 $ zr clad
87 6 -18.58   86   -87 388   -389 u=1 imp:n=1 $ outer fuel
88 2  -6.55   87   -88 388   -389 u=1 imp:n=1 $ zr clad
89 4  -1.00        -89 388   -389 u=1 imp:n=1 $ inner water.....position 12
90 2  -6.55   89   -90 388   -389 u=1 imp:n=1 $ zr clad
91 1 -18.58   90   -91 388   -389 u=1 imp:n=1 $ inner fuel
92 2  -6.55   91   -92 388   -389 u=1 imp:n=1 $ zr clad
93 4  -1.00   92   -93 388   -389 u=1 imp:n=1 $ water
94 2  -6.55   93   -94 388   -389 u=1 imp:n=1 $ zr clad
95 6 -18.58   94   -95 388   -389 u=1 imp:n=1 $ outer fuel
96 2  -6.55   95   -96 388   -389 u=1 imp:n=1 $ zr clad
97 4  -1.00        -97 388   -389 u=1 imp:n=1 $ inner water.....position 13
98 2  -6.55   97   -98 388   -389 u=1 imp:n=1 $ zr clad
99 1 -18.58   98   -99 388   -389 u=1 imp:n=1 $ inner fuel
100 2  -6.55  99  -100 388   -389 u=1 imp:n=1 $ zr clad
101 4  -1.00  100 -101 388   -389 u=1 imp:n=1 $ water
102 2  -6.55  101 -102 388   -389 u=1 imp:n=1 $ zr clad
103 6 -18.58  102 -103 388   -389 u=1 imp:n=1 $ outer fuel
104 2  -6.55  103 -104 388   -389 u=1 imp:n=1 $ zr clad
105 4  -1.00      -105 388   -389 u=1 imp:n=1 $ inner water.....position 14
106 2  -6.55  105 -106 388   -389 u=1 imp:n=1 $ zr clad
107 1 -18.58  106 -107 388   -389 u=1 imp:n=1 $ inner fuel
108 2  -6.55  107 -108 388   -389 u=1 imp:n=1 $ zr clad
109 4  -1.00  108 -109 388   -389 u=1 imp:n=1 $ water
110 2  -6.55  109 -110 388   -389 u=1 imp:n=1 $ zr clad
111 6 -18.58  110 -111 388   -389 u=1 imp:n=1 $ outer fuel
112 2  -6.55  111 -112 388   -389 u=1 imp:n=1 $ zr clad
113 4  -1.00      -113 388   -389 u=1 imp:n=1 $ inner water.....position 15
114 2  -6.55  113 -114 388   -389 u=1 imp:n=1 $ zr clad
115 1 -18.58  114 -115 388   -389 u=1 imp:n=1 $ inner fuel
116 2  -6.55  115 -116 388   -389 u=1 imp:n=1 $ zr clad
117 4  -1.00  116 -117 388   -389 u=1 imp:n=1 $ water
118 2  -6.55  117 -118 388   -389 u=1 imp:n=1 $ zr clad
119 6 -18.58  118 -119 388   -389 u=1 imp:n=1 $ outer fuel
120 2  -6.55  119 -120 388   -389 u=1 imp:n=1 $ zr clad
121 4  -1.00      -121 388   -389 u=1 imp:n=1 $ inner water.....position 16
122 2  -6.55  121 -122 388   -389 u=1 imp:n=1 $ zr clad
123 1 -18.58  122 -123 388   -389 u=1 imp:n=1 $ inner fuel
124 2  -6.55  123 -124 388   -389 u=1 imp:n=1 $ zr clad
125 4  -1.00  124 -125 388   -389 u=1 imp:n=1 $ water
126 2  -6.55  125 -126 388   -389 u=1 imp:n=1 $ zr clad
127 6 -18.58  126 -127 388   -389 u=1 imp:n=1 $ outer fuel
128 2  -6.55  127 -128 388   -389 u=1 imp:n=1 $ zr clad
129 4  -1.00      -129 388   -389 u=1 imp:n=1 $ inner water.....position 17
130 2  -6.55  129 -130 388   -389 u=1 imp:n=1 $ zr clad
131 1 -18.58  130 -131 388   -389 u=1 imp:n=1 $ inner fuel
132 2  -6.55  131 -132 388   -389 u=1 imp:n=1 $ zr clad
133 4  -1.00  132 -133 388   -389 u=1 imp:n=1 $ water
134 2  -6.55  133 -134 388   -389 u=1 imp:n=1 $ zr clad
```

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135 6 -18.58   134 -135 388  -389 u=1 imp:n=1 $ outer fuel
136 2  -6.55   135 -136 388  -389 u=1 imp:n=1 $ zr clad
137 4  -1.00       -137 388  -389 u=1 imp:n=1 $ inner water.....position 18
138 2  -6.55   137 -138 388  -389 u=1 imp:n=1 $ zr clad
139 1 -18.58   138 -139 388  -389 u=1 imp:n=1 $ inner fuel
140 2  -6.55   139 -140 388  -389 u=1 imp:n=1 $ zr clad
141 4  -1.00   140 -141 388  -389 u=1 imp:n=1 $ water
142 2  -6.55   141 -142 388  -389 u=1 imp:n=1 $ zr clad
143 6 -18.58   142 -143 388  -389 u=1 imp:n=1 $ outer fuel
144 2  -6.55   143 -144 388  -389 u=1 imp:n=1 $ zr clad
145 4  -1.00       -145 388  -389 u=1 imp:n=1 $ inner water.....position 19
146 2  -6.55   145 -146 388  -389 u=1 imp:n=1 $ zr clad
147 1 -18.58   146 -147 388  -389 u=1 imp:n=1 $ inner fuel
148 2  -6.55   147 -148 388  -389 u=1 imp:n=1 $ zr clad
149 4  -1.00   148 -149 388  -389 u=1 imp:n=1 $ water
150 2  -6.55   149 -150 388  -389 u=1 imp:n=1 $ zr clad
151 6 -18.58   150 -151 388  -389 u=1 imp:n=1 $ outer fuel
152 2  -6.55   151 -152 388  -389 u=1 imp:n=1 $ zr clad
153 4  -1.00       -153 388  -389 u=1 imp:n=1 $ inner water.....position 20
154 2  -6.55   153 -154 388  -389 u=1 imp:n=1 $ zr clad
155 1 -18.58   154 -155 388  -389 u=1 imp:n=1 $ inner fuel
156 2  -6.55   155 -156 388  -389 u=1 imp:n=1 $ zr clad
157 4  -1.00   156 -157 388  -389 u=1 imp:n=1 $ water
158 2  -6.55   157 -158 388  -389 u=1 imp:n=1 $ zr clad
159 6 -18.58   158 -159 388  -389 u=1 imp:n=1 $ outer fuel
160 2  -6.55   159 -160 388  -389 u=1 imp:n=1 $ zr clad
161 4  -1.00       -161 388  -389 u=1 imp:n=1 $ inner water.....position 21
162 2  -6.55   161 -162 388  -389 u=1 imp:n=1 $ zr clad
163 1 -18.58   162 -163 388  -389 u=1 imp:n=1 $ inner fuel
164 2  -6.55   163 -164 388  -389 u=1 imp:n=1 $ zr clad
165 4  -1.00   164 -165 388  -389 u=1 imp:n=1 $ water
166 2  -6.55   165 -166 388  -389 u=1 imp:n=1 $ zr clad
167 6 -18.58   166 -167 388  -389 u=1 imp:n=1 $ outer fuel
168 2  -6.55   167 -168 388  -389 u=1 imp:n=1 $ zr clad
169 4  -1.00       -169 388  -389 u=1 imp:n=1 $ inner water.....position 22
170 2  -6.55   169 -170 388  -389 u=1 imp:n=1 $ zr clad
171 1 -18.58   170 -171 388  -389 u=1 imp:n=1 $ inner fuel
172 2  -6.55   171 -172 388  -389 u=1 imp:n=1 $ zr clad
173 4  -1.00   172 -173 388  -389 u=1 imp:n=1 $ water
174 2  -6.55   173 -174 388  -389 u=1 imp:n=1 $ zr clad
175 6 -18.58   174 -175 388  -389 u=1 imp:n=1 $ outer fuel
176 2  -6.55   175 -176 388  -389 u=1 imp:n=1 $ zr clad
177 4  -1.00       -177 388  -389 u=1 imp:n=1 $ inner water.....position 23
178 2  -6.55   177 -178 388  -389 u=1 imp:n=1 $ zr clad
179 1 -18.58   178 -179 388  -389 u=1 imp:n=1 $ inner fuel
180 2  -6.55   179 -180 388  -389 u=1 imp:n=1 $ zr clad
181 4  -1.00   180 -181 388  -389 u=1 imp:n=1 $ water
182 2  -6.55   181 -182 388  -389 u=1 imp:n=1 $ zr clad
183 6 -18.58   182 -183 388  -389 u=1 imp:n=1 $ outer fuel
184 2  -6.55   183 -184 388  -389 u=1 imp:n=1 $ zr clad
185 4  -1.00       -185 388  -389 u=1 imp:n=1 $ inner water.....position 24
186 2  -6.55   185 -186 388  -389 u=1 imp:n=1 $ zr clad
187 1 -18.58   186 -187 388  -389 u=1 imp:n=1 $ inner fuel
188 2  -6.55   187 -188 388  -389 u=1 imp:n=1 $ zr clad
189 4  -1.00   188 -189 388  -389 u=1 imp:n=1 $ water
190 2  -6.55   189 -190 388  -389 u=1 imp:n=1 $ zr clad
191 6 -18.58   190 -191 388  -389 u=1 imp:n=1 $ outer fuel
192 2  -6.55   191 -192 388  -389 u=1 imp:n=1 $ zr clad
193 4  -1.00       -193 388  -389 u=1 imp:n=1 $ inner water.....position 25
194 2  -6.55   193 -194 388  -389 u=1 imp:n=1 $ zr clad
195 1 -18.58   194 -195 388  -389 u=1 imp:n=1 $ inner fuel
196 2  -6.55   195 -196 388  -389 u=1 imp:n=1 $ zr clad
197 4  -1.00   196 -197 388  -389 u=1 imp:n=1 $ water
198 2  -6.55   197 -198 388  -389 u=1 imp:n=1 $ zr clad
199 6 -18.58   198 -199 388  -389 u=1 imp:n=1 $ outer fuel
200 2  -6.55   199 -200 388  -389 u=1 imp:n=1 $ zr clad
201 4  -1.00       -201 388  -389 u=1 imp:n=1 $ inner water.....position 26
202 2  -6.55   201 -202 388  -389 u=1 imp:n=1 $ zr clad
203 1 -18.58   202 -203 388  -389 u=1 imp:n=1 $ inner fuel
204 2  -6.55   203 -204 388  -389 u=1 imp:n=1 $ zr clad
205 4  -1.00   204 -205 388  -389 u=1 imp:n=1 $ water
206 2  -6.55   205 -206 388  -389 u=1 imp:n=1 $ zr clad
207 6 -18.58   206 -207 388  -389 u=1 imp:n=1 $ outer fuel
208 2  -6.55   207 -208 388  -389 u=1 imp:n=1 $ zr clad
209 4  -1.00       -209 388  -389 u=1 imp:n=1 $ inner water.....position 27
210 2  -6.55   209 -210 388  -389 u=1 imp:n=1 $ zr clad
```

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211 1 -18.58   210 -211 388   -389 u=1 imp:n=1 $ inner fuel
212 2  -6.55   211 -212 388   -389 u=1 imp:n=1 $ zr clad
213 4  -1.00   212 -213 388   -389 u=1 imp:n=1 $ water
214 2  -6.55   213 -214 388   -389 u=1 imp:n=1 $ zr clad
215 6 -18.58   214 -215 388   -389 u=1 imp:n=1 $ outer fuel
216 2  -6.55   215 -216 388   -389 u=1 imp:n=1 $ zr clad
217 4  -1.00       -217 388   -389 u=1 imp:n=1 $ inner water.....position 28
218 2  -6.55   217 -218 388   -389 u=1 imp:n=1 $ zr clad
219 1 -18.58   218 -219 388   -389 u=1 imp:n=1 $ inner fuel
220 2  -6.55   219 -220 388   -389 u=1 imp:n=1 $ zr clad
221 4  -1.00   220 -221 388   -389 u=1 imp:n=1 $ water
222 2  -6.55   221 -222 388   -389 u=1 imp:n=1 $ zr clad
223 6 -18.58   222 -223 388   -389 u=1 imp:n=1 $ outer fuel
224 2  -6.55   223 -224 388   -389 u=1 imp:n=1 $ zr clad
225 4  -1.00       -225 388   -389 u=1 imp:n=1 $ inner water.....position 29
226 2  -6.55   225 -226 388   -389 u=1 imp:n=1 $ zr clad
227 1 -18.58   226 -227 388   -389 u=1 imp:n=1 $ inner fuel
228 2  -6.55   227 -228 388   -389 u=1 imp:n=1 $ zr clad
229 4  -1.00   228 -229 388   -389 u=1 imp:n=1 $ water
230 2  -6.55   229 -230 388   -389 u=1 imp:n=1 $ zr clad
231 6 -18.58   230 -231 388   -389 u=1 imp:n=1 $ outer fuel
232 2  -6.55   231 -232 388   -389 u=1 imp:n=1 $ zr clad
233 4  -1.00       -233 388   -389 u=1 imp:n=1 $ inner water.....position 30
234 2  -6.55   233 -234 388   -389 u=1 imp:n=1 $ zr clad
235 1 -18.58   234 -235 388   -389 u=1 imp:n=1 $ inner fuel
236 2  -6.55   235 -236 388   -389 u=1 imp:n=1 $ zr clad
237 4  -1.00   236 -237 388   -389 u=1 imp:n=1 $ water
238 2  -6.55   237 -238 388   -389 u=1 imp:n=1 $ zr clad
239 6 -18.58   238 -239 388   -389 u=1 imp:n=1 $ outer fuel
240 2  -6.55   239 -240 388   -389 u=1 imp:n=1 $ zr clad
241 4  -1.00       -241 388   -389 u=1 imp:n=1 $ inner water.....position 31
242 2  -6.55   241 -242 388   -389 u=1 imp:n=1 $ zr clad
243 1 -18.58   242 -243 388   -389 u=1 imp:n=1 $ inner fuel
244 2  -6.55   243 -244 388   -389 u=1 imp:n=1 $ zr clad
245 4  -1.00   244 -245 388   -389 u=1 imp:n=1 $ water
246 2  -6.55   245 -246 388   -389 u=1 imp:n=1 $ zr clad
247 6 -18.58   246 -247 388   -389 u=1 imp:n=1 $ outer fuel
248 2  -6.55   247 -248 388   -389 u=1 imp:n=1 $ zr clad
249 4  -1.00       -249 388   -389 u=1 imp:n=1 $ inner water.....position 32
250 2  -6.55   249 -250 388   -389 u=1 imp:n=1 $ zr clad
251 1 -18.58   250 -251 388   -389 u=1 imp:n=1 $ inner fuel
252 2  -6.55   251 -252 388   -389 u=1 imp:n=1 $ zr clad
253 4  -1.00   252 -253 388   -389 u=1 imp:n=1 $ water
254 2  -6.55   253 -254 388   -389 u=1 imp:n=1 $ zr clad
255 6 -18.58   254 -255 388   -389 u=1 imp:n=1 $ outer fuel
256 2  -6.55   255 -256 388   -389 u=1 imp:n=1 $ zr clad
257 4  -1.00       -257 388   -389 u=1 imp:n=1 $ inner water.....position 33
258 2  -6.55   257 -258 388   -389 u=1 imp:n=1 $ zr clad
259 1 -18.58   258 -259 388   -389 u=1 imp:n=1 $ inner fuel
260 2  -6.55   259 -260 388   -389 u=1 imp:n=1 $ zr clad
261 4  -1.00   260 -261 388   -389 u=1 imp:n=1 $ water
262 2  -6.55   261 -262 388   -389 u=1 imp:n=1 $ zr clad
263 6 -18.58   262 -263 388   -389 u=1 imp:n=1 $ outer fuel
264 2  -6.55   263 -264 388   -389 u=1 imp:n=1 $ zr clad
265 4  -1.00       -265 388   -389 u=1 imp:n=1 $ inner water.....position 34
266 2  -6.55   265 -266 388   -389 u=1 imp:n=1 $ zr clad
267 1 -18.58   266 -267 388   -389 u=1 imp:n=1 $ inner fuel
268 2  -6.55   267 -268 388   -389 u=1 imp:n=1 $ zr clad
269 4  -1.00   268 -269 388   -389 u=1 imp:n=1 $ water
270 2  -6.55   269 -270 388   -389 u=1 imp:n=1 $ zr clad
271 6 -18.58   270 -271 388   -389 u=1 imp:n=1 $ outer fuel
272 2  -6.55   271 -272 388   -389 u=1 imp:n=1 $ zr clad
273 4  -1.00       -273 388   -389 u=1 imp:n=1 $ inner water.....position 35
274 2  -6.55   273 -274 388   -389 u=1 imp:n=1 $ zr clad
275 1 -18.58   274 -275 388   -389 u=1 imp:n=1 $ inner fuel
276 2  -6.55   275 -276 388   -389 u=1 imp:n=1 $ zr clad
277 4  -1.00   276 -277 388   -389 u=1 imp:n=1 $ water
278 2  -6.55   277 -278 388   -389 u=1 imp:n=1 $ zr clad
279 6 -18.58   278 -279 388   -389 u=1 imp:n=1 $ outer fuel
280 2  -6.55   279 -280 388   -389 u=1 imp:n=1 $ zr clad
281 4  -1.00       -281 388   -389 u=1 imp:n=1 $ inner water.....position 36
282 2  -6.55   281 -282 388   -389 u=1 imp:n=1 $ zr clad
283 1 -18.58   282 -283 388   -389 u=1 imp:n=1 $ inner fuel
284 2  -6.55   283 -284 388   -389 u=1 imp:n=1 $ zr clad
285 4  -1.00   284 -285 388   -389 u=1 imp:n=1 $ water
286 2  -6.55   285 -286 388   -389 u=1 imp:n=1 $ zr clad
```

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287 6 -18.58   286 -287 388  -389 u=1 imp:n=1 $ outer fuel
288 2  -6.55   287 -288 388  -389 u=1 imp:n=1 $ zr clad
289 4  -1.00       -289 388  -389 u=1 imp:n=1 $ inner water.....position 37
290 2  -6.55   289 -290 388  -389 u=1 imp:n=1 $ zr clad
291 1 -18.58   290 -291 388  -389 u=1 imp:n=1 $ inner fuel
292 2  -6.55   291 -292 388  -389 u=1 imp:n=1 $ zr clad
293 4  -1.00   292 -293 388  -389 u=1 imp:n=1 $ water
294 2  -6.55   293 -294 388  -389 u=1 imp:n=1 $ zr clad
295 6 -18.58   294 -295 388  -389 u=1 imp:n=1 $ outer fuel
296 2  -6.55   295 -296 388  -389 u=1 imp:n=1 $ zr clad
297 4  -1.00       -297 388  -389 u=1 imp:n=1 $ inner water.....position 38
298 2  -6.55   297 -298 388  -389 u=1 imp:n=1 $ zr clad
299 1 -18.58   298 -299 388  -389 u=1 imp:n=1 $ inner fuel
300 2  -6.55   299 -300 388  -389 u=1 imp:n=1 $ zr clad
301 4  -1.00   300 -301 388  -389 u=1 imp:n=1 $ water
302 2  -6.55   301 -302 388  -389 u=1 imp:n=1 $ zr clad
303 6 -18.58   302 -303 388  -389 u=1 imp:n=1 $ outer fuel
304 2  -6.55   303 -304 388  -389 u=1 imp:n=1 $ zr clad
305 4  -1.00       -305 388  -389 u=1 imp:n=1 $ inner water.....position 39
306 2  -6.55   305 -306 388  -389 u=1 imp:n=1 $ zr clad
307 1 -18.58   306 -307 388  -389 u=1 imp:n=1 $ inner fuel
308 2  -6.55   307 -308 388  -389 u=1 imp:n=1 $ zr clad
309 4  -1.00   308 -309 388  -389 u=1 imp:n=1 $ water
310 2  -6.55   309 -310 388  -389 u=1 imp:n=1 $ zr clad
311 6 -18.58   310 -311 388  -389 u=1 imp:n=1 $ outer fuel
312 2  -6.55   311 -312 388  -389 u=1 imp:n=1 $ zr clad
313 4  -1.00       -313 388  -389 u=1 imp:n=1 $ inner water.....position 40
314 2  -6.55   313 -314 388  -389 u=1 imp:n=1 $ zr clad
315 1 -18.58   314 -315 388  -389 u=1 imp:n=1 $ inner fuel
316 2  -6.55   315 -316 388  -389 u=1 imp:n=1 $ zr clad
317 4  -1.00   316 -317 388  -389 u=1 imp:n=1 $ water
318 2  -6.55   317 -318 388  -389 u=1 imp:n=1 $ zr clad
319 6 -18.58   318 -319 388  -389 u=1 imp:n=1 $ outer fuel
320 2  -6.55   319 -320 388  -389 u=1 imp:n=1 $ zr clad
321 4  -1.00       -321 388  -389 u=1 imp:n=1 $ inner water.....position 41
322 2  -6.55   321 -322 388  -389 u=1 imp:n=1 $ zr clad
323 1 -18.58   322 -323 388  -389 u=1 imp:n=1 $ inner fuel
324 2  -6.55   323 -324 388  -389 u=1 imp:n=1 $ zr clad
325 4  -1.00   324 -325 388  -389 u=1 imp:n=1 $ water
326 2  -6.55   325 -326 388  -389 u=1 imp:n=1 $ zr clad
327 6 -18.58   326 -327 388  -389 u=1 imp:n=1 $ outer fuel
328 2  -6.55   327 -328 388  -389 u=1 imp:n=1 $ zr clad
329 4  -1.00       -329 388  -389 u=1 imp:n=1 $ inner water.....position 42
330 2  -6.55   329 -330 388  -389 u=1 imp:n=1 $ zr clad
331 1 -18.58   330 -331 388  -389 u=1 imp:n=1 $ inner fuel
332 2  -6.55   331 -332 388  -389 u=1 imp:n=1 $ zr clad
333 4  -1.00   332 -333 388  -389 u=1 imp:n=1 $ water
334 2  -6.55   333 -334 388  -389 u=1 imp:n=1 $ zr clad
335 6 -18.58   334 -335 388  -389 u=1 imp:n=1 $ outer fuel
336 2  -6.55   335 -336 388  -389 u=1 imp:n=1 $ zr clad
337 4  -1.00       -337 388  -389 u=1 imp:n=1 $ inner water.....position 43
338 2  -6.55   337 -338 388  -389 u=1 imp:n=1 $ zr clad
339 1 -18.58   338 -339 388  -389 u=1 imp:n=1 $ inner fuel
340 2  -6.55   339 -340 388  -389 u=1 imp:n=1 $ zr clad
341 4  -1.00   340 -341 388  -389 u=1 imp:n=1 $ water
342 2  -6.55   341 -342 388  -389 u=1 imp:n=1 $ zr clad
343 6 -18.58   342 -343 388  -389 u=1 imp:n=1 $ outer fuel
344 2  -6.55   343 -344 388  -389 u=1 imp:n=1 $ zr clad
345 4  -1.00       -345 388  -389 u=1 imp:n=1 $ inner water.....position 44
346 2  -6.55   345 -346 388  -389 u=1 imp:n=1 $ zr clad
347 1 -18.58   346 -347 388  -389 u=1 imp:n=1 $ inner fuel
348 2  -6.55   347 -348 388  -389 u=1 imp:n=1 $ zr clad
349 4  -1.00   348 -349 388  -389 u=1 imp:n=1 $ water
350 2  -6.55   349 -350 388  -389 u=1 imp:n=1 $ zr clad
351 6 -18.58   350 -351 388  -389 u=1 imp:n=1 $ outer fuel
352 2  -6.55   351 -352 388  -389 u=1 imp:n=1 $ zr clad
353 4  -1.00       -353 388  -389 u=1 imp:n=1 $ inner water.....position 45
354 2  -6.55   353 -354 388  -389 u=1 imp:n=1 $ zr clad
355 1 -18.58   354 -355 388  -389 u=1 imp:n=1 $ inner fuel
356 2  -6.55   355 -356 388  -389 u=1 imp:n=1 $ zr clad
357 4  -1.00   356 -357 388  -389 u=1 imp:n=1 $ water
358 2  -6.55   357 -358 388  -389 u=1 imp:n=1 $ zr clad
359 6 -18.58   358 -359 388  -389 u=1 imp:n=1 $ outer fuel
360 2  -6.55   359 -360 388  -389 u=1 imp:n=1 $ zr clad
361 4  -1.00       -361 388  -389 u=1 imp:n=1 $ inner water.....position 46
362 2  -6.55   361 -362 388  -389 u=1 imp:n=1 $ zr clad
```

```
363 1 -18.58  362 -363 388  -389 u=1 imp:n=1 $ inner fuel
364 2  -6.55  363 -364 388  -389 u=1 imp:n=1 $ zr clad
365 4  -1.00  364 -365 388  -389 u=1 imp:n=1 $ water
366 2  -6.55  365 -366 388  -389 u=1 imp:n=1 $ zr clad
367 6 -18.58  366 -367 388  -389 u=1 imp:n=1 $ outer fuel
368 2  -6.55  367 -368 388  -389 u=1 imp:n=1 $ zr clad
369 4  -1.00      -369 388  -389 u=1 imp:n=1 $ inner water.....position 47
370 2  -6.55  369 -370 388  -389 u=1 imp:n=1 $ zr clad
371 1 -18.58  370 -371 388  -389 u=1 imp:n=1 $ inner fuel
372 2  -6.55  371 -372 388  -389 u=1 imp:n=1 $ zr clad
373 4  -1.00  372 -373 388  -389 u=1 imp:n=1 $ water
374 2  -6.55  373 -374 388  -389 u=1 imp:n=1 $ zr clad
375 6 -18.58  374 -375 388  -389 u=1 imp:n=1 $ outer fuel
376 2  -6.55  375 -376 388  -389 u=1 imp:n=1 $ zr clad
377 4  -1.00      -377 388  -389 u=1 imp:n=1 $ inner water.....position 48
378 2  -6.55  377 -378 388  -389 u=1 imp:n=1 $ zr clad
379 1 -18.58  378 -379 388  -389 u=1 imp:n=1 $ inner fuel
380 2  -6.55  379 -380 388  -389 u=1 imp:n=1 $ zr clad
381 4  -1.00  380 -381 388  -389 u=1 imp:n=1 $ water
382 2  -6.55  381 -382 388  -389 u=1 imp:n=1 $ zr clad
383 6 -18.58  382 -383 388  -389 u=1 imp:n=1 $ outer fuel
384 2  -6.55  383 -384 388  -389 u=1 imp:n=1 $ zr clad
385 4  -1.00  -385      388  -389
                 8   16   24   32   40
                48   56   64   72   80
                88   96  104  112  120
               128  136  144  152  160
               168  176  184  192  200
               208  216  224  232  240
               248  256  264  272  280
               288  296  304  312  320
               328  336  344  352  360
               368  376  384  386              u=1 imp:n=1 $ water
386  3  -8.0    387 -386  388  -389            u=1 imp:n=1 $ ss insert
387  4  -1.00  -387       388  -389            u=1 imp:n=1 $ water inside ss
388  6 -18.82  -390                            u=2 imp:n=1 $ fuel scrap
389  2  -6.55   390 -391                       u=2 imp:n=1 $ fuel clad
390  4  -1.00   391                            u=2 imp:n=1 $ lattice water
391  0   -392  393 -396  395 -394  397   lat=2  u=3 fill=2  imp:n=1
392  4  -1.00  -404  405 -424                  u=4 imp:n=1 $ top water reflector
393  0   -398  -405  406  402           fill=3 u=4 imp:n=1 $ scrap in basket      #1
394  3  -8.0   -405  407 -402   403            u=4 imp:n=1 $ ss insert in basket #1
395  4  -1.00  -405  407 -403                  u=4 imp:n=1 $ water inside ss insert
396  3  -8.0   -406  407 -398   402            u=4 imp:n=1 $ ss plate             #1
397  4  -1.00  -407  408 -424   402            u=4 imp:n=1 $ water in gap         #2
398  3  -8.0   -407  408 -402   403            u=4 imp:n=1 $ ss insert in gap     #2
399  4  -1.00  -407  408 -403                  u=4 imp:n=1 $ water inside ss insert
400  0   -424  -408  409                fill=1 u=4 imp:n=1 $ intact fuel -        #2
401  3  -8.0   -409  410 -424   402            u=4 imp:n=1 $ ss plate             #2
402  4  -1.00  -410  411 -424   402            u=4 imp:n=1 $ water in gap         #3
403  3  -8.0   -409  411 -402   403            u=4 imp:n=1 $ ss insert in gap     #3
404  4  -1.00  -409  411 -403                  u=4 imp:n=1 $ water inside ss insert
405  0   -424  -411  412                fill=1 u=4 imp:n=1 $ intact fuel -        #3
406  3  -8.0   -412  413 -424   402            u=4 imp:n=1 $ ss plate             #3
407  4  -1.00  -413  414 -424   402            u=4 imp:n=1 $ water in gap         #4
408  3  -8.0   -412  414 -402   403            u=4 imp:n=1 $ ss insert in gap     #4
409  4  -1.00  -412  414 -403                  u=4 imp:n=1 $ water inside ss insert
410  0   -424  -414  415                fill=1 u=4 imp:n=1 $ intact fuel -        #4
411  3  -8.0   -415  416 -424   402            u=4 imp:n=1 $ ss plate             #4
412  4  -1.00  -416  417 -424   402            u=4 imp:n=1 $ water in gap         #5
413  3  -8.0   -415  417 -402   403            u=4 imp:n=1 $ ss insert in gap     #5
414  4  -1.00  -415  417 -403                  u=4 imp:n=1 $ water inside ss insert
415  0   -424  -417  418                fill=1 u=4 imp:n=1 $ intact fuel -        #5
416  3  -8.0   -418  419 -424   402            u=4 imp:n=1 $ ss plate             #5
417  3  -8.0   -418  419 -402   403            u=4 imp:n=1 $ ss insert in gap     #4
418  4  -1.00  -418  419 -403                  u=4 imp:n=1 $ water inside ss insert
419  0   -398  -419  420  402           fill=3 u=4 imp:n=1 $ scrap in basket      #6
420  3  -8.0   -419  421 -402   403            u=4 imp:n=1 $ ss insert in basket #6
421  4  -1.00  -419  421 -403                  u=4 imp:n=1 $ water inside ss insert
422  3  -8.0   -420  421 -424   402            u=4 imp:n=1 $ ss plate             #6
423  3  -8.0   -421  422 -400                  u=4 imp:n=1 $ ss mco bottom end cap
424  3  -8.0    398 -424 -405   407            u=4 imp:n=1 $ side of top steel basket
425  3  -8.0    398 -424 -419   420            u=4 imp:n=1 $ side of bottom basket
426  3  -8.0    425 -400 -428   421            u=4 imp:n=1 $ steel on side of mco
427  0          (429:427:-422)
                (400:-422:428)                 u=4 imp:n=1 $ outside world of u=4
```

```
429  3  -8.0    424 -399 -404   421              u=4 imp:n=1 $ mco liner
430  0   399 -425 -404   421             u=4 imp:n=1 $ water gap
431  0  #434 #435 #436 431 -432 -433 423 -430 434 435 -436
                                                  imp:n=1 $ interstitial
432  3  -8.0  -425 404 -426                      u=4 imp:n=1
433  3  -8.0  (-429 428 -427)(425:426)           u=4 imp:n=1
434  0   423 -401 -430                     fill=4  imp:n=1
435  like 434 but trcl=1                   fill=4  imp:n=1
436  like 434 but trcl=2                   fill=4  imp:n=1
437  4 -1.00  (-423:430:-431:432:433:-434:-435:436) #434 #435 #436 $ water reflector
       (437 -438 -439 440 -441)      imp:n=1
438  0 (-437:438:439:-440:441) imp:n=0

   1  c/z     10.66800    6.15917  0.5588  $ inner water.....position 1
   2  c/z     10.66800    6.15917  0.6223  $ cladding
   3  c/z     10.66800    6.15917  1.4808  $ inner fuel
   4  c/z     10.66800    6.15917  1.5824  $ cladding
   5  c/z     10.66800    6.15917  2.2403  $ water region
   6  c/z     10.66800    6.15917  2.2962  $ cladding
   7  c/z     10.66800    6.15917  2.9896  $ outer fuel
   8  c/z     10.66800    6.15917  3.0531  $ cladding
   9  c/z      7.11200   12.31835  0.5588  $ inner water.....position 2
  10  c/z      7.11200   12.31835  0.6223  $ cladding
  11  c/z      7.11200   12.31835  1.4808  $ inner fuel
  12  c/z      7.11200   12.31835  1.5824  $ cladding
  13  c/z      7.11200   12.31835  2.2403  $ water region
  14  c/z      7.11200   12.31835  2.2962  $ cladding
  15  c/z      7.11200   12.31835  2.9896  $ outer fuel
  16  c/z      7.11200   12.31835  3.0531  $ cladding
  17  c/z       .00000   12.31835  0.5588  $ inner water.....position 3
  18  c/z       .00000   12.31835  0.6223  $ cladding
  19  c/z       .00000   12.31835  1.4808  $ inner fuel
  20  c/z       .00000   12.31835  1.5824  $ cladding
  21  c/z       .00000   12.31835  2.2403  $ water region
  22  c/z       .00000   12.31835  2.2962  $ cladding
  23  c/z       .00000   12.31835  2.9896  $ outer fuel
  24  c/z       .00000   12.31835  3.0531  $ cladding
  25  c/z     -7.11200   12.31835  0.5588  $ inner water.....position 4
  26  c/z     -7.11200   12.31835  0.6223  $ cladding
  27  c/z     -7.11200   12.31835  1.4808  $ inner fuel
  28  c/z     -7.11200   12.31835  1.5824  $ cladding
  29  c/z     -7.11200   12.31835  2.2403  $ water region
  30  c/z     -7.11200   12.31835  2.2962  $ cladding
  31  c/z     -7.11200   12.31835  2.9896  $ outer fuel
  32  c/z     -7.11200   12.31835  3.0531  $ cladding
  33  c/z    -10.66800    6.15917  0.5588  $ inner water.....position 5
  34  c/z    -10.66800    6.15917  0.6223  $ cladding
  35  c/z    -10.66800    6.15917  1.4808  $ inner fuel
  36  c/z    -10.66800    6.15917  1.5824  $ cladding
  37  c/z    -10.66800    6.15917  2.2403  $ water region
  38  c/z    -10.66800    6.15917  2.2962  $ cladding
  39  c/z    -10.66800    6.15917  2.9896  $ outer fuel
  40  c/z    -10.66800    6.15917  3.0531  $ cladding
  41  c/z    -14.22400     .00000  0.5588  $ inner water.....position 6
  42  c/z    -14.22400     .00000  0.6223  $ cladding
  43  c/z    -14.22400     .00000  1.4808  $ inner fuel
  44  c/z    -14.22400     .00000  1.5824  $ cladding
  45  c/z    -14.22400     .00000  2.2403  $ water region
  46  c/z    -14.22400     .00000  2.2962  $ cladding
  47  c/z    -14.22400     .00000  2.9896  $ outer fuel
  48  c/z    -14.22400     .00000  3.0531  $ cladding
  49  c/z    -10.66800   -6.15917  0.5588  $ inner water.....position 7
  50  c/z    -10.66800   -6.15917  0.6223  $ cladding
  51  c/z    -10.66800   -6.15917  1.4808  $ inner fuel
  52  c/z    -10.66800   -6.15917  1.5824  $ cladding
  53  c/z    -10.66800   -6.15917  2.2403  $ water region
  54  c/z    -10.66800   -6.15917  2.2962  $ cladding
  55  c/z    -10.66800   -6.15917  2.9896  $ outer fuel
  56  c/z    -10.66800   -6.15917  3.0531  $ cladding
  57  c/z     -7.11200  -12.31835  0.5588  $ inner water.....position 8
  58  c/z     -7.11200  -12.31835  0.6223  $ cladding
  59  c/z     -7.11200  -12.31835  1.4808  $ inner fuel
  60  c/z     -7.11200  -12.31835  1.5824  $ cladding
  61  c/z     -7.11200  -12.31835  2.2403  $ water region
  62  c/z     -7.11200  -12.31835  2.2962  $ cladding
  63  c/z     -7.11200  -12.31835  2.9896  $ outer fuel
```

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 64  c/z   -7.11200 -12.31835  3.0531  $ cladding
 65  c/z     .00000 -12.31835  0.5588  $ inner water.....position 9
 66  c/z     .00000 -12.31835  0.6223  $ cladding
 67  c/z     .00000 -12.31835  1.4808  $ inner fuel
 68  c/z     .00000 -12.31835  1.5824  $ cladding
 69  c/z     .00000 -12.31835  2.2403  $ water region
 70  c/z     .00000 -12.31835  2.2962  $ cladding
 71  c/z     .00000 -12.31835  2.9896  $ outer fuel
 72  c/z     .00000 -12.31835  3.0531  $ cladding
 73  c/z    7.11200 -12.31835  0.5588  $ inner water.....position 10
 74  c/z    7.11200 -12.31835  0.6223  $ cladding
 75  c/z    7.11200 -12.31835  1.4808  $ inner fuel
 76  c/z    7.11200 -12.31835  1.5824  $ cladding
 77  c/z    7.11200 -12.31835  2.2403  $ water region
 78  c/z    7.11200 -12.31835  2.2962  $ cladding
 79  c/z    7.11200 -12.31835  2.9896  $ outer fuel
 80  c/z    7.11200 -12.31835  3.0531  $ cladding
 81  c/z   10.66800  -6.15917  0.5588  $ inner water.....position 11
 82  c/z   10.66800  -6.15917  0.6223  $ cladding
 83  c/z   10.66800  -6.15917  1.4808  $ inner fuel
 84  c/z   10.66800  -6.15917  1.5824  $ cladding
 85  c/z   10.66800  -6.15917  2.2403  $ water region
 86  c/z   10.66800  -6.15917  2.2962  $ cladding
 87  c/z   10.66800  -6.15917  2.9896  $ outer fuel
 88  c/z   10.66800  -6.15917  3.0531  $ cladding
 89  c/z   14.22400    .00000  0.5588  $ inner water.....position 12
 90  c/z   14.22400    .00000  0.6223  $ cladding
 91  c/z   14.22400    .00000  1.4808  $ inner fuel
 92  c/z   14.22400    .00000  1.5824  $ cladding
 93  c/z   14.22400    .00000  2.2403  $ water region
 94  c/z   14.22400    .00000  2.2962  $ cladding
 95  c/z   14.22400    .00000  2.9896  $ outer fuel
 96  c/z   14.22400    .00000  3.0531  $ cladding
 97  c/z   17.78000   6.15917  0.5588  $ inner water.....position 13
 98  c/z   17.78000   6.15917  0.6223  $ cladding
 99  c/z   17.78000   6.15917  1.4808  $ inner fuel
100  c/z   17.78000   6.15917  1.5824  $ cladding
101  c/z   17.78000   6.15917  2.2403  $ water region
102  c/z   17.78000   6.15917  2.2962  $ cladding
103  c/z   17.78000   6.15917  2.9896  $ outer fuel
104  c/z   17.78000   6.15917  3.0531  $ cladding
105  c/z   14.22400  12.31835  0.5588  $ inner water.....position 14
106  c/z   14.22400  12.31835  0.6223  $ cladding
107  c/z   14.22400  12.31835  1.4808  $ inner fuel
108  c/z   14.22400  12.31835  1.5824  $ cladding
109  c/z   14.22400  12.31835  2.2403  $ water region
110  c/z   14.22400  12.31835  2.2962  $ cladding
111  c/z   14.22400  12.31835  2.9896  $ outer fuel
112  c/z   14.22400  12.31835  3.0531  $ cladding
113  c/z   10.66800  18.47752  0.5588  $ inner water.....position 15
114  c/z   10.66800  18.47752  0.6223  $ cladding
115  c/z   10.66800  18.47752  1.4808  $ inner fuel
116  c/z   10.66800  18.47752  1.5824  $ cladding
117  c/z   10.66800  18.47752  2.2403  $ water region
118  c/z   10.66800  18.47752  2.2962  $ cladding
119  c/z   10.66800  18.47752  2.9896  $ outer fuel
120  c/z   10.66800  18.47752  3.0531  $ cladding
121  c/z    3.55600  18.47752  0.5588  $ inner water.....position 16
122  c/z    3.55600  18.47752  0.6223  $ cladding
123  c/z    3.55600  18.47752  1.4808  $ inner fuel
124  c/z    3.55600  18.47752  1.5824  $ cladding
125  c/z    3.55600  18.47752  2.2403  $ water region
126  c/z    3.55600  18.47752  2.2962  $ cladding
127  c/z    3.55600  18.47752  2.9896  $ outer fuel
128  c/z    3.55600  18.47752  3.0531  $ cladding
129  c/z   -3.55600  18.47752  0.5588  $ inner water.....position 17
130  c/z   -3.55600  18.47752  0.6223  $ cladding
131  c/z   -3.55600  18.47752  1.4808  $ inner fuel
132  c/z   -3.55600  18.47752  1.5824  $ cladding
133  c/z   -3.55600  18.47752  2.2403  $ water region
134  c/z   -3.55600  18.47752  2.2962  $ cladding
135  c/z   -3.55600  18.47752  2.9896  $ outer fuel
136  c/z   -3.55600  18.47752  3.0531  $ cladding
137  c/z  -10.66800  18.47752  0.5588  $ inner water.....position 18
138  c/z  -10.66800  18.47752  0.6223  $ cladding
139  c/z  -10.66800  18.47752  1.4808  $ inner fuel
```

```
140 c/z  -10.66800  18.47752 1.5824 $ cladding
141 c/z  -10.66800  18.47752 2.2403 $ water region
142 c/z  -10.66800  18.47752 2.2962 $ cladding
143 c/z  -10.66800  18.47752 2.9896 $ outer fuel
144 c/z  -10.66800  18.47752 3.0531 $ cladding
145 c/z  -14.22400  12.31835 0.5588 $ inner water.....position 19
146 c/z  -14.22400  12.31835 0.6223 $ cladding
147 c/z  -14.22400  12.31835 1.4808 $ inner fuel
148 c/z  -14.22400  12.31835 1.5824 $ cladding
149 c/z  -14.22400  12.31835 2.2403 $ water region
150 c/z  -14.22400  12.31835 2.2962 $ cladding
151 c/z  -14.22400  12.31835 2.9896 $ outer fuel
152 c/z  -14.22400  12.31835 3.0531 $ cladding
153 c/z  -17.78000   6.15918 0.5588 $ inner water.....position 20
154 c/z  -17.78000   6.15918 0.6223 $ cladding
155 c/z  -17.78000   6.15918 1.4808 $ inner fuel
156 c/z  -17.78000   6.15918 1.5824 $ cladding
157 c/z  -17.78000   6.15918 2.2403 $ water region
158 c/z  -17.78000   6.15918 2.2962 $ cladding
159 c/z  -17.78000   6.15918 2.9896 $ outer fuel
160 c/z  -17.78000   6.15918 3.0531 $ cladding
161 c/z  -21.33600    .00000 0.5588 $ inner water.....position 21
162 c/z  -21.33600    .00000 0.6223 $ cladding
163 c/z  -21.33600    .00000 1.4808 $ inner fuel
164 c/z  -21.33600    .00000 1.5824 $ cladding
165 c/z  -21.33600    .00000 2.2403 $ water region
166 c/z  -21.33600    .00000 2.2962 $ cladding
167 c/z  -21.33600    .00000 2.9896 $ outer fuel
168 c/z  -21.33600    .00000 3.0531 $ cladding
169 c/z  -17.78000  -6.15917 0.5588 $ inner water.....position 22
170 c/z  -17.78000  -6.15917 0.6223 $ cladding
171 c/z  -17.78000  -6.15917 1.4808 $ inner fuel
172 c/z  -17.78000  -6.15917 1.5824 $ cladding
173 c/z  -17.78000  -6.15917 2.2403 $ water region
174 c/z  -17.78000  -6.15917 2.2962 $ cladding
175 c/z  -17.78000  -6.15917 2.9896 $ outer fuel
176 c/z  -17.78000  -6.15917 3.0531 $ cladding
177 c/z  -14.22400 -12.31834 0.5588 $ inner water.....position 23
178 c/z  -14.22400 -12.31834 0.6223 $ cladding
179 c/z  -14.22400 -12.31834 1.4808 $ inner fuel
180 c/z  -14.22400 -12.31834 1.5824 $ cladding
181 c/z  -14.22400 -12.31834 2.2403 $ water region
182 c/z  -14.22400 -12.31834 2.2962 $ cladding
183 c/z  -14.22400 -12.31834 2.9896 $ outer fuel
184 c/z  -14.22400 -12.31834 3.0531 $ cladding
185 c/z  -10.66800 -18.47751 0.5588 $ inner water.....position 24
186 c/z  -10.66800 -18.47751 0.6223 $ cladding
187 c/z  -10.66800 -18.47751 1.4808 $ inner fuel
188 c/z  -10.66800 -18.47751 1.5824 $ cladding
189 c/z  -10.66800 -18.47751 2.2403 $ water region
190 c/z  -10.66800 -18.47751 2.2962 $ cladding
191 c/z  -10.66800 -18.47751 2.9896 $ outer fuel
192 c/z  -10.66800 -18.47751 3.0531 $ cladding
193 c/z   -3.55601 -18.47752 0.5588 $ inner water.....position 25
194 c/z   -3.55601 -18.47752 0.6223 $ cladding
195 c/z   -3.55601 -18.47752 1.4808 $ inner fuel
196 c/z   -3.55601 -18.47752 1.5824 $ cladding
197 c/z   -3.55601 -18.47752 2.2403 $ water region
198 c/z   -3.55601 -18.47752 2.2962 $ cladding
199 c/z   -3.55601 -18.47752 2.9896 $ outer fuel
200 c/z   -3.55601 -18.47752 3.0531 $ cladding
201 c/z    3.55599 -18.47752 0.5588 $ inner water.....position 26
202 c/z    3.55599 -18.47752 0.6223 $ cladding
203 c/z    3.55599 -18.47752 1.4808 $ inner fuel
204 c/z    3.55599 -18.47752 1.5824 $ cladding
205 c/z    3.55599 -18.47752 2.2403 $ water region
206 c/z    3.55599 -18.47752 2.2962 $ cladding
207 c/z    3.55599 -18.47752 2.9896 $ outer fuel
208 c/z    3.55599 -18.47752 3.0531 $ cladding
209 c/z   10.66799 -18.47752 0.5588 $ inner water.....position 27
210 c/z   10.66799 -18.47752 0.6223 $ cladding
211 c/z   10.66799 -18.47752 1.4808 $ inner fuel
212 c/z   10.66799 -18.47752 1.5824 $ cladding
213 c/z   10.66799 -18.47752 2.2403 $ water region
214 c/z   10.66799 -18.47752 2.2962 $ cladding
215 c/z   10.66799 -18.47752 2.9896 $ outer fuel
```

```
216  c/z   10.66799 -18.47752  3.0531  $ cladding
217  c/z   14.22399 -12.31835  0.5588  $ inner water.....position 28
218  c/z   14.22399 -12.31835  0.6223  $ cladding
219  c/z   14.22399 -12.31835  1.4808  $ inner fuel
220  c/z   14.22399 -12.31835  1.5824  $ cladding
221  c/z   14.22399 -12.31835  2.2403  $ water region
222  c/z   14.22399 -12.31835  2.2962  $ cladding
223  c/z   14.22399 -12.31835  2.9896  $ outer fuel
224  c/z   14.22399 -12.31835  3.0531  $ cladding
225  c/z   17.78000  -6.15918  0.5588  $ inner water.....position 29
226  c/z   17.78000  -6.15918  0.6223  $ cladding
227  c/z   17.78000  -6.15918  1.4808  $ inner fuel
228  c/z   17.78000  -6.15918  1.5824  $ cladding
229  c/z   17.78000  -6.15918  2.2403  $ water region
230  c/z   17.78000  -6.15918  2.2962  $ cladding
231  c/z   17.78000  -6.15918  2.9896  $ outer fuel
232  c/z   17.78000  -6.15918  3.0531  $ cladding
233  c/z   21.33600   -.00002  0.5588  $ inner water.....position 30
234  c/z   21.33600   -.00002  0.6223  $ cladding
235  c/z   21.33600   -.00002  1.4808  $ inner fuel
236  c/z   21.33600   -.00002  1.5824  $ cladding
237  c/z   21.33600   -.00002  2.2403  $ water region
238  c/z   21.33600   -.00002  2.2962  $ cladding
239  c/z   21.33600   -.00002  2.9896  $ outer fuel
240  c/z   21.33600   -.00002  3.0531  $ cladding
241  c/z   24.89200   6.15917  0.5588  $ inner water.....position 31
242  c/z   24.89200   6.15917  0.6223  $ cladding
243  c/z   24.89200   6.15917  1.4808  $ inner fuel
244  c/z   24.89200   6.15917  1.5824  $ cladding
245  c/z   24.89200   6.15917  2.2403  $ water region
246  c/z   24.89200   6.15917  2.2962  $ cladding
247  c/z   24.89200   6.15917  2.9896  $ outer fuel
248  c/z   24.89200   6.15917  3.0531  $ cladding
249  c/z   21.33600  12.31835  0.5588  $ inner water.....position 32
250  c/z   21.33600  12.31835  0.6223  $ cladding
251  c/z   21.33600  12.31835  1.4808  $ inner fuel
252  c/z   21.33600  12.31835  1.5824  $ cladding
253  c/z   21.33600  12.31835  2.2403  $ water region
254  c/z   21.33600  12.31835  2.2962  $ cladding
255  c/z   21.33600  12.31835  2.9896  $ outer fuel
256  c/z   21.33600  12.31835  3.0531  $ cladding
257  c/z   17.78000  18.47752  0.5588  $ inner water.....position 33
258  c/z   17.78000  18.47752  0.6223  $ cladding
259  c/z   17.78000  18.47752  1.4808  $ inner fuel
260  c/z   17.78000  18.47752  1.5824  $ cladding
261  c/z   17.78000  18.47752  2.2403  $ water region
262  c/z   17.78000  18.47752  2.2962  $ cladding
263  c/z   17.78000  18.47752  2.9896  $ outer fuel
264  c/z   17.78000  18.47752  3.0531  $ cladding
265  c/z    7.11200  24.63669  0.5588  $ inner water.....position 34
266  c/z    7.11200  24.63669  0.6223  $ cladding
267  c/z    7.11200  24.63669  1.4808  $ inner fuel
268  c/z    7.11200  24.63669  1.5824  $ cladding
269  c/z    7.11200  24.63669  2.2403  $ water region
270  c/z    7.11200  24.63669  2.2962  $ cladding
271  c/z    7.11200  24.63669  2.9896  $ outer fuel
272  c/z    7.11200  24.63669  3.0531  $ cladding
273  c/z     .00000  24.63669  0.5588  $ inner water.....position 35
274  c/z     .00000  24.63669  0.6223  $ cladding
275  c/z     .00000  24.63669  1.4808  $ inner fuel
276  c/z     .00000  24.63669  1.5824  $ cladding
277  c/z     .00000  24.63669  2.2403  $ water region
278  c/z     .00000  24.63669  2.2962  $ cladding
279  c/z     .00000  24.63669  2.9896  $ outer fuel
280  c/z     .00000  24.63669  3.0531  $ cladding
281  c/z   -7.11200  24.63669  0.5588  $ inner water.....position 36
282  c/z   -7.11200  24.63669  0.6223  $ cladding
283  c/z   -7.11200  24.63669  1.4808  $ inner fuel
284  c/z   -7.11200  24.63669  1.5824  $ cladding
285  c/z   -7.11200  24.63669  2.2403  $ water region
286  c/z   -7.11200  24.63669  2.2962  $ cladding
287  c/z   -7.11200  24.63669  2.9896  $ outer fuel
288  c/z   -7.11200  24.63669  3.0531  $ cladding
289  c/z  -17.78000  18.47752  0.5588  $ inner water.....position 37
290  c/z  -17.78000  18.47752  0.6223  $ cladding
291  c/z  -17.78000  18.47752  1.4808  $ inner fuel
```

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292  c/z   -17.78000  18.47752  1.5824  $ cladding
293  c/z   -17.78000  18.47752  2.2403  $ water region
294  c/z   -17.78000  18.47752  2.2962  $ cladding
295  c/z   -17.78000  18.47752  2.9896  $ outer fuel
296  c/z   -17.78000  18.47752  3.0531  $ cladding
297  c/z   -21.33600  12.31835  0.5588  $ inner water.....position 38
298  c/z   -21.33600  12.31835  0.6223  $ cladding
299  c/z   -21.33600  12.31835  1.4808  $ inner fuel
300  c/z   -21.33600  12.31835  1.5824  $ cladding
301  c/z   -21.33600  12.31835  2.2403  $ water region
302  c/z   -21.33600  12.31835  2.2962  $ cladding
303  c/z   -21.33600  12.31835  2.9896  $ outer fuel
304  c/z   -21.33600  12.31835  3.0531  $ cladding
305  c/z   -24.89200   6.15918  0.5588  $ inner water.....position 39
306  c/z   -24.89200   6.15918  0.6223  $ cladding
307  c/z   -24.89200   6.15918  1.4808  $ inner fuel
308  c/z   -24.89200   6.15918  1.5824  $ cladding
309  c/z   -24.89200   6.15918  2.2403  $ water region
310  c/z   -24.89200   6.15918  2.2962  $ cladding
311  c/z   -24.89200   6.15918  2.9896  $ outer fuel
312  c/z   -24.89200   6.15918  3.0531  $ cladding
313  c/z   -24.89200  -6.15917  0.5588  $ inner water.....position 40
314  c/z   -24.89200  -6.15917  0.6223  $ cladding
315  c/z   -24.89200  -6.15917  1.4808  $ inner fuel
316  c/z   -24.89200  -6.15917  1.5824  $ cladding
317  c/z   -24.89200  -6.15917  2.2403  $ water region
318  c/z   -24.89200  -6.15917  2.2962  $ cladding
319  c/z   -24.89200  -6.15917  2.9896  $ outer fuel
320  c/z   -24.89200  -6.15917  3.0531  $ cladding
321  c/z   -21.33600 -12.31834  0.5588  $ inner water.....position 41
322  c/z   -21.33600 -12.31834  0.6223  $ cladding
323  c/z   -21.33600 -12.31834  1.4808  $ inner fuel
324  c/z   -21.33600 -12.31834  1.5824  $ cladding
325  c/z   -21.33600 -12.31834  2.2403  $ water region
326  c/z   -21.33600 -12.31834  2.2962  $ cladding
327  c/z   -21.33600 -12.31834  2.9896  $ outer fuel
328  c/z   -21.33600 -12.31834  3.0531  $ cladding
329  c/z   -17.78000 -18.47751  0.5588  $ inner water.....position 42
330  c/z   -17.78000 -18.47751  0.6223  $ cladding
331  c/z   -17.78000 -18.47751  1.4808  $ inner fuel
332  c/z   -17.78000 -18.47751  1.5824  $ cladding
333  c/z   -17.78000 -18.47751  2.2403  $ water region
334  c/z   -17.78000 -18.47751  2.2962  $ cladding
335  c/z   -17.78000 -18.47751  2.9896  $ outer fuel
336  c/z   -17.78000 -18.47751  3.0531  $ cladding
337  c/z    -7.11201 -24.63669  0.5588  $ inner water.....position 43
338  c/z    -7.11201 -24.63669  0.6223  $ cladding
339  c/z    -7.11201 -24.63669  1.4808  $ inner fuel
340  c/z    -7.11201 -24.63669  1.5824  $ cladding
341  c/z    -7.11201 -24.63669  2.2403  $ water region
342  c/z    -7.11201 -24.63669  2.2962  $ cladding
343  c/z    -7.11201 -24.63669  2.9896  $ outer fuel
344  c/z    -7.11201 -24.63669  3.0531  $ cladding
345  c/z     -.00001 -24.63669  0.5588  $ inner water.....position 44
346  c/z     -.00001 -24.63669  0.6223  $ cladding
347  c/z     -.00001 -24.63669  1.4808  $ inner fuel
348  c/z     -.00001 -24.63669  1.5824  $ cladding
349  c/z     -.00001 -24.63669  2.2403  $ water region
350  c/z     -.00001 -24.63669  2.2962  $ cladding
351  c/z     -.00001 -24.63669  2.9896  $ outer fuel
352  c/z     -.00001 -24.63669  3.0531  $ cladding
353  c/z     7.11199 -24.63669  0.5588  $ inner water.....position 45
354  c/z     7.11199 -24.63669  0.6223  $ cladding
355  c/z     7.11199 -24.63669  1.4808  $ inner fuel
356  c/z     7.11199 -24.63669  1.5824  $ cladding
357  c/z     7.11199 -24.63669  2.2403  $ water region
358  c/z     7.11199 -24.63669  2.2962  $ cladding
359  c/z     7.11199 -24.63669  2.9896  $ outer fuel
360  c/z     7.11199 -24.63669  3.0531  $ cladding
361  c/z    17.77999 -18.47753  0.5588  $ inner water.....position 46
362  c/z    17.77999 -18.47753  0.6223  $ cladding
363  c/z    17.77999 -18.47753  1.4808  $ inner fuel
364  c/z    17.77999 -18.47753  1.5824  $ cladding
365  c/z    17.77999 -18.47753  2.2403  $ water region
366  c/z    17.77999 -18.47753  2.2962  $ cladding
367  c/z    17.77999 -18.47753  2.9896  $ outer fuel
```

```
368  c/z    17.77999 -18.47753  3.0531  $ cladding
369  c/z    21.33599 -12.31836  0.5588  $ inner water.....position 47
370  c/z    21.33599 -12.31836  0.6223  $ cladding
371  c/z    21.33599 -12.31836  1.4808  $ inner fuel
372  c/z    21.33599 -12.31836  1.5824  $ cladding
373  c/z    21.33599 -12.31836  2.2403  $ water region
374  c/z    21.33599 -12.31836  2.2962  $ cladding
375  c/z    21.33599 -12.31836  2.9896  $ outer fuel
376  c/z    21.33599 -12.31836  3.0531  $ cladding
377  c/z    24.89200  -6.15919  0.5588  $ inner water.....position 48
378  c/z    24.89200  -6.15919  0.6223  $ cladding
379  c/z    24.89200  -6.15919  1.4808  $ inner fuel
380  c/z    24.89200  -6.15919  1.5824  $ cladding
381  c/z    24.89200  -6.15919  2.2403  $ water region
382  c/z    24.89200  -6.15919  2.2962  $ cladding
383  c/z    24.89200  -6.15919  2.9896  $ outer fuel
384  c/z    24.89200  -6.15919  3.0531  $ cladding
385  cz     29.21001                    $ basket radius 11.375"
386  cz      8.41375                    $ ss insert outer radius
387  cz      7.3025                     $ ss insert inner radius
388  pz   -170.4975                     $ lowest scrap position
389  pz    171.45                       $ highest scrap position
390  cz      0.70                       $ optimum scrap radius
391  cz      0.76268                    $ scrap token clad radius
392  px      1.22848                    $ lattice hexagon planes
393  px     -1.22848
394  p      -0.57735  1.0  0.0  1.41853
395  p       0.57735  1.0  0.0 -1.41853
396  p       0.57735  1.0  0.0  1.41853
397  p      -0.57735  1.0  0.0 -1.41853
398  cz     28.8925                     $ basket radius 11.375"
399  cz     30.48                       $ mco opening radius 12"
400  cz     50.5587                     $ outer steel radius
401  cz     50.5588                     $ water outside mco
402  cz      8.41375                    $ ss insert outer radius
403  cz      7.3025                     $ ss insert inner radius
404  pz    196.6975                     $ top of water reflector
405  pz    171.4499                     $ top of scrap basket #1
406  pz    115.2525                     $ top of ss plate     #1
407  pz    114.3                        $ top of water gap    #2
408  pz    111.1377                     $ top of intact fuel  #2
409  pz     58.1025                     $ top of ss plate     #2
410  pz     57.15                       $ top of water gap    #3
411  pz     53.9877                     $ top of intact fuel  #3
412  pz      0.9525                     $ top of ss plate     #3
413  pz      0.0                        $ top of water gap    #4
414  pz     -3.1623                     $ top of intact fuel  #4
415  pz    -56.1975                     $ top of ss plate     #4
416  pz    -57.15                       $ top of water gap    #5
417  pz    -60.3123                     $ top of intact fuel  #5
418  pz   -113.3475                     $ top of ss plate     #5
419  pz   -114.3                        $ top of scrap basket #6
420  pz   -170.49749                    $ top of ss plate     #6
421  pz   -171.45                       $ top of ss end cap
422  pz   -195.2752                     $ bottom of ss end cap
423  pz   -195.2753                     $ water below mco
424  cz     29.21                       $ mco liner
425  cz     31.9913                     $ water gap
426  pz  227.1775
427  pz  236.0675
428  pz  218.2875
429  cz  39.37
430  pz  236.0676
431  py  -50.5587
432  p  -1.73205 1 0 101.1174
433  p  1.73205 1 0 276.2578
434  p  1.73205 1 0 -50.5587
435  p  -1.73205 1 0 -225.6991
436  py  112.8495
437  py  -81.0387
438  p  -1.73205 1 0 162.0774
439  p  1.73205 1 0 337.2178
440  pz  -225.7553
441  pz  266.5476

tr1      101.118 0 0
```

```
tr2      50.5588 87.571
mode n
kcode   3000 0.5  10  50
ksrc        9.82784  0.0        143.35125  $ start of first cask
           -9.82784  0.0        143.35125
            0.0       9.67545    84.6201
            0.0      -9.67545    84.6201
            0.0       9.67545    27.4701
            0.0      -9.67545    27.4701
            0.0       9.67545   -29.6799
            0.0      -9.67545   -29.6799
            0.0       9.67545   -86.8299
            0.0      -9.67545   -86.8299
            9.82784  0.0       -142.39875
           -9.82784  0.0       -142.39875
          110.94584  0.0        143.35125  $ start of second cask
           91.29016  0.0        143.35125  $ +101.118 added to x
          101.118     9.67545    84.6201
          101.118    -9.67545    84.6201
          101.118     9.67545    27.4701
          101.118    -9.67545    27.4701
          101.118     9.67545   -29.6799
          101.118    -9.67545   -29.6799
          101.118     9.67545   -86.8299
          101.118    -9.67545   -86.8299
          110.95584  0.0       -142.39875
           91.29016  0.0       -142.39875
           60.38664  87.571     143.35125  $ start of third cask
           40.73096  87.571     143.35125  $ +50.5588 added to x
           50.5588  97.24645     84.6201   $ +87.571 added to y
           50.5588  77.89555     84.6201
           50.5588  97.24645     27.4701
           50.5588  77.89555     27.4701
           50.5588  97.24645    -29.6799
           50.5588  77.89555    -29.6799
           50.5588  97.24645    -86.8299
           50.5588  77.89555    -86.8299
           60.38664  87.571    -142.39875
           40.73096  87.571    -142.39875
m1     92235.50c  -0.009471 92238.50c  -0.990529 $ mkia inners
m2     40000.50c  -1.000                         $ zr clad
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
m3     6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
       28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m4       1001.50c  -0.1119     8016.50c  -0.8881   $ water
mt4      lwtr.01t
m5       6000.50c  -0.000396                       $ borated stainless steel 304
        25055.50c  -0.0198                         $ (8.03 g/cc)
        14000.50c  -0.0099
        24000.50c  -0.1881
        28000.50c  -0.091575
        26000.55c  -0.680229
         5010.50c  -0.00199
         5011.55c  -0.00801
m6      92235.50c  -0.012491 92238.50c  -0.987509 $ mkia outers
m7      92235.50c  -0.011494 92238.50c  -0.988506 $ mkia scrap
m8           8016.50c    0.22000     7014.50c    0.78000          $ Air
totnu
ctme 350.
dbcn    7j    20000
```

FILE i1.IV.10

```
message:

MCO SARP, normal condition, MKIV, MCO density 1.0, annulus density 0.0
 1 4  -1.00        -1 436  -437 imp:n=1 u=1 $ inner water.....position 1
 2 2  -6.55    1   -2 436  -437 imp:n=1 u=1 $ zr clad
 3 1 -18.58    2   -3 436  -437 imp:n=1 u=1 $ inner fuel
 4 2  -6.55    3   -4 436  -437 imp:n=1 u=1 $ zr clad
 5 4  -1.00    4   -5 436  -437 imp:n=1 u=1 $ water
 6 2  -6.55    5   -6 436  -437 imp:n=1 u=1 $ zr clad
 7 6 -18.58    6   -7 436  -437 imp:n=1 u=1 $ outer fuel
 8 2  -6.55    7   -8 436  -437 imp:n=1 u=1 $ zr clad
 9 4  -1.00        -9 436  -437 imp:n=1 u=1 $ inner water.....position 2
10 2  -6.55    9  -10 436  -437 imp:n=1 u=1 $ zr clad
11 1 -18.58   10  -11 436  -437 imp:n=1 u=1 $ inner fuel
12 2  -6.55   11  -12 436  -437 imp:n=1 u=1 $ zr clad
13 4  -1.00   12  -13 436  -437 imp:n=1 u=1 $ water
14 2  -6.55   13  -14 436  -437 imp:n=1 u=1 $ zr clad
15 6 -18.58   14  -15 436  -437 imp:n=1 u=1 $ outer fuel
16 2  -6.55   15  -16 436  -437 imp:n=1 u=1 $ zr clad
17 4  -1.00       -17 436  -437 imp:n=1 u=1 $ inner water.....position 3
18 2  -6.55   17  -18 436  -437 imp:n=1 u=1 $ zr clad
19 1 -18.58   18  -19 436  -437 imp:n=1 u=1 $ inner fuel
20 2  -6.55   19  -20 436  -437 imp:n=1 u=1 $ zr clad
21 4  -1.00   20  -21 436  -437 imp:n=1 u=1 $ water
22 2  -6.55   21  -22 436  -437 imp:n=1 u=1 $ zr clad
23 6 -18.58   22  -23 436  -437 imp:n=1 u=1 $ outer fuel
24 2  -6.55   23  -24 436  -437 imp:n=1 u=1 $ zr clad
25 4  -1.00       -25 436  -437 imp:n=1 u=1 $ inner water.....position 4
26 2  -6.55   25  -26 436  -437 imp:n=1 u=1 $ zr clad
27 1 -18.58   26  -27 436  -437 imp:n=1 u=1 $ inner fuel
28 2  -6.55   27  -28 436  -437 imp:n=1 u=1 $ zr clad
29 4  -1.00   28  -29 436  -437 imp:n=1 u=1 $ water
30 2  -6.55   29  -30 436  -437 imp:n=1 u=1 $ zr clad
31 6 -18.58   30  -31 436  -437 imp:n=1 u=1 $ outer fuel
32 2  -6.55   31  -32 436  -437 imp:n=1 u=1 $ zr clad
33 4  -1.00       -33 436  -437 imp:n=1 u=1 $ inner water.....position 5
34 2  -6.55   33  -34 436  -437 imp:n=1 u=1 $ zr clad
35 1 -18.58   34  -35 436  -437 imp:n=1 u=1 $ inner fuel
36 2  -6.55   35  -36 436  -437 imp:n=1 u=1 $ zr clad
37 4  -1.00   36  -37 436  -437 imp:n=1 u=1 $ water
38 2  -6.55   37  -38 436  -437 imp:n=1 u=1 $ zr clad
39 6 -18.58   38  -39 436  -437 imp:n=1 u=1 $ outer fuel
40 2  -6.55   39  -40 436  -437 imp:n=1 u=1 $ zr clad
41 4  -1.00       -41 436  -437 imp:n=1 u=1 $ inner water.....position 6
42 2  -6.55   41  -42 436  -437 imp:n=1 u=1 $ zr clad
43 1 -18.58   42  -43 436  -437 imp:n=1 u=1 $ inner fuel
44 2  -6.55   43  -44 436  -437 imp:n=1 u=1 $ zr clad
45 4  -1.00   44  -45 436  -437 imp:n=1 u=1 $ water
46 2  -6.55   45  -46 436  -437 imp:n=1 u=1 $ zr clad
47 6 -18.58   46  -47 436  -437 imp:n=1 u=1 $ outer fuel
48 2  -6.55   47  -48 436  -437 imp:n=1 u=1 $ zr clad
49 4  -1.00       -49 436  -437 imp:n=1 u=1 $ inner water.....position 7
50 2  -6.55   49  -50 436  -437 imp:n=1 u=1 $ zr clad
51 1 -18.58   50  -51 436  -437 imp:n=1 u=1 $ inner fuel
52 2  -6.55   51  -52 436  -437 imp:n=1 u=1 $ zr clad
53 4  -1.00   52  -53 436  -437 imp:n=1 u=1 $ water
54 2  -6.55   53  -54 436  -437 imp:n=1 u=1 $ zr clad
55 6 -18.58   54  -55 436  -437 imp:n=1 u=1 $ outer fuel
56 2  -6.55   55  -56 436  -437 imp:n=1 u=1 $ zr clad
57 4  -1.00       -57 436  -437 imp:n=1 u=1 $ inner water.....position 8
58 2  -6.55   57  -58 436  -437 imp:n=1 u=1 $ zr clad
59 1 -18.58   58  -59 436  -437 imp:n=1 u=1 $ inner fuel
60 2  -6.55   59  -60 436  -437 imp:n=1 u=1 $ zr clad
61 4  -1.00   60  -61 436  -437 imp:n=1 u=1 $ water
62 2  -6.55   61  -62 436  -437 imp:n=1 u=1 $ zr clad
63 6 -18.58   62  -63 436  -437 imp:n=1 u=1 $ outer fuel
64 2  -6.55   63  -64 436  -437 imp:n=1 u=1 $ zr clad
65 4  -1.00       -65 436  -437 imp:n=1 u=1 $ inner water.....position 9
66 2  -6.55   65  -66 436  -437 imp:n=1 u=1 $ zr clad
67 1 -18.58   66  -67 436  -437 imp:n=1 u=1 $ inner fuel
68 2  -6.55   67  -68 436  -437 imp:n=1 u=1 $ zr clad
69 4  -1.00   68  -69 436  -437 imp:n=1 u=1 $ water
70 2  -6.55   69  -70 436  -437 imp:n=1 u=1 $ zr clad
```

```
71 6 -18.58   70   -71 436   -437 imp:n=1 u=1 $ outer fuel
72 2  -6.55   71   -72 436   -437 imp:n=1 u=1 $ zr clad
73 4  -1.00        -73 436   -437 imp:n=1 u=1 $ inner water.....position 10
74 2  -6.55   73   -74 436   -437 imp:n=1 u=1 $ zr clad
75 1 -18.58   74   -75 436   -437 imp:n=1 u=1 $ inner fuel
76 2  -6.55   75   -76 436   -437 imp:n=1 u=1 $ zr clad
77 4  -1.00   76   -77 436   -437 imp:n=1 u=1 $ water
78 2  -6.55   77   -78 436   -437 imp:n=1 u=1 $ zr clad
79 6 -18.58   78   -79 436   -437 imp:n=1 u=1 $ outer fuel
80 2  -6.55   79   -80 436   -437 imp:n=1 u=1 $ zr clad
81 4  -1.00        -81 436   -437 imp:n=1 u=1 $ inner water.....position 11
82 2  -6.55   81   -82 436   -437 imp:n=1 u=1 $ zr clad
83 1 -18.58   82   -83 436   -437 imp:n=1 u=1 $ inner fuel
84 2  -6.55   83   -84 436   -437 imp:n=1 u=1 $ zr clad
85 4  -1.00   84   -85 436   -437 imp:n=1 u=1 $ water
86 2  -6.55   85   -86 436   -437 imp:n=1 u=1 $ zr clad
87 6 -18.58   86   -87 436   -437 imp:n=1 u=1 $ outer fuel
88 2  -6.55   87   -88 436   -437 imp:n=1 u=1 $ zr clad
89 4  -1.00        -89 436   -437 imp:n=1 u=1 $ inner water.....position 12
90 2  -6.55   89   -90 436   -437 imp:n=1 u=1 $ zr clad
91 1 -18.58   90   -91 436   -437 imp:n=1 u=1 $ inner fuel
92 2  -6.55   91   -92 436   -437 imp:n=1 u=1 $ zr clad
93 4  -1.00   92   -93 436   -437 imp:n=1 u=1 $ water
94 2  -6.55   93   -94 436   -437 imp:n=1 u=1 $ zr clad
95 6 -18.58   94   -95 436   -437 imp:n=1 u=1 $ outer fuel
96 2  -6.55   95   -96 436   -437 imp:n=1 u=1 $ zr clad
97 4  -1.00        -97 436   -437 imp:n=1 u=1 $ inner water.....position 13
98 2  -6.55   97   -98 436   -437 imp:n=1 u=1 $ zr clad
99 1 -18.58   98   -99 436   -437 imp:n=1 u=1 $ inner fuel
100 2  -6.55  99 -100 436   -437 imp:n=1 u=1 $ zr clad
101 4  -1.00 100 -101 436   -437 imp:n=1 u=1 $ water
102 2  -6.55 101 -102 436   -437 imp:n=1 u=1 $ zr clad
103 6 -18.58 102 -103 436   -437 imp:n=1 u=1 $ outer fuel
104 2  -6.55 103 -104 436   -437 imp:n=1 u=1 $ zr clad
105 4  -1.00     -105 436   -437 imp:n=1 u=1 $ inner water.....position 14
106 2  -6.55 105 -106 436   -437 imp:n=1 u=1 $ zr clad
107 1 -18.58 106 -107 436   -437 imp:n=1 u=1 $ inner fuel
108 2  -6.55 107 -108 436   -437 imp:n=1 u=1 $ zr clad
109 4  -1.00 108 -109 436   -437 imp:n=1 u=1 $ water
110 2  -6.55 109 -110 436   -437 imp:n=1 u=1 $ zr clad
111 6 -18.58 110 -111 436   -437 imp:n=1 u=1 $ outer fuel
112 2  -6.55 111 -112 436   -437 imp:n=1 u=1 $ zr clad
113 4  -1.00     -113 436   -437 imp:n=1 u=1 $ inner water.....position 15
114 2  -6.55 113 -114 436   -437 imp:n=1 u=1 $ zr clad
115 1 -18.58 114 -115 436   -437 imp:n=1 u=1 $ inner fuel
116 2  -6.55 115 -116 436   -437 imp:n=1 u=1 $ zr clad
117 4  -1.00 116 -117 436   -437 imp:n=1 u=1 $ water
118 2  -6.55 117 -118 436   -437 imp:n=1 u=1 $ zr clad
119 6 -18.58 118 -119 436   -437 imp:n=1 u=1 $ outer fuel
120 2  -6.55 119 -120 436   -437 imp:n=1 u=1 $ zr clad
121 4  -1.00     -121 436   -437 imp:n=1 u=1 $ inner water.....position 16
122 2  -6.55 121 -122 436   -437 imp:n=1 u=1 $ zr clad
123 1 -18.58 122 -123 436   -437 imp:n=1 u=1 $ inner fuel
124 2  -6.55 123 -124 436   -437 imp:n=1 u=1 $ zr clad
125 4  -1.00 124 -125 436   -437 imp:n=1 u=1 $ water
126 2  -6.55 125 -126 436   -437 imp:n=1 u=1 $ zr clad
127 6 -18.58 126 -127 436   -437 imp:n=1 u=1 $ outer fuel
128 2  -6.55 127 -128 436   -437 imp:n=1 u=1 $ zr clad
129 4  -1.00     -129 436   -437 imp:n=1 u=1 $ inner water.....position 17
130 2  -6.55 129 -130 436   -437 imp:n=1 u=1 $ zr clad
131 1 -18.58 130 -131 436   -437 imp:n=1 u=1 $ inner fuel
132 2  -6.55 131 -132 436   -437 imp:n=1 u=1 $ zr clad
133 4  -1.00 132 -133 436   -437 imp:n=1 u=1 $ water
134 2  -6.55 133 -134 436   -437 imp:n=1 u=1 $ zr clad
135 6 -18.58 134 -135 436   -437 imp:n=1 u=1 $ outer fuel
136 2  -6.55 135 -136 436   -437 imp:n=1 u=1 $ zr clad
137 4  -1.00     -137 436   -437 imp:n=1 u=1 $ inner water.....position 18
138 2  -6.55 137 -138 436   -437 imp:n=1 u=1 $ zr clad
139 1 -18.58 138 -139 436   -437 imp:n=1 u=1 $ inner fuel
140 2  -6.55 139 -140 436   -437 imp:n=1 u=1 $ zr clad
141 4  -1.00 140 -141 436   -437 imp:n=1 u=1 $ water
142 2  -6.55 141 -142 436   -437 imp:n=1 u=1 $ zr clad
143 6 -18.58 142 -143 436   -437 imp:n=1 u=1 $ outer fuel
144 2  -6.55 143 -144 436   -437 imp:n=1 u=1 $ zr clad
145 4  -1.00     -145 436   -437 imp:n=1 u=1 $ inner water.....position 19
146 2  -6.55 145 -146 436   -437 imp:n=1 u=1 $ zr clad
```

```
147 1 -18.58  146 -147 436  -437 imp:n=1 u=1 $ inner fuel
148 2  -6.55  147 -148 436  -437 imp:n=1 u=1 $ zr clad
149 4  -1.00  148 -149 436  -437 imp:n=1 u=1 $ water
150 2  -6.55  149 -150 436  -437 imp:n=1 u=1 $ zr clad
151 6 -18.58  150 -151 436  -437 imp:n=1 u=1 $ outer fuel
152 2  -6.55  151 -152 436  -437 imp:n=1 u=1 $ zr clad
153 4  -1.00      -153 436  -437 imp:n=1 u=1 $ inner water.....position 20
154 2  -6.55  153 -154 436  -437 imp:n=1 u=1 $ zr clad
155 1 -18.58  154 -155 436  -437 imp:n=1 u=1 $ inner fuel
156 2  -6.55  155 -156 436  -437 imp:n=1 u=1 $ zr clad
157 4  -1.00  156 -157 436  -437 imp:n=1 u=1 $ water
158 2  -6.55  157 -158 436  -437 imp:n=1 u=1 $ zr clad
159 6 -18.58  158 -159 436  -437 imp:n=1 u=1 $ outer fuel
160 2  -6.55  159 -160 436  -437 imp:n=1 u=1 $ zr clad
161 4  -1.00      -161 436  -437 imp:n=1 u=1 $ inner water.....position 21
162 2  -6.55  161 -162 436  -437 imp:n=1 u=1 $ zr clad
163 1 -18.58  162 -163 436  -437 imp:n=1 u=1 $ inner fuel
164 2  -6.55  163 -164 436  -437 imp:n=1 u=1 $ zr clad
165 4  -1.00  164 -165 436  -437 imp:n=1 u=1 $ water
166 2  -6.55  165 -166 436  -437 imp:n=1 u=1 $ zr clad
167 6 -18.58  166 -167 436  -437 imp:n=1 u=1 $ outer fuel
168 2  -6.55  167 -168 436  -437 imp:n=1 u=1 $ zr clad
169 4  -1.00      -169 436  -437 imp:n=1 u=1 $ inner water.....position 22
170 2  -6.55  169 -170 436  -437 imp:n=1 u=1 $ zr clad
171 1 -18.58  170 -171 436  -437 imp:n=1 u=1 $ inner fuel
172 2  -6.55  171 -172 436  -437 imp:n=1 u=1 $ zr clad
173 4  -1.00  172 -173 436  -437 imp:n=1 u=1 $ water
174 2  -6.55  173 -174 436  -437 imp:n=1 u=1 $ zr clad
175 6 -18.58  174 -175 436  -437 imp:n=1 u=1 $ outer fuel
176 2  -6.55  175 -176 436  -437 imp:n=1 u=1 $ zr clad
177 4  -1.00      -177 436  -437 imp:n=1 u=1 $ inner water.....position 23
178 2  -6.55  177 -178 436  -437 imp:n=1 u=1 $ zr clad
179 1 -18.58  178 -179 436  -437 imp:n=1 u=1 $ inner fuel
180 2  -6.55  179 -180 436  -437 imp:n=1 u=1 $ zr clad
181 4  -1.00  180 -181 436  -437 imp:n=1 u=1 $ water
182 2  -6.55  181 -182 436  -437 imp:n=1 u=1 $ zr clad
183 6 -18.58  182 -183 436  -437 imp:n=1 u=1 $ outer fuel
184 2  -6.55  183 -184 436  -437 imp:n=1 u=1 $ zr clad
185 4  -1.00      -185 436  -437 imp:n=1 u=1 $ inner water.....position 24
186 2  -6.55  185 -186 436  -437 imp:n=1 u=1 $ zr clad
187 1 -18.58  186 -187 436  -437 imp:n=1 u=1 $ inner fuel
188 2  -6.55  187 -188 436  -437 imp:n=1 u=1 $ zr clad
189 4  -1.00  188 -189 436  -437 imp:n=1 u=1 $ water
190 2  -6.55  189 -190 436  -437 imp:n=1 u=1 $ zr clad
191 6 -18.58  190 -191 436  -437 imp:n=1 u=1 $ outer fuel
192 2  -6.55  191 -192 436  -437 imp:n=1 u=1 $ zr clad
193 4  -1.00      -193 436  -437 imp:n=1 u=1 $ inner water.....position 25
194 2  -6.55  193 -194 436  -437 imp:n=1 u=1 $ zr clad
195 1 -18.58  194 -195 436  -437 imp:n=1 u=1 $ inner fuel
196 2  -6.55  195 -196 436  -437 imp:n=1 u=1 $ zr clad
197 4  -1.00  196 -197 436  -437 imp:n=1 u=1 $ water
198 2  -6.55  197 -198 436  -437 imp:n=1 u=1 $ zr clad
199 6 -18.58  198 -199 436  -437 imp:n=1 u=1 $ outer fuel
200 2  -6.55  199 -200 436  -437 imp:n=1 u=1 $ zr clad
201 4  -1.00      -201 436  -437 imp:n=1 u=1 $ inner water.....position 26
202 2  -6.55  201 -202 436  -437 imp:n=1 u=1 $ zr clad
203 1 -18.58  202 -203 436  -437 imp:n=1 u=1 $ inner fuel
204 2  -6.55  203 -204 436  -437 imp:n=1 u=1 $ zr clad
205 4  -1.00  204 -205 436  -437 imp:n=1 u=1 $ water
206 2  -6.55  205 -206 436  -437 imp:n=1 u=1 $ zr clad
207 6 -18.58  206 -207 436  -437 imp:n=1 u=1 $ outer fuel
208 2  -6.55  207 -208 436  -437 imp:n=1 u=1 $ zr clad
209 4  -1.00      -209 436  -437 imp:n=1 u=1 $ inner water.....position 27
210 2  -6.55  209 -210 436  -437 imp:n=1 u=1 $ zr clad
211 1 -18.58  210 -211 436  -437 imp:n=1 u=1 $ inner fuel
212 2  -6.55  211 -212 436  -437 imp:n=1 u=1 $ zr clad
213 4  -1.00  212 -213 436  -437 imp:n=1 u=1 $ water
214 2  -6.55  213 -214 436  -437 imp:n=1 u=1 $ zr clad
215 6 -18.58  214 -215 436  -437 imp:n=1 u=1 $ outer fuel
216 2  -6.55  215 -216 436  -437 imp:n=1 u=1 $ zr clad
217 4  -1.00      -217 436  -437 imp:n=1 u=1 $ inner water.....position 28
218 2  -6.55  217 -218 436  -437 imp:n=1 u=1 $ zr clad
219 1 -18.58  218 -219 436  -437 imp:n=1 u=1 $ inner fuel
220 2  -6.55  219 -220 436  -437 imp:n=1 u=1 $ zr clad
221 4  -1.00  220 -221 436  -437 imp:n=1 u=1 $ water
222 2  -6.55  221 -222 436  -437 imp:n=1 u=1 $ zr clad
```

```
223 6 -18.58  222 -223 436  -437 imp:n=1 u=1 $ outer fuel
224 2  -6.55  223 -224 436  -437 imp:n=1 u=1 $ zr clad
225 4  -1.00      -225 436  -437 imp:n=1 u=1 $ inner water.....position 29
226 2  -6.55  225 -226 436  -437 imp:n=1 u=1 $ zr clad
227 1 -18.58  226 -227 436  -437 imp:n=1 u=1 $ inner fuel
228 2  -6.55  227 -228 436  -437 imp:n=1 u=1 $ zr clad
229 4  -1.00  228 -229 436  -437 imp:n=1 u=1 $ water
230 2  -6.55  229 -230 436  -437 imp:n=1 u=1 $ zr clad
231 6 -18.58  230 -231 436  -437 imp:n=1 u=1 $ outer fuel
232 2  -6.55  231 -232 436  -437 imp:n=1 u=1 $ zr clad
233 4  -1.00      -233 436  -437 imp:n=1 u=1 $ inner water.....position 30
234 2  -6.55  233 -234 436  -437 imp:n=1 u=1 $ zr clad
235 1 -18.58  234 -235 436  -437 imp:n=1 u=1 $ inner fuel
236 2  -6.55  235 -236 436  -437 imp:n=1 u=1 $ zr clad
237 4  -1.00  236 -237 436  -437 imp:n=1 u=1 $ water
238 2  -6.55  237 -238 436  -437 imp:n=1 u=1 $ zr clad
239 6 -18.58  238 -239 436  -437 imp:n=1 u=1 $ outer fuel
240 2  -6.55  239 -240 436  -437 imp:n=1 u=1 $ zr clad
241 4  -1.00      -241 436  -437 imp:n=1 u=1 $ inner water.....position 31
242 2  -6.55  241 -242 436  -437 imp:n=1 u=1 $ zr clad
243 1 -18.58  242 -243 436  -437 imp:n=1 u=1 $ inner fuel
244 2  -6.55  243 -244 436  -437 imp:n=1 u=1 $ zr clad
245 4  -1.00  244 -245 436  -437 imp:n=1 u=1 $ water
246 2  -6.55  245 -246 436  -437 imp:n=1 u=1 $ zr clad
247 6 -18.58  246 -247 436  -437 imp:n=1 u=1 $ outer fuel
248 2  -6.55  247 -248 436  -437 imp:n=1 u=1 $ zr clad
249 4  -1.00      -249 436  -437 imp:n=1 u=1 $ inner water.....position 32
250 2  -6.55  249 -250 436  -437 imp:n=1 u=1 $ zr clad
251 1 -18.58  250 -251 436  -437 imp:n=1 u=1 $ inner fuel
252 2  -6.55  251 -252 436  -437 imp:n=1 u=1 $ zr clad
253 4  -1.00  252 -253 436  -437 imp:n=1 u=1 $ water
254 2  -6.55  253 -254 436  -437 imp:n=1 u=1 $ zr clad
255 6 -18.58  254 -255 436  -437 imp:n=1 u=1 $ outer fuel
256 2  -6.55  255 -256 436  -437 imp:n=1 u=1 $ zr clad
257 4  -1.00      -257 436  -437 imp:n=1 u=1 $ inner water.....position 33
258 2  -6.55  257 -258 436  -437 imp:n=1 u=1 $ zr clad
259 1 -18.58  258 -259 436  -437 imp:n=1 u=1 $ inner fuel
260 2  -6.55  259 -260 436  -437 imp:n=1 u=1 $ zr clad
261 4  -1.00  260 -261 436  -437 imp:n=1 u=1 $ water
262 2  -6.55  261 -262 436  -437 imp:n=1 u=1 $ zr clad
263 6 -18.58  262 -263 436  -437 imp:n=1 u=1 $ outer fuel
264 2  -6.55  263 -264 436  -437 imp:n=1 u=1 $ zr clad
265 4  -1.00      -265 436  -437 imp:n=1 u=1 $ inner water.....position 34
266 2  -6.55  265 -266 436  -437 imp:n=1 u=1 $ zr clad
267 1 -18.58  266 -267 436  -437 imp:n=1 u=1 $ inner fuel
268 2  -6.55  267 -268 436  -437 imp:n=1 u=1 $ zr clad
269 4  -1.00  268 -269 436  -437 imp:n=1 u=1 $ water
270 2  -6.55  269 -270 436  -437 imp:n=1 u=1 $ zr clad
271 6 -18.58  270 -271 436  -437 imp:n=1 u=1 $ outer fuel
272 2  -6.55  271 -272 436  -437 imp:n=1 u=1 $ zr clad
273 4  -1.00      -273 436  -437 imp:n=1 u=1 $ inner water.....position 35
274 2  -6.55  273 -274 436  -437 imp:n=1 u=1 $ zr clad
275 1 -18.58  274 -275 436  -437 imp:n=1 u=1 $ inner fuel
276 2  -6.55  275 -276 436  -437 imp:n=1 u=1 $ zr clad
277 4  -1.00  276 -277 436  -437 imp:n=1 u=1 $ water
278 2  -6.55  277 -278 436  -437 imp:n=1 u=1 $ zr clad
279 6 -18.58  278 -279 436  -437 imp:n=1 u=1 $ outer fuel
280 2  -6.55  279 -280 436  -437 imp:n=1 u=1 $ zr clad
281 4  -1.00      -281 436  -437 imp:n=1 u=1 $ inner water.....position 36
282 2  -6.55  281 -282 436  -437 imp:n=1 u=1 $ zr clad
283 1 -18.58  282 -283 436  -437 imp:n=1 u=1 $ inner fuel
284 2  -6.55  283 -284 436  -437 imp:n=1 u=1 $ zr clad
285 4  -1.00  284 -285 436  -437 imp:n=1 u=1 $ water
286 2  -6.55  285 -286 436  -437 imp:n=1 u=1 $ zr clad
287 6 -18.58  286 -287 436  -437 imp:n=1 u=1 $ outer fuel
288 2  -6.55  287 -288 436  -437 imp:n=1 u=1 $ zr clad
289 4  -1.00      -289 436  -437 imp:n=1 u=1 $ inner water.....position 37
290 2  -6.55  289 -290 436  -437 imp:n=1 u=1 $ zr clad
291 1 -18.58  290 -291 436  -437 imp:n=1 u=1 $ inner fuel
292 2  -6.55  291 -292 436  -437 imp:n=1 u=1 $ zr clad
293 4  -1.00  292 -293 436  -437 imp:n=1 u=1 $ water
294 2  -6.55  293 -294 436  -437 imp:n=1 u=1 $ zr clad
295 6 -18.58  294 -295 436  -437 imp:n=1 u=1 $ outer fuel
296 2  -6.55  295 -296 436  -437 imp:n=1 u=1 $ zr clad
297 4  -1.00      -297 436  -437 imp:n=1 u=1 $ inner water.....position 38
298 2  -6.55  297 -298 436  -437 imp:n=1 u=1 $ zr clad
```

```
299 1 -18.58  298 -299 436  -437 imp:n=1 u=1 $ inner fuel
300 2  -6.55  299 -300 436  -437 imp:n=1 u=1 $ zr clad
301 4  -1.00  300 -301 436  -437 imp:n=1 u=1 $ water
302 2  -6.55  301 -302 436  -437 imp:n=1 u=1 $ zr clad
303 6 -18.58  302 -303 436  -437 imp:n=1 u=1 $ outer fuel
304 2  -6.55  303 -304 436  -437 imp:n=1 u=1 $ zr clad
305 4  -1.00      -305 436  -437 imp:n=1 u=1 $ inner water.....position 39
306 2  -6.55  305 -306 436  -437 imp:n=1 u=1 $ zr clad
307 1 -18.58  306 -307 436  -437 imp:n=1 u=1 $ inner fuel
308 2  -6.55  307 -308 436  -437 imp:n=1 u=1 $ zr clad
309 4  -1.00  308 -309 436  -437 imp:n=1 u=1 $ water
310 2  -6.55  309 -310 436  -437 imp:n=1 u=1 $ zr clad
311 6 -18.58  310 -311 436  -437 imp:n=1 u=1 $ outer fuel
312 2  -6.55  311 -312 436  -437 imp:n=1 u=1 $ zr clad
313 4  -1.00      -313 436  -437 imp:n=1 u=1 $ inner water.....position 40
314 2  -6.55  313 -314 436  -437 imp:n=1 u=1 $ zr clad
315 1 -18.58  314 -315 436  -437 imp:n=1 u=1 $ inner fuel
316 2  -6.55  315 -316 436  -437 imp:n=1 u=1 $ zr clad
317 4  -1.00  316 -317 436  -437 imp:n=1 u=1 $ water
318 2  -6.55  317 -318 436  -437 imp:n=1 u=1 $ zr clad
319 6 -18.58  318 -319 436  -437 imp:n=1 u=1 $ outer fuel
320 2  -6.55  319 -320 436  -437 imp:n=1 u=1 $ zr clad
321 4  -1.00      -321 436  -437 imp:n=1 u=1 $ inner water.....position 41
322 2  -6.55  321 -322 436  -437 imp:n=1 u=1 $ zr clad
323 1 -18.58  322 -323 436  -437 imp:n=1 u=1 $ inner fuel
324 2  -6.55  323 -324 436  -437 imp:n=1 u=1 $ zr clad
325 4  -1.00  324 -325 436  -437 imp:n=1 u=1 $ water
326 2  -6.55  325 -326 436  -437 imp:n=1 u=1 $ zr clad
327 6 -18.58  326 -327 436  -437 imp:n=1 u=1 $ outer fuel
328 2  -6.55  327 -328 436  -437 imp:n=1 u=1 $ zr clad
329 4  -1.00      -329 436  -437 imp:n=1 u=1 $ inner water.....position 42
330 2  -6.55  329 -330 436  -437 imp:n=1 u=1 $ zr clad
331 1 -18.58  330 -331 436  -437 imp:n=1 u=1 $ inner fuel
332 2  -6.55  331 -332 436  -437 imp:n=1 u=1 $ zr clad
333 4  -1.00  332 -333 436  -437 imp:n=1 u=1 $ water
334 2  -6.55  333 -334 436  -437 imp:n=1 u=1 $ zr clad
335 6 -18.58  334 -335 436  -437 imp:n=1 u=1 $ outer fuel
336 2  -6.55  335 -336 436  -437 imp:n=1 u=1 $ zr clad
337 4  -1.00      -337 436  -437 imp:n=1 u=1 $ inner water.....position 43
338 2  -6.55  337 -338 436  -437 imp:n=1 u=1 $ zr clad
339 1 -18.58  338 -339 436  -437 imp:n=1 u=1 $ inner fuel
340 2  -6.55  339 -340 436  -437 imp:n=1 u=1 $ zr clad
341 4  -1.00  340 -341 436  -437 imp:n=1 u=1 $ water
342 2  -6.55  341 -342 436  -437 imp:n=1 u=1 $ zr clad
343 6 -18.58  342 -343 436  -437 imp:n=1 u=1 $ outer fuel
344 2  -6.55  343 -344 436  -437 imp:n=1 u=1 $ zr clad
345 4  -1.00      -345 436  -437 imp:n=1 u=1 $ inner water.....position 44
346 2  -6.55  345 -346 436  -437 imp:n=1 u=1 $ zr clad
347 1 -18.58  346 -347 436  -437 imp:n=1 u=1 $ inner fuel
348 2  -6.55  347 -348 436  -437 imp:n=1 u=1 $ zr clad
349 4  -1.00  348 -349 436  -437 imp:n=1 u=1 $ water
350 2  -6.55  349 -350 436  -437 imp:n=1 u=1 $ zr clad
351 6 -18.58  350 -351 436  -437 imp:n=1 u=1 $ outer fuel
352 2  -6.55  351 -352 436  -437 imp:n=1 u=1 $ zr clad
353 4  -1.00      -353 436  -437 imp:n=1 u=1 $ inner water.....position 45
354 2  -6.55  353 -354 436  -437 imp:n=1 u=1 $ zr clad
355 1 -18.58  354 -355 436  -437 imp:n=1 u=1 $ inner fuel
356 2  -6.55  355 -356 436  -437 imp:n=1 u=1 $ zr clad
357 4  -1.00  356 -357 436  -437 imp:n=1 u=1 $ water
358 2  -6.55  357 -358 436  -437 imp:n=1 u=1 $ zr clad
359 6 -18.58  358 -359 436  -437 imp:n=1 u=1 $ outer fuel
360 2  -6.55  359 -360 436  -437 imp:n=1 u=1 $ zr clad
361 4  -1.00      -361 436  -437 imp:n=1 u=1 $ inner water.....position 46
362 2  -6.55  361 -362 436  -437 imp:n=1 u=1 $ zr clad
363 1 -18.58  362 -363 436  -437 imp:n=1 u=1 $ inner fuel
364 2  -6.55  363 -364 436  -437 imp:n=1 u=1 $ zr clad
365 4  -1.00  364 -365 436  -437 imp:n=1 u=1 $ water
366 2  -6.55  365 -366 436  -437 imp:n=1 u=1 $ zr clad
367 6 -18.58  366 -367 436  -437 imp:n=1 u=1 $ outer fuel
368 2  -6.55  367 -368 436  -437 imp:n=1 u=1 $ zr clad
369 4  -1.00      -369 436  -437 imp:n=1 u=1 $ inner water.....position 47
370 2  -6.55  369 -370 436  -437 imp:n=1 u=1 $ zr clad
371 1 -18.58  370 -371 436  -437 imp:n=1 u=1 $ inner fuel
372 2  -6.55  371 -372 436  -437 imp:n=1 u=1 $ zr clad
373 4  -1.00  372 -373 436  -437 imp:n=1 u=1 $ water
374 2  -6.55  373 -374 436  -437 imp:n=1 u=1 $ zr clad
```

```
375 6 -18.58  374 -375 436  -437 imp:n=1 u=1 $ outer fuel
376 2  -6.55  375 -376 436  -437 imp:n=1 u=1 $ zr clad
377 4  -1.00      -377 436  -437 imp:n=1 u=1 $ inner water.....position 48
378 2  -6.55  377 -378 436  -437 imp:n=1 u=1 $ zr clad
379 1 -18.58  378 -379 436  -437 imp:n=1 u=1 $ inner fuel
380 2  -6.55  379 -380 436  -437 imp:n=1 u=1 $ zr clad
381 4  -1.00  380 -381 436  -437 imp:n=1 u=1 $ water
382 2  -6.55  381 -382 436  -437 imp:n=1 u=1 $ zr clad
383 6 -18.58  382 -383 436  -437 imp:n=1 u=1 $ outer fuel
384 2  -6.55  383 -384 436  -437 imp:n=1 u=1 $ zr clad
385 4  -1.00      -385 436  -437 imp:n=1 u=1 $ inner water.....position 49
386 2  -6.55  385 -386 436  -437 imp:n=1 u=1 $ zr clad
387 1 -18.58  386 -387 436  -437 imp:n=1 u=1 $ inner fuel
388 2  -6.55  387 -388 436  -437 imp:n=1 u=1 $ zr clad
389 4  -1.00  388 -389 436  -437 imp:n=1 u=1 $ water
390 2  -6.55  389 -390 436  -437 imp:n=1 u=1 $ zr clad
391 6 -18.58  390 -391 436  -437 imp:n=1 u=1 $ outer fuel
392 2  -6.55  391 -392 436  -437 imp:n=1 u=1 $ zr clad
393 4  -1.00      -393 436  -437 imp:n=1 u=1 $ inner water.....position 50
394 2  -6.55  393 -394 436  -437 imp:n=1 u=1 $ zr clad
395 1 -18.58  394 -395 436  -437 imp:n=1 u=1 $ inner fuel
396 2  -6.55  395 -396 436  -437 imp:n=1 u=1 $ zr clad
397 4  -1.00  396 -397 436  -437 imp:n=1 u=1 $ water
398 2  -6.55  397 -398 436  -437 imp:n=1 u=1 $ zr clad
399 6 -18.58  398 -399 436  -437 imp:n=1 u=1 $ outer fuel
400 2  -6.55  399 -400 436  -437 imp:n=1 u=1 $ zr clad
401 4  -1.00      -401 436  -437 imp:n=1 u=1 $ inner water.....position 51
402 2  -6.55  401 -402 436  -437 imp:n=1 u=1 $ zr clad
403 1 -18.58  402 -403 436  -437 imp:n=1 u=1 $ inner fuel
404 2  -6.55  403 -404 436  -437 imp:n=1 u=1 $ zr clad
405 4  -1.00  404 -405 436  -437 imp:n=1 u=1 $ water
406 2  -6.55  405 -406 436  -437 imp:n=1 u=1 $ zr clad
407 6 -18.58  406 -407 436  -437 imp:n=1 u=1 $ outer fuel
408 2  -6.55  407 -408 436  -437 imp:n=1 u=1 $ zr clad
409 4  -1.00      -409 436  -437 imp:n=1 u=1 $ inner water.....position 52
410 2  -6.55  409 -410 436  -437 imp:n=1 u=1 $ zr clad
411 1 -18.58  410 -411 436  -437 imp:n=1 u=1 $ inner fuel
412 2  -6.55  411 -412 436  -437 imp:n=1 u=1 $ zr clad
413 4  -1.00  412 -413 436  -437 imp:n=1 u=1 $ water
414 2  -6.55  413 -414 436  -437 imp:n=1 u=1 $ zr clad
415 6 -18.58  414 -415 436  -437 imp:n=1 u=1 $ outer fuel
416 2  -6.55  415 -416 436  -437 imp:n=1 u=1 $ zr clad
417 4  -1.00      -417 436  -437 imp:n=1 u=1 $ inner water.....position 53
418 2  -6.55  417 -418 436  -437 imp:n=1 u=1 $ zr clad
419 1 -18.58  418 -419 436  -437 imp:n=1 u=1 $ inner fuel
420 2  -6.55  419 -420 436  -437 imp:n=1 u=1 $ zr clad
421 4  -1.00  420 -421 436  -437 imp:n=1 u=1 $ water
422 2  -6.55  421 -422 436  -437 imp:n=1 u=1 $ zr clad
423 6 -18.58  422 -423 436  -437 imp:n=1 u=1 $ outer fuel
424 2  -6.55  423 -424 436  -437 imp:n=1 u=1 $ zr clad
425 4  -1.00      -425 436  -437 imp:n=1 u=1 $ inner water.....position 54
426 2  -6.55  425 -426 436  -437 imp:n=1 u=1 $ zr clad
427 1 -18.58  426 -427 436  -437 imp:n=1 u=1 $ inner fuel
428 2  -6.55  427 -428 436  -437 imp:n=1 u=1 $ zr clad
429 4  -1.00  428 -429 436  -437 imp:n=1 u=1 $ water
430 2  -6.55  429 -430 436  -437 imp:n=1 u=1 $ zr clad
431 6 -18.58  430 -431 436  -437 imp:n=1 u=1 $ outer fuel
432 2  -6.55  431 -432 436  -437 imp:n=1 u=1 $ zr clad
433 4  -1.00 -433       436  -437
                8   16   24    32   40
               48   56   64    72   80
               88   96  104   112  120
              128  136  144   152  160
              168  176  184   192  200
              208  216  224   232  240
              248  256  264   272  280
              288  296  304   312  320
              328  336  344   352  360
              368  376  384   392  400
              408  416  424   432  434        u=1 imp:n=1 $ water
434  3  -8.03  -434  435 -437   436           u=1 imp:n=1 $ ss insert
435  4  -1.00  -435 -437 436                  u=1 imp:n=1 $ water inside ss
436  6 -18.82  -438                           u=2 imp:n=1 $ fuel scrap
437  2  -6.55   438 -439                      u=2 imp:n=1 $ fuel clad
438  4  -1.00   439                           u=2 imp:n=1 $ lattice water
439  0  -440  441 -444  443 -442  445   lat=2  u=3 fill=2  imp:n=1
```

```
440  4  -1.00   -452  453 -469                         u=4 imp:n=1 $ top water reflector
441  0     -446  -453  454  450              fill=3  u=4 imp:n=1 $ scrap in basket    #1
442  3  -8.03   -453  454 -450   451                   u=4 imp:n=1 $ ss insert in basket #1
443  4  -1.00   -453  454 -451                         u=4 imp:n=1 $ water inside ss insert
444  3  -8.03   -454  455 -469   450                   u=4 imp:n=1 $ ss plate            #1
445  4  -1.00   -455  456 -469   450                   u=4 imp:n=1 $ water in gap        #2
446  3  -8.03   -454  456 -450   451                   u=4 imp:n=1 $ ss insert in gap    #2
447  4  -1.00   -454  456 -451                         u=4 imp:n=1 $ water inside ss insert
448  0     -469  -456  457                   fill=1  u=4 imp:n=1 $ intact fuel -       #2
449  3  -8.03   -457  458 -469   450                   u=4 imp:n=1 $ ss plate            #2
450  4  -1.00   -458  459 -469   450                   u=4 imp:n=1 $ water in gap        #3
451  3  -8.03   -457  459 -450   451                   u=4 imp:n=1 $ ss insert in gap    #3
452  4  -1.00   -457  459 -451                         u=4 imp:n=1 $ water inside ss insert
453  0     -469  -459  460                   fill=1  u=4 imp:n=1 $ intact fuel -       #3
454  3  -8.03   -460  461 -469   450                   u=4 imp:n=1 $ ss plate            #3
455  4  -1.00   -461  462 -469   450                   u=4 imp:n=1 $ water in gap        #4
456  3  -8.03   -460  462 -450   451                   u=4 imp:n=1 $ ss insert in gap    #4
457  4  -1.00   -460  462 -451                         u=4 imp:n=1 $ water inside ss insert
458  0     -469  -462  463                   fill=1  u=4 imp:n=1 $ intact fuel -       #4
459  3  -8.03   -463  464 -469   450                   u=4 imp:n=1 $ ss plate            #4
460  3  -8.03   -463  464 -450   451                   u=4 imp:n=1 $ ss insert in gap    #4
461  4  -1.00   -463  464 -451                         u=4 imp:n=1 $ water inside ss insert
462  0     -446  -464  465  450              fill=3  u=4 imp:n=1 $ scrap in basket     #5
463  3  -8.03   -464  466 -450   451                   u=4 imp:n=1 $ ss insert in basket #5
464  4  -1.00   -464  466 -451                         u=4 imp:n=1 $ water inside ss insert
465  3  -8.03   -465  466 -446   450                   u=4 imp:n=1 $ ss plate            #5
466  3  -8.03   -466  467 -448                         u=4 imp:n=1 $ ss mco bottom end cap
467  3  -8.03    446 -469 -453   454                   u=4 imp:n=1 $ side of top steel basket
468  3  -8.03    446 -469 -464   466                   u=4 imp:n=1 $ side of bottom basket
469  3  -8.03    470 -448 -473   466                   u=4 imp:n=1 $ steel on side of mco
470  0          (474:472:-467)
                (448:-467:473)                         u=4 imp:n=1 $
472  3  -8.03    469 -447 -452   466                   u=4 imp:n=1 $ mco liner
473  0           447 -470 -452 466                     u=4 imp:n=1 $ water gap
474  0  #477 #478 #479 476 -477 -478 468 -475 479 480 -481
                                                           imp:n=1 $ interstitial
475  3  -8.03  -470 452 -471                           u=4 imp:n=1
476  3  -8.03  (-474 473 -472)(470:471)                u=4 imp:n=1
477  0  468 -449 -475                             fill=4 imp:n=1
478  like 477 but trcl=1                          fill=4 imp:n=1
479  like 477 but trcl=2                          fill=4 imp:n=1
480  4  -1.00  (-468:475:-476:477:478:-479:-480:481) #477 #478 #479
               (482 -483 -484 485 -486)                imp:n=1 $ water surrounding mco
481  0  (-482:483:484:-485:486)                        imp:n=0 $ outside world

   1  c/z     3.55600    6.15917  0.6095  $ inner water.....position 1
   2  c/z     3.55600    6.15917  0.6605  $ cladding
   3  c/z     3.55600    6.15917  1.5480  $ inner fuel
   4  c/z     3.55600    6.15917  1.6245  $ cladding
   5  c/z     3.55600    6.15917  2.1605  $ water region
   6  c/z     3.55600    6.15917  2.2110  $ cladding
   7  c/z     3.55600    6.15917  3.0165  $ outer fuel
   8  c/z     3.55600    6.15917  3.0800  $ cladding
   9  c/z    -3.55600    6.15917  0.6095  $ inner water.....position 2
  10  c/z    -3.55600    6.15917  0.6605  $ cladding
  11  c/z    -3.55600    6.15917  1.5480  $ inner fuel
  12  c/z    -3.55600    6.15917  1.6245  $ cladding
  13  c/z    -3.55600    6.15917  2.1605  $ water region
  14  c/z    -3.55600    6.15917  2.2110  $ cladding
  15  c/z    -3.55600    6.15917  3.0165  $ outer fuel
  16  c/z    -3.55600    6.15917  3.0800  $ cladding
  17  c/z    -7.11200     .00000  0.6095  $ inner water.....position 3
  18  c/z    -7.11200     .00000  0.6605  $ cladding
  19  c/z    -7.11200     .00000  1.5480  $ inner fuel
  20  c/z    -7.11200     .00000  1.6245  $ cladding
  21  c/z    -7.11200     .00000  2.1605  $ water region
  22  c/z    -7.11200     .00000  2.2110  $ cladding
  23  c/z    -7.11200     .00000  3.0165  $ outer fuel
  24  c/z    -7.11200     .00000  3.0800  $ cladding
  25  c/z    -3.55600   -6.15917  0.6095  $ inner water.....position 4
  26  c/z    -3.55600   -6.15917  0.6605  $ cladding
  27  c/z    -3.55600   -6.15917  1.5480  $ inner fuel
  28  c/z    -3.55600   -6.15917  1.6245  $ cladding
  29  c/z    -3.55600   -6.15917  2.1605  $ water region
  30  c/z    -3.55600   -6.15917  2.2110  $ cladding
  31  c/z    -3.55600   -6.15917  3.0165  $ outer fuel
```

```
 32  c/z    -3.55600  -6.15917  3.0800  $ cladding
 33  c/z     3.55600  -6.15917  0.6095  $ inner water.....position 5
 34  c/z     3.55600  -6.15917  0.6605  $ cladding
 35  c/z     3.55600  -6.15917  1.5480  $ inner fuel
 36  c/z     3.55600  -6.15917  1.6245  $ cladding
 37  c/z     3.55600  -6.15917  2.1605  $ water region
 38  c/z     3.55600  -6.15917  2.2110  $ cladding
 39  c/z     3.55600  -6.15917  3.0165  $ outer fuel
 40  c/z     3.55600  -6.15917  3.0800  $ cladding
 41  c/z     7.11200    .00000  0.6095  $ inner water.....position 6
 42  c/z     7.11200    .00000  0.6605  $ cladding
 43  c/z     7.11200    .00000  1.5480  $ inner fuel
 44  c/z     7.11200    .00000  1.6245  $ cladding
 45  c/z     7.11200    .00000  2.1605  $ water region
 46  c/z     7.11200    .00000  2.2110  $ cladding
 47  c/z     7.11200    .00000  3.0165  $ outer fuel
 48  c/z     7.11200    .00000  3.0800  $ cladding
 49  c/z    10.66800   6.15917  0.6095  $ inner water.....position 7
 50  c/z    10.66800   6.15917  0.6605  $ cladding
 51  c/z    10.66800   6.15917  1.5480  $ inner fuel
 52  c/z    10.66800   6.15917  1.6245  $ cladding
 53  c/z    10.66800   6.15917  2.1605  $ water region
 54  c/z    10.66800   6.15917  2.2110  $ cladding
 55  c/z    10.66800   6.15917  3.0165  $ outer fuel
 56  c/z    10.66800   6.15917  3.0800  $ cladding
 57  c/z     7.11200  12.31835  0.6095  $ inner water.....position 8
 58  c/z     7.11200  12.31835  0.6605  $ cladding
 59  c/z     7.11200  12.31835  1.5480  $ inner fuel
 60  c/z     7.11200  12.31835  1.6245  $ cladding
 61  c/z     7.11200  12.31835  2.1605  $ water region
 62  c/z     7.11200  12.31835  2.2110  $ cladding
 63  c/z     7.11200  12.31835  3.0165  $ outer fuel
 64  c/z     7.11200  12.31835  3.0800  $ cladding
 65  c/z      .00000  12.31835  0.6095  $ inner water.....position 9
 66  c/z      .00000  12.31835  0.6605  $ cladding
 67  c/z      .00000  12.31835  1.5480  $ inner fuel
 68  c/z      .00000  12.31835  1.6245  $ cladding
 69  c/z      .00000  12.31835  2.1605  $ water region
 70  c/z      .00000  12.31835  2.2110  $ cladding
 71  c/z      .00000  12.31835  3.0165  $ outer fuel
 72  c/z      .00000  12.31835  3.0800  $ cladding
 73  c/z    -7.11200  12.31835  0.6095  $ inner water.....position 10
 74  c/z    -7.11200  12.31835  0.6605  $ cladding
 75  c/z    -7.11200  12.31835  1.5480  $ inner fuel
 76  c/z    -7.11200  12.31835  1.6245  $ cladding
 77  c/z    -7.11200  12.31835  2.1605  $ water region
 78  c/z    -7.11200  12.31835  2.2110  $ cladding
 79  c/z    -7.11200  12.31835  3.0165  $ outer fuel
 80  c/z    -7.11200  12.31835  3.0800  $ cladding
 81  c/z   -10.66800   6.15917  0.6095  $ inner water.....position 11
 82  c/z   -10.66800   6.15917  0.6605  $ cladding
 83  c/z   -10.66800   6.15917  1.5480  $ inner fuel
 84  c/z   -10.66800   6.15917  1.6245  $ cladding
 85  c/z   -10.66800   6.15917  2.1605  $ water region
 86  c/z   -10.66800   6.15917  2.2110  $ cladding
 87  c/z   -10.66800   6.15917  3.0165  $ outer fuel
 88  c/z   -10.66800   6.15917  3.0800  $ cladding
 89  c/z   -14.22400    .00000  0.6095  $ inner water.....position 12
 90  c/z   -14.22400    .00000  0.6605  $ cladding
 91  c/z   -14.22400    .00000  1.5480  $ inner fuel
 92  c/z   -14.22400    .00000  1.6245  $ cladding
 93  c/z   -14.22400    .00000  2.1605  $ water region
 94  c/z   -14.22400    .00000  2.2110  $ cladding
 95  c/z   -14.22400    .00000  3.0165  $ outer fuel
 96  c/z   -14.22400    .00000  3.0800  $ cladding
 97  c/z   -10.66800  -6.15917  0.6095  $ inner water.....position 13
 98  c/z   -10.66800  -6.15917  0.6605  $ cladding
 99  c/z   -10.66800  -6.15917  1.5480  $ inner fuel
100  c/z   -10.66800  -6.15917  1.6245  $ cladding
101  c/z   -10.66800  -6.15917  2.1605  $ water region
102  c/z   -10.66800  -6.15917  2.2110  $ cladding
103  c/z   -10.66800  -6.15917  3.0165  $ outer fuel
104  c/z   -10.66800  -6.15917  3.0800  $ cladding
105  c/z    -7.11200 -12.31835  0.6095  $ inner water.....position 14
106  c/z    -7.11200 -12.31835  0.6605  $ cladding
107  c/z    -7.11200 -12.31835  1.5480  $ inner fuel
```

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108  c/z   -7.11200 -12.31835  1.6245  $ cladding
109  c/z   -7.11200 -12.31835  2.1605  $ water region
110  c/z   -7.11200 -12.31835  2.2110  $ cladding
111  c/z   -7.11200 -12.31835  3.0165  $ outer fuel
112  c/z   -7.11200 -12.31835  3.0800  $ cladding
113  c/z     .00000 -12.31835  0.6095  $ inner water.....position 15
114  c/z     .00000 -12.31835  0.6605  $ cladding
115  c/z     .00000 -12.31835  1.5480  $ inner fuel
116  c/z     .00000 -12.31835  1.6245  $ cladding
117  c/z     .00000 -12.31835  2.1605  $ water region
118  c/z     .00000 -12.31835  2.2110  $ cladding
119  c/z     .00000 -12.31835  3.0165  $ outer fuel
120  c/z     .00000 -12.31835  3.0800  $ cladding
121  c/z    7.11200 -12.31835  0.6095  $ inner water.....position 16
122  c/z    7.11200 -12.31835  0.6605  $ cladding
123  c/z    7.11200 -12.31835  1.5480  $ inner fuel
124  c/z    7.11200 -12.31835  1.6245  $ cladding
125  c/z    7.11200 -12.31835  2.1605  $ water region
126  c/z    7.11200 -12.31835  2.2110  $ cladding
127  c/z    7.11200 -12.31835  3.0165  $ outer fuel
128  c/z    7.11200 -12.31835  3.0800  $ cladding
129  c/z   10.66800  -6.15917  0.6095  $ inner water.....position 17
130  c/z   10.66800  -6.15917  0.6605  $ cladding
131  c/z   10.66800  -6.15917  1.5480  $ inner fuel
132  c/z   10.66800  -6.15917  1.6245  $ cladding
133  c/z   10.66800  -6.15917  2.1605  $ water region
134  c/z   10.66800  -6.15917  2.2110  $ cladding
135  c/z   10.66800  -6.15917  3.0165  $ outer fuel
136  c/z   10.66800  -6.15917  3.0800  $ cladding
137  c/z   14.22400    .00000  0.6095  $ inner water.....position 18
138  c/z   14.22400    .00000  0.6605  $ cladding
139  c/z   14.22400    .00000  1.5480  $ inner fuel
140  c/z   14.22400    .00000  1.6245  $ cladding
141  c/z   14.22400    .00000  2.1605  $ water region
142  c/z   14.22400    .00000  2.2110  $ cladding
143  c/z   14.22400    .00000  3.0165  $ outer fuel
144  c/z   14.22400    .00000  3.0800  $ cladding
145  c/z   17.78000   6.15917  0.6095  $ inner water.....position 19
146  c/z   17.78000   6.15917  0.6605  $ cladding
147  c/z   17.78000   6.15917  1.5480  $ inner fuel
148  c/z   17.78000   6.15917  1.6245  $ cladding
149  c/z   17.78000   6.15917  2.1605  $ water region
150  c/z   17.78000   6.15917  2.2110  $ cladding
151  c/z   17.78000   6.15917  3.0165  $ outer fuel
152  c/z   17.78000   6.15917  3.0800  $ cladding
153  c/z   14.22400  12.31835  0.6095  $ inner water.....position 20
154  c/z   14.22400  12.31835  0.6605  $ cladding
155  c/z   14.22400  12.31835  1.5480  $ inner fuel
156  c/z   14.22400  12.31835  1.6245  $ cladding
157  c/z   14.22400  12.31835  2.1605  $ water region
158  c/z   14.22400  12.31835  2.2110  $ cladding
159  c/z   14.22400  12.31835  3.0165  $ outer fuel
160  c/z   14.22400  12.31835  3.0800  $ cladding
161  c/z   10.66800  18.47752  0.6095  $ inner water.....position 21
162  c/z   10.66800  18.47752  0.6605  $ cladding
163  c/z   10.66800  18.47752  1.5480  $ inner fuel
164  c/z   10.66800  18.47752  1.6245  $ cladding
165  c/z   10.66800  18.47752  2.1605  $ water region
166  c/z   10.66800  18.47752  2.2110  $ cladding
167  c/z   10.66800  18.47752  3.0165  $ outer fuel
168  c/z   10.66800  18.47752  3.0800  $ cladding
169  c/z    3.55600  18.47752  0.6095  $ inner water.....position 22
170  c/z    3.55600  18.47752  0.6605  $ cladding
171  c/z    3.55600  18.47752  1.5480  $ inner fuel
172  c/z    3.55600  18.47752  1.6245  $ cladding
173  c/z    3.55600  18.47752  2.1605  $ water region
174  c/z    3.55600  18.47752  2.2110  $ cladding
175  c/z    3.55600  18.47752  3.0165  $ outer fuel
176  c/z    3.55600  18.47752  3.0800  $ cladding
177  c/z   -3.55600  18.47752  0.6095  $ inner water.....position 23
178  c/z   -3.55600  18.47752  0.6605  $ cladding
179  c/z   -3.55600  18.47752  1.5480  $ inner fuel
180  c/z   -3.55600  18.47752  1.6245  $ cladding
181  c/z   -3.55600  18.47752  2.1605  $ water region
182  c/z   -3.55600  18.47752  2.2110  $ cladding
183  c/z   -3.55600  18.47752  3.0165  $ outer fuel
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184  c/z   -3.55600  18.47752  3.0800  $ cladding
185  c/z  -10.66800  18.47752  0.6095  $ inner water.....position 24
186  c/z  -10.66800  18.47752  0.6605  $ cladding
187  c/z  -10.66800  18.47752  1.5480  $ inner fuel
188  c/z  -10.66800  18.47752  1.6245  $ cladding
189  c/z  -10.66800  18.47752  2.1605  $ water region
190  c/z  -10.66800  18.47752  2.2110  $ cladding
191  c/z  -10.66800  18.47752  3.0165  $ outer fuel
192  c/z  -10.66800  18.47752  3.0800  $ cladding
193  c/z  -14.22400  12.31835  0.6095  $ inner water.....position 25
194  c/z  -14.22400  12.31835  0.6605  $ cladding
195  c/z  -14.22400  12.31835  1.5480  $ inner fuel
196  c/z  -14.22400  12.31835  1.6245  $ cladding
197  c/z  -14.22400  12.31835  2.1605  $ water region
198  c/z  -14.22400  12.31835  2.2110  $ cladding
199  c/z  -14.22400  12.31835  3.0165  $ outer fuel
200  c/z  -14.22400  12.31835  3.0800  $ cladding
201  c/z  -17.78000   6.15918  0.6095  $ inner water.....position 26
202  c/z  -17.78000   6.15918  0.6605  $ cladding
203  c/z  -17.78000   6.15918  1.5480  $ inner fuel
204  c/z  -17.78000   6.15918  1.6245  $ cladding
205  c/z  -17.78000   6.15918  2.1605  $ water region
206  c/z  -17.78000   6.15918  2.2110  $ cladding
207  c/z  -17.78000   6.15918  3.0165  $ outer fuel
208  c/z  -17.78000   6.15918  3.0800  $ cladding
209  c/z  -21.33600    .00000  0.6095  $ inner water.....position 27
210  c/z  -21.33600    .00000  0.6605  $ cladding
211  c/z  -21.33600    .00000  1.5480  $ inner fuel
212  c/z  -21.33600    .00000  1.6245  $ cladding
213  c/z  -21.33600    .00000  2.1605  $ water region
214  c/z  -21.33600    .00000  2.2110  $ cladding
215  c/z  -21.33600    .00000  3.0165  $ outer fuel
216  c/z  -21.33600    .00000  3.0800  $ cladding
217  c/z  -17.78000  -6.15917  0.6095  $ inner water.....position 28
218  c/z  -17.78000  -6.15917  0.6605  $ cladding
219  c/z  -17.78000  -6.15917  1.5480  $ inner fuel
220  c/z  -17.78000  -6.15917  1.6245  $ cladding
221  c/z  -17.78000  -6.15917  2.1605  $ water region
222  c/z  -17.78000  -6.15917  2.2110  $ cladding
223  c/z  -17.78000  -6.15917  3.0165  $ outer fuel
224  c/z  -17.78000  -6.15917  3.0800  $ cladding
225  c/z  -14.22400 -12.31834  0.6095  $ inner water.....position 29
226  c/z  -14.22400 -12.31834  0.6605  $ cladding
227  c/z  -14.22400 -12.31834  1.5480  $ inner fuel
228  c/z  -14.22400 -12.31834  1.6245  $ cladding
229  c/z  -14.22400 -12.31834  2.1605  $ water region
230  c/z  -14.22400 -12.31834  2.2110  $ cladding
231  c/z  -14.22400 -12.31834  3.0165  $ outer fuel
232  c/z  -14.22400 -12.31834  3.0800  $ cladding
233  c/z  -10.66800 -18.47751  0.6095  $ inner water.....position 30
234  c/z  -10.66800 -18.47751  0.6605  $ cladding
235  c/z  -10.66800 -18.47751  1.5480  $ inner fuel
236  c/z  -10.66800 -18.47751  1.6245  $ cladding
237  c/z  -10.66800 -18.47751  2.1605  $ water region
238  c/z  -10.66800 -18.47751  2.2110  $ cladding
239  c/z  -10.66800 -18.47751  3.0165  $ outer fuel
240  c/z  -10.66800 -18.47751  3.0800  $ cladding
241  c/z   -3.55601 -18.47752  0.6095  $ inner water.....position 31
242  c/z   -3.55601 -18.47752  0.6605  $ cladding
243  c/z   -3.55601 -18.47752  1.5480  $ inner fuel
244  c/z   -3.55601 -18.47752  1.6245  $ cladding
245  c/z   -3.55601 -18.47752  2.1605  $ water region
246  c/z   -3.55601 -18.47752  2.2110  $ cladding
247  c/z   -3.55601 -18.47752  3.0165  $ outer fuel
248  c/z   -3.55601 -18.47752  3.0800  $ cladding
249  c/z    3.55599 -18.47752  0.6095  $ inner water.....position 32
250  c/z    3.55599 -18.47752  0.6605  $ cladding
251  c/z    3.55599 -18.47752  1.5480  $ inner fuel
252  c/z    3.55599 -18.47752  1.6245  $ cladding
253  c/z    3.55599 -18.47752  2.1605  $ water region
254  c/z    3.55599 -18.47752  2.2110  $ cladding
255  c/z    3.55599 -18.47752  3.0165  $ outer fuel
256  c/z    3.55599 -18.47752  3.0800  $ cladding
257  c/z   10.66799 -18.47752  0.6095  $ inner water.....position 33
258  c/z   10.66799 -18.47752  0.6605  $ cladding
259  c/z   10.66799 -18.47752  1.5480  $ inner fuel
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260  c/z   10.66799 -18.47752  1.6245  $ cladding
261  c/z   10.66799 -18.47752  2.1605  $ water region
262  c/z   10.66799 -18.47752  2.2110  $ cladding
263  c/z   10.66799 -18.47752  3.0165  $ outer fuel
264  c/z   10.66799 -18.47752  3.0800  $ cladding
265  c/z   14.22399 -12.31835  0.6095  $ inner water.....position 34
266  c/z   14.22399 -12.31835  0.6605  $ cladding
267  c/z   14.22399 -12.31835  1.5480  $ inner fuel
268  c/z   14.22399 -12.31835  1.6245  $ cladding
269  c/z   14.22399 -12.31835  2.1605  $ water region
270  c/z   14.22399 -12.31835  2.2110  $ cladding
271  c/z   14.22399 -12.31835  3.0165  $ outer fuel
272  c/z   14.22399 -12.31835  3.0800  $ cladding
273  c/z   17.78000  -6.15918  0.6095  $ inner water.....position 35
274  c/z   17.78000  -6.15918  0.6605  $ cladding
275  c/z   17.78000  -6.15918  1.5480  $ inner fuel
276  c/z   17.78000  -6.15918  1.6245  $ cladding
277  c/z   17.78000  -6.15918  2.1605  $ water region
278  c/z   17.78000  -6.15918  2.2110  $ cladding
279  c/z   17.78000  -6.15918  3.0165  $ outer fuel
280  c/z   17.78000  -6.15918  3.0800  $ cladding
281  c/z   21.33600   -.00002  0.6095  $ inner water.....position 36
282  c/z   21.33600   -.00002  0.6605  $ cladding
283  c/z   21.33600   -.00002  1.5480  $ inner fuel
284  c/z   21.33600   -.00002  1.6245  $ cladding
285  c/z   21.33600   -.00002  2.1605  $ water region
286  c/z   21.33600   -.00002  2.2110  $ cladding
287  c/z   21.33600   -.00002  3.0165  $ outer fuel
288  c/z   21.33600   -.00002  3.0800  $ cladding
289  c/z   24.89200   6.15917  0.6095  $ inner water.....position 37
290  c/z   24.89200   6.15917  0.6605  $ cladding
291  c/z   24.89200   6.15917  1.5480  $ inner fuel
292  c/z   24.89200   6.15917  1.6245  $ cladding
293  c/z   24.89200   6.15917  2.1605  $ water region
294  c/z   24.89200   6.15917  2.2110  $ cladding
295  c/z   24.89200   6.15917  3.0165  $ outer fuel
296  c/z   24.89200   6.15917  3.0800  $ cladding
297  c/z   21.33600  12.31835  0.6095  $ inner water.....position 38
298  c/z   21.33600  12.31835  0.6605  $ cladding
299  c/z   21.33600  12.31835  1.5480  $ inner fuel
300  c/z   21.33600  12.31835  1.6245  $ cladding
301  c/z   21.33600  12.31835  2.1605  $ water region
302  c/z   21.33600  12.31835  2.2110  $ cladding
303  c/z   21.33600  12.31835  3.0165  $ outer fuel
304  c/z   21.33600  12.31835  3.0800  $ cladding
305  c/z   17.78000  18.47752  0.6095  $ inner water.....position 39
306  c/z   17.78000  18.47752  0.6605  $ cladding
307  c/z   17.78000  18.47752  1.5480  $ inner fuel
308  c/z   17.78000  18.47752  1.6245  $ cladding
309  c/z   17.78000  18.47752  2.1605  $ water region
310  c/z   17.78000  18.47752  2.2110  $ cladding
311  c/z   17.78000  18.47752  3.0165  $ outer fuel
312  c/z   17.78000  18.47752  3.0800  $ cladding
313  c/z    7.11200  24.63669  0.6095  $ inner water.....position 40
314  c/z    7.11200  24.63669  0.6605  $ cladding
315  c/z    7.11200  24.63669  1.5480  $ inner fuel
316  c/z    7.11200  24.63669  1.6245  $ cladding
317  c/z    7.11200  24.63669  2.1605  $ water region
318  c/z    7.11200  24.63669  2.2110  $ cladding
319  c/z    7.11200  24.63669  3.0165  $ outer fuel
320  c/z    7.11200  24.63669  3.0800  $ cladding
321  c/z     .00000  24.63669  0.6095  $ inner water.....position 41
322  c/z     .00000  24.63669  0.6605  $ cladding
323  c/z     .00000  24.63669  1.5480  $ inner fuel
324  c/z     .00000  24.63669  1.6245  $ cladding
325  c/z     .00000  24.63669  2.1605  $ water region
326  c/z     .00000  24.63669  2.2110  $ cladding
327  c/z     .00000  24.63669  3.0165  $ outer fuel
328  c/z     .00000  24.63669  3.0800  $ cladding
329  c/z   -7.11200  24.63669  0.6095  $ inner water.....position 42
330  c/z   -7.11200  24.63669  0.6605  $ cladding
331  c/z   -7.11200  24.63669  1.5480  $ inner fuel
332  c/z   -7.11200  24.63669  1.6245  $ cladding
333  c/z   -7.11200  24.63669  2.1605  $ water region
334  c/z   -7.11200  24.63669  2.2110  $ cladding
335  c/z   -7.11200  24.63669  3.0165  $ outer fuel
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336 c/z   -7.11200  24.63669 3.0800 $ cladding
337 c/z  -17.78000  18.47752 0.6095 $ inner water.....position 43
338 c/z  -17.78000  18.47752 0.6605 $ cladding
339 c/z  -17.78000  18.47752 1.5480 $ inner fuel
340 c/z  -17.78000  18.47752 1.6245 $ cladding
341 c/z  -17.78000  18.47752 2.1605 $ water region
342 c/z  -17.78000  18.47752 2.2110 $ cladding
343 c/z  -17.78000  18.47752 3.0165 $ outer fuel
344 c/z  -17.78000  18.47752 3.0800 $ cladding
345 c/z  -21.33600  12.31835 0.6095 $ inner water.....position 44
346 c/z  -21.33600  12.31835 0.6605 $ cladding
347 c/z  -21.33600  12.31835 1.5480 $ inner fuel
348 c/z  -21.33600  12.31835 1.6245 $ cladding
349 c/z  -21.33600  12.31835 2.1605 $ water region
350 c/z  -21.33600  12.31835 2.2110 $ cladding
351 c/z  -21.33600  12.31835 3.0165 $ outer fuel
352 c/z  -21.33600  12.31835 3.0800 $ cladding
353 c/z  -24.89200   6.15918 0.6095 $ inner water.....position 45
354 c/z  -24.89200   6.15918 0.6605 $ cladding
355 c/z  -24.89200   6.15918 1.5480 $ inner fuel
356 c/z  -24.89200   6.15918 1.6245 $ cladding
357 c/z  -24.89200   6.15918 2.1605 $ water region
358 c/z  -24.89200   6.15918 2.2110 $ cladding
359 c/z  -24.89200   6.15918 3.0165 $ outer fuel
360 c/z  -24.89200   6.15918 3.0800 $ cladding
361 c/z  -24.89200  -6.15917 0.6095 $ inner water.....position 46
362 c/z  -24.89200  -6.15917 0.6605 $ cladding
363 c/z  -24.89200  -6.15917 1.5480 $ inner fuel
364 c/z  -24.89200  -6.15917 1.6245 $ cladding
365 c/z  -24.89200  -6.15917 2.1605 $ water region
366 c/z  -24.89200  -6.15917 2.2110 $ cladding
367 c/z  -24.89200  -6.15917 3.0165 $ outer fuel
368 c/z  -24.89200  -6.15917 3.0800 $ cladding
369 c/z  -21.33600 -12.31834 0.6095 $ inner water.....position 47
370 c/z  -21.33600 -12.31834 0.6605 $ cladding
371 c/z  -21.33600 -12.31834 1.5480 $ inner fuel
372 c/z  -21.33600 -12.31834 1.6245 $ cladding
373 c/z  -21.33600 -12.31834 2.1605 $ water region
374 c/z  -21.33600 -12.31834 2.2110 $ cladding
375 c/z  -21.33600 -12.31834 3.0165 $ outer fuel
376 c/z  -21.33600 -12.31834 3.0800 $ cladding
377 c/z  -17.78000 -18.47751 0.6095 $ inner water.....position 48
378 c/z  -17.78000 -18.47751 0.6605 $ cladding
379 c/z  -17.78000 -18.47751 1.5480 $ inner fuel
380 c/z  -17.78000 -18.47751 1.6245 $ cladding
381 c/z  -17.78000 -18.47751 2.1605 $ water region
382 c/z  -17.78000 -18.47751 2.2110 $ cladding
383 c/z  -17.78000 -18.47751 3.0165 $ outer fuel
384 c/z  -17.78000 -18.47751 3.0800 $ cladding
385 c/z   -7.11201 -24.63669 0.6095 $ inner water.....position 49
386 c/z   -7.11201 -24.63669 0.6605 $ cladding
387 c/z   -7.11201 -24.63669 1.5480 $ inner fuel
388 c/z   -7.11201 -24.63669 1.6245 $ cladding
389 c/z   -7.11201 -24.63669 2.1605 $ water region
390 c/z   -7.11201 -24.63669 2.2110 $ cladding
391 c/z   -7.11201 -24.63669 3.0165 $ outer fuel
392 c/z   -7.11201 -24.63669 3.0800 $ cladding
393 c/z    -.00001 -24.63669 0.6095 $ inner water.....position 50
394 c/z    -.00001 -24.63669 0.6605 $ cladding
395 c/z    -.00001 -24.63669 1.5480 $ inner fuel
396 c/z    -.00001 -24.63669 1.6245 $ cladding
397 c/z    -.00001 -24.63669 2.1605 $ water region
398 c/z    -.00001 -24.63669 2.2110 $ cladding
399 c/z    -.00001 -24.63669 3.0165 $ outer fuel
400 c/z    -.00001 -24.63669 3.0800 $ cladding
401 c/z    7.11199 -24.63669 0.6095 $ inner water.....position 51
402 c/z    7.11199 -24.63669 0.6605 $ cladding
403 c/z    7.11199 -24.63669 1.5480 $ inner fuel
404 c/z    7.11199 -24.63669 1.6245 $ cladding
405 c/z    7.11199 -24.63669 2.1605 $ water region
406 c/z    7.11199 -24.63669 2.2110 $ cladding
407 c/z    7.11199 -24.63669 3.0165 $ outer fuel
408 c/z    7.11199 -24.63669 3.0800 $ cladding
409 c/z   17.77999 -18.47753 0.6095 $ inner water.....position 52
410 c/z   17.77999 -18.47753 0.6605 $ cladding
411 c/z   17.77999 -18.47753 1.5480 $ inner fuel
```

```
412 c/z   17.77999 -18.47753  1.6245  $ cladding
413 c/z   17.77999 -18.47753  2.1605  $ water region
414 c/z   17.77999 -18.47753  2.2110  $ cladding
415 c/z   17.77999 -18.47753  3.0165  $ outer fuel
416 c/z   17.77999 -18.47753  3.0800  $ cladding
417 c/z   21.33599 -12.31836  0.6095  $ inner water.....position 53
418 c/z   21.33599 -12.31836  0.6605  $ cladding
419 c/z   21.33599 -12.31836  1.5480  $ inner fuel
420 c/z   21.33599 -12.31836  1.6245  $ cladding
421 c/z   21.33599 -12.31836  2.1605  $ water region
422 c/z   21.33599 -12.31836  2.2110  $ cladding
423 c/z   21.33599 -12.31836  3.0165  $ outer fuel
424 c/z   21.33599 -12.31836  3.0800  $ cladding
425 c/z   24.89200  -6.15919  0.6095  $ inner water.....position 54
426 c/z   24.89200  -6.15919  0.6605  $ cladding
427 c/z   24.89200  -6.15919  1.5480  $ inner fuel
428 c/z   24.89200  -6.15919  1.6245  $ cladding
429 c/z   24.89200  -6.15919  2.1605  $ water region
430 c/z   24.89200  -6.15919  2.2110  $ cladding
431 c/z   24.89200  -6.15919  3.0165  $ outer fuel
432 c/z   24.89200  -6.15919  3.0800  $ cladding
433 cz    29.2101                     $ basket radius 11.375"
434 cz     3.302                      $ ss insert outer radius
435 cz     2.2225                     $ ss insert inner radius
436 pz  -169.545                      $ lowest scrap position
437 pz   170.4975                     $ highest scrap position
438 cz     0.9                        $ optimum scrap radius
439 cz     0.96444                    $ scrap token clad radius
440 px     1.51418                    $ scrap lattice hexagon planes
441 px    -1.51418
442 p     -0.57735  1.0  0.0  1.74842
443 p      0.57735  1.0  0.0 -1.74842
444 p      0.57735  1.0  0.0  1.74842
445 p     -0.57735  1.0  0.0 -1.74842
446 cz    28.8925                     $ basket radius 11.375"
447 cz    30.48                       $ mco opening radius 12"
448 cz    50.5587                     $ outer steel radius 20"
449 cz    50.5588                     $ water outside mco
450 cz     3.302                      $ ss insert outer radius
451 cz     2.2225                     $ ss insert inner radius
452 pz   197.6501                     $ top of water reflector
453 pz   170.49749                    $ top of scrap basket #1
454 pz   103.251                      $ top of ss plate     #1
455 pz   102.2985                     $ top of water gap    #2
456 pz   101.346                      $ top of intact fuel  #2
457 pz    35.052                      $ top of ss plate     #2
458 pz    34.0995                     $ top of water gap    #3
459 pz    33.147                      $ top of intact fuel  #3
460 pz   -33.147                      $ top of ss plate     #3
461 pz   -34.0995                     $ top of water gap    #4
462 pz   -35.052                      $ top of intact fuel  #4
463 pz  -101.346                      $ top of ss plate     #4
464 pz  -102.2985                     $ top of scrap basket #5
465 pz  -169.5449                     $ top of ss plate     #5
466 pz  -170.4975                     $ top of ss end cap
467 pz  -194.3227                     $ bottom of ss end cap
468 pz  -194.3228                     $ water below ss end cap
469 cz    29.21                       $ mco liner
470 cz    31.9913                     $ water gap
471 pz   228.1301                     $ top of shield plug
472 pz   237.0201                     $ top of cask lid
473 pz   219.2401                     $ top of cask side
474 cz 39.37                          $ lid radius
475 pz   237.0202                     $ top of cell with fill=4
476 py  -50.5587
477 p  -1.73205 1 0 101.1174
478 p  1.73205 1 0 276.2578
479 p  1.73205 1 0 -50.5587
480 p  -1.73205 1 0 -225.6991
481 py  112.8495
482 py  -81.0387
483 p  -1.73205 1 0 162.0774
484 p  1.73205 1 0 337.2178
485 pz  -224.8028    $ bottom of water reflector
486 pz  267.5002     $ top of water reflector
```

```
tr1      101.118 0 0
tr2      50.5588  87.571
mode n
kcode   3000 1.0  10  50
ksrc       6.05672  0.0        136.87425
          -6.05672  0.0        136.87425
           6.00775  0.0         68.199
          -6.00775  0.0         68.199
           6.00775  0.0          0.0
          -6.00775  0.0          0.0
           6.00775  0.0        -68.199
          -6.00775  0.0        -68.199
           6.05672  0.0       -135.92175
          -6.05672  0.0       -135.92175        $ 10 source points
         107.17472  0.0        136.87425  $ start of second MCO
          95.06128  0.0        136.87425  $ +101.118 added to x
         107.12575  0.0         68.199
          95.11025  0.0         68.199
         107.12575  0.0          0.0
          95.11025  0.0          0.0
         107.12575  0.0        -68.199
          95.11025  0.0        -68.199
         107.17472  0.0       -135.92175
          95.06128  0.0       -135.92175        $ 10 source points
          56.61552 87.571      136.87425   $ start of third MCO
          44.50208 87.571      136.87425   $ +50.5588 added to x
          56.56655 87.571       68.199     $ +87.571 added to y
          44.55105 87.571       68.199
          56.56655 87.571        0.0
          44.55105 87.571        0.0
          56.56655 87.571      -68.199
          44.55105 87.571      -68.199
          56.61552 87.571     -135.92175
          44.50208 87.571     -135.92175        $ 10 source points
m1     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv inners
m2     40000.50c  -1.000                         $ zr clad
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
m3    6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
      28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m4      1001.50c  -0.1119    8016.50c  -0.8881   $ water
mt4     lwtr.01t
m5      6000.50c  -0.000396                      $ borated stainless steel 304
       25055.50c  -0.0198                        $ (8.03 g/cc)
       14000.50c  -0.0099
       24000.50c  -0.1881
       28000.50c  -0.091575
       26000.55c  -0.680229
        5010.50c  -0.00199
        5011.55c  -0.00801
m6     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv outers
m7     92235.50c  -0.011494 92238.50c  -0.988506 $ mkia scrap
m8     92235.50c  -0.012491 92238.50c  -0.987509 $ 1.25 wt% scrap
m9          8016.50c   0.22000    7014.50c   0.78000          $ Air
totnu
ctme 350.
```

FILE i2.IA.10

```
message:

MCO SARP Vertical Drop, MKIA, MCO density of 1.0 g/cc, gap 0.0 g/cc
 1  6 -18.82   -1                              u=1 imp:n=1 $ MKIA fuel scrap
 2  2  -6.55    1 -2                           u=1 imp:n=1 $ fuel clad
 3  4  -1.00    2                              u=1 imp:n=1 $ lattice water
 4  0  -5  6 -9  8 -7  10           lat=2     u=2 fill=1  imp:n=1
 5  7 -18.82   -3                              u=3 imp:n=1 $ MKIA fuel rubble
 6  2  -6.55    3 -4                           u=3 imp:n=1 $ fuel clad
 7  4  -1.00    4                              u=3 imp:n=1 $ lattice water
 8  0  -11  12 -15  14 -13  16      lat=2     u=4 fill=3  imp:n=1
10  4  -1.00  -405 24 -398  17                     imp:n=1 $ water in gap       #1
11  3  -8.0   -405 24 -17   18                     imp:n=1 $ ss insert in gap   #1
12  4  -1.00  -405 24 -18                          imp:n=1 $ water inside ss insert
13  0   -424  -24  25  17           fill=2         imp:n=1 $ scrap in basket    #1
```

```
14  3  -8.0   -24  25 -17   18                    imp:n=1 $ ss insert in basket #1
15  4  -1.00  -24  25 -18                         imp:n=1 $ water inside ss insert
16  3  -8.0   -25  26 -424  17                    imp:n=1 $ ss plate            #1
20  0   -424  -26  27  17            fill=4       imp:n=1 $ MKIA rubble         #2
21  3  -8.0   -25  27 -17   18                    imp:n=1 $ ss insert in basket #2
22  4  -1.00  -25  27 -18                         imp:n=1 $ water inside ss insert
23  3  -8.0   -27  28 -424  17                    imp:n=1 $ ss plate            #2
27  0   -424  -28  29  17            fill=4       imp:n=1 $ MKIA rubble         #3
28  3  -8.0   -27  29 -17   18                    imp:n=1 $ ss insert in basket #3
29  4  -1.00  -27  29 -18                         imp:n=1 $ water inside ss insert
30  3  -8.0   -29  30 -424  17                    imp:n=1 $ ss plate            #3
34  0   -424  -30  31  17            fill=4       imp:n=1 $ MKIA rubble         #4
35  3  -8.0   -29  31 -17   18                    imp:n=1 $ ss insert in basket #4
36  4  -1.00  -29  31 -18                         imp:n=1 $ water inside ss insert
37  3  -8.0   -31  32 -424  17                    imp:n=1 $ ss plate            #4
41  0   -424  -32  33  17            fill=4       imp:n=1 $ MKIA rubble         #5
42  3  -8.0   -31  33 -17   18                    imp:n=1 $ ss insert in basket #5
43  4  -1.00  -31  33 -18                         imp:n=1 $ water inside ss insert
44  3  -8.0   -33  34 -424  17                    imp:n=1 $ ss plate            #5
48  0   -398  -34  35  17            fill=2       imp:n=1 $ scrap in basket     #6
49  3  -8.0   -33 421 -17   18                    imp:n=1 $ ss insert in basket #6
50  4  -1.00  -33 421 -18                         imp:n=1 $ water inside ss insert
51  3  -8.0   -35 421 -424  17                    imp:n=1 $ ss plate            #6
423  3  -8.0    -421  422 -400                     imp:n=1 $ ss mco bottom end cap
424  3  -8.0     398 -424 -405    24               imp:n=1 $ side of top steel basket
425  3  -8.0     398 -424 -34     35               imp:n=1 $ side of bottom basket
426  3  -8.0     425 -400 -428   421               imp:n=1 $ steel on side of mco
427  4  -1.00   ((423 -401 -430)(429:427:-422))
                (400:-422:428)   imp:n=1 $ water surrounding mco
429  3  -8.0     424 -399 -404   421               imp:n=1 $ mco liner
430  0   399 -425 -404   421             imp:n=1 $ water gap
431  0          -423:401:430                       imp:n=0 $ outside world
432  3  -8.0   -425 404 -426                       imp:n=1
433  3  -8.0   (-429 428 -427)(425:426)            imp:n=1
392  4  -1.00  -404  405 -424                      imp:n=1 $ top water reflector

 1  cz      0.70                          $ optimum scrap radius
 2  cz      0.76268                       $ scrap token clad radius
 3  cz      1.5                           $ optimum rubble radius
 4  cz      1.63431                       $ rubble token clad radius
 5  px      1.22848                       $ lattice hexagon planes for scrap
 6  px     -1.22848
 7  p      -0.57735  1.0  0.0  1.41853
 8  p       0.57735  1.0  0.0 -1.41853
 9  p       0.57735  1.0  0.0  1.41853
10  p      -0.57735  1.0  0.0 -1.41853
11  px      2.25861                       $ lattice hexagon planes for rubble
12  px     -2.25861
13  p      -0.57735  1.0  0.0  2.60802
14  p       0.57735  1.0  0.0 -2.60802
15  p       0.57735  1.0  0.0  2.60802
16  p      -0.57735  1.0  0.0 -2.60802
17  c/z    -5.08 0 8.41375          $ thicker ss insert outer radius
18  c/z    -5.08 0 7.3025           $ thicker ss insert inner radius
20  cz      50.8                          $ outer steel radius 20"
21  cz      81.28                         $ water outside mco
24  pz     144.14498                      $ top of scrap #1
25  pz      87.94748                      $ top of ss plate #1
26  pz      86.99498                      $ top of rubble #2
27  pz      37.62371                      $ top of ss plate #2
28  pz      36.67121                      $ top of rubble #3
29  pz     -12.70006                      $ top of ss plate #3
30  pz     -13.65256                      $ top of rubble #4
31  pz     -63.02383                      $ top of ss plate #4
32  pz     -63.97633                      $ top of rubble #5
33  pz    -113.3476                       $ top of ss plate #5
34  pz    -114.3001                       $ top of scrap #6
35  pz    -170.49764                      $ top of ss plate #6
 398  cz      28.8925                       $ basket radius 11.375"
 399  cz      30.48                         $ mco opening radius 12"
 400  cz      50.5587                       $ outer steel radius
 401  cz      81.0387                       $ water outside mco
 402  cz       8.41375                      $ ss insert outer radius
 403  cz       7.3025                       $ ss insert inner radius
 404  pz     196.6975                       $ top of water reflector
 405  pz     171.4499                       $ top of scrap basket #1
```

```
406  pz    115.2525                    $ top of ss plate     #1
407  pz    114.3                       $ top of water gap    #2
408  pz    111.1377                    $ top of intact fuel  #2
409  pz     58.1025                    $ top of ss plate     #2
410  pz     57.15                      $ top of water gap    #3
411  pz     53.9877                    $ top of intact fuel  #3
412  pz      0.9525                    $ top of ss plate     #3
413  pz      0.0                       $ top of water gap    #4
414  pz     -3.1623                    $ top of intact fuel  #4
415  pz    -56.1975                    $ top of ss plate     #4
416  pz    -57.15                      $ top of water gap    #5
417  pz    -60.3123                    $ top of intact fuel  #5
418  pz   -113.3475                    $ top of ss plate     #5
419  pz   -114.3                       $ top of scrap basket #6
420  pz   -170.49749                   $ top of ss plate     #6
421  pz   -171.45                      $ top of ss end cap
422  pz   -195.2752                    $ bottom of ss end cap
423  pz   -225.7552                    $ water below mco
424  cz     29.5275                    $ mco liner
425  cz     31.9913                    $ water gap
426  pz  227.1775
427  pz  236.0675
428  pz  218.2875
429  cz  39.37
430  pz  266.5475

mode n
kcode    1000 1.0  10  50
ksrc       22.11264  0.0       109.67079
          -22.11264  0.0       109.67079
           22.5861   0.0        57.28964
          -22.5861   0.0        57.28964
           22.5861   0.0        10.15359
          -22.5861   0.0        10.15359
           22.5861   0.0       -36.98246
          -22.5861   0.0       -36.98246
           22.5861   0.0       -84.59476
          -22.5861   0.0       -84.59476
           22.11264  0.0      -136.97591
          -22.11264  0.0      -136.97591        $ 12 source points
m1     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv inners
m2     40000.50c  -1.000                         $ zr clad
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
m3     6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
       28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m4       1001.50c  -0.1119    8016.50c  -0.8881   $ water
mt4      lwtr.01t
m5       6000.50c  -0.000396                     $ borated stainless steel 304
        25055.50c  -0.0198                       $ (8.03 g/cc)
        14000.50c  -0.0099
        24000.50c  -0.1881
        28000.50c  -0.091575
        26000.55c  -0.680229
         5010.50c  -0.00199
         5011.55c  -0.00801
m6     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv outers
m7     92235.50c  -0.011494 92238.50c  -0.988506 $ mkia scrap
m8     92235.50c  -0.012491 92238.50c  -0.987509 $ 1.25 wt% scrap
m9          8016.50c   0.22000    7014.50c   0.78000          $ Air
totnu
ctme 350.
print
```

FILE i2.IV.10

```
message:

MCO SARP, vertical drop, MKIV, MCO density 1.0, annulus density 0.0
1  1 -18.82  -1                                   u=1 imp:n=1 $ MKIV fuel scrap
2  2  -6.55   1 -2                                u=1 imp:n=1 $ fuel clad
3  4  -1.00   2                                   u=1 imp:n=1 $ lattice water
4  0  -5 6 -9  8 -7  10                lat=2      u=2 fill=1  imp:n=1
5  1 -18.82  -3                                   u=3 imp:n=1 $ MKIV fuel rubble
6  2  -6.55   3 -4                                u=3 imp:n=1 $ fuel clad
7  4  -1.00   4                                   u=3 imp:n=1 $ lattice water
8  0  -11  12 -15  14 -13  16          lat=2      u=4 fill=3  imp:n=1
10  4  -1.00 -469  22 -453                            imp:n=1 $ water in gap #1
11  0     -446 -22  23                 fill=2         imp:n=1 $ scrap in basket #1
12  3  -8.0   -23  24 -469                            imp:n=1 $ ss plate #1
13  0     -469 -24  25                 fill=4         imp:n=1 $ MKIV rubble #2
14  3  -8.0   -25  26 -469                            imp:n=1 $ ss plate #2
15  0     -469 -26  27                 fill=4         imp:n=1 $ MKIV rubble #3
16  3  -8.0   -27  28 -469                            imp:n=1 $ ss plate #3
17  0     -469 -28  29                 fill=4         imp:n=1 $ MKIV rubble #4
18  3  -8.0   -29  30 -469                            imp:n=1 $ ss plate #4
19  0     -446 -30  31                 fill=2         imp:n=1 $ scrap in basket #5
20  3  -8.0   -31 466 -469                            imp:n=1 $ ss plate #5
440  4  -1.00  -452  453 -469                          imp:n=1 $ top water reflector
466  3  -8.0   -466  467 -448                          imp:n=1 $ ss mco bottom end cap
467  3  -8.0    446 -469 -22   23                     imp:n=1 $ side of top steel basket
468  3  -8.0    446 -469 -30    31                     imp:n=1 $ side of bottom basket
469  3  -8.0    470 -448 -473   466                    imp:n=1 $ steel on side of mco
470  4  -1.00  ((468 -449 -475)(474:472:-467))
               (448:-467:473)                          imp:n=1 $ water surrounding mco
472  3  -8.0    469 -447 -452   466                    imp:n=1 $ mco liner
473  0   447 -470 -452   466                      imp:n=1 $ water gap
474  0        -468:449:475                             imp:n=0 $ outside world
475  3  -8.0   -470 452 -471                           imp:n=1
476  3  -8.0   (-474 473 -472)(470:471)                imp:n=1

1   cz      0.9                               $ optimum scrap radius
2   cz      0.96444                           $ scrap token clad radius
3   cz      1.5                               $ optimum rubble radius
4   cz      1.60741                           $ rubble token clad radius
5   px      1.51418                           $ lattice hexagon planes for scrap
6   px     -1.51418
7   p      -0.57735  1.0  0.0  1.74842
8   p       0.57735  1.0  0.0 -1.74842
9   p       0.57735  1.0  0.0  1.74842
10  p      -0.57735  1.0  0.0 -1.74842
11  px      2.25861                           $ lattice hexagon planes for rubble
12  px     -2.25861
13  p      -0.57735  1.0  0.0  2.60802
14  p       0.57735  1.0  0.0 -2.60802
15  p       0.57735  1.0  0.0  2.60802
16  p      -0.57735  1.0  0.0 -2.60802
17  cz     29.5275                            $ basket diameter 23.25"
18  cz     50.8                               $ outer steel radius 20"
19  cz     81.28                              $ water outside mco
22  pz    152.5287                            $ top of scrap #1
23  pz     85.2822                            $ top of ss plate #1
24  pz     84.3297                            $ top of MKIV rubble #2
25  pz     23.0728                            $ top of ss plate #2
26  pz     22.1203                            $ top of MKIV rubble #3
27  pz    -39.1366                            $ top of ss plate #3
28  pz    -40.0891                            $ top of MKIV rubble #4
29  pz   -101.3460                            $ top of ss plate #4
30  pz   -102.2985                            $ top of scrap #5
31  pz   -169.5450                            $ top of ss plate #5
 446  cz     28.8925                             $ basket radius 11.375"
 447  cz     30.48                               $ mco opening radius 12"
 448  cz     50.5587                             $ outer steel radius 20"
 449  cz     81.0387                             $ water outside mco
 450  cz      3.302                              $ ss insert outer radius
 451  cz      2.2225                             $ ss insert inner radius
 452  pz    197.6501                             $ top of water reflector
 453  pz    170.49749                            $ top of scrap basket #1
 454  pz    103.251                              $ top of ss plate     #1
```

```
455  pz    102.2985                    $ top of water gap     #2
456  pz    101.346                     $ top of intact fuel   #2
457  pz     35.052                     $ top of ss plate      #2
458  pz     34.0995                    $ top of water gap     #3
459  pz     33.147                     $ top of intact fuel   #3
460  pz    -33.147                     $ top of ss plate      #3
461  pz    -34.0995                    $ top of water gap     #4
462  pz    -35.052                     $ top of intact fuel   #4
463  pz   -101.346                     $ top of ss plate      #4
464  pz   -102.2985                    $ top of scrap basket  #5
465  pz   -169.5449                    $ top of ss plate      #5
466  pz   -170.4975                    $ top of ss end cap
467  pz   -194.3227                    $ bottom of ss end cap
468  pz   -224.8027                    $ water below ss end cap
469  cz     29.5275                    $ mco liner
470  cz     31.9913                    $ water gap
471  pz    228.1301                    $ top of shield plug
472  pz    237.0201                    $ top of cask lid
473  pz    219.2401                    $ top of cask side
474  cz 39.37                          $ lid radius
475  pz    267.5001                    $ top of cell with fill=4

mode n
kcode   3000 1.0  10  100
ksrc      12.11344  0.0      114.3834
         -12.11344  0.0      114.3834
           9.03444  0.0       50.68655
          -9.03444  0.0       50.68655
           9.03444  0.0       -8.50815
          -9.03444  0.0       -8.50815
           9.03444  0.0      -67.70285
          -9.03444  0.0      -67.70285
          12.11344  0.0     -131.3997
         -12.11344  0.0     -131.3997          $ 10 source points
m1     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv inners
m2     40000.50c  -1.000                         $ zr clad
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
m3     6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
       28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m4      1001.50c  -0.1119    8016.50c  -0.8881   $ water
mt4     lwtr.01t
m5      6000.50c  -0.000396                      $ borated stainless steel 304
       25055.50c  -0.0198                        $ (8.03 g/cc)
       14000.50c  -0.0099
       24000.50c  -0.1881
       28000.50c  -0.091575
       26000.55c  -0.680229
        5010.50c  -0.00199
        5011.55c  -0.00801
m6     92235.50c  -0.009471 92238.50c  -0.990529 $ mkiv outers
m7     92235.50c  -0.011494 92238.50c  -0.988506 $ mkia scrap
m8     92235.50c  -0.012491 92238.50c  -0.987509 $ 1.25 wt% scrap
m9          8016.50c    0.22000     7014.50c    0.78000          $ Air
totnu
ctme 350.
print
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7.0 STRUCTURAL EVALUATION

This section presents the structural performance evaluation of the MCO Cask package. The MCO Cask package consists of the MCO Cask (designed by TN), MCO (being designed by Parsons/VECTRA), fuel baskets (being designed by Parsons/VECTRA), and N Reactor fuel. The MCO Cask tiedown and transport system are not a structural part of the cask package and are discussed in Part B, Section 10.0. Structural performance of the MCO Cask package is evaluated for Hanford Site-specific environmental loading conditions and for normal and accident conditions as defined in the *Packaging Design Criteria for the MCO Cask* (WHC 1996) and the specification (WHC 1995).

The MCO Cask is designed by TN to meet the performance requirements outlined in the WHC specification. As designed, the MCO Cask system is to maintain containment of the payload during the NCT, and during and after accident conditions. The analyses summarized in this section verify the cask package performance conforms with all applicable transportation structural requirements. Performance of this cask package is verified by analysis in lieu of testing. Results of the performance evaluations demonstrate the MCO Cask package meets all the requirements of the specification and the risk assessment (Part B, Section 3.0).

7.1 STRUCTURAL EVALUATION OF PACKAGE

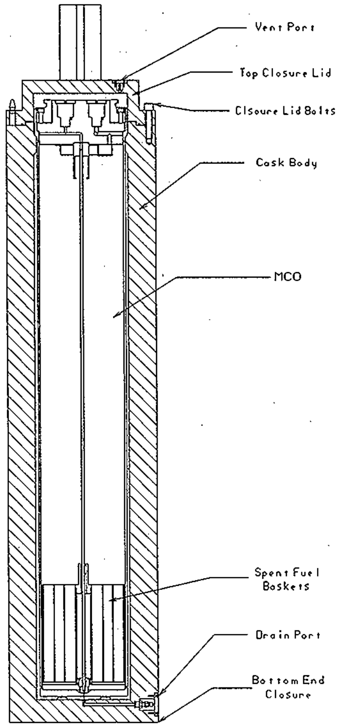
7.1.1 Structural Design Features

7.1.1.1 Design Features. The basic structural features of the MCO Cask are described in this section.

The MCO Cask, as shown in Figure B7-1, consists of the MCO Cask, MCO, baskets, and fuel. The MCO Cask provides the containment boundary under normal and accident conditions of transport. Inside the MCO Cask, another fuel retention boundary is provided by the MCO, but no credit for that retention boundary is taken. Within the MCO are five or six storage baskets, which hold the spent fuel assemblies in a circular array and, for Mark IA fuel, provide criticality control via the center tube.

The MCO Cask containment structure is a heavy-walled, right circular cylinder closed at the bottom end with welded-on forging. The top end is sealed with a bolt-on closure lid. Attached at 180° intervals at the top of the closure lid are two brackets of 304 stainless steel plate welded construction fitted with the cask lifting trunnions. The cask body, bottom end closure, and bolt-on closure lid are of 304 stainless steel forged construction. The lifting brackets and trunnions are constructed of welded 304 stainless steel and attached to the cask lid with 1.27-cm (0.5-in.) fillet welds. Overall exterior dimensions of the cask are 101.1 cm (39.81 in.) in diameter with a total length of 432.4 cm (170.3 in.), excluding the lifting brackets. The MCO Cask cavity is 63.98 cm (25.19 in.) in diameter and 407.7 cm (160.5 in.) in length.

Figure B7-1. Multicanister Overpack (MCO) Cask Package Sketch.



Nominal wall thickness of the cylindrical portion of the cask body is 18.57 cm (7.31 in.), which provides both structural integrity and shielding. At the top end of the cask body are 12, equally spaced, 1½-in.-6 UNC bolt holes, which mate to the hat-shaped closure lid. As an integral part of the cask, the body is fitted with a 5.72-cm- (2.25-in.-) thick, 2.54-cm- (1-in.-) tall shear ring on the top end radial surface.

Forming the bottom closure of the cask is a 15.57-cm- (6.13-in.-) thick forged section, which is welded to the cask body by a full penetration weld. Imbedded in the bottom closure forging is a cover drain port for cask drainage. The drain port is equipped with a double shut-off quick-release interface.

The containment closure of the MCO Cask is provided by the hat-shaped closure lid. Except for the lifting device, the lid is fabricated from a single forging. Nominal diameter of the flange section is 101.12 cm (39.81 in.). Thickness of the hat section is 8.89 cm (3.50 in.). The flange section has a thickness of 10.16 cm (4.00 in.) and is equipped with 12 equally spaced through holes placed on a 92.558-cm- (36.440-in.-) diameter bolt circle for the 1½-in. closure bolts. Located on the cask mating surface of the flange is a dovetail seal groove (for capturing the containment O-ring seal) and a recess for the shear ring. The dovetail seal groove diameter to the interior edge is 80.19 cm (31.57 in.). Welded to the top of the closure lid are two lifting brackets. The brackets are each fitted with trunnions for lifting and handling both the cask and lid.

7.1.1.2 Design Criteria. The MCO Cask is designed and fabricated to performance specification (WHC 1995) and evaluated to the requirements of the PDC. Structural design and fabrication criteria outlined in the specification and PDC are derived from requirements for packaging and transportation that are specific to the normal and accident conditions within the Hanford Site boundary.

The MCO is not considered as a containment boundary. Its function in conjunction with the spent fuel baskets is to maintain criticality control. The center pipe of the spent fuel baskets provides structural criticality control of the payload. This center pipe is designed and fabricated to the intent of ASME B&PV Code, Subsection NG (1995c). As required by the PDC, under all NCT and accident conditions the center pipe must be shown not to deform more than 5.1 cm (2 in.) from the centerline.

7.1.2 Mechanical Properties of Materials

The MCO Cask primary structural and containment components are constructed of forged 304 stainless steel, manufactured to ASME (1995a) SA-336 requirements. The closure bolts are fabricated from alloy steel conforming the requirements of ASME (1995a) SA-479, XM-19 requirements. The mechanical properties of the stainless steel and alloy steel materials used in the containment boundary evaluation are shown in Table B7-1.

Table B7-1. Mechanical Properties of Steels.

ASTM spec./ comp.	Type or grade	Temp. °F	Yield S_y[1] ksi	Ult. S_u[2] ksi	S_m[3] ksi	Modulus[4] (10^6 psi)	Coeff. of exp.[5] 10^{-6} in/in/°F
SA-336 cask body, bottom, and lid	304	-20 to 100 200 300 400 500	30 25.0 22.5 20.7 19.4	70 66.2 61.5 60 59.3	20.0 20.0 20.0 18.7 17.5	28.3* 27.6 27.0 26.5 25.8	8.63* 9.08 9.46 9.8 10.10
SA-479 closure lid bolts	XM-19	-20 to 100 200 300 400 500	105 99 94 91 89	135 133 129 126 124	35 33 31.3 30.3 29.7	28.3* 27.6 27.0 26.5 25.8	8.63* 9.08 9.46 9.8 10.10
Assumed SA-182 trunnions	304	-20 to 100 200 300	30 25.0 22.5	70 66.2 61.5	17.5 16.6 15.5	28.3* 27.6 26.5	8.63* 9.08 9.46

ASTM = American Society for Testing and Materials.
ASME, 1995a, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section II, American Society of Mechanical Engineers, New York, New York:
[1]Part D, Table Y-1.
[2]Part D, Table U.
[3]Part D, Table 2A.
[4]Part D, Table TM-1.
[5]Part D, Table TE-1.
*These values are taken at 70 °F.

The primary containment O-ring seal, located between the lid and the cask body, is manufactured from Butyl rubber. This rubber is a vulcanized petroleum product, made from co-polymerizing isobutylene and isoprene, with high resistance to gas permeation. Due to its gas permeation resistance, it is commonly used in vacuum applications. The service temperature range for this rubber is -54 °C (-65 °F) to 107 °C (225 °F). Butyl rubber has a density of 0.92 gm/cm^3, a hardness range of 45 to 80 Shore A durometer, and a tensile strength of 21 MPa (3000 psi [Machine Design 1988]).

The MCO is constructed of materials conforming to ASME B&PV Code, Subsection NB (ASME 1995b), Class 1 requirements. MCO components are fabricated from ASME (1995a) SA-312, Type TP304L, and SA-182, Type 304L, stainless steel for Class 1 components, except for the mechanical closure hardware. These components, the locking ring and shield plug, are manufactured from fine-grain, low-alloy carbon steel to prevent thread galling. The compression bolts are manufactured from high-strength alloy steel. Providing the seal on the MCO mechanical closure is metallic seal manufactured by Helicoflex. The criticality control spent fuel basket center pipe is constructed of SA-312, Type TP304 or 304L, for Class 1 components.

7.1.3 Chemical and Galvanic Reactions

Exterior surface corrosion of the MCO Cask is not a concern since the entire containment boundary is of 304 stainless steel construction, and all steel components in contact with the cask are painted. However, interior surface corrosion is of concern since, during transport from the K Basins to the CVDF, the spent fuel and baskets are submerged, and the MCO and MCO Cask are filled with K Basin water. Consequently, the spent fuel baskets, MCO, and MCO Cask are susceptible to localized corrosion processes (e.g., pitting, crevice corrosion, or stress corrosion cracking) if certain aggressive corrosive agents are present under certain conditions.

The MCOs and baskets are fabricated using welded construction without post-weld heat treatment. Consequently, residual stresses (near yield strength) in and surrounding the weld areas may occur. This would make the MCO susceptible to stress corrosion cracking near the welds if aggressive corrosion agents are present. To minimize the potential for stress corrosion cracking, a low-carbon stainless steel was selected for containment components. In addition, several operational parameters and physical characteristics of the materials of construction preclude stress corrosion cracking from being a problem during transport.

As with 304 stainless steel, 304L stainless steel materials develop a passive chromium oxide film when exposed to air. Therefore, properly fabricated and cleaned critical components of the MCO, spent fuel basket, and MCO Cask have a passive layer that protects against corrosion. This passive film is retained in natural water, whether hot or cold, with relatively high pollution levels (Butler and Ison 1966). Since the conductivity of the water in the K Basins ranges from 1 μS/cm to 5 μS/cm, which is only slightly higher than distilled or demineralized water, the corrosion restraint properties of critical stainless steel components are retained after the wet loading operations, in the absence of aggressive corrosive agents. It has been observed that at elevated temperatures (greater than boiling), water containing dissolved oxygen can cause stress corrosion cracking of sensitized stainless steel (carbide precipitation at the grain boundaries). However, the relatively low temperature of the water in the MCO and MCO Cask (less than boiling) and the use of low-carbon stainless steel preclude this type of stress corrosion cracking.

The two most important aggressive agents of stainless steel corrosion are chloride and fluoride ions. These two halogens will cause localized corrosion of stainless steel in the form of pitting, crevice corrosion, or stress corrosion cracking in moderate concentrations. The chloride content in the K Basins is below the detectable limit (0.083 p/M by weight), and the fluoride ion content is 0.248 p/M by weight. The water quality typically used for mixing cleaning solutions, rinsing, and flushing of nuclear reactor components requires halogen ion contents of less than 1 p/M by weight. Consequently, neither of these halogen ions are of sufficient concentration to cause localized corrosion during transport.

The MCO cask containment seal, manufactured from Butyl rubber, is not a halogenated hydrocarbon and does not contain high levels of halogens or other agents that are corrosive to 304 stainless steel. Butyl rubber is also highly resistant to oxidation and ozone degradation.

There are two possibilities for dissimilar metal contact in the MCO and MCO Cask during wet transport. The Zircaloy-2 fuel cladding will contact the MCO stainless steel baskets. Both the cladding and the stainless steel have passive oxide layers and exhibit the same galvanic potential. Consequently, there is no galvanic corrosion for this alloy combination. The uranium fuel may also come in contact with the MCO and spent fuel baskets in some locations. Since the uranium is corroding with a nonprotective oxide layer, this galvanic couple will not lead to accelerated corrosion of the stainless steel baskets. During dry transport (CVDF to CSB) with the liquid removed, galvanic corrosion is no longer possible.

7.1.4 Size of Package and Cavity

The MCO Cask is basically a hollow right circular cylinder with an outer diameter of 103.05 cm (40.57 in.) and length of 432.44 cm (170.25 in.). The contents cavity is 63.98 cm (25.19 in.) in diameter and 407.67 cm (160.5 in.) in length.

7.1.5 Weight and Center of Gravity

The gross weight of the package without water is 26,433 kg (57,910 lb), with the center of gravity of the package located 211 cm (83.6 in.) from the bottom. Empty weight of the package is 17,783 kg (39,204 lb), with the center of gravity located 207.82 cm (81.82 in.) from the bottom of the package. Weights of the individual components are shown in Table B7-2.

Table B7-2. Component Weights.

Component	Weight kg (lb)
Cask body shell	15,895 (34,300)
Cask body bottom	965 (2,270)
Closure lid	927 (1,890)
Empty weight of cask	17,783 (38,460)
Dry weight of Multicanister Overpack	8,310 (18,950)
Gross weight of cask (without water)	26,433 (57,910)

7.1.6 Tamper-Indicating Feature

This feature is not required due the weight of the lid, number of closure bolts, and MCO closure. Removal of the lid and MCO closure for access to the payload requires specialized handling and lifting equipment.

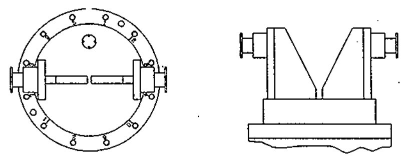
7.1.7 Positive Closure

Positive closure of the MCO Cask is provided by 12, high-strength, steel socket head cap screws (1½-6 UNC-2A x 7.25 in. long), which clamp the closure lid to the top of the cask body. A second positive closure is provided by the mechanical closure system of the MCO.

7.1.8 Lifting and Tiedown Devices

The MCO Cask is equipped with two trunnions (180° apart) for lifting and handling. The trunnions are mounted on brackets which are welded to the top of the lid as shown in Figure B7-2. As designed, the trunnions and brackets are constructed of 304 stainless steel material. The trunnions and brackets are evaluated in Part B, Section 7.6, by classical linear-elastic methods. Based on the yield and ultimate strength of common 304 stainless steel, the evaluation shows the trunnion and bracket strength meets the requirements of the PDC (WHC 1996) for lifting of the MCO Cask.

Figure B7-2. MCO Lifting Trunnions and Brackets.



7.1.9 Brittle Fracture

The containment boundary of the MCO Cask is constructed of 304 austenitic stainless steel. Austenitic stainless steels are not susceptible to brittle fracture at temperatures encountered in transport. Consequently, the use of this material has been accepted by the U.S. Nuclear Regulatory Commission (NRC) without testing.

The closure bolts are a high alloy ferritic steel. However, NUREG/CR-1815 (NRC 1981) states that bolts are generally not considered a fracture critical component. This is justified on the basis that bolts have multiple load paths, and failure of one or more bolts can be tolerated since failure normally does not lead to penetration or rupture of the package. Therefore, since there are 12 closure bolts on the package, failure of one or two bolts in brittle fracture will not lead to penetration or rupture of the package. Consequently, brittle fracture of the closure bolts does not need to be evaluated or tested for this design.

7.2 NORMAL TRANSFER CONDITIONS

7.2.1 Conditions To Be Evaluated

The following conditions or events are intended to envelop the effects of Hanford Site normal transfer conditions. The structural verification of the MCO cask design is contained in this section and in Part B, Section 7.7.

- Reduced external pressure of 24.1 KPa (3.5 psia)
- Increased external pressure of 137.9 KPa (20 psia)
- Internal pressure load of 1.03 MPa (150 psig)
- Free drop from a height of 0.3 m (1 ft) onto a 20.32 cm (8 in.) thick reinforced concrete surface with the following characteristics:
  - Concrete strength: 27.6 MPa (4,000 psi)
  - Soil modulus: 193 MPa (28,000 psi)
  - Concrete reinforcement: No. 7 rebar with a yield strength of 413.7 MPa (60,000 psi), spaced on 30.5 cm (12.0 in.) centers with a 5.08 cm (2 in.) cover
- Package impact in the orientation expected to cause maximum damage

The most critical conditions and events are evaluated for the worst-case environmental conditions. Load combinations for these evaluations are taken from NRC Regulatory Guide 7.8 (NRC 1977).

7.2.2 Acceptance Criteria

Under the above Hanford Site normal conditions, it must be demonstrated that the design of the MCO Cask maintains containment and shielding of the MCO. The containment boundary is defined as the cask structure. Stress allowables used in the analyses are taken from NRC Regulatory Guide 7.6 (NRC 1978) and are compatible with the ASME B&PV Code, Section III, Article NB-3000 (ASME 1995b). These stress allowables, combined with linear-elastic analysis, are used to demonstrate containment during the NCT. ASME B&PV Code, Section III, Subsection NB, Service Level A criteria are used for analytical acceptance. The allowable stresses are given in Table B7-3.

NRC Regulatory Guide 7.6 recommends the use of linear-elastic analysis stress allowables in Table B7-3. Bolts allowables are taken from NUREG/CR-6007 (Mok 1989). The use of these allowables prevents permanent deformation of the critical structural components of the containment barrier. As specified in NRC Regulatory Guide 7.6 (NRC 1978), the NCT loads are evaluated to Service Level A requirements.

Table B7-3. Containment Boundary Stresses Evaluation Criteria.

	Stress category	Normal conditions
Components other than bolts	Primary membrane stress intensity[(a)]	S_m
	Primary membrane + bending stress intensity[(a)]	1.5 S_m
	Range of primary + secondary stress intensity[(b)]	3.0 S_m
	Pure primary shear stress[(c)]	0.6 S_m
Bolts[(d)]	Average tension	S_m
	Average shear	0.6 S_m
	Average tension + average shear Stress ratio of average stress/allowable Rt: Stress ratio for average tensile Rs: Stress ratio for average shear	$Rt^2 + Rs^2 < 1$
	Bolts having tensile strength of > 100 ksi Tension + shear + bending + residual torsion	1.35 S_m

[a]Definitions according to: NRC, 1978, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, Regulatory Guide 7.6, Rev. 1, Paragraph B.4 and C.2, U.S. Nuclear Regulatory Commission, Washington, D.C.

[b]Definitions according to: NRC, 1978, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, Regulatory Guide 7.6, Paragraph C.4, U.S. Nuclear Regulatory Commission, Washington D.C.

[c]Definitions from: ASME, 1995b, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Subsection NB-3227.2, American Society of Mechanical Engineers, New York, New York.

[d]Definitions from: Mok, G. C., 1989, Stress Analysis of Closure Bolts for Shipping Casks, NUREG/CR-6007, Table 6.1, (under Lawrence Livermore National Laboratory contract to the NRC), U.S. Nuclear Regulatory Commission, Washington, D.C., March 1978.

The normal conditions MCO Cask containment boundary consists of the cask body, bottom end closure, top closure lid, and O-ring seal which is compressed by 12 closure bolts. Containment is also provided by the vent and drainport covers and O-ring seals, each of which are compressed by four closure bolts. The cask body, bottom end closure, and top closure lid are thick-walled sections manufactured from an ASME SA-336 stainless steel forging. Joining the cask body and bottom is a full penetration ASME B&PV Code, Section III, Subsection NB weld, forming the lower end closure. The upper closure is formed by the cask body and the top closure lid. On the mating surface of the cask body is a 2.54-cm- (1.0-in.-) thick shear ring. This shear ring is designed to reduce shear loading on the bolts. The seating surface of the top closure lid flange section is fitted with 12, 4.11-cm (1.62-in.), underside countered bore holes; a dovetail machined groove to accommodate a Butyl rubber O-ring; and a recess for the shear ring. Twelve, 1½-in.-6 UNC closure bolts secure the top lid onto the cask body and compress the O-ring seal, forming the upper closure seal. The bolts are manufactured from ASME SA-540, Grade B24, Class 1 material. The evaluations presented use the ASME B&PV Code material properties given in Table B7-1. Table B7-4 shows the allowable stresses as a function of temperature and loading.

The ASME B&PV Code stress intensity used for comparison to ASME allowables is defined as the largest difference among the principal stresses. For example, if $\sigma 1$, $\sigma 2$, and $\sigma 3$ are the three principal stresses and $\sigma 1 > \sigma 2 > \sigma 3$, then the ASME B&PV Code stress intensity is $(\sigma 1 - \sigma 3)$. In all evaluation cases, the results of the finite element calculations are retrieved and processed to obtain the ASME B&PV Code stress intensities. Comparison of the ASME B&PV Code stress intensities versus the ASME B&PV Code allowables are used to demonstrate the structural integrity and containment performance of the cask except in critical areas where plastic deformation is a primary factor, such as with the spent fuel baskets.

Table B7-4. Containment Boundary Normal Condition Allowable Stresses, MPa (ksi).

	Stress category	70 °F	100 °F	200 °F	300 °F	400 °F
Components other than bolts	Material	SA-336, 304 stainless steel				
	Primary membrane stress intensity (ksi)	137.9 (20.0)	137.9 (20.0)	137.9 (20.0)	137.9 (20.0)	128.9 (18.7)
	Primary membrane + bending stress intensity (ksi)	206.8 (30.0)	206.8 (30.0)	206.8 (30.0)	206.8 (30.0)	193.7 (28.1)
	Range of primary + secondary stress intensity (ksi)	413.7 (60.0)	413.7 (60.0)	413.7 (60.0)	413.7 (60.0)	386.8 (56.1)
	Primary shear stress (ksi)	82.7 (12.0)	82.7 (12.0)	82.7 (12.0)	82.7 (12.0)	77.2 (11.2)
Bolts	Material	SA-479, XM-19				
	Average tension stress	241.3 (35.0)	241.3 (35.0)	227.5 (33.0)	215.8 (31.3)	208.9 (30.3)
	Average shear stress	144.8 (21.0)	144.8 (21.0)	136.5 (19.8)	129.6 (18.8)	125.5 (18.2)
	Tension + shear + bending + residual torsion	326.1 (47.3)	326.1 (47.3)	307.5 (44.6)	291.6 (42.3)	282.0 (40.9)

Although peak accelerations are determined, they are not used in evaluation of the stresses. As determined from British Nuclear Fuels Limited (BNFL) impact tests on concrete (Stokley and Williamson 1996), the use of peak acceleration for quasi-static evaluations is overly conservative. The integrity of the cask is a function of total impulse of the impact scenario. Consequently, for this evaluation, the equivalent average stress over the total impulse is used to determine the ASME B&PV Code stress intensity.

7.2.3 Structural Model

Structural evaluation of the cask system was performed using a variety of analytical tools. Cask pressures are analyzed by the ABAQUS/Standard (HKS 1995) finite-element analysis (FEA) program. Drop stresses and deformation of the cask were analyzed using the ABAQUS/Explicit (ABAQUS 1995) FEA program. Lifting evaluations are performed using classic linear-elastic methods.

Data for benchmarking of the analytical impact models was obtained from cask drop tests onto various concrete and soil surfaces, which were conducted by Sandia National Laboratory (SNL) in 1986. Actual cask impact test data is summarized in an SNL report (Gonzales 1987), and pertinent data is shown in Table B7-5 of this document.

Table B7-5. SNL Target Hardness Test Results.*

Test		Maximum recorded acceleration (gs)	Penetration cm (in.)
Concrete runway	13 m/s (44 ft/s)	480	0.64 (0.25)
	20 m/s (66 ft/s)	900	10 (4)
	27 m/s (88 ft/s)	1000	20 (8)
Concrete highway	13 m/s (44 ft/s)	350	10 (4)
	20 m/s (66 ft/s)	----	10 (4)
	27 m/s (88 ft/s)	7500	48 (19)

SNL = Sandia National Laboratory.
*Gonzales, A., 1987, Target Effects on Package Response: An Experimental and Analytical Evaluation, SAND86-2275, Sandia National Laboratory, Albuquerque, New Mexico.

This test data is used to develop and benchmark realistic two-dimensional (2-D) and three-dimensional (3-D) models simulating cask impacts onto concrete surfaces with the ABAQUS/Explicit (ABAQUS 1995) general purpose finite element program. The resulting computer simulations are used to determine concrete/soil target behavior and simulation parameters.

Comparisons from three 2-D calibrated simulations to test data are shown in Table B7-6 to demonstrate the validity of the ABAQUS/Explicit FEA modeling methods for cask impact evaluation. The 2-D model used both the runway concrete and highway concrete cask impact test data to study material behavior and develop simulation parameters for target models. In the 2-D model, the concrete is modeled as a uniform isotropic material and the soil as nonlinear spring elements.

Table B7-6. 2-D Model Comparison of Highway and Runway Concrete Impact.

Impact velocity m/s (ft/s)	Target	Calculated peak g load	Measured peak g load	Calculated penetration cm (in.)	Measured penetration cm (in.)
13.4 (44.0)	concrete highway	583	350	9.4 (3.7)	10.2 (4.0)
13.4 (44.0)	concrete runway	814	480	0.8 (0.3)	0.64 (0.25)
26.8 (88.0)	concrete runway	1128	1000	13.5 (5.3)	20.3 (8.0)

2-D = Two-dimensional.

Results comparing 3-D calibrated simulations to actual test data are shown in Table B7-7 to demonstrate the accuracy and realistic representation of the ABAQUS/Explicit FEA modeling methods used in the evaluation of casks. The 3-D model differs from 2-D model in that the soil and concrete are represented by eight-node brick elements. These changes were made for a more accurate representation of the concrete and soil behavior. Comparison of the 2-D and 3-D modeling results with actual test data demonstrates the 3-D model substantially improves simulation accuracy of cask impacts onto concrete surfaces.

Table B7-7. 3-D Model Comparison of Runway Concrete Impact.

Impact velocity m/s (ft/s)	Calculated peak g load	Measured peak g load	Calculated penetration cm (in.)	Measured penetration cm (in.)
20.1 (66.0)	894	900	11.9 (4.7)	10.2 (4.0)
26.8 (88.0)	1343	1000	22.1 (8.7)	20.3 (8.0)

3-D = Three-dimensional.

7.2.3.1 ABAQUS/Explicit Model Description. The ABAQUS/Explicit computer code is a dynamic FEA program that can be used for elastic, plastic, and other inelastic analysis of structural members. The primary feature of ABAQUS/Explicit is that it has the ability to solve impact problems.

Three different models are constructed to address different drop conditions: the bottom end flat drop, the bottom end oblique drop, and the top end oblique drop. All of these models use a half (180°) section for both the projectile and target. The lid, lifting brackets, and payload remain the same for all cases while the cask body's meshes are modified to have finer meshes around the impact point. The orientation of the cask/lid is kept unchanged for all cases (i.e., Z for the vertical coordinate, and X and Y for two horizontal coordinates).

The target model remains the same in all cases; only the orientation is changed. The initial impact velocity in each case is modified in X, Y, and Z axis components to reflect the impact orientation. These techniques minimize the modeling efforts.

The ABAQUS/Explicit (ABAQUS 1995) FEA computer code evaluates the impact by modeling two parts, a projectile and target. The projectile is defined as the cask body, closure lid, closure lid bolts, and contents. The target surface is defined as the reinforced concrete pad and soil. In each case, the two impacting parts are defined, and the contact force is calculated from the two impacting parts.

Several contact pairs are defined in each drop case depending on drop orientations. There is always a contact pair between the cask (projectile) and the concrete pad (target). The concrete pad contact surface includes a large central portion of the concrete pad through its entire depth. Because the concrete and the smeared rebars in this study are allowed to undergo large deformations, the lower layers of the concrete can become contact surfaces. The other contact surface (or surfaces) for this pair is the cask impact surface. For example, in the bottom end oblique drop, the cask impact surfaces include the bottom surface of the cask, the lower portion of the cask outside wall, and the outside surface of the drain port cover plate. The contact surfaces form contact pairs from which the contact force can be obtained.

The lid bottom surface and the cask top surface form another contact pair. These two surfaces are allowed to move apart, but are not allowed to penetrate one another. Relative movement of the lid to the cask body is restrained by the 12 closure bolts. The shear key on the cask body takes up the shear loads, subjecting the lid bolts to only tensile loads.

The payload (MCO and spent fuel basket) inside the cask cavity is modeled by two separate contact pairs. The first pair is the exterior surface of the payload and the interior surface of the cask body; the second pair is the exterior surface of the payload and the interior surface of the lid. The main function of the payload is to generate a total weight of 27,215 kg (60,000 lb) of the entire cask/transportation assembly (13,607 kg [30,000 lb] in this half-section model) by modifying its density. Assuming the payload initially rests in the cask when the cask is dropped in the top-down orientation, the payload is free to slide and impact the ends of the cask. This results in additional load effects on the cask. The payload is modeled as a solid cylindrical body to conserve computing resources. (The primary function of this model is to simulate the loaded weight of the MCO per the section evaluation by modifying its density. The interfaces of the payload and the cask interior surfaces share the same nodes for this analysis.)

The cask model uses finer meshes at the bottom section and the outer cylindrical wall of the cask. Coarser meshes are on the top section and the inner cylindrical wall. The 180° section of the cask is divided into four 7.5° sectors and ten 15°. Finer meshes are also used around the drain port. The lid is modeled separately from the cask body. The lid, shear key, and lid bolts are modeled with moderate detail. The lid bolts are modeled by using ABAQUS tensile truss element (T3D2). These truss elements can only withstand tensile loads, but provide better simulation bolt behavior during the impact.

The bottom end drop cases are modeled with the drain port at the bottom corner of the cask. The drain port is fitted with a cover plate and fastened to the cask body with four ½-in.-13 UNC bolts. A contact pair is defined between the cover plate and the drain port hole, which allows them to move independently without penetrating each other. Movement is assumed to be restrained by four bolts on the cover plate. The FEA model of the bottom end flat drop is a half (180°) section of the MCO Cask and concrete pad.

In the case of the bottom-oblique-drop FEA model, the cask model is the same as for the bottom-end-flat drop. To obtain the worst-case bottom oblique impact, the vectors of initial velocity and gravitational load must pass through the bottom edge of the cask. The concrete/soil target is rotated by an angle of 13.16° to have its normal in-line with the velocity and gravitational vectors. Subsequently, the axis of the cask and concrete surface form a 76.84° angle. The impact is in both the X and Z directions for this model. The velocity components for this model are 0.56 m/s (21.92 in/sec) in the X direction and 2.38 m/s (93.77 in/s) in the Z direction. The longitudinal mesh of the cask is the same as for the bottom-end-drop model, with a finer mesh at the bottom impact location and drain port area.

Due the hat-shaped geometry of the top lid with the trunnions brackets extending out (as shown in Figures B7-1 and B7-2), the top oblique model has the impact occurring initially at one of the trunnion brackets. The drain port is not included in this model to conserve computing resources. The impact location is at the tip of one lifting bracket. Due to the bracket height (51 cm [20 in.] over the top of lid), the top of the lid and the flange of the lid cannot have an impact with initial velocity and gravitational loads oriented directly through the top edge of the closure lid. Therefore, a 78.4° impact formed by the longitudinal axis of the cask with the target was determined as the worst-case orientation after an examination of data from several impact orientations. Subsequently, the impact is in the X and Z directions. The velocity components for this model are 0.34 m/s (13.2 in/sec) in the X direction and 2.42 m/s (95.4 in/s) in the Z direction. The cask model for this case has a finer mesh in the top section of the cask.

All the models are modeled as half-sections with the appropriate symmetric boundary conditions specified at the symmetrical surfaces. The soil bottom nodes are fixed in all three directions.

The concrete/soil target is also modeled as a half-section. The concrete region model is composed of eight-noded brick elements and defined as a half-section of a square block of 609.6 cm x 609.6 cm (240 in. x 240 in.) by 20.32 cm (8 in.) thick with reinforcing steel bars. However, in the end drop cases, an equivalent circular concrete pad is used for easier incorporation of the reinforcing steels. The reinforcing steels are smeared into the concrete elements with the ABAQUS *REBAR command. Within the concrete region, symmetry conditions are imposed on the nodes that are on the symmetry plane--no other nodes are constrained. The constitutive model is a Drucker-Prager plasticity model. The soil region in the FEA model is also composed of eight-noded brick elements. Nodes at the bottom of the soil region are fixed, and the nodes on the lateral surface have no boundary conditions. Depth of the soil region is 254 cm (100 in.). The soil constitutive model is a Drucker-Prager plasticity model developed originally for analysis of underground tanks (Julyk 1994). In all three cases, the initial velocity is defined as 2.45 m/s (96.3 in/s) for the 0.3-m (1-ft) drop. The total time of the analysis is carried 10 ms beyond the cask rebound. The ABAQUS computer code selects the initial time step based on the model element dimension and automatically adjusts the step size for efficient processing.

7.2.3.2 Element Model Map. As an aid to determining locations of the stresses and strains tabulated in the following tables, element and node maps are provided in this section. These maps are applicable for all cases in determining the stress and strain locations. Figure B7-3 maps the general elevation locations of elements and nodes. Figures B7-4 and B7-5 show the location of elements at the bottom of the cask and near the drain port. General element layer locations at the drain port are shown in Figures B7-6 and B7-7. Figures B7-8 to B7-20 show specific element locations in the drain port and cover plate regions. Trunnions are not shown since they are not part of the containment boundary, nor are they evaluated in the drop evaluation.

Figure B7-3. MCO Cask Overall Element Map.

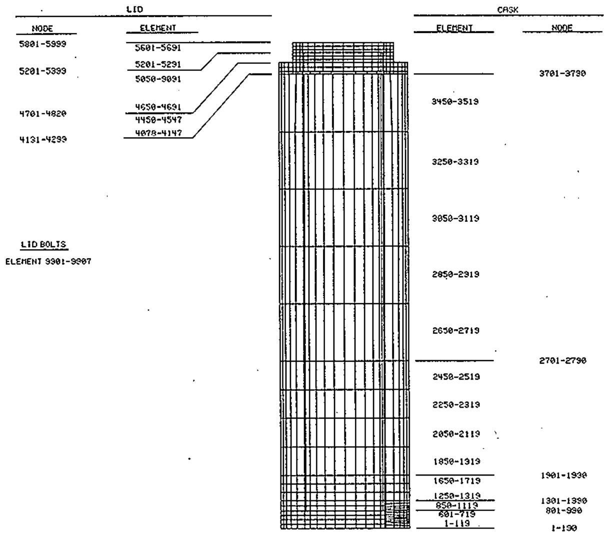


Figure B7-4. MCO Cask Bottom Element Map.

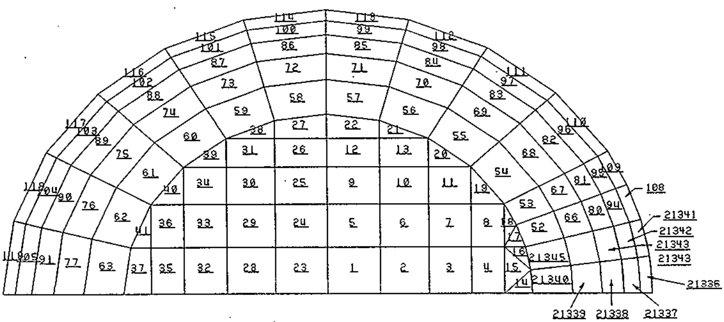


Figure B7-5. Element Map Near Drain Port.

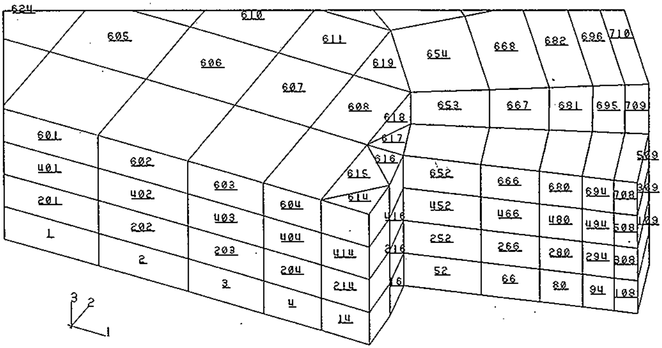


Figure B7-6. View of Drain Port from Inside Cask.

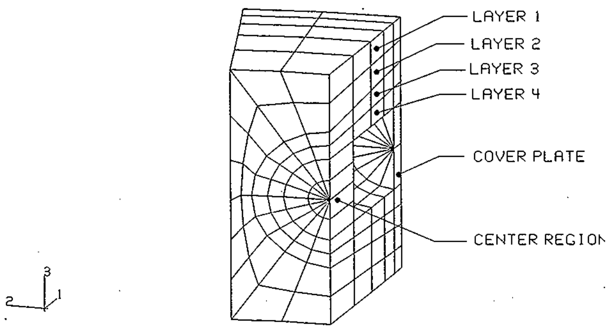


Figure B7-7. Drain Port Viewed from Outside Cask.

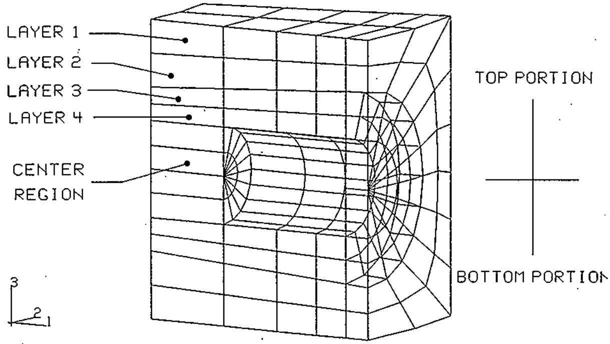


Figure B7-8. Drain Port Layer 1, Top Portion.

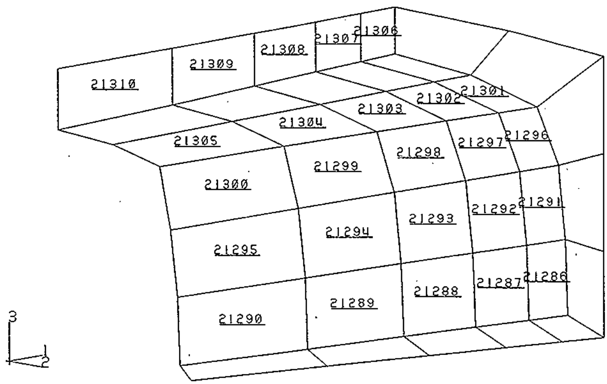


Figure B7-9. Drain Port Layer 1, Bottom Portion.

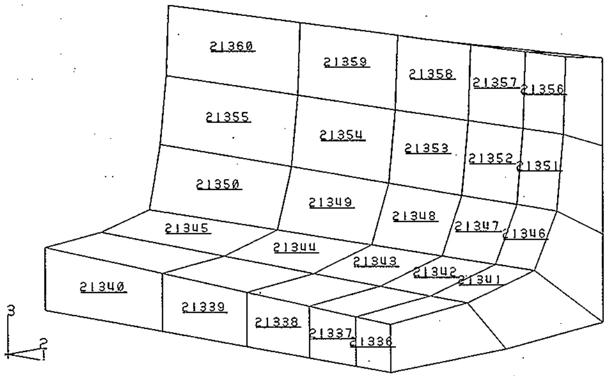


Figure B7-10. Drain Port Layer 2, Bottom Portion.

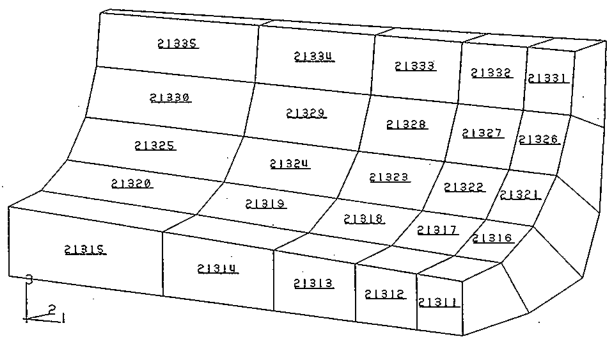


Figure B7-11. Drain Port Layer 2, Top Portion.

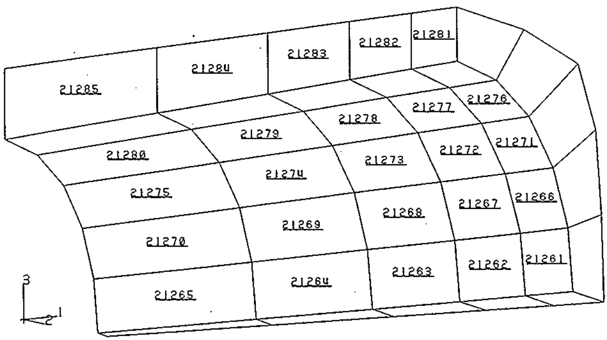


Figure B7-12. Drain Port Layer 3, Bottom Portion.

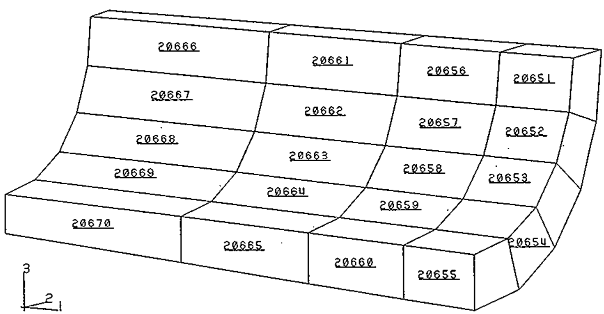


Figure B7-13. Drain Port Layer 3, Top Portion.

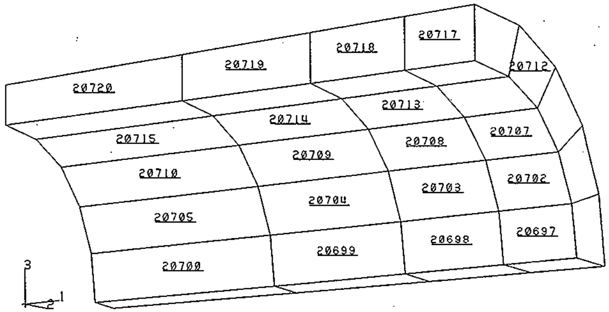


Figure B7-14. Drain Port Layer 4, Bottom Portion.

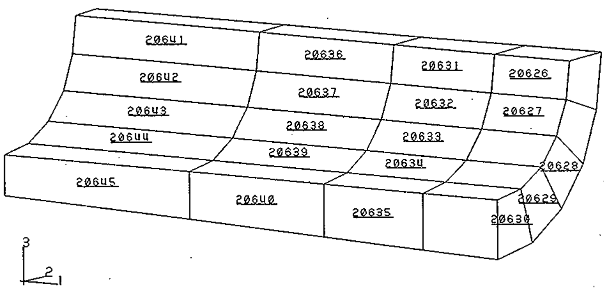


Figure B7-15. Drain Port Layer 4, Top Portion.

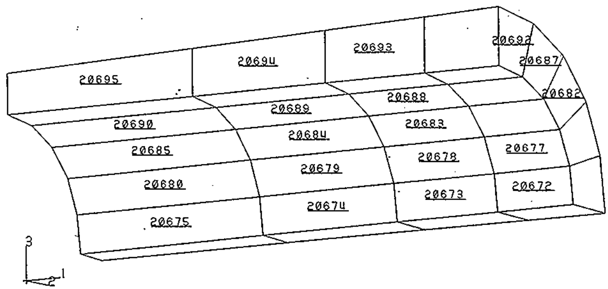


Figure B7-16. Drain Port Cover Plate (Half Section).

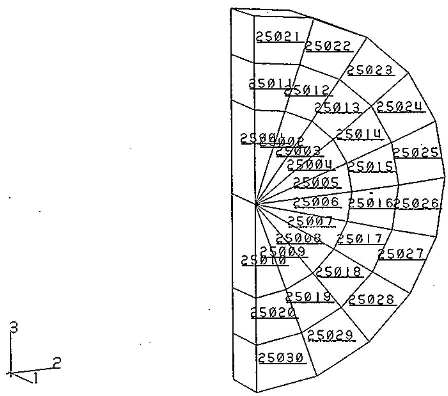


Figure B7-17. Drain Port Cover, Center Portion.

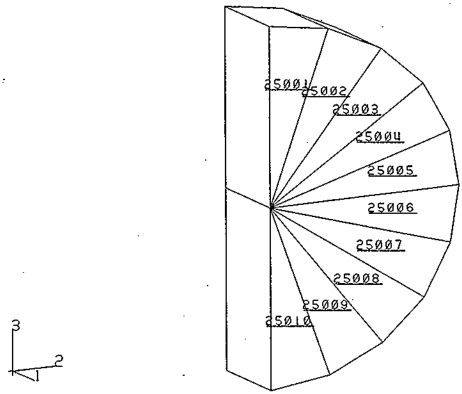


Figure B7-18. Drain Port Cover Plate (Outer Portion).

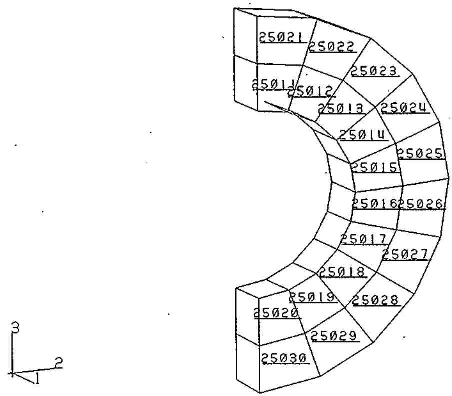


Figure B7-19. Drain Port Containment Boundary Side, Center Portion.

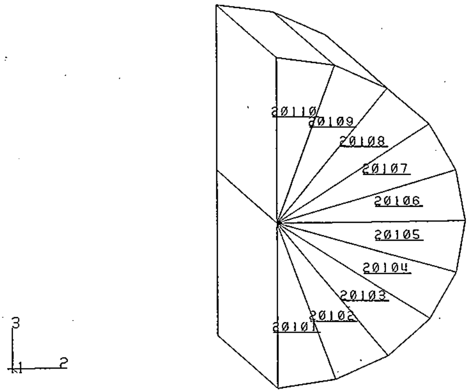
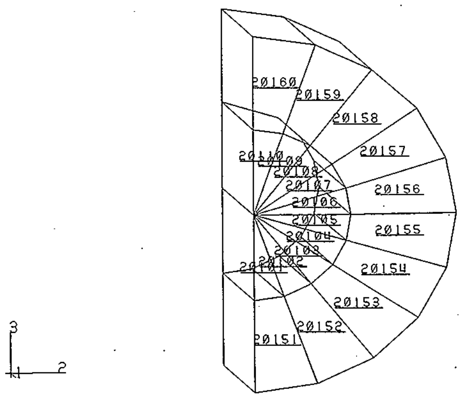


Figure B7-20. Drain Port Containment Boundary Side, Half Section.



Element maps of the top lid are shown in Figures B7-21 through B7-26. Figures B7-21 and B7-24 show the general orientation of the elements. Detailed element locations are shown on Figures B7-22, B7-23, B7-25, and B7-26.

Figure B7-21. Top View of Cask Lid.

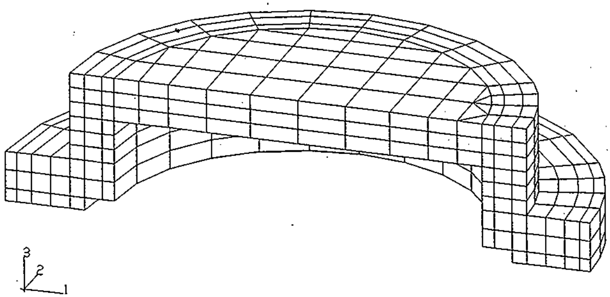


Figure B7-22. Exterior Elements of Lid.

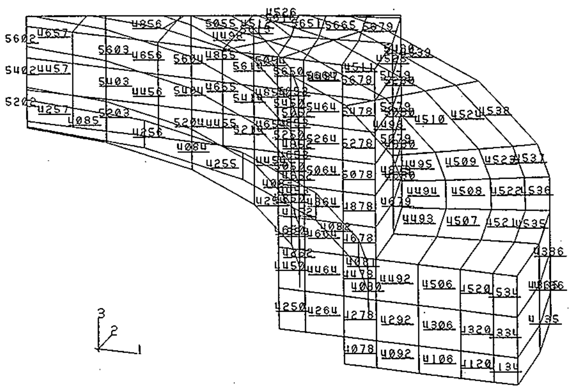


Figure B7-23. Interior Elements of Shear Key and Cask Wall.

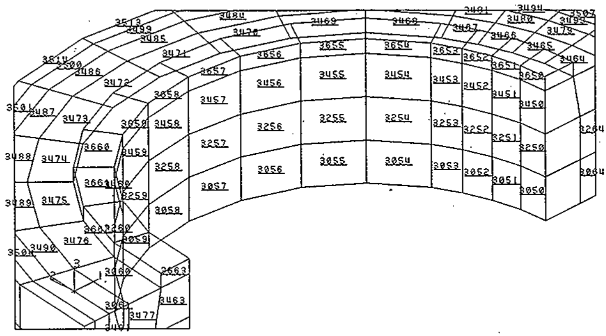


Figure B7-24. Bottom View of Cask Lid.

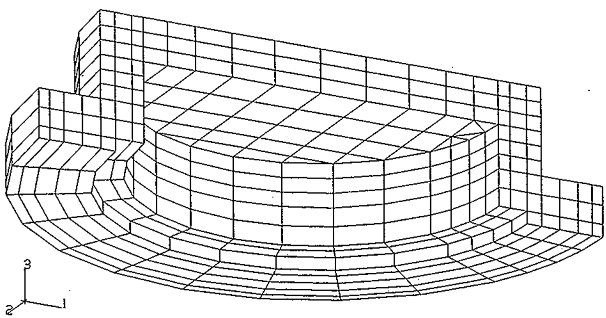


Figure B7-25. Interior of Cask Lid Plate.

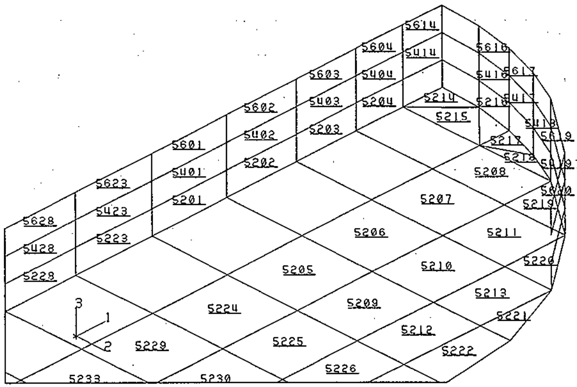
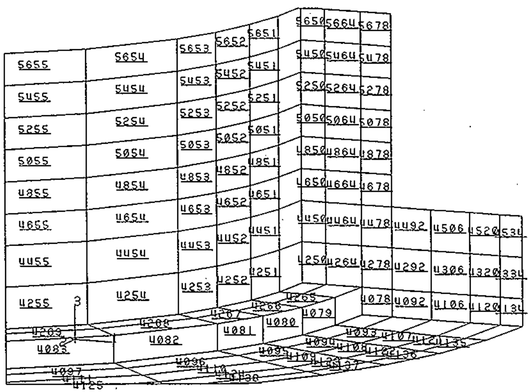


Figure B7-26. Interior of Cask Lid Wall and Flange.



7.2.4 Initial Conditions

7.2.4.1 Environmental Heating Loading. Part B, Section 8.0, gives the temperatures of the MCO Cask under maximum ambient conditions. The worst-case loading under normal transfer conditions is assumed to be the design pressure of 1.03 MPa (150 psi) at 20° C (70° F) under hot conditions. Since the MCO Cask contents impose a heat load in the cask, transient and steady-state effects of this heat load are evaluated.

7.2.4.2 Maximum Thermal and Pressure Stresses. Under normal conditions, the steady-state thermal stresses due to a temperature gradient are based on a design interior temperature of 75 °C (167 °F) and exterior cold temperature of -33 °C (-27 °F) are evaluated. Transient thermal stresses are evaluated for a temperature gradient produced just after loading, where the cask interior temperature is 75 °C (167 °F) and the exterior temperature is at an ambient of 21 °C (70 °F). The exterior cold temperature produces the largest gradient and is considered the worst-case loading. The thermal and pressure loadings are combined to give the highest stress value on the cask.

The transient stress arises when the cask is heated due to the heat generation of the contents. If the cask has an initial temperature and, beginning at time t=0, the inside surface is heated, the transient temperature gradients throughout the wall can be obtained. Assuming the cask is suddenly heated on the inside surface, a skin effect is created on the inside surface. In the transient phase, there is insufficient time for heat conduction to occur. Consequently, a vertical thermal gradient through the wall can be assumed. Since the mean temperature of the entire cylindrical wall is unchanged, the axial σ_a and the tangential σ_t thermal stress at the inside wall are equal and are:

$$\sigma_a = \sigma_t = \frac{-\alpha\ E\ \Delta T}{1 - \mu}$$

where: α = Thermal expansion coefficient, per °F
E = Modulus of Elasticity, psi
μ = Poisson's ratio
ΔT = the difference between the mean temperature of the entire wall section and the temperature at the desired location.

Under this condition, the skin effect of thermal stress is experienced at the inside surface. The outer surface of the cask does not experience any thermal stress. The axial and tangential thermal stress at the inside surface at time zero is:

$$\sigma_a = \sigma_t = \frac{\alpha\ E\ \Delta T}{1 - \mu} = \frac{(8.63 \cdot 10^{-6})\ (28.3 \cdot 10^{6})\ (118.5 - 167)}{(1 - 0.3)}$$

$$= -16.9\ ksi\ (116.5\ MPa)$$

where the mean temperature is defined as: $\frac{(167 + 70)}{2} = 118.5\ °F$

This shows the cask inside surface is in compression while the exterior surface experiences no thermal stress.

During transport, the cask is assumed to be in a thermally steady-state condition. Under steady-state conditions, the thermal gradient slope becomes logarithmic, which can be simplified by approximating it as a linear thermal gradient. By this simplification, the thermal stresses at the cask inside and outside wall surfaces can be determined from the equations described above. The mean temperature of the cylinder wall thickness is half the differential between the mean temperature and the inner or outer wall temperature. The worst-case mean temperature for the NCT is defined as:

$$\frac{(167 - 27)}{2} = 70\ °F$$

The thermal stress at the inner wall surface is then:

$$\sigma_a = \sigma_t = \frac{\alpha\ E\ \Delta T}{2\ (1 - \mu)} = \frac{(8.63 \cdot 10^{-6})\ (28.3 \cdot 10^{6})\ (70 - 167)}{2\ (1 - 0.3)}$$

$$= -16{,}9\ ksi\ (116.5\ MPa)$$

The outer wall surface thermal stress is:

$$\sigma_a = \sigma_t = \frac{\alpha\ E\ \Delta T}{2\ (1 - \mu)} = \frac{(8.63 \cdot 10^{-6})\ (28.3 \cdot 10^{6})\ (70 + 27)}{2\ (1 - 0.3)}$$

$$= 16.9\ ksi\ (116.5\ MPa)$$

The inner wall surface is in compression, and the outer wall surface is in tension.

Loading of the MCO Cask due to the internal design pressure of 1.03 MPa (150 psi) was evaluated using the ABAQUS/Standard (HKS 1995) FEA program (Part B, Section 7.6). The cask is modeled with four-noded axisymmetric elements, and the closure bolts are modeled as truss elements. This bolt element attaches the lid mesh to the main mesh of the cask body. The shear force on the bolts is by spring elements between the horizontal degrees of freedom at the top bolt node and the bottom bolt node. Contact conditions are specified at the junctions between the lid and cask to model the flange action.

Results of this analysis show that the peak stress intensity is 10.3 MPa (1.5 ksi) at the top plate of the closure lid. For conservatism, this maximum stress intensity is assumed to be a primary membrane stress applied uniformly with the cask interior. The evaluation also shows that axial loading on the bolts is negligible and the preload stress of 87.6 MPa (12.7 ksi) predominates.

For the NCT, the stress intensities are combined by Level A, Service Limits (ASME 1995b), Subsection NB requirements. This requires combining the pressure loads with the thermal loads. In this evaluation the maximum differential thermal stress, calculated above, is considered secondary and acting at the maximum pressure stress intensity location. The maximum stress intensity from the pressure and thermal loading is determined by superimposing the thermal and pressure stresses. The maximum combined stress intensity at the inner wall surface for thermal and pressure loading under normal conditions is:

$$s_{ipt} = 16.9\ ksi + 1.5\ ksi = 18.4\ ksi\ (126.9\ MPa)$$

Assuming the allowable stress intensity of the material is 413.7 MPa (60 ksi) at 93 °C (200 °F), from Table B7-4, the margin of safety is:

$$MS = \frac{3\ S_m}{s_{ipt}} - 1 = \frac{60.0\ ksi}{18.4\ ksi} - 1 = 2.26$$

7.2.4.3 Normal Condition Drop Evaluations. The stresses due to an NCT drop are determined using the ABAQUS/Explicit FEA computer code. Three models are developed to simulate probable drop orientations, which would result in the most damage, during a normal condition drop. These three drop orientations are the flat-bottom end drop, bottom-end oblique drop, and top-end oblique drop. These models are described in Part B, Section 7.2.3.

Analytically, the cask is impacted onto a 20-cm- (8-in.-) thick concrete surface described in Part B, Section 7.2.3. The impact duration (rise time) and deceleration load factors for the three orientations are determined by the ABAQUS/Explicit FEA computer code. Impact duration and time-averaged deceleration load factors are summarized in the tables for each drop case.

To illustrate the overall cask response, the acceleration due to impact is determined by three methods. The most conservative is by dividing the total reaction force of impact by the total cask assembly weight and defining the peak acceleration as a function of time. The other two methods are based on the change in velocity. The time-averaged acceleration over the impact period more accurately reflects actual cask global behavior by accounting for the cask response time during the impact. Consequently, a more accurate method to estimate the acceleration is to use the nodal velocity data. The more conservative method is to determine a linear peak acceleration by determining the steepest slope along the time dependent curve. An alternate and less conservative method is to average the change in velocity over the entire impact event. These accelerations are provided only for quasi-static evaluation of the MCO and spent fuel baskets which use the conservative force determined from the peak acceleration. Dynamic evaluation of the MCO Cask loadings, such as stress and strain determination, are performed directly by the ABAQUS/Explicit (ABAQUS 1995) FEA computer code.

As with an actual cask test, these simulated cask impacts result in noise from high-frequency strain waves, similar to those recorded during instrumented cask drop tests. The frequency magnitude of these strain waves are such that the material is not capable of reacting to them. In recognition of this behavior, International Atomic Energy Agency (IAEA) Safety Series 37

(IAEA 1990) recommends filtering out frequencies higher than 100 to 200 Hz for a heavy package drop test. For conservatism in the following computational impact simulation, frequencies higher than 1000 Hz are filtered out. Also, in the following cases the peak impact acceleration is determined by dividing the total reaction force by the total cask assembly weight. This total force is the summation of all nodal reaction forces at the cask contact area with the target. In some cases a sharp spike appears, resembling a high-frequency noise, at time zero of the impact. This is a result of interaction among the residual forces from the myriad number of contact surfaces. Consequently, these are computational anomalies that do not represent the actual cask response. Filtering of higher frequencies also eliminates these numerical anomalies.

The ASME Code stress intensity is defined as the largest difference among the principal stresses. If P1, P2, and P3 are the three principal stresses and P1 < P2 < P3, then the ASME Code stress intensity is (P3 - P1). Results of the principal stresses at the most critical elements/locations of the cask body are retrieved from the ABAQUS run and processed to obtain the ASME Code stress intensities. The ASME Code stress intensities of the lid bolts are obtained in the same manner. These stress intensities also contain high-frequency noise. For simplicity and conservative consideration, the estimated average ASME stress intensity is obtained as the larger of (1) half of the maximum peak stress intensity or (2) the stress intensity at the end of impact period.

The ASME B&PV Code stress intensities, determined as specified in Subsection NB, at the most critical elements and locations are presented in the tables for each drop case. The maximum stress intensities are summarized in Table B7-8 for the NCT. The stress intensities are classified as primary and secondary based on the type of loading, stress location, geometry of structure, and deformation. By the ASME methods for stress categorization, primary stresses are stresses required to satisfy equilibrium of the loading, which is a load-controlled quantity. Secondary stresses are not required to balance the loading and are a deformation-controlled quantity that is self-relieving. An example of secondary stresses by ASME code definition are thermal stresses. For conservatism, all stresses determined in this drop evaluation are assumed to be primary membrane stresses.

The closure lid bolt stress intensities shown in Table B7-8 are based on the cask being equipped with a shear ring, which acts to limit the shear forces generated by the side and oblique drops. Consequently, the bolts are subjected to only axial tension loading and prying forces.

Table B7-8. Overall Maximum Stress Intensity of the 0.3-m (1-ft) Drops.

Orientation	Cask body/closure lid				Lid bolts[b]	
	Exterior		Containment		Element	Stress (ksi)
	Element	Stress MPa (ksi)	Element	Stress MPa (ksi)		
Bottom end drop	25030	29.16 (4.23)	20109	31.72 (4.60)	9907	124.93 (18.12)
Bottom oblique drop	21336	155.5 (22.56)	20695	22.82 (3.31)	9907	7.17 (1.04)
Top oblique drop	5664	64.26 (9.32)	3652	54.12 (7.85)	9907	21.99 (3.19)

7.2.4.3.1 0.3 m (1 ft) Bottom-End Flat Drop. In this case the MCO Cask performance is evaluated for a 0.3-m (1-ft) bottom-end flat drop on the concrete/soil target. The unfiltered impact acceleration history is shown in Figure B7-27. After filtering out frequencies higher than 1000 Hz, the acceleration history appears to have an impact period of about 26 ms (Figure B7-28). As seen in Figure B7-28, the peak acceleration is found to be 21.0*g*.

Figure B7-27. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Acceleration History (Unfiltered).

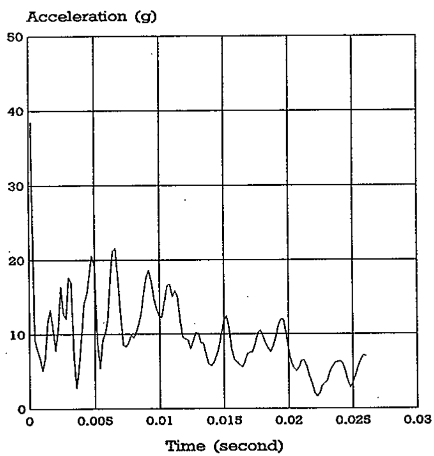
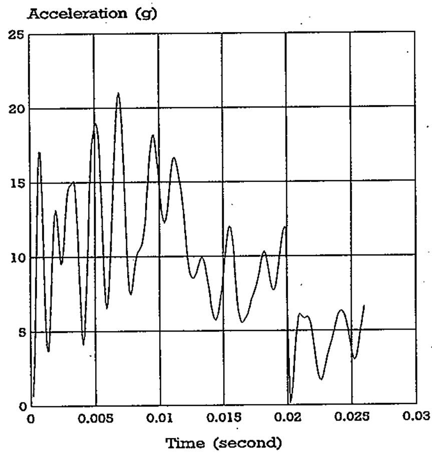


Figure B7-28. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Acceleration History (Filtered at 1000 Hz).



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of lid, respectively, are shown in Figures B7-29 through B7-31. The data points are the center of the plate (except the center-of-gravity level does not have this point), 0° point, and 180° point from the drain-port in the circumferential direction. All three figures indicate that the 0.3-m (1-ft) drop impact period of about 26 ms. The cask has an initial impact velocity of 2.4 m/s (96.3 in/s). In the initial 15 ms the cask is seen to have a linear average peak acceleration of approximately 13.2*g*. However, averaging the velocity change over the impact period the cask has an average acceleration of 10.4*g*. Pertinent impact acceleration data are shown in Table B7-9.

Figure B7-29. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Velocity History at the Bottom of Cask.

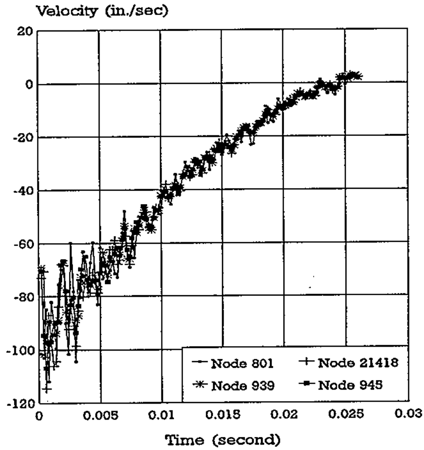


Figure B7-30. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Velocity History at the Center of Gravity of Cask.

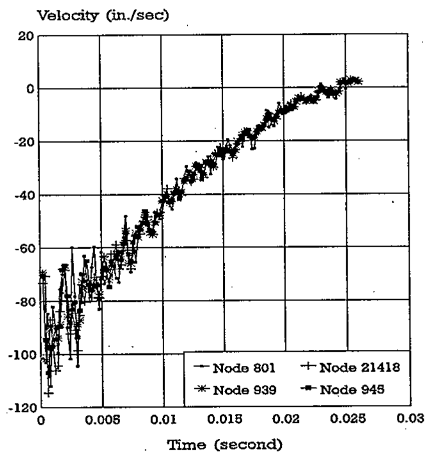


Figure B7-31. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Velocity History at the Top Lid.

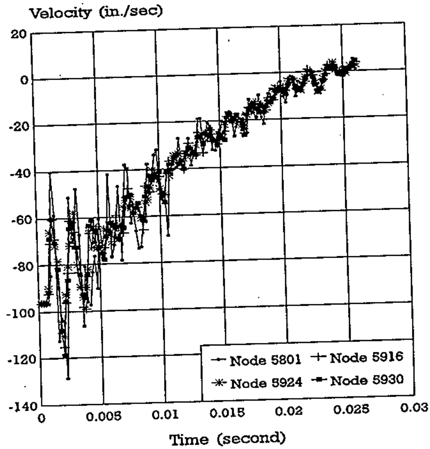


Table B7-9. Impact Acceleration Data of the 0.3-m (1-ft) Bottom-End Flat Drop.

Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
13.2	10.4	21.0	24

Stress Intensity. The estimated average ASME Code stress intensities are shown in Table B7-10 at the most critical cask exterior shell and containment boundary locations and at all lid bolts. The stress intensity plots at the most critical locations are shown in Figures B7-32 through B7-35. The stress intensity plots of lid bolts are shown in Figures B7-36 through B7-42.

Table B7-10. Estimated Average ASME Code Stress Intensity at Critical Locations from the 0.3-m (1-ft) Bottom-End Flat Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
21336	11.93 (1.73)	614	13.58 (1.97)	9901	123.21 (17.87)
21337	17.93 (2.60)	615	14.82 (2.15)	9902	122.38 (17.75)
21338	25.72 (3.73)	616	27.1 (3.93)	9903	113.62 (16.48)
21339	11.79 (1.71)	21310	16.82 (2.44)	9904	107.56 (15.60)
21340	15.44 (2.24)	21305	19.10 (2.77)	9905	112.52 (16.32)
21341	13.93 (2.02)	21300	23.99 (3.48)	9906	120.59 (17.49)
21342	20.27 (2.94)	21295	15.86 (2.30)	9907	124.93 (18.12)
21343	26.41 (3.83)	21290	13.03 (1.89)		
21344	14.62 (2.12)	21285	16.34 (2.37)		
21345	18.00 (2.61)	21280	23.17 (3.36)		
21311	18.00 (2.61)	21275	23.10 (3.35)		
21316	12.13 (1.76)	21270	19.10 (2.77)		
21346	7.45 (1.08)	20720	21.37 (3.10)		
25030	29.16 (4.23)	20715	26.61 (3.86)		
25029	21.72 (3.15)	20710	30.41 (4.41)		
25020	16.96 (2.46)	20705	21.79 (3.16)		
25019	23.65 (3.43)	20695	30.61 (4.44)		
25010	23.79 (3.45)	20690	26.48 (3.84)		
25009	21.51 (3.12)	20685	27.37 (3.97)		
		20680	14.96 (2.17)		
		20160	19.03 (2.76)		
		20159	22.55 (3.27)		
		20158	22.61 (3.28)		
		20157	24.41 (3.54)		
		20110	29.79 (4.32)		
		20109	31.72 (4.60)		
		20108	30.06 (4.36)		
		20107	27.72 (3.73)		
		20106	26.34 (3.82)		

ASME = American Society of Mechanical Engineers.
Average stress intensity = half of peak stress intensity.

Figure B7-32. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at the Interior of Cask Wall (EL 20109).

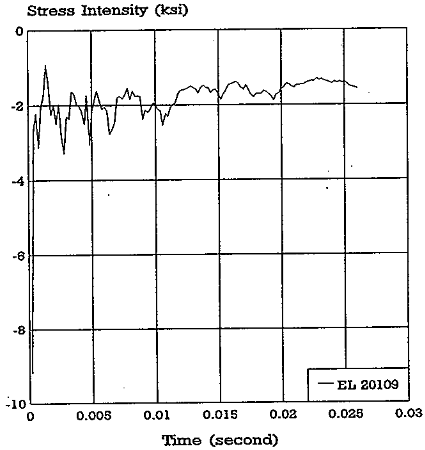


Figure B7-33. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at the Interior of Cask Bottom (EL 616).

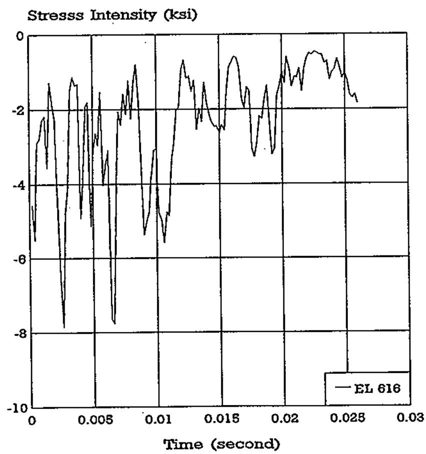


Figure B7-34. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at the Exterior of Cask (EL 21343).

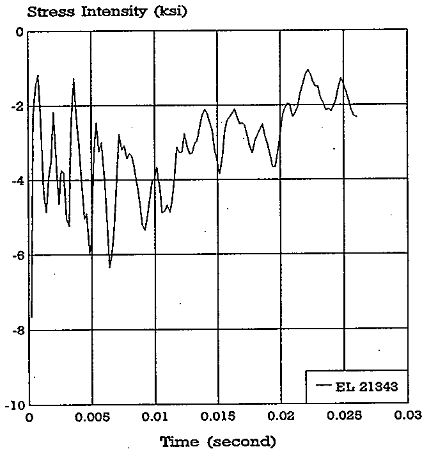


Figure B7-35. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at the Drain Port Cover Plate (EL 25030).

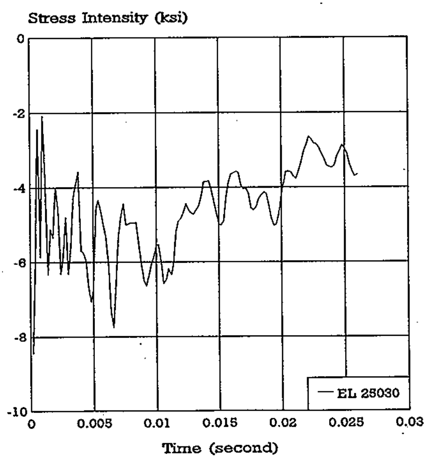


Figure B7-36. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

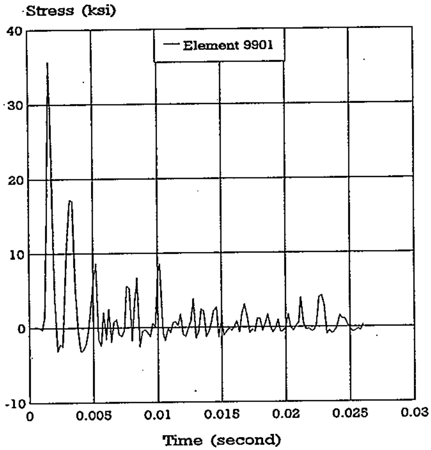


Figure B7-37. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

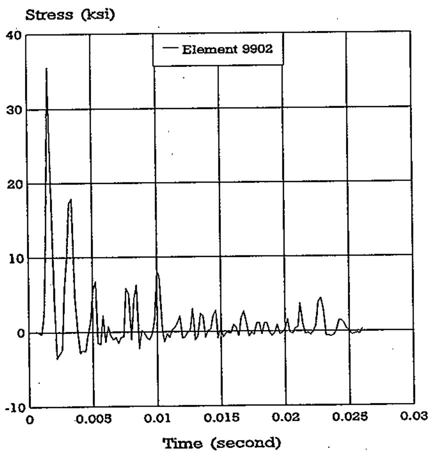


Figure B7-38. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

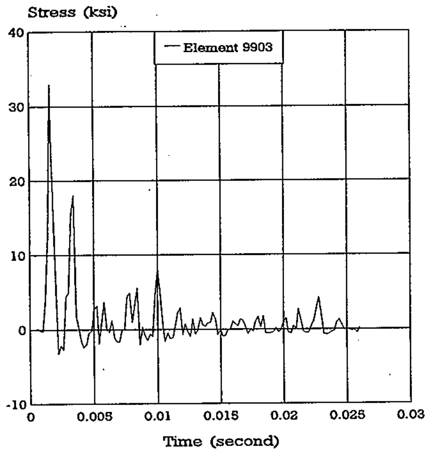


Figure B7-39. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

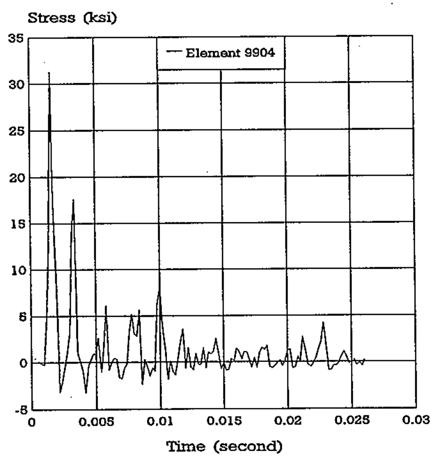


Figure B7-40. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

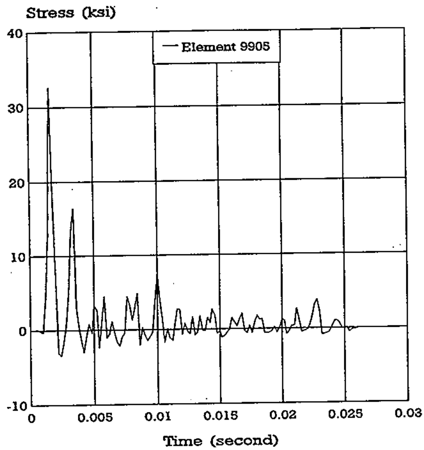


Figure B7-41. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

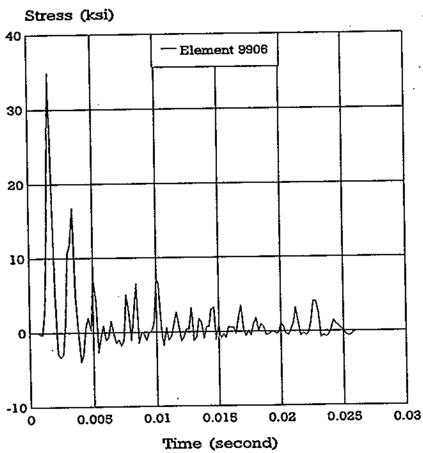
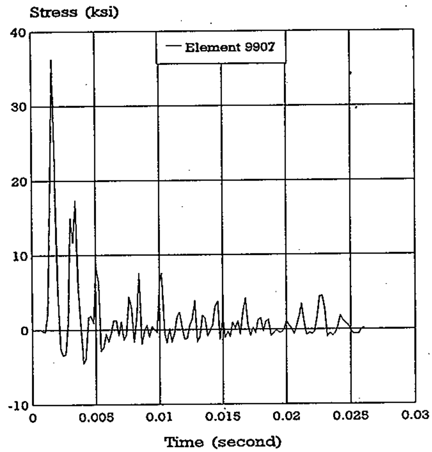


Figure B7-42. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



The resulting force at the drain port cover plate area is found to have a maximum in the range of 28,468 N (6,400 lb) (Figure B7-43). The estimated average force is in the range of 14,234 N (3,200 lb).

Deformation Results. No plastic deformation of cask assembly has been found in this case since the stress intensities are well below the ASME primary membrane allowables for the cask material. Figure B7-44 shows the concrete deformation of about 1 cm (0.4 in.) due to the cask impact.

Figure B7-43. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Force at Drain Port Cover Plate.

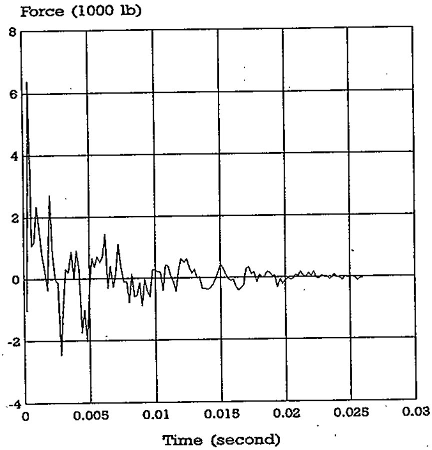
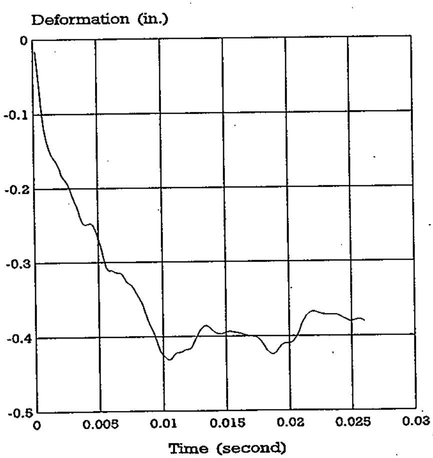


Figure B7-44. MCO Cask 0.3-m (1-ft) Bottom-End Flat-Drop Concrete Deformation Depth.



7.2.4.3.2 0.3-m (1-ft) Bottom-End Oblique Drop. This case evaluates the MCO Cask for a 0.3-m (1-ft) bottom-end oblique drop onto the 20-cm (8-in.) concrete pad. The center of gravity of the cask assembly and payload is over the corner, or the cask axis is 13.16° from the normal axis of the concrete surface.

In this case, because of the small initial impact area, the cask penetrates well into the target before the target can provide sufficient resistance to noticeably affect the cask momentum. Subsequently, as shown in Figures B7-45 and B7-46, the peak acceleration is delayed from initial contact, until sufficient target resistance is available to begin a change in the cask momentum. As a result of this small initial impact area, a large deformation of the target occurs.

This drop case results in an impact acceleration history with a sharp spike at time zero as shown in Figure B7-45. The initial sharp spike is a result of residual forces from many contact surfaces and do not reflect the real cask response. By filtering out this residual force and high frequency noise over 1000 Hz, the maximum acceleration is determined to be about 7.1*g* (Figure B7-46).

Figure B7-45. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Acceleration History (Unfiltered).

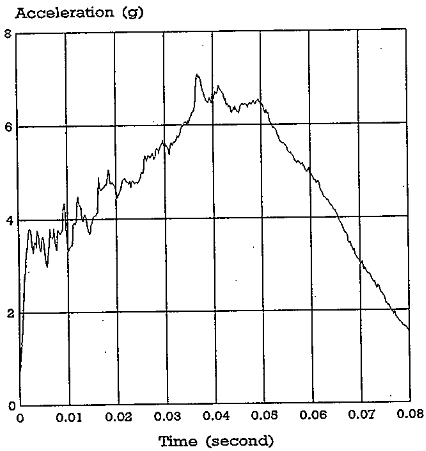
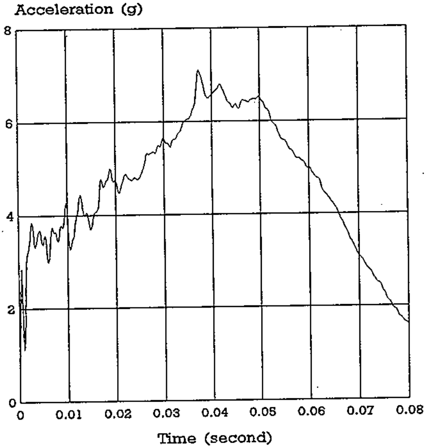


Figure B7-46. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Acceleration History (Filtered at 1000 Hz).



Three velocity plots for the bottom of cask, the center of gravity level of the cask, and the top of the lid are shown in Figures B7-47 through B7-49, respectively. The data points are the center of the plate (except center-of-gravity level does not have this point), 0° point, 90° point, and 180° point from the drain port in the circumferential direction. The velocity data among three elevations do not deviate significantly. Subsequently, the velocity data at the center-of-gravity level can be used to represent cask behavior. Using the velocity data of the 90° point at the center-of-gravity elevation, from an impact period of 58 ms, the impact average acceleration of the cask is calculated as 4.3*g*. Using the steep portion of the velocity curve at the center-of-gravity elevation, the maximum acceleration is found to be 5.7*g*. The acceleration results are summarized in Table B7-11.

Figure B7-47. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Velocity History at the Bottom of Cask.

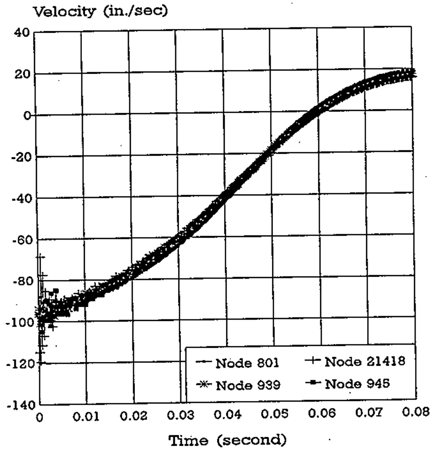


Figure B7-48. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Velocity History at the Center-of-Gravity Level of Cask.

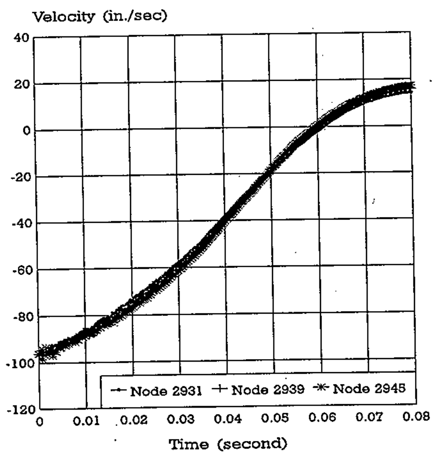


Figure B7-49. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Velocity History at the Top of Lid.

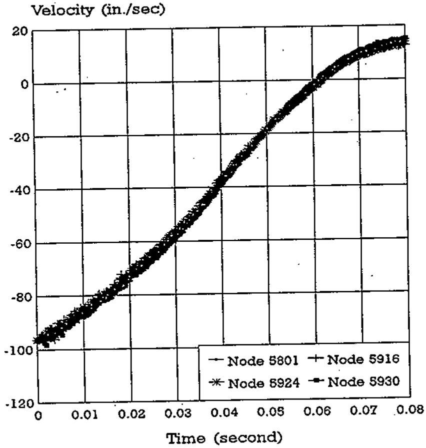


Table B7-11. Impact Acceleration Data of the 0.3-m (1-ft) Bottom-End Oblique Drop.

Linear Peak Acceleration (*g*)	Average Impact-Period Acceleration (*g*)	Peak Acceleration (*g*)	Impact Period (ms)
5.7	4.3	7.1	58.0

The estimated average ASME Code stress intensities are shown in Table B7-12 at the most critical exterior shell and containment boundary locations and at the lid bolts. The stress intensity plots at the most critical locations are shown in Figures B7-50 through B7-53. The exterior boundary of the cask near the drain port sustains high-stress intensities. However, the stress intensities at the containment boundary of the cask are well below the yield strength of the cask material. Consequently, containment is maintained in this case. The stress intensity plots of lid bolts (Figures B7-54 through B7-60) show the impact of this drop produces very low-stress intensities on the lid bolts.

Table B7-12. Estimated Average ASME Code Stress Intensity at Critical Locations from the 0.3-m (1-ft) Bottom-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
21336	155.5 (22.56)	614	8.27 (1.20)	9901	5.86 (0.85)
21337	73.43 (10.65)	615	6.76 (0.98)	9902	4.55 (0.66)
21338	42.89 (6.22)	616	14.34 (2.08)	9903	3.72 (0.54)
21339	23.79 (3.45)	21310	8.55 (1.24)	9904	4.83 (0.70)
21340	18.75 (2.72)	21305	5.31 (0.77)	9905	4.07 (0.59)
21341	97.35 (14.12)	21300	8.2 (1.19)	9906	5.1 (0.74)
21342	31.72 (4.60)	21295	10.27 (1.49)	9907	7.17 (1.04)
21343	29.3 (4.25)	21290	9.17 (1.33)		
21344	19.58 (2.84)	21285	7.24 (1.05)		
21345	16.55 (2.40)	21280	9.17 (1.33)		
21311	124.2 (18.02)	21275	8.62 (1.25)		
21316	91.29 (13.24)	21270	9.45 (1.37)		
21346	31.65 (4.59)	20720	8.89 (1.29)		
25030	90.8 (13.17)	20715	11.38 (1.65)		
25029	85.22(12.36)	20710	15.58 (2.26)		
25022	40.61 (5.89)	20705	9.93 (1.44)		
25021	40.4 (5.86)	20695	22.82 (3.31)		
25020	70.1 (10.16)	20690	16.0 (2.32)		
25019	73.22 (10.62)	20685	9.58 (1.39)		
25012	44.13 (6.40)	20680	8.41 (1.22)		
25011	43.99 (6.38)	20160	8.14 (1.18)		
25010	66.4 (9.63)	20159	8.41 (1.22)		
25009	72.12 (10.46)	20158	7.93 (1.15)		
25002	53.16 (7.71)	20157	8.55 (1.24)		
25001	54.33 (7.88)	20110	9.65 (1.40)		
		20109	10.41 (1.51)		
		20108	10.2 (1.48)		
		20107	8.27 (1.20)		
		20106	8.14 (1.18)		

Average stress intensity (SI) = larger of the half of peak SI or the SI at the end of impact period.

Figure B7-50. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Interior of Cask Wall (EL 20695).

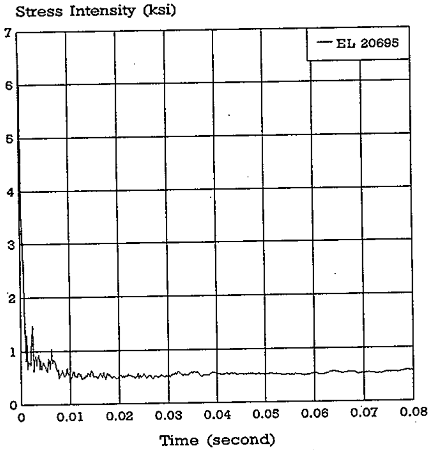


Figure B7-51. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Interior of Cask Bottom (EL 616).

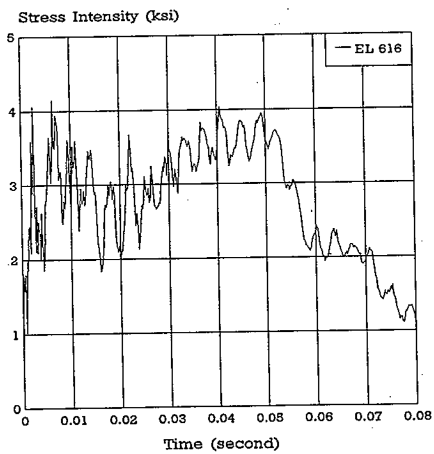


Figure B7-52. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Exterior of Cask (EL 21336).

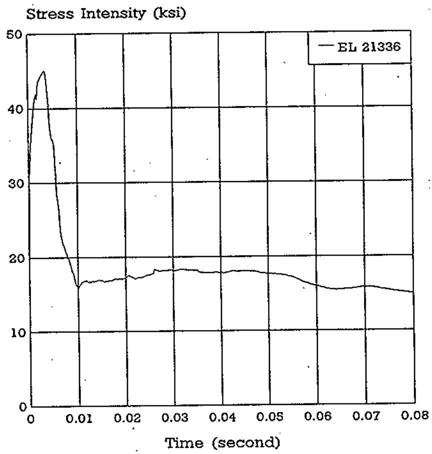


Figure B7-53. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Drain Port Cover (EL 25030).

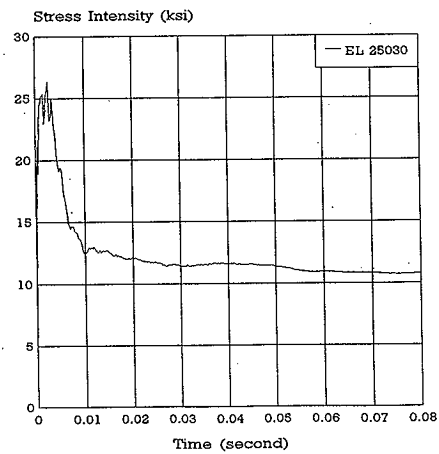


Figure B7-54. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

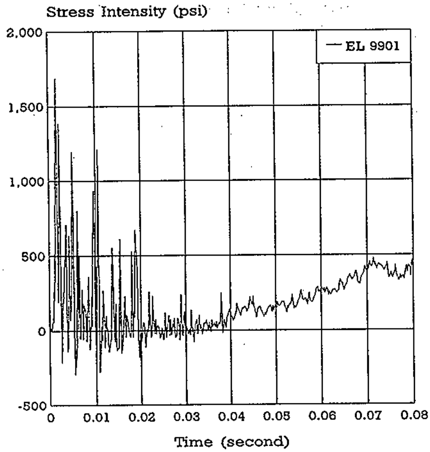


Figure B7-55. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

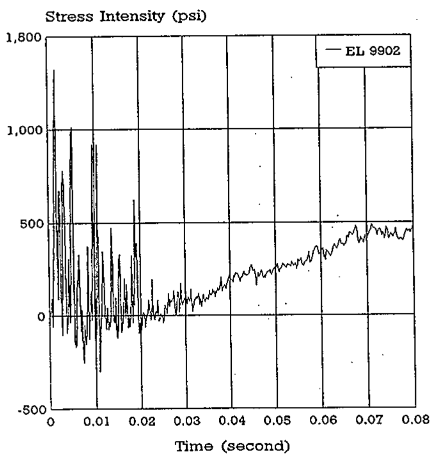


Figure B7-56. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

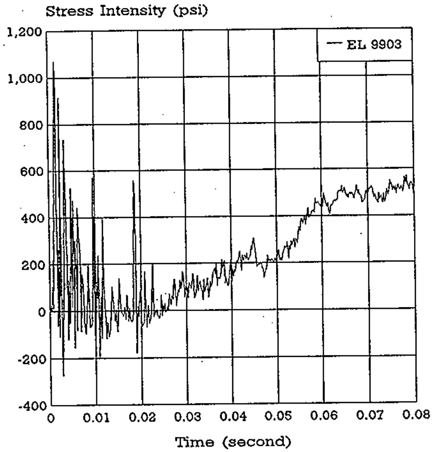


Figure B7-57. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

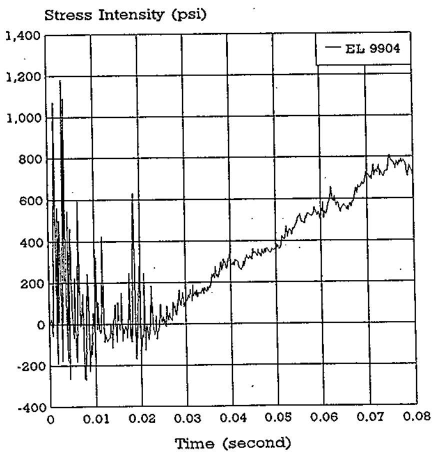


Figure B7-58. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

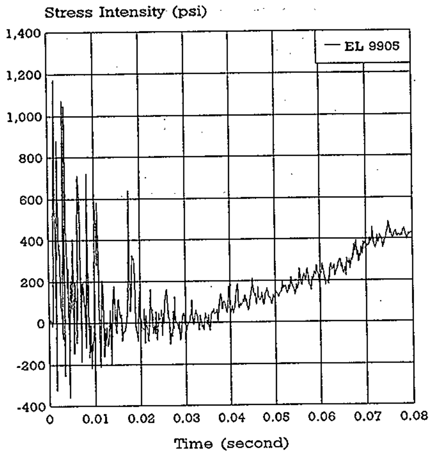


Figure B7-59. MCO Cask 0.3-m (1-ft) Bottom-End Oblique Drop Stress Intensity History at Bolt No. 6 (EL 9906).

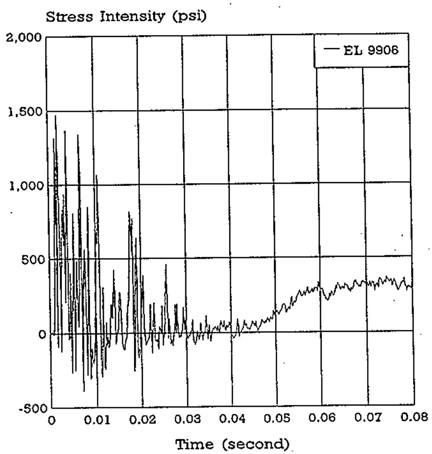
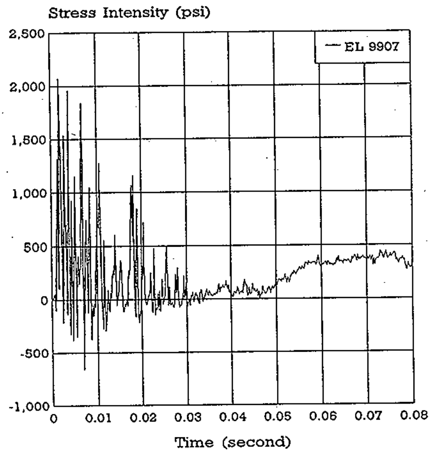


Figure B7-60. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-13. The accumulated strains are defined as the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of strain of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-61 through B7-64. The largest overall accumulated strain of the entire cask is over 7.0% at the exterior bottom boundary of the drain port (Figure B7-63). The largest accumulated strain on the drain port cover plate is about 0.4% (Figure B7-64). However, the largest accumulated strain of the containment boundary of the cask/lid is only 0.03%, occurring near the drain port region (Figure B7-61). The strain plots of lid bolts are shown in Figures B7-65 through B7-71. The accumulated strains of the lid bolts are negligible.

Table B7-13. Accumulated Strains at Critical Locations from the 0.3-m (1-ft) Bottom-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
21336	0.07010	614	0.00011	9901	0.00002
21337	0.00098	615	0.00009	9902	0.00002
21338	0.00057	616	0.00019	9903	0.00002
21339	0.00032	21310	0.00010	9904	0.00002
21340	0.00025	21305	0.00007	9905	0.00001
21341	0.00526	21300	0.00016	9906	0.00001
21342	0.00042	21295	0.00014	9907	0.00001
21343	0.00039	21290	0.00012		
21344	0.00026	21285	0.00010		
21345	0.00022	21280	0.00012		
21311	0.02322	21275	0.00011		
21316	0.00397	21270	0.00013		
21346	0.00042	20720	0.00016		
25030	0.00377	20715	0.00015		
25029	0.00174	20710	0.00021		
25022	0.00054	20705	0.00013		
25021	0.00054	20695	0.00030		
25020	0.00093	20690	0.00021		
25019	0.00098	20685	0.00013		
25012	0.00059	20680	0.00011		
25011	0.00059	20160	0.00015		
25010	0.00088	20159	0.00011		
25009	0.00096	20158	0.00011		
25002	0.00071	20157	0.00011		
25001	0.00072	20110	0.00013		
		20109	0.00014		
		20108	0.00014		
		20107	0.00011		
		20106	0.00011		

Figure B7-61. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at the Interior Cask Wall (EL 20695).

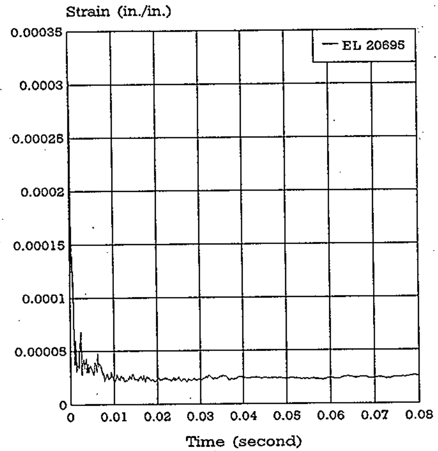


Figure B7-62. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at the Interior of Cask Bottom (EL 616).

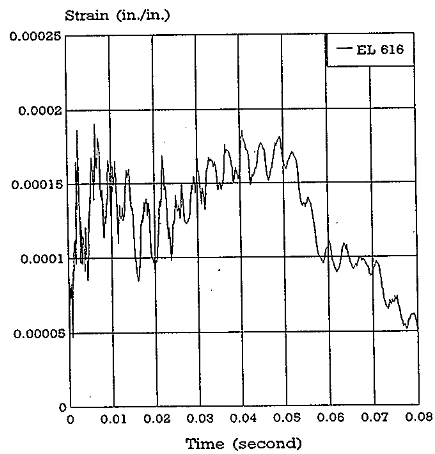


Figure B7-63. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Drain History at the Exterior of Cask (EL 21336).

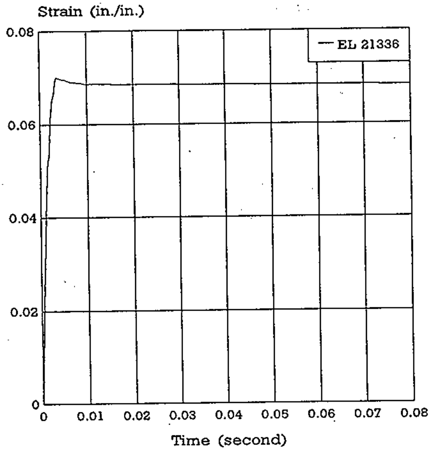


Figure B7-64. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at the Drain Port Cover (EL 25030).

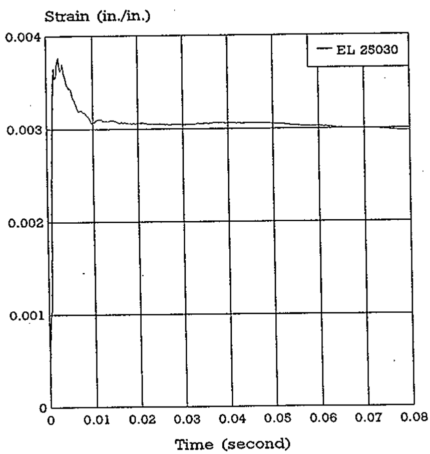


Figure B7-65. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 1 (EL 9901).

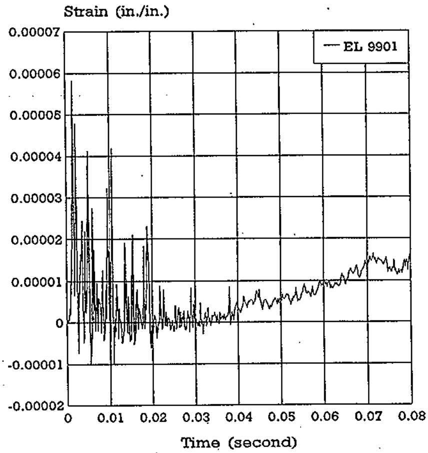


Figure B7-66. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 2 (EL 9902).

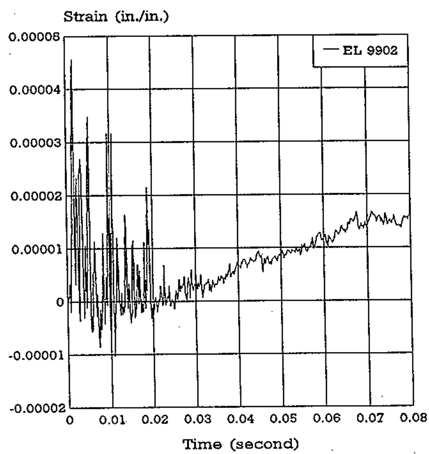


Figure B7-67. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 3 (EL 9903).

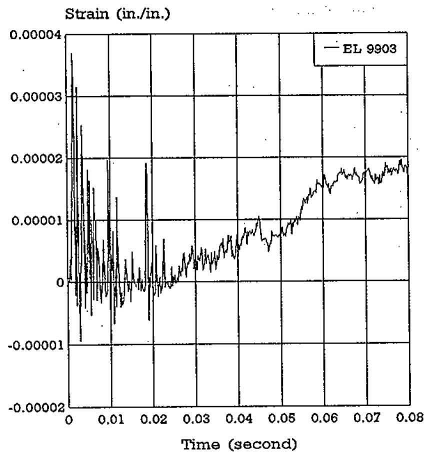


Figure B7-68. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 4 (EL 9904).

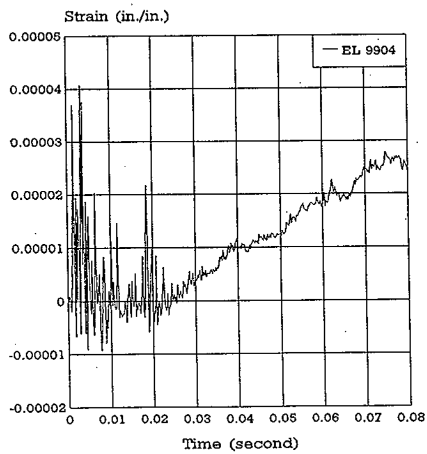


Figure B7-69. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 5 (EL 9905).

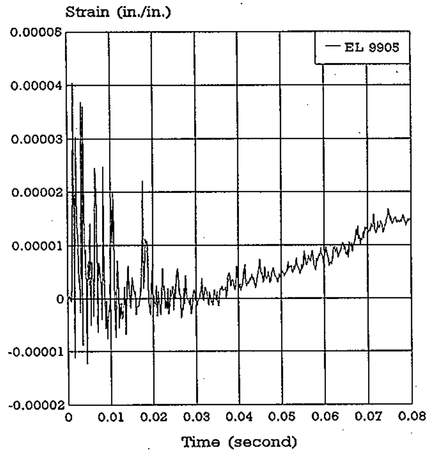


Figure B7-70. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Stain History at Bolt No. 6 (EL 9906).

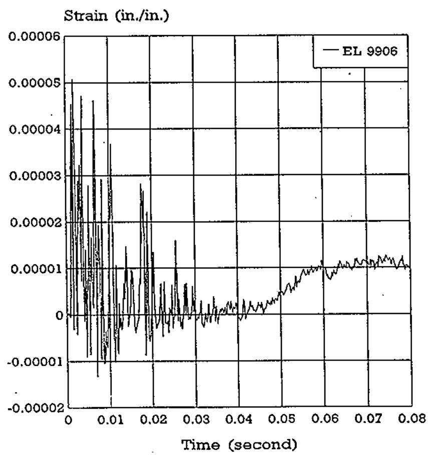
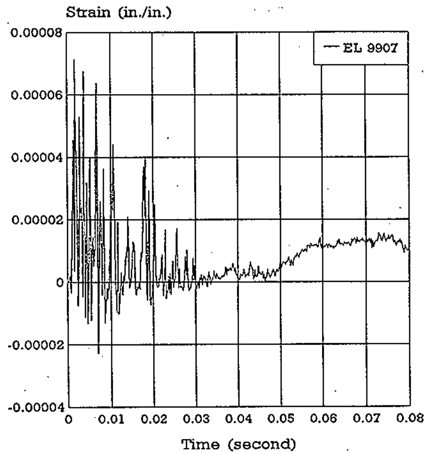


Figure B7-71. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. The maximum resultant force at the drain port cover plate is found to be in the range of 31,137 N (7,000 lb) (Figure B7-72). The estimated average force is in the range of 15,568 N (3,500 lb).

Figure B7-73 shows the concrete displacement of approximately 7.9 cm (3.1 in.) at the cask impact point.

Figure B7-72. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Force at Drain Port Cover.

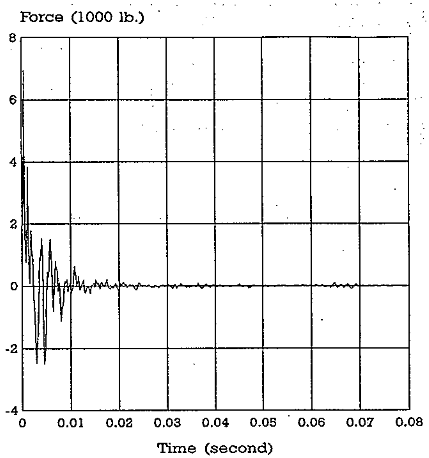
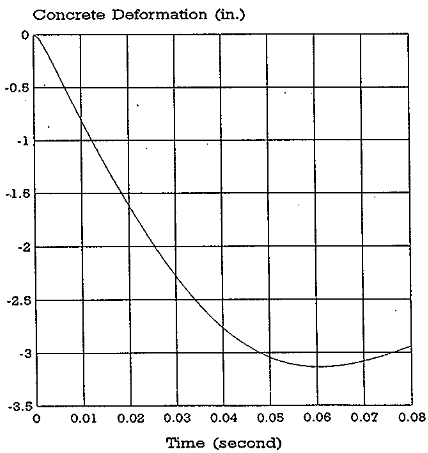


Figure B7-73. MCO Cask 0.3-m (1-ft) Bottom-End Oblique-Drop Concrete Deformation Depth.



7.2.4.3.3 0.3-m (1-ft) Top-End Oblique Drop. This case evaluates the MCO Cask performance for a 0.3-m (1-ft) top-end oblique drop onto the 20-cm (8-in.) concrete pad. Since the center of gravity of the cask assembly is over the impact point, at the initiation of impact, only one trunnion/bracket contacts the concrete target. Consequently, the top-end oblique drop has an irregular impact area shape, which consists of trunnions, brackets, and some portion of the lid top. The unfiltered acceleration data is presented in Figure B7-74. When the forces with higher frequencies over 1000 Hz are filtered out, the peak acceleration is determined to be 6.5*g*, Figure B7-75.

Figure B7-74. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Acceleration History (Unfiltered).

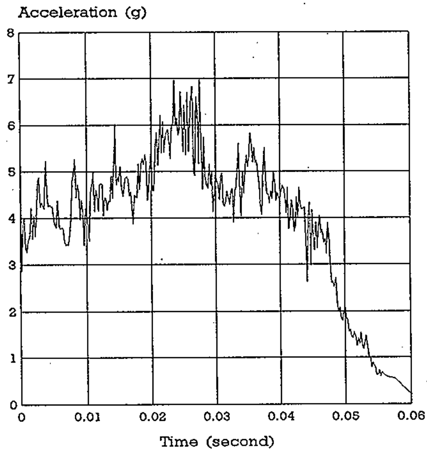
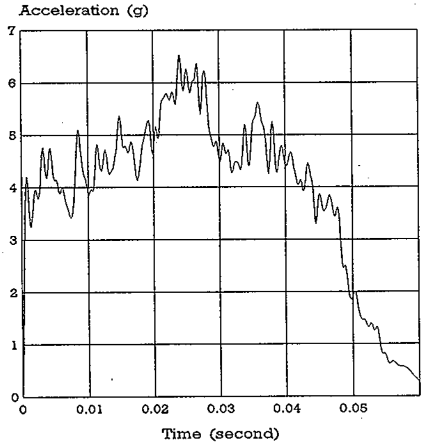


Figure B7-75. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Acceleration History (Filtered at 1,000 Hz).



The three velocity plots at the bottom of the cask, the center-of- gravity level of the cask, and the top of the lid are shown in Figures B7-76 through B7-78, respectively, for this drop case. At the center of gravity, the data points are the 0° point, 90° point, and 180° point from the drain port in the circumferential direction. The data points at the bottom of the cask and the top of the lid are at the center of the plate, 0° point, 90° point, and 180° point from the drain port in the circumferential direction. All three elevations show about the same impact period of 40.0 ms. The velocities at each elevation also converge to indicate the thick-wall cask behaves as a rigid body motion although the velocity data at the top of the lid is somewhat scattered due to its proximity to the impact. Based on the average impact period of 40.0 ms, the average impact-period acceleration of the 0.3-m (1-ft) top-end oblique drop is calculated as 6.2*g*. The linear peak acceleration (the steepest slope of the velocity curve) taken at the center of gravity of the cask is 8.6*g*. The acceleration results are summarized in Table B7-14. The peak acceleration is based on the reaction force history of the cask contact area as stated above.

Figure B7-76. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Velocity History at the Bottom of Cask.

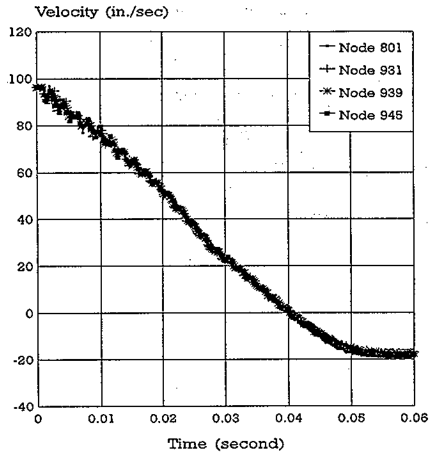


Figure B7-77. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Velocity History at the Center of Gravity of Cask.

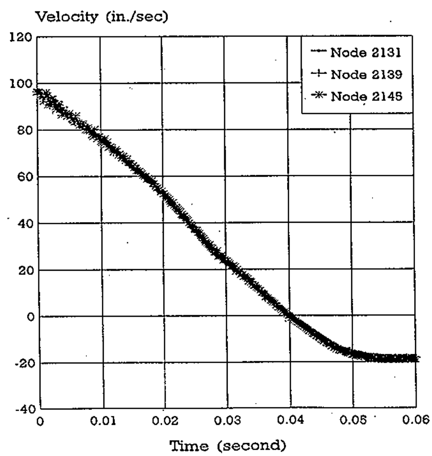


Figure B7-78. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Velocity History at the Top Lid.

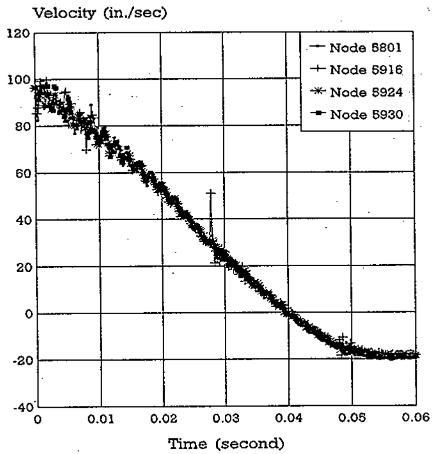


Table B7-14. Impact Acceleration Data of the 0.3-m (1-ft) Top-End Oblique Drop.

Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
8.6	6.2	6.5	40.0

Stress Intensity. In this case, some of the stress intensities do not have sharp spikes as a result of numerical anomalies. For those locations, the peak stress intensities are used and shown appropriately in Table B7-15. In this 0.3-m (1-ft) top oblique drop, the highest stress intensity on the containment boundary occurs at the lid wall between the top plate and the lid flange at a stress level of 54 MPa (7,830 psi). At the exterior surface, the maximum stress intensity is a little higher at about 64 MPa (9,300 psi). The stress intensity plots at the most critical locations are shown in Figures B7-79 through B7-84. The average stress intensity plots of lid bolts are shown in Figures B7-85 through B7-91, in which the average stress intensity is assumed to be half of the peak stress intensity. Of all the NCT cases evaluated, this impact orientation produces the highest average stress intensity in the lid bolts at 22 MPa (3,190 psi) above preload.

Table B7-15. Estimated Average ASME Code Stress Intensity at the Bottom Critical Locations from the 0.3-m (1-ft) Top-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
5650	39.02 (5.66)*	5214	35.85 (5.20)*	9901	1.52 (0.22)
5664	64.26 (9.32)*	5215	20.48 (2.97)*	9902	1.24 (0.18)
5678	25.23 (3.66)*	5216	32.2 (4.67)*	9903	4.62 (0.67)
5450	52.4 (7.60)*	5217	35.09 (5.09)*	9904	10.51 (1.51)
5464	57.23 (8.30)*	5218	27.79 (4.03)*	9905	14.82 (2.15)
5478	48.26 (7.00)*	5250	53.99 (7.83)*	9906	20.06 (2.91)
5264	44.26 (6.42)*	5251	51.57 (7.48)*	9907	21.99 (3.19)
5278	35.78 (5.19)*	5252	43.64 (6.33)*		
5064	39.16 (5.68)*	5253	41.44 (6.01)*		
5078	47.92 (6.95)*	5050	51.37 (7.45)*		
		5051	48.13 (6.98)*		
		5052	46.61 (6.76)*		
		5053	43.85 (6.36)*		
		4850	37.85 (5.49)*		
		4851	36.12 (5.25)*		
		4852	35.58 (5.16)*		
		4853	34.89 (5.06)*		
		4650	33.44 (4.85)*		
		4651	32.96 (4.78)*		
		4652	32.75 (4.75)*		
		4653	32.68 (4.74)*		
		4450	36.68 (5.32)*		
		4451	35.37 (5.13)*		
		4452	34.34 (4.98)*		
		4453	32.61 (4.73)*		
		4250	46.47 (6.74)*		
		4251	46.06 (6.68)*		
		4252	40.95 (5.94)*		
		4253	37.09 (5.38)*		
		4264	47.49 (6.96)*		
		4265	44.33 (6.43)*		
		4266	43.99 (6.38)*		
		4267	39.37 (5.71)*		
		3650	29.99 (4.35)*		
		3651	46.82 (6.79)*		
		3652	54.12 (7.85)*		
		3450	28.89 (4.19)*		
		3451	42.82 (6.21)*		
		3452	50.19 (7.28)*		
		3453	28.75 (4.17)*		

* = peak stress intensity.
Average stress intensity (SI) = larger of the half of peak SI or the SI at the end of impact period.

Figure B7-79. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Interior of Lid (EL 5217).

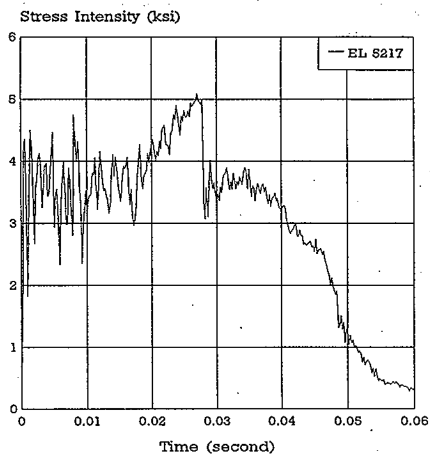


Figure B7-80. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Interior Lid Wall (EL 5250).

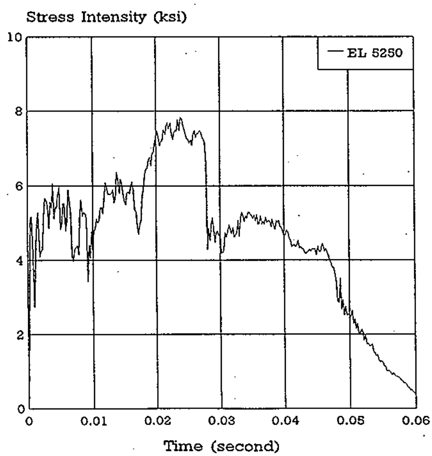


Figure B7-81. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Interior Lid Flange (EL 4264).

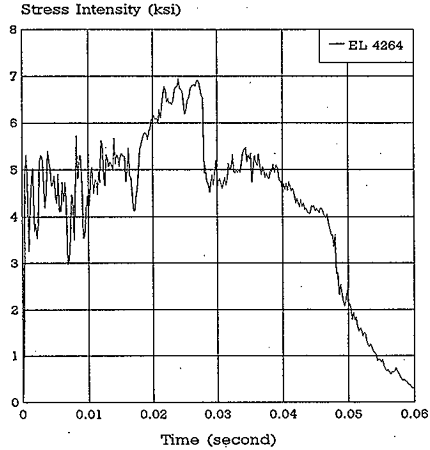


Figure B7-82. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Shear Key (EL 3652).

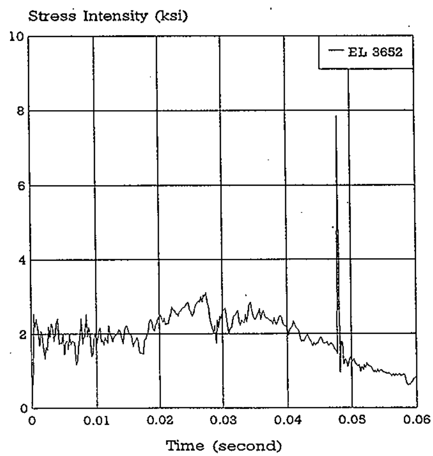


Figure B7-83. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Interior of Cask Wall (EL 3452).

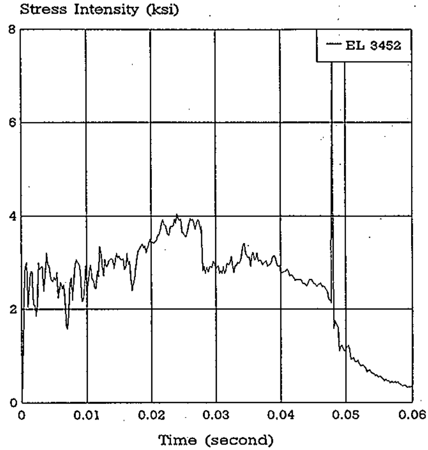


Figure B7-84. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at the Exterior of Lid (EL 5664).

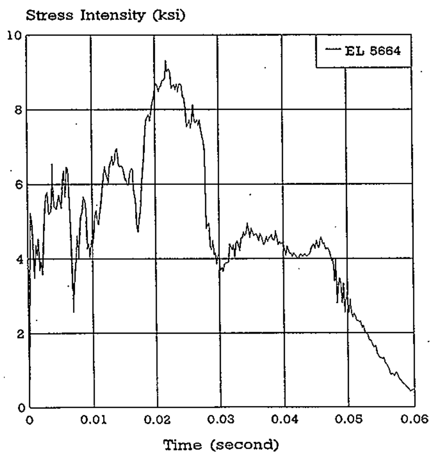


Figure B7-85. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

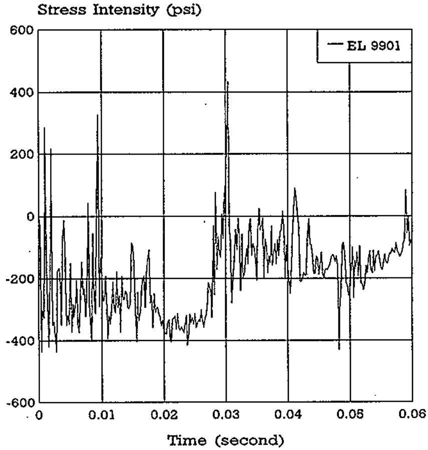


Figure B7-86. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

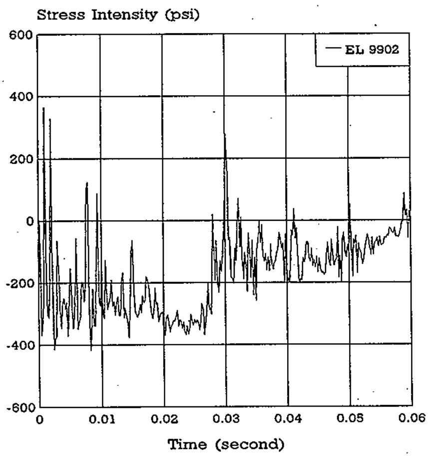


Figure B7-87. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

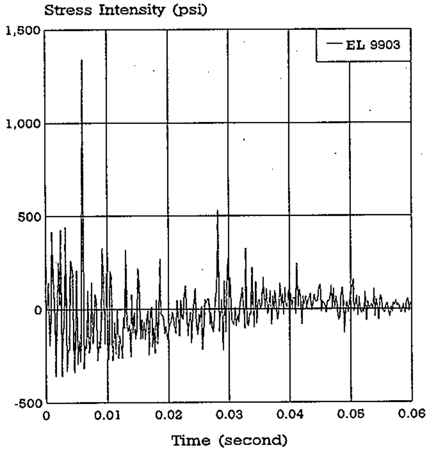


Figure B7-88. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

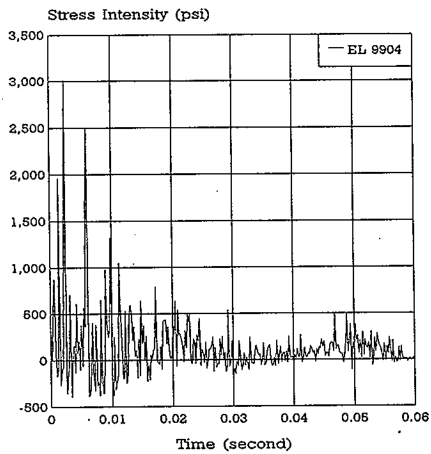


Figure B7-89. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

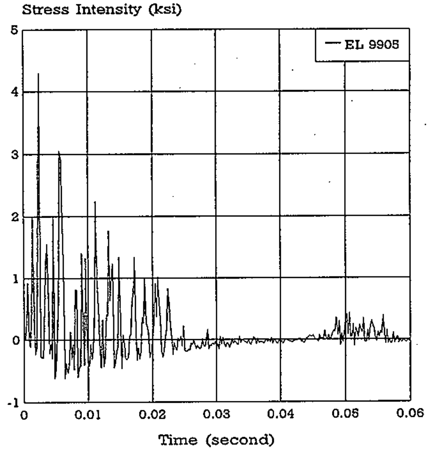


Figure B7-90. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

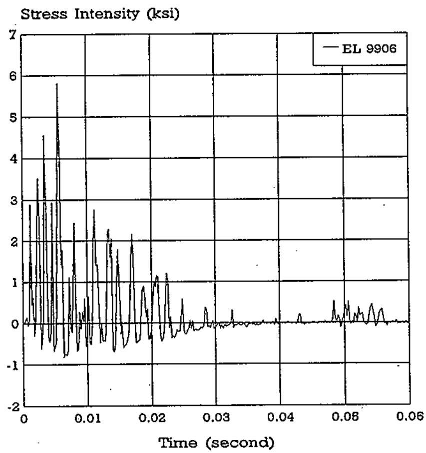
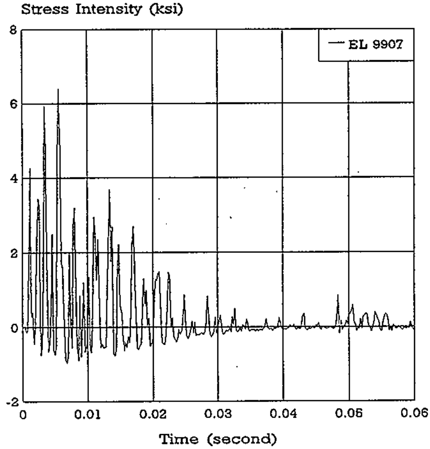


Figure B7-91. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. For the NCT, the strain data are included as reference only. The accumulated strain at the critical locations of the cask and lid, and at the lid bolts are shown in Table B7-16. The accumulated strains reported are in the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the strain counterpart of the ASME stress intensity.

The strain plots at the most critical locations are shown in Figures B7-92 through B7-97. The strain plots of lid bolts are shown in Figures B7-98 through B7-104. All accumulated strains in this case are negligible.

Table B7-16. Accumulated Strains at the Bottom Critical Locations from the 0.3-m (1-ft) Top-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
5650	0.00026	5214	0.00024	9901	0.00001
5664	0.00043	5215	0.00014	9902	0.00001
5678	0.00017	5216	0.00021	9903	0.00005
5450	0.00035	5217	0.00023	9904	0.00010
5464	0.00038	5218	0.00019	9905	0.00015
5478	0.00032	5250	0.00036	9906	0.00020
5264	0.00030	5251	0.00034	9907	0.00022
5278	0.00024	5252	0.00029		
5064	0.00026	5253	0.00028		
5078	0.00032	5050	0.00034		
		5051	0.00032		
		5052	0.00031		
		5053	0.00029		
		4850	0.00025		
		4851	0.00024		
		4852	0.00024		
		4853	0.00023		
		4650	0.00022		
		4651	0.00022		
		4652	0.00022		
		4653	0.00022		
		4450	0.00024		
		4451	0.00024		
		4452	0.00023		
		4453	0.00022		
		4250	0.00031		
		4251	0.00031		
		4252	0.00027		
		4253	0.00025		
		4264	0.00032		
		4265	0.00030		
		4266	0.00029		
		4267	0.00026		
		3650	0.00020		
		3651	0.00031		
		3652	0.00036		
		3450	0.00014		
		3451	0.00029		
		3452	0.00033		
		3453	0.00019		

Figure B7-92. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at the Interior of Lid (EL 5217).

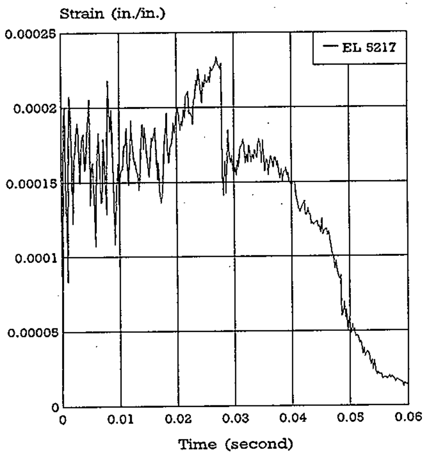


Figure B7-93. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at the Interior of Lid Wall (EL 5250).

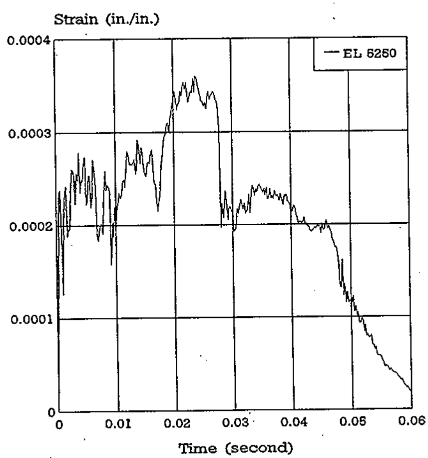


Figure B7-94. MCO Cask 0.9-m (1-ft) Top-End Oblique-Drop Strain History at the Interior of Lid Flange (EL 4264).

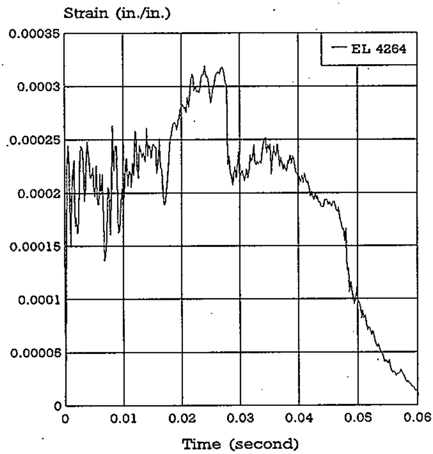


Figure B7-95. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at the Shear Key (EL 3652).

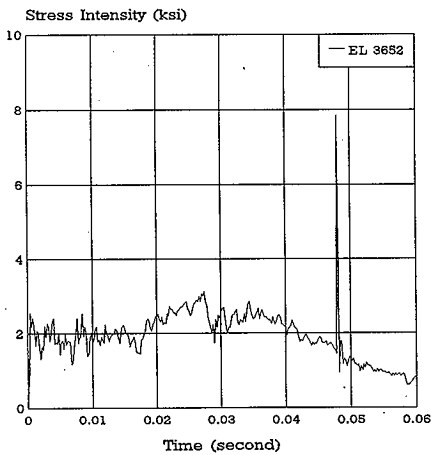


Figure B7-96. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at the Interior Cask Wall (EL 3452).

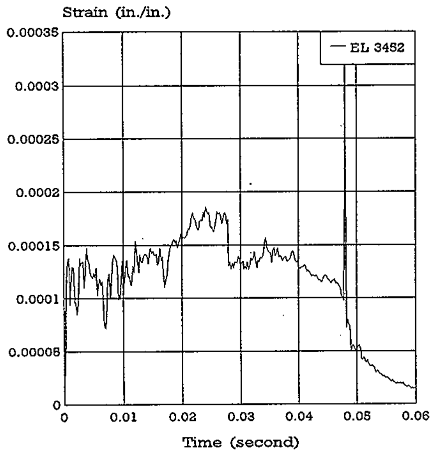


Figure B7-97. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at the Exterior of Lid (EL 5664).

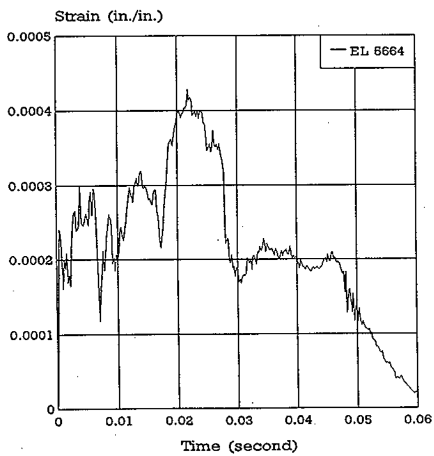


Figure B7-98. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 1 (EL 9901).

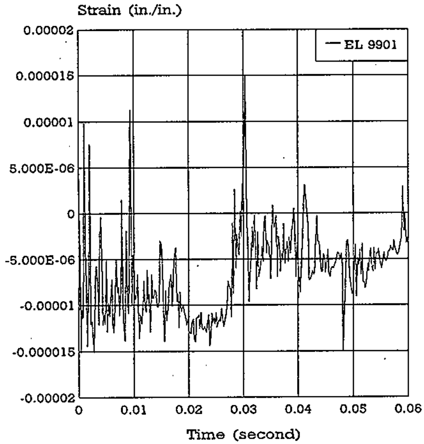


Figure B7-99. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 2 (EL 9902).

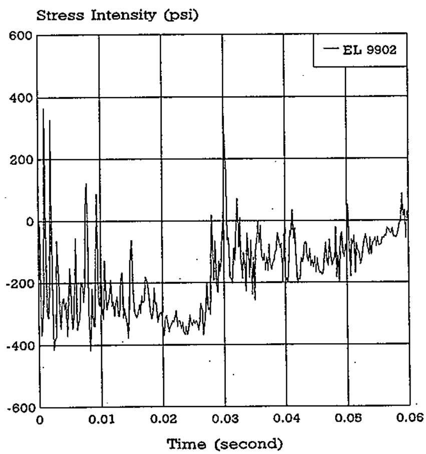


Figure B7-100. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 3 (EL 9903).

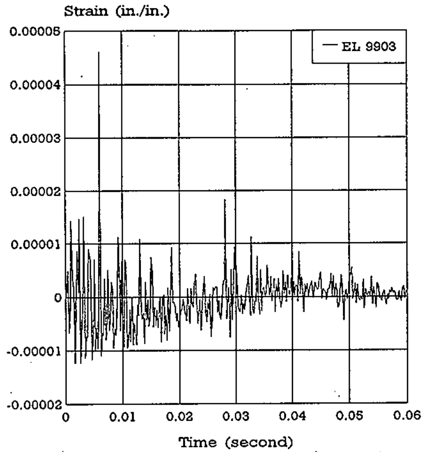


Figure B7-101. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 4 (EL 9904).

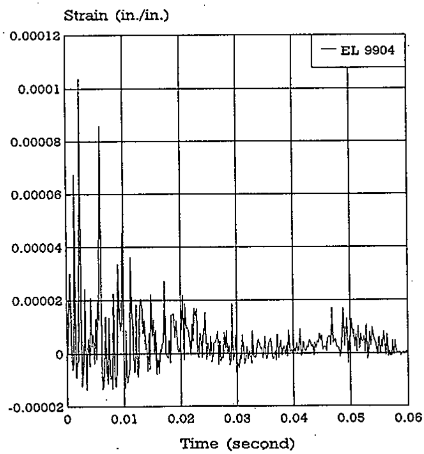


Figure B7-102. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 5 (EL 9905).

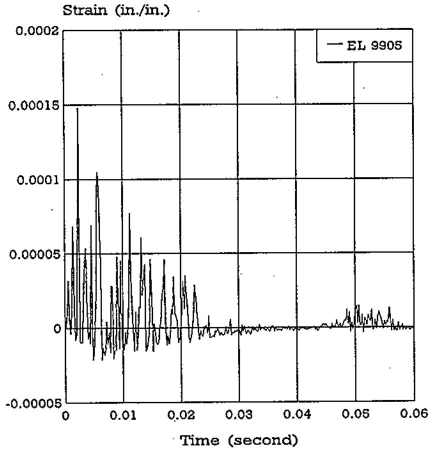
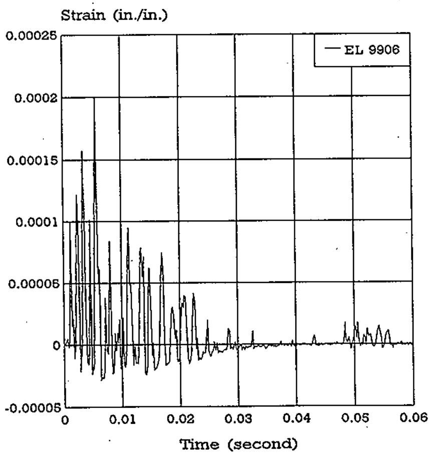


Figure B7-103. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 6 (EL 9906).



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Document number: SD-TP-SARP-017

Section 2 **of** 2

Title: Safety Analysis Report for Packaging (Onsite) Multicanister Overpack Cask

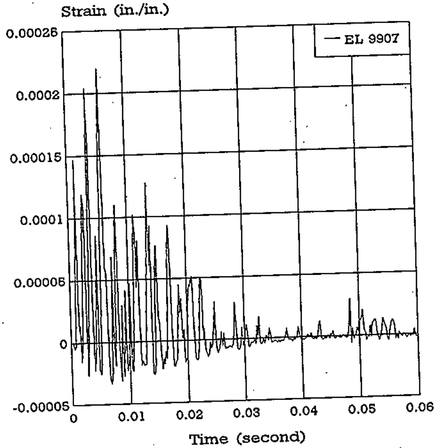
Date: 7/14/97 **Revision:** A000

Originator: Edwards, WS
Co: WMNW

Recipient:
Co:

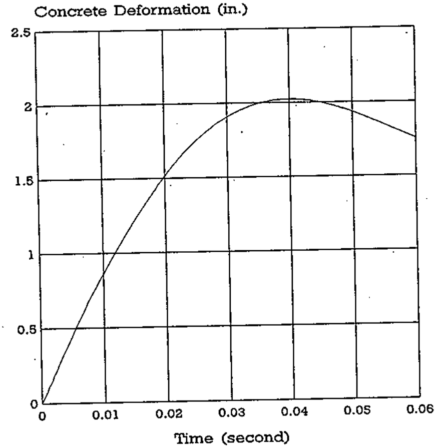
References: EDT-618195

Figure B7-104. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. The drain port is not modeled in this evaluation. In this case, the impact does not affect the structural integrity at the drain port region. Figure B7-105 shows the concrete displacement of about 5.1 cm (2 in.) at the trunnion impact point.

Figure B7-105. MCO Cask 0.3-m (1-ft) Top-End Oblique-Drop Concrete Deformation Depth.



7.2.4.4 Structural Evaluation and Conclusions. From the above evaluations, it is shown that the worst drop orientation, which causes the most severe loading to the cask body, closure lid, and closure lid bolts, is the bottom-end oblique (corner) drop. In this case, exterior locations on the cask body and closure lid are subject to high localized stresses above the ASME primary stress allowables for the material. However, these stresses are localized around the exterior surfaces and are a combination of primary and secondary stress intensities. Only in the impact region do the combined stress levels exceed the yield strength of the material. These exterior surface stresses are localized in the impact area, causing only minor surface damage to the cask. The combined primary and secondary stress intensities, however, remain below ASME allowables. All interior containment boundary combined stresses remain well below ASME allowables for primary membrane. The most vulnerable area is the drain port region of the cask. In this area, the maximum accumulative strain is slightly over 7% on the exterior surface. The maximum interior strain is 0.03%, which is well under the elastic strain of the cask and bolting material. In all drop orientations, the peak stress intensities at the interior of the cask (containment boundary) are well below the ASME allowables for primary membrane stress. Consequently, for the worst-case drop orientation, the cask will experience minor surface damage, but the containment performance of the cask is not affected.

The primary stress intensities developed in the 0.3-m (1-ft) drop are low compared to the combined ASME primary and secondary stress allowables. The worst-case overall containment boundary maximum primary plus secondary stress intensity occurs for a top end oblique drop at the inside the cask at the shear key. The stress intensity value at this location is 54.12 MPa

(7.85 ksi), well below the primary stress intensity allowable. Combining this with the stress intensity from thermal and pressure loading stress intensity of 126.9 MPa (18.4 ksi) from Part B, Section 7.3.4.2, results in a combined primary and secondary stress intensity of 181.0 MPa (26.3 ksi). Consequently, the margin of safety based on the ASME allowable stress intensity for the combined primary plus secondary stress at 93 °C (200 °F) is:

$$MS = \frac{3\ S_m}{26.3\ ksi} - 1 = 1.28$$

The containment boundary is retained during NCT as demonstrated by the worst-case interior stress intensities remaining below ASME values for Level A Service Limits.

7.3 ACCIDENT CONDITIONS

The stresses due to accident conditions are determined using the ABAQUS/Explicit FEA computer code. Five models are developed to simulate probable drop orientations, which would result in the most damage, during an accident condition drop. These drop orientations are the flat-bottom end drop, bottom-end oblique drop, top-end oblique drop, flat-top end drop, and side drop. These models are described in Part B, Section 7.3.3.

Analytically, the cask is impacted onto a 20-cm- (8-in.-) thick concrete surface described in Part B, Section 7.2.3. The impact duration (rise time) and deceleration load factors for the three orientations are determined by the ABAQUS/Explicit FEA computer code. Impact duration and time-averaged deceleration load factors are summarized in the following tables.

To illustrate the overall cask response, the acceleration due to impact is determined by three methods. The most conservative is by dividing the total reaction force of impact by the total cask assembly weight and defining the peak acceleration as a function of time. The other two methods are based on the change in velocity. This time-averaged acceleration over the impact period more accurately reflects actual cask global behavior by accounting for the cask response time during the impact. Consequently, a more accurate method to estimate the acceleration is to use the nodal velocity data. The more conservative method is to determine a linear peak acceleration by determining the steepest slope along the time curve. An alternate and less conservative method is to average the change in velocity over the entire impact event. These accelerations are provided only for quasi-static evaluation of the MCO and spent fuel baskets. For this evaluation, the conservative force determined by the linear peak acceleration is used in quasi-static evaluations of the MCO and spent fuel baskets. Dynamic evaluation of the MCO Cask loadings, such as stress and strain determination, are performed directly by the ABAQUS/Explicit (ABAQUS 1995) FEA computer code.

As with an actual cask test, the simulated cask impacts result in noise from high-frequency strain waves, similar to those recorded during instrumented cask drop tests. The frequency magnitude of these strain waves are such that the structure is not capable of reacting to them. In recognition of this behavior, International Atomic Energy Agency Safety Series 37 (IAEA 1990) recommends filtering out frequencies higher than 100 to 200 Hz for a heavy package drop test. For conservatism in the following computational impact simulation, frequencies higher than 1000 Hz are filtered out. Also, in the following cases the peak impact acceleration is determined by dividing the total reaction force by the total cask assembly weight. This total force is the summation of all nodal reaction forces at the cask contact area with the target. In some cases a sharp spike appears, resembling a high-frequency noise appears at time zero. This is a result of interaction among the residual forces from the myriad number of contact surfaces. Consequently, these are computational anomalies that do not represent the actual cask response. Filtering of higher frequencies eliminates these numerical anomalies.

The ASME Code stress intensity is defined as the largest difference among the principal stresses. If P1, P2, and P3 are the three principal stresses and P1 < P2 < P3, then the ASME Code stress intensity is (P3 - P1). Results of the principal stresses at the most critical elements/locations of the cask body are retrieved from the ABAQUS run and processed to obtain the ASME Code stress intensities. The ASME Code stress intensities of the lid bolts are obtained in the same manner. These stress intensities also contains high-frequency noise. For simplicity and conservative consideration, the estimated average ASME stress intensity is obtained as the larger of (1) the half of the maximum peak stress intensity or (2) the stress intensity at the end of impact period.

The ASME Code stress intensities, determined as specified in Subsection NB, at the most critical elements and locations are presented. The stress intensities are classified as primary and secondary based on the type of loading, stress location, geometry of structure, and deformation. By the ASME methods for stress categorization, primary stresses are stresses required to satisfy equilibrium of the loading, which is a load-controlled quantity. Secondary stresses are not required to balance the loading and are a deformation-controlled quantity that is self-relieving. An example of secondary stresses by ASME code definition are thermal stresses. For conservatism, all stresses determined in this drop evaluation are assumed to be primary membrane stresses.

7.3.1 Conditions To Be Evaluated

The following conditions or events are intended to envelop the effects of Hanford Site accident transport conditions. Verifications of the MCO Cask are presented in Part B, Section 7.7. The following scenarios related to accident conditions are addressed:

- Free drop from a height of 9 m (30 ft) with a dry MCO and 6.4 m (21 ft) for a water-filled MCO onto an 20-cm- (8-in.-) thick reinforced concrete surface with the following characteristics:
    - Concrete strength: 27.6 MPa (4,000 psi)
    - Soil modulus: 193 MPa (28,000 psi)

- Concrete reinforcement: No. 7 rebar with a yield strength of 413.7 MPa (60,000 psi), spaced 30.5 cm (12 in.) apart with 5.08 cm (2 in.) cover

- Package impact in the orientation expected to cause maximum damage

- Exposure of the MCO Cask to 800 °C (1475 °F) fully engulfing fire for 30 minutes, with 45 minutes of quenching. Part B, Section 3.4, shows that the failure threshold for the MCO cask is exposure to a six minute fully engulfing fire. However, if the MCO cask can be shown to maintain its structural integrity during a 30 minute fully engulfing fire, then it will survive a six minute fire.

The most critical conditions and events were evaluated for the worst case environmental conditions and external pressures.

7.3.2 Acceptance Criteria

Under the above accident conditions, verification of the preliminary design must demonstrate that the MCO Cask maintains containment and shielding of the MCO. Structural adequacy is demonstrated by showing the stress in the containment boundary does not exceed the limits specified for Level D Service Limits of the ASME B&PV Code, Section III, Subsection NB (ASME 1995a), Class 1 nuclear components. Guidance for stress allowables is obtained form NRC Regulatory Guide 7.6 (NRC 1978) and NUREG/CR-6007 (Mok 1989).

Both NRC Regulatory Guide 7.6 and NUREG/CR-6007 recommend the containment boundary stress allowables in Table B7-17, which are comparable to Article F-1000 of the ASME B&PV Code, Section III Appendices. These allowables prevent ductile rupture of the structural components of the containment boundary, which is defined as the cask body, bottom end closure, top closure lid, and closure bolts. These stress allowables coupled with linear-elastic or plastic-elastic analysis are used to demonstrate maintenance of containment during accident conditions loading. The ASME B&PV Code, Section III, Subsection NB (ASME 1995a), Service Level D criteria are used for analytical acceptance. Table B7-18 shows the allowable stress as a function of temperature.

7.3.3 Structural Model

With two exceptions, the cask and target models used for accident evaluations are the same as those used for evaluation of the NCT. The ABAQUS/Explicit computer code models not described in Part B, Section 7.2.3.1, are the side drop and 6.4-m (21-ft) water-filled bottom-end oblique drop. These two models are described below. As with the NCT evaluation, a

Table B7-17. Containment Boundary Stress Evaluation Criteria.

	Stress category	Accident conditions
Components other than bolts	Primary membrane stress intensity[a]	Lesser of 2.4 S_m and 0.7 S_u
	Primary membrane + bending stress intensity[a]	Lesser of 3.6 S_m and S_u
	Range of primary + secondary stress intensity[b]	2 S_a
	Pure primary shear stress[c]	0.42 S_u
Bolts[d]	Average tension	0.7 S_u or S_y
	Average shear	0.6 S_y or 0.42 S_u
	Average tension + average shear Stress ratio of average stress/allowable Rt: Stress ratio for average tensile Rs: Stress ratio for average shear	$Rt^2 + Rs^2 < 1$

Definitions according to: NRC, 1978, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, Regulatory Guide 7.6, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1978:

[a]Paragraph C.6.

[b]Paragraph C.4 and C.6.

[c]Definitions from: ASME, 1995b, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Subsection NB-3227.2, American Society of Mechanical Engineers, New York, New York.

[d]Definitions from: Mok, G. C., 1989, Stress Analysis of Closure Bolts for Shipping Casks, NUREG/CR-6007, Table 6.3, (under Lawrence Livermore National Laboratory contract to the NRC), U.S. Nuclear Regulatory Commission, Washington, D.C.

Table B7-18. Containment Boundary Accident Condition Allowable Stresses (ksi).

	Stress category	70 °F	100 °F	200 °F	300 °F	400 °F
Components other than bolts	Material	SA-336, 304 Stainless Steel				
	Primary membrane stress intensity (ksi)	289.5 (42.0)	289.5 (42.0)	274.4 (39.8)	256.5 (37.2)	249.6 (36.2)
	Primary membrane + bending stress intensity (ksi)	434.4 (63.0)	434.4 (63.0)	412.3 (59.8)	384.7 (55.8)	375.1 (54.4)
	Primary shear stress (ksi)	202.7 (29.4)	202.7 (29.4)	191.7 (27.8)	117.9 (25.8)	173.8 (25.2)
Bolts	Material	SA-479, XM-19				
	Average tension stress	651.5 (94.5)	651.5 (94.5)	641.9 (93.1)	622.6 (90.3)	608.1 (88.2)
	Average shear stress	390.9 (56.7)	390.9 (56.7)	385.4 (55.9)	373.7 (54.2)	364.7 (52.9)

combination of ABAQUS/Explicit and ABAQUS/Standard computer codes are used to evaluate cask performance. The cask impact performance under accident conditions is evaluated using the ABAQUS/Explicit computer code. Accident condition MCO and spent fuel basket drop evaluations are performed by the ABAQUS/Standard (HKS 1995) FEA code. The ABAQUS/Standard computer code is also used to evaluate the accident condition thermal performance of the MCO Cask. For cask impact evaluations under accident conditions, the velocity input parameters are changed to simulate a 9-m (30-ft) or 6.4-m (21-ft) drop.

The side-drop FEA model is a half-section (180°) model of the cask and target. The orientation of the cask model is unchanged. The target model has been rotated by 90° to have its top surface impact the cask side. The impact direction in this case is in the X direction. The 180° symmetric section of the cask is divided into 12 sections with a finer mesh at the impacting edge. This model mesh is coarser than for the bottom-end drop. However, the mesh size of the cask body at the impact edge in both radial and circumferential directions is the same as for the bottom-end-drop model. In the longitudinal direction, the cylindrical wall is divided into 15 equal sections. The closure lid is divided into 12 sectors with a finer mesh at the impacting edge. Seven closure lid bolt elements are modeled. At the symmetric edges are two half-bolt areas with the remaining five having full-bolt areas. To simulate the side drop, the gravity and velocity are applied in the X direction.

The MCO Cask 6.4-m (21-ft) water-filled drop model is the same as for a 9-m (30-ft) bottom oblique drop with two exceptions: (1) the lower drop height and (2) addition of a water simulation model. The water is treated as a simple ABAQUS hydrodynamic material model with zero shear strength and a bulk response defined as $p = K\,\epsilon_{vol}$, where p is the pressure, K is the bulk modulus of elasticity, and ϵ is the volumetric strain. The ABAQUS equation of state (*EOS) with USUP type is specified. When a hydrostatic simplification is assumed, this yields the relationship $K = \rho_o c_o^2$, where ρ_o is the density of water and c_o is the speed of sound in water. The water model consists of solid elements (C3D8R) with the water density at 1 kg/L (62.4 lbf/ft^3), a bulk modulus of elasticity 2,068 MPa (300,000 psi), and sonic speed of 1,422 m/s (56,660 in/s).

7.3.4 Initial Conditions

Initial conditions required for hypothetical accident evaluations are the same as those required for the evaluation of NCT. See Part B, Section 7.2.4.

7.3.4.1 Environmental Heat Loading. The fire accident condition is assumed to be independent of all other accident conditions. Also, for conservatism, it is assumed that the fire duration is for 30 minutes. Thermal evaluation of the hypothetical accident conditions are provided in Part B, Section 8.0. Based on these assumptions, the thermal loads are evaluated during an accident fire.

7.3.4.2 Accident Condition Drop Stresses. The accident condition drops are evaluated in the same manner as for the normal conditions with the addition of three cases. The additional cases are the side drop, top-end flat drop, and a

6.4-m (21-ft) bottom-end oblique drop with the cask and MCO filled with water. The highest ASME Code stress intensities at critical elements and locations are shown in Table B7-19.

Table B7-19. Maximum Stress Intensity and Location Accident Condition Drops.

Drop orientation	Cask body/closure lid				Lid bolts	
	Exterior		Containment		Element	Stress MPa (ksi)
	Element	Stress MPa (ksi)	Element	Stress MPa (ksi)		
Bottom end	25009	149.13 (21.63)	20110	102.87 (14.92)	9901	109.69 (15.91)
Bottom end corner	21336	417.4 (60.54)	616	81.7 (11.85)	9905	40.82 (5.92)
Side	25001	257.8 (37.39)	20695	98.18 (14.24)	9907	177.26 (25.71)
Top end oblique	5478	67.91 (9.85)	3652	103.14 (14.96)	9907	55.16 (8.00)
Top end flat	5078	119.48 (17.33)	4850	70.81 (10.27)	9905	27.37 (3.97)
6.4-m (21-ft) bottom oblique, filled with water	21336	244.07 (35.40)	616	68.39 (9.92)	9907	39.44 (5.72)

7.3.4.3 Accident Condition Drop Evaluation.

7.3.4.3.1 9-m (30-ft) Bottom-End Flat Drop. This case evaluates the MCO Cask performance for a 9-m (30-ft) bottom-end flat drop onto the 20-cm (8-in.) concrete pad. The total run time of this case is 100 ms. This drop results in an impact acceleration history with high frequency noise as shown in Figure B7-106. After filtering out frequencies higher than 1000 Hz, the peak acceleration is determined to be approximately 57.6*g* (Figure B7-107).

Figure B7-106. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Acceleration History (Unfiltered).

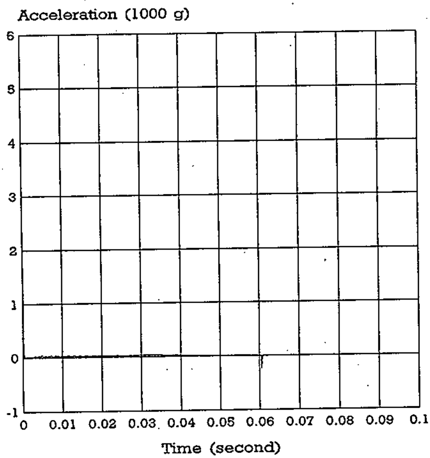
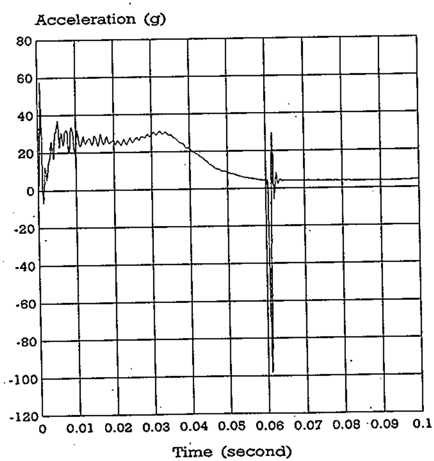


Figure B7-107. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Acceleration History (Filtered at 1000 Hz).



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of the lid, respectively, are shown in Figures B7-108 through Figure B7-110. The data points are the center of the plate (except center-of-gravity level does not have this point), 0° point, and 180° point from the drain port in the circumferential direction. All three figures indicate a 9-m (30-ft) drop impact period of about 114.5 ms. Pertinent impact acceleration data are shown in Table B7-20.

Figure B7-108. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Velocity History at the Bottom of Cask.

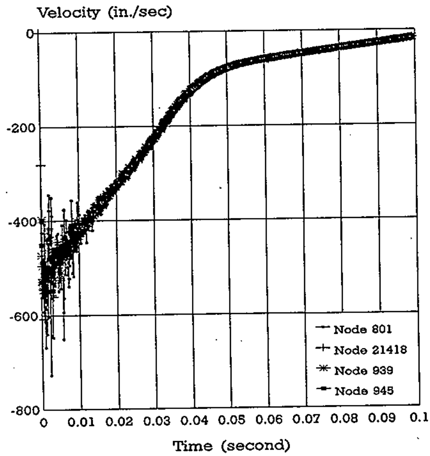


Figure B7-109. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Velocity History at the Center of Gravity Level of Cask.

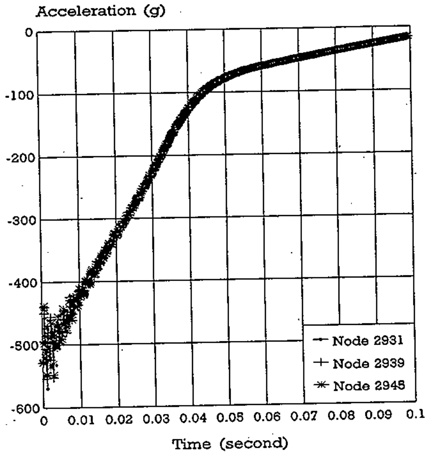


Figure B7-110. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Velocity History at the Top of Cask Lid.

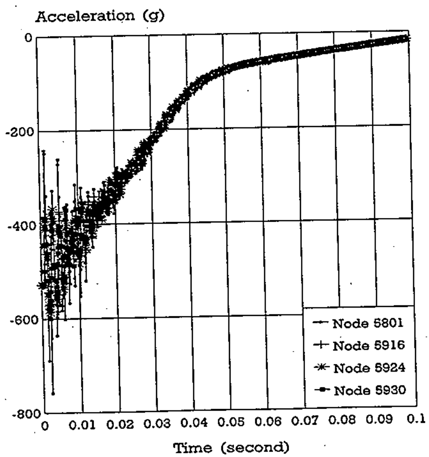


Table B7-20. Impact Acceleration Data of the 9-m (30-ft) Bottom-End Flat Drop.

Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
28.6	11.9	57.6	114.5

Stress Intensity. The estimated average ASME Code stress intensities are shown in Table B7-21 at the most critical exterior shell and containment boundary locations and at all lid bolts. The stress intensity plots at the most critical locations are shown in Figures B7-111 through B7-114. The stress intensity plots of lid bolts are shown in Figures B7-115 through B7-121.

Table B7-21. ASME Code Stress Intensity at Critical Locations from the 9-m (30-ft) Bottom End Flat Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
21336	52.12 (7.56)	614	66.81 (9.69)	9901	109.69 (15.91)
21337	54.33 (7.88)	615	51.16 (7.42)	9902	103.97 (15.08)
21338	46.81 (6.79)	616	86.46 (12.54)	9903	103.83 (15.06)
21339	55.57 (8.06)	21310	72.05 (10.45)	9904	107.14 (15.54)
21340	49.30 (7.15)	21305	62.26 (9.03)	9905	106.25 (15.41)
21341	93.42 (13.55)	21300	56.40 (8.18)	9906	104.94 (15.22)
21342	64.05 (9.29)	21295	52.61 (7.63)	9907	101.90 (14.78)
21343	62.95 (9.13)	21290	76.05 (11.03)		
21344	72.53 (10.52)	21285	72.39 (10.50)		
21345	77.36 (11.22)	21280	59.91 (8.69)		
21311	77.29 (11.21)	21275	48.74 (7.07)		
21316	87.77 (12.73)	21270	57.09 (8.28)		
21346	72.81 (10.56)	20720	81.63 (11.84)		
25030	51.99 (7.54)	20715	57.29 (8.31)		
25029	64.60 (9.37)	20710	63.57 (9.22)		
25022	48.33 (7.01)	20705	54.81 (7.95)		
25021	43.78 (6.35)	20695	66.60 (9.66)		
25020	47.71 (6.92)	20690	67.43 (9.78)		
25019	108.59 (15.75)	20685	65.84 (9.55)		
25012	89.97 (13.05)	20680	60.53 (8.78)		
25011	81.49 (11.82)	20160	87.77 (12.73)		
25010	111.21 (16.13)	20159	72.05 (10.45)		
25009	149.13 (21.63)	20158	67.29 (9.76)		
25002	90.73 (13.16)	20157	54.47 (7.90)		
25001	103.35 (14.99)	20110	102.87 (14.92)		
		20109	84.32 (12.23)		
		20108	100.59 (14.59)		
		20107	56.88 (8.25)		
		20106	61.22 (8.88)		

Figure B7-111. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at the Interior of the Cask Wall (EL 21295).

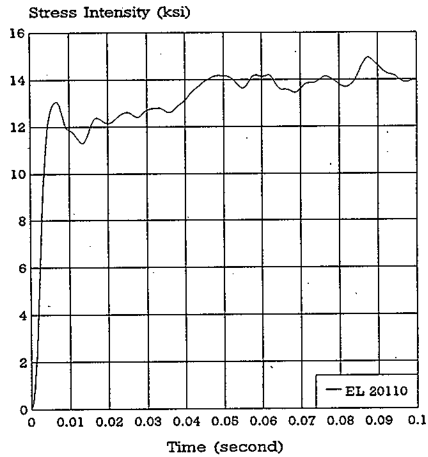


Figure B7-112. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at the Interior of the Cask Bottom (EL 614).

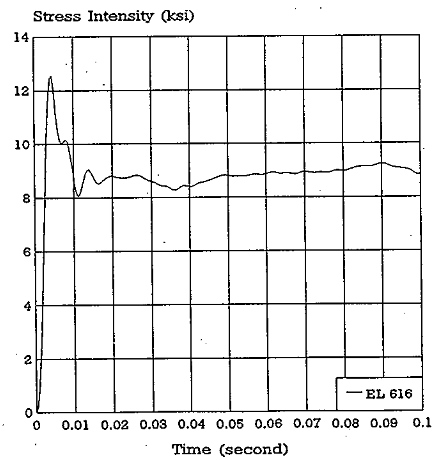


Figure B7-113. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at the Exterior of the Cask (EL 21346).

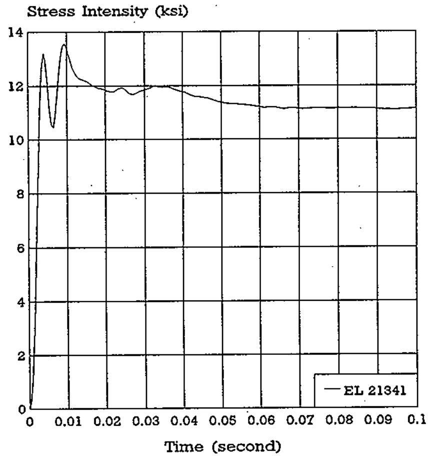


Figure B7-114. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at the Drain Port Cover Plate (EL 25002).

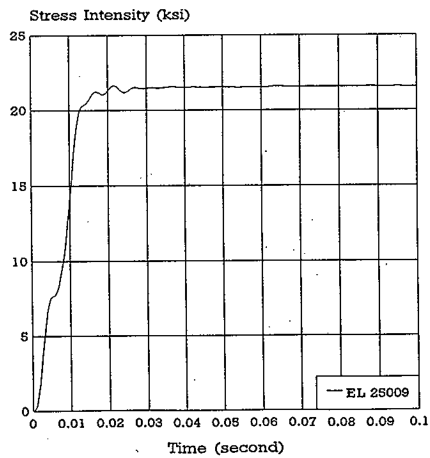


Figure B7-115. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

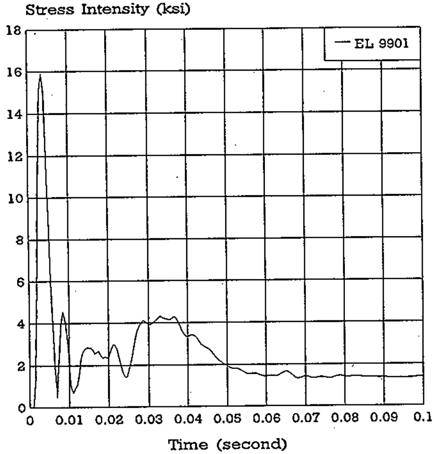


Figure B7-116. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

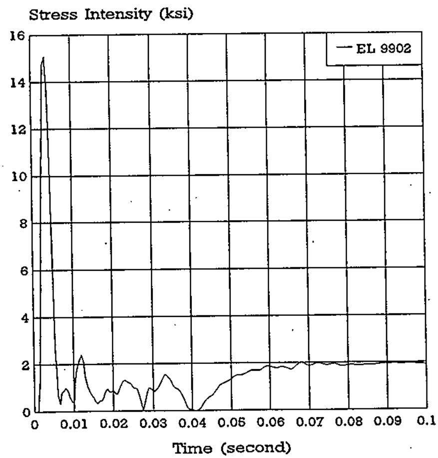


Figure B7-117. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

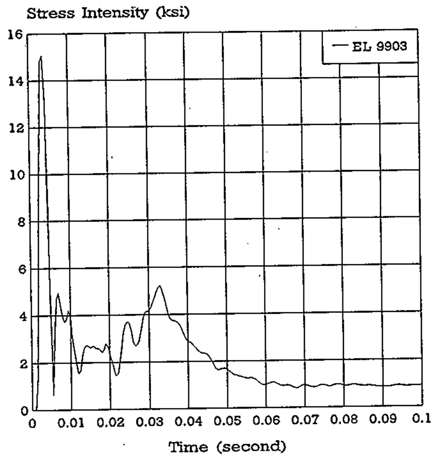


Figure B7-118. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

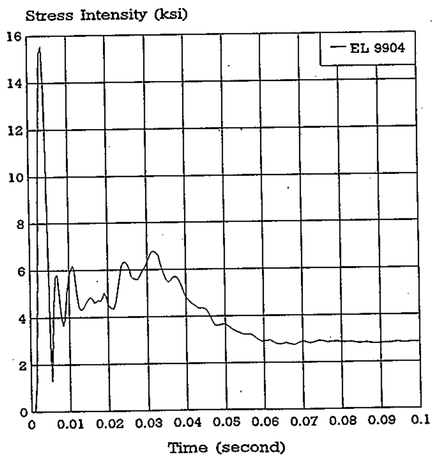


Figure B7-119. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No 5 (EL 9905).

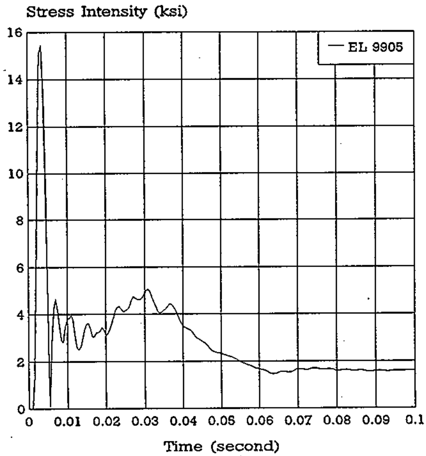


Figure B7-120. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

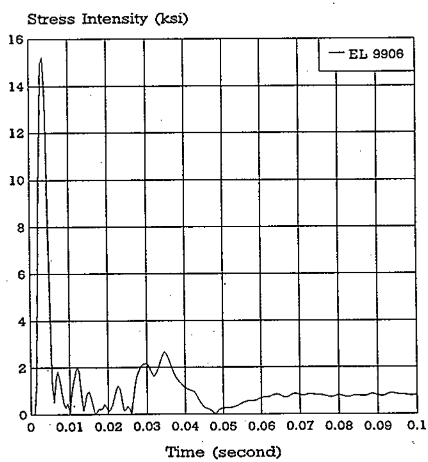
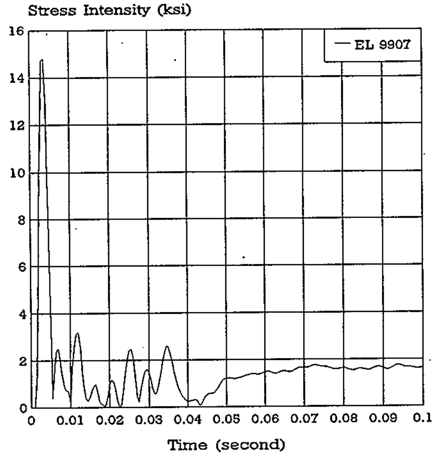


Figure B7-121. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-22. The accumulated strains are the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the strain counterpart of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-122 through B7-125. The largest accumulated strain is 0.633% at the drain port cover plate. The largest accumulated strain on the containment boundary of the cask/lid is 0.47%, occurring in the drain port region.

The strain plots of lid bolts are shown in Figures B7-126 through B7-132. The maximum accumulated strains of the lid bolts are approximately 1.0% during this 9-m (30-ft) bottom-end flat drop.

Table B7-22. Accumulated Strains at Critical Locations from the 9-m (30-ft) Bottom End Flat Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in./in.)	Element	Strain (in./in.)	Element	Strain (in./in.)
21336	0.00168	614	0.00109	9901	0.00902
21337	0.00213	615	0.00205	9902	0.00964
21338	0.00210	616	0.00221	9903	0.01006
21339	0.00158	21310	0.00174	9904	0.01001
21340	0.00108	21305	0.00158	9905	0.00938
21341	0.00099	21300	0.00232	9906	0.00865
21342	0.00148	21295	0.00421	9907	0.00841
21343	0.00192	21290	0.00465		
21344	0.00120	21285	0.00169		
21345	0.00114	21280	0.00183		
21311	0.00068	21275	0.00151		
21316	0.00228	21270	0.00129		
21346	0.00283	20720	0.00175		
25030	0.00035	20715	0.00186		
25029	0.00043	20710	0.00200		
25022	0.00032	20705	0.00178		
25021	0.00029	20695	0.00188		
25020	0.00032	20690	0.00179		
25019	0.00072	20685	0.00134		
25012	0.00060	20680	0.00087		
25011	0.00054	20160	0.00211		
25010	0.00074	20159	0.00157		
25009	0.00099	20158	0.00119		
25002	0.00060	20157	0.00099		
25001	0.00069	20110	0.00190		
		20109	0.00191		
		20108	0.00155		
		20107	0.00165		
		20106	0.00157		

Figure B7-122. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at the Interior of the Cask Wall (EL 21290).

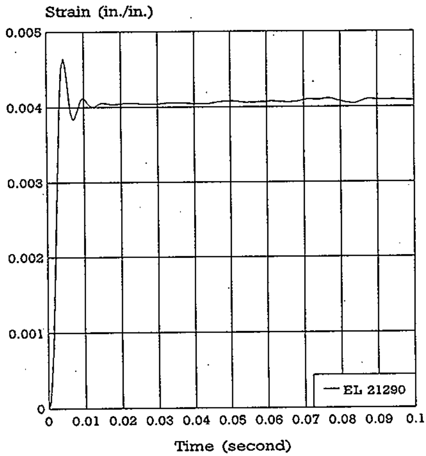


Figure B7-123. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Interior of the Cask Bottom (EL 616).

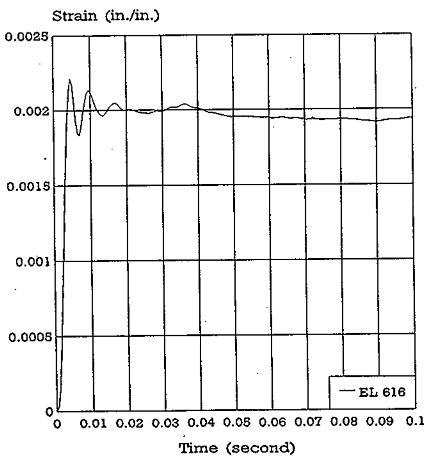


Figure B7-124. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at the Exterior of the Cask (EL 21346).

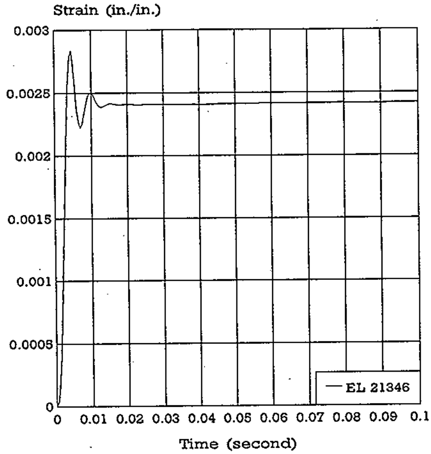


Figure B7-125. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at the Drain Port Cover Plate (EL 25030).

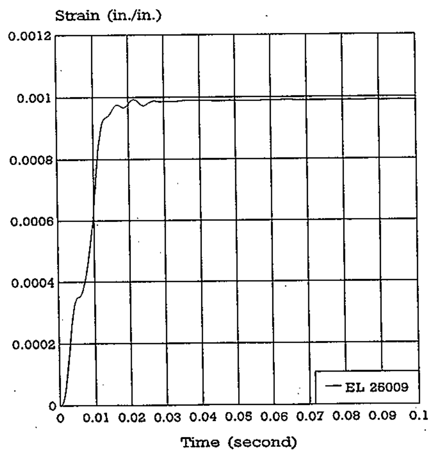


Figure B7-126. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Bolt No. 1 (EL 9901).

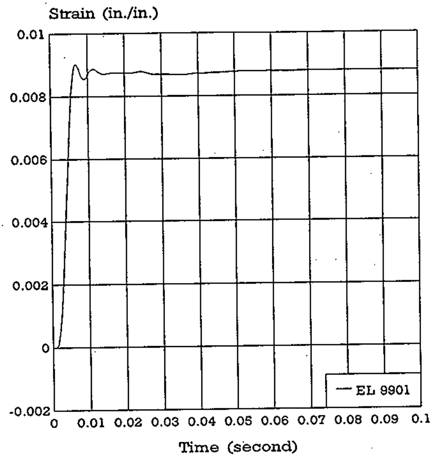


Figure B7-127. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Bolt No. 2 (EL 9902).

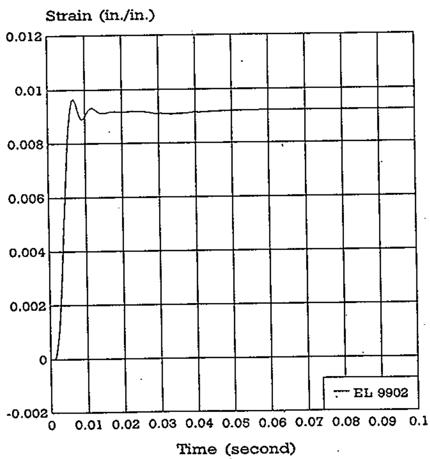


Figure B7-128. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain at Bolt No. 3 (EL 9903).

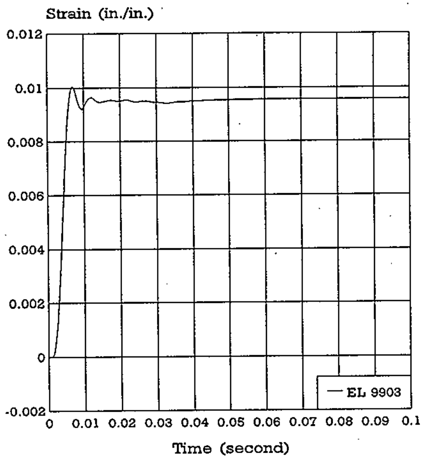


Figure B7-129. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History in Bolt No. 4 (EL 9904).

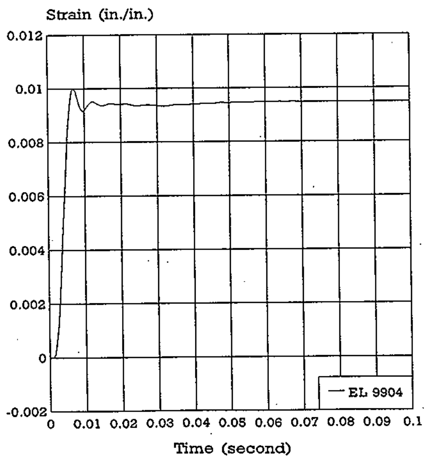


Figure B7-130. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Bolt No. 5 (EL 9905).

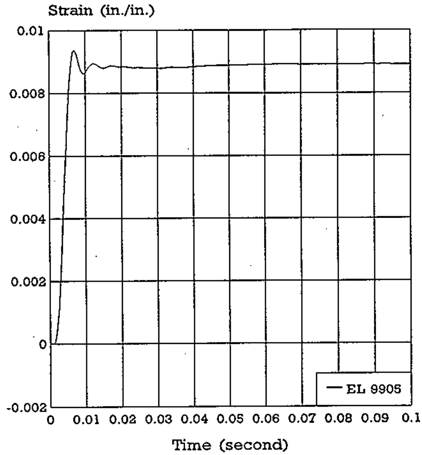


Figure B7-131. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Bolt No. 6 (EL 9906).

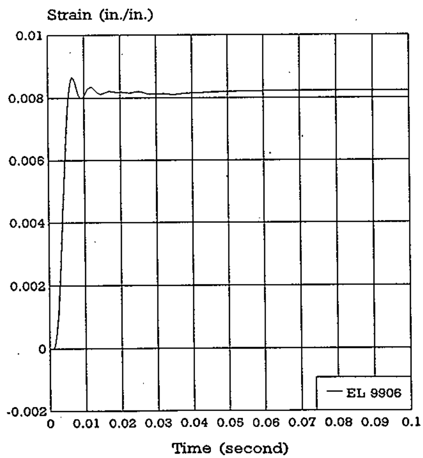
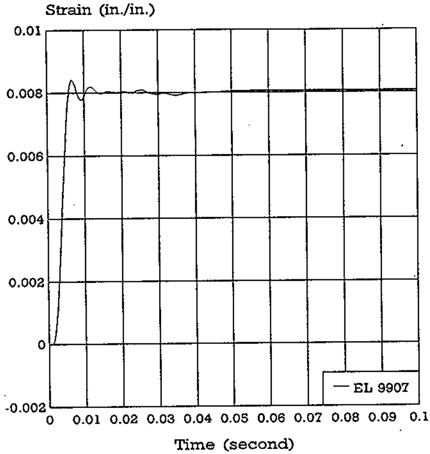


Figure B7-132. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. Evaluation of the four cover plate cap screws shows the drain port cover plate remains secured to the cask body and containment is maintained. Since the bolt pattern is symmetrical, only two of the four bolts is shown. The low bolt stress shows that the cover plate remains secured to the cask body. The low axial strain on the bolts shows that there is only minor axial deformation, and consequently containment is maintained. The cap screws are manufactured from SA-193, Grade B8 material, with an ASME tensile strength of 517 MPa (75 ksi) and a yield strength of 207 MPa (30 ksi). The plasticity of the cap screws material is represented by a bilinear curve with a stress of 207 MPa (30,033 psi) at 0% plastic strain, and a rupture stress of 672 MPa (97.5 ksi) at 30% plastic strain. As shown in Figures B7-133 through B7-135, the maximum tensile stress of the cap screws is 96.66 MPa (14.02 ksi) an axial strain of 0.58%. The maximum shear stress in the cap screws is only 1.2 MPa (180 psi). Figure B7-136 shows the concrete deformation is approximately 41.91 cm (16.5 in.).

Figure B7-133. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Drain Port Cover Plate Cap Screw Axial Stress.

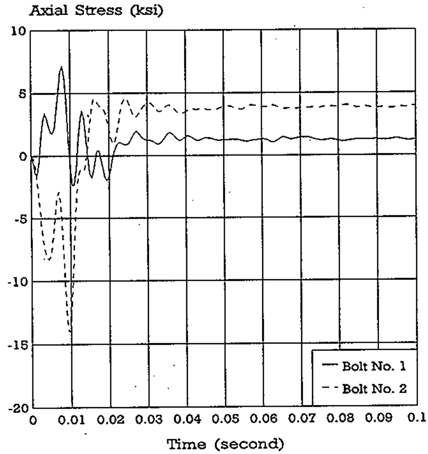
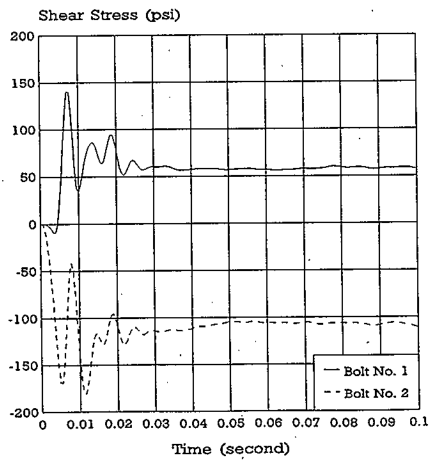


Figure B7-134. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Drain Port Cover Plate Cap Screw Shear Stress.



7.3.4.3.2 9-m (30-ft) Bottom-End Corner Drop. This case evaluates the MCO Cask performance for a 9-m (30-ft) bottom-end corner drop onto the 20-cm (8-in.) concrete target. The center of gravity of the cask assembly and payload is over the impacting corner. The total duration of this case is 62 ms at the impact point.

In this case, because the initial impact area is very small, the cask penetrates well into the target before the target can provide sufficient resistance to noticeably affect cask momentum. Subsequently, the peak acceleration is delayed from initial contact until sufficient target resistance is available to begin a change in cask momentum (Figures B7-135 and B7-136).

The drop results in an impact acceleration history filled with a few sharp spikes as shown in Figure B7-135. The spikes are the results of residual forces from many contact surfaces, which are numerical errors, not the real cask responses. After smoothing out these sharp spikes, the maximum acceleration is found to be about 34.5*g* (Figure B7-136).

Figure B7-135. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Drain Port Cover Plate Cap Screw Axial Strain.

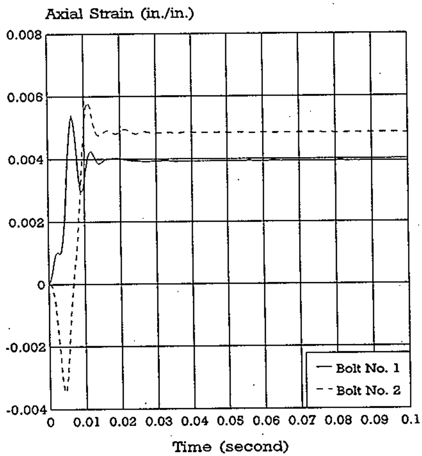
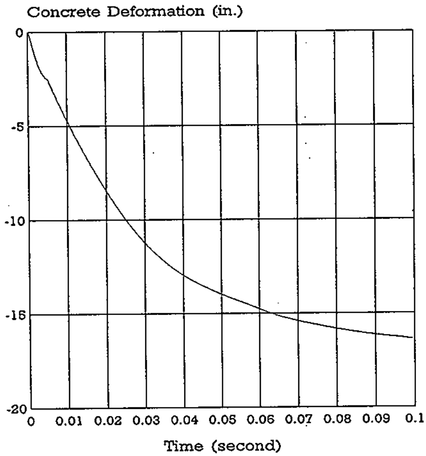


Figure B7-136. MCO Cask 9-m (30-ft) Bottom-End Flat-Drop Concrete Deformation Depth.



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of the lid, respectively, are shown in Figures B7-137 through B7-139. The data points are the center of the lid and bottom plates (center-of-gravity level does not have this point), 0° point, 90° point, and 180° point from the drain port in the circumferential direction (middle curve). The typical (or average) data point is the 90° point. Using the 90° point data, the bottom of cask has an impact period of 57 ms, which is shorter than the impact period of the center-of-gravity level of the cask of 65.2 ms. The top of the lid has the longest impact period of a little over 82 ms. The impact periods for the center of gravity and the top lid levels are extrapolated from the time curves. The maximum acceleration is determined from the steepest slope of these velocity curves. They are 35.7*g* at the bottom of the cask, 33.3*g* at the center-of- gravity level of the cask, and 28.7*g* at the top of the lid. Using the impact durations at different elevations, the average accelerations are found to be 24.0*g*, 21.0*g*, and 16.7*g* at the bottom, center-of-gravity, and top elevations, respectively.

The acceleration results are shown in Table B7-23. The linear peak acceleration is obtained from the steepest slope of the velocity curve. The average impact-period acceleration is calculated from (528-0)/(impact period)/(386.4). The peak acceleration is obtained from the reaction force history at the bottom of the cask.

Figure B7-137. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Velocity History at the Bottom of the Cask.

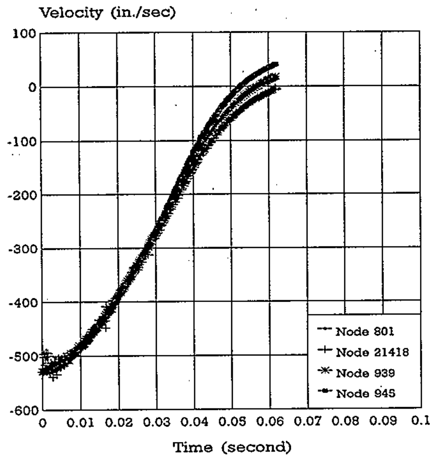


Figure B7-138. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Velocity History at the Cask Center of Gravity.

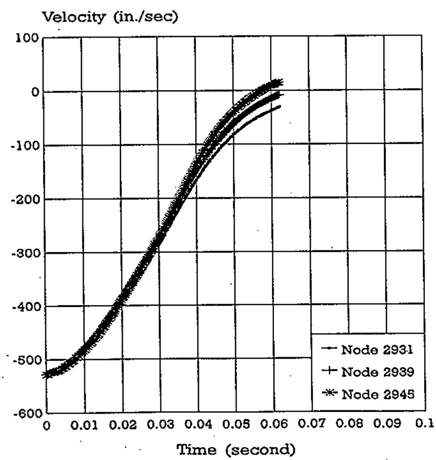


Figure B7-139. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Velocity History at the Top of the Lid.

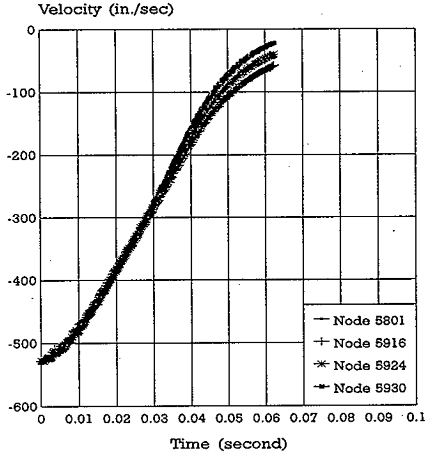


Table B7-23. Impact Acceleration Data of the 9-m (30-ft) Bottom-End Corner Drop.

Location	Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
Bottom	35.7	24.0	34.5	57.0
Center of gravity	33.3	21.0	NA	65.2
Top	28.7	16.7	NA	81.7

Stress Intensity. The estimated average ASME Code stress intensities are shown in Table B7-24 at the most critical exterior shell and containment boundary locations and at all lid bolts. The stress intensity plots at the most critical locations are shown in Figures B7-140 through B7-143. The exterior boundary of the cask near the drain port has experienced a high stress intensity; however, the containment boundary of the cask stress intensity is well below the allowable stress of the cask material. The stress intensity plots of the lid bolts are shown in Figures B7-144 through B7-150. The impact of this drop produces very low stress intensities on the lid bolts.

Table B7-24. ASME Code Stress Intensity at Critical Locations from the 9-m (30-ft) Bottom-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
21336	416.78 (60.54)	614	23.65 (3.43)	9901	10.82 (1.57)
21337	236.83 (34.35)	615	24.89 (3.61)	9902	8.27 (1.20)
21338	180.29 (26.15)	616	81.70 (11.85)	9903	16.55 (2.40)
21339	106.18 (15.40)	21310	12.62 (1.83)	9904	38.89 (5.64)
21340	86.04 (12.48)	21305	13.68 (2.01)	9905	40.82 (5.92)
21341	259.72 (37.67)	21300	23.86 (3.46)	9906	33.99 (4.93)
21342	154.23 (22.37)	21295	34.54 (5.01)	9907	25.79 (3.74)
21343	80.05 (11.61)	21290	38.47 (5.58)		
21344	55.29 (8.02)	21285	13.58 (1.97)		
21345	34.34 (4.98)	21280	14.89 (2.16)		
21311	334.11 (48.46)	21275	14.96 (2.17)		
21316	250.41 (36.32)	21270	19.30 (2.80)		
21346	146.17 (21.20)	20720	16.34 (2.37)		
25030	197.12 (28.59)	20715	18.62 (2.70)		
25029	191.46 (27.77)	20710	22.82 (3.31)		
25022	95.83 (13.90)	20705	19.99 (2.90)		
25021	83.91 (12.17)	20695	21.37 (3.10)		
25020	150.58 (21.84)	20690	20.37 (2.94)		
25019	171.68 (24.90)	20685	33.09 (4.80)		
25012	91.56 (13.28)	20680	20.41 (2.96)		
25011	85.01 (12.33)	20160	19.93 (2.89)		
25010	98.52 (14.29)	20159	20.68 (3.00)		
25009	128.79 (18.68)	20158	20.13 (2.92)		
25002	115.28 (16.72)	20157	24.54 (3.56)		
25001	82.32 (11.94)	20110	25.85 (3.75)		
		20109	22.61 (3.28)		
		20108	31.92 (4.63)		
		20107	28.06 (4.07)		
		20106	25.58 (3.71)		

Figure B7-140. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at the Interior of the Cask Wall (EL 20110).

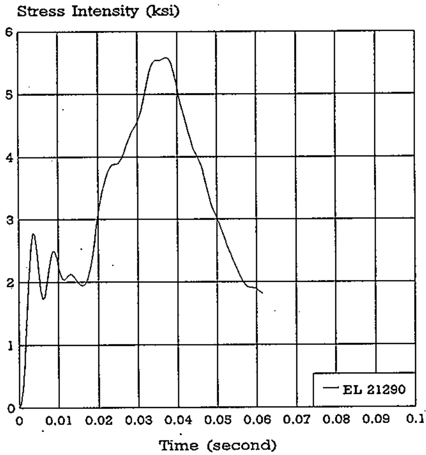


Figure B7-141. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at the Interior of the Cask Bottom (EL 616).

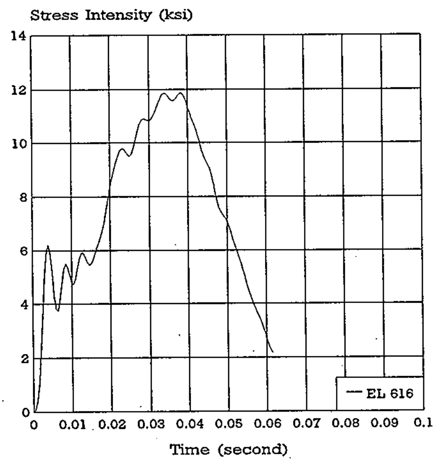


Figure B7-142. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at the Exterior of the Cask (EL 21336).

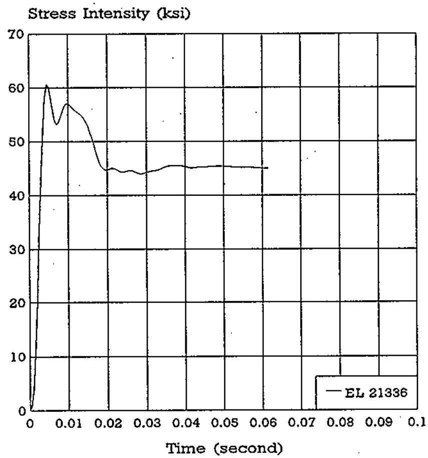


Figure B7-143. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at the Drain Port Cover Plate (EL 25030).

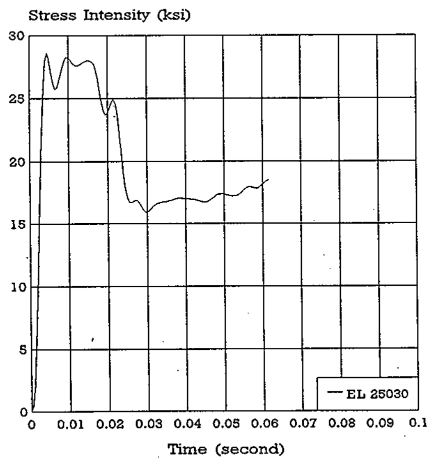


Figure B7-144. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

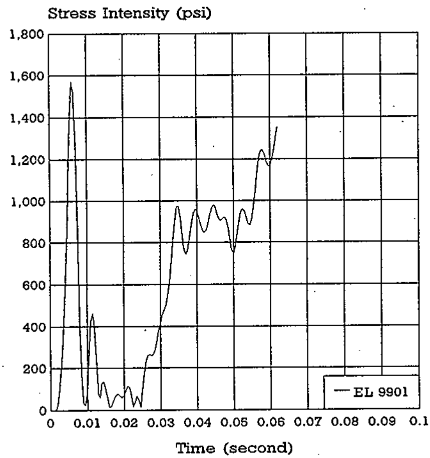


Figure B7-145. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

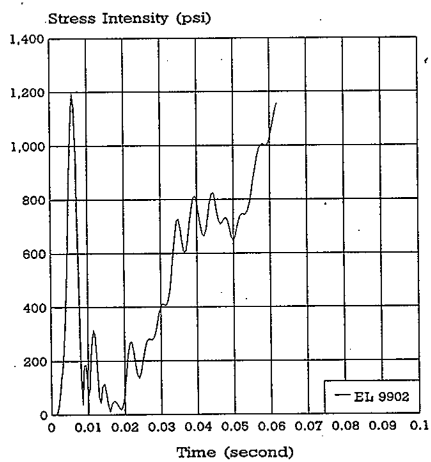


Figure B7-146. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

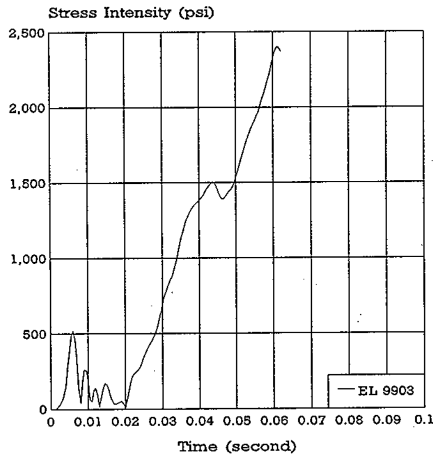


Figure B7-147. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

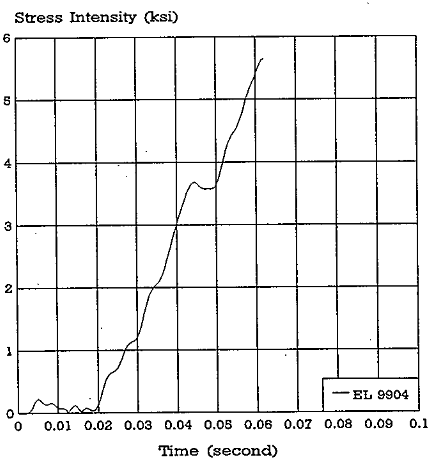


Figure B7-148. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

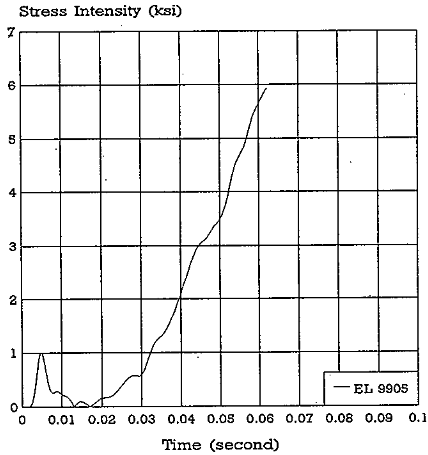


Figure B7-149. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

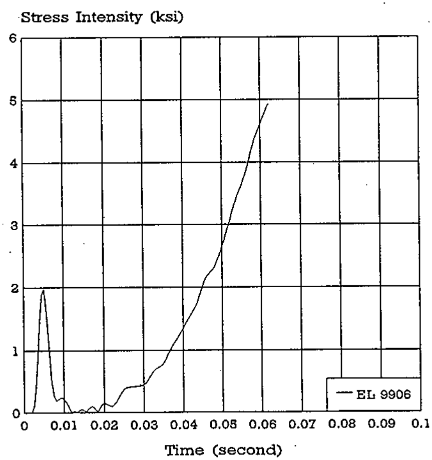
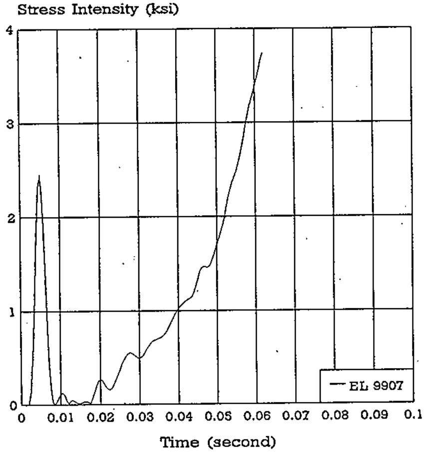


Figure B7-150. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-25. The accumulated strains reported are in the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of strain of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-151 through B7-154. The largest overall accumulated strain of the entire cask is over 15.3% at the exterior bottom boundary of the drain port (Figure B7-153). The largest accumulated strain on the drain port cover plate is about 1.8% (Figure B7-154). However, the largest accumulated strain of the containment boundary of the cask/lid is only 0.05%, occurring near the drain port region (Figure B7-151).

The strain plots of lid bolts are shown in Figures B7-155 through B7-161. The accumulated strains of the lid bolts are very small, about 0.02% during this 9-m (30-ft) bottom-end corner drop.

Table B7-25. Accumulated Strains at Critical Locations from the 9-m (30-ft) Bottom-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in./in.)	Element	Strain (in./in.)	Element	Strain (in./in.)
21336	0.1527	614	0.00016	9901	0.00006
21337	0.01745	615	0.00017	9902	0.00004
21338	0.00298	616	0.00054	9903	0.00009
21339	0.00071	21310	0.00008	9904	0.00020
21340	0.00057	21305	0.00009	9905	0.00021
21341	0.02153	21300	0.00016	9906	0.00018
21342	0.00345	21295	0.00023	9907	0.00014
21343	0.00053	21290	0.00026		
21344	0.00037	21285	0.00009		
21345	0.00023	21280	0.00010		
21311	0.07338	21275	0.00010		
21316	0.02172	21270	0.00013		
21346	0.00119	20720	0.00011		
25030	0.04425	20715	0.00012		
25029	0.02092	20710	0.00015		
25022	0.00515	20705	0.00013		
25021	0.00793	20695	0.00014		
25020	0.01742	20690	0.00014		
25019	0.01053	20685	0.00022		
25012	0.00276	20680	0.00014		
25011	0.00364	20160	0.00018		
25010	0.00418	20159	0.00014		
25009	0.00459	20158	0.00013		
25002	0.00128	20157	0.00016		
25001	0.00141	20110	0.00017		
		20109	0.00015		
		20108	0.00021		
		20107	0.00019		
		20106	0.00017		

Figure B7-151. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at the Interior of the Cask Wall (EL 21290).

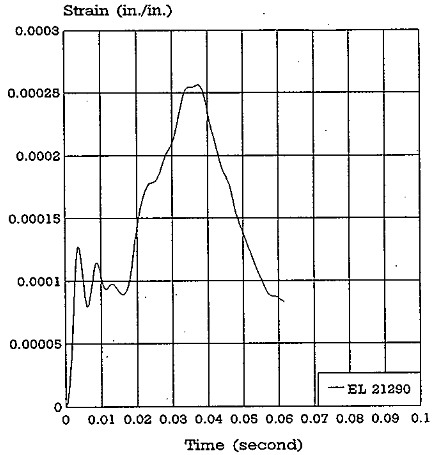


Figure B7-152. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at the Interior of the Cask Bottom (EL 616).

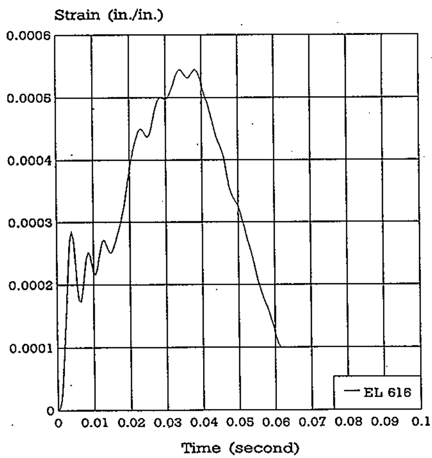


Figure B7-153. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at the Exterior of the Cask (EL 21336).

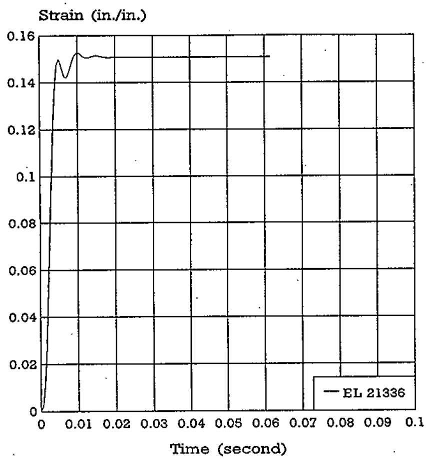


Figure B7-154. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at the Drain Port Cover Plate (EL 25030).

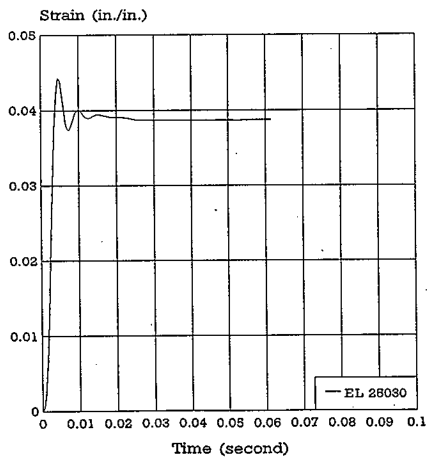


Figure B7-155. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 1 (EL 9901).

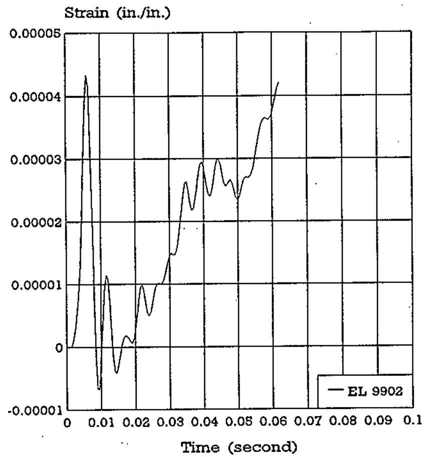


Figure B7-156. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 2 (EL 9902).

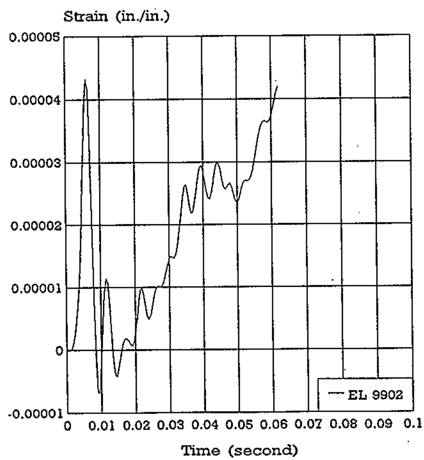


Figure B7-157. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 3 (EL 9903).

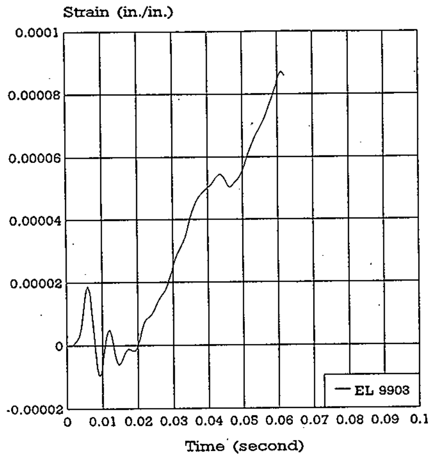


Figure B7-158. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 4 (EL 9904).

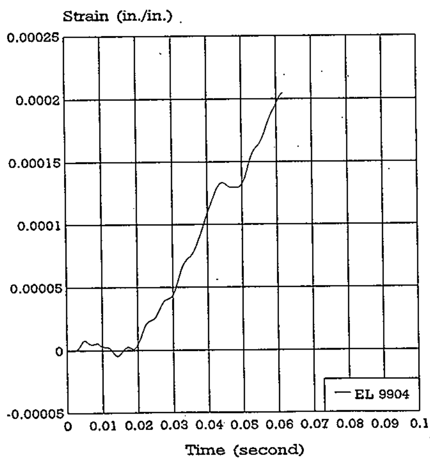


Figure B7-159. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 5 (EL 9905).

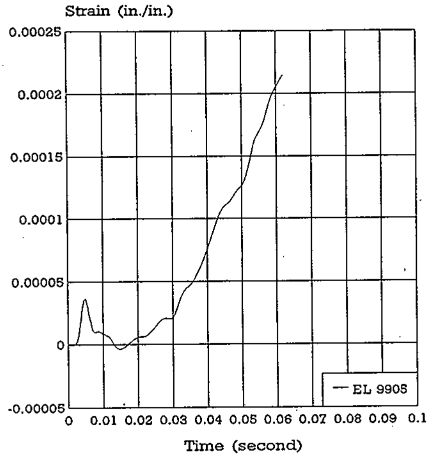


Figure B7-160. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 6 (EL 9906).

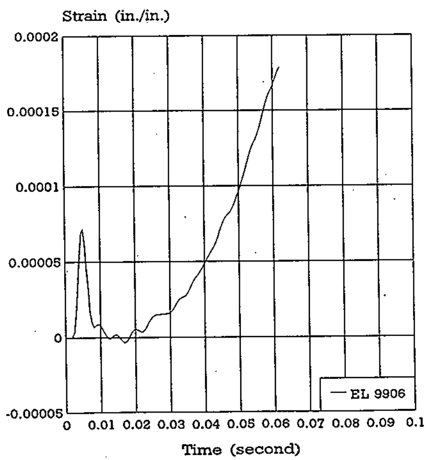
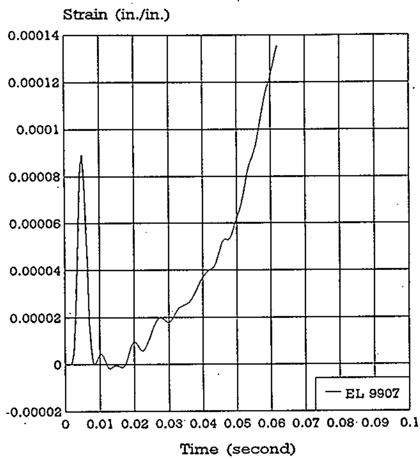


Figure B7-161. MCO Cask 9-m (30-ft) Bottom-End Corner-Drop Strain History at Bolt No. 7 (EL 9907).



Other results. Evaluation of the four cover plate cap screws shows the drain port cover plate remains secured to the cask body and containment is maintained. Since the bolt pattern is symmetrical, only two of the four bolts is shown. The low bolt stress shows that the cover plate remains secured to the cask body. The low axial strain on the bolts shows that there is only minor axial deformation; consequently, containment is maintained. The cap screws are manufactured from SA-193, Grade B8 material, with an ASME tensile strength of 517 MPa (75 ksi) and a yield strength of 207 MPa (30 ksi). The plasticity of the cap screws material is represented by a bilinear curve with a stress of 207 MPa (30,033 psi) at 0% plastic strain, and a rupture stress of 672 MPa (97.5 ksi) at 30% plastic strain. As shown in Figures B7-162 to B7-164, the maximum tensile stress of the cap screws is 194.4 MPa (28.2 ksi) with an axial strain of 0.8% (0.008 in/in). The maximum shear stress in the cap screws is only 0.6 MPa (81 psi). Figure B7-165 shows the concrete deformation is approximately 39.4 cm (15.5 in.).

7.3.4.3.3 9-m (30-ft) Side Drop. This case is to study an accident condition of the MCO Cask having a 9-m (30-ft) side drop onto the 20-cm (8-in.) concrete target. The side of the cask assembly is assumed to be perfectly horizontal just before impact such that all side points contact the concrete pad at the same time. The total run time of this case is 40 ms. The side drop has a large impact area, which is difficult to control both in actual testing and in numerical analysis. This results in an initial impact acceleration of 2,050*g* at time zero. This numerical anomaly due to the largely distributed contact areas, not the real cask response (Figure B7-166). After smoothing out this initial spike and filtering out forces with high frequencies over 1,000 Hz, the maximum peak acceleration is found to be about 177*g* (Figure B7-167).

Figure B7-162. MCO Cask 9-m (30-ft) Bottom-End Oblique-Drop Axial Stresses at Drain Port Cover Plate Cap Screws.

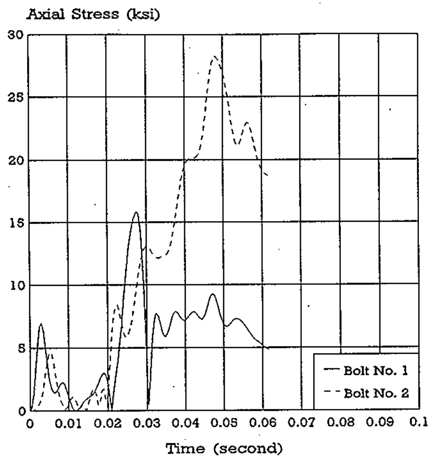


Figure B7-163. MCO Cask 9-m (30-ft) Bottom-End Oblique-Drop Drain Shear Stresses at Port Cover Plate Cap Screws.

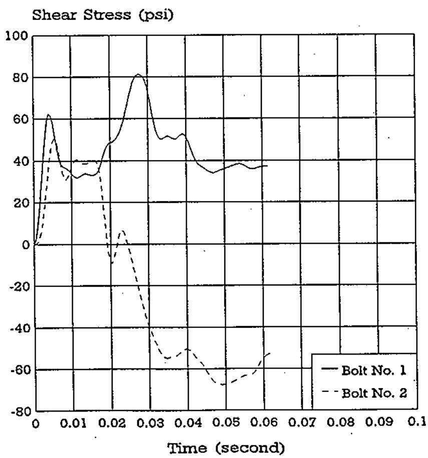


Figure B7-164. MCO Cask 9-m (30-ft) Bottom-End Oblique-Drop Axial Strain at Drain Port Cover Plate Cap Screws.

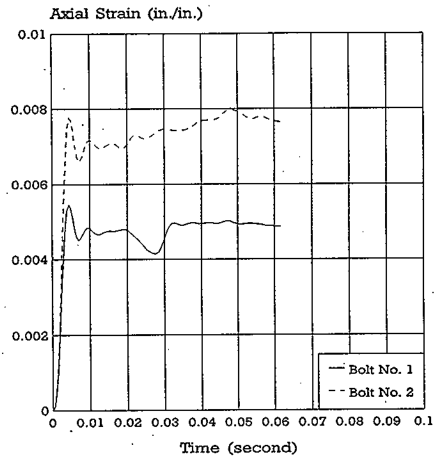


Figure B7-165. MCO Cask 9-m (30-ft) Bottom-End Oblique-Drop Concrete Deformation Depth.

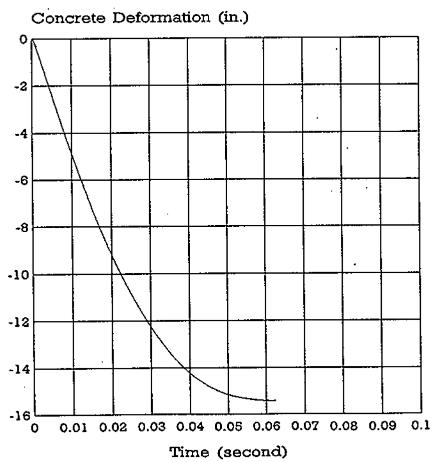


Figure B7-166. MCO Cask 9-m (30-ft) Side-Drop Acceleration History (Unfiltered).

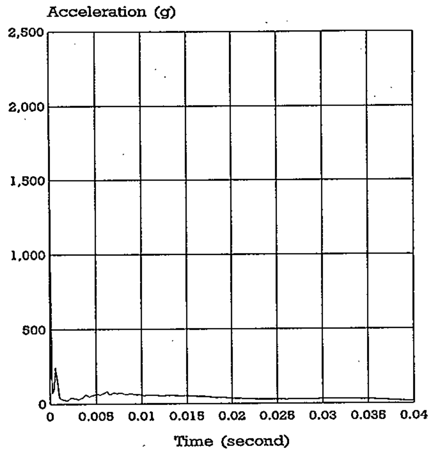
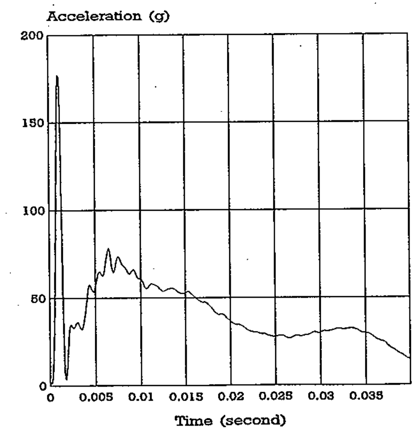


Figure B7-167. MCO Cask 9-m (30-ft) Side-Drop Acceleration History (Filtered).



Four velocity plots at the bottom of the cask, the center-of-gravity level of the cask, the flange of the lid, and the top of lid are shown in Figures B7-168 through B7-171, respectively. At the bottom of the cask and at the center-of-gravity and the lid flange levels, the data points are the 45° point, 90° point, 135° point, and 180° point from the drain port in the circumferential direction. The data points at the top of the lid are at the center of the plate, 0° point, 90° point, and 180° point from the drain port in the circumferential direction. The velocities at each elevation converge well to indicate the thick-wall cask behaves like a rigid body motion. Although the top of the cask rebounds a few milliseconds earlier than the bottom of the cask, the initial maximum accelerations show the opposite behavior. The maximum acceleration (the steepest slope of the velocity curve) at the bottom of the cask is higher than that of the top of the cask. The calculated linear peak acceleration of the cask is 60*g* at the center-of-gravity level. The average impact period is about 30 ms, which gives the average impact-period acceleration of the side drop as 45.5*g*. The acceleration results are summarized in Table B7-26. The peak acceleration is obtained from the reaction force history of the cask contact area.

Figure B7-168. MCO Cask 9-m (30-ft) Side-Drop Velocity History at the Bottom of the Cask.

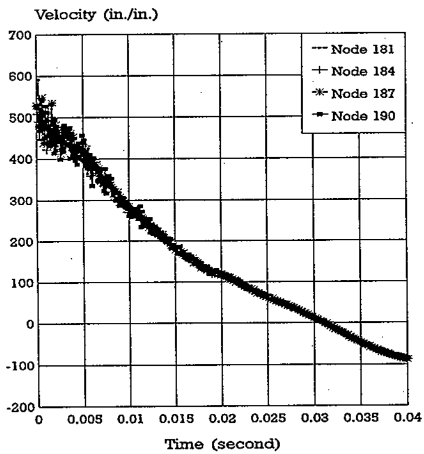


Figure B7-169. MCO Cask 9-m (30-ft) Side-Drop Velocity History at the Cask Center of Gravity.

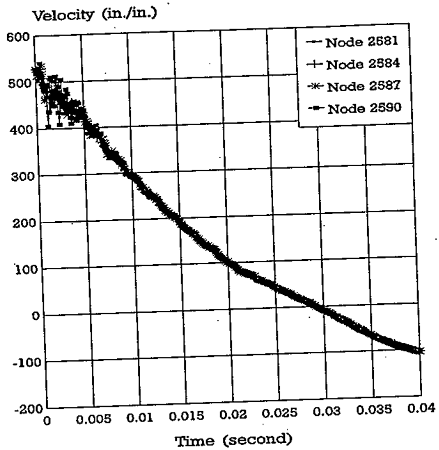


Figure B7-170. MCO Cask 9-m (30-ft) Side-Drop Velocity History at the Flange of the Lid.

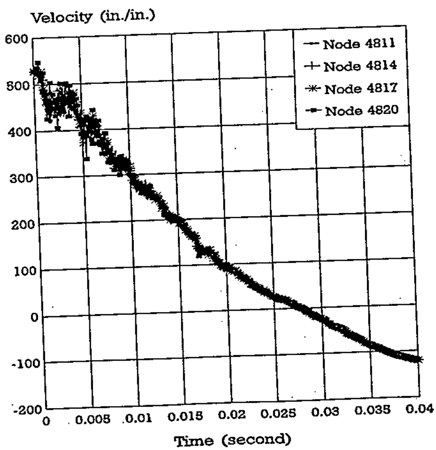


Figure B7-171. MCO Cask 9-m (30-ft) Side-Drop Velocity History at the Top of the Lid.

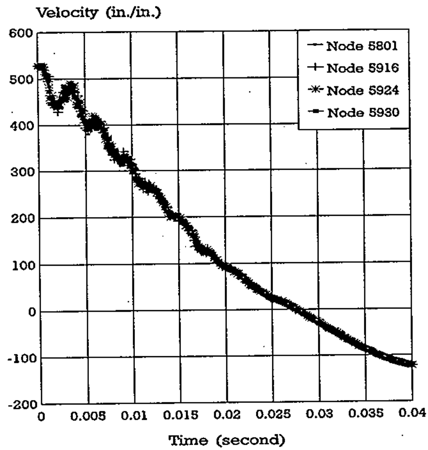


Table B7-26. Impact Acceleration Data of the 9-m (30-ft) Side Drop.

Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
60.0	45.5	177	30.0

Stress Intensity. The estimated average ASME Code stress intensities are shown in Tables B7-27 and B7-28 at the most critical exterior shell and containment boundary locations and at all lid bolts. The highest stress intensity occurs on the exterior of the cask near the drain port cover plate. At the end of impact, the stress intensity at this location is over 317 MPa (46 ksi). Other exterior boundary locations of the cask at the bottom of the drain port also sustain high stresses. However, at the end of the impact, these stresses drop to a level below the yield strength of the material. The containment boundary (interior locations of the cask) stress intensities are well below the yield strength of the cask material. The stress intensity plots at the most critical locations are shown in Figures B7-172 through B7-177. The stress intensity plots of lid bolts are shown in Figures B7-178 through B7-184. The impact produces low stress intensities on the lid bolts compared with the yield strength of lid bolt material.

Table B7-27. Estimated Average ASME Code Stress Intensity at the Bottom Critical Locations from the 9-m (30-ft) Side Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress Intensity MPa (ksi)	Element	Stress Intensity MPa (ksi)	Element	Stress Intensity MPa (ksi)
21336	184.77 (26.77)	614	41.02 (5.95)	9901	129.41 (18.77)
21337	156.1 (22.64)	615	47.02 (6.82)	9902	128.38 (18.62)
21338	98.94 (14.35)	616	68.88 (9.99)	9903	140.72 (20.41)
21339	83.98 (12.18)	21310	54.54 (7.91)	9904	125.21 (18.16)
21340	70.46 (10.22)	21305	50.26 (7.29)	9905	138.52 (20.09)
21341	137.62 (19.96)	21300	78.6 (11.40)	9906	118.52 (17.19)
21342	87.98 (12.76)	21295	65.29 (9.47)	9907	177.26 (25.71)
21343	86.37 (12.60)	21290	53.92 (7.82)		
21344	83.01 (12.04)	21285	50.88 (7.38)		
21345	80.32 (11.65)	21280	51.09 (7.41)		
21311	156.17 (22.65)	21275	41.92 (6.08)		
21316	129.28 (18.75)	21270	57.23 (8.30)		
21346	110.04 (15.96)	20720	94.8 (13.75)		
25030	224.01 (32.49)	20715	57.5 (8.34)		
25029	170.58 (24.74)	20710	70.53 (10.23)		
25022	233.25 (33.83)	20705	73.36 (10.64)		
25021	205.6 (29.82)	20695	98.18 (14.24)		
25020	319.92 (46.40)	20690	70.4 (10.21)		
25019	199.67 (28.96)	20685	73.77 (10.70)		
25012	167.4 (24.28)	20680	66.95 (9.71)		
25011	226.22 (32.81)	20160	91.77 (13.31)		
25010	257.04 (37.28)	20159	77.2 (11.20)		
25009	238.21 (34.55)	20158	77.36 (11.22)		
25002	223.6 (32.43)	20157	62.47 (9.06)		
25001	257.8 (37.39)	20110	90.74 (13.16)		
		20109	87.29 (12.66)		
		20108	54.88 (7.96)		
		20107	65.36 (9.48)		
		20106	52.95 (7.68)		

Average stress intensity (SI) = larger of the half of peak SI or the SI at the end of impact period.

Table B7-28. Estimated Average ASME Code Stress Intensity at the Top Critical Locations from the 9-m (30-ft) Side Drop.

Cask Body/Lid				Lid Bolt	
Exterior		Containment Boundary			
Element	Stress Intensity MPa (ksi)	Element	Stress Intensity MPa (ksi)	Element	Stress Intensity MPa (ksi)
5664	81.29 (11.79)	4078	86.6 (12.56)	----	----
5678	50.54 (7.33)	4079	86.39 (12.53)		
5064	39.85 (5.78)	5050	54.47 (7.90)		
5078	71.15 (10.32)	3650	79.22 (11.49)		
5650	43.3 (6.28)	3651	67.78 (9.83)		
		3652	67.22 (9.75)		
		3450	50.81 (7.37)		

Average stress intensity (SI) = larger of the half of peak SI or the SI at the end of impact period.

Figure B7-172. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Interior of the Cask Wall (EL 20695).

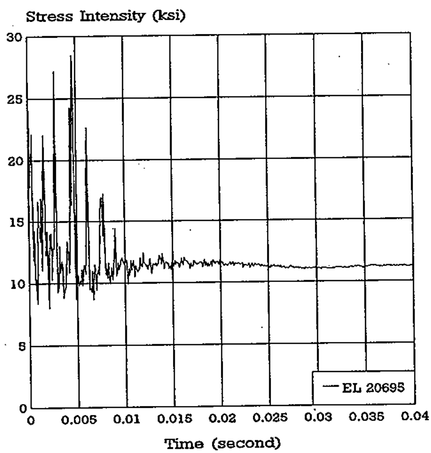


Figure B7-173. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Interior of the Cask Bottom (EL 616).

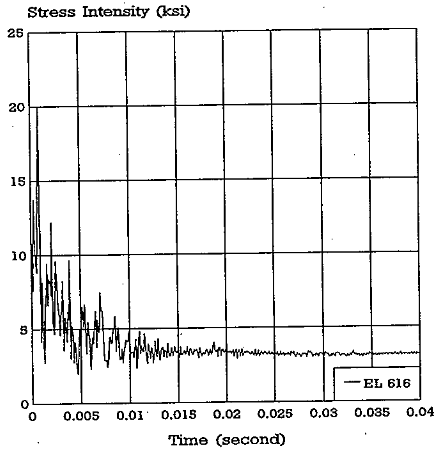


Figure B7-174. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Exterior of the Cask (EL 21311).

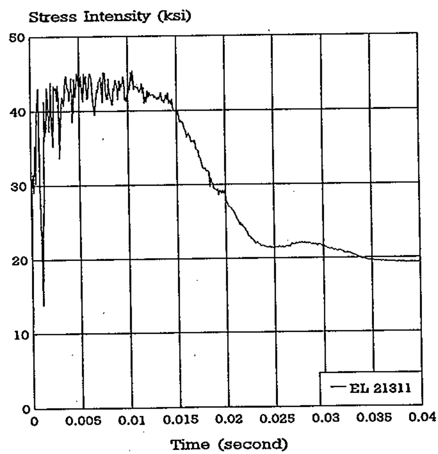


Figure B7-175. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Drain Port Cover Plate (EL 25020).

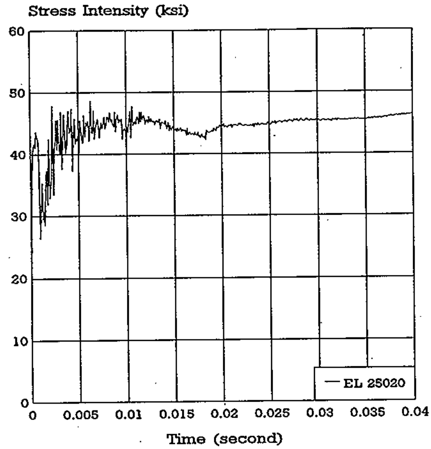


Figure B7-176. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Interior of the Lid (EL 4078).

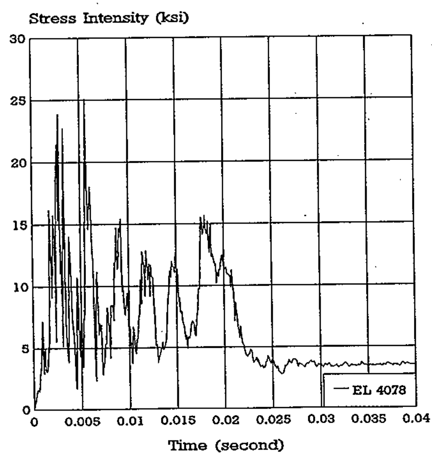


Figure B7-177. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at the Exterior of the Lid (EL 5664).

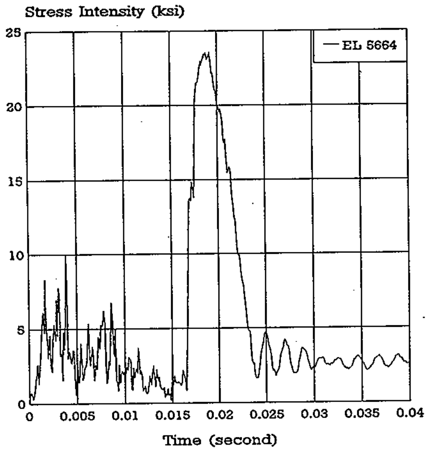


Figure B7-178. MCO Cask 9-m (30-ft) Side Drop Stress Intensity History at Bolt No. 1 (EL 9901).

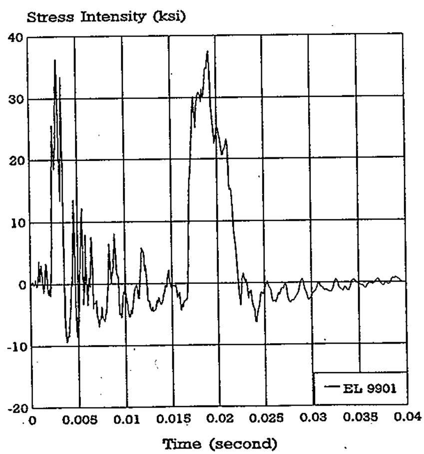


Figure B7-179. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

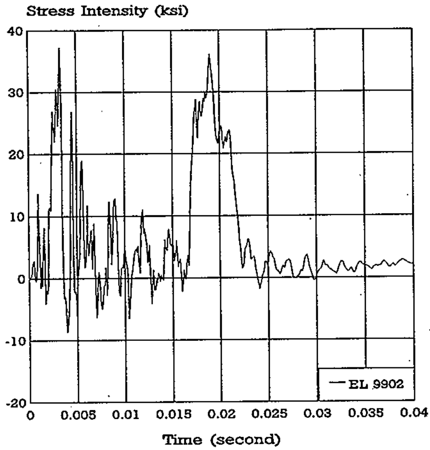


Figure B7-180. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

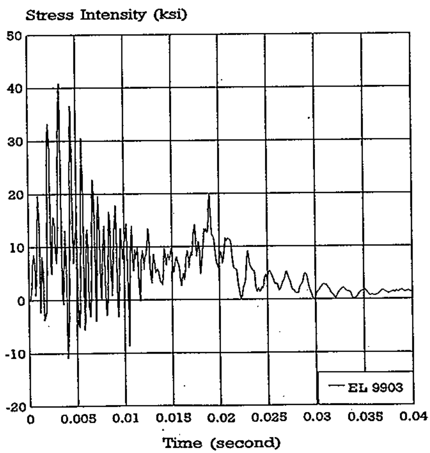


Figure B7-181. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

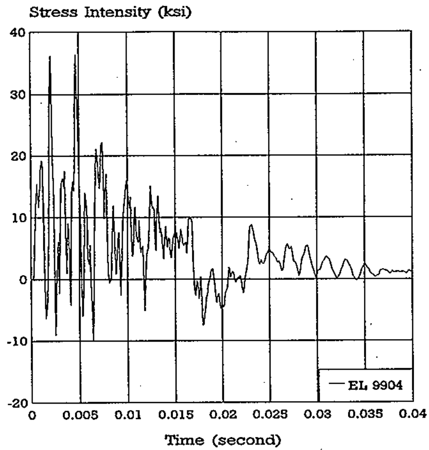


Figure B7-182. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

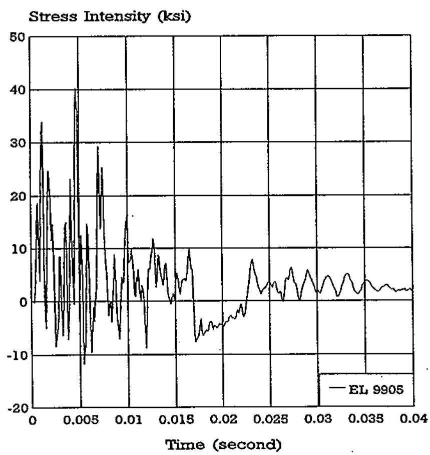


Figure B7-183. MCO Cask 9-m (30-ft) Side-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

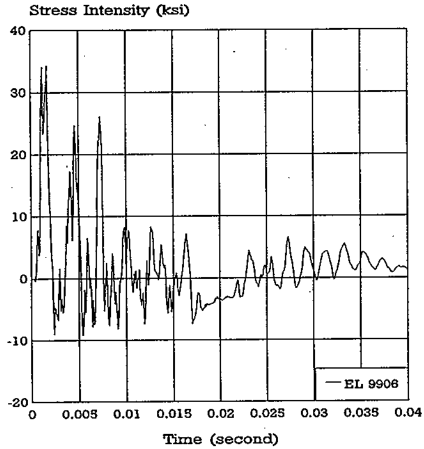
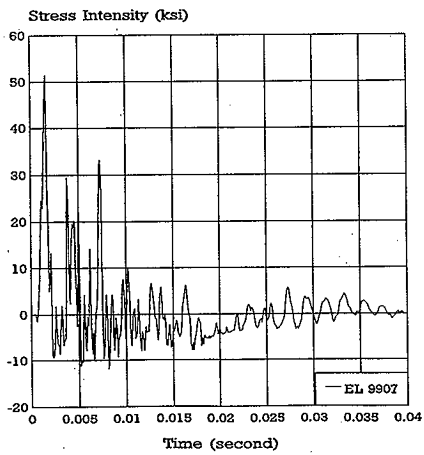


Figure B7-184. MCO Cask 9-m (30-ft) Side Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Tables B7-29 and B7-30 at the bottom portion and top portion of the cask, respectively. The accumulated strains reported in the tables are the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of strain of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-185 through B7-190. The largest overall accumulated strain of the entire cask is approximately 9.6% at the drain port cover plate (Figure B7-188). The largest accumulated strain of the cask exterior is about 7.1% at the bottom of the drain port (Figure B7-187). However, the largest accumulated strain of the containment boundary of the cask/lid is only 0.61%, occurring near the drain port region (Figure B7-185).

The strain plots of lid bolts are shown in Figures B7-191 through B7-197. The accumulated strains of the lid bolts are inconsequential, about 0.1% during this 9-m (30-ft) side drop.

Table B7-29. Accumulated Strains at the Bottom Critical Locations from the 9-m (30-ft) Side Drop.

Cask body/lid				Lid Bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
21336	0.02340	614	0.00246	9901	0.00129
21337	0.01465	615	0.00269	9902	0.00128
21338	0.00624	616	0.00206	9903	0.00141
21339	0.00295	21310	0.00416	9904	0.00125
21340	0.00270	21305	0.00356	9905	0.00139
21341	0.00371	21300	0.00440	9906	0.00119
21342	0.00205	21295	0.00541	9907	0.00177
21343	0.00290	21290	0.00398		
21344	0.00294	21285	0.00199		
21345	0.00275	21280	0.00068		
21311	0.07104	21275	0.00056		
21316	0.00913	21270	0.00231		
21346	0.00443	20720	0.00418		
25030	0.09618	20715	0.00076		
25029	0.03752	20710	0.00169		
25022	0.01649	20705	0.00234		
25021	0.07841	20695	0.00614		
25020	0.08656	20690	0.00224		
25019	0.04745	20685	0.00271		
25012	0.03147	20680	0.00234		
25011	0.06366	20160	0.00417		
25010	0.08662	20159	0.00244		
25009	0.05680	20158	0.00240		
25002	0.05869	20157	0.00189		
25001	0.04130	20110	0.00317		
		20109	0.00114		
		20108	0.00100		
		20107	0.00103		
		20106	0.00087		

Table B7-30. Accumulated Strains at the Top Critical Locations from the 9-m (30-ft) Side Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
5664	0.00133	4078	0.00149	----	----
5678	0.00067	4079	0.00118		
5064	0.00053	5050	0.00073		
5078	0.00095	3650	0.00106		
5650	0.00058	3651	0.00090		
		3652	0.00090		
		3450	0.00068		

Figure B7-185. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Interior of the Cask Wall (EL 20695).

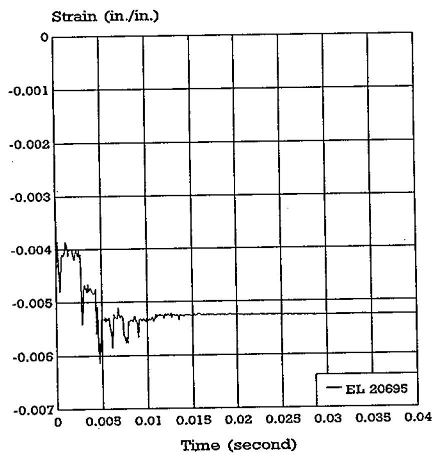


Figure B7-186. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Interior of the Cask Bottom (EL 615).

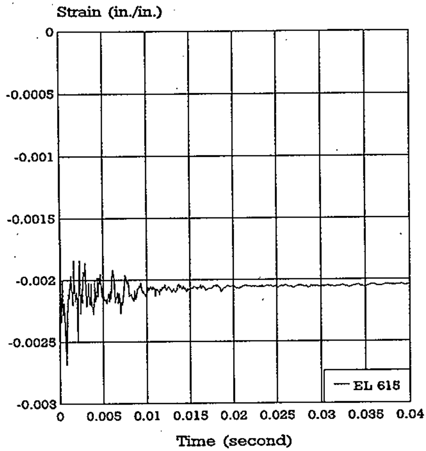


Figure B7-187. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Exterior of the Cask (EL 21311).

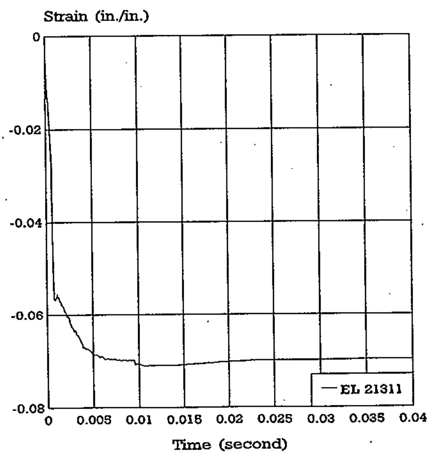


Figure B7-188. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Drain Port Cover Plate (EL 25030).

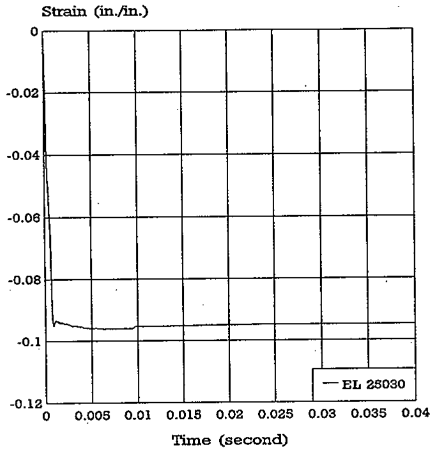


Figure B7-189. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Interior of the Lid (EL 4078).

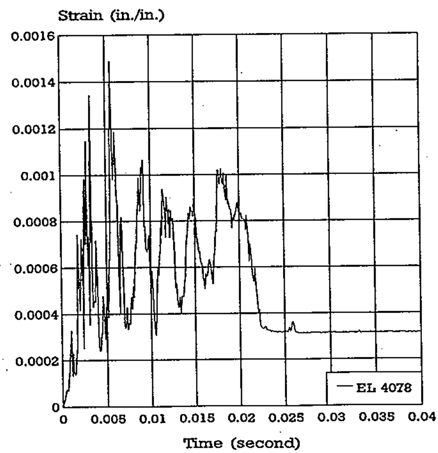


Figure B7-190. MCO Cask 9-m (30-ft) Side-Drop Strain History at the Exterior of the Lid (EL 5664).

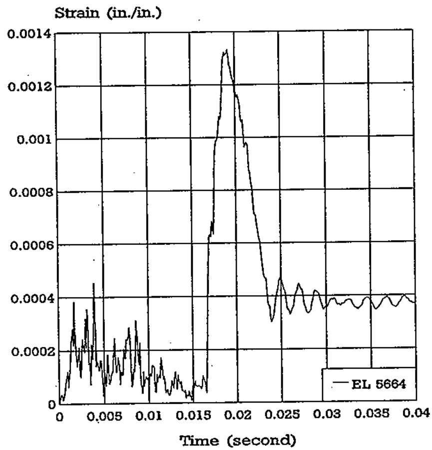


Figure B7-191. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 1 (EL 9901).

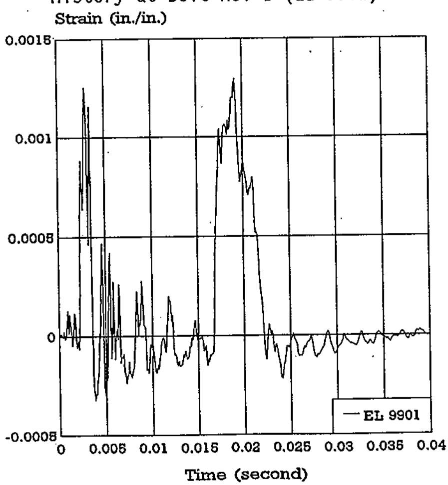


Figure B7-192. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 1 (EL 9901).

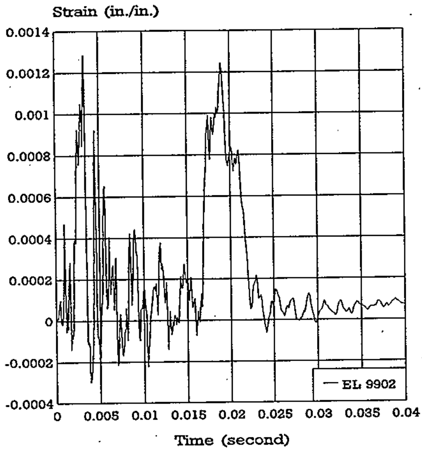


Figure B7-193. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 3 (EL 9903).

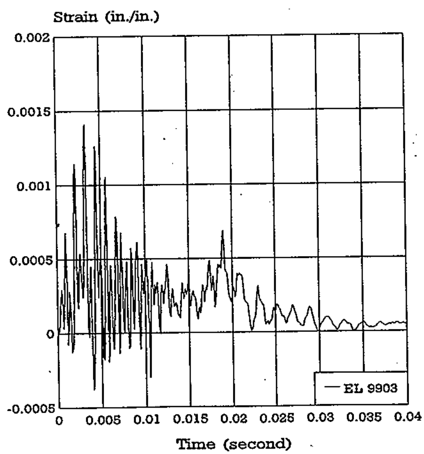


Figure B7-194. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 4 (EL 9904).

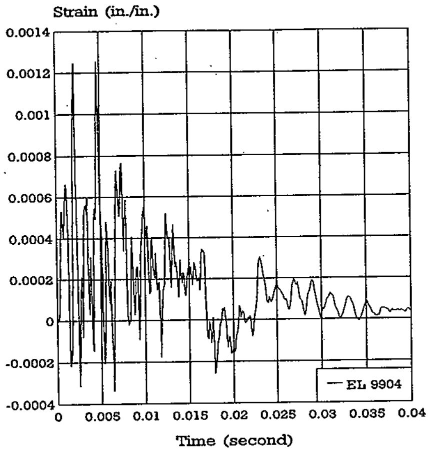


Figure B7-195. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 5 (EL 9905).

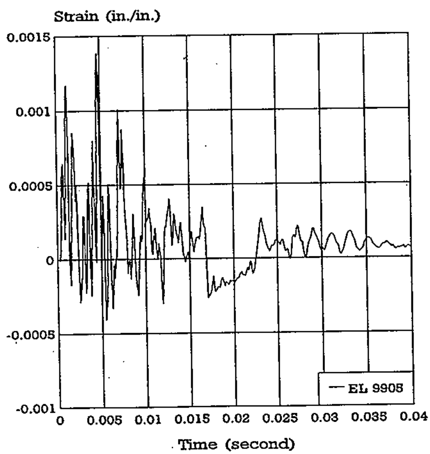


Figure B7-196. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 6 (EL 9906).

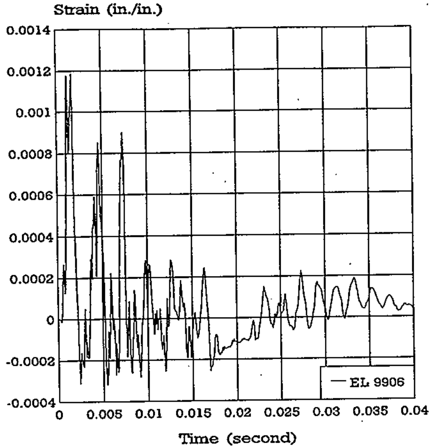
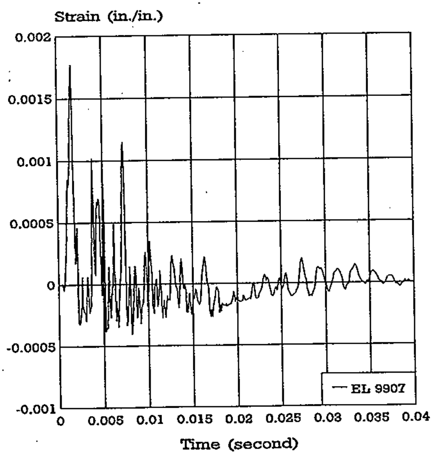


Figure B7-197. MCO Cask 9-m (30-ft) Side-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. Since the drain port cover plate is recessed into the cask, the cover plate is not subjected to large impact forces. The maximum predicted resultant force in the vicinity of the drain port cover plate area is 435,916 N (98,000 lb [Figure B7-198]). The estimated average force is 217,958 N (49,000 lb).

Figure B7-198. MCO Cask 9-m (30-ft) Side-Drop Force at Drain Port Cover Plate.

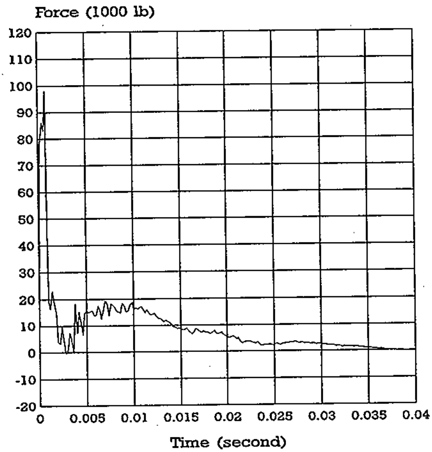
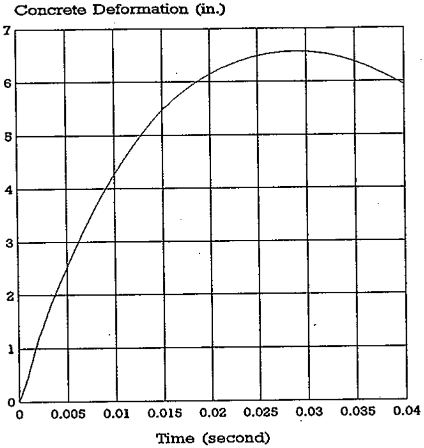


Figure B7-199 shows the concrete displacement of about 16.8 cm (6.6 in.) at the cask impact point. The concrete pad is not totally penetrated in this drop case.

Figure B7-199. MCO Cask 9-m (30-ft) Side-Drop Concrete Deformation Depth.



7.3.4.3.4 9-m (30-ft) Top-End Oblique Drop. This case is to evaluate MCO Cask performance for a 9-m (30-ft) top-end oblique drop onto a 20-cm (8-in.) concrete target. In this case only one trunnion/bracket impacts the concrete target initially, and the center of gravity of the cask assembly is over the impact point.

The top end oblique drop has an irregularly shaped impact area, which consists of trunnions, brackets, and some portion of the lid top. This complex configuration of the impact area results in numerical instabilities beyond a 50-ms drop duration. The unfiltered acceleration data is presented in Figure B7-200. When frequencies higher than 1000 Hz are filtered out, the peak acceleration is found at 19.9*g* (Figure B7-201).

Figure B7-200. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Acceleration History (Unfiltered).

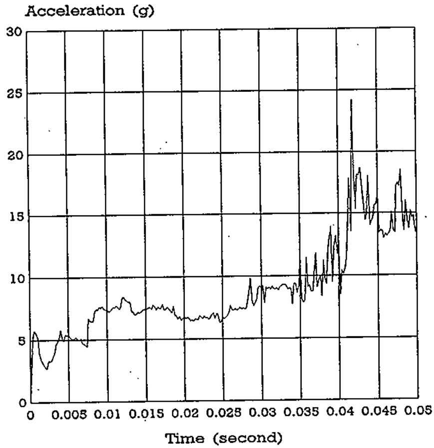
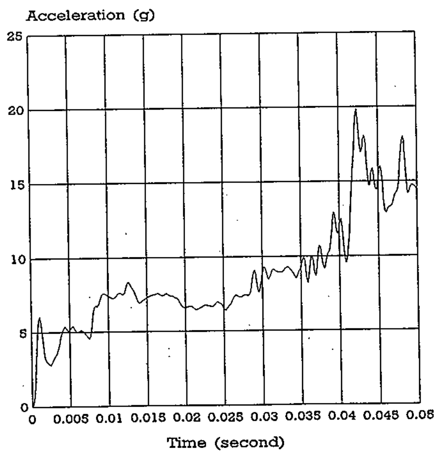


Figure B7-201. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Acceleration History (Filtered at 1000 Hz).



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of the lid are shown in Figures B7-202 through B7-204, respectively. At the center of gravity, the data points are the 0° point, 90° point, and 180° point from the drain port in the circumferential direction. The data points at the bottom of the cask and the top of the lid are at the center of the plate, 0° point, 90° point, and 180° point from the drain port in the circumferential direction. Because the run was stopped at 50 ms, it is impossible to predict the impact period of this drop based on the available data. However, the maximum acceleration (steepest slope of velocity curve) within this 50-ms period is about 26*g*. The experience from other drop analyses indicates a higher acceleration will come at a later stage, but may not be much higher than this. The acceleration results are shown in Table B7-31. The peak acceleration is based on the reaction force history of the cask contact area as mentioned above.

Figure B7-202. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Velocity History at the Bottom of Cask.

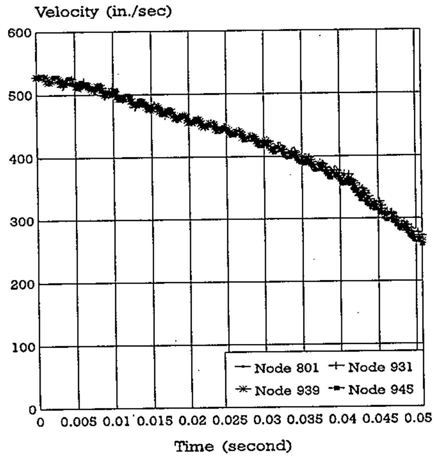


Figure B7-203. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Velocity History at Center-of-Gravity Level of Cask.

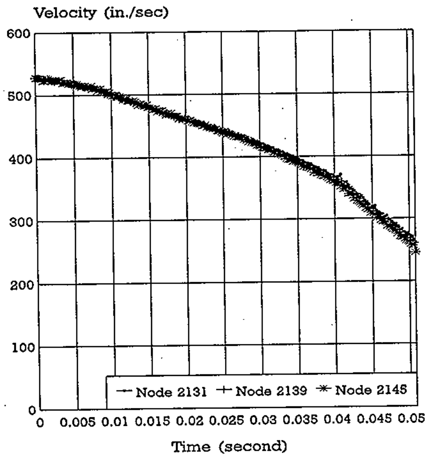


Figure B7-204. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Velocity History at the Top of the Lid.

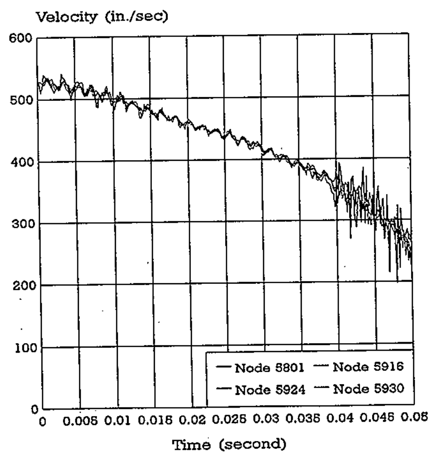


Table B7-31. Impact Acceleration Data of the 9-m (30-ft) Top-End Oblique Drop.

Linear Peak Acceleration (*g*)	Average Impact-Period Acceleration (*g*)	Peak Acceleration (*g*)	Impact Period (ms)
> 26	NA	19.9	NA

Stress Intensity. The stress intensity plots at the most critical locations are shown in Figures B7-205 through B7-210. In this 9-m (30-ft) top-end oblique drop, the highest stress intensity on the containment boundary occurs at the shear key near the impact edge at a stress level of 103 MPa (14,960 psi [Figure B7-208]). The adjacent cask wall and the mating lid surface stresses are lower at 74.8 MPa (10,830 psi) and 69.1 MPa (10,060 psi), respectively (Figures B7-209 and B7-207). At the exterior surface, the maximum stress intensity is approximately 69.3 MPa (10,450 psi). The stress intensity plots of lid bolts are shown in Figures B7-211 through B7-217, from which the average stress intensity is assumed to be half of the peak stress intensity. The impact of this drop produces the highest average stress intensity of the lid bolts at 55.2 MPa (8,000 psi) for the bolt farthest from the impact point. The stress intensities at the most critical locations are shown below in Table B7-32.

Figure B7-205. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Interior of the Lid (EL 5218).

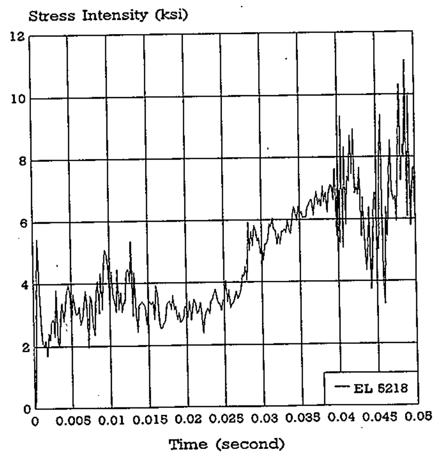


Figure B7-206. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Interior Lid Wall (EL 4450).

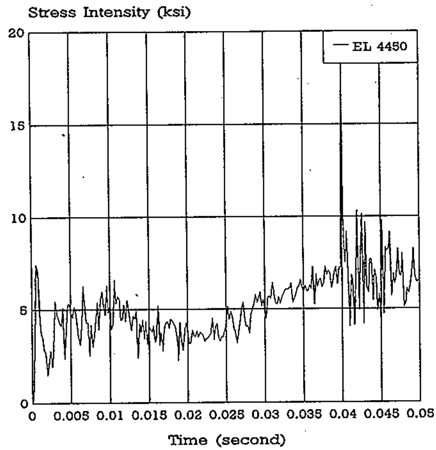


Figure B7-207. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Interior of the Flange (EL 4080).

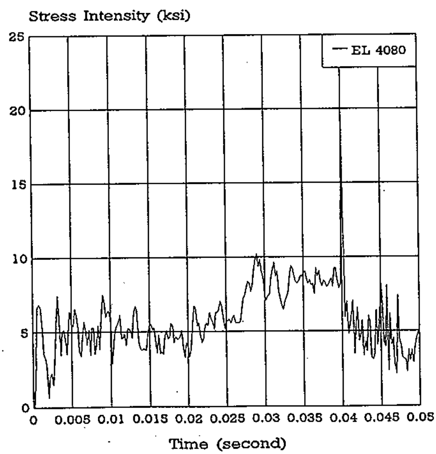


Figure B7-208. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Shear Key (EL 3652).

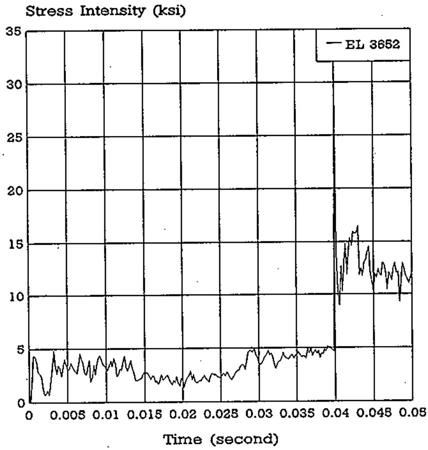


Figure B7-209. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Interior of the Cask Wall (EL 3453).

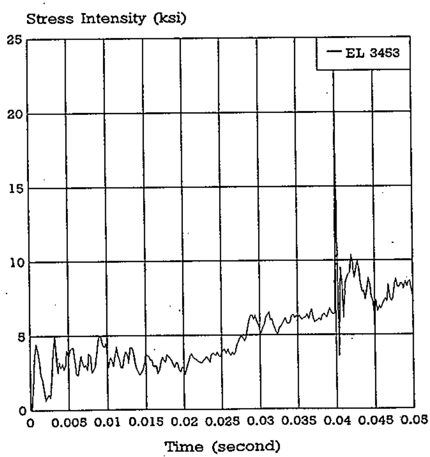


Figure B7-210. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at the Exterior of the Lid (EL 5664).

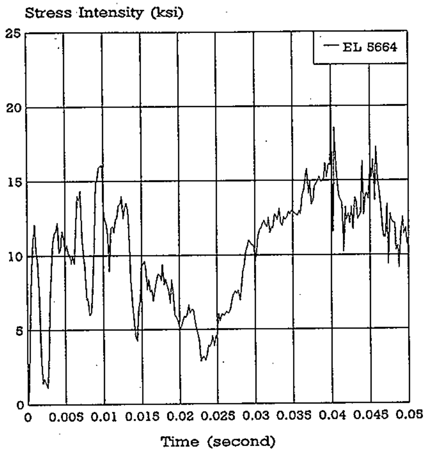


Figure B7-211. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

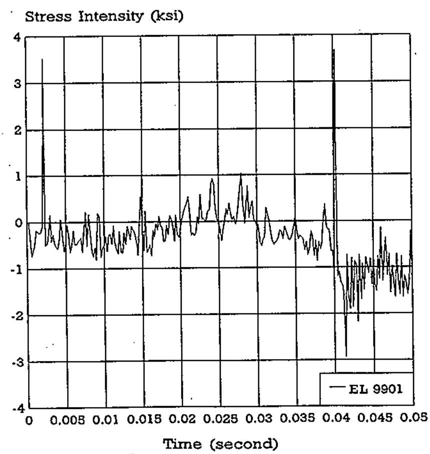


Figure B7-212. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

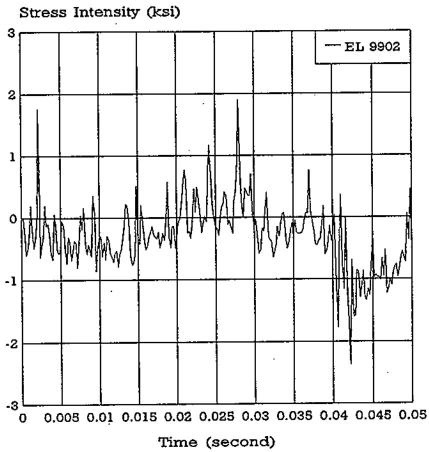


Figure B7-213. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

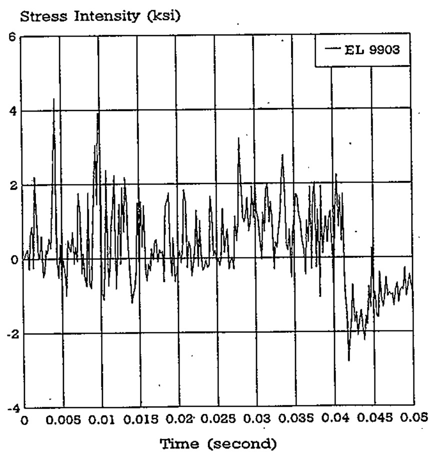


Figure B7-214. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

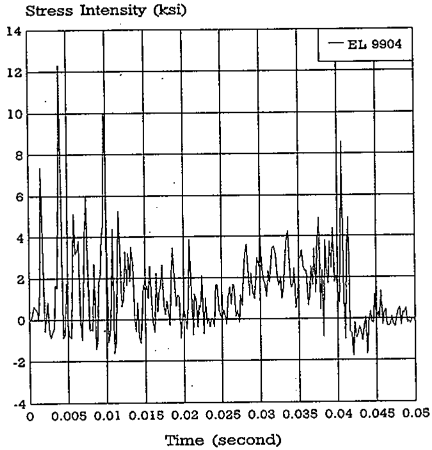


Figure B7-215. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

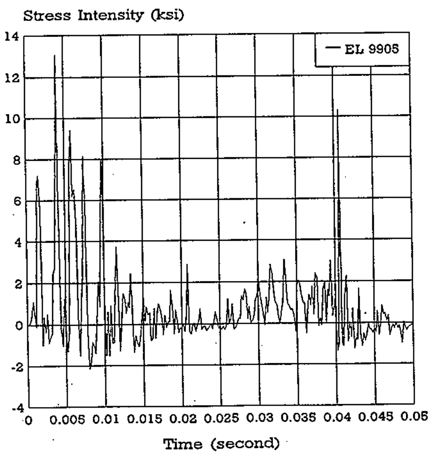


Figure B7-216. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

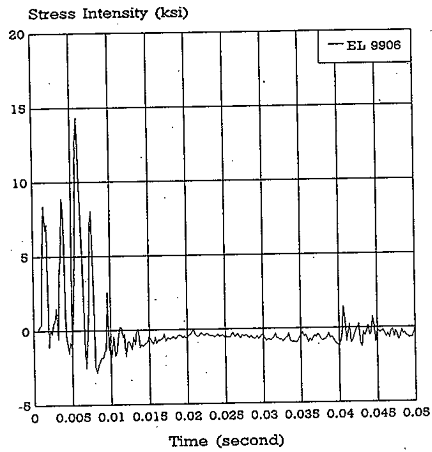


Figure B7-217. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 7 (EL 9907).

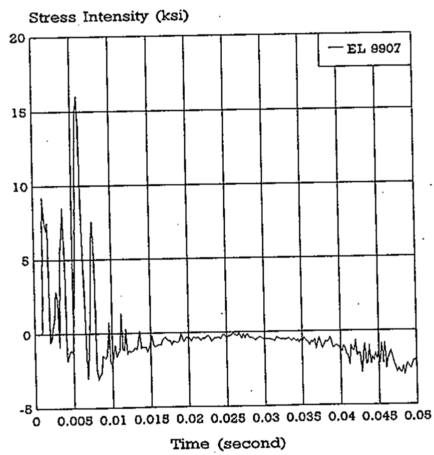


Table B7-32. Estimated Average ASME Code Stress Intensity at the Critical Locations from the 9-m (30-ft) Top-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
5650	39,92 (5.79)	5214	35.71 (5.18)	9901	12.69 (1.84)
5664	72.05 (10.45)	5215	33.58 (4.87)	9902	6.55 (0.95)
5678	46.33 (6.72)	5216	36.54 (5.30)	9903	14.89(2.16)
5450	43.57 (6.32)	5217	34.82 (5.05)	9904	42.4 (6.15)
5464	66.95 (9.71)	5218	38.27 (5.55)	9905	45.02 (6.53)
5478	67.91 (9.85)	5250	54.88 (7.96)	9906	49.37 (7.16)
5264	48.33 (7.01)	5251	49.92 (7.24)	9907	55.16 (8.00)
5278	57.71 (8.37)	5252	47.71 (6.92)		
5064	49.23 (7.14)	5253	43.02 (6.24)		
5078	62.6 (9.08)	5050	42.75 (6.20)		
		5051	36.82 (5.34)		
		5052	35.03 (5.08)		
		5053	31.92 (4.63)		
		4850	47.64 (6.91)		
		4851	37.85 (5.49)		
		4852	29.44 (4.27)		
		4853	36.4 (5.28)		
		4650	49.85 (7.23)		
		4651	35.85 (5.20)		
		4652	32.47 (4.71)		
		4653	35.51 (5.15)		
		4450	65.35 (9.48)		
		4451	47.57 (6.90)		
		4452	57.43 (8.33)		
		4453	41.58 (6.03)		
		4250	47.99 (6.96)		
		4251	36.89 (5.35)		
		4252	52.06 (7.55)		
		4253	48.33 (7.01)		
		4078	49.23 (7.14)		
		4079	47.78 (6.93)		
		4080	69.36 (10.06)		
		4081	42.06 (6.10)		
		3650	60.81 (8.82)		
		3651	98.87 (14.34)		
		3652	103.15 (14.96)		
		3450	53.02 (7.69)		
		3451	71.08 (10.31)		
		3452	66.88 (9.70)		
		3453	74.67 (10.83)		

Average stress intensity (SI) = larger of the half of peak SI or the SI at the end of impact period.

Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-33. The accumulated strains reported herein are the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of strain of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-218 through B7-223. The strain plots of lid bolts are shown in Figures B7-224 through B7-230. In the 50-ms period, all accumulated strains in this case are negligible, with the largest one of about 0.4% at the shear key (Figure B7-221).

Table B7-33. Accumulated Strains at the Critical Locations from the 9-m (30-ft) Top-End Oblique Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
5650	0.00053	5214	0.00048	9901	0.00013
5664	0.00096	5215	0.00045	9902	0.00007
5678	0.00062	5216	0.00049	9903	0.00015
5450	0.00058	5217	0.00046	9904	0.00042
5464	0.00089	5218	0.00051	9905	0.00045
5478	0.00091	5250	0.00073	9906	0.00049
5264	0.00064	5251	0.00067	9907	0.00055
5278	0.00077	5252	0.00064		
5064	0.00066	5253	0.00057		
5078	0.00083	5050	0.00057		
		5051	0.00049		
		5052	0.00047		
		5053	0.00043		
		4850	0.00063		
		4851	0.00050		
		4852	0.00039		
		4853	0.00048		
		4650	0.00066		
		4651	0.00048		
		4652	0.00043		
		4653	0.00047		
		4450	0.00087		
		4451	0.00070		
		4452	0.00077		
		4453	0.00055		
		4250	0.00064		
		4251	NA		
		4252	NA		
		4253	0.00081		
		4078	0.00066		
		4079	0.00064		
		4080	0.00092		
		4081	0.00056		
		3650	0.00089		
		3651	0.00338		
		3652	0.00421		
		3450	0.00071		
		3451	0.00182		
		3452	0.00165		
		3453	0.00109		

Figure B7-218. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Interior of the Lid (EL 5218).

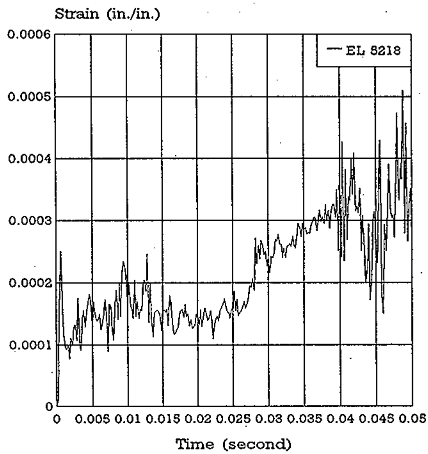


Figure B7-219. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Interior Lid Wall (EL 4450).

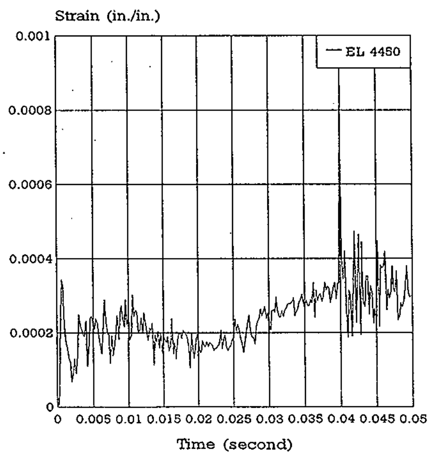


Figure B7-220. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Interior of the Flange (EL 4080).

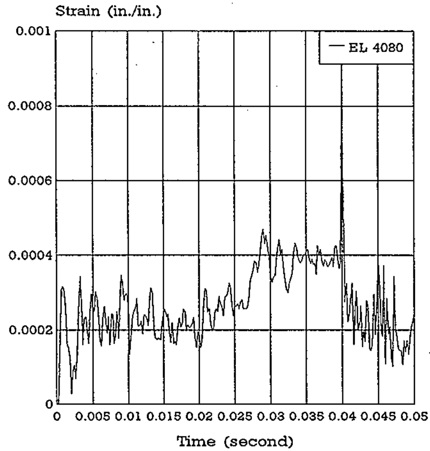


Figure B7-221. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Shear Key (EL 3652).

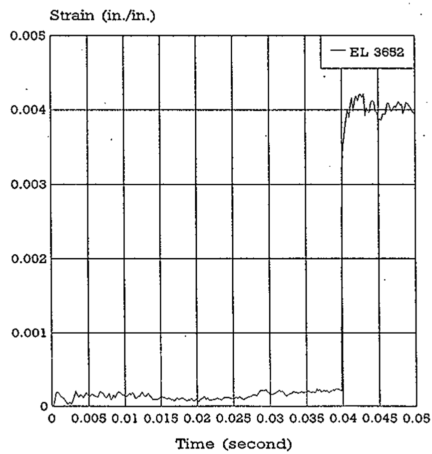


Figure B7-222. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Interior of the Cask Wall (EL 3451).

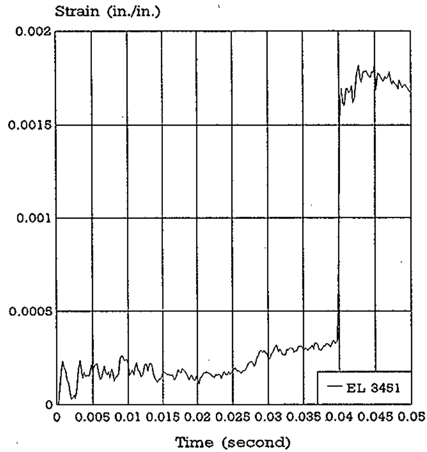


Figure B7-223. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at the Exterior of the Lid (EL 5664).

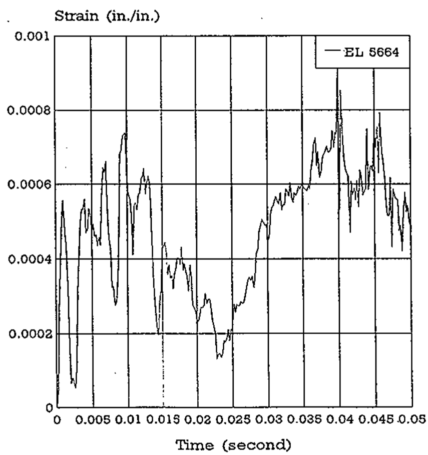


Figure B7-224. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 1 (EL 9901).

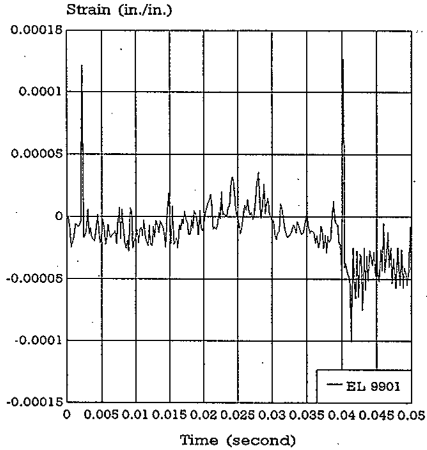


Figure B7-225. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 2 (EL 9902).

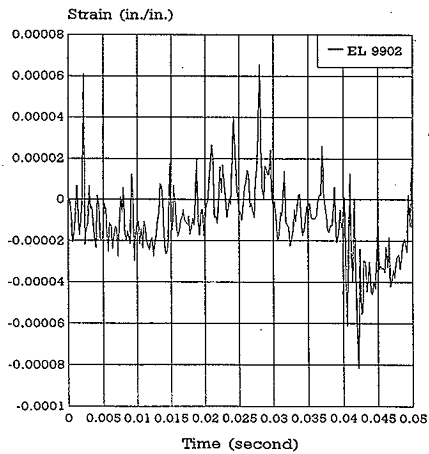


Figure B7-226. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 3 (EL 9903).

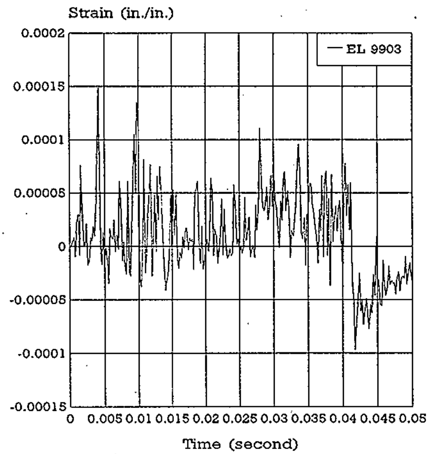


Figure B7-227. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

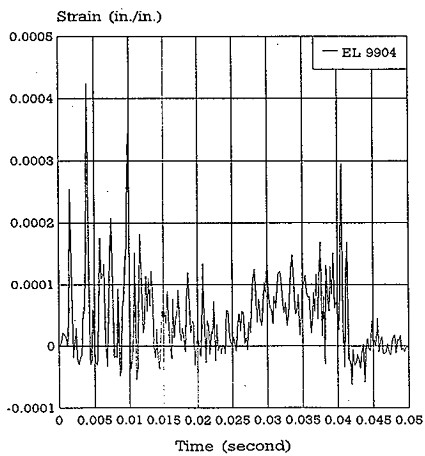


Figure B7-228. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 5 (EL 9905).

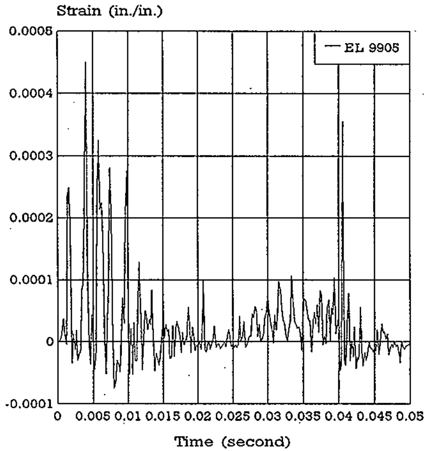


Figure B7-229. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 6 (EL 9906).

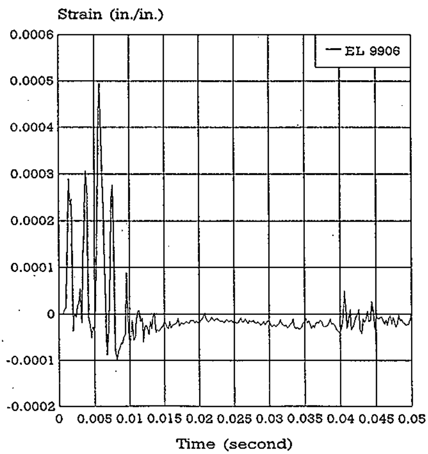
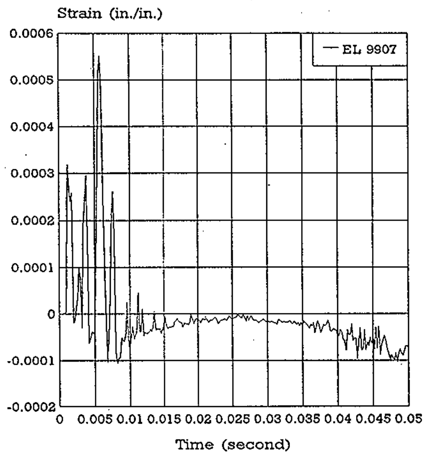


Figure B7-230. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. Figure B7-231 shows the concrete displacement of more than 45.7 cm (18 in. [total penetration]) at the trunnion impact point.

7.3.4.3.5 9-m (30-ft) Top-End Flat Drop. This case is to evaluate the MCO Cask accident conditions of a 9-m (30-ft) top-end flat drop onto a 20-cm- (8-in.-) thick concrete target. In this case, both trunnions/brackets impact the concrete target at the same time. The top-end flat drop has an irregularly shaped impact area, consisting of trunnions, brackets, and a portion of the lid top. As with the top end oblique drop, this complex configuration can cause some numerical instability. The drop results in a peak acceleration of 21.95*g* for the unfiltered history (Figure B7-232) and 21.3*g* after filtering out forces with frequencies higher than 1,000 Hz (Figure B7-233).

Figure B7-231. MCO Cask 9-m (30-ft) Top-End Oblique-Drop Concrete Deformation Depth.

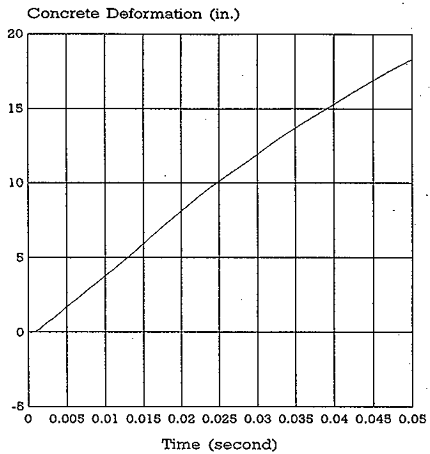


Figure B7-232. MCO Cask 9-m (30-ft) Top-End Flat-Drop Acceleration History (Unfiltered).

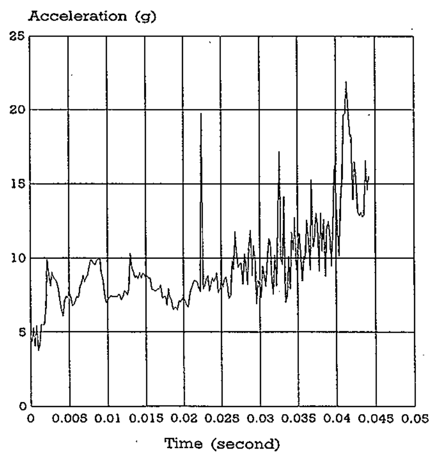
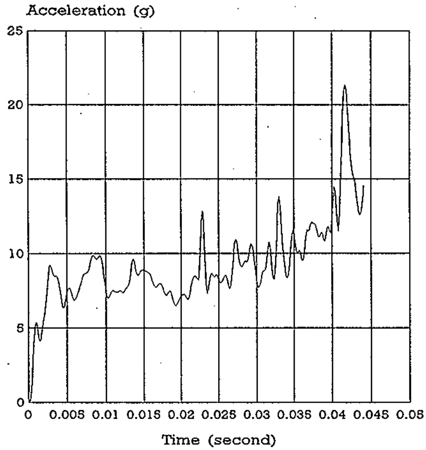


Figure B7-233. MCO Cask 9-m (30-ft) Top-End Flat-Drop Acceleration History (Filtered at 1000 Hz).



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of the lid are shown in Figures B7-234 through B7-236, respectively. At the center-of-gravity elevation, the data points are the 0° point, 90° point, and 180° point from the drain port in the circumferential direction. The data points at the bottom-of-cask and the top-of-lid elevations are at the center of the plate, 0° point, 90° point, and 180° point from the drain port in the circumferential direction. Since the run is shortened at 44.2 ms, the maximum linear peak acceleration is determined by using the steepest slope of the velocity curve, which indicates a value of 23.7*g*. The acceleration results are shown in Table B7-34. The peak acceleration is obtained from the reaction force history of the cask contact area.

Figure B7-234. MCO Cask 9-m (30-ft) Top-End Flat-Drop Velocity History at the Bottom of the Cask.

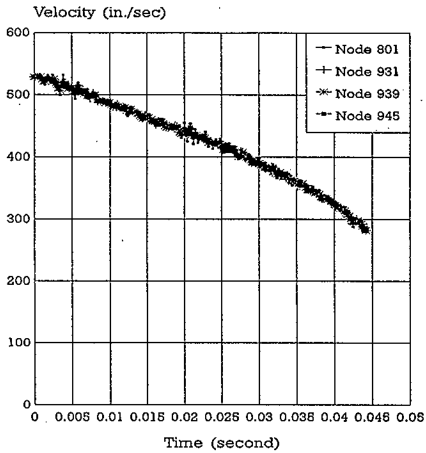


Figure B7-235. MCO Cask 9-m (30-ft) Top-End Flat-Drop Velocity History at the Center of Gravity of the Cask.

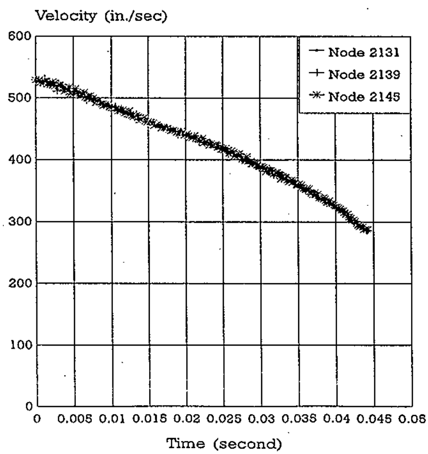


Figure B7-236. MCO Cask 9-m (30-ft) Top-End Flat-Drop Velocity History at the Top of the Lid.

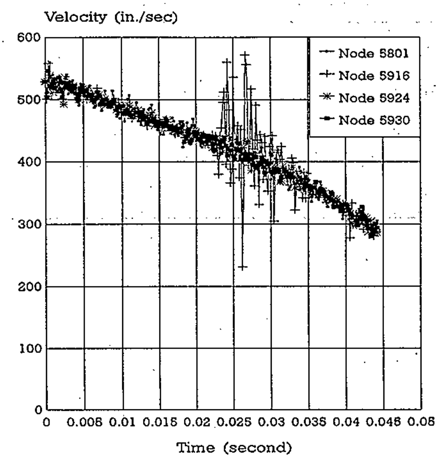


Table B7-34. Impact Acceleration Data of the 9-m (30-ft) Top-End Flat Drop.

Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
23.7	NA	21.3	NA

Stress Intensity. In this case the impact duration cannot be defined due to the shortened run time. Consequently, the estimated average stress intensity is conservatively taken as half of the maximum peak stress intensity. Table B7-35 shows the estimated average stress intensities at the most critical exterior shell and containment boundary locations and at all lid bolts. The highest stress intensity occurs at the exterior of the lid with a value of 119.3 MPa (17,300 psi). The containment boundary stresses are well below this value. The stress intensity plots at the most critical locations are shown in Figures B7-237 through B7-242. The stress intensity plots of lid bolts are shown in Figures B7-243 through B7-249. The impact of this drop produces negligible tensile stresses in the lid bolts.

Table B7-35. Estimated Average ASME Code Stress Intensity at the Bottom Critical Locations from the 9-m (30-ft) Top-End Flat Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)	Element	Stress intensity MPa (ksi)
5650	47.44 (6.88)	5214	44.13 (6.40)	9901	8.83 (1.28)
5664	64.47 (9.35)	5215	35.58 (5.16)	9902	10.41 (1.51)
5678	72.33 (10.49)	5216	34.68 (5.03)	9903	22.13 (3.21)
5450	70.95 (10.29)	5217	37.65 (5.46)	9904	40.33 (5.85)
5464	70.46 (10.22)	5218	32.41 (4.70)	9905	27.37 (3.97)
5478	69.84 (10.13)	5050	56.95 (8.26)	9906	19.17 (2.78)
5264	45.09 (6.54)	5051	65.5 (9.50)	9907	22.75 (3.30)
5278	57.16 (8.29)	5052	57.43 (8.33)		
5064	71.08 (10.31)	5053	49.85 (7.23)		
5078	119.49 (17.33)	4850	70.81 (10.27)		
		4851	65.16 (9.45)		
		4852	43.09 (6.25)		
		4853	34.61 (5.02)		
		4650	48.75 (7.07)		
		4651	48.75 (6.49)		
		4652	45.09 (6.54)		
		4653	28.17 (4.17)		
		4450	50.95 (7.39)		
		4451	35.99 (5.22)		
		4452	28.34 (4.11)		
		4453	23.51 (3.41)		
		4250	39.3 (5.70)		
		4251	39.51 (5.73)		
		4252	38.54 (5.59)		
		4253	27.85 (4.04)		
		4264	36.2 (5.25)		
		4265	39.44 (5.72)		
		4266	38.54 (5.59)		
		4267	30.34 (4.40)		
		3661	17.93 (2.60)		
		3662	20.68 (3.00)		
		3663	20.27 (2.94)		
		3450	21.89 (3.16)		
		3451	22.89 (3.32)		
		3452	21.93 (3.18)		
		3453	19.17 (2.78)		

Average stress intensity (SI) = larger of the half of peak SI.

Figure B7-237. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Interior of the Lid Plate (EL 5214).

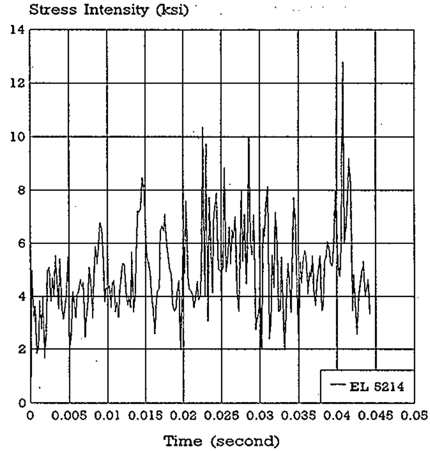


Figure B7-238. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Interior Lid Wall (EL 4850).

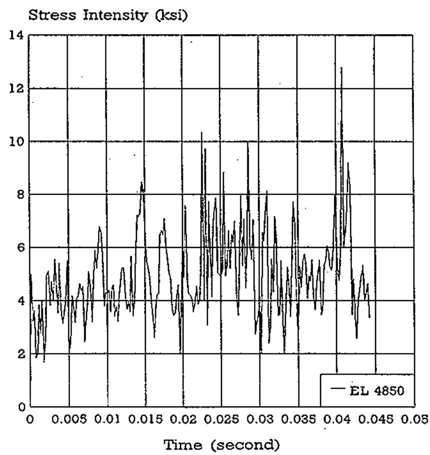


Figure B7-239. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Interior of the Lid Flange (EL 4265).

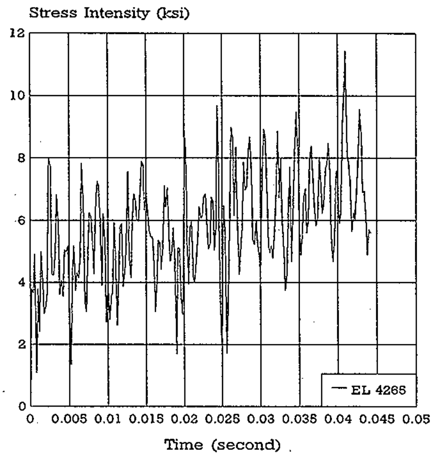


Figure B7-240. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Shear Key (EL 3662).

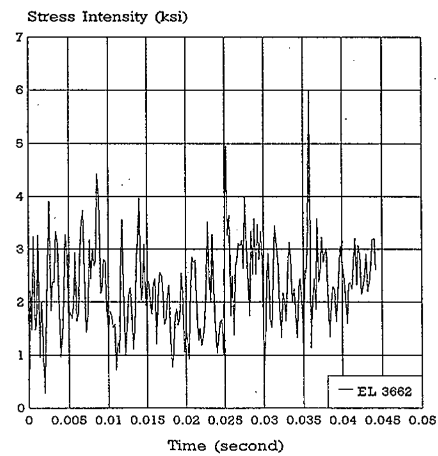


Figure B7-241. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Interior of the Cask Wall (EL 3451).

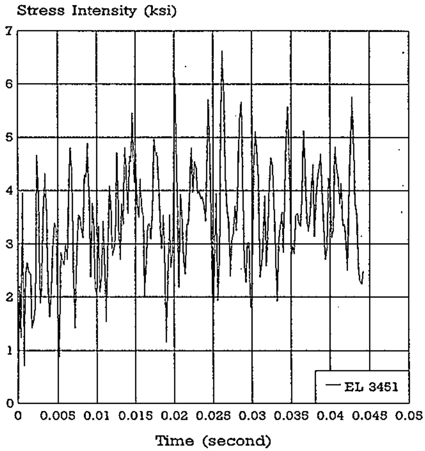


Figure B7-242. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at the Exterior of the Lid (EL 5078).

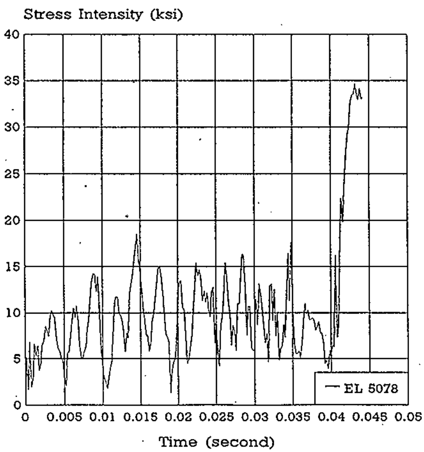


Figure B7-243. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

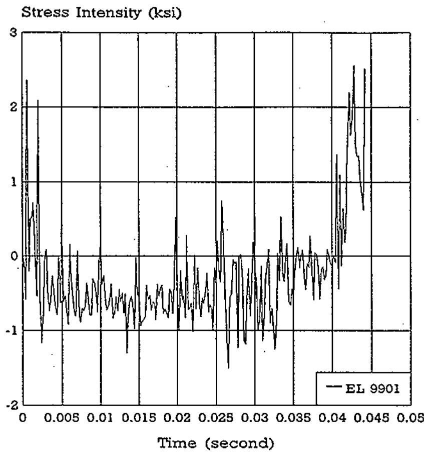


Figure B7-244. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

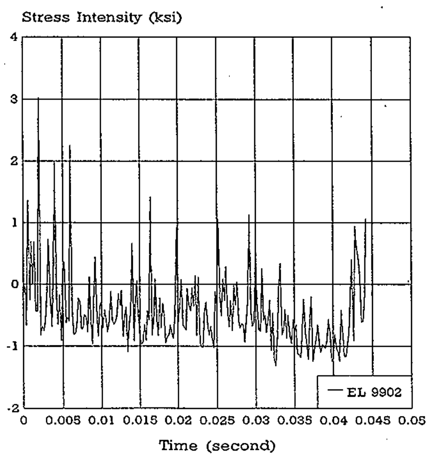


Figure B7-245. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

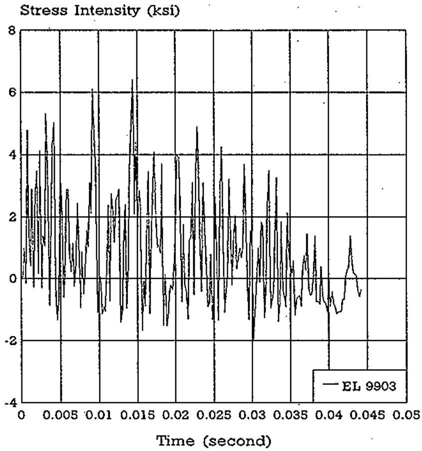


Figure B7-246. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

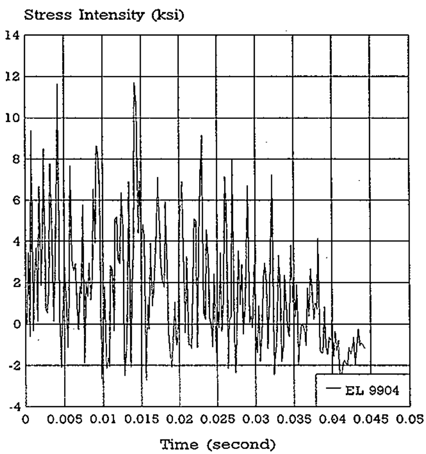


Figure B7-247. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

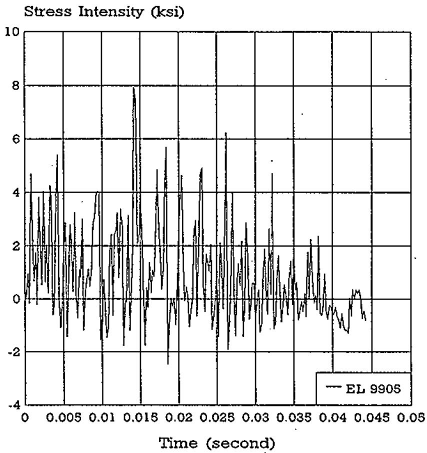


Figure B7-248. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

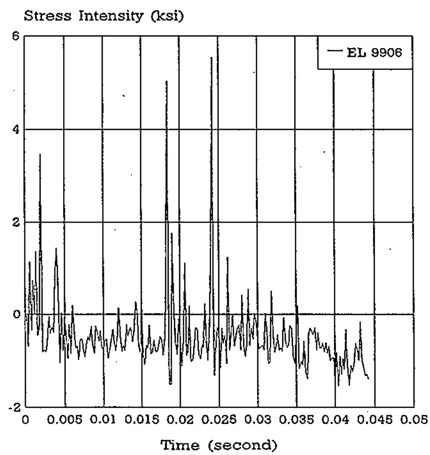
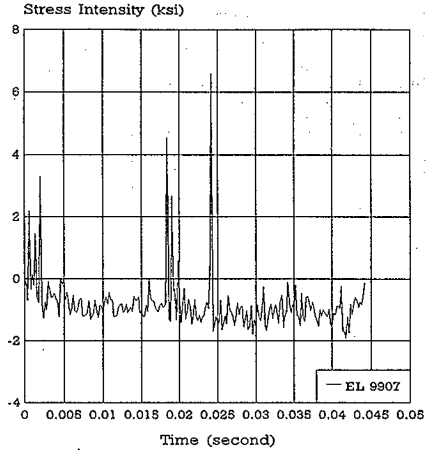


Figure B7-249. MCO Cask 9-m (30-ft) Top-End Flat-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-36. The accumulated strains reported herein are the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of strain of the stress intensity in the ASME stress intensity definition. The strains reported here are in the first 44.2 ms before the run was stopped.

The strain plots at the most critical locations are shown in Figures B7-250 through B7-255. Within the 44.2 ms, the strains are negligible with the highest value 1.4% at the exterior of the lid (Figure B7-255). The strain plots of lid bolts are shown in Figures B7-256 through B7-262. The accumulated strains of the lid bolts are negligible.

Table B7-36. Accumulated Strains at the Bottom Critical Locations from the 9-m (30-ft) Top-End Flat Drop.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
5650	0.00063	5214	0.00079	9901	0.00009
5664	0.00088	5215	0.00047	9902	0.00010
5678	0.00096	5216	0.00046	9903	0.00022
5450	0.00103	5217	0.00050	9904	0.00040
5464	0.00149	5218	0.00043	9905	0.00027
5478	0.00239	5050	0.00068	9906	0.00019
5264	0.00327	5051	0.00100	9907	0.00023
5278	0.00781	5052	0.00076		
5064	0.00441	5053	0.00066		
5078	0.01388	4850	0.00094		
		4851	0.00087		
		4852	0.00058		
		4853	0.00046		
		4650	0.00071		
		4651	0.00060		
		4652	0.00060		
		4653	0.00038		
		4450	0.00068		
		4451	0.00048		
		4452	0.00038		
		4453	0.00031		
		4250	0.00052		
		4251	0.00053		
		4252	0.00051		
		4253	0.00037		
		4264	0.00048		
		4265	0.00052		
		4266	0.00051		
		4267	0.00040		
		3661	0.00024		
		3662	0.00028		
		3663	0.00027		
		3450	0.00029		
		3451	0.00030		
		3452	0.00029		
		3453	0.00026		

Figure B7-250. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Interior of the Lid Plate (EL 5216).

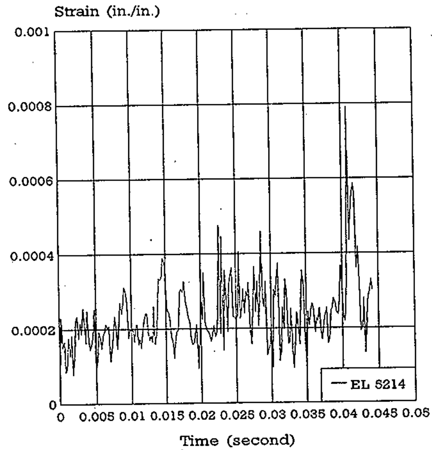


Figure B7-251. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Interior Lid Wall (EL 4252).

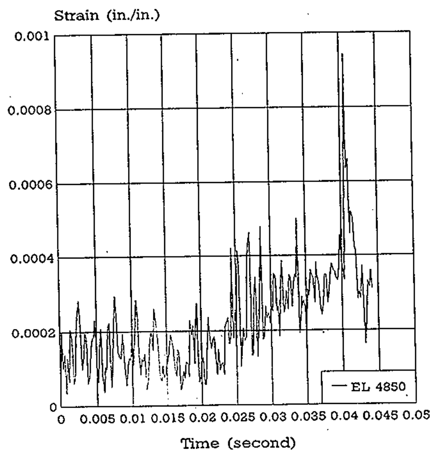


Figure B7-252. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Interior of the Lid Flange (EL 4266).

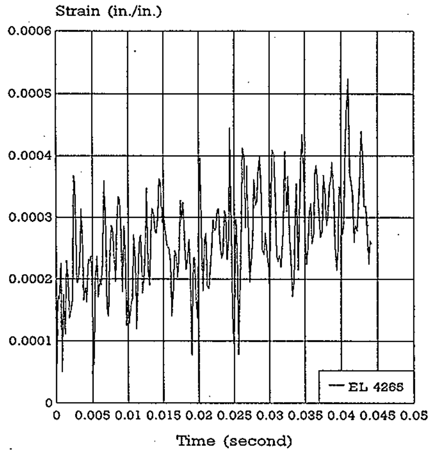


Figure B7-253. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Shear Key (EL 3662).

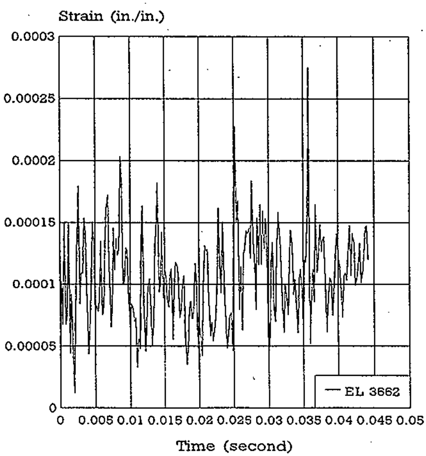


Figure B7-254. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Interior of the Cask Wall (EL 3450).

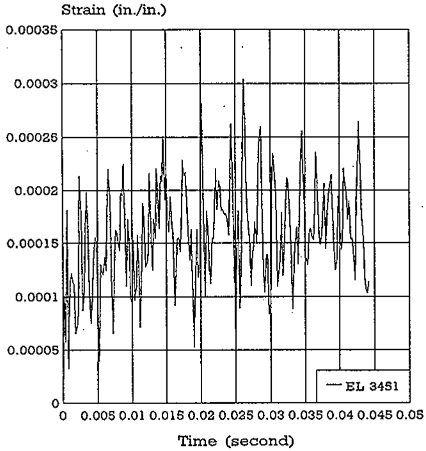


Figure B7-255. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at the Exterior of the Lid (EL 5664).

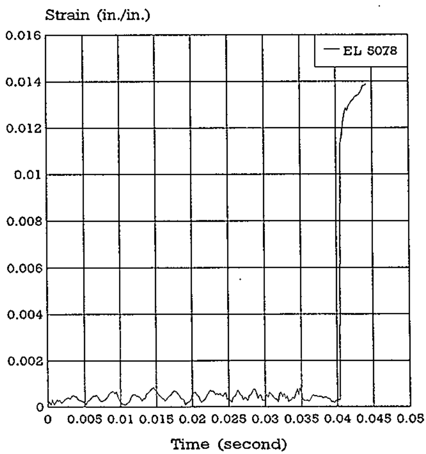


Figure B7-256. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 1 (EL 9901).

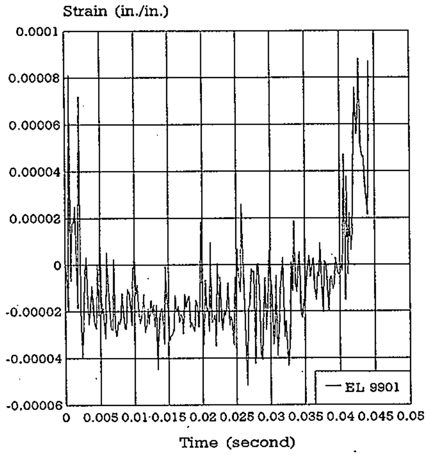


Figure B7-257. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 2 (EL 9902).

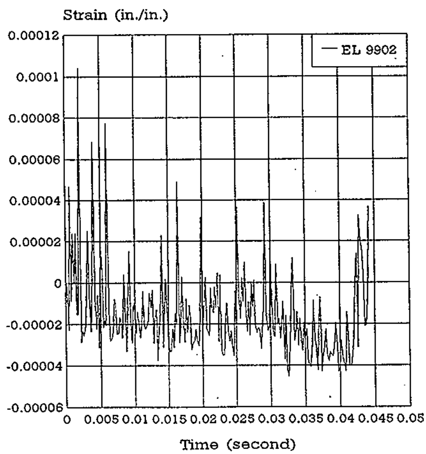


Figure B7-258. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 3 (EL 9903).

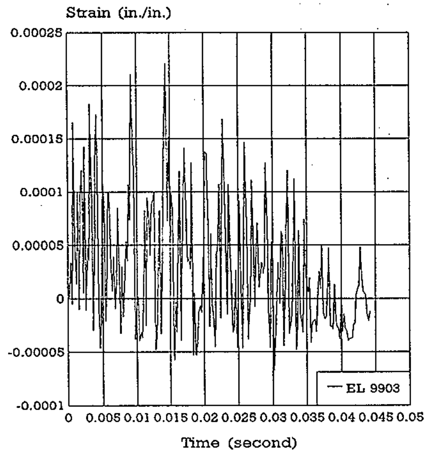


Figure B7-259. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 4 (EL 9904).

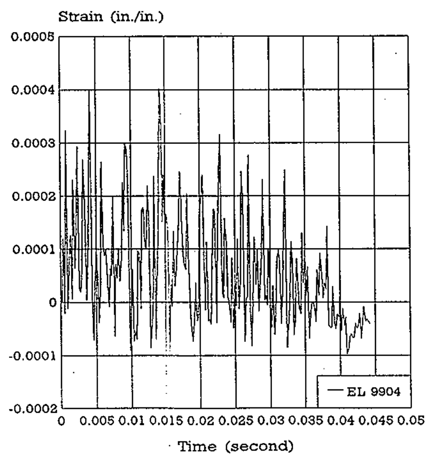


Figure B7-260. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 5 (EL 9905).

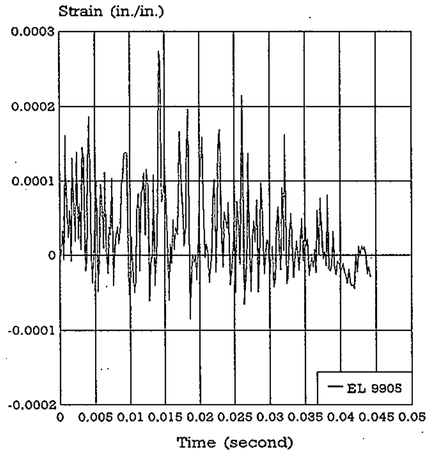


Figure B7-261. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 6 (EL 9906).

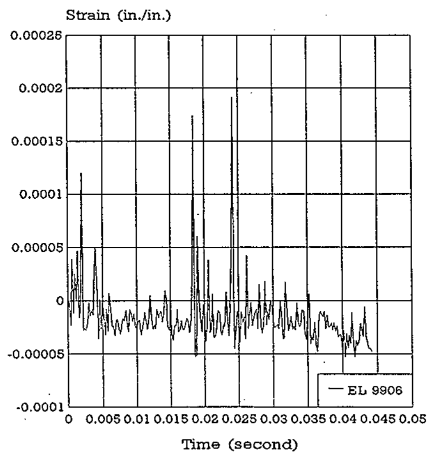
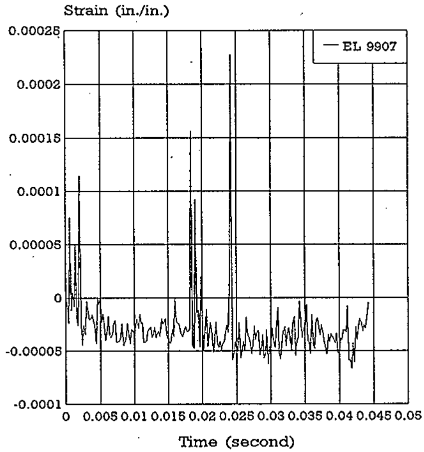


Figure B7-262. MCO Cask 9-m (30-ft) Top-End Flat-Drop Strain History at Bolt No. 7 (EL 9907).



7.3.4.3.6 6.4-m (21-ft) Bottom-End Oblique Drop with Water. This case is to evaluate a transport accident condition of the MCO Cask from the K Basins to the CVDF. For this accident case the MCO Cask is assumed to be filled with water and drops 6.4 m (21 ft) onto a 20-cm (8-in.) concrete target. As a worst case, the drop is assumed to be an oblique bottom-end impact near the bottom drain port. The center of gravity of the cask assembly and payload is assumed to be over the drain port corner. Water is assumed to be inside the MCO and between the MCO and the cask cavity. The FEA model is modified from the bottom end-drop by adding a water model between the MCO payload and the cask inside surface up to the MCO top level.

Impact Acceleration. The total run time of this case is 80 ms. In this case, because the initial impact area is very small, the cask penetrates well into the target before the target can provide sufficient resistance to noticeably affect cask momentum. Subsequently, the peak acceleration is delayed from initial contact until sufficient target resistance is available to begin a change in cask momentum (see Figures B7-263 and B7-264). The peak acceleration occurs at a later stage when a larger amount of cask momentum is transferred to the concrete/soil target.

The drop results in an impact acceleration history with a sharp spike at time zero as shown in Figure B7-263. After filtering out the forces with frequencies higher than 1000 Hz, the maximum acceleration is found to be about 24*g* (Figure B7-264).

Figure B7-263. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Acceleration History (Unfiltered).

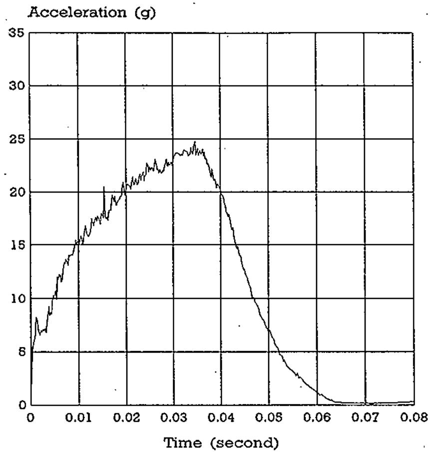
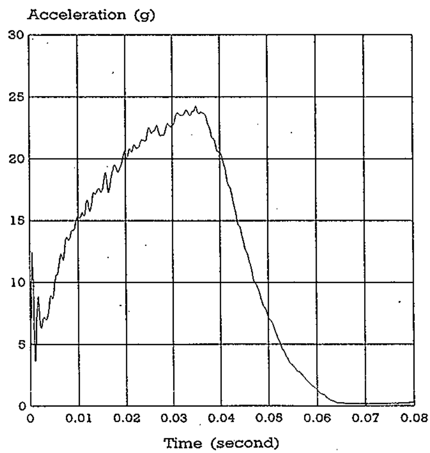


Figure B7-264. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Acceleration History (Filtered).



Three velocity plots at the bottom of the cask, the center-of-gravity level of the cask, and the top of the lid, respectively, are shown in Figures B7-265 through B7-267. Except at the center of gravity, the data points are at the center of the plates and at the 0°, 90°, 180° points from the drain port in the circumferential direction. The typical (or average) data point can be seen as the 90° point from the drain port. Using the 90° point data, the bottom of the cask has a shorter impact period (38.9 ms) than the center-of-gravity level of the cask (40 ms). The top of the lid has the longest impact period of slightly over 41.2 ms. The linear peak acceleration is determined from the steepest slope of these velocity curves. They are 39.4*g* at the bottom of the cask, 33.7*g* at the center-of-gravity level of the cask, and 33.3*g* at the top of the lid. The initial velocity of this drop is 11.2 m/s (441.3 in/s). Using the impact durations at different elevations, the average impact duration accelerations are found to be 29.4*g*, 28.6*g*, and 27.7*g* at the bottom, center-of-gravity, and top elevations, respectively. The acceleration results are summarized in Table B7-37. The peak acceleration is obtained from the reaction force history at the bottom of the cask.

Figure B7-265. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Velocity History at the Bottom of the Cask.

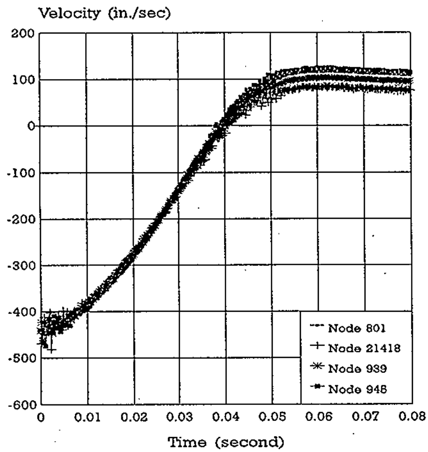


Figure B7-266. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Velocity History at the Cask Center of Gravity.

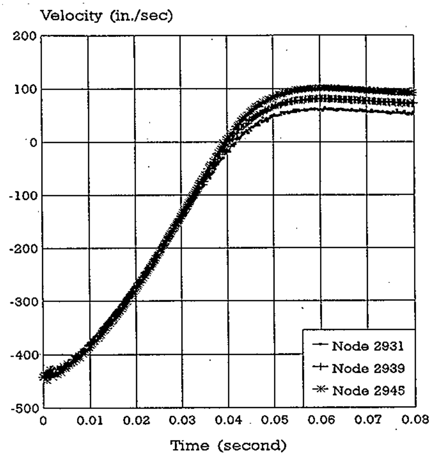


Figure B7-267. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Velocity History at the Top of the Lid.

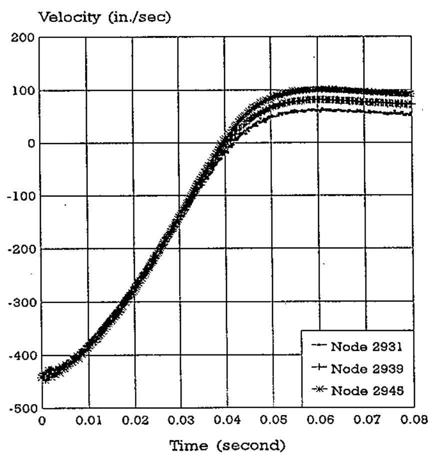


Table B7-37. Impact Acceleration Data of the 6.4-m (21-ft) Bottom-End Oblique Drop with Water.

Location	Linear peak acceleration (*g*)	Average impact-period acceleration (*g*)	Peak acceleration (*g*)	Impact period (ms)
Bottom	39.4	29.4	24	38.9
Center of gravity	35.7	28.6	NA	40.0
Top	33.3	27.7	NA	41.2

Stress Intensity. The estimated average ASME Code stress intensities are shown in Table B7-38 at the most critical exterior shell and containment boundary locations and at all lid bolts. The stress intensity plots at the most critical locations are shown in Figures B7-268 through B7-271. As can be seen, the exterior boundary of the cask near the drain port has sustained high stress intensities. However, the containment boundary stress intensities are near or below the yield strength of the cask material. The stress intensity plots of the lid bolts are shown in Figures B7-272 through B7-278. In this case the impact of this drop results in very low stress intensities on the lid bolts.

Table B7-38. Estimated Average ASME Code Stress Intensity at Critical Locations from the 6.4-m (21-ft) Bottom-End Oblique Drop with Water.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Stress intensity (ksi)	Element	Stress intensity (ksi)	Element	Stress intensity (ksi)
21336	244.07 (35.40)	614	64.74 (9.39)	9901	37.23 (5.40)
21337	180.99 (26.25)	615	46.61 (6.76)	9902	34.61 (5.02)
21338	123.42 (17.90)	616	68.4 (9.92)	9903	25.72 (3.73)
21339	59.23 (8.59)	21310	36.75 (5.33)	9904	18.34 (2.66)
21340	45.57 (6.61)	21305	65.57 (9.51)	9905	23.03 (3.34)
21341	117.21 (17.00)	21300	54.26 (7.87)	9906	34.89 (5.06)
21342	79.08 (11.47)	21295	40.54 (5.88)	9907	39.44 (5.72)
21343	75.84 (11.00)	21290	36.13 (5.24)		
21344	62.54 (9.07)	21285	33.72 (4.89)		
21345	42.68 (6.19)	21280	40.54 (5.88)		
21311	151.75 (22.01)	21275	50.47 (7.32)		
21316	129.55 (18.79)	21270	25.92 (3.76)		
21346	67.5 (9.79)	20720	45.57 (6.61)		
25030	112.66 (16.34)	20715	39.85 (5.78)		
25029	121.97 (17.69)	20710	39.51 (5.73)		
25022	70.19 (10.18)	20705	59.85 (8.68)		
25021	41.51 (6.02)	20695	54.54 (7.91)		
25020	104.39 (15.14)	20690	43.02 (6.24)		
25019	90.53 (13.13)	20685	37.58 (5.45)		
25012	72.81 (10.56)	20680	47.64 (6.91)		
25011	62.49 (9.47)	20160	34.61 (5.02)		
25010	87.22 (12.65)	20159	34.2 (4.96)		
25009	87.36 (12.67)	20158	36.68 (5.32)		
25002	117.92 (17.03)	20157	42.2 (6.12)		
25001	71.43 (10.36)	20110	42.47 (6.16)		
		20109	40.13 (5.82)		
		20108	39.99 (5.80)		
		20107	37.3 (5.41)		
		20106	37.58 (5.45)		

Figure B7-268. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at the Interior of the Cask Wall (EL 21300).

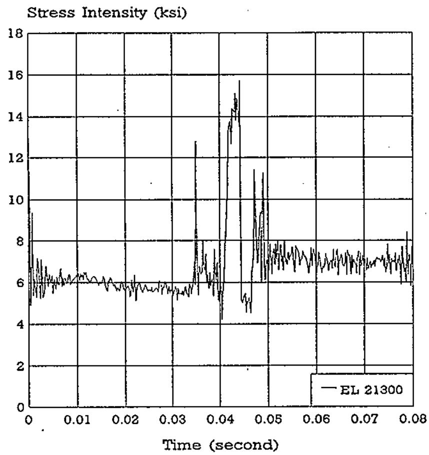


Figure B7-269. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at the Interior of the Cask Bottom (EL 616).

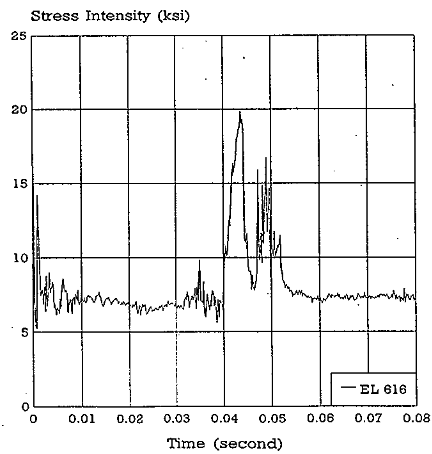


Figure B7-270. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at the Exterior of the Cask (EL 21336).

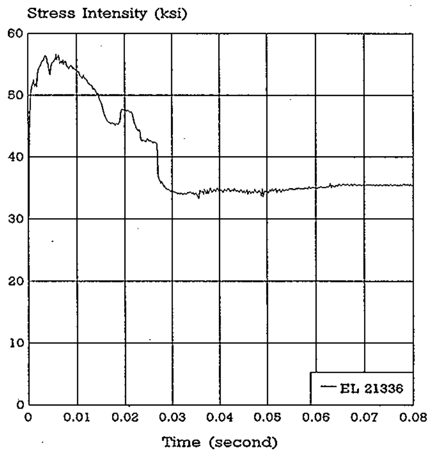


Figure B7-271. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History Drain Port Cover Plate (EL 25030).

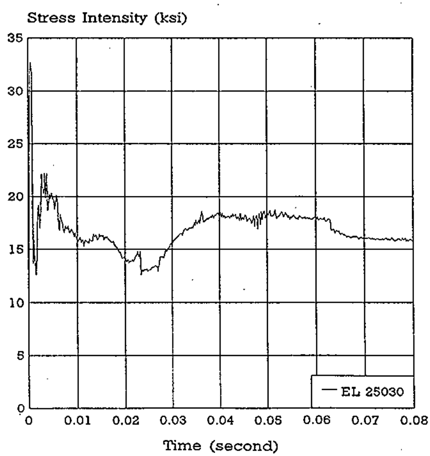


Figure B7-272. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 1 (EL 9901).

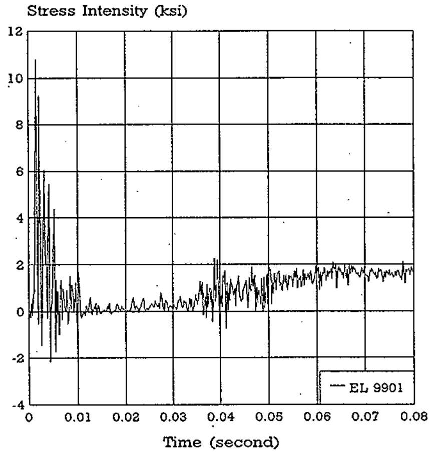


Figure B7-273. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 2 (EL 9902).

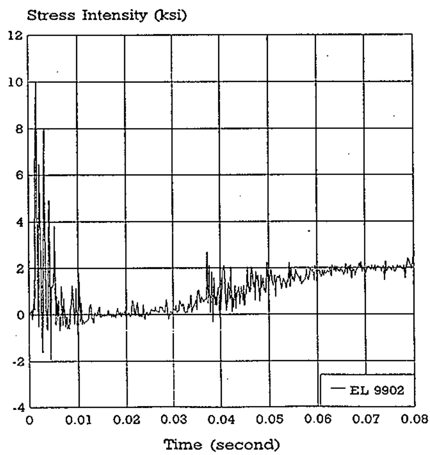


Figure B7-274. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 3 (EL 9903).

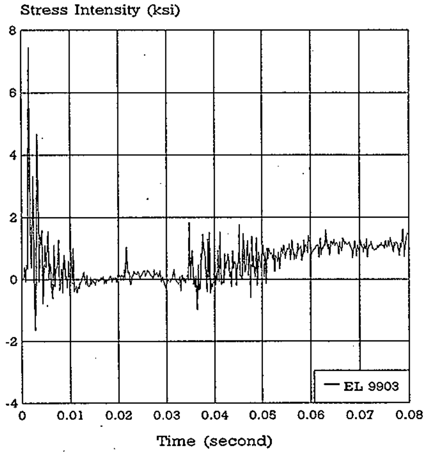


Figure B7-275. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 4 (EL 9904).

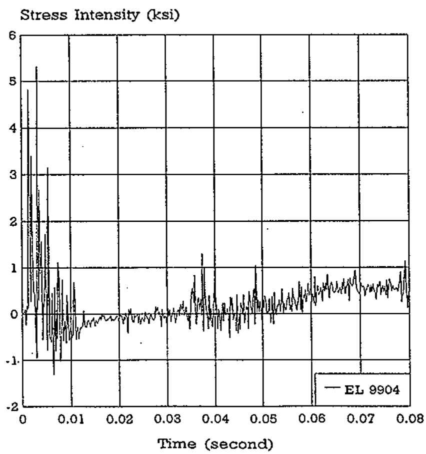


Figure B7-276. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 5 (EL 9905).

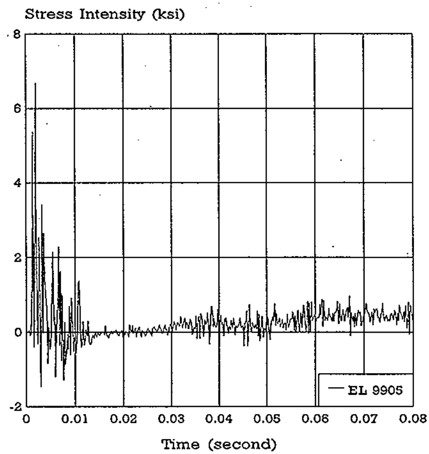


Figure B7-277. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 6 (EL 9906).

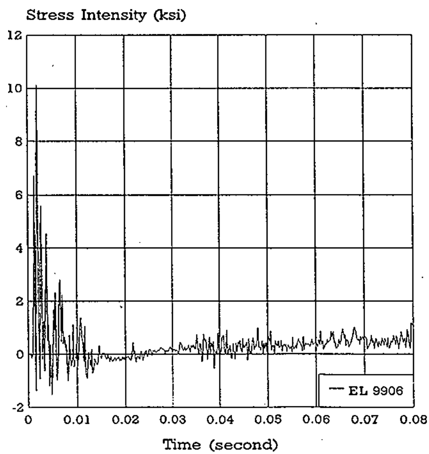
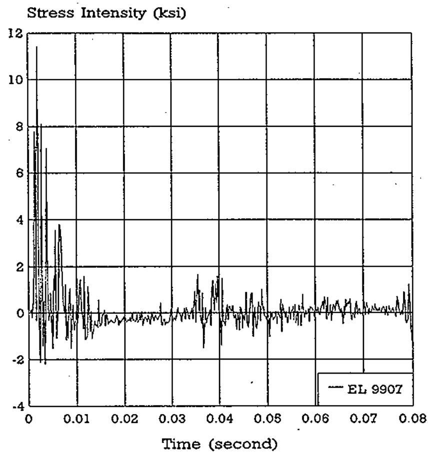


Figure B7-278. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Stress Intensity History at Bolt No. 7 (EL 9907).



Deformation Results. The accumulated strain at the critical locations of the cask and lid and at the lid bolts are shown in Table B7-39. The accumulated strains reported herein are in the range of the largest principal logarithmic strain and the smallest principal logarithmic strain. This is the counterpart of the stress intensity in the ASME stress intensity definition.

The strain plots at the most critical locations are shown in Figures B7-279 through B7-282. The largest overall accumulated strain of the entire cask is 15.1% at the exterior bottom boundary of the drain port (Figure B7-281). The largest accumulated strain on the drain port cover plate is about 1.3% (Figure B7-282). However, the largest accumulated strain of the containment boundary of the cask/lid is only 0.29%, occurring near the drain port region (Figure B7-279).

The strain plots of the lid bolts are shown in Figures B7-283 through B7-287. The accumulated strains of the lid bolts are minor with a maximum of approximately 0.04% during this bottom-end oblique drop with water.

Table B7-39. Accumulated Strains at Critical Locations from the 6.4-m (21-ft) Bottom-End Oblique Drop with Water.

Cask body/lid				Lid bolt	
Exterior		Containment boundary			
Element	Strain (in/in)	Element	Strain (in/in)	Element	Strain (in/in)
21336	0.151	614	0.00180	9901	0.00037
21337	0.00257	615	0.00145	9902	0.00035
21338	0.00106	616	0.00125	9903	0.00026
21339	0.00137	21310	0.00100	9904	0.00018
21340	0.00029	21305	0.00121	9905	0.00023
21341	0.01023	21300	0.00151	9906	0.00035
21342	0.00077	21295	0.00266	9907	0.00039
21343	0.00051	21290	0.00289		
21344	0.00045	21285	0.00075		
21345	0.00029	21280	0.00079		
21311	0.04543	21275	0.00057		
21316	0.01006	21270	0.00062		
21346	0.00145	20720	0.00061		
25030	0.01298	20715	0.00055		
25029	0.00911	20710	0.00055		
25022	0.00176	20705	0.00061		
25021	0.00198	20695	0.00073		
25020	0.00767	20690	0.00057		
25019	0.00601	20685	0.00050		
25012	0.00224	20680	0.00064		
25011	0.00205	20160	0.00059		
25010	0.00297	20159	0.00042		
25009	0.00317	20158	0.00046		
25002	0.00272	20157	0.00061		
25001	0.00274	20110	0.00057		
		20109	0.00052		
		20108	0.00051		
		20107	0.00046		
		20106	0.00064		

Figure B7-279. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at the Interior of the Cask Wall (EL 21290).

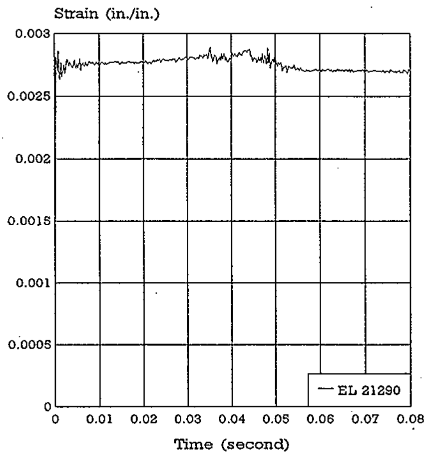


Figure B7-280. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at the Interior of the Cask Bottom (EL 614).

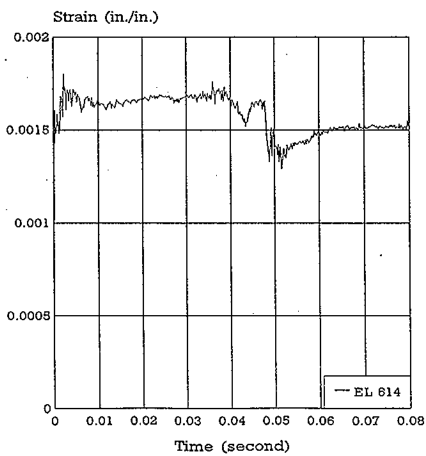


Figure B7-281. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at the Exterior of the Cask (EL 21336).

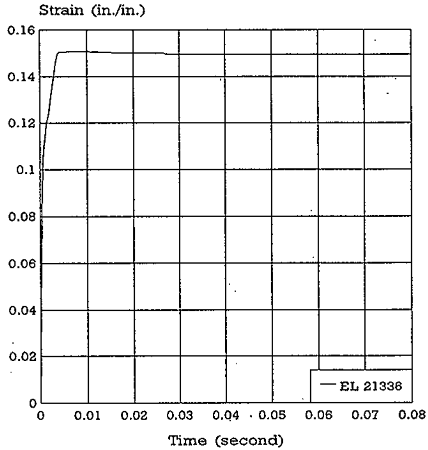


Figure B7-282. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at the Drain Port Cover Plate (EL 25030).

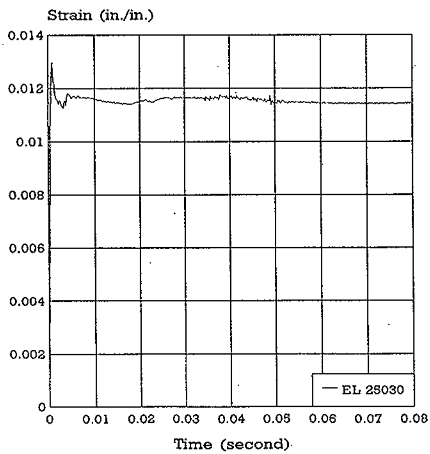


Figure B7-283. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 1 (EL 9901).

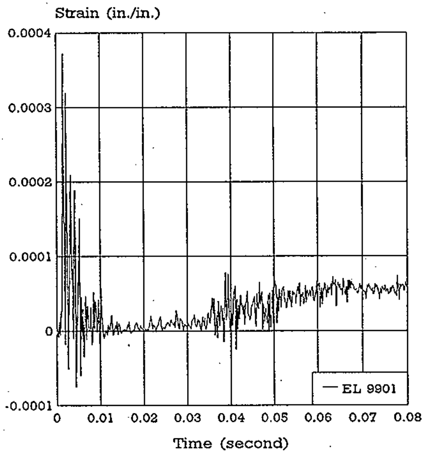


Figure B7-284. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 2 (EL 9902).

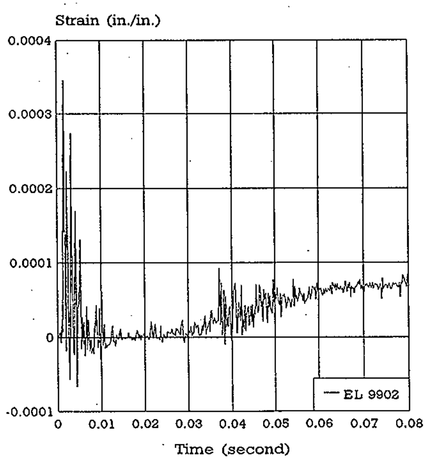


Figure B7-285. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 3 (EL 9903).

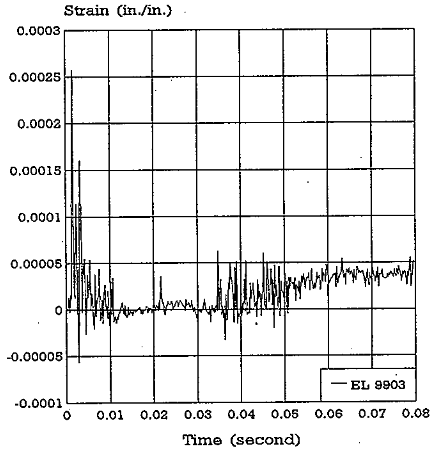


Figure B7-286. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 4 (EL 9904).

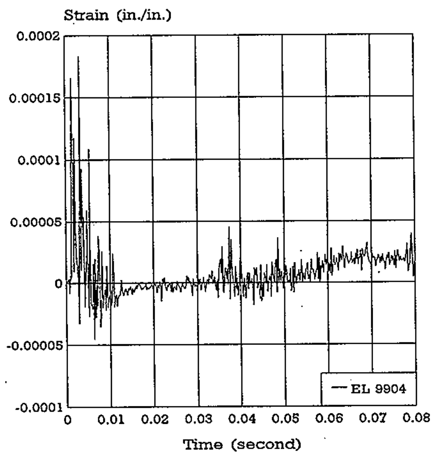


Figure B7-287. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 5 (EL 9905).

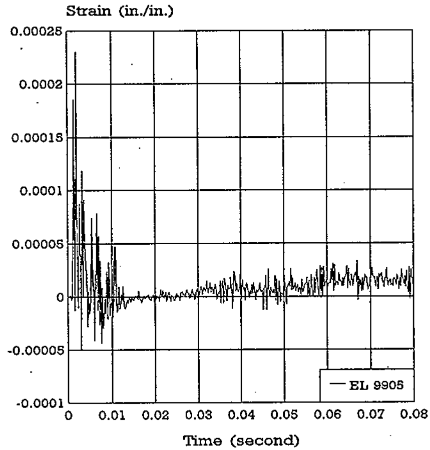


Figure B7-288. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 6 (EL 9906).

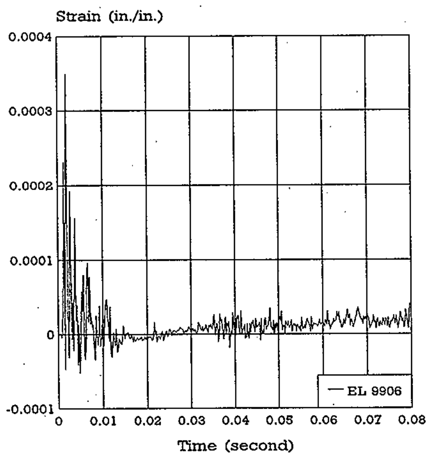
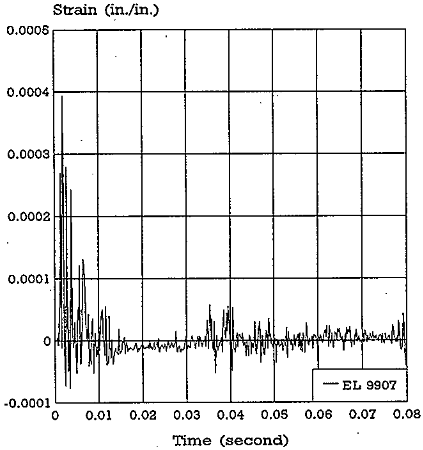


Figure B7-289. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Strain History at Bolt No. 7 (EL 9907).



Other Results. The maximum resultant force at the drain port cover plate is 93,855 N (21,100 lb [see Figure B7-290]). The estimated average force is 47,150 N (10,600 lb).

Figure B7-291 shows the concrete displacement of about 24.6 cm (9.7 in.) at the cask impact point.

Figure B7-290. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Force at the Drain Port Cover Plate.

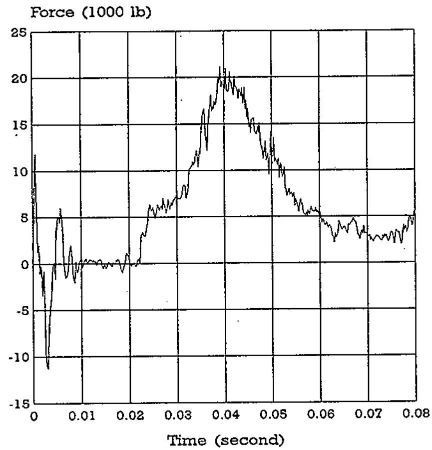
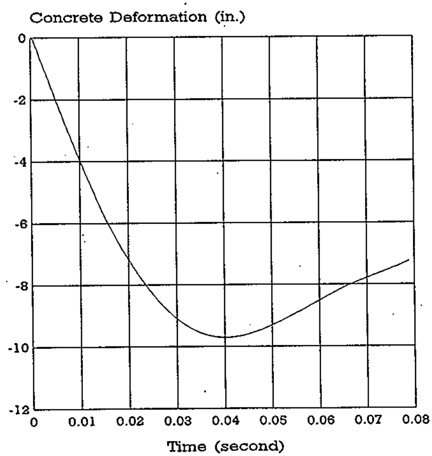


Figure B7-291. MCO Cask 6.4-m (21-ft) Bottom-End Corner-Drop Concrete Deformation Depth.



7.3.4.4 Maximum Thermal and Pressure Stresses. The thermal and pressure stresses of the MCO Cask during a fire accident are computed using the ABAQUS/Standard (HKS 1995) FEA program. Analytical methods and results are provided in Part B, Section 7.7 (Appendices). As a worst case, the results show that the combined stresses on the inside of the cask lid wall during the conservative 30-minute fire reaches a maximum of 199.25 MPa (28.9 ksi). Conservatively assuming this is a primary membrane stress intensity, the stress is well below the Service Level D allowable of 330.9 MPa (48 ksi) at a worst-case temperature of 350 °C (662 °F) on the inside cask lid wall. In the fire case, differential heating between the cask body and top lid, as well as differential thermal expansion and increased pressure, produce increased stress on the closure bolts. The analysis shows the maximum bolt tensile stress is 216.5 MPa (31.4 ksi) and the shear is 27.7 MPa (4.01 ksi). For the fire condition, these stresses are below the ASME bolt allowables. The allowable for average tension is 584.0 MPa (84.7 ksi), and average shear is 350 MPa (50.8 ksi).

7.3.4.5 Structural Evaluation and Conclusions. From the above evaluations, it is shown that the drop orientations, which cause the most severe loading to the exterior of the cask body, are the side drop, the bottom-end corner drop, and the water-filled bottom-end corner drop. In these cases, the exterior locations on the cask body and closure lid are subject to high localized stresses above the yield strength of the material. However, these stresses are localized around the exterior impact surfaces, causing only surface damage to the cask, and do not affect the containment performance of the cask.

In all drop orientations the containment (interior surface) boundary stress intensities are well below ASME allowables for primary membrane. Combining the drop stresses with NCT thermal and pressure stress intensities at the worst-case interior locations (top-end oblique drop, EL 5478) results in a stress intensity of 43.4 ksi. This stress intensity is a combination of primary and secondary stress intensities and is below the Service Level D allowable of 412.3 MPa (59.8 ksi) at temperature. The highest drop stress intensity on the closure lid bolts is 518.97 MPa (75.27 ksi) at EL 9904 during the bottom-end flat drop. Superimposing the stress intensity from the drop onto the NCT thermal and pressure stress intensity results in a combined stress intensity of 606.53 MPa (87.97 ksi). This stress intensity is below the average tensile stress allowable of 987.33 MPa (143.2 ksi [at temperature]) for Service Level D limits. The maximum accumulated strain on the lid bolts is approximately 0.6%. Consequently, under worst-case conditions the cask will maintain containment of the contents.

The most vulnerable area for the cask is the drain port region. Although the stress intensities are well below Service Level D allowables, the strains in this area were evaluated to determine if the drain port cover plate maintains containment after a worst-case accident drop. The worst-case accident drop of the cask with respect to the drain port is the bottom-end oblique drop. At the exterior surface at the edge of the drain port region, the maximum accumulated strain is approximately 15.5%. The largest accumulated strain on the exterior surface of the drain port cover is 1.8%. The maximum accumulated strain of the containment boundary is 0.44%, located in the interior of the drain port. However, the maximum accumulated strain near the drain port seal and bolt is approximately 0.02% on the exterior surface and 0.001% on the interior containment boundary surface. Averaging the maximum accumulated worst-case strains results in a strain of 0.011. This strain is assumed to be tensile applied to the drain port cover bolts and results in an elongation of the bolt of 0.02 cm (0.008 in.). Using worst-case tolerance conditions the port cover O-ring is compressed approximately 0.12 cm (0.047 in.). Based on the amount of compression of the O-ring versus the elongation of the bolt and the elastomeric O-rings being considered self-energizing, Part B, Section 4.7 demonstrates that the drain port cover will maintain containment after a drop accident. Consequently, based on the worst-case conditions, the drain port cover will experience minor damage, but the containment performance of the cask will not be affected.

The accident condition thermal and pressure evaluation, presented above, shows that during an accident condition fire, the cask and closure bolt stresses remain below Service Level D limits. Consequently, it is concluded that the cask and closure bolts will maintain the contents. Closure seal integrity and requirements are evaluated in the Part B, Section 3.0.

7.4 MCO STRUCTURAL INTEGRITY

The MCO provides a level of containment for the contents, but no credit is taken for this boundary. However, the MCO center tube also provides criticality control of the contents during accident conditions. Consequently, the structural integrity of the MCO center criticality control tube is evaluated during accident conditions. Only preliminary analysis of the MCO is performed since the MCO final design is not complete. Part B, Section 6.0, indicates that criticality of control of the contents is dependent upon the stability of the spent fuel basket center tube when loaded with MARK IA fuel. Subsequently, the MCO is evaluated only for the highest vertical acceleration loads, which is from a bottom-end flat drop to ensure MCO behavior does not affect the spent fuel baskets.

Evaluation (Part B, Section 7.0) of the current MCO design shows that the MCO will not buckle under a vertical acceleration. Euler buckling loads computed by the use of ABAQUS/Standard (HKS 1995) are in excess of 4,000*g*. Based on cask impact data, the average axial load in the MCO shell under a 27*g* impact is negligible. Consequently, the MCO will not buckle during a bottom-end flat drop (Part B, Section 7.3.4.3.1) of the cask.

7.5 CRITICALITY CONTROL

Final design of the spent fuel baskets is in progress. Evaluation of the spent fuel baskets is based on preliminary drawings. Consequently, the finding in this evaluation is preliminary.

As stated in Part B, Section 6.0, the criticality control of this package is provided by the center tube of the spent fuel baskets for MARK IA fuel. Part B, Section 6.0, indicates that to maintain criticality control of the fuel, the center tube cannot deform more than 5 cm (2 in.). Analysis of the behavior of the center tube during accident drop conditions is presented in Part B, Section 7.7 (Appendices). The evaluation is performed for six MARK 1A baskets under a vertical inertial load, and the crushing analysis is performed for one MARK 1A basket under a horizontal inertial load. The acceleration loadings are taken from the MCO Cask impact analyses. The ABAQUS/Standard (HKS 1995) FEA program is used to model the MARK 1A baskets.

7.5.1 Center Tube Buckling Under a Vertical Inertial Load

The vertical inertial loading on the center tube is analyzed by both quasi-static and dynamic methods. For both methods, the center tube is assumed to have the total mass of a loaded basket. Also, the center is assumed to be pinned at the bottom and restrained horizontally at the top. As a deflection reference, a rigid surface, running the length of the center tube, approximately 1.27 cm (0.5 in.) from the center tube is used. Contact is enforced between the surface and nodes to model the interaction of the baskets and the MCO.

In the quasi-static analysis the vertical acceleration of the MCO was assumed from the bottom-end flat drop as 27*g*, with a dynamic amplification factor of 1.65, resulting in a quasi-static inertial load of 44.56*g*. Also, for conservatism, an initial imperfection of tube straightness is assumed as 0.64 cm (0.25 in.) off center. Quasi-static analysis shows that the center deflection does not exceed the 1.27-cm (0.5-in.) clearance between the center tube and the rigid reference surface. With this model it has been determined that a quasi-static load of 81*g* is required to induce a deflection of 5 cm (2 in.) on the center tube. As a additional check of tube buckling, the basket stack design was determined to meet ASME Code Case N-284-1 (ASME 1995e) requirements. In this code case the minimum multiple of 1.2 times the initial prebuckling stress state is recommended for a buckling stress state. The minimum multiple for the basket stack is determined to be 3 times the stress state induced by the quasi-static inertial load of 44.56*g*.

As a further check the quasi-static analysis model was modified and used in a dynamic analysis. In this analysis the center tube does not have an initial imperfection, and the nodes have an initial downward speed corresponding to a 9-m (30-ft) drop. The bottom node is accelerated upward at constant 27*g* until it is brought to rest. The axial compressive forces reach a maximum value of 2.04×10^6 N (457,890 lb), which corresponds to the 2.03×10^6 N (456,000-lb) maximum axial compressive force obtained in the quasi-static evaluation, therefore verifying the quasi-static use of a dynamic load factor. Consequently, by these two methods it can be demonstrated that buckling of the center tube will not exceed 5 cm (2 in.) after a worst-case vertical-loading accident condition drop.

7.5.2 Horizontal Load Analysis

Horizontal loading of the MCO spent fuel baskets is evaluated using the ABAQUS/Standard FEA code. The element mesh of the basket is constructed of four-noded shell elements. The basket material is idealized as and elastic-plastic material with strain hardening typical of 304 or 304L stainless steel. The MCO shell is modeled as rigid elements fixed in space. There is enforced contact between the basket shell and the MCO shell. The preliminary drawings indicate that the ends of the basket stack are constrained during a horizontal drop. Consequently, the nodes at each end of the center tube are tied together with multi-point constraints, which limit the rotation of the center tube. Input files of the ABAQUS/Standard are provided in Part B, Section 7.7 (Appendices).

Since the fuel distribution in the baskets varies, the load is applied by increasing the acceleration load on an empty basket to the total inertial load on the baskets. In the case of the MCO Cask horizontal drop, the quasi-static acceleration load factor is 68*g*. As a worst case, the loading is increased by the dynamic load factor (1.65) determined in the above vertical loading case. This produces an inertial load of 876,279 N (197,000 lb) on the baskets. The conservative loading parameters result in deformations larger than actual. In an actual basket, the load will react as a bearing load against the MCO shell wall and will be more uniformly distributed.

Results of the FEA show that the basket web buckles and the center tube deflects 1.12 cm (0.44 in) in the direction of the inertial load. The maximum stress intensity at the outer surface of the center tube is approximately 415.1 MPa (60.2 ksi). This stress intensity is very localized and is a result of the multi-point constraints. A more representative stress intensity is near 172.4 MPa (25 ksi), which is approximately the average stress through the midsurface of the center tube.

The deformation results, based on conservative analyses and the preliminary basket design, show the center tube under horizontal inertial loading does not exceed the 5-cm (2-in.) deformation as required in Part B, Section 6.0. However, after a side drop the spent fuel baskets themselves will sustain significant damage, which does not affect criticality control or retention of the MCO contents.

7.5.3 Fuel Structural Behavior

Since fuel fragmentation and rubblization could result in an unacceptable criticality condition, the worst-case irradiated N Reactor fuel (MARK 1A) structural behavior is evaluated during accident condition drops. The details of the evaluation are presented in Part B, Section 7.7 (Appendices). Previous analyses (Schwinkendorf 1996) show that if the "good condition" fuel remains intact after a postulated accident, then an acceptable criticality condition is probable. Fuel that is not in "good condition" is already accounted for by this criticality analysis. "Good condition" fuel is defined as fuel elements that after irradiation and storage have the same geometric characteristics as new fuel and post-irradiation properties as documented in the literature. It is anticipated that 60% for the K East Basin inventory can be considered "good condition" fuel.

The evaluations presented in Part B, Section 7.7, are based on the linear peak acceleration determined for the MCO Cask bottom-end flat drop and side drop. The analysis shows that in the bottom-end flat drop condition the worst-case loading occurs on the outer fuel elements. For the Zircaloy-2 components the maximum predicted stress is 58.05 MPa (8,420 psi), which is lower than the unirradiated yield strength of 317.2 MPa (46 ksi). The maximum equivalent stress in the U-601 (uranium) fuel is 37.2 MPa (5,400 psi), which is well below the unirradiated ultimate stress of 344.7 MPa (50 ksi). Consequently, it can be demonstrated that the fuel in "good condition" does not fragment or rubblize after a bottom-end flat-drop accident.

The side drop condition shows the maximum equivalent stress in both the Zr-2 and U-601 is 157.9 MPa (22.9 ksi). The maximum equivalent stress is less than their respective strengths.

Under accident drop conditions, the analyses of the spent fuel predict that "good condition" fuel cladding and end cap systems remain intact and that the uranium will also remain intact. In addition, examinations of the fuel elements with moderate end damage in the 327 Hot Cells show that the majority of the fuel is "uncracked." This provides additional assurance that fuel with a "good condition" element will remain intact and at a minimum will be contained.

7.6 REFERENCES

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7.7 APPENDICES

7.7.1 MCO Cask 1 ft and 30 ft Finite Element Drop Analysis

Checklist for Checking of Analysis/Calculations

Document Checked - Number: N\A **Revision:** 0

Title: MCO-Cask 1 ft and 30 ft Finite Element Drop Analyses

Yes	No	N/A	
[✓]	[ ]	[ ]	Problem completely defined.
[✓]	[ ]	[ ]	Appropriate analytical method used.
[✓]	[ ]	[ ]	Necessary assumptions are approriate, explicitly stated, and stated.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[ ]	[ ]	[✓]	Sources of non-standard formulae/data are referenced and the correctness of the reference verified.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand calculations checked for errors.
[✓]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[✓]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[ ]	[ ]	Safety Margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

I have checked the ~~analysis/~~calculation and ~~it~~ is complete and accurate to the best of my knowledge.

R. G. Marlow [signature] 1/23/97

Engineer/Checker Date

Note: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

7.7.2 MCO Cask Lifting Fixture Weld Evaluation

ENGINEERING SAFETY EVALUATION

Subject: MCO-Cask Lifting Fixture Weld Evaluation	Page: 1 of 5
Originator: S. S. Shiraga	Date: 1/23/97
Checker: S. R. Crow	Date: 1/24/97

I. Objective:

The objective this evaluation is to determine the safety performance of the MCO Cask trunnion and lifting bracket welds. ANSI N14.6 requires RAM cask lifting fixtures have a safety factor of 3 based on yield strength or 5 based on ultimate strength.

II. References:

ANSI, 1993, *American National Standard for Radioactive Materials-Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More*, ANSI N14.6, American National Standard Institute, New York, New York, 1993.

ASME, 1992, *Boiler and Pressure Vessel Code*, Section VIII, Division I, "Properties", American Society of Mechanical Engineers, New York, New York, 1995

ASME, 1995, *Boiler and Pressure Vessel Code*, Section II, Part D, "Properties", American Society of Mechanical Engineers, New York, New York, 1995.

III. Results and Conclusions:

Results of this evaluation shows all MCO cask trunnion and lifting bracket critical welds have a safety factor over 3 based on yield strength of the material. This demonstrates that the trunnion and lifting bracket welds meet the requirements of ANSI N14.6.

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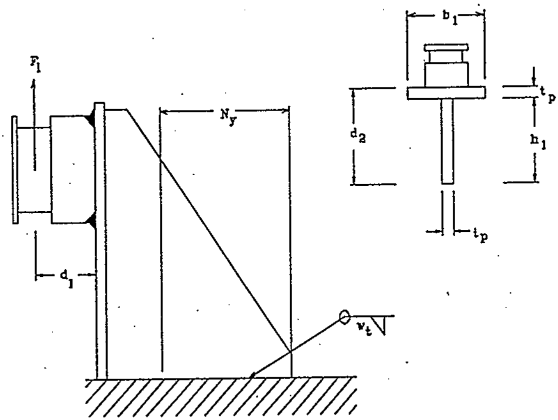
IV Evaluation:

Lifting Trunnion and Bracket Weld Evaluation:



Weight of Cask: $W_{cask} := 60000 lbf$ Number of trunnions: $n_t := 2$

Load on each trunnion: $F_1 := \frac{W_{cask}}{n_t}$ $F_1 = 30000 \cdot lbf$

Assumed distance from lift load to vertical plate: $d_1 := \left(4.0 + \frac{3}{2}\right) \cdot in$

Moment on trunnion to vertical plate weld: $M_{tr} := F_1 \cdot d_1$ $M_{tr} = 13750 \, ft \cdot lbf$

Evaluate welds using line method, and treat all loading as parallel loading for conservatism.

Assumed yield strength of 304 sst at room temperature (ASME 1995): $s_y := 30 \cdot ksi$

Trunnion weld to vertical plate is single bevel with fillet weld. Assume for conservatism a singe fillet, based on ASME Section VIII, joint configurations (ASME 1992, UW-18).

Fillet weld joint efficiency based on leg size (ASME 1992, UW-18): $j_{ef} := 0.55$

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Trunnion to vertical plate weld leg size: $w_{tr} := 1.5 \cdot in$

Allowable load on welds trunnion to plate weld: $f_{alltr} := j_{ef} \cdot s_y \cdot w_{tr}$ $\quad f_{alltr} = 297000 \cdot \frac{lbf}{ft}$

Trunnion Weld Evaluation:

Diameter of trunnion: $d_{trun} := 7 \cdot in$ Length of weld: $l_{wtr} := \pi \cdot d_{trun}$

Line weld modulus: $s_{wtr} := \frac{\pi}{4} \cdot d_{trun}^2$

Bending load on weld: $f_{trb} := \frac{M_{tr}}{s_{wtr}}$ $\quad f_{trb} = 51449 \cdot \frac{lbf}{ft}$

Shear load on weld: $f_{trsh} := \frac{F_1}{l_{wtr}}$ $\quad f_{trsh} = 16370 \cdot \frac{lbf}{ft}$

Total load on weld: $f_{trt} := \sqrt{f_{trb}^2 + f_{trsh}^2}$ $\quad f_{trt} = 53991 \cdot \frac{lbf}{ft}$

Safety factor: $SF_w := \frac{f_{alltr}}{f_{trt}}$ $\quad SF_w = 5.5$

Exceeds ANSI N14.6 Safety Factor requirements of 3, therefore OK.

Bracket Weld Evaluation:

$b_1 := 11 \cdot in$ $\quad t_p := 2 \cdot in$ $\quad h_1 := 11.5 \cdot in$ $\quad d_2 := t_p + h_1$

Centroid of weld treated as a line:

$$N_y := \frac{b_1 \cdot (h_1 + t_p) + (b_1 - t_p) \cdot h_1 + 2 \cdot t_p \cdot \left(h_1 + \frac{t_p}{2}\right) + 2 \cdot h_1 \cdot \left(\frac{h_1}{2}\right)}{b_1 + (b_1 - t_p) + 2 \cdot (h_1) + 3 \cdot t_p} \qquad N_y = 8.9 \cdot in$$

Moment of inertia unit leg of weld:

$$I_w := 2 \cdot \left[\frac{t_p^3}{12} + t_p \cdot \left[\left(h_1 + \frac{t_p}{2}\right) - N_y\right]^2\right] + b_1 \cdot \left[(d_2) - N_y\right]^2 + (b_1 - t_p) \cdot (h_1 - N_y)^2 \ldots$$
$$+ 2 \cdot \left[\frac{h_1^3}{12} + h_1 \cdot \left(N_y - \frac{h_1}{2}\right)^2\right] + t_p \cdot N_y^2 \qquad I_w = 986.8 \cdot in^3$$

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Length of weld: $l_{wb} := 3 \cdot t_p + 2 \cdot h_1 + b_1 + (b_1 - t_p)$ $\quad l_{wb} = 49 \cdot in$

Section Modulus of weld:

Top: $s_{wbt} := \dfrac{I_w}{d_2 - N_y}$ $\quad s_{wbt} = 212.8 \cdot in^2$

Bottom: $s_{wbb} := \dfrac{I_w}{N_y}$ $\quad s_{wbb} = 111.4 \cdot in^2$

Moment load applied to bracket: $M_{brac} := F_1 \cdot \left[\left(\dfrac{3}{2} + 4 \right) \cdot in + d_2 - N_y \right]$ $\quad M_{brac} = 304133 \cdot lbf \cdot in$

Force per length of weld:

Top (tensile): $f_{wtop} := \dfrac{M_{brac}}{s_{wbt}} + \dfrac{F_1}{l_{wb}}$ $\quad f_{wtop} = 2042 \cdot \dfrac{lbf}{in}$

Bottom (compression): $f_{wbot} := \dfrac{M_{brac}}{s_{wbb}} - \dfrac{F_1}{l_{wb}}$ $\quad f_{wbot} = 2119 \cdot \dfrac{lbf}{in}$

Bracket weld leg size: $w_t := 0.5 \cdot in$ $\quad$ ASME Section VIII Joint efficiency: $j_{ef} = 0.55$

Allowable load on bracket welds: $f_{allbr} := j_{ef} \cdot s_y \cdot w_t$ $\quad f_{allbr} = 8250 \cdot \dfrac{lbf}{in}$

Safety factor: $SF_{wb} := \dfrac{f_{allbr}}{f_{wtop}}$ $\quad SF_{wb} = 4.04$

Exceeds the ANSI N14.6 requirements for safety factor of 3, therefore OK.

Vertical weld to gusset plate evaluation:

Conservatively assume no strength contribution from the bottom 1/2 inch welds in shear. Assume the gusset plate weld is to carry the shear load and bottom weld restrains bending loads.

Gusset weld size: $w_g := 0.25 \cdot in$ $\quad$ Length of weld: $l_w := 20 \cdot in$

ENGINEERING SAFETY EVALUATION

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Shear load per unit length on weld: $f_{gs} := \frac{F_l}{2 \cdot l_w}$ $f_{gs} = 750 \cdot \frac{lbf}{in}$

Allowable load on bracket welds: $f_{allgs} := j_{ef} s_y \cdot w_g$ $f_{allgs} = 4125 \cdot \frac{lbf}{in}$

Safety factor: $SF_{gs} := \frac{f_{allgs}}{f_{gs}}$ $SF_{gs} = 5.5$

Exceeds the ANSI N14.6 requirements for safety factor of 3, therefore OK.

7.7.3 MCO Cask Pressurization Analysis

MCO Cask Pressurization Analysis

Randall S. Marlow
11/18/96

1.0 Introduction

This document describes the stress analysis of the MCO cask loaded by an internal pressure of 150 lbf/in^2.

2.0 Analytical Methods and Results

The stress distribution in the cask is computed using the ABAQUS/Standard (HKS 1995) finite-element program. The cask mesh is shown in Figure 2.0-1. A close-up of the mesh of the lid and nearby cask wall is shown in Figure 2.0-2. The ABAQUS input file for the analysis is in Attachment A. The cask is modeled with 4-noded axisymmetric elements. The cask material constitutive model is elastic-plastic with properties typical of 304 stainless-steel. The bolts which attach the lid to the main body of the cask are modeled as a truss element which has the same cross-sectional area as all twelve bolts combined. The bolting material constitutive model is elastic with properties typical for steel. The shear force at the bolt is carried by a spring element between the horizontal degrees of freedom at the top bolt node and the bottom bolt node. The bolt elements attach the lid mesh to the main mesh of the cask. The lid mesh is not otherwise connected the rest of the cask mesh. Contact conditions are specified at the juncture between the two to model the flange.

In step 1 of the analysis, the temperature in the free length of the bolt elements is reduced in order to establish the preload. The axial prestress in the bolts is 12,700 lbf/in^2. The stress distribution of the component of stress normal to the flange is shown in Figure 2.0-3. The stress is dominated by localized effects associated with the bolt elements and by a tensile stress on the inside vertical surface of the lid. The stress level is negligible.

In step 2 of the analysis, the pressure is applied to the inside surface of the cask. A displaced shape of the lid is shown in Figure 2.0-4. The displacements are magnified by a factor of 500 to show the shape. Figures 2.0-5 through 2.0-8 are contour plots of the stress components in the vicinity of the flange. The remainder of the cask is essentially unstressed by the pressure. Figure 2.0-9 is a contour plot of the stress intensity (which is called TRESC in the ABAQUS code). The peak stress intensity is 1500 lbf/in^2. The local stress field associated with the bolts may be ignored.

The peak stress intensity in the lid should be comparable to the stress in the center of a circular plate simply-supported at the edge and loaded by a uniform pressure. This stress is given by:

$$\sigma_{max} = 3\,(3 + \nu)qa^2/(8h^2) = 3(3.3)(150)(12.75)^2/(8(3.5)^2) = 2463 \text{ lbf/in}^2 ,$$

where σ_{max} is the stress, ν is Poisson's ratio, q is the pressure, a is the radius of the plate, and h is the thickness of the plate (Timoshenko 1987). Because the central portion of the lid is not simply-supported, the maximum stress intensity computed numerically is somewhat lower as expected.

3.0 References

Timoshenko, S. and S. Woinowsky-Krieger, 1987, *Theory of Plates and Shells*, McGraw-Hill, New York, New York.

HKS, 1995, *ABAQUS/Standard User's Manual, Vol. I and II*, Hibbit, Karlsson, & Sorensen, Pawtucket, Rhode Island.

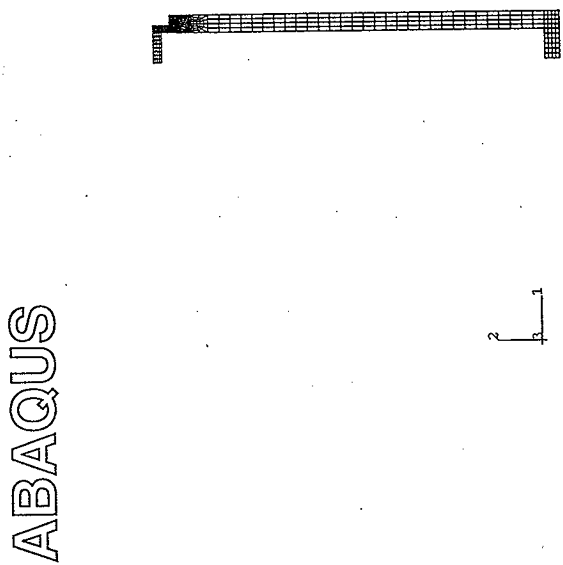

Figure 2.0-1. Cask Mesh

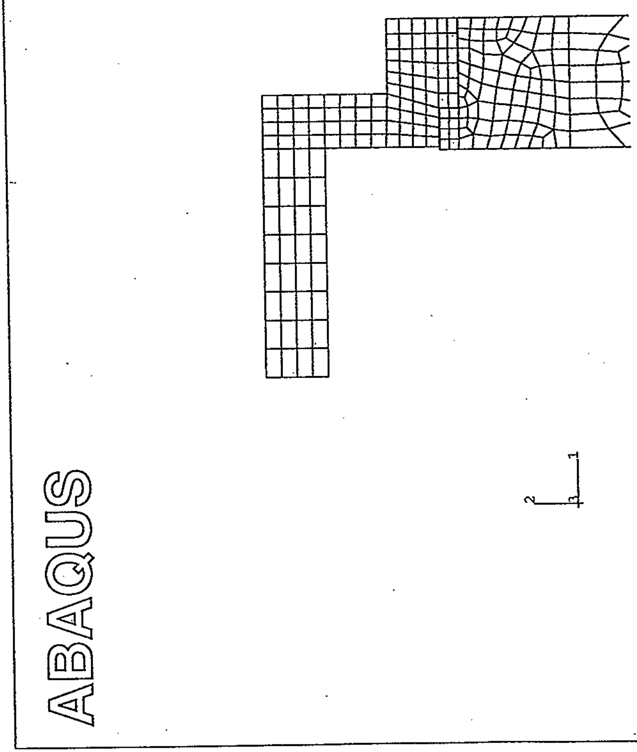

Figure 2.0-2. Lid and Cask Wall

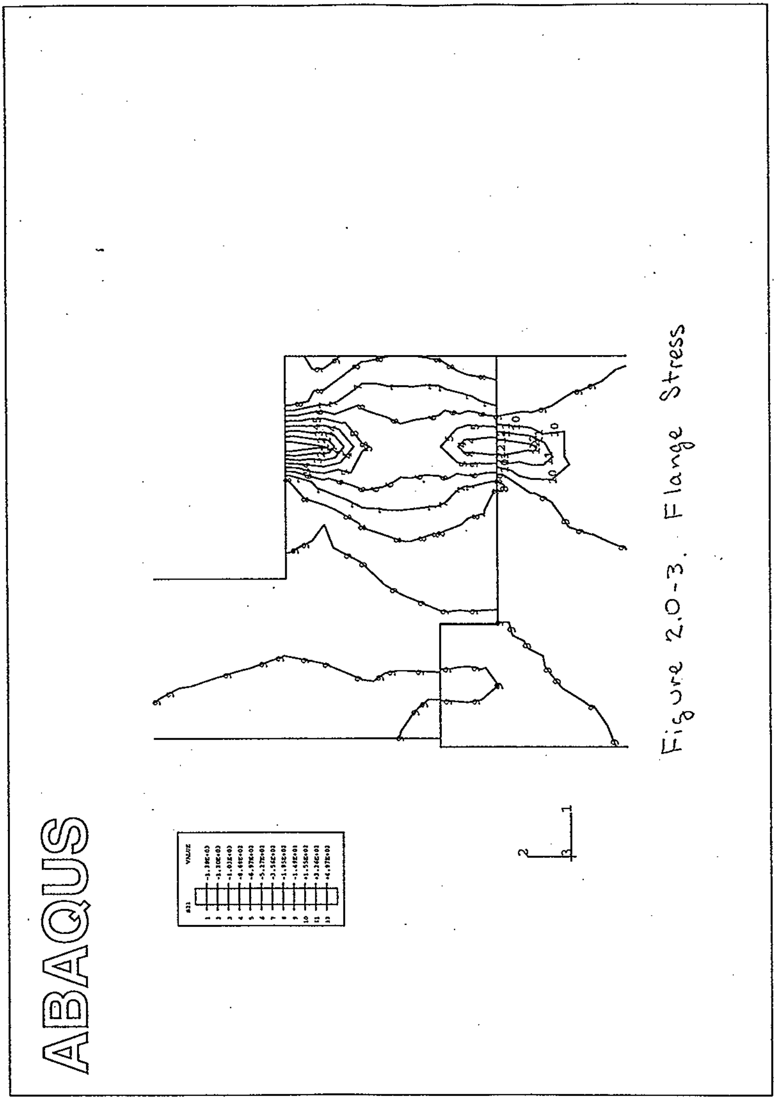

Figure 2.0-3. Flange Stress

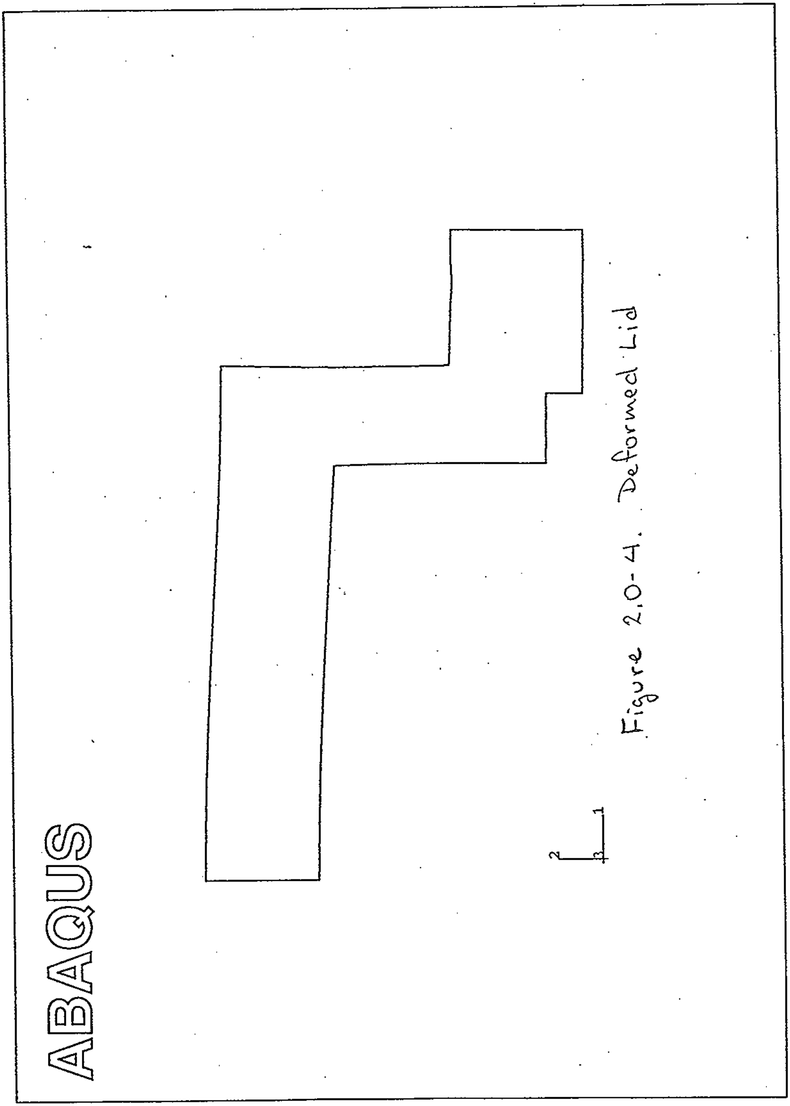

Figure 2.0-4. Deformed Lid

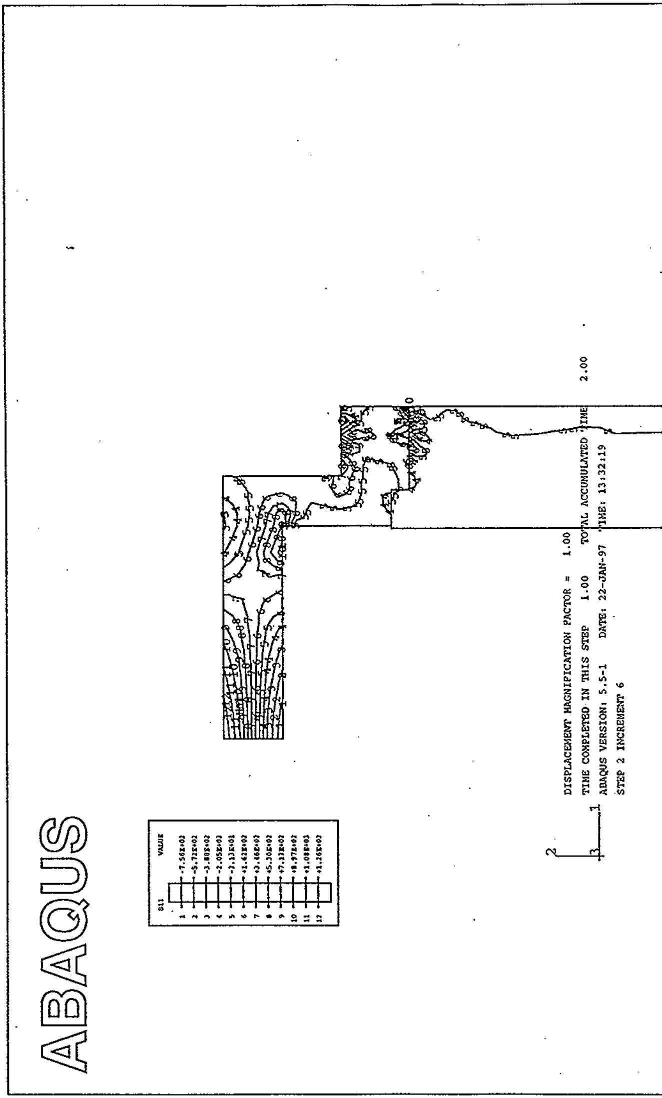

Figure 2.0-5. Stress Component S11.

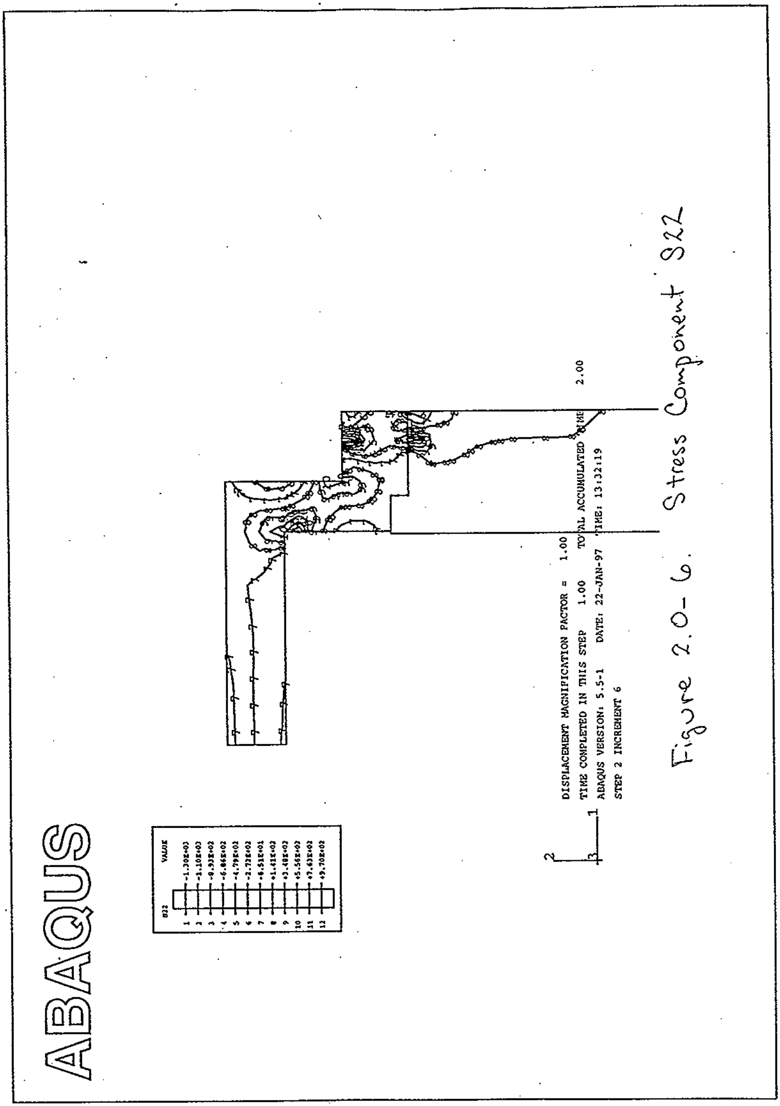

Figure 2.0-6. Stress Component S22

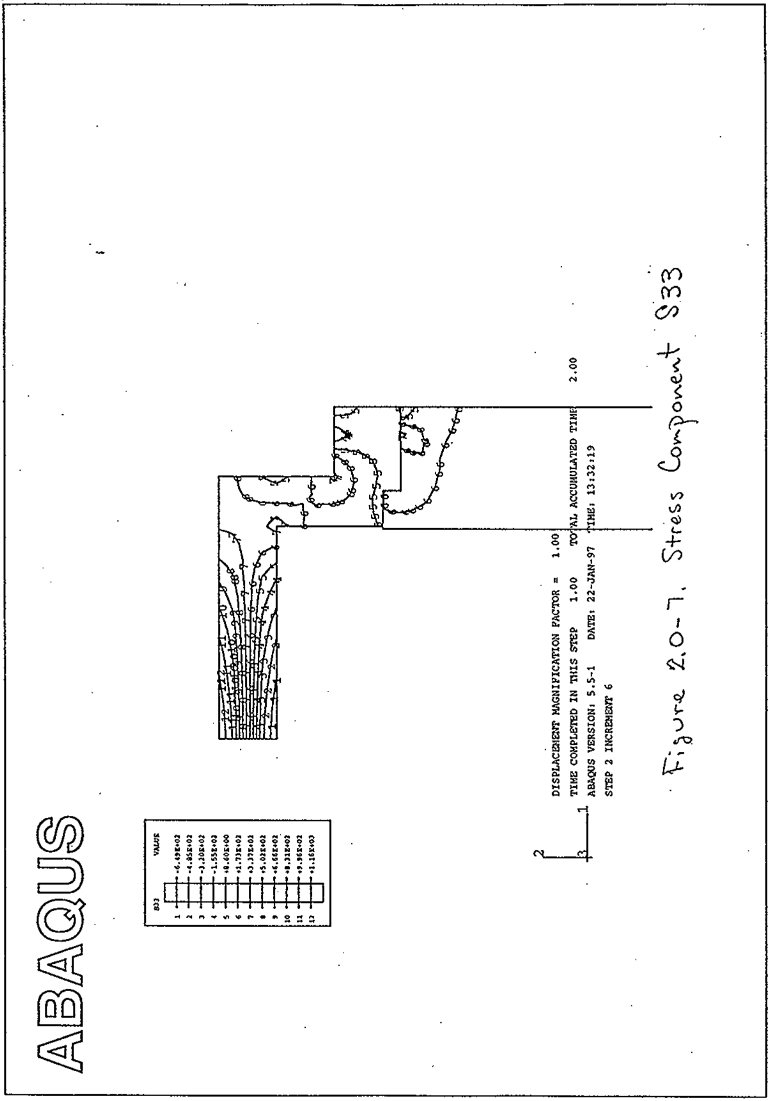

Figure 2.0-7. Stress Component S33

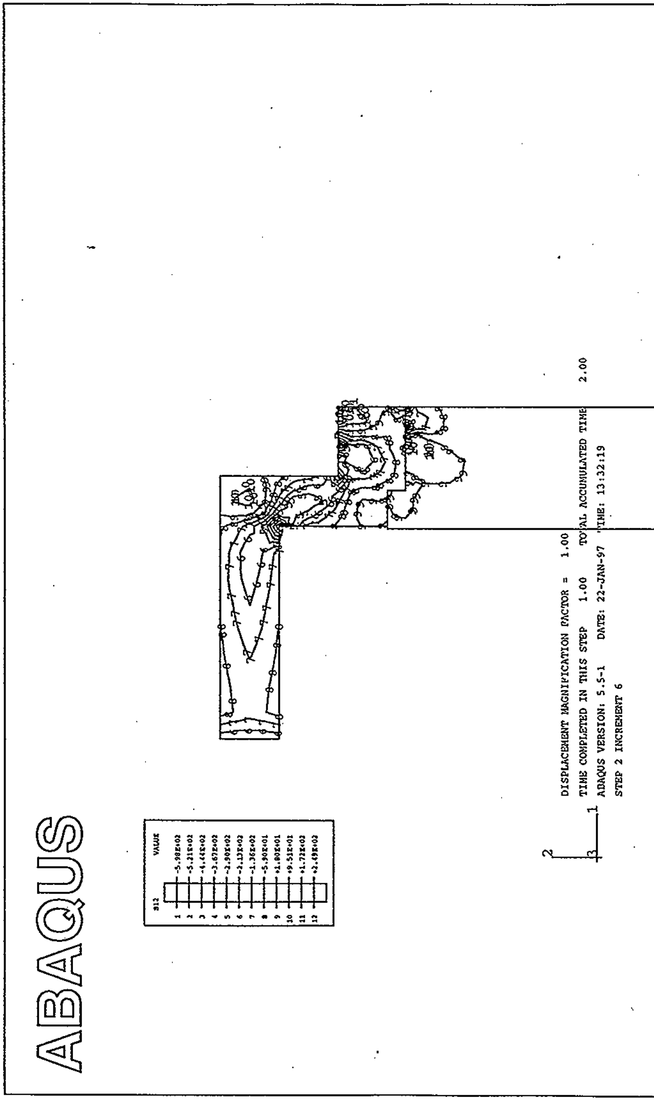

Figure 2.0-8. Stress Component S12

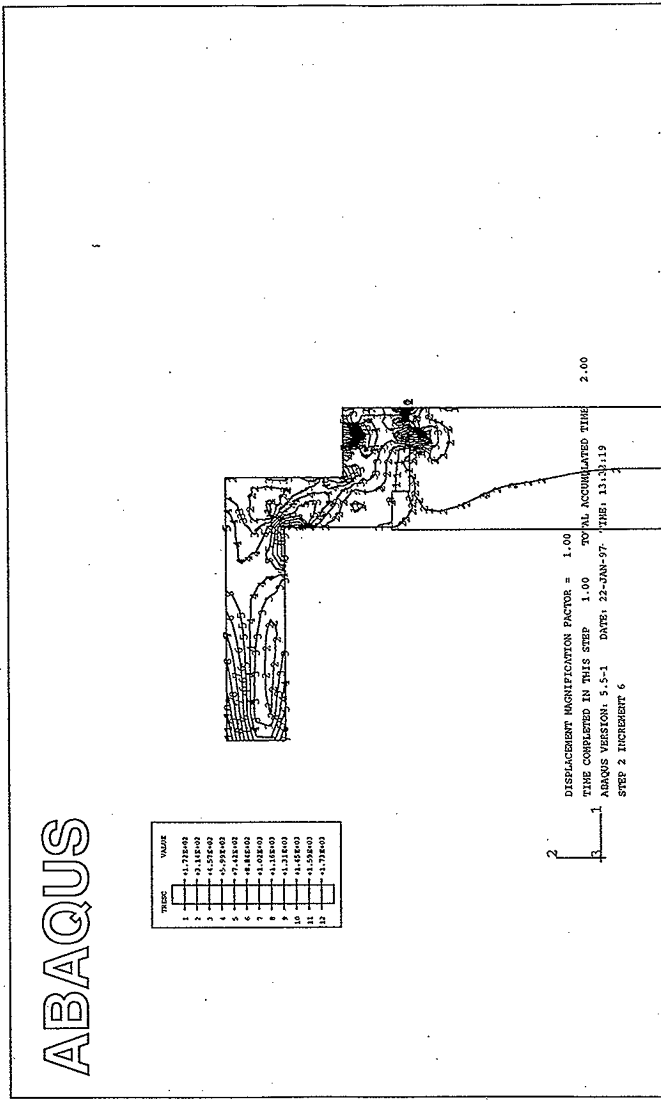

Figure 2.0-9. TRESCA Stress

Attachment A. ABAQUS/Standard Input File

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fsurf,esurf
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Checklist for Checking of Analysis/Calculations

Document Checked - Number: N/A **Revision:** 0

Title: MCO Cask Pressurization Analysis

Yes	No	N/A	
[✓]	[ ]	[ ]	Problem completely defined.
[✓]	[ ]	[ ]	Appropriate analytical method used.
[✓]	[ ]	[ ]	Necessary assumptions are approriate, explicitly stated, and stated.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Sources of non-standard formulae/data are referenced and the correctness of the reference verified.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand calculations checked for errors.
[✓]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[✓]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[ ]	[ ]	Safety Margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

S. N. Huang — *SN Huang* — 1/23/97

Engineer/Checker — Date

Note: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

7.7.4 MCO Cask Thermal Stress Analysis

MCO Cask Thermal Stress Analysis

Randall S. Marlow
1/22/97

1.0 Introduction

This document describes the stress analysis of the MCO cask loaded by an internal pressure of 150 lbf/in^2 and the temperature field at the end of the hypothetical fire accident.

2.0 Analytical Methods and Results

The stress distribution in the cask is computed using the ABAQUS/Standard (HKS 1995) finite-element program. The cask mesh is shown in Figure 2.0-1. A close-up of the mesh of the lid and nearby cask wall is shown in Figure 2.0-2. The ABAQUS input file for the analysis is in Attachment A. The cask is modeled with 4-noded axisymmetric elements. The cask material constitutive model is elastic-plastic with temperature-dependent properties typical of 304 stainless-steel. The bolts which attach the lid to the main body of the cask are modeled as a truss element which has the same cross-sectional area as all twelve bolts combined. The bolting material constitutive model is elastic with temperature-dependent properties typical for the stainless steel bolting material (SA479 XM19 hot-rolled). The shear force at the bolt is carried by a spring element between the horizontal degrees of freedom at the top bolt node and the bottom bolt node. The bolt elements attach the lid mesh to the main mesh of the cask. The lid mesh is not otherwise connected the rest of the cask mesh. Contact conditions are specified at the juncture between the two to model the flange.

In step 1 of the analysis, the temperature in the free length of the bolt elements is reduced in order to establish the preload. The axial prestress in the bolts is 12,700 lbf/in^2. The stress distribution of the component of stress normal to the flange is shown in Figure 2.0-3. The stress is dominated by localized effects associated with the bolt elements and by a tensile stress on the inside vertical surface of the lid. The stress level is negligible.

In step 2 of the analysis, a pressure of 150 lbf/in^2 is applied to the inside surface of the cask. In step 3 of the analysis, the temperature distribution is applied to the cask. The temperature distribution in the bolt is scaled to compensate for the preload. A field variable is used to adjust the bolt material properties to the applied temperature. The axial stress in the bolt is 31,440 lbf/in^2. The shear stress in the bolt is 4010 lbf/in^2.

3.0 References

HKS, 1995, *ABAQUS/Standard User's Manual, Vol. I and II*, Hibbit, Karlsson, & Sorensen, Pawtucket, Rhode Island.

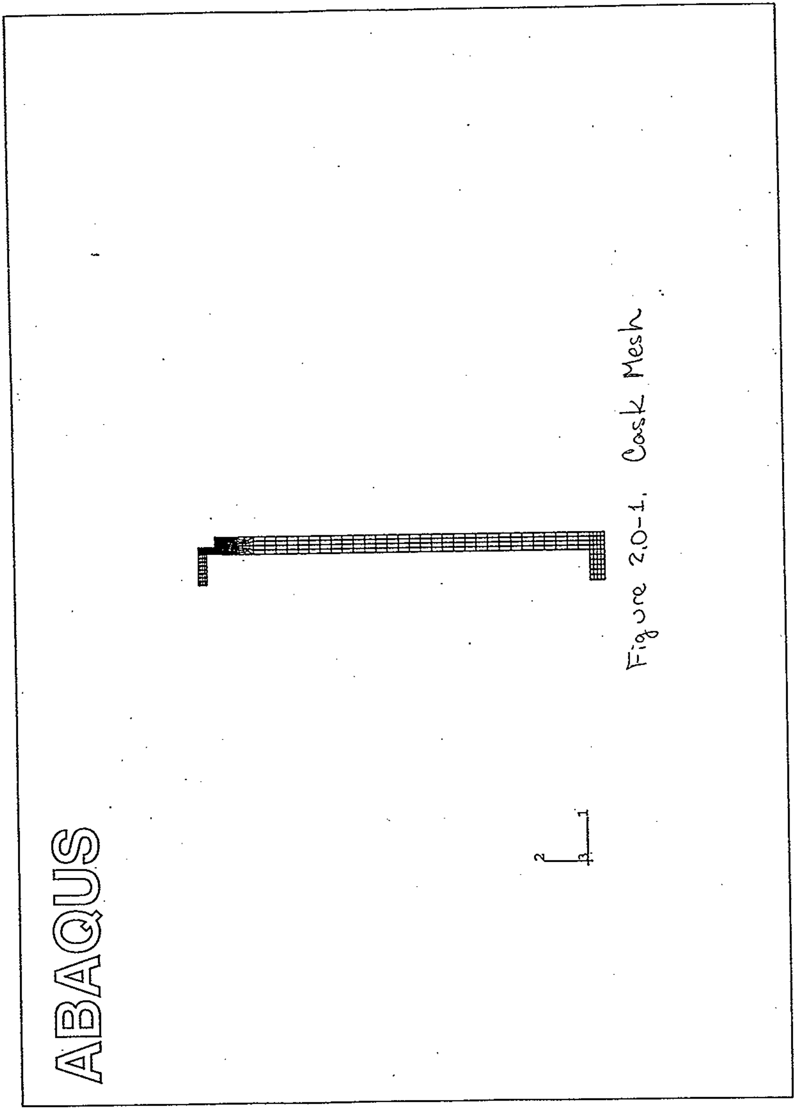

Figure 2.0-1. Cask Mesh

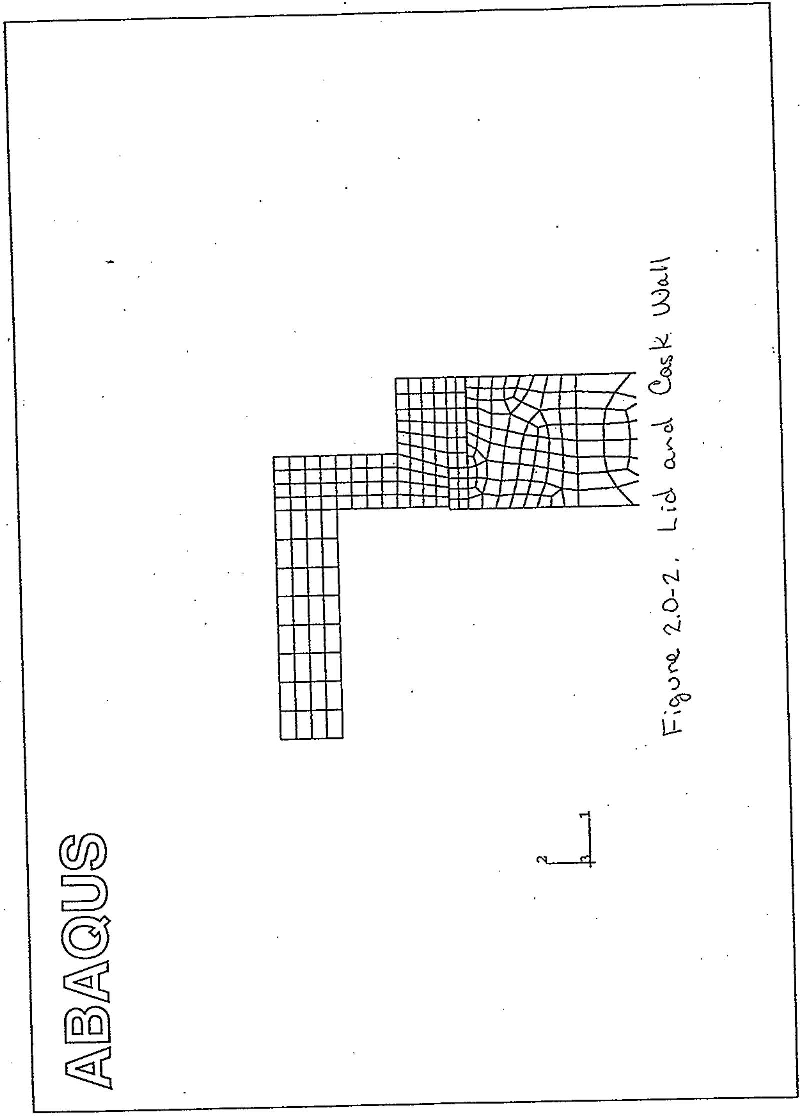

Figure 2.0-2. Lid and Cask Wall

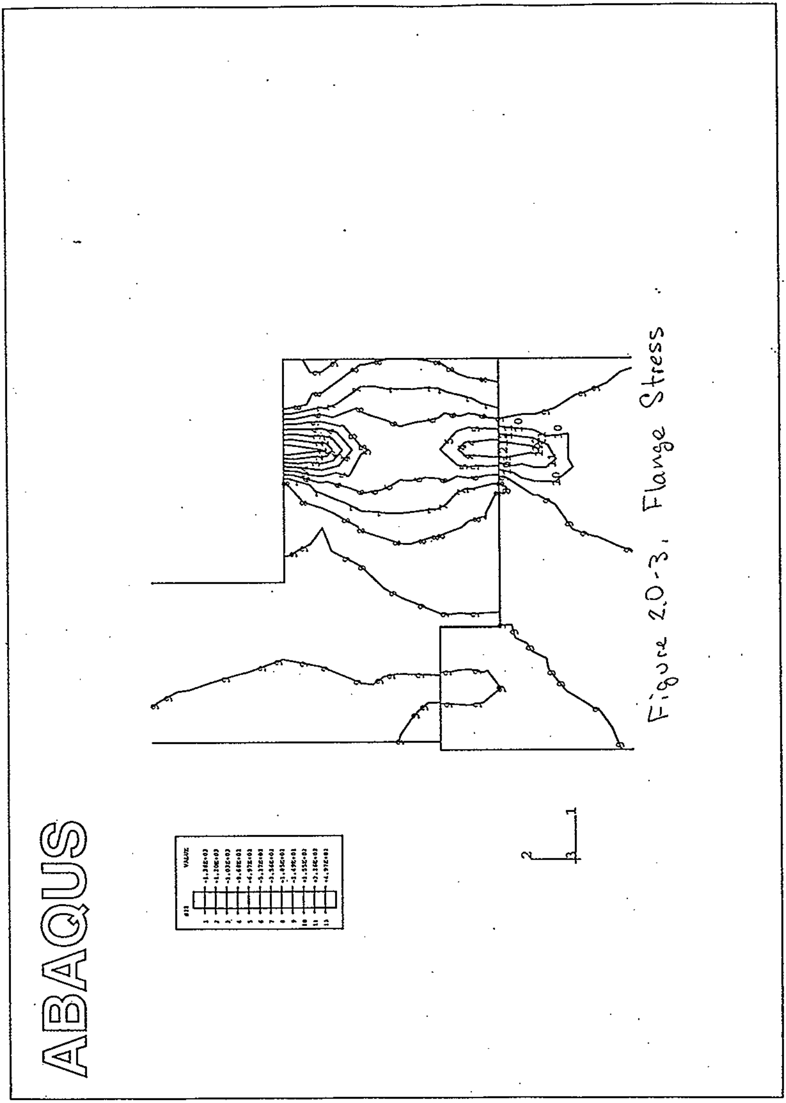

Figure 2.0-3, Flange Stress

Attachment A. ABAQUS/Standard Input File

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Checklist for Checking of Analysis/Calculations

Document Checked - Number: N/A **Revision:** 0

Title: MCO Cask Thermal Stress Analysis

Yes	No	N/A	
[✓]	[ ]	[ ]	Problem completely defined.
[✓]	[ ]	[ ]	Appropriate analytical method used.
[✓]	[ ]	[ ]	Necessary assumptions are approriate, explicitly stated, and stated.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Sources of non-standard formulae/data are referenced and the correctness of the reference verified.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand calculations checked for errors.
[✓]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[✓]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[ ]	[ ]	Safety Margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

S. N. Huang *SN Huang* 1/23/97

Engineer/Checker Date

Note: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

7.7.5 MCO Structural Integrity Analysis

MCO Analyses

Randall S. Marlow
11/12/96

1.0 Introduction

This document describes analyses of the MCO scrap baskets for loads caused by hypothetical drop accidents. The analyses include an analysis of the stack of six MARK IA baskets under a vertical inertial load, a crushing analysis of one MARK IA scrap basket under a horizontal inertial load, and a buckling analysis of the MCO itself under a vertical acceleration.

2.0 Analyses

2.1 Buckling Under a Vertical Inertial Load

Figure 2.1-1 shows the ABAQUS/Standard (HKS 1995) finite-element model which was used to determine the deformation of the stack of baskets under a vertical inertial load. The ABAQUS/Standard input file for the static analysis of the basket stack under a vertical inertial load is in Attachment A. The center tube is modeled with two-noded B21 beam elements. The basket plates and the fuel are modeled as mass elements lumped on nodes along the length of the center tube. The mass elements appear as squares in Figure 2.1-1. Each mass weighs 2,055 lbf in the standard gravitational field. The center tube material is an elastic-plastic material with hardening that is typical of 304 or 304L stainless steel. The center tube is pinned at the bottom node and restrained in the horizontal degree-of-freedom at the top node. A rigid surface runs the length of the center tube at a distance of 0.5 in. from the bottom and top nodes. Contact is enforced between the rigid surface and the nodes which have lumped masses. The contact is designed to model the interaction of the stack of baskets and the lateral surface of the MCO as the baskets deflect horizontally.

The nodes along the center tube are defined in such a way that its undeformed shape is the first buckled shape of a perfectly straight center tube under a vertical inertial load. The maximum imperfection is approximately 0.25 in. off-center. Thus, as a vertical inertial load is applied, the center tube deflects horizontally until contact develops along the rigid surface.

The vertical inertial load applied in this analysis is 44.56g. MCO Cask analyses show that the vertical acceleration of a loaded cask dropped on a concrete slab averages 27g. The dynamic analysis of a basket stack under a uniform acceleration of 27g shows that the compressive force in the bottom of the center tube reaches 457,890 lbf. This analysis is described in Section 2.1.1. Because the mass above the bottom of the center tube is comprised of the mass of five baskets, the dynamic amplification is 457,890/(5*2055*27) = 1.65. An inertial load of $1.65 \times 27g = 44.56g$ is applied to the entire stack of baskets. The inertial load is applied slowly over a 10 second interval to obtain the quasi-static solution.

Figure 2.1-2 shows the deflected shape of the center tube. Obviously, the maximum horizontal deflection does not exceed the initial gap size between the center tube and the rigid surface. Figure 2.1-3 is a contour plot of the axial compressive force in the center tube under the full inertial load. The maximum force indicated by the contour plot is 456,000 lbf. (The maximum is slightly less than the expected value of 457,890 lbf due to averaging effects.) The maximum occurs at the bottom. Figure 2.1-4 is a contour plot of the shear in the center tube. The maximum shear of 5,880 lbf also occurs at the bottom. Figure 2.1-5 is a contour plot of the bending moment in the center tube. The maximum moment is 117,000 in-lbf and it occurs near the middle of the stack.

Figure 2.1-6 is a plot of the maximum deflection along the center tube as the inertial load is increased beyond the 44.56g level. The column experiences large uncontrolled deflections at approximately 50g. At a quasi-static 81g (or dynamic 49g), the center tube deflects 2 in. The basket stack design is adequate per ASME Code Case N-284-1 (ASME 1995). In this code case, a minimum multiple of 1.2 times the initial prebuckling stress state is recommended for a buckling stress-state. The minimum multiple for the basket stack is calculated to be 3 times the stress-state induced by the quasi-static inertial load of 44.56g. The buckling load was calculated using the ABAQUS/Standard input file which appears in Attachment B.

2.1.1 Dynamic Analysis of Basket Stack

The finite-element model described in Section 2.1 was modified and used in a dynamic analysis in order to determine a dynamic amplification for the static analysis. In the dynamic analysis, the basket stack does not have an initial imperfection, the nodes have initial downward speed of 527.45 in/s, and the bottom node is accelerated upward at a constant 27g until it is brought to rest. The initial speed corresponds to a drop height of 30 ft. Figure 2.1.1-1 is a time history plot of the compressive force in the bottom of the center tube. The force reaches a maximum value of 457,890 lbf at approximately 7 msec. The ABAQUS/Standard input file for the dynamic analysis appears in Attachment C.

2.2 Horizontal Analysis of Scrap Basket

Figure 2.2-1 shows the finite-element model of the scrap basket and the MCO shell. The mesh of the basket is constructed of four-noded shell elements. The basket material is an elastic-plastic material with hardening that is typical of 304 or 304L stainless steel. The MCO shell is constructed of rigid elements fixed in space. Contact is enforced between the basket shell and the MCO shell. Two nodes, one at either end of the center tube, are tied together with a multi-point constraint which limits the rotation of the tube as the inertial load is applied. The use of this constraint is based on the assumption that the ends of an actual basket stack are constrained during a horizontal drop. Prototype drawings indicate that this is the case (Robinson 1996). Attachment D contains the ABAQUS/Standard input file for the horizontal analysis.

Because the fuel distribution in the scrap basket is not know, the load is applied by increasing the g-level on an empty basket to such an extent that the total inertial load on the basket is 1.65×2055 lbf $\times$ 58g = 197,000 lbf. The load application is extremely conservative and overestimates the deformation. In an actual scrap basket, most of the load will be reacted as a bearing pressure against the MCO wall whereas most of the load in the finite-element model is "hanging" from the basket shell and the center tube.

Figure 2.2-2 shows the deformed shape of the scrap basket. The deformation has been magnified by a factor of 3. The buckling of the basket webs is evident. Figure 2.2-3 is a contour plot of the deflection in the center tube in the direction of the inertial load. The maximum deflection is 0.44 in. Figures 2.2-4, 2.2-5, and 2.2-6 are contour plots of the stress intensity in the center pipe at the inner surface, the middle surface, and the outer surface, respectively. The maximum stress intensity is 60,200 lbf/in^2 and it occurs on the outer surface. However, this extreme stress is a local effect of the multi-point constraint described above and may not be representative of the actual stress near the ends of the center tube. The stress intensity in the center of the tube is in the neighborhood of 20,000 lbf/in^2.

Figures 2.2-7 through 2.2-12 show the stress intensities through the basket shell and base plate. The maximum stress intensity in these components is 50,200 lbf/in^2 and it occurs in a wrinkle which develops in the base plate.

2.3 Buckling of the MCO Under a Vertical Acceleration

The MCO cannot buckle elastically. The Euler buckling load, as computed with the ABAQUS/Standard model listed in Attachment E, is in excess of 4,000g. The average axial stress in the MCO shell under a 27g vertical acceleration is negligible, even with a dynamic ampllification of 2.

3.0 References

HKS, 1995, *ABAQUS/Standard User's Manual, Vol. I and II*, Hibbit, Karlsson, & Sorensen, Pawtucket, Rhode Island.

Robinson, L. J., 1996, *MCO Prototype Mechanical Closure Assembly*, Drawing SK-2-300461, U. S. Department of Energy, Richland Field Office, Richland, Washington.

ASME, 1995, *Code Cases, Nuclear Components*, American Society of Mechanical Engineers, New York, New York.

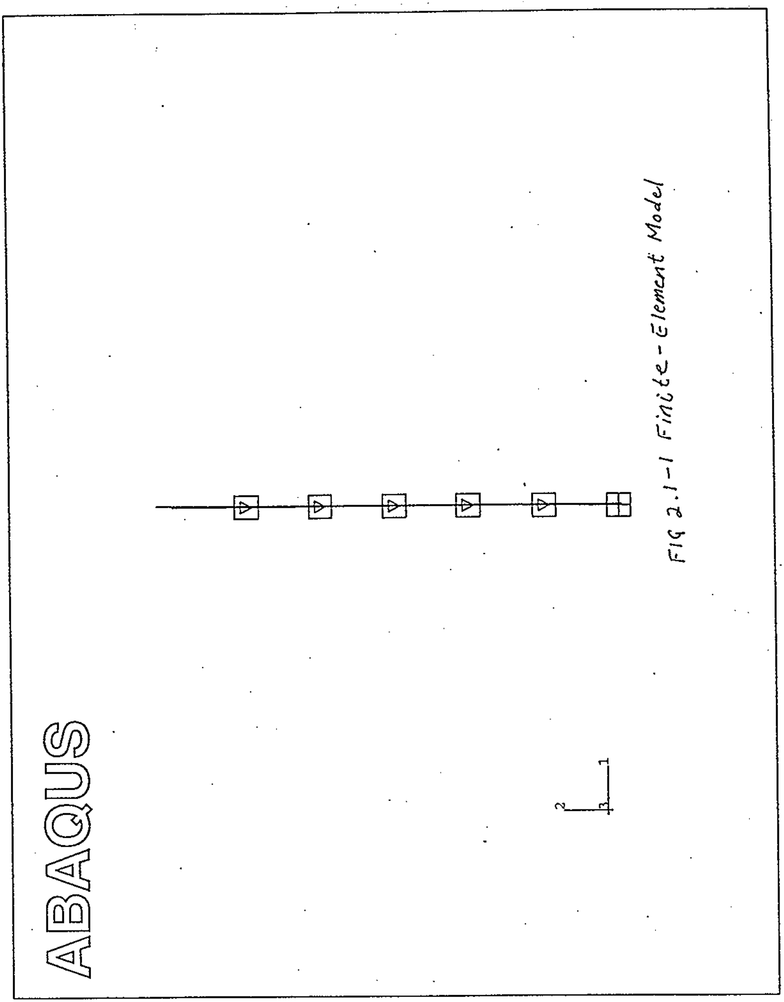


FIG 2.1-1 Finite-Element Model

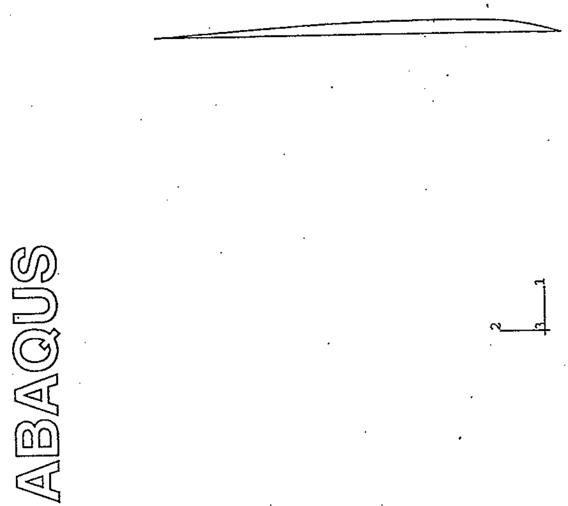


Figure 2.1.2. Deflection Center Tube

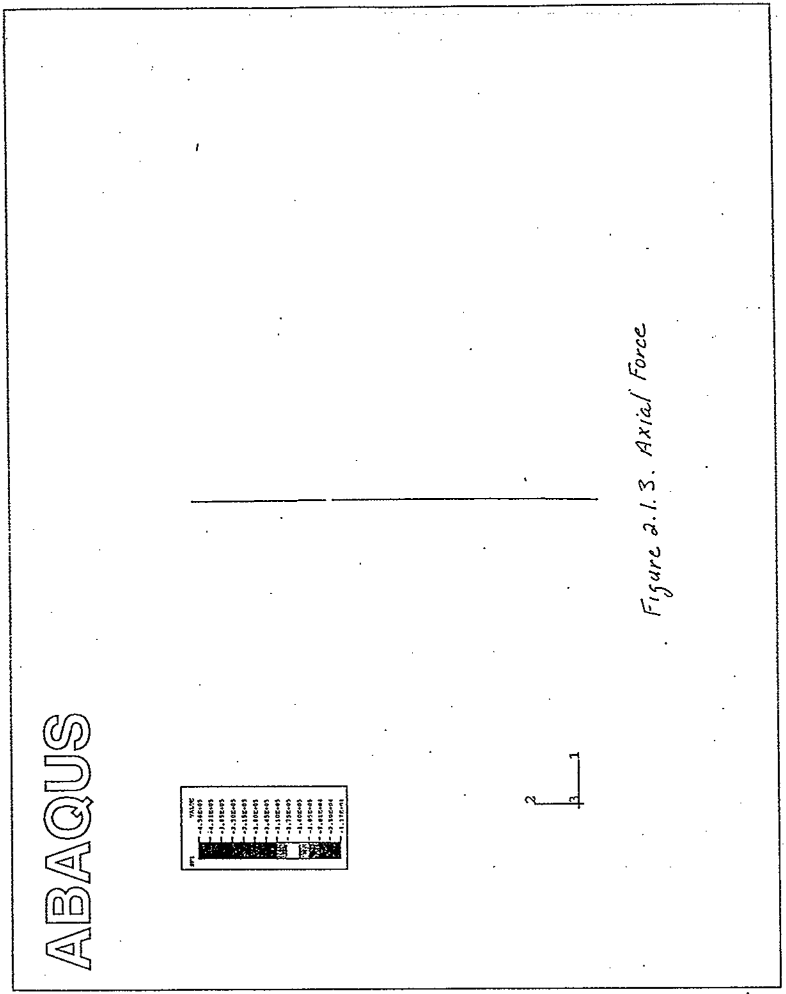


Figure 2.1.3. Axial Force

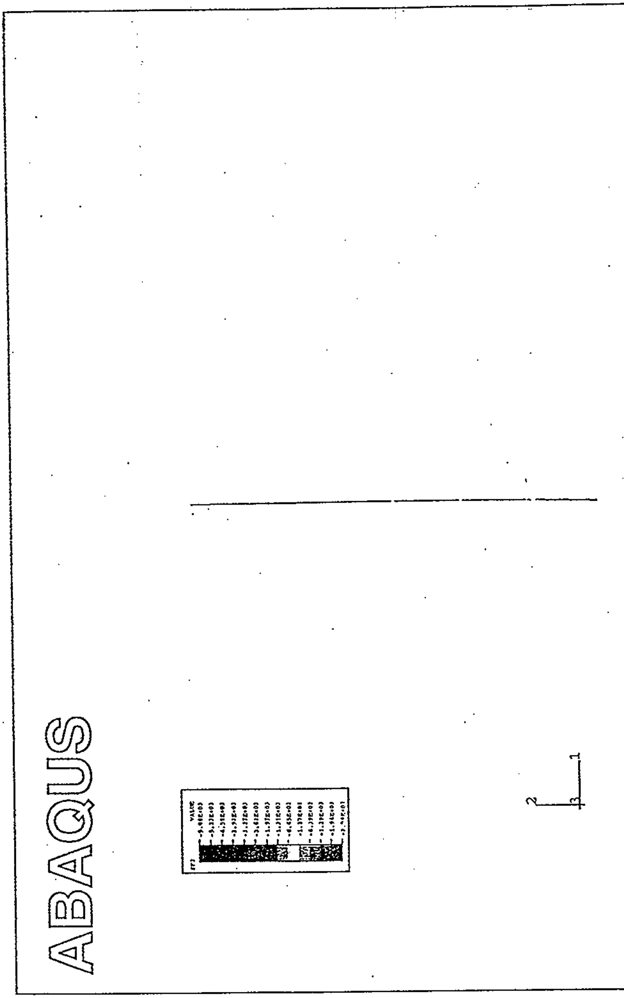


Figure 2.1.4. Shear Force

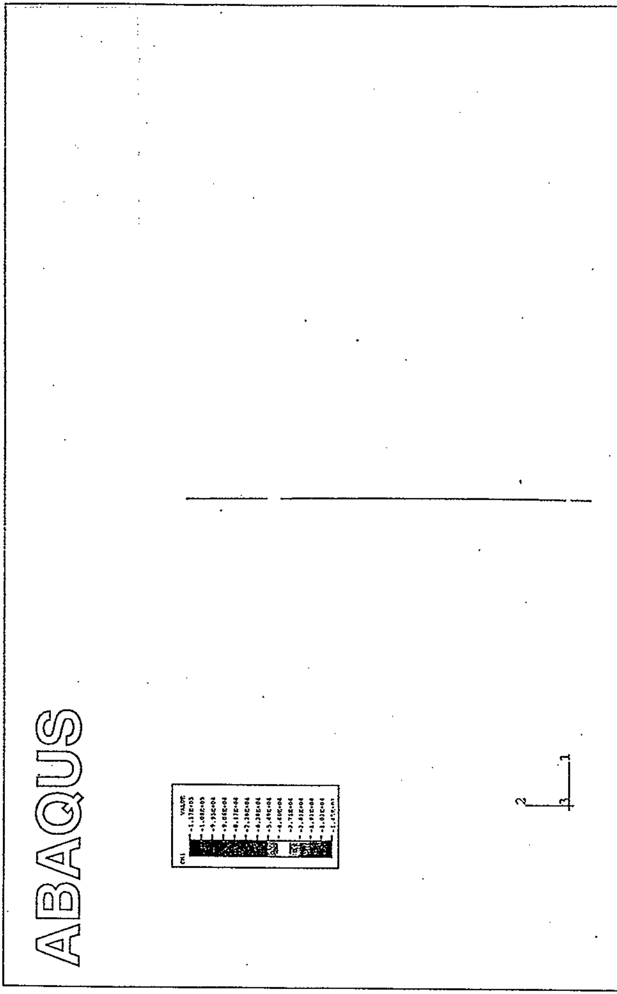


Figure 2.1-5 Bending Moment

Figure 2.1-6. Maximum Lateral Delection of Center Tube Under Vertical Inertial Load

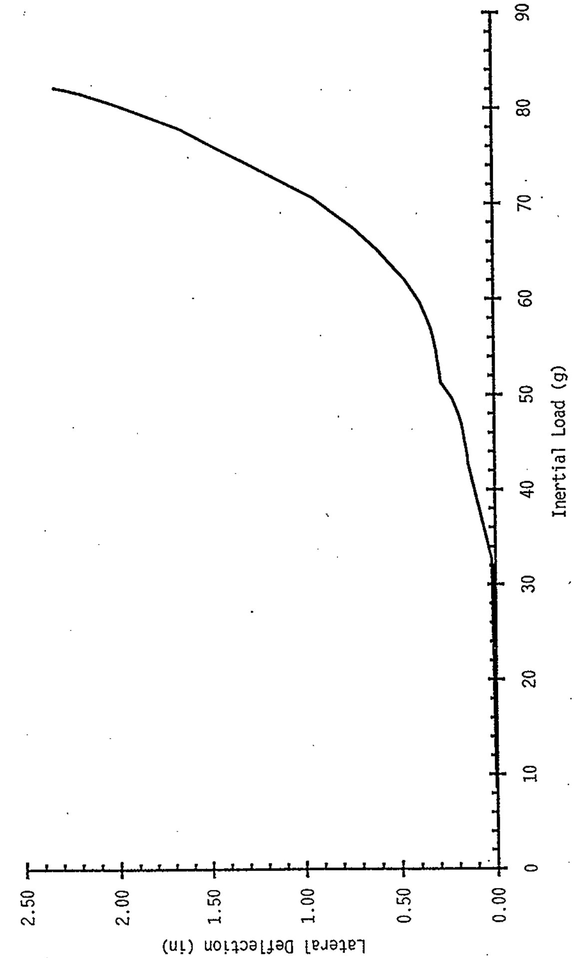
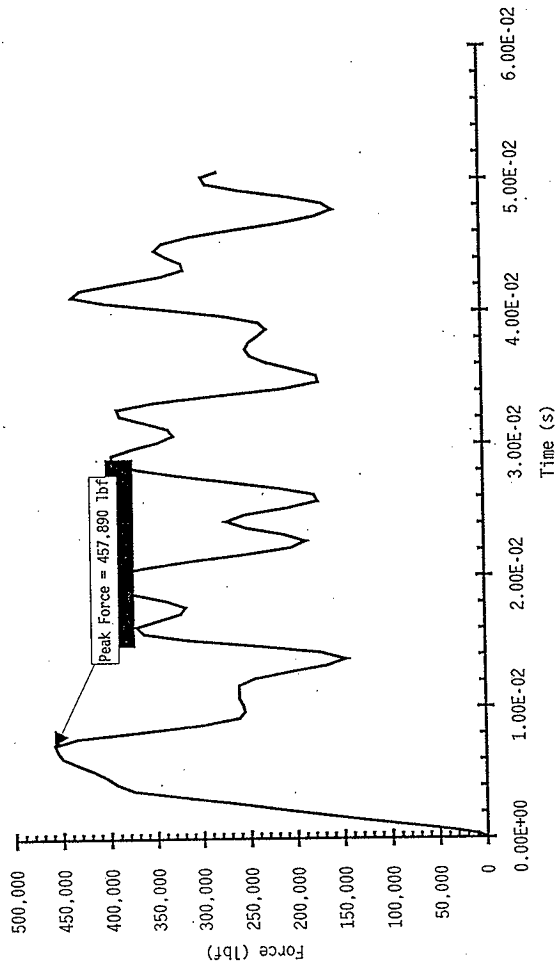


Figure 2.1.1-1. Compressive Force in Bottom Tube



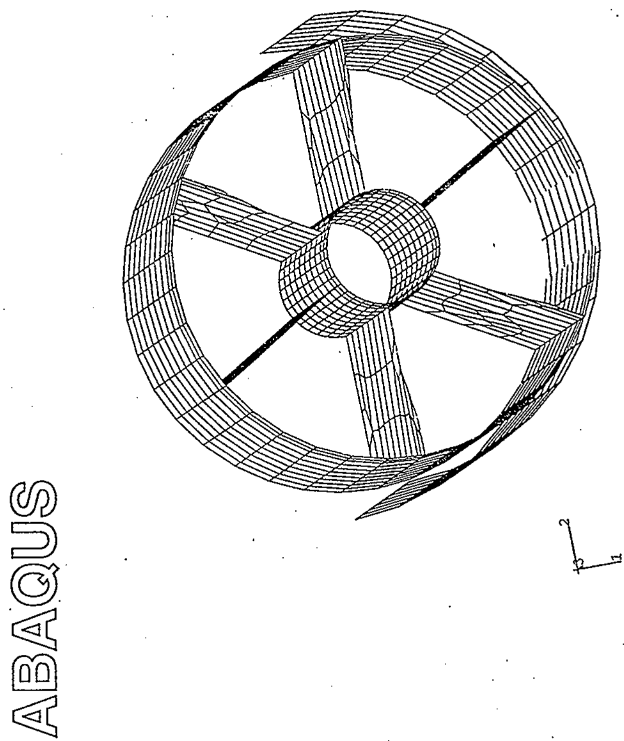


Figure 2.2-1. Finite-Element Model

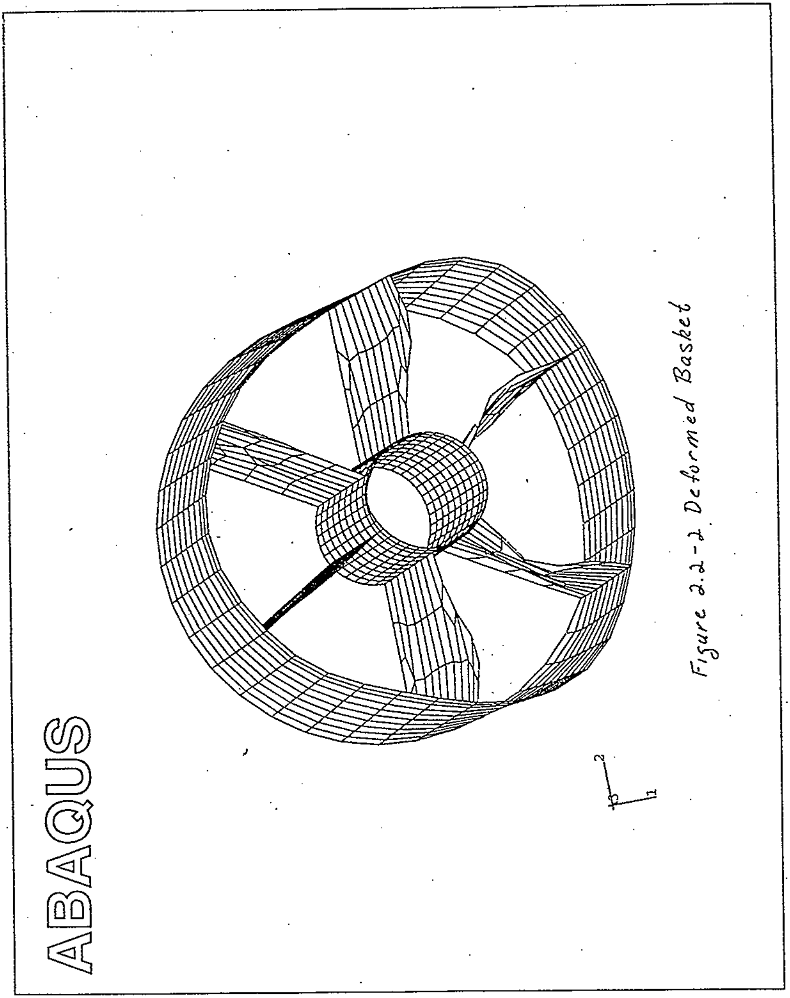


Figure 2.2-2 Deformed Basket

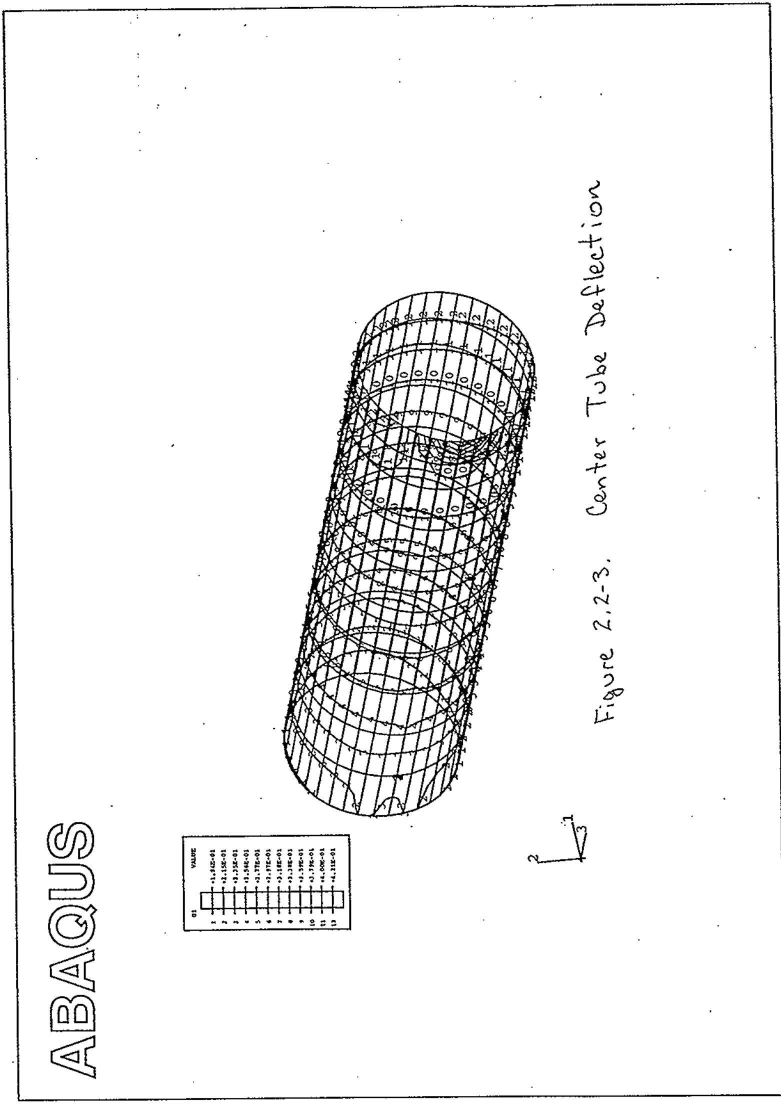


Figure 2.2-3. Center Tube Deflection

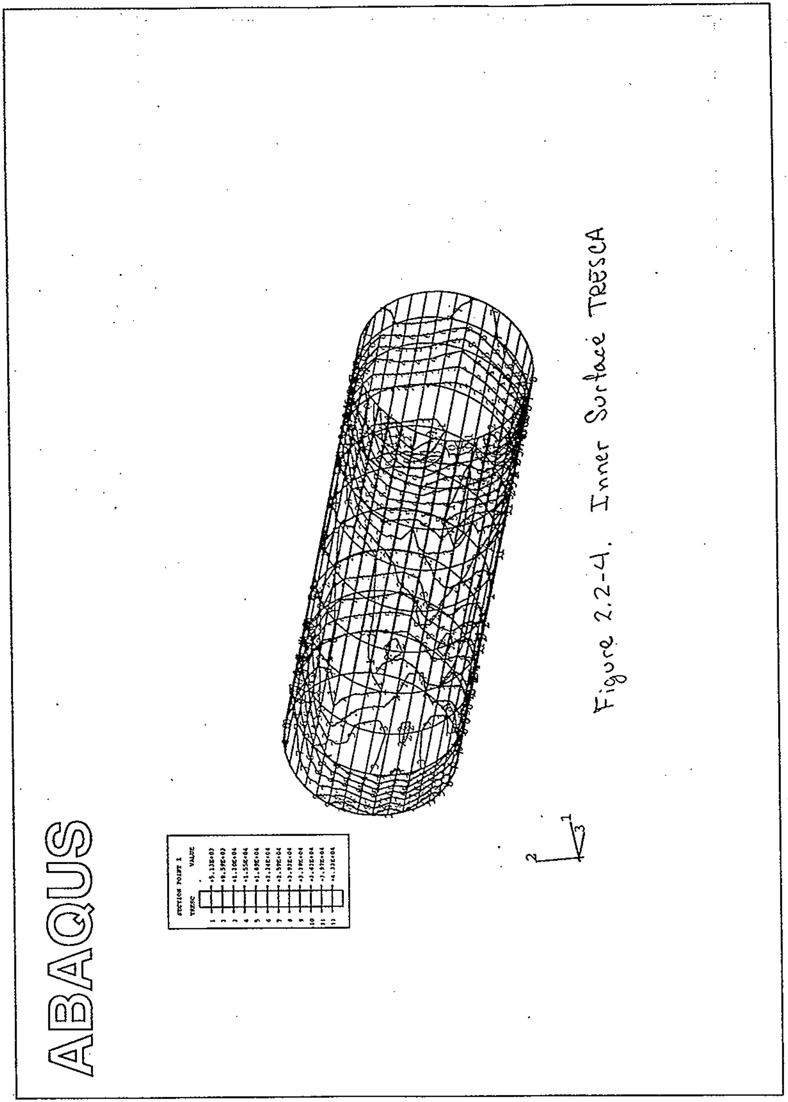


Figure 2.2-4. Inner Surface TRESCA

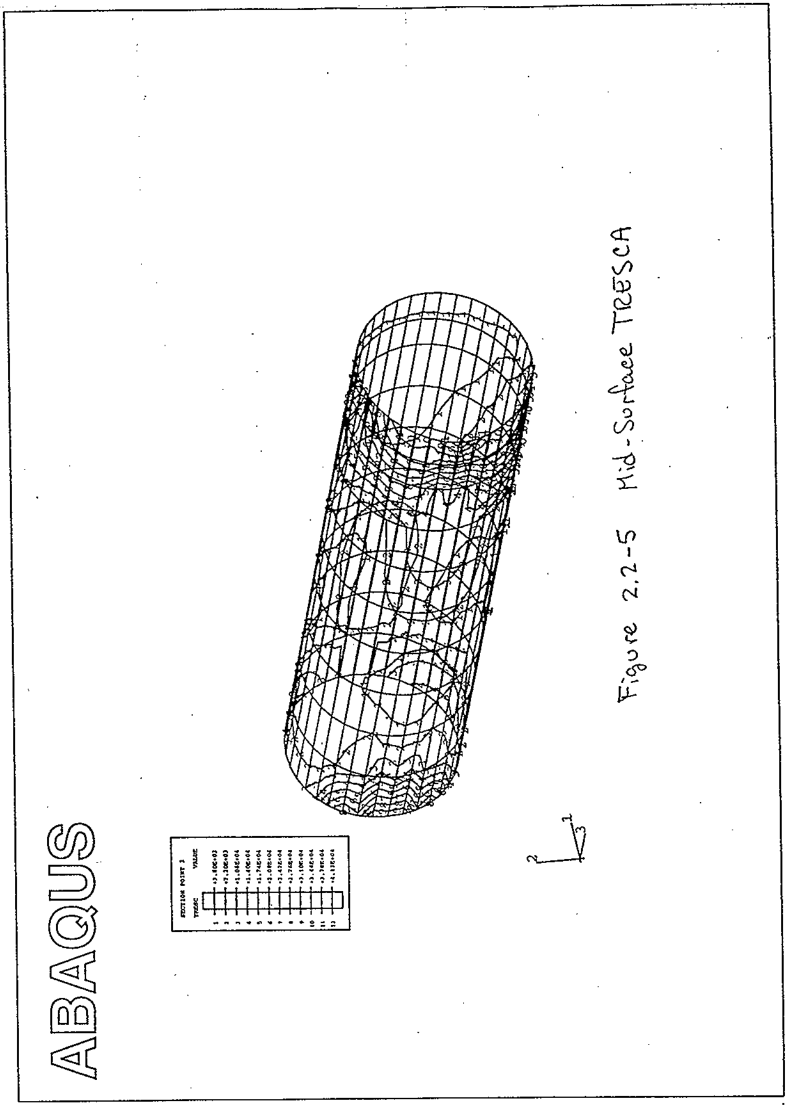


Figure 2.2-5 Mid-Surface TRESCA

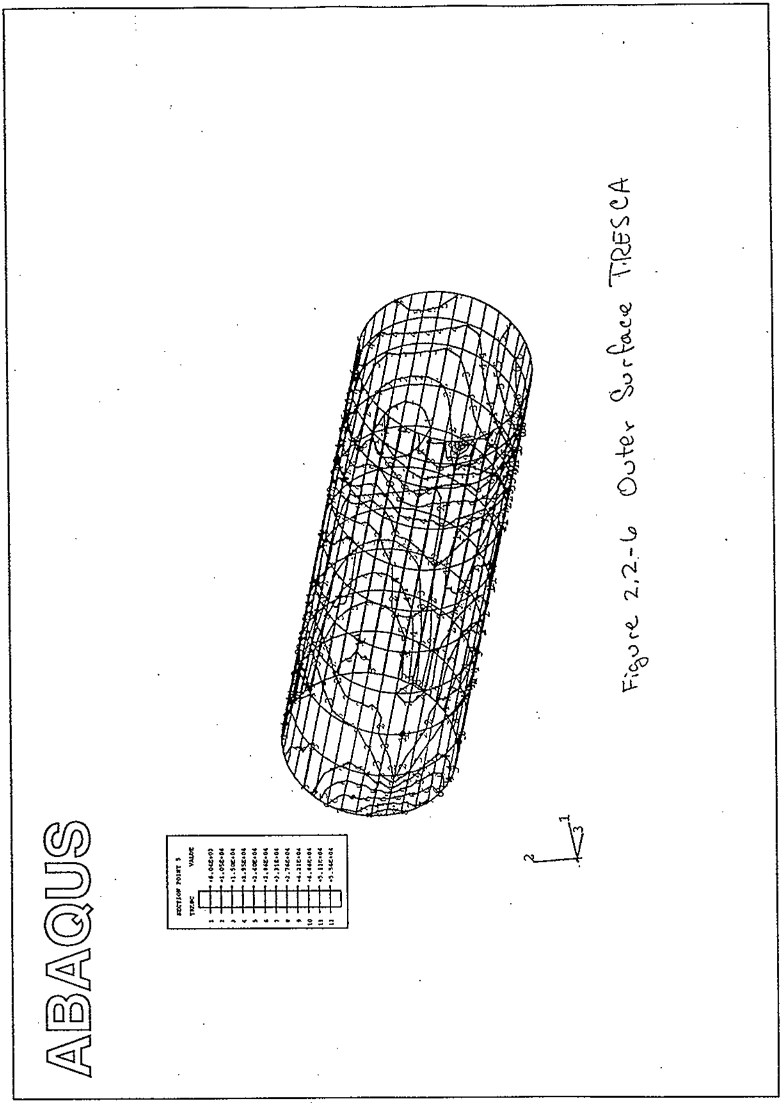


Figure 2.2-6 Outer Surface TRESCA

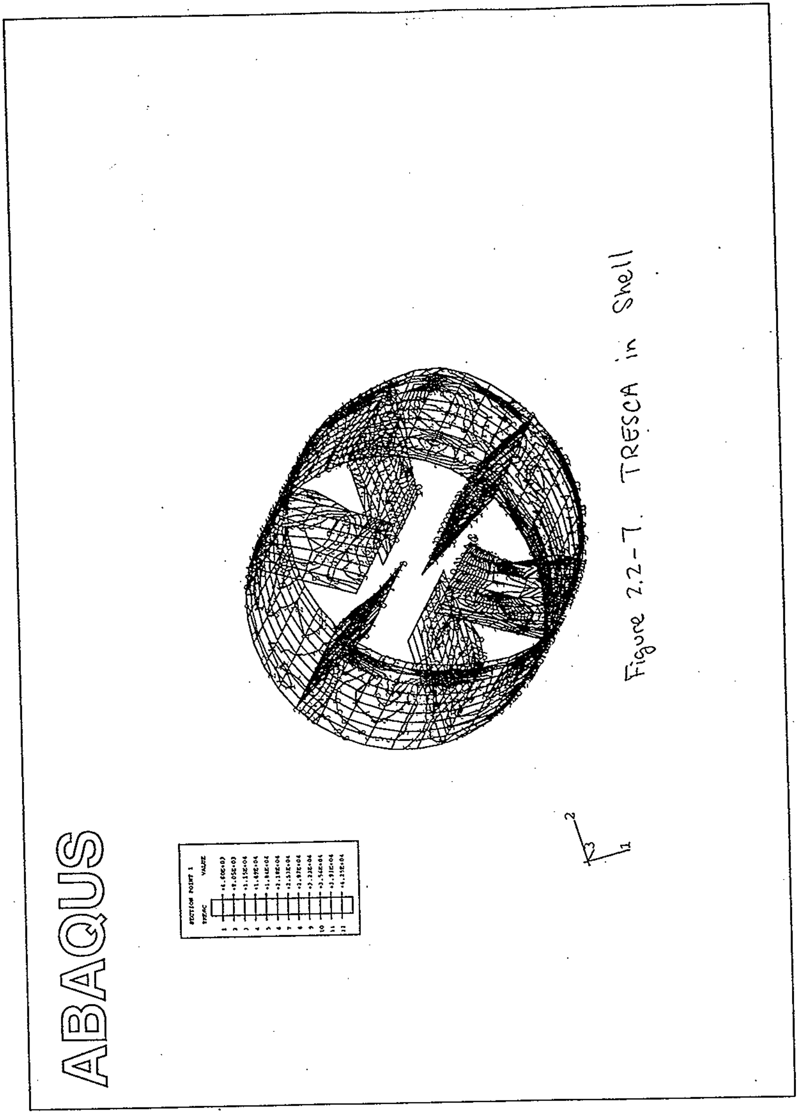


Figure 2.2-7. TRESCA in Shell

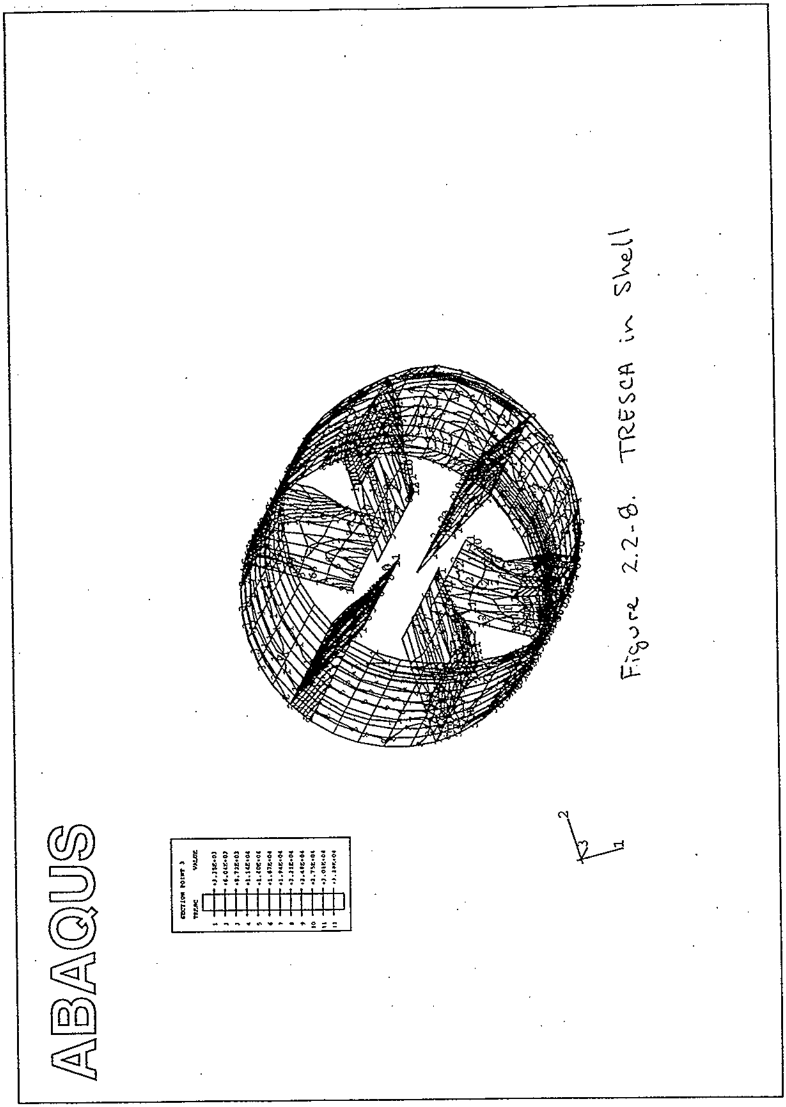


Figure 2.2-8. TRESCA in Shell

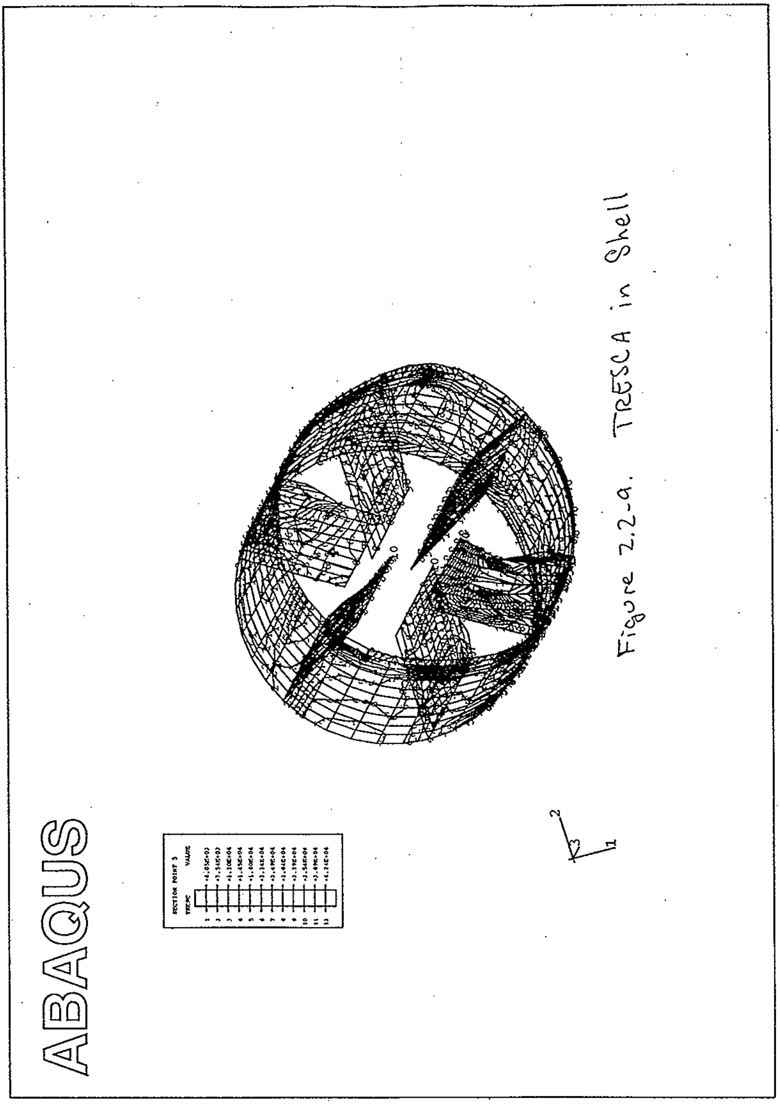


Figure 2.2-9. TRESCA in Shell

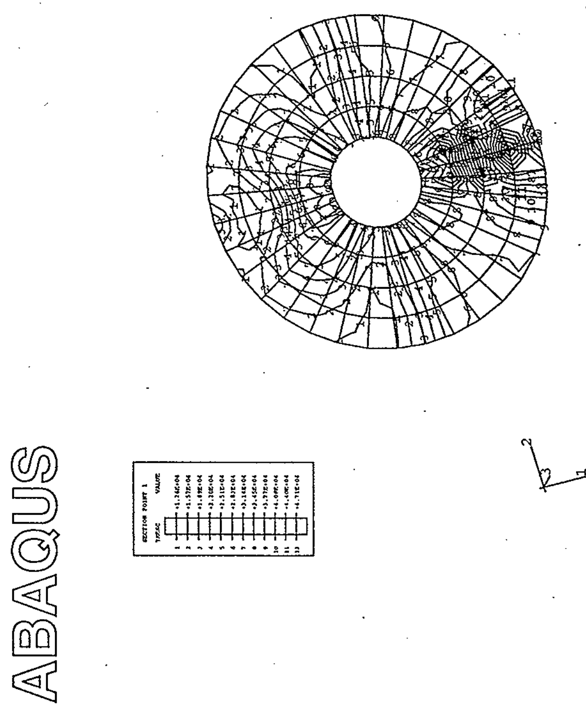


Figure 2.2-10. TRESCA in Base Plate

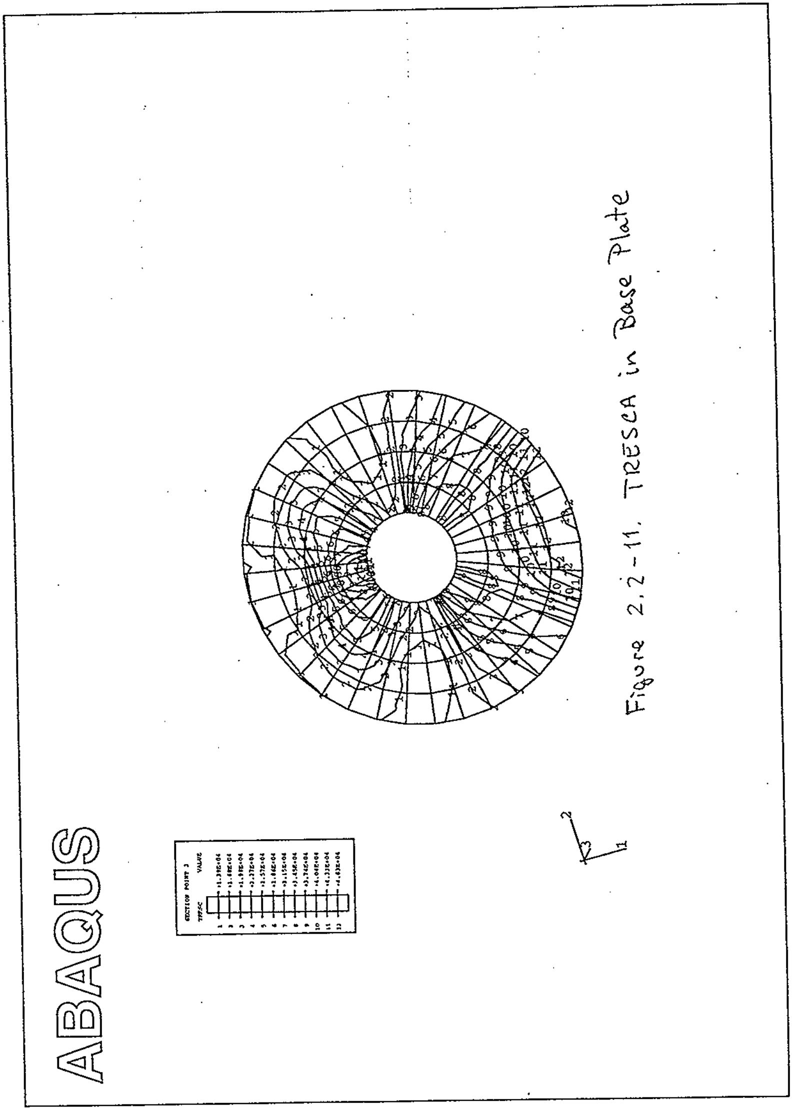


Figure 2.2-11. TRESCA in Base Plate

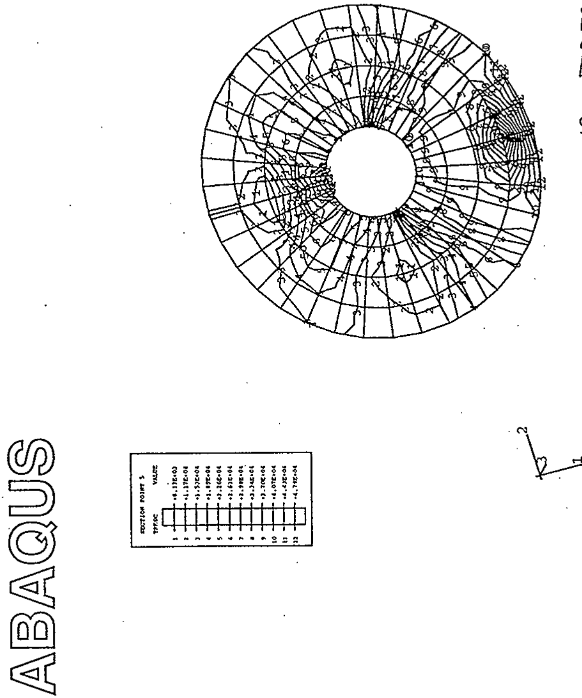


Figure 2.2-12. TRESCA in Base Plate

Attachment A. ABAQUS/Standard Input File for Vertical Analysis

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32,0.27479,69.75
33,0.27139,72
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36,0.257143,78.75
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39,0.237417,85.5
40,0.229746,87.75
```

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47,0.164413,103.5
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49,0.142748,108
50,0.131564,110.25
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9
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1000,1,6
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*surface behavior,no separation
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Attachment B. ABAQUS/Standard Input File for ASME Buckling Analysis

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Attachment C. ABAQUS/Standard Input File for Determination of Dynamic Amplification

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*elastic
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114663,0.403242
117518,0.427469
*beamsection,elset=ctube,material=ssteel,section=pipe
3.3125,0.864

9
*mass,elset=mass
5.3
*boundary
1,1,1
61,1,1
*initial conditions,type=velocity
all,2,-527.45
*restart,write,freq=1
*step,inc=999,nlgeom
*dynamic,haftol=1.E+06
0.0001,0.05056,,0.0005
*boundary,type=acceleration
1,2,2,10432.8
*elprint,freq=0
*nodeprint,freq=0
*monitor,dof=1,node=5
*end step
```

Attachment D. ABAQUS/Standard Input File for Horizontal Basket Analysis

(Note: An ellipsis denotes the omission of lengthy node or element definitions.)

```
*heading
horizontal basket analysis
*node,nset=bnodes
1,0.00000E+00,-6.2500,19.250
...
1058,-8.6180,7.2314,16.844
*node,nset=cnodes
174,9.7428,5.6250,0.00000E+00
...
848,1.9535,11.079,16.844
*node
5000,0,0,0
...
5153,1.1207,12.351,20.875
*element,type=r3d4,elset=rigid
5001,5001,5003,5033,5026
...
5128,5153,5097,5090,5104
*rigid body,elset=rigid,ref node=5000
*element,type=mass,elset=mass
7500,5000
*mass,elset=mass
1.0
*element,type=rotaryi,elset=rotor
7501,5000
*rotary inertia,elset=rotor
1.0,1.0,1.0
*element,type=s4r,elset=sheet
1,1,3,25,40
...
1072,1058,107,98,558
*element,type=s4r,elset=ctube
353,188,447,461,460
...
1024,1023,95,88,470
*element,type=s4r,elset=base
209,4,297,307,13
...
352,446,422,218,221
*material,name=ssteel
*density
```

```
7.35E-04
*elastic
28.5E+06,0.265
*plastic
24721,0.000000
28787,0.000996
30091,0.001991
31026,0.002988
32083,0.003981
32830,0.004974
33467,0.005966
34157,0.006957
34827,0.007947
35296,0.008931
35767,0.009924
39914,0.019748
43094,0.029469
46077,0.039101
48794,0.048630
51544,0.058065
53833,0.067417
56340,0.076683
58632,0.085851
60858,0.094937
79869,0.181481
94067,0.261041
105195,0.334699
114663,0.403242
117518,0.427469
*shellsection,elset=base,material=ssteel
0.25
*shellsection,elset=ctube,material=ssteel
0.864
*shellsection,elset=sheet,material=ssteel
0.109
*restart,write,freq=3
*nset,nset=edge,generate
611,621,5
758,764
424,424
*boundary
edge,xsymm
edge,1,3
5000,1,6
424,1,6
```

```
*amplitude,name=spike
0.0,0.0,1.0,957.0
*mpc
tie,349,492
*surface definition,name=asurf
rigid,sneg
*contact node set,name=bsurf
cnodes,
*surface interaction,name=rough
*surface behavior,no separation
*contact pair,interaction=rough
bsurf,asurf
*step,inc=9999,nlgeom
*static
0.01,1.0
*dload,amp=spike
ctube,grav,386.4,1.0,0.0,0.0
sheet,grav,386.4,1.0,0.0,0.0
base,grav,386.4,1.0,0.0,0.0
*elprint,freq=0
*nodeprint,freq=0
*end step
```

Attachment E. ABAQUS/Standard Input File for MCO Buckling

```
*heading
buckle mco
*node
1,-3.70E-08,2.63E-05,-11.75
...
1921,-1.16E-02,-8.47517,6.188868
*element,type=s4r,elset=base
1601,1646,1661,1673,1645
...
1900,1921,1866,867,868
*elset,elset=base1,generate
1601,1675
*elset,elset=base2,generate
1676,1900
*element,type=s4r,elset=tube
1,1,3,101,62
...
1600,1640,100,52,1289
*nset,nset=top,generate
12,12
52,61
462,462
502,510
872,872
912,920
1281,1289
*material,name=ssteel
*density
7.35E-04
*elastic
28.5E+06,0.265
*plastic
24721,0.000000
28787,0.000996
30091,0.001991
31026,0.002988
32083,0.003981
32830,0.004974
33467,0.005966
34157,0.006957
34827,0.007947
35296,0.008931
35767,0.009924
```

```
39914,0.019748
43094,0.029469
46077,0.039101
48794,0.048630
51544,0.058065
53833,0.067417
56340,0.076683
58632,0.085851
60858,0.094937
79869,0.181481
94067,0.261041
105195,0.334699
114663,0.403242
117518,0.427469
*shellsection,elset=base,material=ssteel
12.0
*shellsection,elset=tube,material=ssteel
0.5
*boundary
top,1,6
*restart,write
*step
*buckle
2,
*dload
tube,grav,386.4,1.0,0.0,0.0
base,grav,386.4,1.0,0.0,0.0
*elprint,freq=0
*node print,freq=0
*end step
```

Checklist for Checking of Analysis/Calculations

Document Checked - Number: N/A **Revision:** 0

Title: MCO Structural Integrity Analysis

Yes	No	N/A	
[✓]	[ ]	[ ]	Problem completely defined.
[✓]	[ ]	[ ]	Appropriate analytical method used.
[✓]	[ ]	[ ]	Necessary assumptions are approriate, explicitly stated, and stated.
[✓]	[ ]	[ ]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Sources of non-standard formulae/data are referenced and the correctness of the reference verified.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand calculations checked for errors.
[✓]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[✓]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[ ]	[ ]	Safety Margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

S. N. Huang *SN Huang* 1/23/97

Engineer/Checker Date

Note: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

7.7.6 Structural Evaluation of N Reactor Fuel

CORRESPONDENCE DISTRIBUTION COVERSHEET

Author	Addressee	Correspondence No.
S. L. Hecht 376-4193	S. S. Shiraga	DESH-9655768 November 19, 1996

Subject: STRUCTURAL EVALUATION OF N REACTOR MK IA FUEL UNDER MULTI-CANISTER OVERPACK CASK DROP ACCIDENT

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November 19, 1996 DESH-9655768

Mr. S. S. Shiraga
Rust Federal Services of Hanford, Inc.
Post Office Box 700
Richland, Washington 99352-0700

Dear Mr. Shiraga:

STRUCTURAL EVALUATION OF N REACTOR MK IA FUEL UNDER MULTI-CANISTER OVERPACK CASK DROP ACCIDENT

References: (1) Memo, K. N. Schwinkendorf to K. E. Smith, "Criticality Analysis of MCO Container," dated January 26, 1996.

(2) A. L. Pitner, KE Basin Underwater Visual Fuel Survey, WHC-SD-SNF-TI-012, dated March 3, 1995.

(3) ANSYS User's Manual, Rev. 5.1, Swanson Analysis Systems, Inc., Houston, PA, dated September 1994.

(4) ALGOR Linear Stress and Vibration Analysis Processor Reference Manual, ALGOR, Inc. Pittsburgh PA, dated July 1992.

(5) S. L. Hecht, ALGOR Computer Code QA, WHC-SD-GN-CSWD-321, dated August 1, 1991.

(6) Memo, K. R. Birney to A. J. Baumgartner, et al., "Distribution of Revised Materials Properties Recommendation to the N Reactor Alternative Mission Task Group," dated February 10, 1989.

(7) V. Fidleris and C. E. Coleman, Mechanical Properties of Zircaloy-2: An Evaluation for Hanford N Reactor Pressure Tubes, AECL, CRNL-2780, dated April 1985.

(8) Fuels Engineering Technical Handbook, UNI-M-61, dated April 1979.

There is a concern that when shipping irradiated N Reactor MK IA Fuel in a Multi-Canister Overpack (MCO) that the possibility of an unacceptable criticality condition could occur should a significant

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amount of MK IA fuel elements "rubblize" during the accident scenario, where a MCO/cask is dropped. Analyses, summarized in the Reference 1, shows that if the "good condition" fuel, which is representative of approximately 60% (Reference 2) of the K East Basin inventory, remains intact under a postulated drop accident, then an acceptable conditions with respect to criticality is likely. The Reference 1 evaluations also concludes that rubblization of the other N Reactor fuel type, MK IV, is not of concern. The purpose of the evaluation, given herein, is to investigate, via analysis, the post drop accident condition of good condition* MK IA fuel.

ANALYSIS

Two analyses were performed to assess the fuel mechanical behavior under the postulated 30 ft. drop accident. These analyses correspond to each of the two cask drop modes analyzed, i.e., flat on the bottom end (vertical) and on the side. Recent cask drop dynamic inelastic analysis (S. Huang, to be published), predicted average impact inertial loads on the cask of 27 and 58 g's for the end and side drop, respectively. A dynamic model of the SNF Storage Baskets (R. S. Marlow, to be published), using results from the cask drop analysis, predicted maximum inertial loads on the baskets to be no greater than that of the cask. It is assumed that the contained fuel decelerations are those which are a experienced by the MCO basket.

End Drop

An elastic three-dimensional (3D) finite element analysis (FEA) of a N Reactor fuel assembly was made to determine the structural response to a postulated worst case drop accident. An FEA analysis was necessary in order to realistically model the fuel support (boundary) conditions within the MCO's. The fuel assembly was modeled as a MK IA-M model (longest) as specified in drawing H-1-39775. Though there is no criticality concern with the MK IV fuel, the designs of theses two fuel assembly models are geometrically similar (except for length) so that one model is sufficient to address the mechanics of either fuel type. Adjustment to the results can be easily made, to account for the geometric differences. It was assumed that the fuel is vertically supported on a single centered 0.25 in. thick horizontal bars, as shown in sketch SK-1-80211. This bar provides vertical displacement support

---

*Good condition fuel is defined herein as fuel elements which after irradiation and storage have the same geometric characteristics as new fuel and has postirradiation properties as documented in the literature.

at only a central strip of the fuel assembly. It is assumed that the support system, and the MCO basket in general remain intact during the postulated drop accident.

As the inner and outer fuel elements of the assembly are essentially decouple for vertical inertial loadings, two models (runs mklin and mklout), i.e., one of each element type were developed. Using two models also enhances computer efficiency (run times and memory requirements). These 3D models (Figures 1 through 3) are a 1/4 minimum section of symmetry for the loading/support conditions. The models represent the lower (0.7 in.) end of a element, where stresses were *a priori* expected to be maximum. To include the mass of a total fuel element, the top ring of elements uses pseudo densities (x 202 nominal). The ALGOR (References 4 and 5) linear stress analysis code employing all 3D Solid Elasticity (Brick and Wedge) Elements (type 5) with six or eight nodes each and default integration was used. Elastic Material properties (Modulus of Elasticity, Poisson's Ratio and Weight density) where taken from References 6 and 8 for the various materials (see below).

The bottom three layers (top in Figures 1 through 3) of element (0.19 in. in total height) represents the end cap region. Here the radially inner and outer 0.025 thick element represent the Zircaloy-2 (Zr-2) cladding. The adjacent elements in the region model the Beryllium-Zr-2 braze zone, and the remaining seven elements in the ring are for the Zr-2 end cap. For the other layers of the model, i.e., a typical fuel region, the braze and end cap representation are replaced with the uranium (U) alloy 601 fuel modeling which is metallurgically bounded to the cladding.

Structural boundary conditions were used to simulate both the support and symmetry conditions. For the support conditions, vertical displacement constrains (U_z=0) were applied at nodes on the bottom surface which interface (rest on) the MCO support bars. The loading analyzed is that of a one g inertial body force acting vertically downward (-Z direction). Stresses/deformations for the desired load condition can be obtained from the normalized values calculated in the linear elastic FEA, by multiplying by the appropriate g load value (27).

Figure 1 shows the equivalent or Von Mises stress, σ_e, profile on the outer Zr-2 surface of the inner fuel element (looking at the bottom). This is where the maximum equivalent stress of 219 psi/g on the inner element occurs. Figure 2 shows the equivalent stress profile on the inner fuel element with the end cap visually removed. Here the maximum stress on the U-601 fuel is 55 psi/g. For the outer fuel element the maximum equivalent stress component on the Zircaloy-2 outer surface is 312 psi/g, as shown in Figure 3. The maximum equivalent stress on the Uranium fuel in the outer element was calculated at 200 psi/g. Stress values for the 27 g vertical load are given in the next paragraph.

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These results show that the outer fuel element is most susceptible element to failure as the stresses are highest. For the Zircaloy-2 components the maximum predicted equivalent stress of 8,420 psi is lower than the Zr-2 minimum room temperature unirradiated yield strength (S_y) of 46,000 psi (References 6 through 8). Furthermore, the effect of irradiation should increase S_y by at least 10% (Reference 7). Hence, as $\sigma_e < S_y$, the Zr-2 components are predicted to maintain their structural integrity. For the braze zone, the maximum equivalent and principal stress components of less than 7,760 psi are calculated. Conservatively assuming that the ultimate tensile strength is that of the unirradiated material, or 50,000 psi (Reference 8) (no available data for S_y or irradiated condition; material should fluence harden), the joints are acceptable. The maximum equivalent stress in U-601 fuel of 5,400 psi is well below the unirradiated ultimate tensile strength of 63,000 psi (References 6 and 8) (pure U significantly fluence hardens), and is hence acceptable.

Side Drop

The first part of this analysis, provided in Attachment 1, is the determination of the inertial loading distribution, when the cask is in a horizontal orientation. This analysis shows that the maximum force on a fuel element is 8.26 times the element weight times the inertial load in g's. For subsequent FEA it is conservatively assumed that this loading acts as two equal and opposite "pinching" force, which gives rise to the maximum combined shear plus bending "ovalizing" response.

This force was than applied to a finite element model (FEM) of the outer fuel element. The inner element would not react the load, unless there was significant "crushing" (plastic) deformations of the outer element, and hence was not modeled. For this analysis, the ANSYS, Rev. 5.2 (Reference 3) commercial general purpose finite element code was used. The FEM is a two-dimensional (2-D) 1/4 symmetric model, as shown in Figure 4. ANSYS PLANE 42 2-D structural solid (plane strain) elements of 1 in. (unit) depth were used. The quadrilateral elements on the inner and outer radii, represent the 0.025 in. thick Zr-2 cladding. The remainder of the quadrilateral elements are for the uranium fuel. Elastic material properties used were the same as in the vertical drop model. Boundary conditions were used for symmetry and the support conditions. A force of 570 lb, due to the 58 g inertial load, is applied to the uppermost center node (conservative--maximum shear and bending). This force was derived from the geometric inertial load distribution factor of 8.26 multiplied by the weight of 1 in. section of a fuel assembly multiplied by the inertial load in g's divided by two for symmetry in the load condition.

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Figure 4, shows the resulting displaced (x28) equivalent stress profile plot. When considering potential error due to mesh size, the maximum equivalent stress is 22,900 psi in both cladding and fuel material, which is less than their respective strengths.

Conclusions

The above evaluation predicts that: (1) the cladding and end cap system, which encapsulates the U-601 fuel will remain intact; and (2) the uranium fuel itself will remain intact. Furthermore, examinations (327 hot cell) of fuel elements with moderate end damage from K West Basin, shows that the majority of the fuel, in a slightly damaged fuel assembly, is uncracked. Therefore, there is redundant assurance that fuel within a "good" element will remain intact or contained. In conclusion, the evaluation given herein, shows that good condition spent N Reactor fuel assemblies will not become fragmented or rubblized under loading caused by the worst case postulated shipping drop accident.

Computer Runs

Input and output files for both the ALGOR and ANSYS runs are stored in a compressed UNIX TAR file, mco_fuel_drop.tar.Z. which can be found on the Hanford Common File System (bluegate.rl.gov) in directory /v92627/fem.

Very truly yours,

S. L. Hecht
Spent Nuclear Fuel Evaluations

jmn

Attachment

ATTACHMENT 1

DESH-9655768
ATTACHMENT

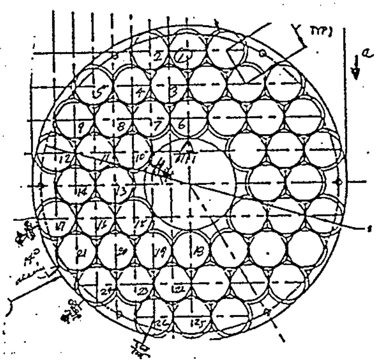
ANALYTICAL CALCULATIONS

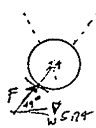
Page 1 of 2

Subject: MCO SIL PREP - MKIA FUEL - HORIZONTAL INERTIAL LOAD / DIST.
Originator: S.C. HEIGHT Date
Checker Date

VERTICAL LOAD DIST.

V:





$F \sin 44 = W$

$F = 1.44\ W$

$F = 8.26$

ROD NO.	VALUE	VALUE #	COMMENT
3	(1+2)/2 + 3	2	
4		1.5	
5		1	
6	(5)/2 + 6	2	→ 0 CANCELS (REACT.)
7	(3+4)/2 + 7	2.75	
8	(4+5)/2 + 8	2.25	
9	(5)/2 + 9	1.5	
10	(7+6)/2 + 10	3.5	→ ~½ REACTS 1.75
11	(8+7)/2 + 11	2.875	
12	(9)/2 + 12	1.75	
13	(10+11)/2 + 13	4.1875	
14	(11+12)/2 + 14	3.313	
15	(13)/2 + 15	3.094	
16	(13+14)/2 + 16	4.75	
17	(14)/2 + 17	2.66	→ REACT SIN 14 = .24, SIN 60 = .866 → 24% WALL → 2.30
18	= 18	1	
19	= (18)/2 + 19	2.55	
20	= (15)/2 + 16/2 + 20	4.92	
21	= (16+17)/2 + 21	4.53	→ REACT WALL SIN 30 / SIN 60 = .5 / .866 = 1.366; .866 / 1.366 = (.634)(4.53) → 2.87
22	(18+19)/2 + 22	2.77	
23	(19+20)/2 + 23	4.74	
24	(20+21)/2 + 24	5.74	⇒ REACTED AT WALL (MAX LOAD)
25	(22)/2 + 25	2.39	
26	(22+23)/2 + 26	4.75	⇒ REACTED NO AS SEVERE AS 24

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

Subject ______

Originator ______ Date ______

Checker ______ Date ______

WEIGHT OF 1" SEGMENT OF MKIA FUEL

U $\rho = .687$ lb/in³ , Zr: $\rho = .235$

OUTER ELEMENT

U: $V = A(1) = \frac{\pi}{4}(D_o^2 - D_i^2) = \frac{\pi}{4}(2.371^2 - 1.779^2) = 2.00$

$W = \rho V = 1.374$ lbs

Zr $A_1 = \frac{\pi}{4}(1.779^2 - 1.754^2) = .0893$

$A_2 = \frac{\pi}{4}(2.416^2 - 2.391^2) = .1202$

$\Sigma = .209 = V$

$W = \rho V = .049$

wt TOT = 1.423 (OUTER)

INNER

CONSERVATIVELY ASSUME ALL U

$V = A = \frac{\pi}{4}(1.256^2 - .431^2) = 1.39$

$W = \rho V = .956$

TOTAL = 1.423 + .956 = 2.38 lb/in

MKIA

= (2.38)(8.26) = 19.64/2 = 9.83 × g

↑

½ ASSEM

AT 58 g's ⇒ 570 lbs

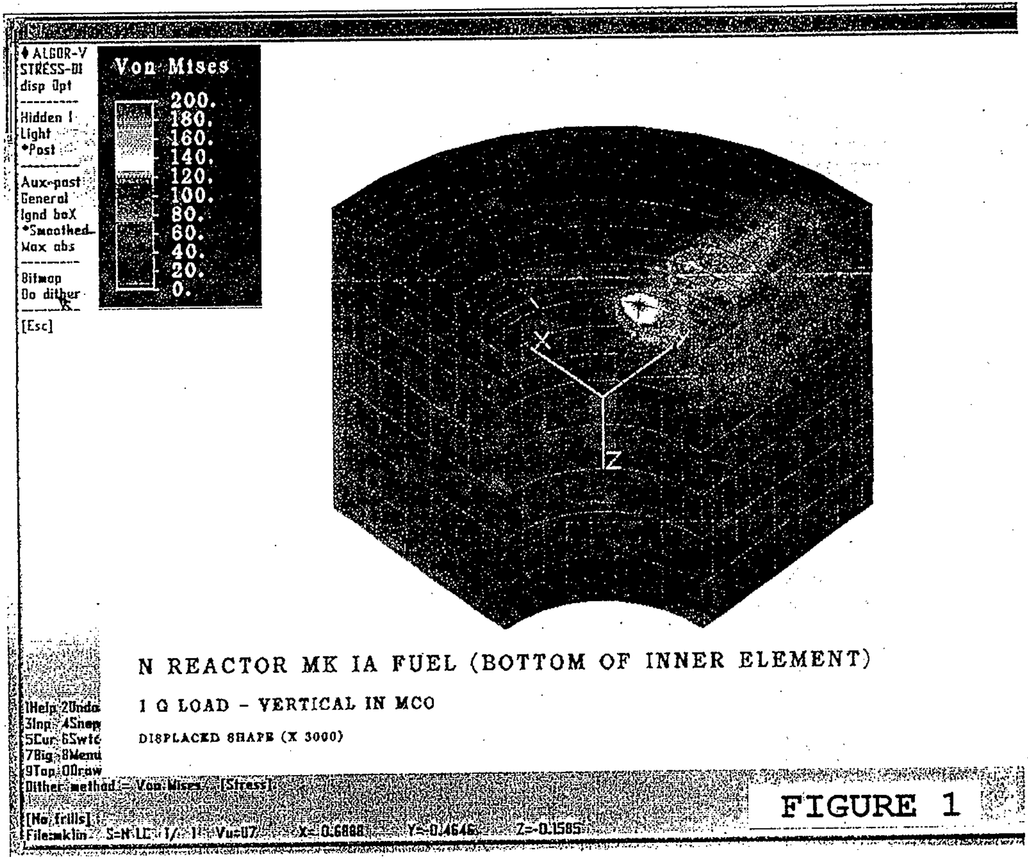

ALGOR-V
STRESS-III
disp Opt
Hidden l
Light
*Post
Aux-post
General
lgnd boX
*Smoothed
Max abs
Bitmap
Do dither
[Esc]
Von Mises
200.
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.
X
Z
N REACTOR MK IA FUEL (BOTTOM OF INNER ELEMENT)
1 G LOAD - VERTICAL IN MCO
DISPLACED SHAPE (X 3000)
Dither method = Von Mises [Stress]
[No frills]
X=0.6888
Y=-0.4646
Z=-0.1585

FIGURE 1

ATTACHMENT

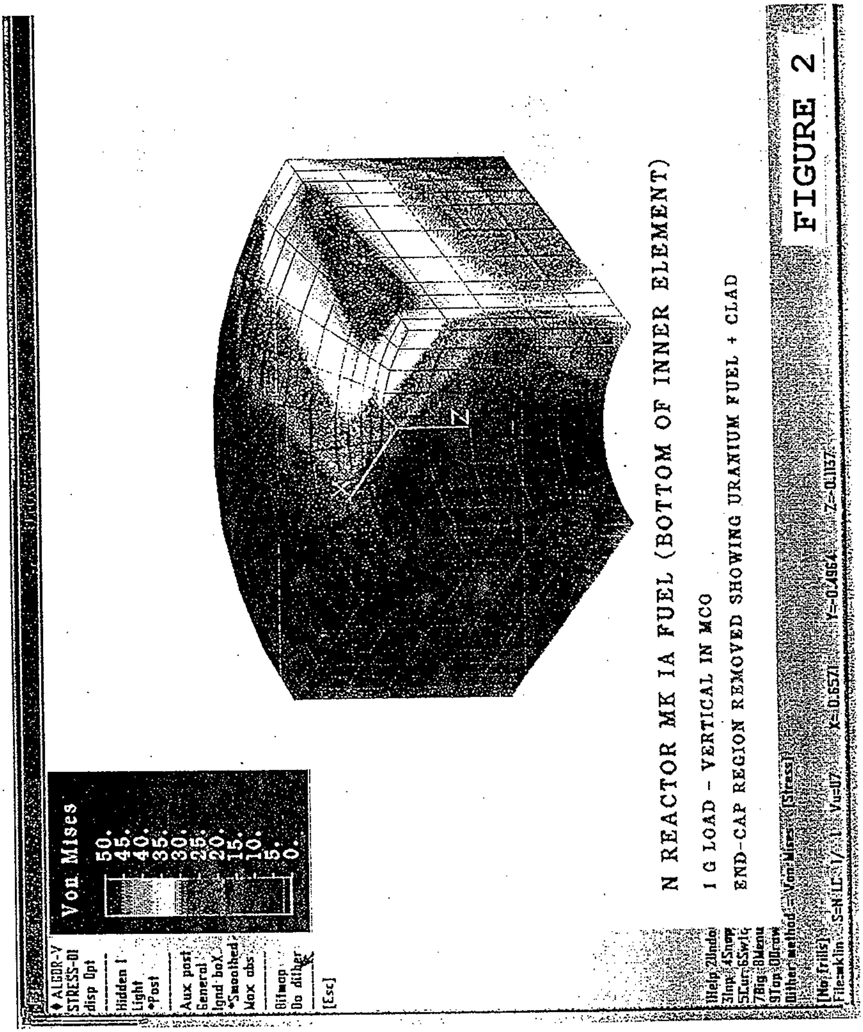
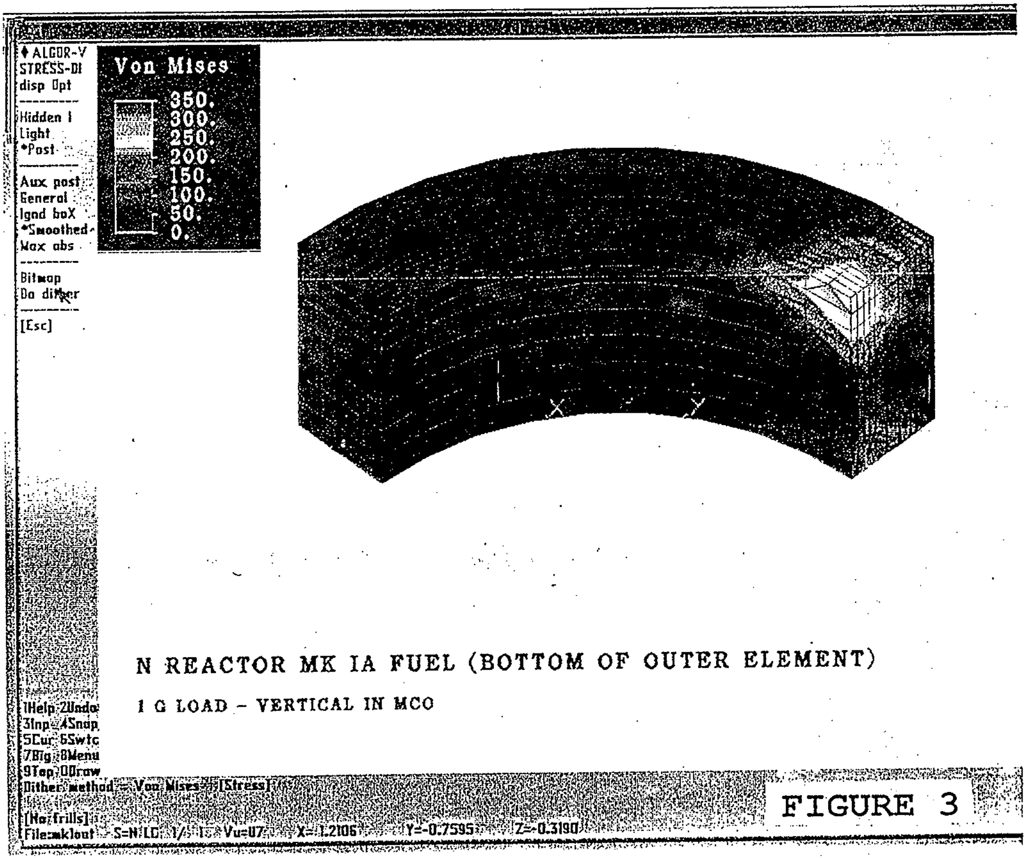


FIGURE 2

ATTACHMENT DESH-9655768



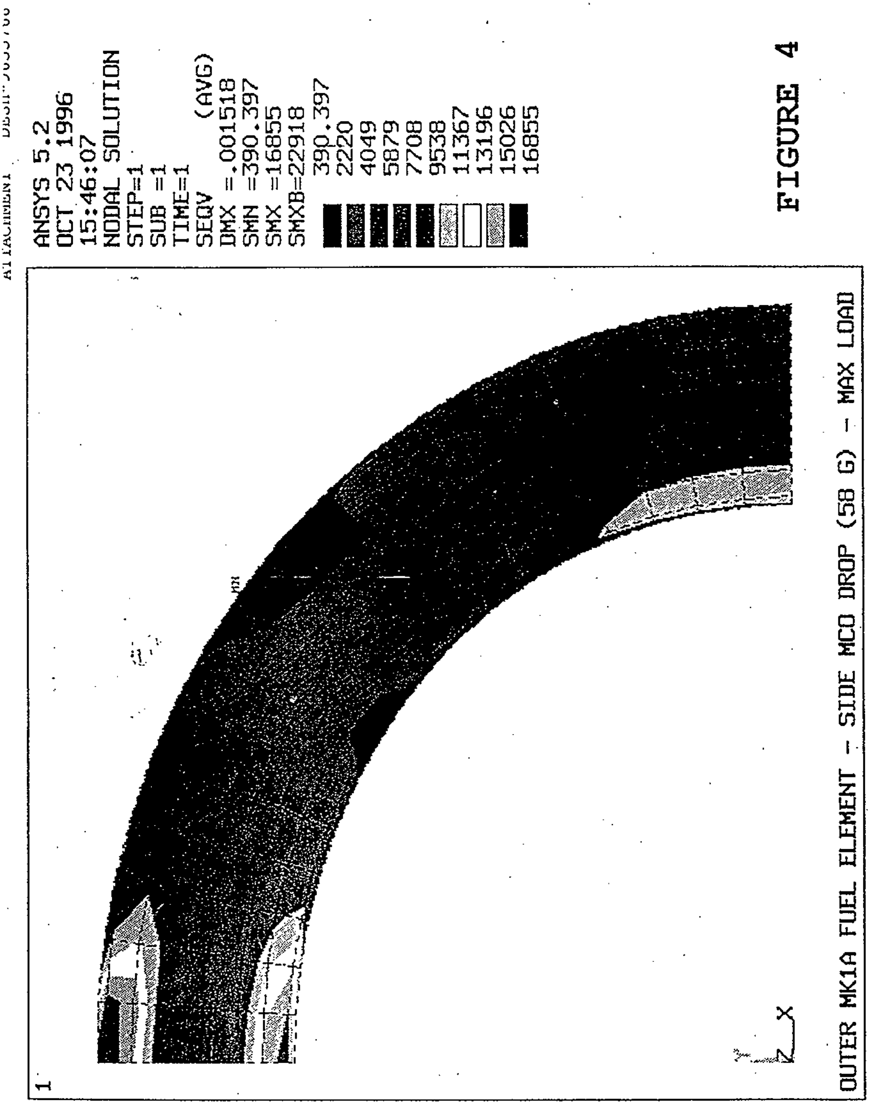

ANSYS 5.2
OCT 23 1996
15:46:07
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV (AVG)
DMX =.001518
SMN =390.397
SMX =16855
SMXB=22918
390.397
2220
4049
5879
7708
9538
11367
13196
15026
16855
1
OUTER MK1A FUEL ELEMENT - SIDE MCO DROP (58 G) - MAX LOAD

FIGURE 4

8.0 THERMAL EVALUATION

8.1 INTRODUCTION

This section presents the design criteria, material properties, and thermal evaluations, which demonstrate that the MCO Cask meets all applicable thermal criteria for the transportation of the MCO between the K Basins and the CVDF and from the CVDF to the CSB. The MCO Cask is designed to safely transfer irradiated nuclear fuel elements positioned in MCOs within the boundaries of the Hanford Site. The MCOs are fabricated of 304 stainless steel pipe with an outside diameter of 61 cm (24 in.) and are approximately 406 cm (160 in.) long. Intact metallic uranium fuel assemblies, damaged assemblies, and broken or rubble-size chunks of fuel elements are contained in a variety of baskets stacked inside. See Part A, Section 1.0, for a system description and Part A, Section 2.0, for an overview of the package design, the significant structural design criteria, and pertinent features of the MCO Cask.

Demonstration of the safety of the MCO Cask for the transportation of the MCOs and the SNF payload between the K Basins and the CSB relies primarily on restricting the transportation time, secondarily on the establishment of a minimum acceptable level of drying during the CVD process, and finally on the provision of equipment and procedures for recovery should events arise that prevent completion of the transport process within the normal shipping window established by this safety analysis. As a result of the restriction on the transportation time, the safety basis of the MCO Cask is based on transient thermal analyses of the transport process. While safe operation under steady-state conditions is possible for most of the potential MCO loadings and ambient conditions, the worst-case conditions for the transportation of damaged fuel assemblies will require that steady-state operations be avoided unless active cooling and/or venting of the MCO Cask and MCO interiors is provided. Because a safety basis does not exist for discerning between MCOs with worst-case loadings that require restrictions on transportation and those MCO loadings that do not, all MCOs will be subjected to the same transportation restrictions.

The thermal evaluation addresses two distinct modes of transfer: wet and dry. Wet transfer occurs during the transfer of the MCO from the K Basins to the CVDF, while dry transfer occurs during the transfer from the CVDF to the CSB. Under wet transfer, the MCO is filled with water to a height approximately 10.2 cm (4 in.) below the bottom of the MCO shield plug. The MCO Cask annulus space is filled with water to a height equal to the water level in the MCO. The remaining void space within the cask and MCO is filled with helium gas at the time of loading to an internal pressure of 20.7 kPa gauge (122.04 kPa absolute [3 psig (17.7 psia)]). The MCO is vented to the cask cavity during wet transfer. As such, expansion of the gases contained in the MCO is allowed to the cask interior void space. The cask is sealed for wet transfer.

Dry transfer of the MCO and cask occurs between the CVDF and the CSB. The cask and MCO are drained of liquid water and the MCO interior vacuum dried. The MCO and cask void volumes are backfilled with helium gas to yield an initial pressure of 20.7 kPa gauge (122.04 kPa absolute [3 psig

(17.7 psia)]). Both the MCO and cask are sealed for dry transfer, but the MCO relief valve and rupture disk can relieve pressure from the MCO to the MCO Cask if their activation pressures are exceeded.

Table B8-1 shows a summary of the pertinent thermal features associated with each mode of transfer. Both the normal transfer conditions and accident evaluations are conducted using analytic techniques. The analytical techniques comply with the methodology presented in Irwin (1994) and Regulatory Guide 7.8 (NRC 1989).

Table B8-1. Thermal Aspects of Wet And Dry Transfer of K Basin Spent Nuclear Fuel.

Design parameter	Wet transfer	Dry transfer
Water volume in MCO, m^3 (ft^3)	0.528 (18.64)	0 (0)
Gas volume in MCO, m^3 (ft^3)	0.027 (0.96)	0.56 (19.6)
Initial MCO gas backfill	helium @ 17.7 psia	helium @ 17.7 psia
Allowed MCO leakage rate	none, open to cask	10 E-4 std cc/s, air
Water volume in cask, m^3 (ft^3)	0.107 (3.79)	0 (0)
Gas volume in cask, m^3 (ft^3)	0.015 (0.54)	0.122 (4.33)
Initial cask gas backfill	helium @ 17.7 psia	helium @ 17.7 psia
Allowed cask leakage rate	10E-7 std cc/s, air	10 E-7 std cc/s, air
Nominal transfer time	8 hours	14 hours
Fire accident scenario	6 minutes @ 1475°F	6 minutes @ 1475 °F
Maximum shipping window	24 hours	36 hours

MCO = Multicanister Overpack.
NOTES:
[1]Water volume refers to liquid, free volume. Chemically bound water absorbed in corrosion products, cracks, crevices, etc., is not included.
[2]Transfer time is defined as from time of closure at the shipping site to the time of venting at the receiving site.

Thermal loads on the MCO Cask arise from three sources: (1) the radioactive decay of the spent nuclear fuel; (2) the chemical reactions at the exposed uranium surfaces and of the uranium hydrides; and (3) the external environment, including insolation. The cask is designed to transfer the dissipated heat from the fuel assemblies to the environment passively, while maintaining critical cask temperatures within their allowable limits. The evaluations for normal transfer conditions are presented in Section 8.4, while the effects of a fire event on the cask, MCO, and its payload are presented in Section 8.5.

Site-specific ambient temperatures and solar heat loads, as specified in Fadeff (1992), are considered in the package thermal evaluations. Normal transfer condition thermal loads consider ambient temperatures ranging from 33 °C (-27 °F) to 46 °C (115 °F); worst-case, nominal, and minimum decay and chemical corrosion heat dissipations; and maximum and minimum solar loading. The accident conditions consider an ambient temperature range of -33 °C (-27 °F) to 46 °C (115 °F) with solar heat loading included before and after the fire event. In accordance with 10 CFR 71, solar heat loading can be ignored during the fire event.

Details and assumptions used in the thermal modeling are described with the thermal evaluations. All evaluations are performed analytically, and when possible, assumptions are supported by test data.

8.2 THERMAL SOURCE SPECIFICATION

The heat flux at the inside surfaces of the MCO under normal transfer conditions will arise from two sources: radiolytic decay and the heat of chemical reaction due to corrosion at the exposed uranium surfaces and from the decomposition of uranium hydrides. The following sections define each of theses source terms and their bases.

8.2.1 Radiolytic Decay Heat Source Term

The radiolytic decay heat source term is based on the estimated MCO inventory (Willis 1995) for the various MCO loadings. Table B8-2 shows the radiolytic decay heat for the nominal (average) and worst-case (maximum) MCO. The minimum decay heat is expected to be on the order of one-third of the nominal value, or 0.489 W per SNF assembly. However, a value of 0 W is assumed for the purposes of computing the minimum temperatures.

The same radiolytic decay heat source term is used for the accident conditions.

Table B8-2. Radiolytic Heat Source Term.

Payload	Average of 390 MCOs	Max. MCO with 270 Mark IV SNF	Max. MCO with 288 Mark IA SNF
Total decay heat	396 W	835 W	630 W
Decay heat per fuel assembly	1.467 W (assuming 270 Mark IVs)	3.093 W	2.188 W

MCO = Multicanister Overpack.
SNF = Spent Nuclear Fuel.

8.2.2 Chemical Reaction Heat Source Term

The heat of chemical reaction arises when the exposed uranium surfaces for the damaged SNF assemblies, scrap, and corrosion products react with the environment within the MCO. At the temperature levels seen during transfer, this reaction consists primarily of the oxidation of uranium with moist air (oxygenated water reactions), oxygen-free water, or dry air. A secondary source of heat and hydrogen gas results from the decomposition of the uranium hydrides contained in the corrosion products remaining on the fuel elements after cleaning. The thermal model used in this analysis addresses the thermal and pressure contributions from both of these sources. Reactions with the hydrates are not included in the thermal model since the temperature levels seen during transfer will not support significant reaction with these compounds (Ogden 1996).

The reaction of uranium in an air or water/water vapor environment are represented by:

$$U + O_2 \Rightarrow UO_2 + 259.3 \text{ kcal/mole of U} \quad (A)$$

and

$$U + 2H_2O \Rightarrow UO_2 + 2H_2 + 143.7 \text{ kcal/mole of U} \quad (B)$$

It is estimated in Cooper (1996a) that 9% of the corrosion product consists of uranium hydride. The hydride in the corrosion product attached to the uranium metal is accounted for as part of the uranium reaction rates given in equations (1) to (10) below. The reaction of uranium hydride with water is represented by (see Equation 11):

$$2UH_3 + 4H_2O \Rightarrow 2UO_2 + 7H_2 + 287.4 \text{ kcal/mole of U} \quad (C)$$

The rate at which the indicated uranium/water or uranium/oxygen reactions occur are a function of the temperature of the uranium, the partial pressure of water (if present), and the surface area involved. The relationships for the chemical reaction rates are taken from the recommendations made in Cooper (1996b) for the corrosion of N Reactor fuel. The relationships consist of Arrhenius Rate Law type equations developed by Pearce (1989) and Ritchie (1981, 1986) for the reaction rate of unirradiated uranium in various environments and temperature ranges. The recommended equations are:

For Dry Air (<10-15 vppm H_2O):

$$T < 597°K, \quad \text{Log } K = 8.9464 - 4638.2/T \quad (1)$$

$$T > 597°K, \quad \text{Log } K = 28.381 - 7\text{Log}(T) - 4638.2/T \quad (2)$$

For Moist Air:

$$T < 373°K, \ 11\text{-}75\%RH, \quad \text{Log } K = 13.6780 - 5290.9/T \quad (3)$$

$$T < 373°K, \ 100\%RH, \quad \text{Log } K = 8.333 - 3730/T \quad (4)$$

$$373°K < T < 463°K, \ <100\%RH, \quad \text{Log } K = 10.566 - 4990/T + 0.3\text{Log}(P) \quad (5)$$

$$T > 463°K, \ <100\%RH, \quad \text{Log } K = 6.1931 - 2963/T + 0.3\text{Log}(P) \quad (6)$$

For Oxygen-Free Water Vapor:

$$T < 373°K, \quad \text{Log } K = 7.364 - 3016/T \quad (7)$$

$$373°K < T < 523°K, \quad \text{Log } K = 4.33 - 2144/T + 0.5\text{Log}(P) \quad (8)$$

$$523°K < T < 735°K, \quad \text{Log } K = -22.915417 + 30066.5/T - 9.119078 \times 10^6/T^2 \quad (9)$$

$$735°K < T < 923°K, \quad \text{Log } K = -23.905197 + 42718.8/T - 1.787581 \times 10^7/T^2 \quad (10)$$

where K is the predicted weight gain from the reaction in $mg/cm^2/h$ (i.e., mg oxygen per cm^2 per hour), P is the partial pressure of the water vapor in kPa, and T is in degrees Kelvin.

The reaction rate of uranium hydride, as provided by Cooper (1996a), is as follows:

$$K = (10^{(5.69034 - 2644.11/T)} \times 1000/241) \times 0.09 \times Exp[10^{(5.69034 - 2644.11/T)} \times \Delta t] \quad (11)$$

where K is the number of gram moles of hydride that reacts per hour per kg of corrosion products, T is in degrees Kelvin, 241 is the molecular weight of UH_3, 0.09 is the weight fraction of uranium hydrides in the corrosion products, and Δt is the time in hours since the MCO was loaded.

The chemical corrosion of the uranium metal occurs at the solid surface and not within the solid volume. As such, an estimate of the exposed surface area is needed. The amount of uranium metal with surfaces exposed to the MCO environment will vary from shipment to shipment depending upon the amount and extent of damaged fuel loaded in each MCO, the presence or absence of a scrap basket, and the amount and composition of corrosion products contained in any shipment. An estimate of the amount and distribution of exposed surface area is presented in Cooper and Johnson (1996). Based on chemical and visual observations of the storage pools, the Cooper and Johnson report recommends as a worst-case scenario an MCO that contains 66,000 cm^2 of exposed surface area in the form of fuel assemblies with split cladding. The damaged fuel assemblies are equally divided over four intact fuel baskets.

In addition to the fuel with split cladding, the worst-case MCO contains a single scrap basket holding portions of fuel assemblies with the equivalent of 54,000 cm^2 of exposed surface area. The total corroding geometric area in the worst-case MCO is 120,000 cm^2. The scrap is assumed to contain the equivalent of 54 fuel assemblies in 2.54-cm- (1-in.-) high slices. Based on the volume of the scrap basket and the contained fuel assemblies, a conservative value 0.52 is assumed for the porosity of the scrap basket. Lower porosity values will yield higher equivalent thermal conductivity within the scrap basket and, thus, lower temperatures.

Since the reaction rate relationships provided above were developed for unirradiated uranium samples, an adjustment factor is required to account for the increased surface area and reactivity of the N Reactor fuel due to corrosion and irradiation. A factor of 10 is recommended by Cooper (1996b) to account for these effects. As such, the equivalent worst-case MCO surface area to be used with the reaction rate equations is 1,200,000 cm^2 after the surface area adjustment factor is included.

Since the majority of the fuel stored in the K Basins storage pools is undamaged, the average or nominal shipment will contain significantly less corroded or damaged fuel than that predicted for the worst-case scenario. The Cooper and Johnson report estimates that the average MCO containing K-East fuel will be slightly less than 3,000 cm^2, or 30,000 cm^2 with inclusion of the area adjustment factor.

The chemical reaction equations (A), (B), and (C) stated previously, together with the reaction rate equations (1) to (11) and the total exposed surface area estimates, are used to predict the surface heat flux on each fuel assembly or scrap section and the rate of hydrogen gas generation. Pressure calculations are based on a total void volume of 0.0425 m^3 (1.50 ft^3) during transfer from the K Basins to the CVDF and 0.555 m^3 (19.60 ft^3) during transfer from the CVDF to the CSB. The pressurization calculations include the absorption of hydrogen gas in the water. See Section 8.9, "Appendices," for additional details.

Table B8-3 shows a summary of the chemical reaction source term assumed for the worst-case and nominal MCO fuel loadings in this analysis.

Table B8-3. Chemical Reaction Heat Source Term.

Payload	Scrap baskets			Intact fuel baskets		
	#	Corrosion area	Corrosion products	#	Corrosion area*	Corrosion products*
Worst case	1	54,000 cm^2	54.4 kg	4	66,000 cm^2	87.6 kg
Nominal	0	-	-	5	3,000 cm^2	87.6 kg

MCO = Multicanister Overpack.
*Corrosion area divided equally among intact fuel baskets for worst-case MCO and lumped in center fuel basket for nominal MCO. Corrosion products divided equally among fuel baskets. A corrosion product mass of 87.6 kg is also used for the "nominal" case for the purpose of providing conservatism.

8.2.3 Hydrogen Gas Generation

The reaction rates for uranium with oxygen, water, and water vapor defined by equations (1) to (10) are in terms of mg of O_2 per cm^2 per hour. Conversion to the number of moles of oxygen and hydrogen per hour is as follows:

$$\text{moles } O_2/(cm^2\text{-hour}) = \text{mg } O_2/(cm^2\text{-hour}) \times 1 \text{ mole } O_2/(32{,}000 \text{ mg}O_2)$$

$$\text{moles } H_2/(cm^2\text{-hour}) = 2 \text{ moles } H_2/(1 \text{ mole } O_2)$$

For the reaction with uranium hydride, the rate described in equation (11) is defined in terms of the number of gram moles of UH_3 that are reduced per hour per kg of corrosion products. There are 7/2 gram moles of H_2 per gram mole of UH_3.

8.3 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The analysis of the heat transfer within the MCO Cask requires that thermal properties be defined for the materials used in its fabrication. Thermal properties are also required for the MCO, the fuel baskets, and the SNF payload. Only properties for materials that constitute a significant heat transfer path are defined. Properties for components, such as fittings, brass vent/test/drain port valves, etc., are not necessary and are not provided.

The MCO Cask is fabricated primarily of SA-336 Type 304 stainless steel. Miscellaneous components include SA-540 Grade B24 stainless steel closure bolts, Butyl rubber O-ring seals, Type 303 stainless steel quick-disconnect couplings, and stainless steel thread inserts. The MCO and fuel baskets are fabricated of 304/304L stainless steel.

The void spaces within the MCO and in the annulus between the MCO and the MCO Cask are filled with water and helium gas during the wet transfer phase and with helium gas during the dry transfer phase. Helium gas is used to create an inert environment and to enhance heat transfer. The MCO and cask cavities are backfilled with helium gas to a pressure of 20.7 kPa gauge (3 psig) above atmosphere, or approximately 122.04 kPa absolute (17.7 psia) at the time of loading. The initial level of pressurization was selected to provide a positive pressure within in the MCO/cask cavities relative to the atmosphere to ensure that any leak will be from the package to the environment, while keeping the initial pressure low to allow for additional pressurization due to hydrogen gas generation.

The average bulk gas temperature within the MCO cavity at the time of the backfill operation is assumed to be equal to the average temperature of SNF payload. Given that the basin pool temperature and the cool-down temperature at the CVDF is 10 °C (50 °F), a nominal value of 15 °C (59 °F) is assumed for the purposes of this SARP. This increase in temperature allows for process variations, additional heat-up as a result of operational delays, etc. A worst-case initial temperature of 25 °C (77 °F) is also examined.

Still air is assumed to surround the package during transfer. A diurnal cycle and Hanford-specific data for ambient temperature and insolation are used for normal transfer, hot-day conditions (see Section 8.9.1). To maximize ambient air and solar heating of the cask during transfer, the simulations assume that the transfer begins at 8 a.m. The presence of the transport trailer is ignored.

The thermal properties of the principal materials used in the thermal evaluations are shown in Tables B8-4, B8-5, and B8-6. Where possible, the data used was taken from the *Spent Nuclear Fuel Project Technical Data Book* (Short and Beary 1995). Other references are listed in the 'Notes' column of the tables.

Table B8-4. Material Properties, Metals.

Material	Temperature, °C	Thermal conductivity, W/m-K	Specific heat, J/kg-K	Density, g/cm³	Notes
Type 304	-33	11.19	573	8.005	1,2
Stainless steel	0	13.38	502		
	21	14.80	456		
	38	15.10	464		
	93	16.07	485		
	204	17.86	523		
	316	19.58	544		
	427	21.23	565		
	649	24.29	586		
	816	27.20	623		
SA-540 Gr B24	-40	30.78	397	7.905	2,3
Carbon steel	0	32.50	428		
	21.1	33.38	444		
	121.1	36.32	515		
	204.4	37.01	556		
	315.6	36.67	602		
	426.7	35.45	657		
	537.8	33.55	724		
	871.1	25.94	640		
Uranium	27	27	117	18.82	1
	100	27	122		
	200	29	131		
	300	31	142		
	400	33	154		

NOTES:
[1]Short, S. M., and M. M. Beary, 1995, Spent Nuclear Fuel Project Technical Data Book, WHC-SD-SNF-TI-015, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
[2]Materials Engineering, Penton Publishing Inc., Cleveland, Ohio.
[3]ASME, 1995, ASME Boiler and Pressure Vessel Code, Section II, Part D Properties, Table TCD, p. 603, American Society of Mechanical Engineers, New York, New York.

Table B8-5. Material Properties, Gases.

Material	Temperature, °C	Thermal conductivity, W/m-K	Specific heat, J/kg-K	Density, g/cm³	Viscosity, centipoise	Notes
Helium	-73	0.1151	5188.2	Use	0.01497	1,2,3
	27	0.1499		ideal	0.01989	
	127	0.1795		gas law	0.02428	
	227	0.2114			0.02827	
	327	0.247			0.03199	
	427	0.278			0.03549	
	527	0.307			0.03884	
	627	0.335			0.04201	
	727	0.363			0.04504	
	927	0.416			0.0508	
Air	-73	0.0181	1002	Use	0.01336	1,3,4,5
	27	0.0261	1006	ideal	0.01853	
	127	0.0331	1014	gas law	0.02294	
	227	0.0395	1030		0.02682	
	327	0.0456	1051		0.0303	
	427	0.0513	1075		0.03349	
	527	0.0569	1099		0.03643	
	627	0.0625	1120		0.03918	
	727	0.0672	1140		0.04177	
	927	0.0759	1174		0.0465	

NOTES:

[1]Touloukian, Y. S., Specific Heat--Nonmetallic Liquids and Gases, Thermophysical Properties Research Center Data Series, Volume 6, Purdue University, West Lafeyette, Indiana.

[2]Touloukian, Y. S., Thermal Conductivity - Nonmetallic Liquids and Gases, Thermophysical Properties Research Center Data Series, Volume 3, Purdue University, West Lafeyette, Indiana.

[3]Touloukian, Y. S., Viscosity, Thermophysical Properties Research Center Data Series, Volume 11, Purdue University, West Lafeyette, Indiana.

[4]Rohsenow, Hartnett, and Ganic, 1985, Handbook of Heat Transfer Fundamentals, 2nd Edition, McGraw-Hill Publishers, New York, New York.

[5]Kreith, F., 1973, Principles of Heat Transfer, 3rd Edition, Harper & Row Publishers, New York, New York.

Table B8-6. Material Properties, Surface Emittance.

Component	Material	Surface treatment[1]	Surface emittance	Solar absorptivity	Notes
Cask outer surface	304SS	M (125μ)	0.3	0.5	2,5
Cask inner surface	304SS	M (125μ)	0.3	N/A	2
Cask closure lid	304SS	M (125μ)	0.3	0.5	2,5
Cask bottom	304SS	M (125μ)	0.3	N/A	2
MCO canister	304LSS	M (125μ)	0.3	N/A	2
MCO closure plug	A36 CS	M (125μ)	0.7	N/A	3
MCO basket	316SS	M (250μ)	0.3	N/A	2
Spent nuclear fuel assembly	---	---	0.6	N/A	4

MCO = Multicanister Overpack.
SS = Stainless steel.
NOTES:

[1]Surface treatment definition: M (125μ/250μ)--machined finish to 125μ or 250μ.

[2]Emissivity testing* on 18 samples of Type 304 stainless steel indicates an emissivity value of 0.25 to 0.28 for the 'as-received' condition. Table 148 of Gubareff** provides values of 0.44 at 420 °F and 0.36 at 914 °F for a light silvery, rough surface. An emissivity value of 0.30 provides an accurate representation of a new, clean MCO Cask.

[3]Gubareff, G. G., J. E. Janssen, and R. H. Torborg, 1960, Thermal Radiation Properties Survey, Honeywell Research Center, Minneapolis, Minnesota, p. 93, gives an emissivity range of 0.66 to 0.79 for oxidized carbon steel.

[4]Baker, L., Jr., E. M. Mouradian, and J. D. Bingle, "Determinations of the Total Emissivity of Polished and Oxidized Uranium Surfaces", Nuclear Science Engineering, Vol. 15, p 215, gives 0.58 to 0.68 for oxidized uranium. The Spent Nuclear Fuel Project Technical Data Book gives values of 0.54 of oxidized uranium and 0.43 for Zircaloy-2. PNL 1985, Verification and Validation Assessments for the Hydra-II Hydrothermal Analysis Code, Volume III, Page 5.8, Section 5.1.22, verifies emissivity value of 0.8 for zircaloy-clad commercial fuel assemblies through comparison with experimental data. 0.6 used for conservative value.

[5]Irwin, J. J., 1994, Thermal Analysis Methods for Safety Analysis for Packaging, WHC-SF-TP-RPT-005, Rev. 0, Westinghouse Hanford Company, Richland, Washington. Table A-51 gives a solar absorption value of 0.52 for oxidized 304 stainless steel.

*Frank, R. C., and W. L. Plagemann, Emissivity Testing of Metal Specimens (coordination sheet to S. Goetsch, Nuclear Packaging, Inc.), testing accomplished by Boeing Analytical Engineering for Nuclear Packaging, Inc.

**Gubareff, G. G., J. E. Janssen, and R. H. Torborg, 1960, Thermal Radiation Properties Survey, Honeywell Research Center, Minneapolis, Minnesota.

8.4 THERMAL EVALUATION FOR NORMAL TRANSFER CONDITIONS

Demonstration of the safety of the MCO Cask for the transfer of the MCOs and the SNF payload under normal transfer conditions requires the application of administrative rules to restrict the transfer time and the establishment of a maximum rate acceptable for the pressure rise during the high-temperature hold point for the CVD process. While safe operation under steady-state conditions is expected to be possible for most of the potential MCO loadings and ambient conditions, the worst-case conditions will require that steady-state operations be avoided unless active cooling and/or venting of the cask/MCO interiors is provided.

The thermal evaluation for normal transfer conditions consists of transient simulations of the transfer process between the K-East and K-West Basins and the CVDF and between the CVDF and CSB. The duration of the transient analysis encompasses the nominal time period required to accomplish the transfer process, plus sufficient additional time to cover normal processing delays and to implement emergency recovery methods. These analyses are used to establish the acceptable time frames for the transfer process and the pressure rise criteria for the CVD process.

8.4.1 Conditions To Be Evaluated

Hanford Site-specific ambient temperatures considered in the normal transfer condition thermal evaluations range from -33 °C (-27 °F) to 46 °C (115 °F). The hot-day conditions are evaluated using a diurnal cycle simulation of the worst-case hot day at Hanford (see Section 8.9.1). Cold day conditions assume a constant air temperature and no insolation. In addition to ambient temperature, maximum and minimum values for decay heat and solar loading are considered. Zero decay heat is considered for determining the minimum package temperatures.

Table B8-7 shows the load combinations considered in this analysis. The difference between the worst-case condition and probable maximum normal transfer condition for the hot ambient case is the assumed starting temperature for the SNF and cask. The difference between the probable minimum normal transfer condition and the worst-case condition is that the probable minimum condition assumes a nominal fuel loading and heat dissipation, while the worst-case normal transfer condition for the cold ambient condition assumes a zero heat load. This latter load combination leads to the analytically trivial result under steady-state conditions of a uniform -33 °C (-27 °F) temperature.

The fuel, MCO, and cask temperatures are expected to be on the order of 10 °C (50 °F) at time of loading at the basins and following CVD. To allow for process variations, additional heat-up as a result of operational delays, etc., a nominal value of 15 °C (59 °F) is assumed for the purposes of this SARP. In addition, an initial temperature of 25 °C (77 °F) is also considered for the worst-case normal transfer condition hot ambient load combination.

Table B8-7. Load Combinations for Normal Transfer Conditions.

Normal transfer load combinations		Applicable conditions							
		Initial spent nuclear fuel temp.			Insolation		Fuel loading		
		25°C	15°C	10°C	Max*	Zero	Max	Nom.	Zero
Hot Amb.,*	Worst case	X			X		X		
46°C/115°F	Probable Max.		X		X		X		
	Nominal		X		X			X	
Cold Amb.	Probable min.			X		X		X	
-33°C/-27°F	Worst case			X		X			X

*Diurnal cycle for ambient temperature and insolation in accordance with Fadeff, J. G., 1992, Environmental Conditions for On-Site Hazardous Materials Packages, WHC-SD-TP-RPT-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

8.4.2 Acceptance Criteria

The acceptance criteria per Edwards (1997) for normal transfer conditions is that the cask maintains containment for the payload and that the leakage rates meet the requirements as shown in Table B8-1. The maximum accessible outside surface temperature of the cask must be less than 85 °C (185 °F) in 38 °C (100 °F) air in the shade. The maximum temperature for the MCO must be low enough to prevent a runaway uranium corrosion reaction from occurring.

The only material used in the MCO Cask that is considered temperature sensitive is the Butyl rubber used for the O-ring seals on the closure lid and the vent and drain ports. The materials used to fabricate the other components of the system have working temperature ranges that extend well beyond the temperature levels seen for this application.

The Butyl rubber O-ring seals are fabricated of Rainier Rubber Company compound No. RR-0405-70, which has a working temperature range of -40 °C (-40 °F) to 177 °C (350 °F). Developmental testing, conducted as part of the Radioisotope Thermoelectric Generator Transportation System packaging design effort (Ferrell 1996), demonstrates that this specific Butyl rubber compound has a peak temperature rating of at least 221 °C (430 °F) for durations of 1 hour or less, 218 °C (425 °F) for 8 hours or less, and 191 °C (375 °F) for 168 hours or less.

The vent port covers on the MCO shield plug assembly are sealed with a composite gasket made of Grafoil[3] flexible graphite and 304 stainless steel retainer. The composite gasket material has a working temperature range of -218 °C (-360 °F) to 871 °C (1600 °F). The 304L stainless steel quick-disconnect couplings use a C-seal manufactured by EG&G Pressure Sciences. This seal material has a minimum temperature rating of -40 °C (-40 °F) to 427 °C (800 °F). A Helicoflex seal serves as the primary containment seal between the shield plug and the MCO vessel. This seal material has a minimum temperature rating of -40 °C (-40 °F) to 370 °C (698 °F).

(3) Grafoil is a trademark of Union Carbide Corporation.

The remaining materials used in the fabrication of the MCO Cask and MCO have significantly higher temperature capabilities. The Type 304/304L stainless steel and the SA 540 Grade B24 carbon steel used for the closure lid bolts have melting points above 1,400 °C (2,550 °F) and a maximum normal service temperature of 427 °C (800 °F). The uranium metal in the SNF assemblies has a melting temperature of 1,090 °C (1,994 °F), while the Zircaloy-2 cladding has a melting temperature above 1,800 °C (3,272 °F).

The maximum pressure allowed within the MCO and cask is 1,034 kPa gauge (150 psig).

8.4.3 Thermal Model

The various analytical thermal models used for the MCO Cask and MCO assembly are developed using the SINDA '85/FLUINT heat transfer code (SINDA 1995). This finite difference, lumped parameter code was developed under the sponsorship of the National Aeronautics and Space Administration Johnson Space Center. The SINDA code has been evaluated and validated for simulating the thermal response of transportation packages (Glass 1988). The SINDA '85/FLUINT code has been used for the analysis of several other transportation packages for nuclear material, including the recently licensed Radioisotope Thermoelectric Generator Transportation System for the U.S. Department of Energy (Ferrell 1996).

The SINDA code provides the capability to simulate steady-state and transient temperatures using temperature-dependent material properties and heat transfer via conduction, convection, and radiation. Complex algorithms may be programmed into the solution process to compute convective heat transfer coefficients as a function of the local geometry, gas thermal properties, and temperatures or to compute the chemical reaction heat as a function of the local temperature and pressure conditions.

A major feature of the SINDA '85/FLUINT code utilized for this modeling is its ability to use submodels to represent common geometry sections of the cask, fuel baskets, etc., and then to combine the individual submodels to form a complete model of the cask and MCO assembly. This approach not only simplifies the modeling but also reduces the verification process by minimizing the amount of original coding required to provide a complete thermal representation of the system. Precisely how this feature is used for this analysis is explained in the following paragraphs.

The radiation heat transfer between the various surfaces is computed assuming the standard gray body relationship (see Appendix B8-8). The surface emissivities assumed are shown in Table B8-6. The view factors for complex geometries within the MCO were computed using the VIEW program (Emery 1991), while view factors for simple geometries are computed using standard relationships or via the string method (Kreith 1973).

Five categories of analytical thermal models are utilized to analyze the performance of the MCO Cask and the MCO assembly for normal transfer and accident conditions. These are the following:

1. A model of the bottom end region of the MCO Cask and MCO assembly
2. A model of the typical axial midsection of the MCO Cask
3. A model of the closure lid end region of the MCO Cask and MCO shield plug
4. A model of a typical intact fuel basket within the MCO assembly
5. A model of a scrap basket within the MCO assembly.

The dimensional data and material specifications used in the thermal models are taken from the figures in Part A, Section 10.0.

Figure B8-1 shows the layout of the various thermal submodels used to evaluate the thermal performance of the MCO Cask and MCO assembly. This layout, showing the MCO arrangement with the Mark IV fuel, consists of five identical submodels (i.e., submodels BSKT1, BSKT2, BSKT3, BSKT4, and BSKT5), together with submodels for the lid and end regions of the cask and MCO. As shown in the figure, the end submodel encompasses the lower 23.8 cm (9.38 in.) of the cask and end plug of the MCO shell. Above the end submodel are five submodels of the MCO fuel baskets and associated sections of the cask wall. Each of these submodels span the 68.2-cm (26.85-in.) length of the fuel baskets. Above the last fuel basket is a thermal submodel of the MCO shield plug, the void space below the shield plug, and a 27.2-cm (10.69-in.) section of the cask wall. The lid submodel encompasses the upper 40.1-cm (15.79-in.) section of the cask wall. The thermal resolution provided within each of the individual submodels is shown in Figures B8-2 to B8-6 by the location of the lumped thermal mass nodes used to represent the various components of the MCO assembly and cask.

Heat transfer through and from the typical midbody section of the cask wall is simulated using an axisymmetric representation of the cask. An axisymmetric model is used because the cask thickness and the relatively small variation in heat flux from the MCO in the circumferential direction results in a minimal variation of cask wall temperatures in the circumferential direction. Figure B8-2 shows the five interior thermal nodes and two surface nodes used to provide this axisymmetric representation of the cask wall at the BSKT3 submodel.

In contrast, modeling of the MCO assembly (Figure B8-3) used a 3-D approach because of the variation in heat flux and the relatively low thermal mass offered by the MCO shell and fuel baskets. The MCO shell is divided into three axial sections over the axial length of the fuel basket and into 30° segments in the circumferential direction. Together, Nodes 70, 72, and 74 represent a 7.62-cm- (3-in.-) high, 90°-wide segment of the MCO. Nodes 170, 172, and 174 represent 27.94-cm- (11-in.-) high segments of the MCO opposite the perforated skirt of the fuel basket, while Nodes 270, 272, and 274 represent the 32.64-cm- (12.85-in.-) high section of the MCO that "sees" the sections of the fuel assemblies extending above the fuel basket skirt.

Figure B8-1. Overview of Thermal Submodels.

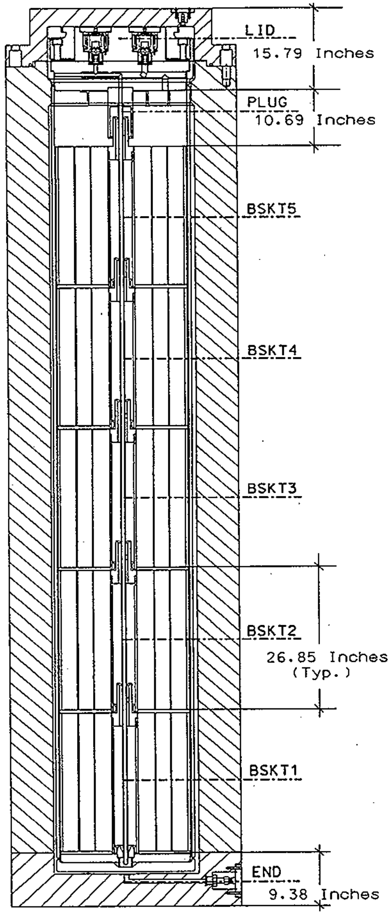
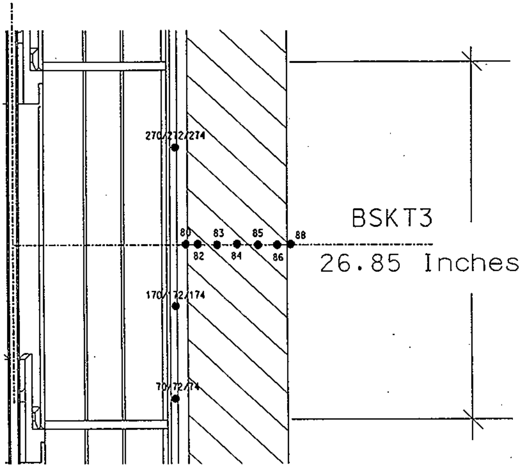


Figure B8-2. Thermal Submodel at Typical Midcask Section.



Taken together, the submodels provide an axisymmetric thermal model of the MCO cask shell and a 3-D thermal model of the cask lid and of the MCO assembly. Heat transfer between the cask inner surface and the MCO is assumed to be via straight conduction (i.e., Nu = 1) through either a water or helium gas medium as appropriate for the transportation mode under consideration. The presence of hydrogen gas is conservatively ignored (the thermal conductivity of hydrogen is 20-30% greater than helium) for this analysis. Grey-body radiation interchange across the gap is also included for those sections with a helium backfill. Heat transfer from the outer surface of the cask is via convection and radiation to the ambient environment.

Figure B8-3 shows an enlarged view of the node layout for the cask bottom end. As with the cask body, an axisymmetric representation is used. Likewise, an axisymmetric model of the end plug of the MCO vessel is used (i.e. Nodes 70 to 570). This axisymmetric representation is transitioned to the 3-D representation used for the BSKT1 submodel. The drain port fitting and cover plate are represented by a separate submodel that is thermally connected to the axisymmetric representation of the cask end. The presence of the transport trailer is ignored for the purposes of this analysis. This assumption maximizes the heat input into the cask during both the normal transfer conditions and accident analysis.

Figure B8-3. Thermal Submodel at Cask Bottom.

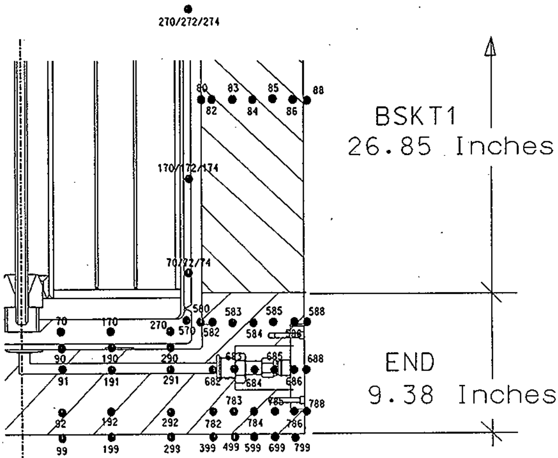


Figure B8-4 shows the thermal node layout for the plug submodel. An axisymmetric representation of the shield plug is used, while the MCO shell sections are represented with three nodes around the circumference. A single thermal node (59) is used to represent the mean gas temperature within the void volume below the shield plug. The cask sections of this submodel (opposite Nodes 870 to 974) are not shown for simplicity, but follow the same layout as shown in Figure B8-2. The upper section of the MCO shield plug thermal model interfaces with the thermal model of the cask lid shown in Figure B8-5. Because of the nonaxisymmetric influence of the cask lifting trunnions (not show in the figures), the cask lid is modeled in three dimensions. Nine thermal nodes are used to simulate the heat lost or gained from the trunnions.

The 3-D representation of the lid is transitioned to the axisymmetric model of the cask side wall at the plug submodel segment. The cask vent port fitting and cover are modeled with a separate thermal submodel, which is thermally connected to the lid thermal model. Although not shown in Figure B8-5, the 12 cask closure bolts comprise a significant thermal path during the fire event and, as such, are modeled separately using four thermal nodes to represent the exposed head, the shank section (two nodes), and the threaded portion.

Figure B8-4. Thermal Model at Multicanister Overpack Shield Plug.

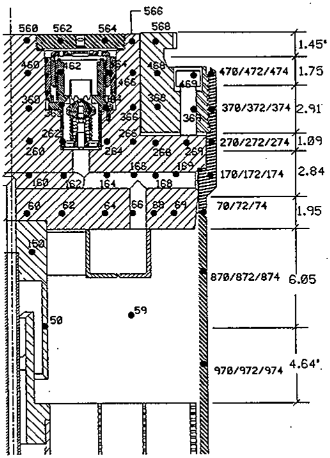
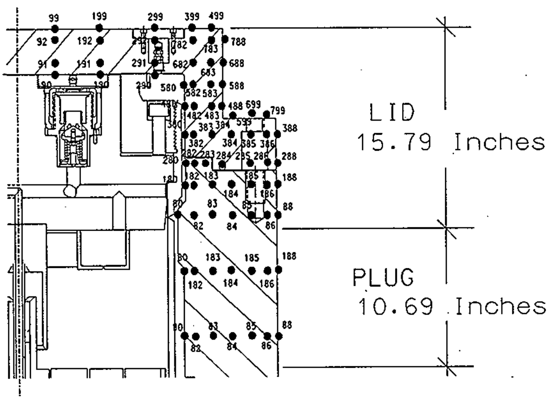


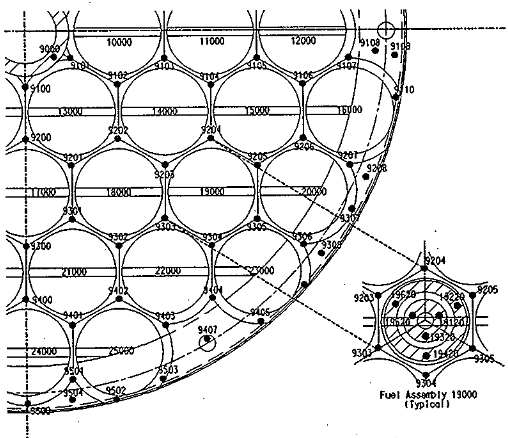
Figure B8-5. Thermal Submodel at Cask Closure Lid.



The basic thermal submodel of the fuel baskets and the fuel elements represents a 90° segment of a single level. The plan view of the Mark IV fuel basket assembly shown in Figure B8-6 illustrates the placement of the thermal nodes used to model the base plate of the Mark IV fuel basket and the lower 6.6-cm (2.6-in.) section of each fuel assembly that fits within the sockets of the fuel basket base plate. Within the 90° segment, 11 complete fuel assemblies and 5 partial fuel assemblies are represented. Symmetry conditions are assumed at the model boundaries. The enlarged view of a representative fuel assembly within the basket illustrates the placement of the thermal nodes used to simulate each fuel assembly and the surrounding basket structure.

Thermal resolution within each full fuel assembly is provided through the use of 24 thermal nodes, 12 for each element, over 4 axial segments within the fuel elements. Each axial segment is represented by three nodes in the circumferential direction. The lowest axial segment (shown in Figure B8-6) is 6.6 cm (2.6 in.) high. The three other axial segments not shown are 27.94 cm (11 in.), 23.88 cm (9.4 in.), and 7.62 cm (3 in.) high, respectively. Heat transfer from the inner to the outer element is treated as conduction and radiation (for dry transfer) across the 0.53-cm (0.21-in.) gap separating the elements. Convection from the outer surface of the outer element is assumed. While the presence of hydrogen gas is conservatively ignored (the thermal conductivity of hydrogen is 20-30% higher than that for helium), the beneficial effect due to pressure increase is included.

Figure B8-6. Thermal Model of Intact Fuel Basket and Lower Fuel Element Section.



The Mark IV scrap basket is modeled as a homogeneous, porous medium using 20 thermal nodes to provide a 2-D, axisymmetric representation of the heat generation and temperatures within the scrap bed. An additional 14 thermal nodes provide a 2-D, axisymmetric thermal representation of the scrap basket side walls, base, and center tube.

In addition to computing temperatures, the thermal model computed the transient pressure rise within the MCO and cask. The calculation includes the pressure rise effects from four sources: (1) the ideal gas expansion with changes in temperature, (2) the pressure rise due to hydrogen gas generation from chemical reactions, (3) the expansion of the water, and (4) the amount of hydrogen dissolved in the water volume for the wet transfer phase. The void volumes and initial backfill pressures assumed are shown in Table B8-1. The pressure rise due to hydrogen gas generation is computed using the chemical reaction and gas generation rates listed in Section 8.2, while the amount of hydrogen dissolved in the water during the wet transfer phase is determined using Henry's law, the volume of the water, and the partial pressure of hydrogen gas.

8.4.4 Thermal Analysis

The evaluation of the thermal performance to demonstrate compliance with Hanford Site transportation safety criteria (Mercado 1994) is accomplished using the analytical model described previously. The evaluation involves a series of analytical simulations of the wet and dry transfer transients that encompass the expected variations in fuel loading, ambient temperature, and initial starting temperature. Table B8-7 shows the specific load combinations considered for normal transfer conditions.

The nominal, probable maximum, and worst-case normal transfer condition loadings for hot ambient conditions are evaluated using a transient simulation of the transfer process with a diurnal cycle for ambient temperature and insolation based on the Hanford peak summer day. To ensure that the cask is exposed to the highest heat flux portion of the diurnal cycle during the projected transfer time frame, an 8 a.m. start time is assumed for the simulated transfer process.

The minimum expected temperatures are also evaluated using a transient simulation based on the nominal-case fuel loading with a steady-state ambient air temperature of -33°C (-27°F) and no solar. The analytically trivial case of no decay or chemical reaction heat, together with the minimum ambient conditions of -33°C (-27°F) and no solar loading, is also considered to ensure material compliance with worst-case minimum temperatures.

8.4.4.1 Thermal Analysis For Wet Transfer. The results of the thermal evaluations of the maximum temperatures expected under normal conditions of wet transfer are shown in Tables B8-8, B8-9, and B8-10 and in Figures B8-7 to B8-10. Table B8-8 shows the maximum temperatures expected for key cask and MCO components during the normal 8-hour operational time frame allotted for wet transfer phase from the K Basins to the CVDF. The results are presented for the worst-case and probable maximum transfer conditions as shown in Table B8-7. All of the temperatures are within the allowable limits of the associated component. In addition, the surface temperature of the cask remains below 85 °C (185 °F) as required by 10 CFR §71.43(g) for exclusive-use packages.

Table B8-8. Multicanister Overpack (MCO) Cask and MCO Assembly Maximum Temperatures for Wet Normal Transfer Conditions.

Location and condition	Maximum wet normal transfer conditions,[a] °C (°F)	
	Worst case[b]	Probable maximum[c]
Spent nuclear fuel, maximum	36 (97)	27 (80)
Spent nuclear fuel, average	35 (95)	26 (79)
Rubble basket fuel, maximum	35 (95)	26 (78)
MCO sidewall, average	35 (95)	26 (78)
MCO sidewall, maximum	35 (95)	27 (80)
MCO shield plug, average	29 (84)	26 (78)
MCO shield plug, seals	30 (86)	27 (81)
Cask sidewall, average	36 (96)	28 (82)
Cask sidewall, maximum	37 (98)	30 (86)
Seal port, lid end	47 (117)	46 (115)
Seal port, bottom end	36 (96)	29 (84)
Closure lid seals, maximum	38 (100)	35 (95)

NOTES:

[a]Temperatures shown are for the end of the normal transfer time of 8 hours. Assumes water in MCO and cask to a level 4 in. below the shield plug. Hanford diurnal cycle on ambient temperature and solar insolation per Irwin (1994), with 46 °C (115 °F) max. ambient. Worst-case payload: maximum decay heat and a total corrosion surface area of 120,000 cm^2. Transfer start at 8 a.m.

[b]Worst-case conditions: Starting temperature for cask and contents is 25 °C (77 °F).

[c]Probable maximum conditions: Starting temperature for cask and contents is 15 °C (59 °F).

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Table B8-9. Multicanister Overpack (MCO) Cask and MCO Assembly Minimum Temperatures for Normal Wet and Dry Transfer Conditions.

Location and condition	Probable minimum temperatures,[a] °C (°F)	
	Wet transfer[b]	Dry transfer[b]
Spent nuclear fuel, maximum	12 (53)	23 (74)
Spent nuclear fuel, average	9 (49)	16 (61)
Rubble basket fuel, maximum	11 (52)	18 (65)
MCO sidewall, average	6 (43)	4 (40)
MCO sidewall, maximum	7 (44)	6 (42)
MCO shield plug, average	4 (39)	-2 (28)
MCO shield plug, seals	3 (38)	-3 (27)
Cask sidewall, average	2 (36)	-3 (26)
Cask sidewall, maximum	3 (38)	-3 (27)
Seal port, lid end	-9 (16)	-14 (6)
Seal port, bottom end	-3 (27)	-8 (17)
Closure lid seals, maximum	-3 (26)	-8 (17)

NOTES:

[a]Temperatures shown are for the end of the normal transfer time of 8 hours for wet transfer and 14 hours for dry transfer. Assumes the nominal MCO fuel loading, a starting temperature for cask and contents of 10 °C (50 °F), and fixed -33°C (-27°F) ambient temperature with no solar.

[b]Worst-case minimum temperatures are -33 °C (-27 °F).

Table B8-10. Multiple Canister Overpack (MCO) Cask and MCO Assembly Maximum Pressures for Normal Transfer Conditions.

Thermal load combination	MCO assembly[a]		MCO Cask[a]	
	Temperature, °C (°F)	Pressure, kPa (psia)	Temperature, °C (°F)	Pressure, kPa (psia)
Wet transfer conditions: hot (diurnal cycle)[b]	33 (91)	241 (35.0)	35 (95)	241 (35.0)
Wet transfer conditions: cold (-33°C/-27°F)[c]	5 (40)	122 (17.7)	4 (40)	122 (17.7)
Dry transfer conditions: hot (diurnal cycle)[b]	54 (129)	187 (27.1)	42 (108)	129 (18.7)
Dry transfer conditions: cold (-33°C/ -27°F)[c]	14 (57)	129 (17.8)	0 (32)	112 (16.2)

NOTES:

[a]Temperatures and pressures shown are for the end of the normal transfer time of 8 hours for wet transfer and 14 hours for dry transfer. Assumes a 0.0425-m^3 gas space for wet transfer (including the cask annulus) and 0.56-m^3 gas space for dry transport. MCO vented to cask for wet transfer and sealed for dry transfer. Payload consists of one scrap basket and four fuel baskets with split cladding on the upper 3 in. of the assemblies. Total corrosion surface area is 120,000 cm^2. Starting temperature for cask and contents is 15 °C (59 °F) with a 17.7 psia helium backfill.

[b]Hot transfer conditions: Hanford diurnal cycle on ambient temperature and solar insolation per Irwin (1994), with 46 °C (115 °F) max. ambient.

[c]Cold transfer conditions: fixed -33 °C (-27 °F) ambient, no solar.

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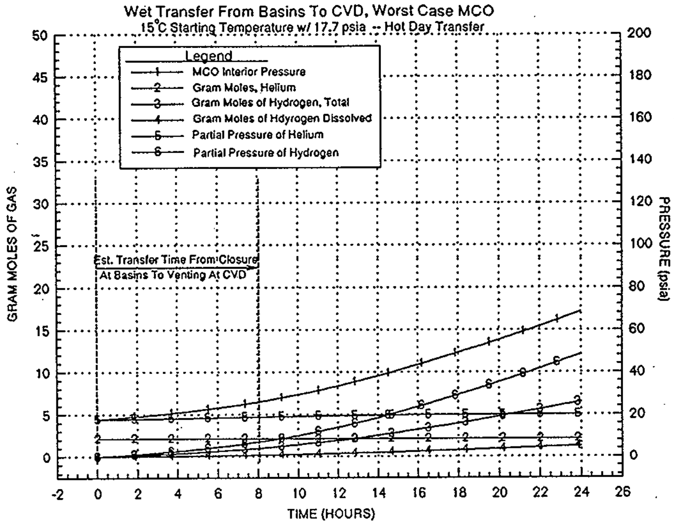
Figure B8-7. Probable Maximum Wet Transfer Transient.



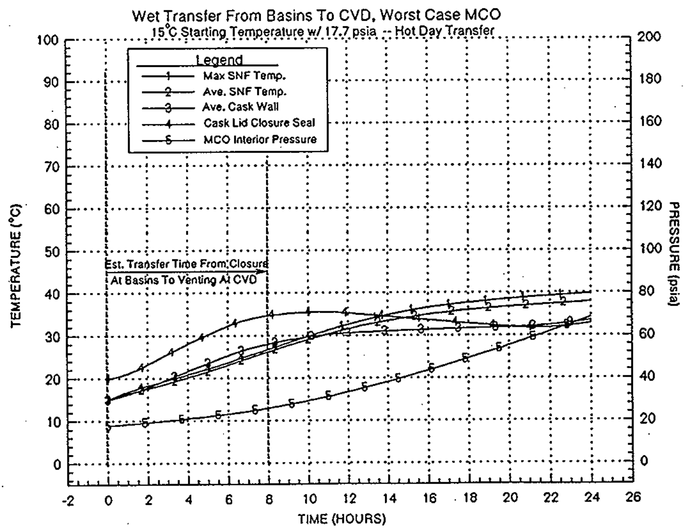
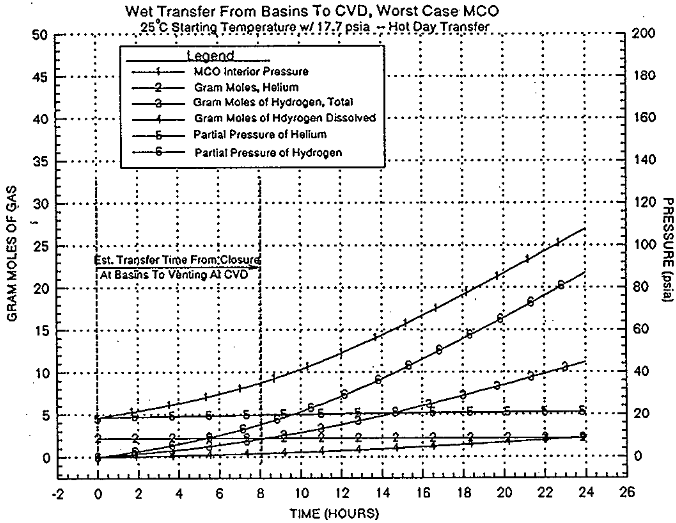


Figure B8-8. Worst-Case Wet Transfer Transient.



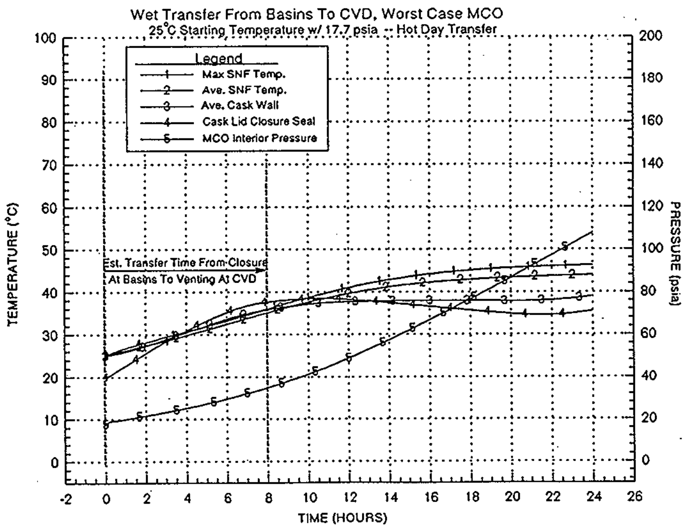


Figure B8-9. Off-Normal Wet Transfer Transient.

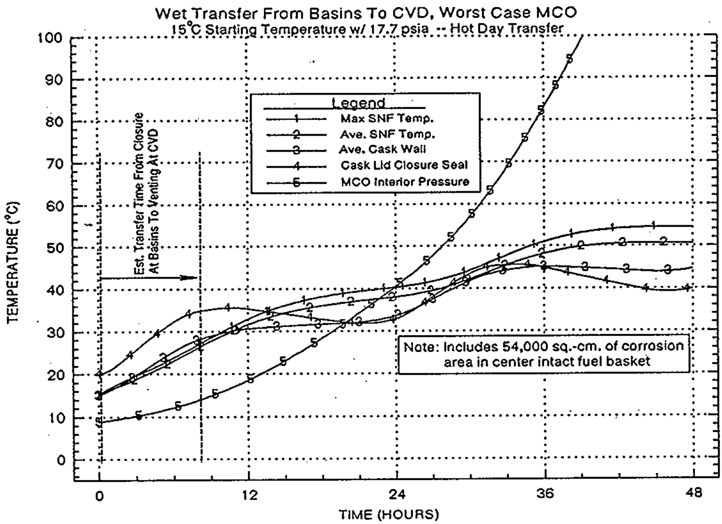
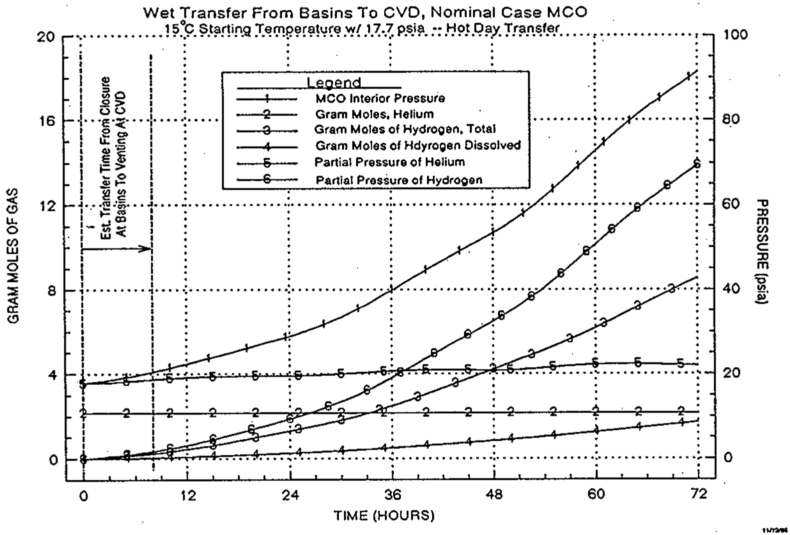
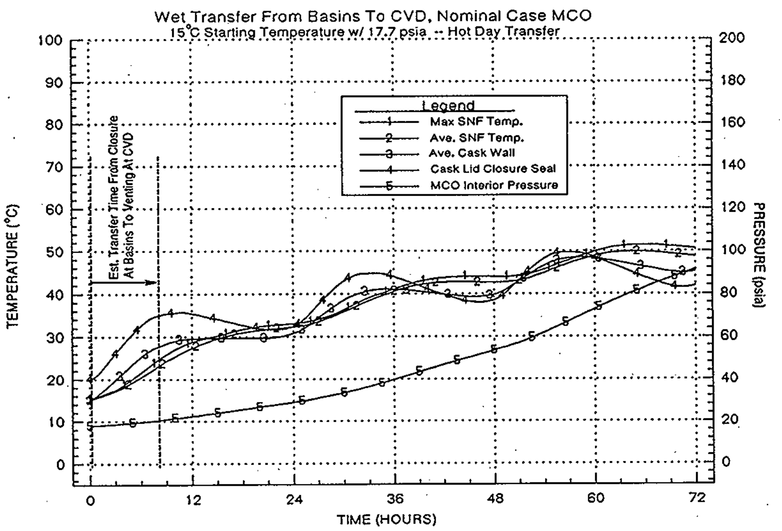


Figure B8-10. Nominal Wet Transfer Transient.





Figures B8-7 and B8-8 show the transient response of the MCO and cask over a 24-hour period for the same cases shown in Table B8-8. The effect of the sinusoidal diurnal cycle for ambient air temperature and insolation are apparent in the figures. The cask lid closure seal temperature begins at 20 °C (68 °F) since the lid is assumed to be at room temperature prior to being placed on the cask. Starting the transfer with a 25 °C (77 °F) SNF temperature results in a 21% increase in cask pressure after 8 hours and a 62% increase after 24 hours over that seen with a 15 °C (59 °F) SNF temperature. However, in both cases the expected cask pressure after 24 hours remains below the 1,034-kPa (150-psig) pressure limitation on the cask.

While the transfer from the K Basins to the CVDF will require less than 8 hours on average and less than 24 hours under most situations, a major failure in the transportation system while en route could require times in excess of 24 hours to remedy. To assess the thermal effects related to an extended transfer delay, a 48-hour transport transient is evaluated using the probable maximum-case load combination for normal transfer conditions with an additional 54,000 cm^2 of corrosion area added to the center fuel basket. The results for this extreme load combination encompasses both the effect of transporting two scrap baskets and the sensitivity of transient results to the differences in the thermal resistance posed by an intact fuel basket versus that of a scrap basket as simulated using a porous media approach.

While, as shown in Figure B8-9, the 48-hour transient is successfully completed without a thermal excursion in the SNF payload, the cask pressure is predicted to exceed its 1,034-kPa (150-psig) pressure limitation after 35 hours due to hydrogen gas generation within the unsealed MCO. As such, it will be necessary to relieve the cask pressure to remain within safety limits if the time to accomplish the transfer is more than approximately 30 hours, or about four times the expected normal transfer time. The principal recovery mode available during the wet transfer phase is to open the cask vent port. The same conclusion is reached based on an extrapolation of the transient trends shown in Figure B8-8 for the worst-case wet transfer. Section 8.6 addresses operations during time frames that extend beyond the nominal shipping-window conditions.

Figures B8-7 to B8-9 show the bounding transport combinations for the nominal shipping-window conditions as required for SARP purposes. However, the majority of the shipments between the K Basins and the CVDF are expected to be within the defined nominal load combination for normal transfer conditions and within the nominal shipping window. Figure B8-10 shows the transient thermal response expected for this load combination. As seen from the figure, no temperature excursions or excessive pressures will occur within the cask during a time frame that is nine times that nominally required to accomplish the transfer.

Table B8-10 shows the minimum temperatures for the probable minimum load combination for normal transfer conditions as shown in Table B8-7. All temperatures are within the thermal capabilities of the associated component. In addition to this analytically derived minimum condition, the worst-case minimum temperature of -33 °C (-27 °F), based on assuming steady-state conditions, no solar, and no radiolytic or chemical reaction heat, is also within the thermal capabilities of all materials used in the MCO and cask.

The maximum internal pressures expected for the 8-hour, wet, normal transfer conditions process and with the probable maximum load combination are shown in Table B8-11. The results show that the pressures will remain well within the pressure limitations of the cask. In addition, per Figures B8-7 to B8-10, the maximum cask pressure is expected to remain within its allowable limit of 1,034 kPa (150 psig) for all load combinations considered during the 8-hour time frame allotted for normal transport plus an additional recovery time period of 20-24 hours for the off-normal transport event. A venting of the cask interior to the atmosphere will be required for wet transfer events requiring more than 24-30 hours to complete. However, no thermal excursion is predicted for time periods up to 48 hours under any of the load combinations examined. Section 8.6 provides more details on operations during time frames beyond the nominal shipping-window conditions.

Table B8-11. Multiple Canister Overpack (MCO) Cask and MCO Assembly Maximum Temperatures for Dry Normal Transfer Conditions.

Location and condition	Maximum dry normal transfer conditions,[a] °C (°F)	
	Worst case[b]	Probable maximum[c]
Spent nuclear fuel, maximum	64 (148)	54 (129)
Spent nuclear fuel, average	56 (133)	47 (117)
Rubble basket fuel, maximum	60 (140)	50 (122)
MCO sidewall, average	44 (112)	37 (99)
MCO sidewall, maximum	46 (114)	39 (102)
MCO shield plug, average	38 (101)	33 (91)
MCO shield plug, seals	39 (102)	34 (93)
Cask sidewall, average	39 (103)	33 (91)
Cask sidewall, maximum	39 (103)	34 (93)
Seal port, lid end	43 (109)	40 (104)
Seal port, bottom end	37 (99)	32 (90)
Closure lid seals, maximum	39 (103)	35 (95)

NOTES:

[a]Temperatures shown are for the end of the normal transfer time of 14 hours. Hanford diurnal cycle on ambient temperature and solar insolation per Irwin (1994), with 46 °C (115 °F) max. ambient. Worst-case payload: maximum decay heat and a total corrosion surface area of 120,000 cm^2. Transfer start at 8 a.m.

[b]Peak conditions: Starting temperature for cask and contents is 25 °C (77 °F).

[c]Nominal conditions: Starting temperature for cask and contents is 15 °C (59 °F).

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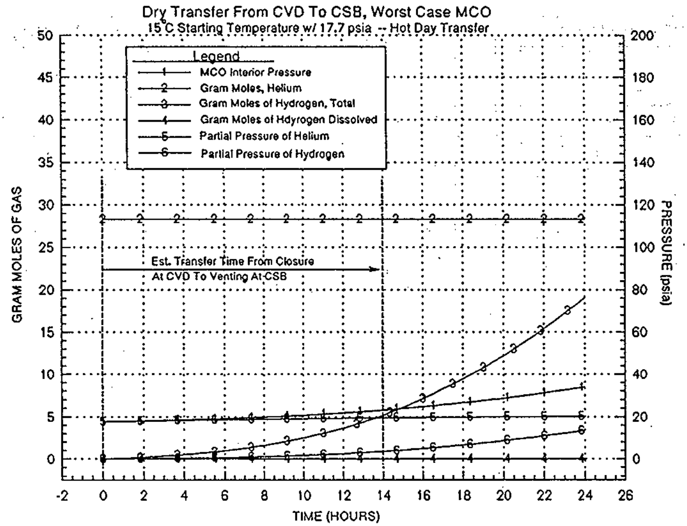
8.4.4.2 Thermal Analysis For Dry Transfer. The results of the thermal evaluations for normal conditions of dry transfer are shown in Tables B8-9 to B8-11 and Figures B8-11 to B8-14. Table B8-11 shows the maximum temperatures expected for key cask and MCO components during the normal 14-hour operational time frame allotted for the dry transfer phase from the CVDF to the CSB. The table presents results for the worst-case and probable maximum transfer conditions as shown in Table B8-7. All of the temperatures are within the allowable limits of the associated component. In addition, the surface temperature of the cask remains below 85 °C (185 °F) as required by 10 CFR §71.43(g) for exclusive-use packages.

Figures B8-11 and B8-12 show the transient results over a 24-hour period for the same cases shown in Table B8-11. The sinusoidal effect of the diurnal cycle for the ambient air temperature and insolation are apparent in the results for the cask wall and closure lid seal. Over the 24-hour period simulated by these analyses, the difference between starting the transfer with a 25 °C (77 °F) SNF temperature versus a 15 °C (59 °F) SNF temperature is not as great as was seen for the wet transfer leg. This is because the drained MCO presents a larger volume in which to absorb the increased hydrogen gas amount that is generated at the higher SNF temperatures. As a result, the difference in MCO pressure is only 83 kPa (12 psi) greater after 24 hours for the higher SNF temperature. In either case, the expected MCO and cask pressures after 24 hours remain well below the 1,034-kPa (150-psig) pressure limitation.

The transfer from the CVDF to the CSB will be 14 hours or less on average and less than 36 hours under most situations, which is defined as the shipping window for the transport system. To assess the thermal effects related to an extended transport delay, a 36-hour transport transient is evaluated using the probable maximum-case load combination for normal transfer conditions. The results are shown in Figure B8-13 for two assumptions on the amount of moisture available to drive the chemical reaction. Under the first assumption, illustrated in the lower plot, there is unlimited moisture available within the MCO following CVD; this moisture is available as steam vapor (i.e., it is not chemically or mechanically bound); and this steam vapor is available at a partial pressure associated with the average fuel temperature. Under these assumptions and the worst-case MCO payload, the transient analysis indicates that a temperature excursion will occur within the fuel after approximately 35 hours.

The second assumption, shown in the upper plot of Figure B8-13, is that the CVD process has removed sufficient moisture from the fuel, scrap, and sludge content within the MCO such that the release rate for the remaining moisture available to drive the reaction is only 5% of that which an unlimited amount of moisture would support. This assumption is maintained until any portion of the fuel payload exceeds 85 °C (185 °F), at which time the reaction rate is returned to its full value as predicted by the chemical reaction rate equations for the given temperature and partial pressure conditions. This switch in reaction rates is necessary because the safety basis for the lower reaction rate is limited by the maximum temperature conditions that will be achieved during the CVD process. The current CVD process calls for a maximum cask-MCO annulus bath temperature of 75 °C (167 °F). An additional 10 °C (50 °F) is included to account for the temperature rise between the MCO sidewall and the centerline temperature within the fuel baskets. Based on the corrosion area assumed for this analysis and a 75 °C (167 °F) average fuel temperature, the assumed 5% limitation equates to a monitored pressure rise limitation of 1.4 kPa (0.2 psi) per hour or less at the CVDF. Under this criteria, those MCOs exhibiting pressure rises in excess of this rate would be required to remain under the CVD process until this criteria is met before being allowed to be transported.

Figure B8-11. Probable Maximum Dry Transfer Transient.



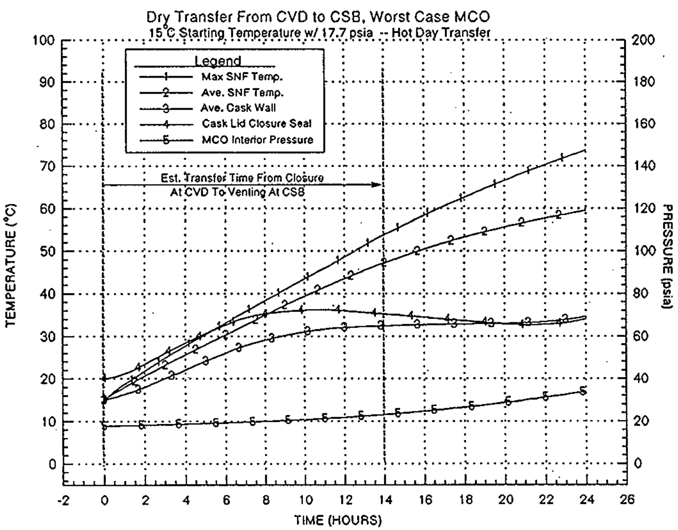
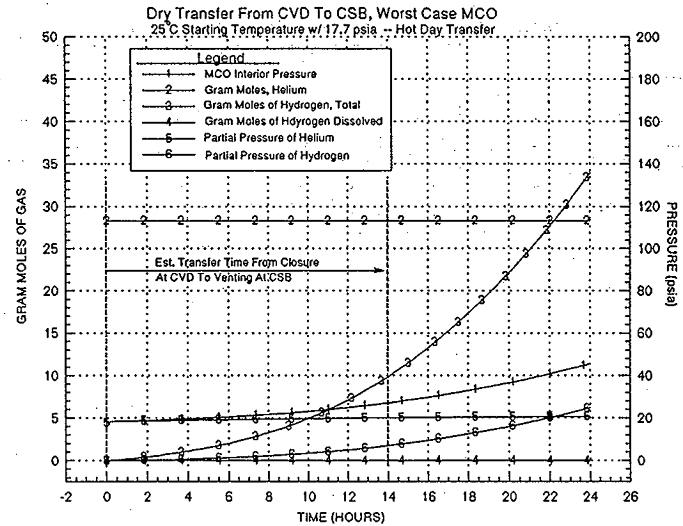


Figure B8-12. Worst-Case Dry Transfer Transient.



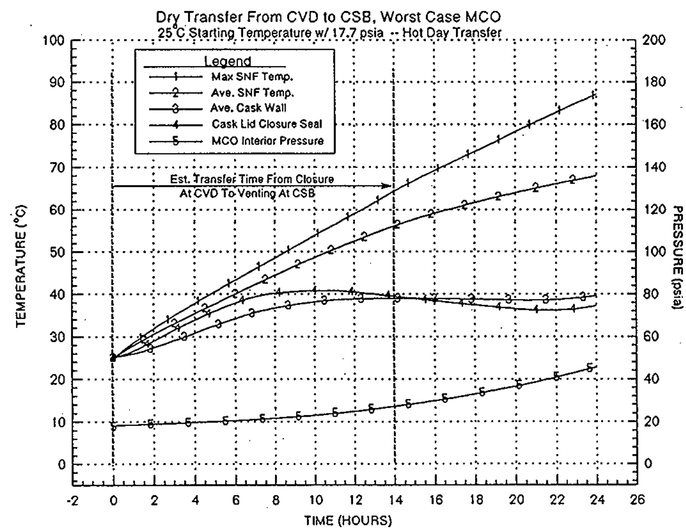
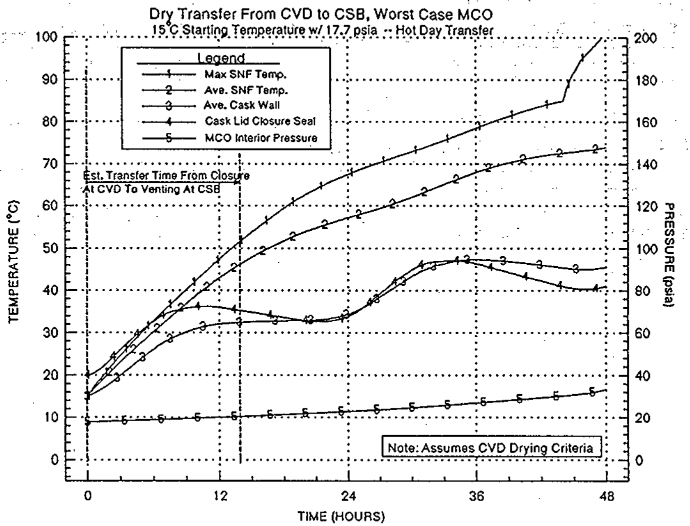
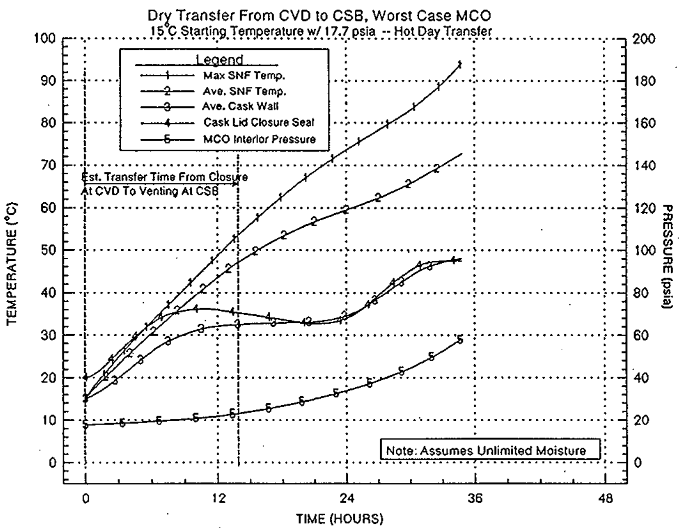


Figure B8-13. Off-Normal Dry Transfer Transient.





The transient results for the dry transfer, assuming implementation of the CVD drying criteria, show that a 48-hour shipping window can be met without a thermal excursion or excessive pressure within the MCO. The sudden rise in the peak SNF fuel temperature after approximately 42 hours is due to the analytical return to the unlimited moisture release assumption because the maximum fuel temperature exceeded 85 °C (185 °F).

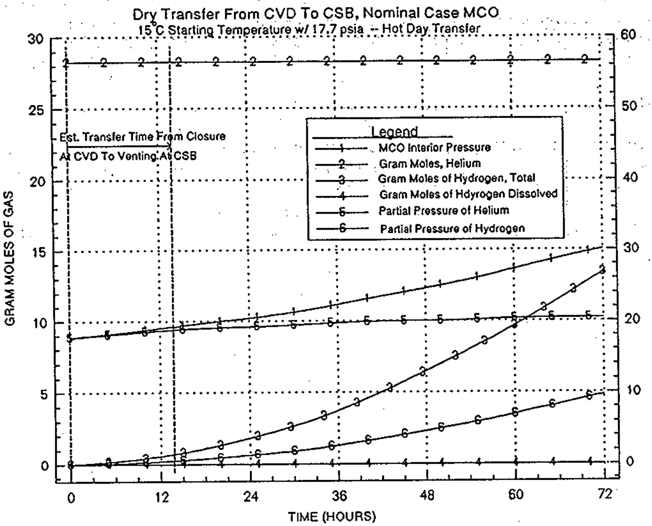
While Figures B8-11 to B8-13 show the bounding conditions assumed, the majority of the shipments are expected to fit within the nominal load combination for normal transfer conditions. Figure B8-14 shows the transient thermal response expected for this load combination with a three-day transport time frame. The results demonstrate that, despite the extended transport time assumed, no temperature excursions or excessive pressures will occur within the MCO or cask. Section 8.6 addresses operations during time frames beyond the nominal shipping-window conditions.

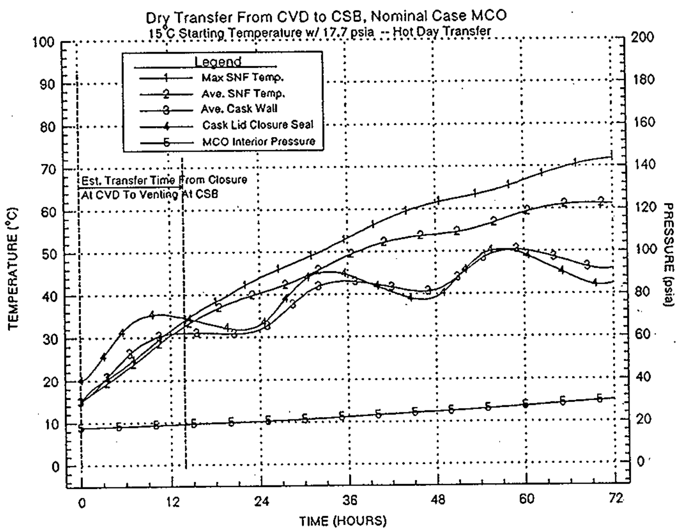
The drying requirement for the CVDF is based on an iterative analysis of the dry transfer stage to establish the maximum moisture release rate within the MCO that can be accommodated for the dry transfer of the worst-case payload over a 48-hour shipping window without causing a temperature excursion within the fuel. The established drying requirement is expressed as a ratio of an observed pressure rise within the MCO during the CVD process to the pressure rise that is predicted to occur for the worst-case payload at the same temperature level and with an unlimited release rate on moisture. As such, a reduction in the observed pressure rise can be attributed to the following or a combination thereof:

- A level of dryness that would not support a dangerous pressure/ temperature rise within the MCO
- A lesser amount of corroded surface area that will yield a similarly safe condition of transfer regardless of the amount of moisture remaining in the MCO.

The CVD drying criteria established by this analysis calls for a maximum pressure rise of 1.4 kPa (0.2 psi) per hour at the 75 °C (167 °F) hold point in the CVD process. The total allowable pressure rise over the 12-hour hold time in the CVD process is 16.8 kPa (2.4 psi) or less. The application of this drying criteria to the dry transfer process yields a transient dry transfer result shown in the upper plot of Figure B8-13. The reduced reaction rate established by this drying criteria is maintained until any portion of the fuel exceeds 85 °C (185 °F), at which time the reaction rate is returned to its full value as predicted by the chemical reaction rate equations for the given temperature and partial pressure conditions, with an unlimited release rate for the remaining water in the MCO. The reasoning behind this switch in reaction rates is that no analytical basis currently exists under which the monitored test results at 75 °C can be extrapolated to higher temperature levels (the 10 °C delta between 75 and 85 °C represents the minimum expected temperature rise in the fuel under the CVD temperature hold point).

Figure B8-14. Nominal Dry Transfer Transient.





The results shown in the upper plot of Figure B8-13 indicates a 48-hour shipping window can safely be accommodated even for the worst-case payload condition. This conclusion is supported by the fact that the release rate for any hydrates remaining after the CVD process will be relatively low for the temperatures and pressures seen during the dry transfer process (Plys 1997).

While Figures B8-11 to B8-13 show the bounding conditions assumed, the majority of the shipments are expected to fit within the nominal normal transfer conditions load combination. Figure B8-14 shows the transient thermal response expected for this load combination with a three-day transfer time frame. The results demonstrate that, despite the extended transfer time assumed, no temperature excursions or excessive pressures will occur within the MCO or cask.

Table B8-9 shows the minimum temperatures for the probable minimum normal transfer conditions load combination as shown in Table B8-7. All temperatures are within the thermal capabilities of the associated component. In addition, the worst-case minimum temperature of -33 °C (-27 °F), which is reached assuming steady-state conditions, no solar, and no radiolytic or chemical reaction heat, is also within the thermal capabilities of all materials used in the MCO and cask.

The maximum internal pressures expected for the 14-hour, dry, normal transfer condition process are shown in Table B8-10. The results show that the pressures will remain well within the pressure limitations of both the MCO and the cask. In addition, per Figures B8-11 to B8-14, the maximum pressures will remain within the allowable limit of 1,034 kPa (150 psig) during the time frame allotted for normal transfer plus off-normal event recovery.

8.5 THERMAL EVALUATION FOR ACCIDENT CONDITIONS

The thermal analysis of the accident conditions for the MCO Cask and MCO assembly are based on the fire accident transient for site specific conditions. The risk assessment, Part B, Section 3.0, shows that if the cask, including seals, performs its function during a fully engulfing fire of 6-minute duration or less, then onsite transportation criteria (Mercado [1994]) are satisfied. As shown in Part B, Section 3.0, the 10 CFR 71 specified requirement for a sequential combination of the drop accident preceding the fire accident is not a credible event for this transportation system. As such, the cask is assumed to remain upright and on its transport trailer during all fire events.

For information, the 10 CFR 71 specified fully engulfing fire duration of 30 minutes is also evaluated for dry transfer. This evaluation, along with Part B, Section 7.4, shows that the cask retains the MCO during the 30-minute fire and that a runaway chemical reaction does not occur within the MCO.

8.5.1 Conditions To Be Evaluated

The site specific ambient temperatures and accident response times are considered in the thermal evaluations for the accident conditions presented in this analysis. The load combinations considered are the same as those considered for normal transfer conditions (see Table B8-7). While ambient temperatures ranging from -33 °C (-27 °F) to 46 °C (115 °F) are considered, only the hot ambient condition is presented in this analysis. The results for the cold ambient conditions are encompassed by those for hot ambient conditions. This is due to the fact that the shipping process will result in the same cask temperatures prior to transfer under all ambient cases and, given the short duration of the transfer process, the difference in cask temperature prior to the start of the fire event will be small between those seen for the hot ambient conditions and those for the cold ambient conditions. As a result, the peak temperatures and the thermal gradients reached in the cask from the fire will be similar for the two ambient conditions.

Since the transfer occurs entirely within the Hanford Site and that advanced notice is given prior to each shipment, the site accident response teams are assumed to be able to reach the site of an accident within 15 minutes after the start of the fire event. Active cooling of the cask surface is assumed to begin at this time or at the end of the fire event, whichever is later. Per Edwards (1997), the active cooling consists of quenching the outer package surfaces using water spray from a fire hose rated at 125 gal/min. Flow at this maximum flow rate is assumed to occur for a maximum of 45 minutes. Additional quenching water flow is assumed for an additional period of up to 100 minutes at a maximum flow rate of 50 gal/min. A water temperature of 29 °C (85 °F) is assumed for the water quench operation.

8.5.2 Acceptance Criteria

The applicable acceptance criteria for the accident conditions are the same as presented in Section 8.4.2.

8.5.3 Package Conditions and Environment

It is assumed that the package is undamaged and in the vertical orientation prior to, during, and after the fire transient. This assumption is based on the risk assessment that finds a drop and fire accident are mutually exclusive events (Part B, Section 3.0). The initial temperature distribution in the package prior to the fire event is taken from the transient analysis for the end of the shipping windows for wet transfer between the K Basins and the CVDF (i.e., 24 hours) and for dry transfer between the CVDF and CSB (i.e., 36 hours) and with the Hanford hot day diurnal cycle. To simulate the effect of the fire transient event, the package is exposed to a fully engulfing convective and radiative heat flux based on an effective ambient air temperature of 802 °C (1475 °F) and with an effective emissivity of 0.90.

The elevated heat flux is continued for 6 minutes (or alternatively 30 minutes), after which time the boundary conditions are returned to the initial conditions as determined from the diurnal cycle for ambient air temperature and solar heat load. In accordance with 10 CFR 71, solar loading during the fire accident is ignored. Following the end of the fire event, the thermal transient analysis is continued for a sufficient time to determine the maximum temperatures for all components. Consistent with the requirements of 10 CFR §71.73(c)(4), the surface absorptivity of all external surfaces is set to 0.8 after the fire event is started.

8.5.4 Thermal Model

The thermal performance of the package is evaluated analytically using the same thermal model described in Section 8.4.3. Because the package remains upright throughout the event, no drop damage will occur and none is modeled. While the transport trailer will provide thermal shielding and additional thermal mass, the presence of the trailer is conservatively ignored for this evaluation. The modifications made to the normal transfer conditions thermal model for fire evaluations consist of increasing the external surface absorptivity to meet the 10 CFR 71 specified value of 0.8 after initiation of the fire and the use of forced convection during the fire event to simulate the convective environment of a pool fire.

The pressure rise within the MCO during the dry transfer analysis is computed assuming the CVD drying criteria has been implemented (see Section 8.4.4.2).

8.5.5 Thermal Analysis

The evaluation of the thermal performance to demonstrate compliance with Edwards (1997) and the 10 CFR §71.73 conditions is accomplished using the analytical model described above. Table B8-12 shows the peak temperatures seen during the fire transients for dry transfer. The table includes results for both the 6-minute and 30-minute fire events. Figures B8-15 through B8-22 show the temperatures and MCO interior pressure as a function of time for the two fire durations.

As seen from the table and the figures, the maximum temperature for all components remain within their respective thermal limits under the 6-minute fire event. Although the temperature of the O-ring in the lower seal port cover reaches its maximum temperature capability of 221 °C (430 °F), all other components have a thermal margin of at least 45 °C (80 °F).

The thermal limits of the O-rings in the upper and lower seal port covers and in the main closure lid are exceeded under the 30-minute fire event. The lower seal port cover O-ring is predicted to fail in approximately 7 minutes, the upper seal port O-ring fails in about 11 minutes, and the main closure lid seal fails in about 24 minutes.

Table B8-12. Multiple Canister Overpack (MCO) Cask and MCO Assembly Maximum Temperatures for Fire Conditions.

Location and condition	Maximum accident temperatures,[a] °C (°F)	
	6-minute fire[b]	30-minute fire[b]
Spent nuclear fuel, maximum	82 (180)	86 (187)
Spent nuclear fuel, average	68 (158)	78 (172)
Rubble basket fuel, maximum	73 (164)	79 (174)
MCO sidewall, average	59 (138)	88 (190)
MCO sidewall, maximum	61 (142)	110 (230)
MCO shield plug, average	49 (120)	69 (156)
MCO shield plug, seals	51 (123)	75 (167)
Cask sidewall, average	85 (185)	212 (413)
Cask sidewall, maximum	227 (440)	486 (907)
Seal port, lid end	177 (351)	400 (752)
Seal port, bottom end	221 (430)	478 (892)
Closure lid seals, maximum	109 (228)	296 (565)

NOTES:

[a]Temperatures shown are the peak temperatures noted during a 40-hour period, which includes 36 hours for an extended dry transfer time, the fire, and a postfire recovery period of approximately 4 hours. Assumes the worst-case MCO fuel loading, a starting temperature for cask and contents of 15 °C (59 °F).

[b]Water quench begins 15 minutes after start of 6-minute fire to provide allowance for emergency team response time. Water quench begins 30 minutes after start of 30-minute fire to provide full 10 CFR 71 heat flux into the cask.

10 CFR 71, 1996, "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, as amended.

Figure B8-15. 6-Minute Fire Transient for Dry Transfer.

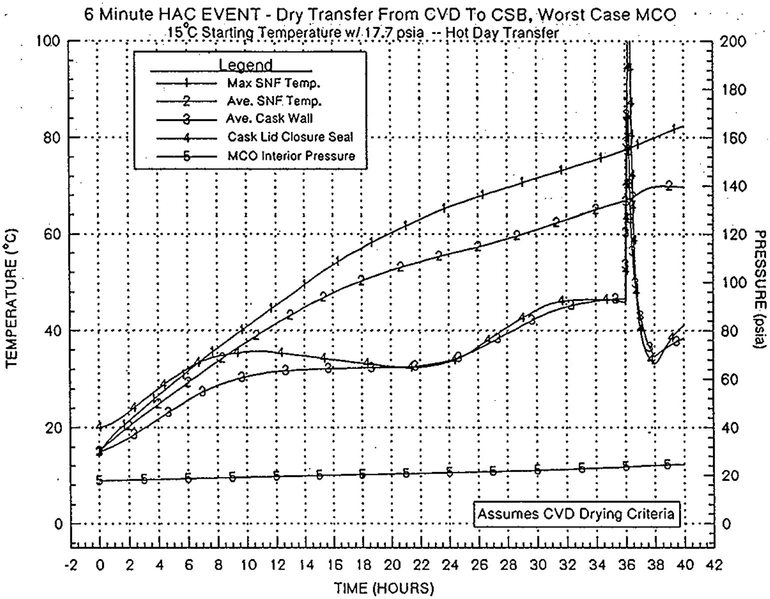


Figure B8-16. 6-Minute Fire Transient for Dry Transfer, Seal Temperatures.

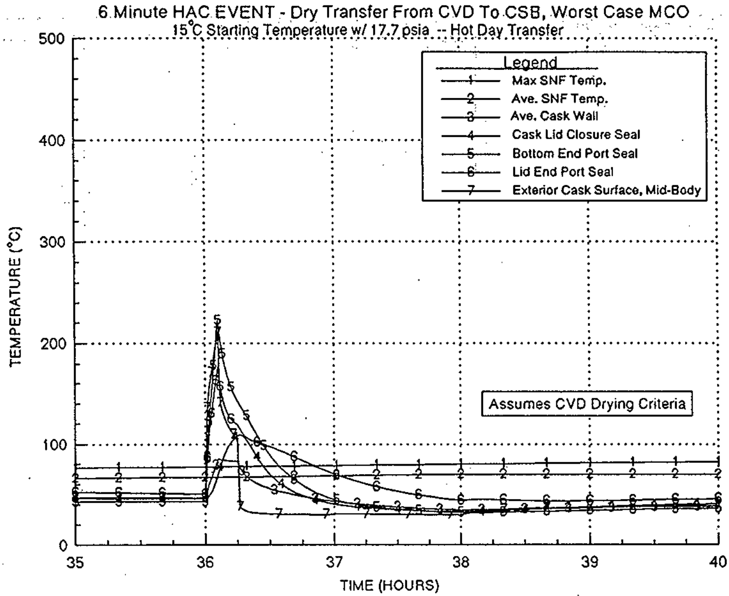


Figure B8-17. Closure Lid Temperature Contours at End of 6-Minute Fire.

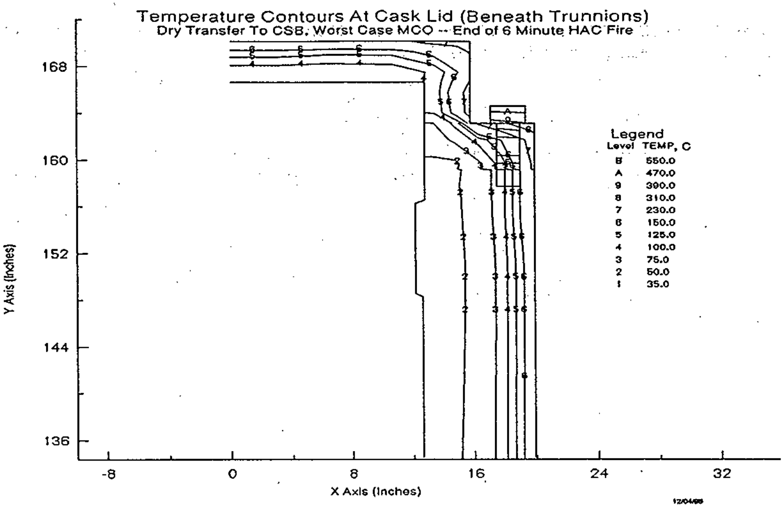


Figure B8-18. Cask Bottom Temperature Contours at End of 6-Minute Fire.

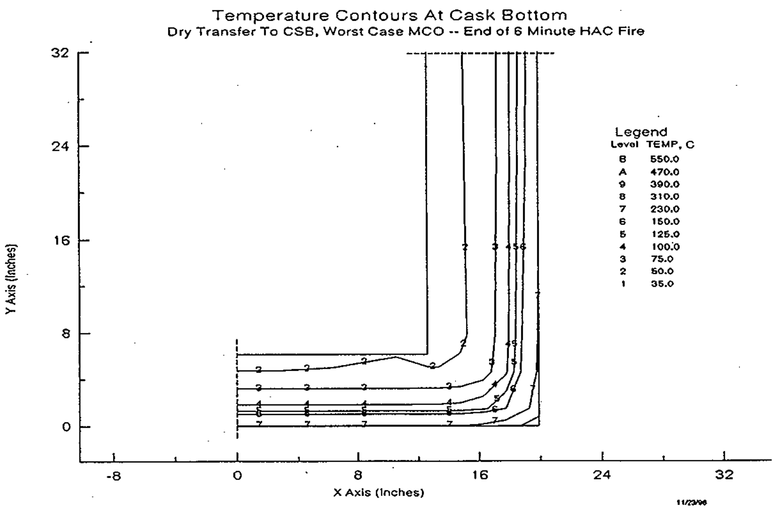


Figure B8-19. 30-Minute Fire Transient for Dry Transfer.

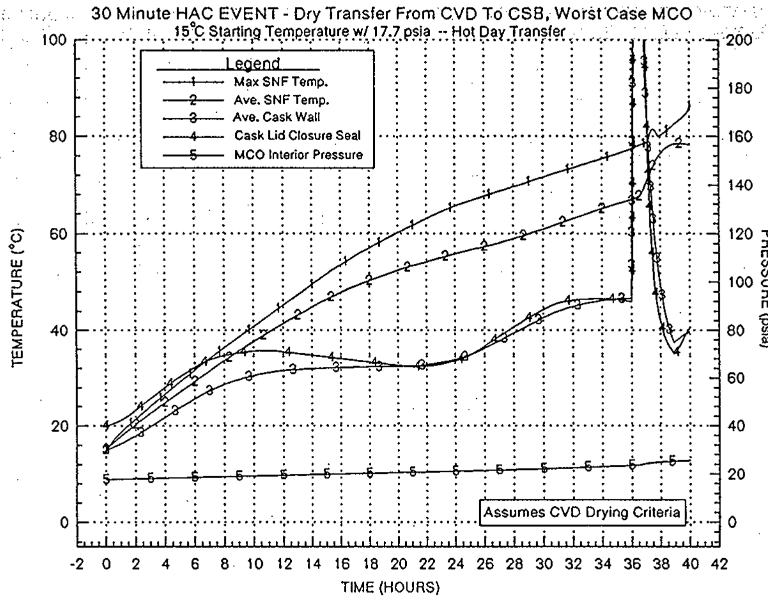


Figure B8-20. 30-Minute Fire Transient for Dry Transfer, Seal Temperatures.

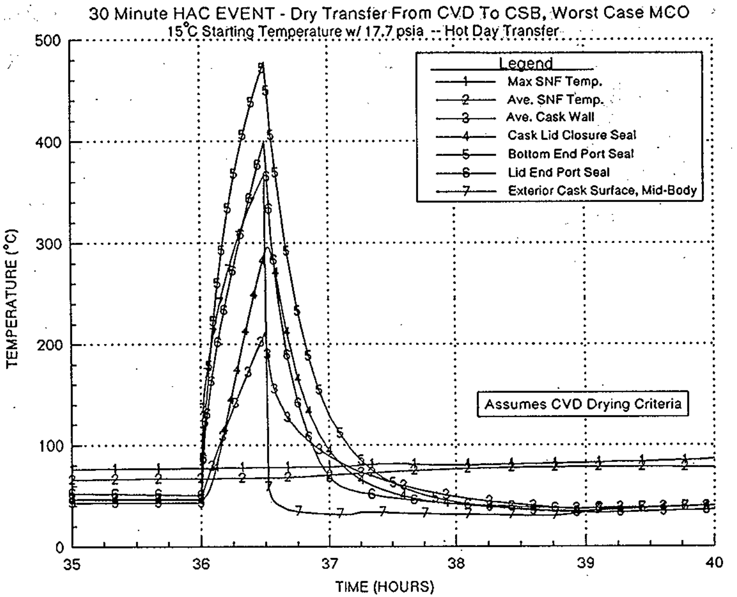


Figure B8-21. Closure Lid Temperature Contours at End of 30-Minute Fire.

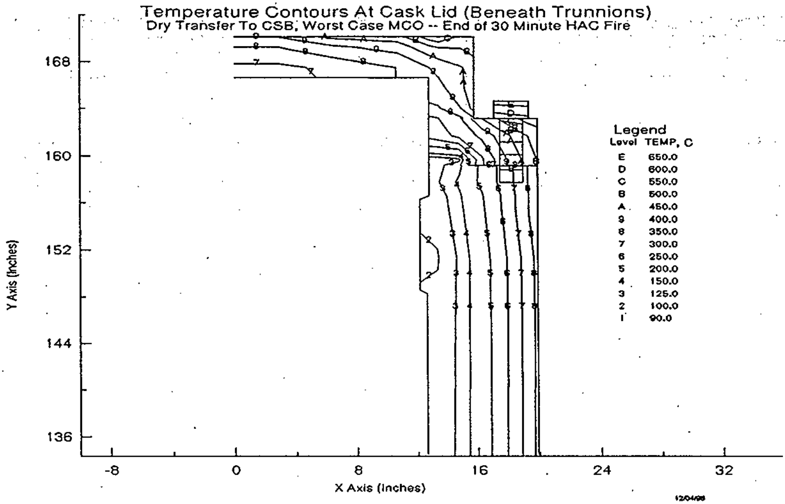
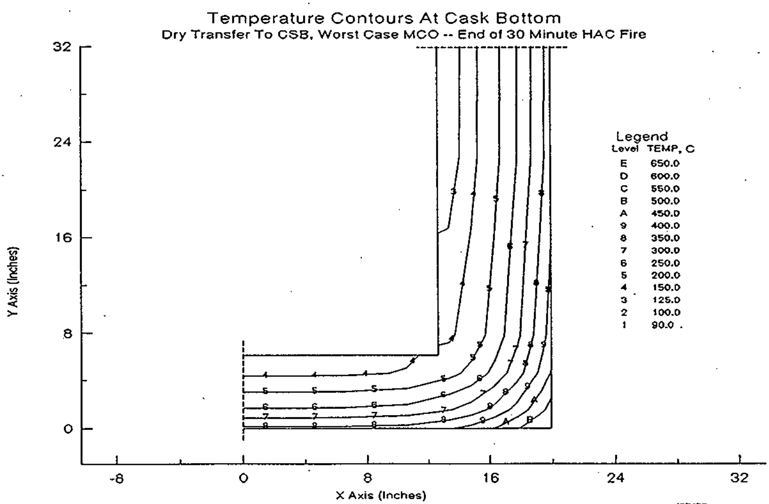


Figure B8-22. Cask Bottom Temperature Contours at End of 30-Minute Fire.



The MCO seals remain within their respective limits under either fire accident duration. No thermal excursions are seen within the SNF payload for either condition analyzed. The effectiveness of the water quench operation is illustrated by comparing the temperatures in Figure B8-15 with those in Figure B8-13 for normal transfer conditions. The similar levels seen at the 40-hour time point illustrates that the water quench effectively removes the heat pulse input to the cask as a result of the 6-minute fire. A similar comparison between Figures B8-19 and B8-13 shows that the effect of the 30-minute fire is also removed by the water quench.

As with the normal transfer conditions, additional recovery time beyond 40 hours can be obtained by circulating cool or chilled water through the MCO Cask annulus.

The maximum internal pressures seen for the fire conditions for dry transfer are shown for both the 6- and 30-minute fire events in Table B8-13. The maximum pressures are well within the 1034 kPa (150 psig) limit for both the MCO and the cask.

Table B8-13. Multiple Canister Overpack (MCO) Cask and MCO Assembly Maximum Pressures for Fire Conditions.

Fire accident condition[a]	MCO assembly		MCO Cask	
	Temperature, °C (°F)	Pressure, kPa (psia)	Temperature, °C (°F)	Pressure, kPa (psia)
6-minute fire: hot ambient, diurnal cycle[b]	47 (117)	170 (24.6)	69 (156)	140 (20.3)
30-minute fire: hot ambient condition[b]	57 (134)	177 (25.6)	136 (277)	168 (24.3)

NOTES:

[a]Temperatures and pressures shown are the maximums seen over the 24-hour period modeled for the fire conditions. Assumes a 0.56-m^3 gas space and a payload consisting of one scrap basket and four fuel baskets with split cladding. Total corrosion surface area is 120,000 cm^2. Starting temperature for cask and contents is 15 °C (59 °F) with a 122-kPa (17.7-psia) helium backfill.

[b]Hot transfer conditions: Hanford diurnal cycle on ambient temperature and solar insolation per Irwin (1994), with 46 °C (115 °F) max. ambient.

Irwin, J. J., 1994, Thermal Analysis Methods for Safety Analysis Reports for Packaging, WHC-SD-TP-RPT-005, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

The evaluation of the 6-minute fire transients for wet transfer is presented in Figures B8-23 and B8-24. The temperatures seen are below those for dry transfer and the SNF fuel temperatures show no evidence of a temperature excursion. While the cask/MCO pressure is rising, additional time is available to start recovery methods or to simply vent the cask to the atmosphere.

Figure B8-23. 6-Minute Fire Transient for Wet Transfer.

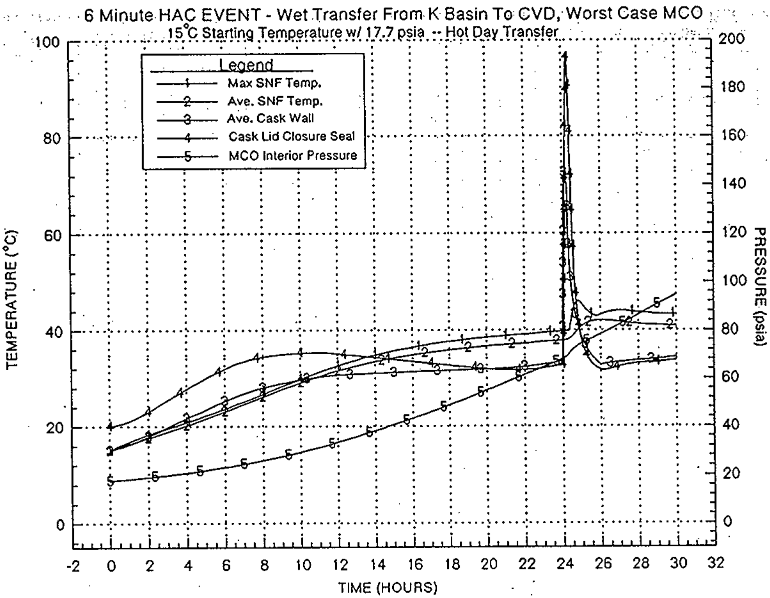
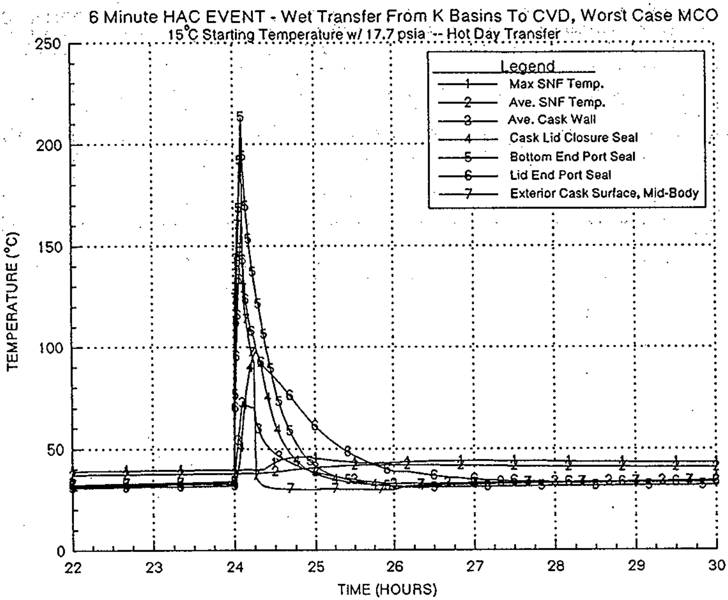


Figure B8-24. 6-Minute Fire Transient for Wet Transfer, Seal Temperatures.



8.6 BEYOND-SHIPPING-WINDOW CONDITIONS

This section presents the thermal analysis of the MCO Cask and MCO assembly for operations outside the nominal shipping-window conditions assumed for Sections 8.4 and 8.5. Included are the recovery actions proposed when off-normal events occur to extend the transfer time between the K Basins and the CVDF or between the CVDF and the CSB as well as the thermal performance associated with those recovery actions. The site-specific ambient temperatures and worst-case load combination considered are the same as for normal transfer conditions (see Table B8-7).

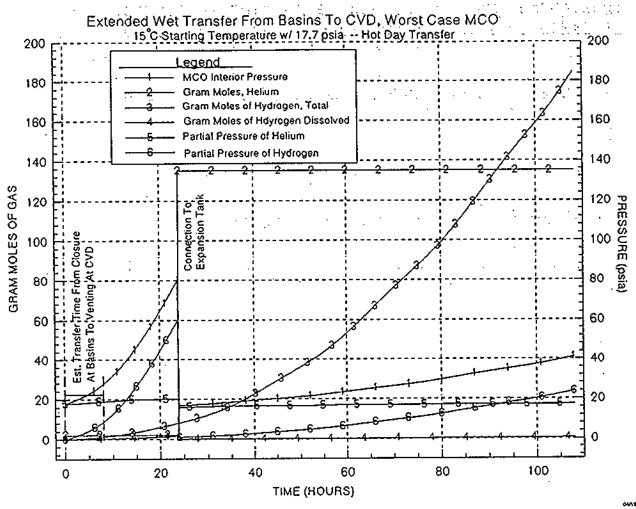
As discussed in Sections 8.4.4.1 and 8.4.4.2, transfer times in excess of 30 hours for wet transfer or 48 hours for dry transfer could result in thermal excursions within the fuel payload and/or excessive pressures due to the increase in chemical reaction rate with increasing temperature. While these time periods are sufficiently longer than the expected shipping time of 8 hours for wet transfer and 14 hours for dry transfer to allow for mechanical breakdown, etc., not all off-normal events may be corrected within this time frame. For shipping times that extend beyond the nominal shipping window, it will be necessary to employ recovery equipment and procedures to ensure that the cask, the MCO, and the payload remain within their respective operational limits until the off-normal event can be corrected and the transport of the cask and MCO is completed.

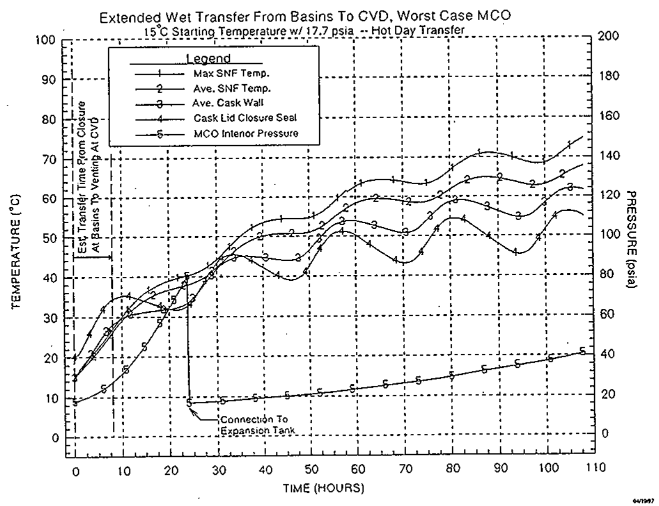
For wet transport, the principal recovery mode will consist of venting the cask to prevent a buildup of excessive pressure. The flooded condition of the MCO and cask during this transfer phase provides sufficient thermal conductance between the fuel and the ambient environment that thermal excursions will not occur for time periods in excess of five days under the worst conditions. Therefore, if the wet transfer time exceeds 24 hours (i.e., three times the normally expected time period), the response will be to have a safety team remove one of the port covers in the cask lid; attach a filtered, pressure relief fitting, which will allow the hydrogen gas to escape, but prevent the ingress of oxygen into cask/MCO; and commence venting of the cask to the atmosphere. Alternately, the excessive pressure within the cask/MCO may be relieved by connecting the cask port to an external tank that provides additional expansion volume.

Figure B8-25 shows the thermal performance of the cask and MCO under the described scenario for a transfer period lasting 108 hours or 4-1/2 days. As seen from the figure, neither the temperatures nor the internal pressure exceeds its respective limits. The pressure rise after the 24-hour time point is computed based on a 946-L (250-gal) expansion tank being connected. The assumption of a smaller or larger tank would have yielded similar temperature results and proportional pressure results. Release of the internal pressure to the atmosphere would have yielded pressures just slightly above atmosphere. In either case, sufficient time will be available to accomplish a safe recovery from all foreseen off-normal events.

Under dry transport, the MCO and cask are sealed. Furthermore, venting of the MCO would require field disassembly of the cask, with its associated worker dose exposure and the potential for ingress of moist air into a nominally dry MCO. As such, the recommended recovery mode will be to provide active cooling to the MCO sidewall by circulating water in the cask-to-MCO

Figure B8-25. Beyond-Shipping-Window Conditions for Wet Transfer.





annulus. This can easily be accomplished by removing the port covers over the upper and lower quick-disconnect fittings in the cask sidewall and lid. Connection to a water source and pump setup would achieve a thermal boundary condition at the MCO sidewall similar to that in the CVDF. However, to avoid the complications of a chiller setup and a recirculating water system, this analysis assumes that water from a fire truck or other such tanker is pumped in a single pass mode through the annulus and then wasted. The water temperature is assumed to be 29 °C (85 °F), and the water flow rate is 76 L/min (20 gpm).

Figure B8-26 shows the thermal performance of the cask and MCO under the described scenario for a transfer period lasting 108 hours or 4-1/2 days. As seen from the figure, once the cooling water is connected to the package at approximately 36 hours, the component temperatures are reduced, and the rate of increase in MCO pressure is greatly reduced. After operation for 72 hours (i.e., 108 hours minus 36-hour start time), the MCO pressure is just slightly over 275 kPa (40 psia), and the peak fuel temperature is below 65 °C (150 °F). Assuming a constant flow of cooling water and extrapolating the results of this analysis, the cask and MCO could be safely maintained for up to 10 days in this condition, providing sufficient time to accomplish a safe recovery from all foreseen off-normal events.

8.7 THERMAL EVALUATION AND CONCLUSIONS

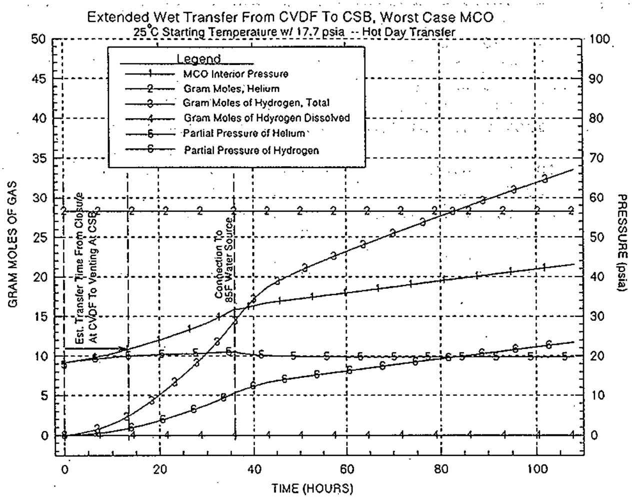
An analytical evaluation was made of the MCO Cask in accordance with the requirements of Edwards (1997). The following are the significant conclusions derived from the thermal evaluation results.

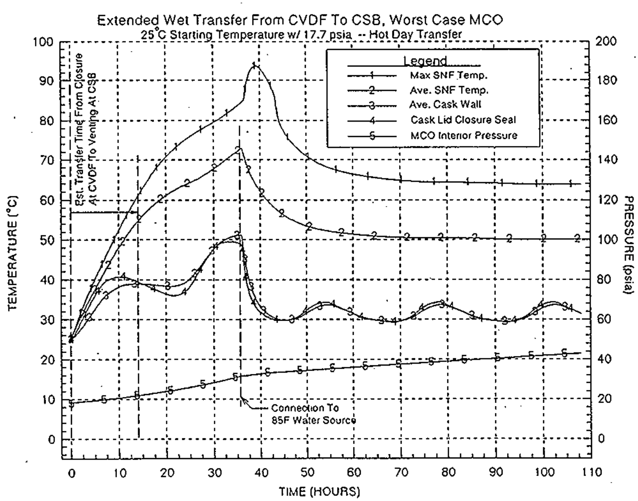
- The demonstration of safety of the MCO cask for the transfer of the MCOs and their payload between the K Basins and the CSB is based on the transfer being accomplished within the time limits established herein and for the moisture removal in the CVD process to be sufficient to limit the pressure rise within the MCO to an acceptable level. Administrative rules governing both these aspects are assumed to be part of the certificate of compliance.

- A minimum transfer window of 30 hours is predicted to be available for all load combinations and for wet and dry transfer without performance of any confirmatory measurements in the CVDF. This time frame is measured from the time the MCO/cask is sealed at the shipping station to the time it is vented at the receiving station. Given the exponential relationship between heat and gas generation with temperature, if no gas generation measurements occur in the CVDF, recovery methods need to be applied prior to the transfer times reaching the end of the 30-hour window.

- Extension of the dry transfer time beyond the 30-hour point without applying artificial cooling will require that the chemical reaction rate within the MCO be limited. Since direct measurement of either the amount of corroding fuel or the amount of moisture remaining within the MCO is not practical, the recommended approach is to

Figure B8-26. Beyond-Shipping-Window Conditions for Dry Transfer.





continue the CVD process until the pressure rise noted within the MCO is 1.4 kPa (0.2 psi) or less per hour while the cask and MCO are held at the 75 °C temperature point in the process.

- All components of the MCO transportation cask closure system (containment seal, vent and drain port seals) remain within their allowable temperature ranges under normal transfer conditions, and within their allowable transient temperature ranges under accident conditions for the 6-minute fire event.

- The Butyl rubber O-ring used for the cask lid closure seal and the upper and lower seal port covers reach a maximum temperature of 47 °C (117 °F) under normal transfer conditions. This is well within the demonstrated working temperature range of 191 °C (375 °F) for Butyl rubber to be used for time periods of 168 hours or less. The Butyl rubber O-rings are predicted to remain intact under the 6-minute fire accident and, thus, provide containment for the MCO and its contents. For fire durations in excess of 7 to 11 minutes, the O-rings on the lower and upper seal ports, respectively, are predicted to exceed their maximum temperature limit of 221 °C (430 °F). The main closure seal is predicted to remain intact for 24 minutes during the 30-minute fire. As such, the cask containment will be lost under the 10 CFR 71-defined fire accident condition. However, no runaway chemical reaction will occur within the MCO during that fire, and the MCO will still retain the MCO contents.

- The seal material used on the MCO shield plug reaches a maximum temperature of 46 °C (114 °F) under normal transfer conditions and 75 °C (167 °F) under fire conditions. This is well within the minimum working range of 40 °C (-40 °F) to 370 °C (800 °F) for the various gasket material used on the shield plug. As such, the MCO seal integrity will be maintained under both normal and accident transfer conditions.

- The maximum predicted volumetric average gas temperature within the MCO cavity under wet transfer is 44 °C (111 °F), with a corresponding maximum pressure of 745 kPa absolute (108 psia). The maximum predicted volumetric average gas temperature within the MCO cavity under dry transfer conditions is 68 °C (154 °F), with a corresponding maximum pressure of 186 kPa absolute (27 psia). Corresponding conditions in the cavity between the MCO and the inner wall of the MCO Cask during dry transfer are 42 °C (108 °F) and 129 kPa absolute (18.7 psia). The 6-minute fire causes increases in the gas temperature and pressure within the MCO by no more than 5 °C (9 °F) and 2 kPa (0.3 psi). These pressures include the contribution of gas generation from the fuel assemblies and corrosion products.

- The maximum temperature predicted for the SNF assemblies during normal transfer conditions is 36 °C (97 °F) and 64 °C (148 °F) for wet and dry transfer, respectively. The maximum fuel assembly temperature for the accident conditions is 82 °C (180 °F).
- The maximum temperature of any accessible surface of the package does not exceed 85 °C (185 °F) as required by 10 CFR 71.43.

Based on these conclusions, the MCO Cask is shown to comply with the thermal acceptance criteria for the transfer of the K Basin irradiated nuclear fuel from the K Basins to the CVDF and from the CVDF to the CSB.

8.8 REFERENCES

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8.9 APPENDICES

8.9.1 Thermal Data and Modeling Approach

The following sections present details of the thermal data and modeling approach used in the various analyses presented in this report.

8.9.1.1 Normal Transfer Conditions. 10 CFR 71 and WHC-SD-TP-RPT-005 (Irwin 1994) are the basis for the environmental conditions in evaluating the cask performance under normal and accident transfer conditions. Table B8.9-1 shows the 10 CFR 71.71 conditions for insolation. However, this data is not specific to the Hanford Site. Therefore, the insolation data for latitude 46°N (i.e., the Hanford Site) contained in Irwin (1994) is used to evaluate the maximum temperatures in the cask and MCO during the wet and dry transfer phases between the K Basins and the CSB. This data is presented in Table B8.9-2. The difference between the insolation data from these sources is that the 10 CFR 71 data yields a total daily insolation on a horizontal surface of 2,950 Btu/h-ft^2, while the site specific value from Irwin (1994) yields a total daily value of 2,516 Btu/h-ft^2.

Table B8.9-1. Insolation Data per 10 CFR 71.

Form and location of surface	Total insolation for a 12-hour period (g cal/cm^2)
Flat surfaces transported horizontally	
Base	None
Other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

10 CFR 71, 1996 "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, as amended.

The actual amount of solar energy absorbed by the package is calculated as the product of the hourly insolation value times the solar absorption factor for the cask surface in question. A solar absorption factor of 0.52 is assumed for the 304 stainless steel cask surface per Irwin (1994), Table A-51.

Table B8.9-2. Insolation Data for Latitude 46°N (Btu/h-ft^2).

Time	Vertical surface facing								Horizontal surface facing up
	N	NE	E	SE	S	SW	W	NW	
4 a.m.	0	0	0	0	0	0	0	0	0
6 a.m.	57	192	211	105	17	17	17	17	64
8 a.m.	35	173	268	208	42	32	32	32	127
10 a.m.	42	56	177	213	126	45	42	42	281
12 noon	45	45	49	120	167	120	49	45	314
2 p.m.	42	42	42	45	126	213	177	56	281
4 p.m.	35	32	32	32	42	208	268	173	127
6 p.m.	57	17	17	17	17	105	211	192	64
8 p.m.	0	0	0	0	0	0	0	0	0

Table B8.9-3. Maximum Diurnal Ambient Temperature, July Day at Hanford Site.

Time	Temperature (°F)
12 a.m.	82
2 a.m.	78
4 a.m.	75
6 a.m.	74
8 a.m.	85
10 a.m.	97
12 p.m.	103
2 p.m.	111
4 p.m.	115
6 p.m.	113
8 p.m.	100
10 p.m.	89
Daily average	93.5

The Site-specific ambient temperature used for hot day conditions is based on a diurnal temperature curve for the peak summer day at Hanford. The diurnal temperature cycle, taken from Irwin (1994), is shown in Table B8.9-3. As seen, the cycle has a peak temperature of 46 °C (115 °F), a minimum of 23.3 °C (74 °F), and a daily average temperature of 34.2 °C (93.5 °F). In comparison, 10 CFR 71 specifies a maximum, steady-state ambient air temperature value of 38 °C (100 °F).

8.9.1.2 Accident Conditions of Transfer. The fire accident transient used in this analysis is based on 10 CFR 71 and on a risk assessment of the transfer routes, timing, etc., to be used for the wet and dry transfers of the K Basin SNF (see Part B, Section 3.0). The strength of the external heat flux source for the fire is based on the 10 CFR 71-specified average flame temperature of 802 °C (1475 °F), with an average emissivity coefficient of 0.9. The length of the fire is assumed to be 6 minutes, based on the risk assessment of the site conditions. An alternative accident condition fire lasting 30 minutes is also analyzed. Per 10 CFR 71, the absorptivity of the external cask surfaces are conservatively assumed to be 0.80 during and after the fire.

In contrast to the requirements of 10 CFR 71, it is assumed that water quenching is available to control temperature excursions in the cask following the fire event. The water used for this operation is contained in fire department trucks and tankers with storage capacities of 1,500 to 4,500 gal each. Because these vehicles can be exposed to the ambient air, and possibly solar insolation, for an extended period of time, it is conservatively assumed that the water available from this source will be 29 °C (85 °F). The water flow rate from the hoses contained on the fire department trucks is between 125 to 500 gal/min per nozzle. For conservatism, a maximum water flow rate of 125 gal/min is assumed during the quenching operation.

Following the first few seconds of quenching, the quenching operation is assumed to keep the cask surface wetted, and the convective heat transfer is assumed to be via nucleate boiling. Figure 10-1 of Kreith (1973) is used to estimate the convective coefficient under nucleate boiling as function of the temperature difference between the cask surface and the saturation of water at atmospheric pressure; i.e., 100 °C (212 °F). Once the outer cask wall temperature falls below 135 °C (275 °F), the convective heat transfer is assumed to revert to single-phase, forced convection with 29 °C (85 °F) water as the medium. An effectiveness factor of 33% is used to account for the fact that water spray impinging on any section of the surface may be intermittent as the hose spray is cycled from one end of the cask to the other.

8.9.1.3 Natural Convection Correlations. The heat transfer from cylindrical and plate surfaces under natural or "free" convection heat transfer is calculated as a function of Rayleigh number using geometry-dependent correlations.

8.9.1.3.1 Vertical Surfaces. Natural convection from vertical surfaces was computed from equations 6-39 to 6-42 of Rohsenow et al. (1985). The characteristic length is the height of the surface. These equations are applicable over the range $1 < Ra < 10^{12}$ and are as follows:

$$Nu^T = C_l \cdot Ra^{0.25}$$
$$Nu_l = 2.8/[\ln(1 + 2.8/Nu^T)]$$
$$Nu_t = C_t^V \cdot Ra^{0.33}$$
$$Nu = h_c \cdot d/k = [(Nu_l)^6 + (Nu_t)^6]^{1/6}; \quad 1 < Ra < 10^{12}$$

8.9.1.3.2 Horizontal Surfaces Facing Upward. Natural convection from horizontal surfaces facing upward was computed from equations 7-21 to 7-22 of Kreith (1973). The characteristic length is the length of the surface. These equations are applicable over the range $10^{05} < Ra < 3x10^{10}$ and are as follows:

$$Nu = h_c \cdot d/k = 0.54 \cdot Ra^{0.25}; \qquad 10^{05} < Ra < 2x10^7$$
$$Nu = h_c \cdot d/k = 0.14 \cdot Ra^{0.33}; \qquad 2x10^7 < Ra < 3x10^{10}$$

8.9.1.3.3 Horizontal Surfaces Facing Downward. Natural convection from horizontal surfaces facing downward was computed from equation 7-23a of Kreith (1973). The characteristic length is the length of the surface. This equation is applicable over the range $3x10^{05} < Ra < 3x10^{10}$ and is as follows:

$$Nu = h_c \cdot d/k = 0.27 \cdot Ra^{0.25}; \qquad 3x10^{05} < Ra < 3x10^{10}$$

8.9.1.3.4 Cylindrical Surfaces. Natural convection from cylindrical surfaces was computed from equation 3-43 of Chapter 1 from Guyer (1989). The characteristic length is the diameter of the cylinder. This equation is applicable over the range $10^{-05} < Ra < 10^{12}$ and is as follows:

$$Nu = h_c \cdot d/k = \{0.60 + (0.387 \cdot Ra^{0.16667})/[1 + (0.559/Pr)^{9/16}]^{8/27}\}^2; \quad 10^{-05} < Ra < 10^{12}$$

8.9.1.3.5 External Surfaces With Forced Convection. Forced convection from the exterior of flat surfaces was computed from the equations in Table 6-5 of Kreith (1973). The characteristic length is the length of the surface in the direction of the flow. These equations are as follows:

$$Nu = 0.664 \cdot (Re^{0.50} \cdot Pr^{0.333}); \qquad Re < 5x10^5 \ \& \ Pr > 0.1$$
$$Nu = 0.036 \cdot Pr^{0.333} \cdot [Re^{0.80} - 23,200]; \qquad Re > 5x10^5 \ \& \ Pr > 0.5$$

8.9.1.4 Radiation Heat Transfer. Radiation heat transfer was calculated assuming standard grey-body equations. The shape factors between the fuel assemblies, the MCO, and the cask were computed using either predefined relationships or the string method for standard geometric configurations. For complex, nonstandard shapes, the VIEW program (Emery 1991) was used to calculate the radiation view factors. Once the view factor F_{1-2} was obtained by either method, it was used to compute the Hottel script $\mathcal{F}$ combined geometric shape and emissivity factor via the equation:

$$\mathcal{F}_{1-2} = 1/[(1/\varepsilon_1 - 1) + 1/F_{1-2} + A_1/A_2 \cdot [(1/\varepsilon_2 - 1)]$$

The heat transferred via radiation interchange is then computed from:

$$q = \sigma \cdot A_1 \cdot \mathcal{F}_{1-2} \cdot (T_1^4 - T_2^4); \quad \text{where } \sigma = \text{Stefan-Boltzmann constant}$$

8.9.1.5 Modeling of Damaged Fuel. The damaged fuel assemblies are equally divided over four intact fuel baskets, with the split cladding limited to the upper 7.62 cm (3 in.) of each fuel assembly. For the Mark IV fuel assembly, the specified area is equivalent to split cladding on inner and outer elements of 34 of the 54 fuel assemblies in each fuel basket, split cladding on the outer element only of another 10 fuel assemblies, and 6 undamaged fuel assemblies. For conservatism, the undamaged fuel assemblies are assumed to be located on the exterior portion of the fuel baskets.

The geometry of the SNF assemblies within the scrap basket is an unknown. While the exact operational procedures have not been established, the general intent is to place in the intact fuel basket those portions of a combined fuel assembly (i.e., an outer <u>and</u> an inner element) that will fit in the basket's base plate socket. Solo outer or inner elements will either be combined to make up a fuel assembly prior to being placed in the intact fuel basket (for criticality reasons) or be placed in the scrap basket. Those portions of the fuel assemblies that are greater than 0.6 cm (0.25 in.) in size, but are less than approximately 20 cm (8 in.) in length, or are too broken up to stand upright in the intact fuel basket, or will not fit in the base plate socket, will also be placed in the scrap basket.

As such, the geometry of any scrap basket will vary from MCO to MCO. For the purposes of this analysis, the scrap basket is treated as a heterogenous, porous media. The effective thermal conductivity within the scrap baskets is computed as a function of the porosity of the scrap basket, the thermal conductivity of the scrap, and the thermal conductivity of the fluid that fills the void fraction. Per Table 3.2 of Kaviany (1995), the porosity of a porous media comprised of particles with a uniform size will range from 0.26 to 0.476. As an alternative calculation, the porosity of the Mark IV scrap basket is computed based on the basket containing the equivalent of 54 intact fuel assemblies evenly packed over the volume of the basket. Given that the total volume of a Mark IV fuel assembly is approximately 1,470 cm^3 and that the total volume in the scrap basket is approximately 165,600 cm^3, the porosity (P) of the scrap basket is computed as:

$$
\begin{aligned}
P &= (\text{basket void volume}) \div (\text{total volume of the basket}) \\
&= (165{,}600\ cm^3 - 54\ \text{assemblies} \cdot 1{,}470\ cm^3) \div (165{,}600\ cm^3) \\
&= 0.52
\end{aligned}
$$

Since the effective thermal conductivity within the corrosion product basket decreases with increasing porosity, the use of the 0.52 value is conservative in relation to the values from Kaviany. Based on this porosity and the density of uranium, the mean density of the scrap basket with helium gas backfill is approximately 9.043 kg/cm^3 (0.326 lbm/in^3). A water-filled scrap basket has a mean density approximately 6% higher.

The effective thermal conductivity of the scrap basket is computed using the Hadley relationship from Table 3.1 of Kaviany (1995). This relationship provides the ratio between the effective conductivity (k_e) and the conductivity of the fluid (k_f) filling the void volume within the scrap. It is defined as:

$$
\frac{k_e}{k_f} = (1-\alpha_o)\left[\frac{Pf_o + (k_s/k_f)(1-Pf_o)}{1-P(1-f_o)+(k_s/k_f)P(1-f_o)}\right] + \alpha_o\left[\frac{2(1-P)(k_s/k_f)^2 + (1+2P)(k_s/k_f)}{(2+P)(k_s/k_f)+1-P}\right]
$$

where

$$
f_o = 0.8 + (0.1)P \ ,
$$

and

$$
\log\alpha_o = -1.084 - 6.778(P-0.298) \ , \qquad 0.298 \le P \le 0.580
$$

$$
\log\alpha_o = 0.405 - 3.154(P-0.0827) \ , \qquad 0.0827 \le P \le 0.298
$$

$$
\log\alpha_o = -4.898P \ , \qquad 0 \le P \le 0.0827 \ .
$$

8.9.1.6 References.

10 CFR 71, 1996, "Packaging and Transportation of Radioactive Material," *Code of Federal Regulations*, as amended.

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8.9.2 Checklist for Independent Technical Review

CHECKLIST FOR INDEPENDENT TECHNICAL REVIEW

DOCUMENT REVIEWED MCO THERMAL ANALYSIS
AUTHOR(s) Gregory J. Banken P.E. of Q-Metrics, Inc.

I. Method(s) of Review

(XX) Input data checked for accuracy
( ) Independent calculation performed
( ) Hand calculation
( ) Alternate computer code: ______
( ) Comparison to experiment or previous results
( ) Alternate method (define) ______

II. Checklist (either check or enter NA if not applied)

(XX) Task completely defined
(XX) Activity consistent with task specification
(XX) Necessary assumptions explicitly stated and supported
(XX) Resources properly identified and referenced
(XX) Resource documentation appropriate for this application
(XX) Input data explicitly stated
(XX) Input data verified to be consistent with original source
(XX) Geometric model adequate representation of actual geometry
(XX) Material properties appropriate and reasonable
(XX) Mathematical derivations checked including dimensional consistency
(NA) Hand calculations checked for errors
(XX) Assumptions explicitly stated and justified
(XX) Computer software appropriate for task and used within range of validity
(NA) Use of resource outside range of established validity is justified
(XX) Software runstreams correct and consistent with results
(XX) Software output consistent with input
(XX) Results consistent with applicable previous experimental or analytical findings
(XX) Results and conclusions address all points and are consistent with task requirements and/or established limits or criteria
(XX) Conclusions consistent with analytical results and established limits
(NA) Uncertainty assessment appropriate and reasonable
( ) Other (define)

______

______

III. Comments:

Presented below is a list of my findings concerning the MCO thermal analysis review. I believe the presence of these items presents solutions which may have a possibility of lacking the degree of conservatism intended.

Page 1

(1) A portion of the radiation conductors representing radiation exchange between the MCO cask and upper sections of the canister shell (at each canister subsection) are missing. Also, over prediction exists for the lower portion (node 70) of each canister shell subsection. This is due to mis-numbering within "CASK.HE-TC".

(2) The capability of forced convection cooling (via water quenching) is taken into account for the bottom face of the cask.

(3) 100% of forced convection capability appears to be displayed for the trunnions versus 33% to account for cycling (refer to "LID-FORCED.VAR" & "LID-BOIL.VAR").

(4) I believe the approach used for calculating forced convection capability (pertains to the 2nd stage of recovery mode) to be a sound one. However, I believe the velocity used to calculate the convection heat transfer conductance is at least an order of magnitude higher than possible given the representation of the configuration. Such velocities provide a cross-sectional flow area (film thickness by characteristic flow width) of 2 sq.in. On the other hand, I would expect the characteristic length to be slightly larger.

(5) Sludge reaction heat production (although relatively minor) is incorrect due to call array increment being mismatched. I was not able to determine whether this provided a liberal or conservative contribution.

A finding which provides a degree of conservatism is that the forced convection attributed to the 2nd stage recovery mode and concerning the third and forth lid sections is low. This is due to mis-numbering within "LID-FORCED.VAR".

IV. REVIEWER: Harold L. Adkins Jr. DATE: 1/23/97

V. Response To Review Comments:

Presented below are the author's responses to the comments raised in the MCO thermal analysis review.

(1) Agree with the comment. File 'CASK.HE-TC' contained mis-labeled conductors. Although the total magnitude of the radiation conductors is correct, the error in the file resulted in all the radiation links between the MCO wall and the inner cask wall being attached to MCO Nodes 70, 72, and 74, while Nodes 170, 172, 174, 270, 272, and 274 had no radiation link with the inner cask wall.

The effect of this error was evaluated by correcting include file 'CASK.HE-TC' and re-running the worst case dry transfer analysis. Attachment #1 lists the changes made to the file. This transient was selected since it provides an extended time frame over which to evaluate the cumulative effect on the computed temperatures for the MCO side wall and the SNF payload (Note: all results presented in the SAR are based on transient analyses, not steady-state).

The revised analysis indicates that the changes raised the peak SNF temperature by 0.4 °C after approx. 35 hours. The average SNF temperature increased by 0.1 °C, while the average MCO wall temperature remained about the same. The greatest change in the local MCO wall temperature occured at Node 70 for the BSKT4 submodel where the temperature increased by about 2 °C, while Node 270 dropped by about 0.3 °C. As a result, no significant effect is seen for the data and conclusions presented in the SAR.

(2) Agree with the comment. The thermal model was originally set up to model the cask on its side for the fire accident. The logic implemented to simulate this assumption was not fully adjusted for the revised assumption that the cask will remain upright during the fire accident. To assess the impact of forced versus natural convection from the bottom of the cask during the post-fire time period, the thermal model was adjusted to use only natural convection for the bottom of the cask. Attachment #2 lists the changes implemented in files 'DRY-F3.INP' and 'DRY-F4.INP' to assess the sensitivity to these changes. These files, which simulate the post -fire transient for dry transport following a 30 minute fire, were selected because the higher cask temperatures achieved during a 30 minute HAC event provide the largest potential sensitivity to the switch in convection modes. The results for this case will encompass those for the 6 minute HAC.

Attachment #3 illustrates the differences in the post-fire transient temperatures between the original thermal model used for the SAR and the revised model. The figure shows the expected result of a slower cool down for the lower end of the cask. These difference in the transient temperatures are not considered significant for the purposes of the SAR. This is especially true given that the run-off of quench water will tend to pond in the socket of the trailer, wetting the bottom of the cask, and result in better heat transfer than that assumed for the purposes of this sensitivity study.

The results for the 6 minute HAC event will be affected to an even lessor degree.

(3) The 'LID-BOIL.VAR' file simulates only natural convection from the trunnions during the initial water quench mode (as opposed to the film boiling convection for the body of the cask). As such, the 33% factor for cycling of the fire hose is not applicable.

The 'LID-FORCED.VAR' file used for the SAR analysis does assume 100% of forced convection capability for the trunnions versus the 33% cycling factor used for the main body of the cask. This was originally done because it was assumed that in the event of the fire, the bulk of the water quench flow would be directed at the trunnion/lid area of the cask to maximize the cool down. However, since this logic is not consistent with that used elsewhere, a sensitivity run was conducted wherein a 33% factor was applied to the trunnions as well.

Attachment #4 presents the changes made to the file 'LID-FORCED.VAR' to incorporate the 33% cycling factor into the forced convection portion of the water quench. While making these changes, it was noted that this file contained a conservative error, that being that some of the convection conductors for the trunnion were left at values appropriate for natural convection. The convection values were handled correctly for the fire portion of the HAC and the natural convection modes outside of the water quench mode.

Attachment #5 presents the combined results for comments 2 and 3. As seen, implementation of the 33% cycling factor, plus the inclusion of the missing forced convection conductors, shows that the analysis as presented in the SAR is conservative in terms of the trunnion temperature. Therefore, the conclusions presented in the SAR are still appropriate.

(4) Agreed. The approach used was intended to be a compromise between the impingement cooling that would be experienced by the area that is directly impacted by the hose flow, and the lower forced convection values experience by areas covered by splash/run-off water. Also, it is assumed that a fire response crew will rapidly "sweep' the hose flow up and down on the cask. Upon further evaluation, it is agreed that the flow velocities used are too high to justify over wide areas on the cask (even with the 33% cycling factor). Therefore, a comparative analysis was made assuming the water flow is spread evenly around the circumference of the cask. This lowered the flow speeds by a factor of 10. The 33% cycling factor was retained.

Attachment #6 presents the changes made to the input deck to implement this change. Attachment #7 illustrates the difference between the original transient following a 30 minute HAC event and that predicted with the changes implemented for comments #2, 3, and 4. As seen, although the cool down rate is lower, the component temperatures reach nearly the same levels within two hours after the start of the fire. The results for the 6 minute HAC event will be impacted even less. As such, no change in the conclusions presented in the SAR will occur as a result of implementing this change.

(5) The sludge reaction heat production was correctly computed. The call array increment mismatch affected only the calculation of the amount of hydrogen gas generation attributed to the sludge. The effect of

this coding error was assessed by correcting the call array (by eliminating the variable 'TSTART') and re-evaluating the extended dry transfer transient. As explained in the response to comment #1, this transient was selected since it provides an extended time frame over which to evaluate the cumulative effect on the computed amount of hydrogen gas.

Attachment #8 presents a listing of the key performance values after a time period of approximately 35 hours. A comparison of the data values shows that the predicted temperatures (i.e. TFMAX, TFAVE, TCASK, TMCO, etc.) are nearly the same between the two runs. The slight temperature differences seen are primarily attributed to the difference in MCO gas pressures since the convective heat transfer in the MCO is computed as a function of the MCO pressure.

As expected, the main effect of the comment 5 changes is on the calculation of the hydrogen gas generation from the sludge, with the revised calculation predicting about 5.5 psi higher pressure in the MCO after 35 hours. The variable PMCO represents the total pressure within the MCO, while PP-H represents the partial pressure of the hydrogen gas. While this is a 9.5% increase in pressure over the results presented in the SAR, the margin of safety is still large. Further, the effect of the comment 5 changes were evaluated for the unlimited water assumption. The pressure increase under the CVD drying criteria assumption is expected to be about 3 psi.

Attachment #9 presents a graphical depiction of the differences in MCO pressure between the original and the comment 5 models.

Response To General Comment: The conductor numbering within the file "LID-FORCED.VAR" was mis-numbered. The effective result is that the forced convection conductors for 1/3 of the lid are reduced to 1/2 of their correct value, while the convection conductors for 1/6 of the lid are left at the values they were set for during the 1st stage of the recovery mode. The combined effect was assessed by correcting the "LID-FORCED.VAR" file and re-running the 30 minute HAC transient. By comparing the transient temperatures in attachment #10 with those presented in attachment #7, it is seen that this change results in essentially the same transient temperature levels with the exception of a slightly longer cool-down period for the lid end port cover. Overall, the change is seen as having no effect on the basic data and conclusions presented in the SAR.

VI. AUTHOR: Gregory J Barker DATE: 1/23/97

ATTACHMENT #1: Changes To Include File 'CASK.HE-TC' For Review Comment #1

```
10,11c10,11
Original File:    C     GEN -973, 3,0,  70,2,  80,0,   0.1111*  0.48    $ 1/4 CONDUCTOR; E= 0.2
Original File:    C     GEN -976, 3,0,  70,2,  80,0,   0.1111*  0.56069 $ 1/4 CONDUCTOR; E= 0.2
---
Replaced With:    C     GEN -973, 3,0, 170,2,  80,0,   0.1111*  0.48    $ 1/4 CONDUCTOR; E= 0.2
Replaced With:    C     GEN -976, 3,0, 270,2,  80,0,   0.1111*  0.56069 $ 1/4 CONDUCTOR; E= 0.2
13,14c13,14
Original File:          GEN -973, 3,0,  70,2,  80,0,   0.1765*  0.48    $ 1/4 CONDUCTOR; E= 0.3
Original File:          GEN -976, 3,0,  70,2,  80,0,   0.1765*  0.56069 $ 1/4 CONDUCTOR; E= 0.3
---
Replaced With:          GEN -973, 3,0, 170,2,  80,0,   0.1765*  0.48    $ 1/4 CONDUCTOR; E= 0.3
Replaced With:          GEN -976, 3,0, 270,2,  80,0,   0.1765*  0.56069 $ 1/4 CONDUCTOR; E= 0.3
16,17c16,17
Original File:    C     GEN -973, 3,0,  70,2,  80,0,   0.3333*  0.48    $ 1/4 CONDUCTOR; E= 0.5
Original File:    C     GEN -976, 3,0,  70,2,  80,0,   0.3333*  0.56069 $ 1/4 CONDUCTOR; E= 0.5
---
Replaced With:    C     GEN -973, 3,0, 170,2,  80,0,   0.3333*  0.48    $ 1/4 CONDUCTOR; E= 0.5
Replaced With:    C     GEN -976, 3,0, 270,2,  80,0,   0.3333*  0.56069 $ 1/4 CONDUCTOR; E= 0.5
```

ATTACHMENT #2: Changes Made To Input File 'dry-f3.inp' For Review Comment #2

```
2c2
Original File:   TITLE TN CASK, MARK IV SNF: HAC Dry Transfer, Max. Probable MCO
---
Replaced With:   TITLE MARK IV: 30 Min. HAC Dry Transfer, Max. Probable MCO, Review Comment 2
5c5
Original File:        OUTPUT= dry-f3.out
---
Replaced With:        OUTPUT= dry-f3-c2.out
7,8c7,8
Original File:        USER1= dry-f3.dat
Original File:        USER2= dcntrf3.dat
---
Replaced With:        USER1= dry-f3-c2.dat
Replaced With:        USER2= dcntrf3-c2.dat
10c10
Original File:        RSO = dry-f3.rsi
---
Replaced With:        RSO = dry-f3-c2.rsi
1721,1723d1720
Original File:        CALL D1D1WM( XK3, A89, 0.349, END.G99 )
Original File:        CALL D1D1WM( XK3, A89, 1.047, END.G199 )
Original File:        CALL D1D1WM( XK3, A89, 2.065, END.G299 )
Original File:        CALL D1D1WM( XK3, A89, 0.815, END.G399 )
Original File:        CALL D1D1WM( XK3, A89, 0.965, END.G499 )
Original File:        CALL D1D1WM( XK3, A89, 1.064, END.G599 )
Original File:        CALL D1D1WM( XK3, A89, 1.162, END.G699 )
Original File:        CALL D1D1WM( XK3, A89, 1.177, END.G799 )
Original File:   C  ignore seal port forced cooling due to its relative small size
---
Replaced With:    C CONVECTION CONDUCTORS W/ AMBIENT AIR FOR OUTER SURFACES
Replaced With:        CALL FRCVHD ( END.G99,  END.T99,   END.T1,  0.349,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G199, END.T199,  END.T1,  1.047,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G299, END.T299,  END.T1,  2.065,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G399, END.T399,  END.T1,  0.815,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G499, END.T499,  END.T1,  0.965,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G599, END.T599,  END.T1,  1.064,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G699, END.T699,  END.T1,  1.162,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVHD ( END.G799, END.T799,  END.T1,  1.177,  4.0,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:
Replaced With:        CALL FRCVV  ( END.G1100, END.T1100,  END.T1, 0.053, 0.5,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVV  ( END.G1102, END.T1101,  END.T1, 0.036, 0.5,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:        CALL FRCVV  ( END.G1104, END.T1111,  END.T1, 0.072, 0.5,
Replaced With:       +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)


1769,1774d1785
Original File:       CALL FOREXCV ( END.G99,  END.T99,   END.T1,  0.349,  1.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:       CALL FOREXCV ( END.G199, END.T199,  END.T1,  1.047,  1.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:       CALL FOREXCV ( END.G299, END.T299,  END.T1,  2.065,  1.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:        END.G99  = XK3* END.G99
Original File:        END.G199 = XK3* END.G199
Original File:        END.G299 = XK3* END.G299
Original File:       CALL FOREXCV ( END.G399, END.T399,  END.T1,  0.815,  1.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:       CALL FOREXCV ( END.G499, END.T499,  END.T1,  0.965,  1.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:       CALL FOREXCV ( END.G599, END.T599,  END.T1,  1.064,  4.0,
Original File:      +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:       CALL FOREXCV ( END.G699, END.T699,  END.T1,  1.162,  1.0,
```

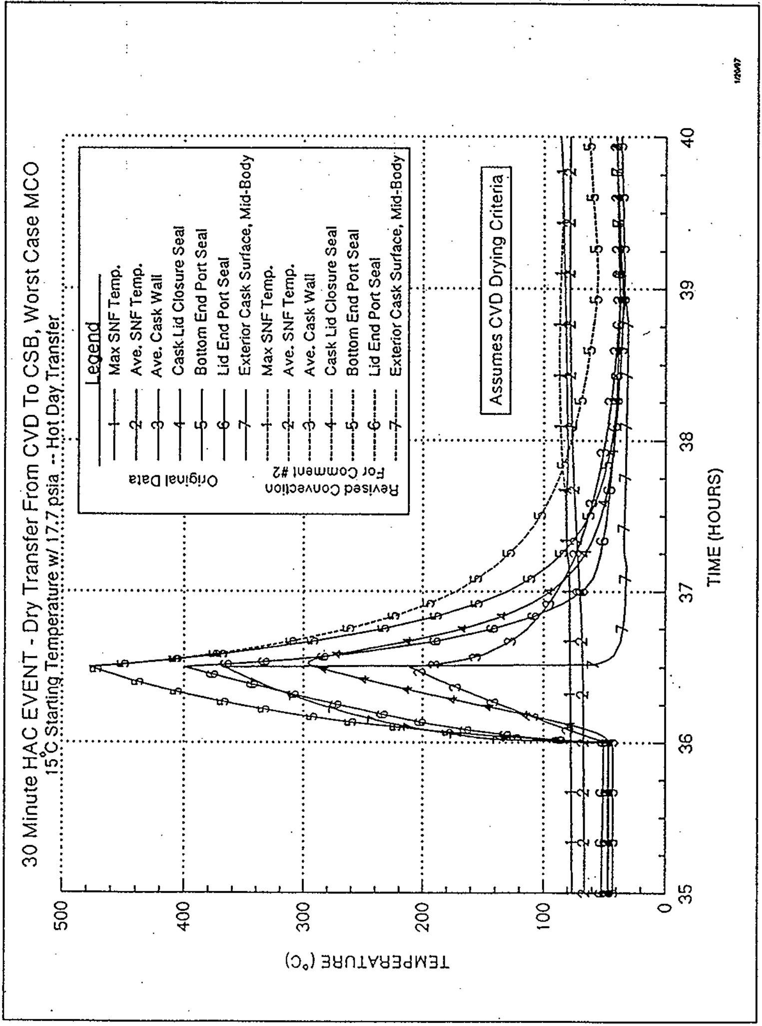
```
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G799, END.T799,  END.T1,  1.177,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:     C  ignore seal port forced cooling due to its relative small size
Original File:          END.G399 = XK3* END.G399
Original File:          END.G499 = XK3* END.G499
Original File:          END.G599 = XK3* END.G599
Original File:          END.G699 = XK3* END.G699
Original File:          END.G799 = XK3* END.G799
---
Replaced With:     C CONVECTION CONDUCTORS W/ AMBIENT AIR FOR OUTER SURFACES
Replaced With:          CALL FRCVHD ( END.G99,  END.T99,   END.T1,  0.349,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G199, END.T199,  END.T1,  1.047,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G299, END.T299,  END.T1,  2.065,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G399, END.T399,  END.T1,  0.815,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G499, END.T499,  END.T1,  0.965,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G599, END.T599,  END.T1,  1.064,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G699, END.T699,  END.T1,  1.162,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G799, END.T799,  END.T1,  1.177,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:
Replaced With:          CALL FRCVV  ( END.G1100, END.T1100,  END.T1, 0.053, 0.5,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVV  ( END.G1102, END.T1101,  END.T1, 0.036, 0.5,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVV  ( END.G1104, END.T1111,  END.T1, 0.072, 0.5,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)


1833,1838d1850
Original File:         CALL FOREXCV ( END.G99,  END.T99,   END.T1,  0.349,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G199, END.T199,  END.T1,  1.047,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G299, END.T299,  END.T1,  2.065,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:          END.G99  = XK3* END.G99
Original File:          END.G199 = XK3* END.G199
Original File:          END.G299 = XK3* END.G299
---
1851a1861,1867
Replaced With:     C CONVECTION CONDUCTORS W/ AMBIENT AIR FOR OUTER SURFACES
Replaced With:          CALL FRCVHD ( END.G99,  END.T99,   END.T1,  0.349,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G199, END.T199,  END.T1,  1.047,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G299, END.T299,  END.T1,  2.065,  4.0,
Replaced With:        +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)


1853,1868c1869,1878
Original File:         CALL FOREXCV ( END.G399, END.T399,  END.T1,  0.815,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G499, END.T499,  END.T1,  0.965,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G599, END.T599,  END.T1,  1.064,  4.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G699, END.T699,  END.T1,  1.162,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:         CALL FOREXCV ( END.G799, END.T799,  END.T1,  1.177,  1.0,
Original File:        +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Original File:     C  ignore seal port forced cooling due to its relative small size
Original File:          END.G399 = XK3* END.G399
Original File:          END.G499 = XK3* END.G499
Original File:          END.G599 = XK3* END.G599
Original File:          END.G699 = XK3* END.G699
Original File:          END.G799 = XK3* END.G799
```

```
---
Replaced With:          CALL FRCVHD ( END.G399, END.T399,  END.T1,  0.815,  4.0,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G499, END.T499,  END.T1,  0.965,  4.0,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G599, END.T599,  END.T1,  1.064,  4.0,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G699, END.T699,  END.T1,  1.162,  4.0,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVHD ( END.G799, END.T799,  END.T1,  1.177,  4.0,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVV  ( END.G1100, END.T1100,  END.T1, 0.053, 0.5,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVV  ( END.G1102, END.T1101,  END.T1, 0.036, 0.5,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
Replaced With:          CALL FRCVV  ( END.G1104, END.T1111,  END.T1, 0.072, 0.5,
Replaced With:         +    GCONST, 0., A15, A14, A16, 0., 14.7, 53.35)
```

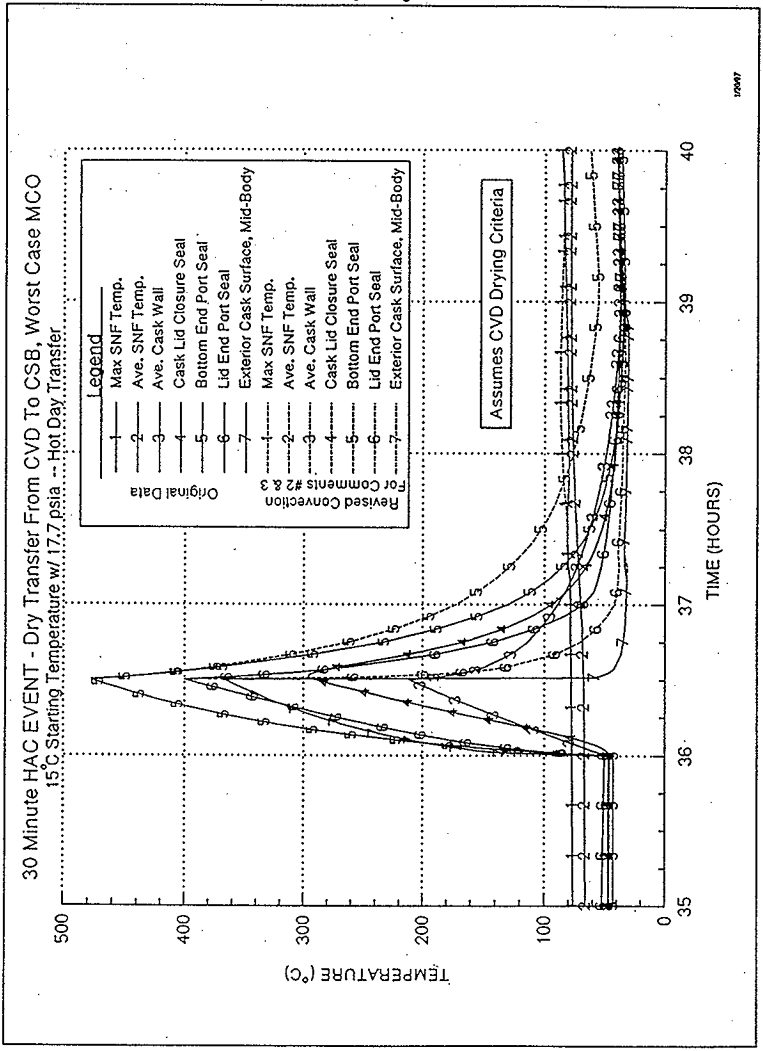
ATTACHMENT #3: Sensitivity of Forced vs. Natural Convecton At Cask Bottom



ATTACHMENT #4: Changes Made To File 'lid-forced.var' For Review Comment #3

```
62c62
Original File:          CALL FOREXCV ( LID1.G1000,  LID1.T1000,   LID1.T1, 0.644,  0.5,
---
Replaced With:          CALL FOREXCV ( LID1.G1000,  LID1.T1000,   LID1.T1, 1.048,  0.5,
64c64
Original File:          CALL FOREXCV ( LID1.G1002,  LID1.T1002,   LID1.T1, 0.763,  0.5,
---
Replaced With:          CALL FOREXCV ( LID1.G1002,  LID1.T1002,   LID1.T1, 0.525,  0.33,
66c66
Original File:          CALL FOREXCV ( LID1.G1004,  LID1.T1004,   LID1.T1, 0.098,  0.5,
---
Replaced With:          CALL FOREXCV ( LID1.G1004,  LID1.T1004,   LID1.T1, 1.582,  0.5,
68c68
Original File:          CALL FOREXCV ( LID4.G1100,  LID4.T1100,   LID1.T1, 0.131,  0.5,
---
Replaced With:          CALL FOREXCV ( LID1.G1006,  LID1.T1006,   LID1.T1, 3.104,  1.0,
Replaced With:          CALL FOREXCV ( LID1.G1008,  LID1.T1008,   LID1.T1, 1.136,  1.0,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID1.G1016,  LID1.T1016,   LID1.T1, 2.333,  1.0,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID1.G1018,  LID1.T1018,   LID1.T1, 1.194,  1.0,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID1.G1026,  LID1.T1026,   LID1.T1, 1.000,  1.0,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID1.G1028,  LID1.T1028,   LID1.T1, 0.562,  1.0,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID4.G1100,  LID4.T1100,   LID1.T1, 0.012,  0.5,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          CALL FOREXCV ( LID4.G1101,  LID4.T1101,   LID1.T1, 0.067,  0.5,
Replaced With:         +    GCONST, FLOW, A53, A79, A52, A50, 0., 0.)
Replaced With:          LID1.G1000 = LID1.G1000 *XK3
Replaced With:          LID1.G1002 = LID1.G1002 *XK3
Replaced With:          LID1.G1004 = LID1.G1004 *XK3
Replaced With:          LID1.G1006 = LID1.G1006 *XK3
Replaced With:          LID1.G1008 = LID1.G1008 *XK3
Replaced With:          LID1.G1016 = LID1.G1016 *XK3
Replaced With:          LID1.G1018 = LID1.G1018 *XK3
Replaced With:          LID1.G1026 = LID1.G1026 *XK3
Replaced With:          LID1.G1028 = LID1.G1028 *XK3
Replaced With:          LID4.G1100 = LID4.G1100 *XK3
Replaced With:          LID4.G1101 = LID4.G1101 *XK3
```

ATTACHMENT #5: Sensitivity of 33% Cycling Factor At Trunnions



ATTACHMENT #6: Changes Made To Input File For Review Comment #4

```
2c2
Original File:     TITLE MARK IV: 30 Min. HAC Dry Transfer, Max. Probable MCO, Review Comment 3
---
Replaced With:     TITLE MARK IV: 30 Min. HAC Dry Transfer, Max. Probable MCO, Review Comment 4
1783c1783
Original File:           FLOW = 20.
---
Replaced With:           FLOW = 2.0
1850c1850
Original File:           FLOW = 8.
---
Replaced With:           FLOW = 0.8
```

ATTACHMENT #8: Comparison Between Original & Review Comment #5 Results After 35 Hours of Dry Transfer Transient

```
TITLE = "EXTENDED DRY TRANSFER; CVD-CSB, MAX DECAY & CORROSION HEATRERACK"
VARIABLES = " TIME"  " QTOT"  "QCTOT"  "QRTOT"  "TFMAX"  "TFAVE"
            "TCASK"  " TMCO"  "SEAL1"  "SEAL2"  "SEAL3"  "SEAL4"
            "EPORT"  "LPORT"  " PLUG"  "BLTHD"  "BLTTL"  " TE88"
            " TE84"  " TE80"  "TL184"  " PMCO"  "PCASK"  " TGAS"
            "TC-CG"  " VOLM"  "   T1"  "RRATE"  "WPRES"  " GMHE"
            "  GMH"  "GMHDI"  "PP-HE"  " PP-H"  "GOXDI"
ZONE T= "MX-Ext", J= 1,  F= POINT

C  Original Results For Extended Dry Transfer w/o CVD Drying Criteria
  3.4832E+01  1.1616E+03  3.2657E+02  8.3500E+02  9.4180E+01  7.2754E+01
  4.8009E+01  5.5743E+01  4.7385E+01  4.7496E+01  4.7606E+01  4.7642E+01
  4.3833E+01  5.2960E+01  4.4677E+01  4.7692E+01  4.5819E+01  4.8614E+01
  4.8683E+01  4.9035E+01  4.5907E+01  5.8239E+01  1.9296E+01  5.0039E+01
  5.1876E+01  5.5500E-01  4.1997E+01  6.2809E+04  8.2198E+01  2.8272E+01
  4.9995E+01  0.0000E+00  2.1037E+01  3.7202E+01  0.0000E+00

C  With Comment #5 Changes Implemented
  3.4832E+01  1.1563E+03  3.2135E+02  8.3500E+02  9.3733E+01  7.2604E+01
  4.7985E+01  5.5687E+01  4.7275E+01  4.7383E+01  4.7489E+01  4.7525E+01
  4.3999E+01  5.2819E+01  4.4604E+01  4.7719E+01  4.5992E+01  4.8582E+01
  4.8651E+01  4.9006E+01  4.5898E+01  6.3963E+01  1.9294E+01  4.9814E+01
  5.1836E+01  5.5500E-01  4.1997E+01  6.1813E+04  8.0756E+01  2.8272E+01
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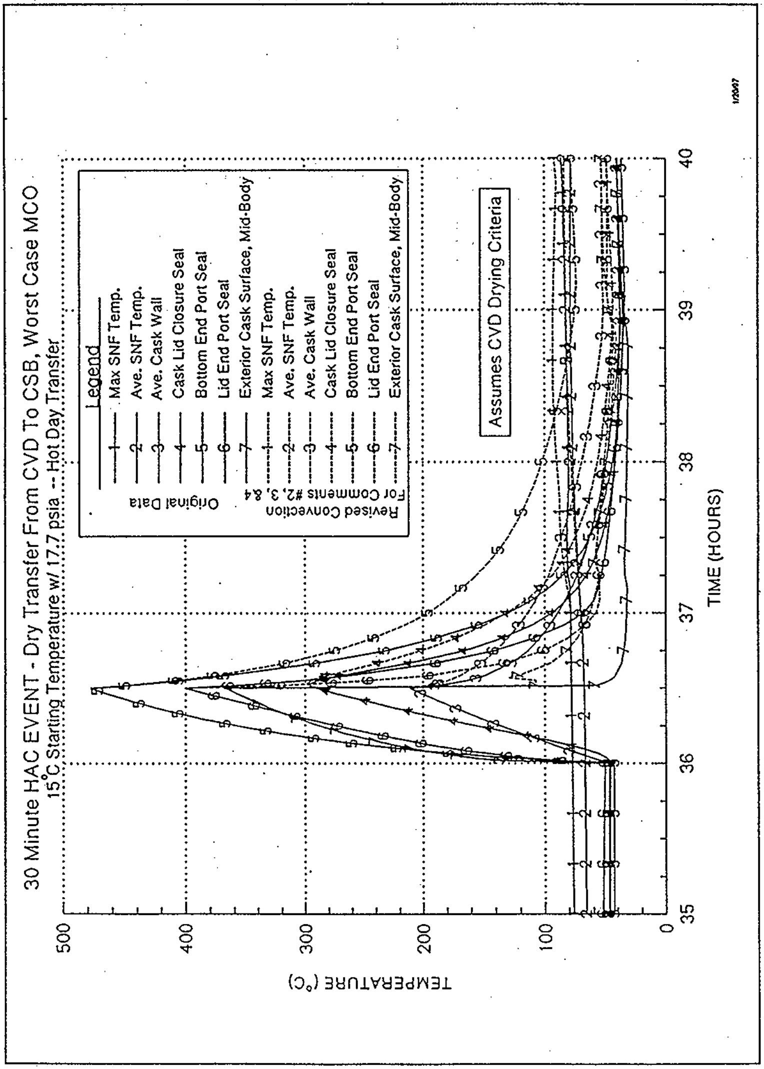
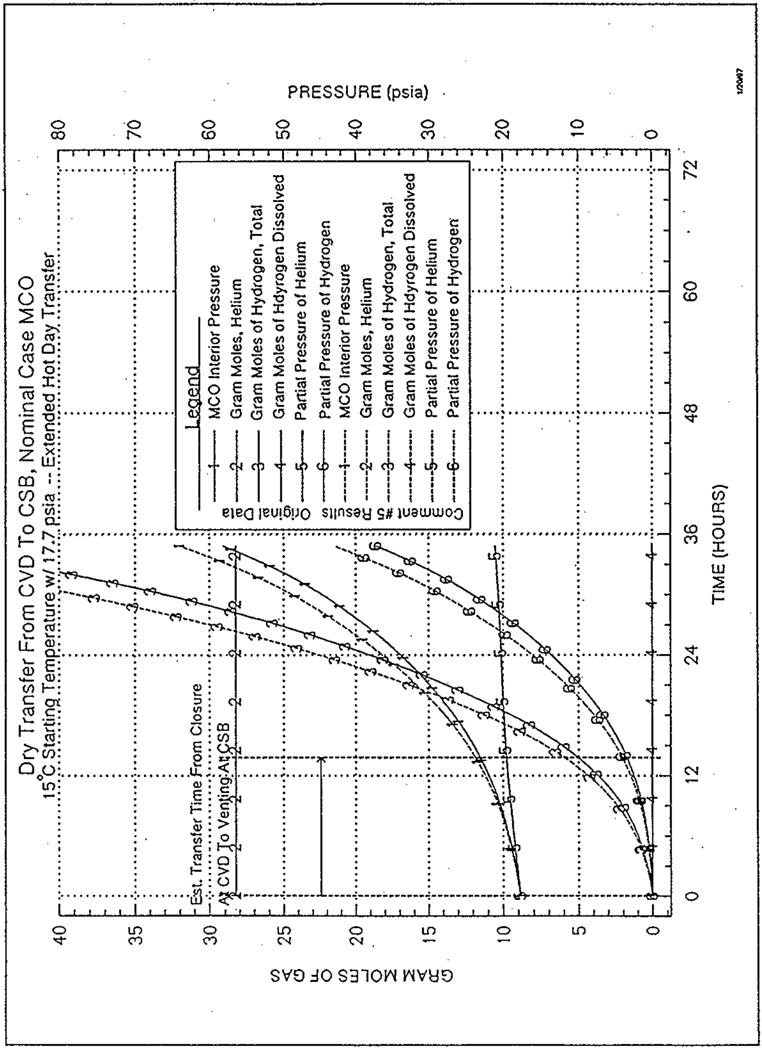
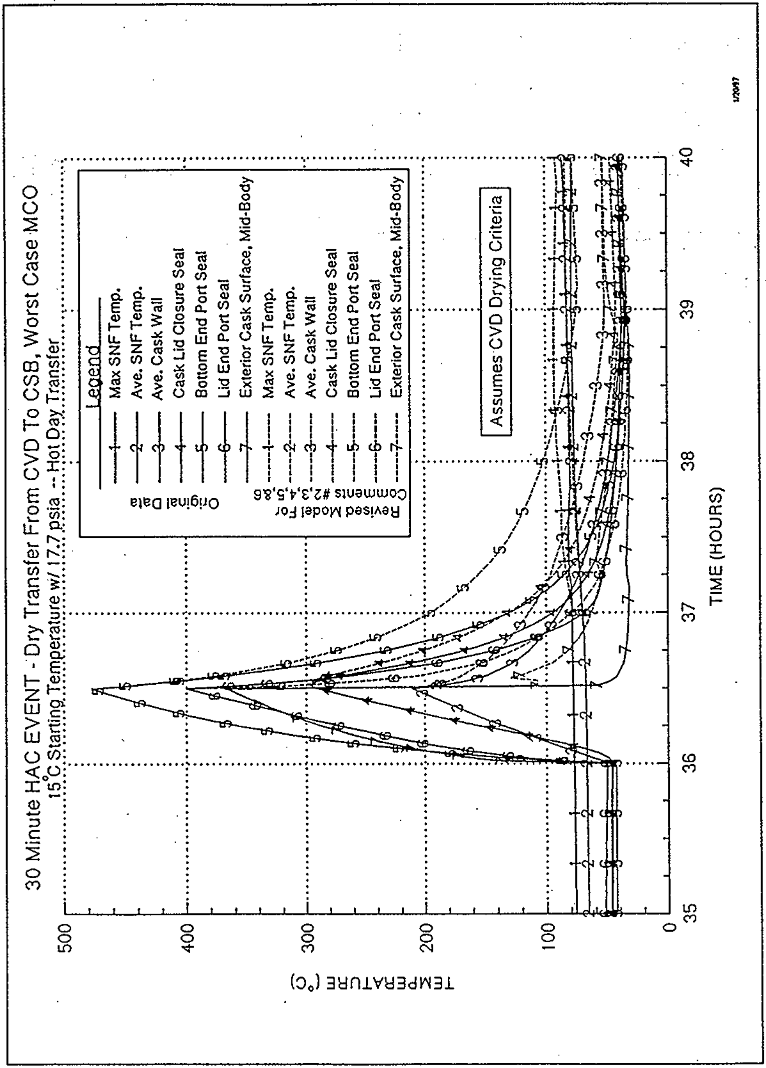
ATTACHMENT #7: Sensitivity of Forced Convection Velocity On Quench Cool Down



Attachment #9: Gas Generation Comparison For Extended Dry Transfer; Original Data vs. Comment 5 Implementation



Attachment #10: Effect of Correcting Forced Convection On Lid



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9.0 PRESSURE AND GAS GENERATION EVALUATION

9.1 INTRODUCTION

Gas generation prior to and during transport of the MCO Cask is a significant factor in evaluating the safety of the packaging system. As discussed in Part B, Section 8.0, the primary source of gas generation is the chemical reactions occurring among the package contents. The gaseous product of interest generated by these chemical reactions is hydrogen. Radiolysis is a minor contributor, as is the release of fission gases.

Evaluation of the gas generation rates due to chemical reactions requires complex analyses because the reaction rates are temperature and pressure dependent. These analyses are contained in Part B, Section 8.0.

9.2 ASSUMPTIONS

9.2.1 K Basins to CVDF

The first shipment leg between the K Basins and the CVDF is a wet transfer; both the MCO and the MCO Cask are filled with water to within 10 cm (4 in.) of the bottom of the MCO shield plug. During this transfer the MCO is vented to the MCO Cask interior. The system is backfilled with 20.7 kPa (3 psig) of helium. The presence of helium ensures that flammable gas mixtures are not present during shipment.

9.2.1.1 Normal Conditions. The normal conditions evaluated for this transfer are described in Part B, Section 8.4.1. The normal shipping window is defined as 24 hours. The case considered involves the worst-case loading (25 °C starting temperature).

9.2.1.2 Accident Conditions. Accident conditions evaluated for this operation are described in Part B, Section 8.5.1. These conditions include a 6-minute fire. Recovery procedures are described in Part A, Section 6.4.1, and involve venting and cooling the cask.

9.2.2 CVDF to CSB

The second shipment leg between the CVDF and the CSB occurs after CVD and is considered a dry transfer. Both the cask and MCO are drained and backfilled with 20.7 kPa (3 psig) of helium. The inert gas ensures that flammable gas mixtures are not present during shipment. During this transfer the MCO is sealed.

9.2.2.1 Normal Conditions. The normal conditions evaluated for the second transfer leg are described in Part B, Section 8.4.1. The actual gas generation rate is measured before transfer is initiated. This operation is described in Part A, Section 6.2.2, based on analysis documented in Part B, Section 8.4.4.2. The normal shipping window is 36 hours. The case considered assumes a 15 °C starting temperature, which is controlled by the CVD process.

9.2.2.2 Accident Conditions. Accident conditions evaluated for this operation are described in Part B, Section 8.5.1. These conditions include a 6-minute fire. Recovery procedures are described in Part A, Section 6.4.2, and involve cooling the cask, removing the cask lid, and venting the MCO.

9.3 GAS GENERATION

9.3.1 Chemical Generation of Hydrogen and Other Gases

The chemical reactions that produce significant quantities of hydrogen are discussed in Part B, Section 8.2.2 and 8.2.3. Figures B8-7, B8-8, B8-10, B8-11, B8-12, and B8-14 show the quantities of hydrogen generated.

9.3.1.1 K Basin to CVDF.

9.3.1.1.1 Normal Conditions for Wet Transfer. For the worst-case loading and starting temperature, the conditions that exist at the end of the shipping window are shown below. See Figure B8-8.

	@ end of 24 hours
Worst Case Loading	
Helium (g-moles)	2.165
Hydrogen (g-moles)	11.12
(hydrogen dissolved in water)	2.23
Pressure/temperature	469 kPa (108.0 psia)/38.1°C

9.3.1.1.2 Accident Conditions for Wet Transfer. After a 6-minute fire at the end of the 24-hour shipping window, the following parameters have been calculated (See Figure B8-23) to show that the effect on the packaging is minimal:

	@ end of 6-minute fire
Helium (g-moles)	2.165
Hydrogen (g-moles)	6.56
(hydrogen dissolved in water)	1.29
Pressure/temperature	471 kPa (68.3 psia)/33.8 °C

9.3.1.2 CVDF to CSB.

9.3.1.2.1 Normal Conditions for Dry Transfer. The conditions that exist at the end of the 36 hour shipping window (for a starting temperature of 15°C) are shown below. See Figure B8-13.

	@ end of 36 hours
Helium (g-moles)	28.272
Hydrogen (g-moles)	3.93
Pressure/temperature	163 kPa (23.6 psia)/48.5°C

9.3.1.2.2 Accident Conditions for Dry Transfer. After a 6-minute fire that occurs at the end of the 36-hour shipping window, the following parameters have been calculated (See Figure B8-15) to show that the effect on the cask is minimal:

	@ end of 6-minute fire
Helium (g-moles)	28.272
Hydrogen (g-moles)	3.95
Pressure/temperature	163 kPa (23.6 psia)/48.5°C

9.3.2 Radiolytic Generation of Hydrogen

In WHC-SD-SNF-ER-014 (Ogden 1996), the gas generation rates due to radiolysis were shown to be at least three orders of magnitude smaller than the gas generation rates due to the uranium/water reactions. Radiolysis is not considered to significantly contribute to gas generation or pressurization during transport of the MCO.

Based on this assessment, no specific calculations are presented in this document to quantify the radiolytic production of hydrogen because the safety of the packaging system is not affected. The evaluation of the chemically generated gases is considered bounding.

9.3.3 Fission Gases

The only fission gas expected to be present in the payload is ^{85}Kr. The shielding source term (Table B2-1) is bounding for this isotope. Calculations show that this component will contribute less than 2% to the pressure of the packaging system, so this contribution is ignored in the pressure calculations.

$$4000 \text{ Ci/MCO} / 390 \text{ Ci/g} / 85 \text{ g/mole} = 0.12 \text{ moles of } ^{85}Kr$$

At the end of 36 hours (dry transfer), the total moles of gas present is:

$$2.165 \text{ (He)} + 3.93 \text{ (}H_2\text{)} + 0.12 \text{ (}^{85}Kr\text{)} = 6.215$$

$$0.12/6.215 = 0.019 \text{ (fraction of } ^{85}Kr \text{ contribution)}$$

9.4 PACKAGE PRESSURE

As presented in Part B, Section 9.2, the calculated pressures for normal and accident conditions do not exceed the 1034 kPa (150 psi) design pressure of the MCO Cask. The pressures calculated for the dry transfer refer to the MCO, which is sealed and isolates the cask from pressurization during this operation.

9.4.1 K Basins to CVDF

The normal conditions evaluated for the wet transfer show a potential maximum pressure of 469 kPa (68 psia) due to hydrogen generation and temperature increases. The 6-minute fire does not have an appreciable effect on the system.

9.4.2 CVDF to CSB

Because the initial gas generation rate will be limited for the dry transfer, the calculated maximum pressures are lower than those determined for the wet transfer leg, notwithstanding the longer shipment window that applies to the CVDF to CSB leg.

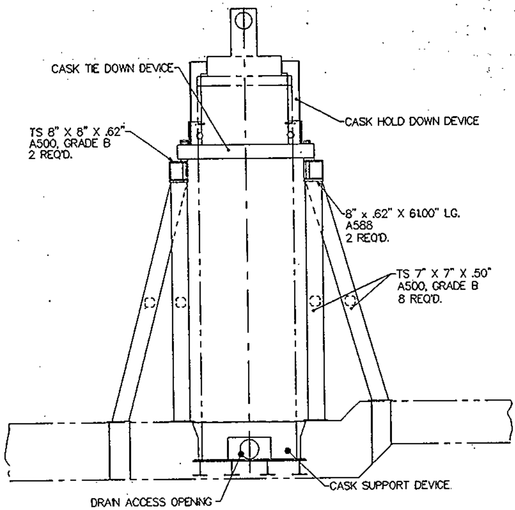
9.5 REFERENCE

Ogden, D. M., 1996, *MCO Pressurization Analysis of Spent Nuclear Fuel Transportation and Storage*, WHC-SD-SNF-ER-014, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

10.0 PACKAGE TIEDOWN SYSTEM EVALUATION

This evaluation verifies the tiedown system design for the MCO Cask (TN 1996) as shown in Figure B10-1. For this verification of the design, key elements of the tiedown system are evaluated.

Figure B10-1. Multicanister Overpack Cask Tiedown.



10.1 SYSTEM DESIGN

The tiedown system is designed by TN in conjunction with Nelson Manufacturing Company (TN 1996). As designed, the tiedown system is a fixed system that is an integral part of the conveyance system. The conveyance system is based on a custom double-drop semi-trailer designed specifically for securement and transport of the MCO Cask. The cask is to be transported in the vertical position and fits into the cask support device, which is a 39.47-cm- (15.54-in.-) deep well located beneath the deck of the trailer. Approximately 300 cm (118 in.) above the deck of the trailer, the cask is secured by a cask tiedown device mounted onto a fixed frame constructed of structural tube members and braced to the trailer deck with four structural tube members. The tiedown system is constructed of rectangular structural steel tubing (ASTM A500, Grade B [ASTM 1989]) frame, which is welded to the transport trailer bed. The cask tiedown device is designed as a hinged clamshell ring where each half section pivots about a fixed 3.81-cm (1.5-in.) hinge pin and secured with three 1.5-in. hex head bolts. The inside diameter of the clamping ring is constructed of 6061-T6 aluminum and equipped with a Neoprene[4] gasket which forms a tight fit with the cask. Attached to the clamping ring are four cask hold-down brackets, equally spaced around the circumference, which restrain vertical movement of the cask.

10.2 TIEDOWN LOADS

The cask must remain secured to the trailer for loads higher than required by 49 CFR 173. Consequently, the tiedown system is designed to meet the higher load requirements of IAEA guidelines (IAEA 1990) for securement systems as specified in the packaging design criteria (Edwards 1997). The tiedown system must be capable of resisting acceleration loads of 2*g* in the longitudinal direction, 1*g* in the lateral direction, 3*g* in the vertical downward direction, and 2*g* in the vertical upward direction.

10.3 TIEDOWN EVALUATION

As a verification of the design, the major load-bearing components of tiedown system are evaluated. The MCO cask tiedown system is evaluated by both classical and finite-element methods. Details of the structural analysis of the tiedown system are presented in Part B, Section 10.5 (appendix).

The finite-element method is used to determine the stresses in the tiedown frame, clamp, and support plate. Classical linear elastic calculations are used to determine weld, bolt, pin, and hold-down device stresses. The classical calculations utilize results from the finite-element calculations.

ABAQUS/Standard computer code (HKS 1995) was used to perform a finite-element analysis of the tiedown system. The finite-element model is constructed primarily of beam and shell elements. The pins and bolts of the hold-down clamp are modeled with truss elements, and the MCO Cask is modeled with a rigid element.

Lateral and longitudinal loads are applied by forcing the rigid cask elements into the clamp until the reaction forces correspond to the specified acceleration loads. In the lateral case the reaction force is 266,887 N (60,000 lb), and in the longitudinal case the reaction force is 533,774 N (120,000 lb). The vertical upward load case is a point load of 133,444 N (30,000 lb) and is applied to each one of the arms. In the vertical downward direction, a pressure of 1,034 kPa (150 psi) is applied uniformly to the plate. This conservative load generates a total applied load of 1.5×10^6 N (338,400 lb), which exceeds the required load of 800,661 N (180,000 lb).

Steel and stainless steel components are modeled as linearly elastic materials with a modulus of 199,943 MPa (29×10^6 psi) and a Poisson's ratio of 0.3. Aluminum components are also modeled as linearly elastic materials with a modulus of 68,946 MPa (10×10^6 psi) and a Poisson's ratio of 0.3. The yield strength of 6061 T6 aluminum components is assumed to be 276 MPa

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[4]Neoprene is a trademark of E. I. du Pont de Nemours & Company.

(40 ksi). The yield strength of ASTM A500, Grade B components is assumed to be 317 MPa (46 ksi). ASTM A-479 XM-19, hot rolled, stainless steel components are assumed to have a yield strength of 724 MPa (105 ksi).

A summary of the results shows welds between the hold-down brackets and the clamp have a margin of safety of 1.4 against yielding. The welds between the tiedown frame and the trailer have a minimum margin of safety of 0.52 against yield. Shear stresses in the hold-down device bolts and the clamp bolts and pins is negligible for these components constructed of ASTM A-479, hot rolled XM-19. The maximum Von Mises stress in the tubular frame members is 220 MPa (32 ksi) and occurs in the top cross-member under longitudinal loading. The margin of safety against yield for these tubular frame members is 0.44. The maximum Von Mises stress in the clamp during longitudinal loading is 182 MPa (26.4 ksi) and in the lateral loading case is 165 MPa (23.9 ksi). The maximum Von Mises stresses in the clamp occur during vertical upward loading. In this case the maximum stress of 247 MPa (35.8 ksi) is associated with discontinuities near the truss elements. Consequently, the minimum margin of safety of the clamp is 0.12. The maximum Von Mises stress in the support plate is 54 MPa (7.85 ksi), which is significantly below the yield strength of the material. Evaluation of trailer loading is not part of this analysis. However, in the vertically downward load case, design of the tiedown system as an integral part of the trailer necessitates inclusion of some trailer components. The maximum Von Mises stress in these trailer components was determined as 214 MPa (31.1 ksi).

Calculational results at critical locations and critical components show that the performance of the tiedown system meets the requirements of the packaging design criteria (Edwards 1997). This is demonstrated by the positive margins of safety (based on the minimum yield strength of the material) under all loading cases evaluated.

10.4 REFERENCES

49 CFR 173, 1996, ""Shippers--General Requirements for Shipments and Packagings," *Code of Federal Regulations*, as amended.

ASTM, 1989, *Annual Book of ASTM Standards*, Vol. 01.04, American Society of Testing, Philadelphia, Pennsylvania.

Edwards, W. S., 1997, *Packaging Design Criteria for the MCO Cask*, WHC-SD-TP-PDC-030, Rev. 4, Rust Federal Services Inc. Northwest Operations, Richland, Washington.

HKS, 1995, *ABAQUS/Standard User's Manual, Volume I and II*, Hibbit, Karlsson & Sorensen, Inc., Pawtucket, Rhode Island.

IAEA, 1990, *Safety Series No. 37, IAEA Safety Guides*, Third Edition, International Atomic Energy Agency, Vienna, Austria.

TN, 1996, *TN-WHC Cask Transportation System Tie Down System*, Drawing 3035-7, Transnuclear, Inc., Hawthorne, New York.

10.5 APPENDIX: TIEDOWN ANALYSIS

Checklist for Checking of Analysis/Calculations

Document Checked - Number: N/A **Revision:** 0

Title: MCO-Cask Tiedown Evaluation

Yes	No	N/A	
[x]	[ ]	[ ]	Problem completely defined.
[x]	[ ]	[ ]	Appropriate analytical method used.
[x]	[ ]	[ ]	Necessary assumptions are approriate, explicitly stated, and stated.
[x]	[ ]	[ ]	Computer codes and data files documented.
[x]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[ ]	[ ]	[x]	Sources of non-standard formulae/data are referenced and the correctness of the reference verified.
[x]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[x]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[x]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[x]	[ ]	[ ]	Hand calculations checked for errors.
[x]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[x]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[x]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[x]	[ ]	[ ]	Safety Margins consistent with good engineering practices.
[x]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[x]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

I have checked the analysis/calculation and it is complete and accurate to the best of my knowledge.

S. S. Shiraga [signature] 1/23/57

Engineer/Checker Date

Note: Any hand calculations, notes or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

MCO Tiedown Analysis

Randall S. Marlow
1/14/97

1.0 Introduction

This document describes a structural analysis of the MCO cask tiedown system (Transnuclear 1996) which is attached to the trailer used to transport the MCO cask. The tiedown system is analyzed for the inertial loading from a 60,000-lbf MCO cask. The weight of the tiedown system itself is neglected. The various loading directions and load factors considered are summarized in Table 1.0-1. The load factors are applied to the weight of the cask to obtain the force which is then applied to the tiedown system in the appropriate direction.

Table 1.0-1. Tiedown Loadings

Longitudinal	2g fore
Lateral	1g
Vertical	.3g down 2g up

The longitudinal direction refers to the longitudinal axis of the trailer. The lateral direction is the direction in the horizontal plane which is perpendicular to the longitudinal axis. Vertical refers to the direction of the gravitational force.

2.0 Analytical Methods

The structural effects of the loadings described above are determined with a combination of the finite-element method and standard hand calculations. The finite-element method is used primarily to determine the stresses in the tiedown frame, the clamp, and the support plate. The hand calculations are used to determine weld stresses, bolt and pin stresses, and stresses in the hold-down device. The hand calculations utilize some results from the finite-element calculations. For example, the reaction forces determined in the finite-element calculations are used to determine the stresses in the welds which attach the tiedown frame to the trailer.

The ABAQUS/Standard (HKS 1995) finite-element model of the tiedown frame is shown in Figure 2.0-1. The model is constructed mainly of beam and shell elements, although the pins and bolts of the clamp are modeled with truss elements and the MCO cask is modeled with rigid elements. The tiedown frame is modeled with two-noded beam elements. The clamp and hold-down device are modeled with four-noded shell elements. The arms of the hold-down device are attached to the brackets with multipoint constraints. The brackets are attached to the top of the clamp with multi-point constraints. The clamp is secured to the tiedown frame by multi-point constraints between the truss nodes and nodes on the cross-members. The tiedown frame is constrained at the end nodes. In the vertically up load case, nodes on the edge of the clamp are constrained to model the effect of contact between the cross-members and the clamp.

The finite-element model of the plate which supports the cask in the vertically downward case is shown in Figure 2.0-2. The finite-element mesh is constructed of four-noded shell elements constrained at the locations where the cross-beams and the steel plate are welded to the trailer. Note that this model necessarily contains details of the trailer. Excerpts from the finite-element input file for the longitudinal and vertically downward load cases are contained in Attachments A and B. The hand calculations are in Attachment C.

In the lateral and longitudinal cases, the loads are applied by forcing the rigid cask elements into the clamp until the desired reaction force is developed at the rigid-body node. The reaction force is 60,000 lbf for the lateral case and 120,000 lbf for the longitudinal case. In the vertically upward case the load, a point load of 30,000 lbf is applied to each one of the arms. In the vertically downward case, a pressure of 150 psi is applied uniformly to the plate. The total load applied in this case is 338,400 lbf, which is far above the required force of 180,000 lbf and is therefore extremely conservative.

The steel and stainless steel components are modeled as linearly elastic with modulus of 29,000,000 lbf/in^2 and a Poisson's ratio of 0.3. The aluminum components are modeled as linearly elastic with a modulus of 10,000,000 lbf/in^2 and a Poisson's ratio of 0.3. The yield stress of 6061T6 components is taken to be 40,000 lbf/in^2. The yield stress of A500 Gr.B components is taken to be 46,000 lbf/in^2. The yield stress of the A-479 XM19 components is taken as 105,000 lbf/in^2.

3.0 Results and Conclusions

Calculations show that the stress in the tiedown system is acceptable in every case. (The deformed shapes of the tiedown frame are shown in Figures 3.0-1, 3.0-2, and 3.0-3.) The welds between the hold-down brackets and the clamp have a 1.4 margin against yielding. The welds between the tiedown frame and the trailer have a margin of at least 0.52 against yielding. The shear stresses in the hold-down device bolts and the clamp bolts and pins are not significant for these A-479 XM19 components. The maximum Von Mises stress in the tubular components of the tiedown frame is 32,000 lbf/in^2. The maximum occurs in the top cross-member in the longitudinal case. The margin against yield in this A500 Gr.B structural member is 0.44. The maximum Von Mises stress in the clamp in the lateral case is 23,900 lbf/in^2. The maximum stress in the clamp is 26,400 lbf/in^2 longitudinal case. The maximum Von Mises stress in the clamp is 35,800 lbf/in^2 in the vertically upward case. (In this case, the maximum is associated with discontinuities near the truss elements.) The minimum margin against yield in the clamp is therefore 0.12. The maximum Von Mises in the support plate is 7,850 lbf/in^2, which is far below the yield. Although the trailer is not part of this analysis, the vertically downward load case necessarily included parts of the trailer as described above. The maximum Von Mises stress in these trailer components is 31,100 lbf/in^2.

4.0 References

HKS, 1995, *ABAQUS/Standard User's Manual, Volumes I and II*, Hibbit, Karlsson & Sorensen, Inc., Pawtucket, Rhode Island.

Transnuclear, 1996, *Design Analysis Report for the TN-WHC Cask and Transportation System*, Project 3035, Item no. 8, Transnuclear Inc, Hawthorne, New York.

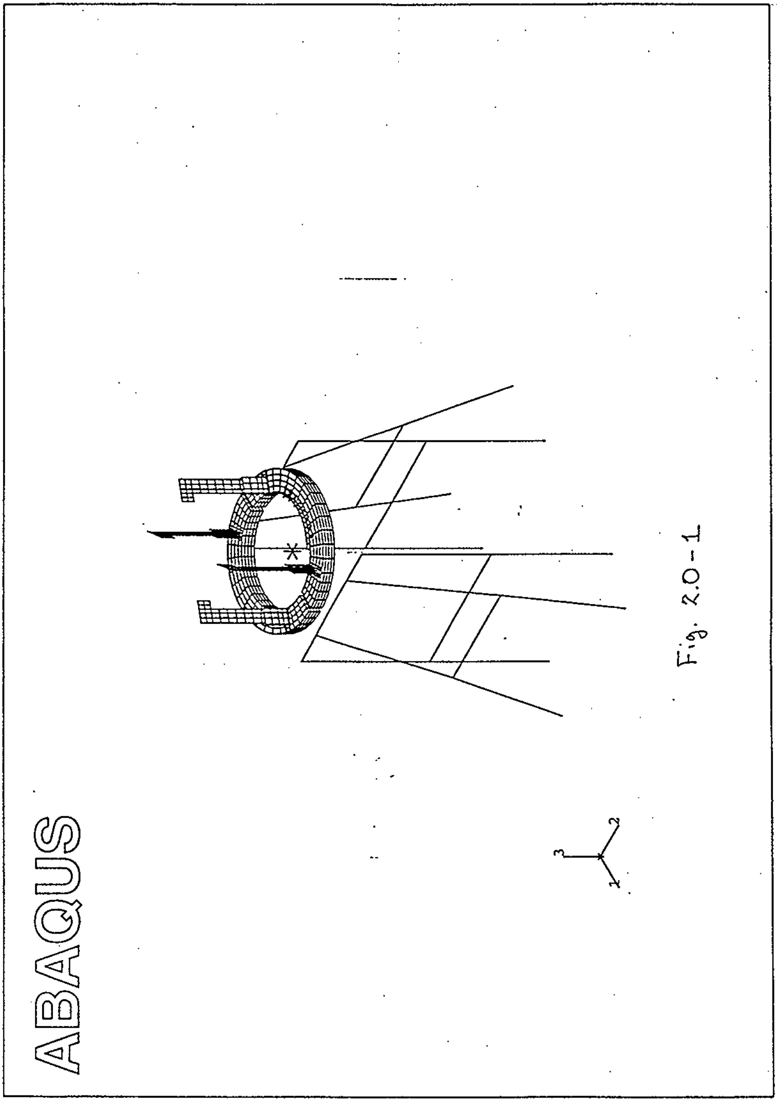

Fig. 2.0-1

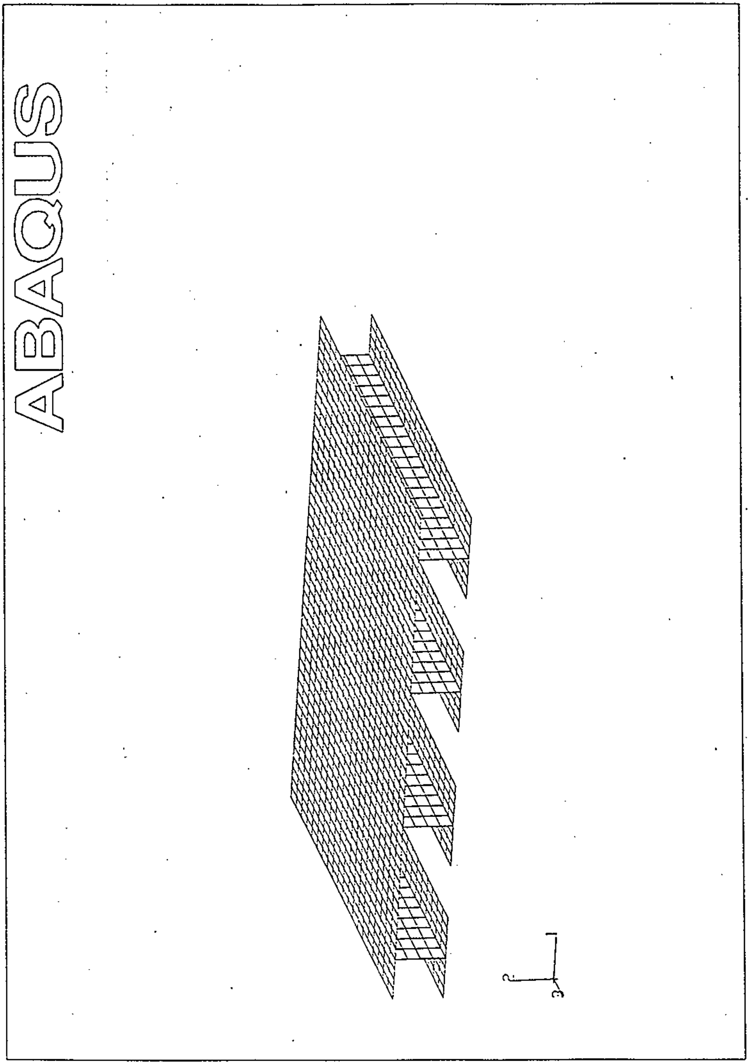

Fig. 2.0-2

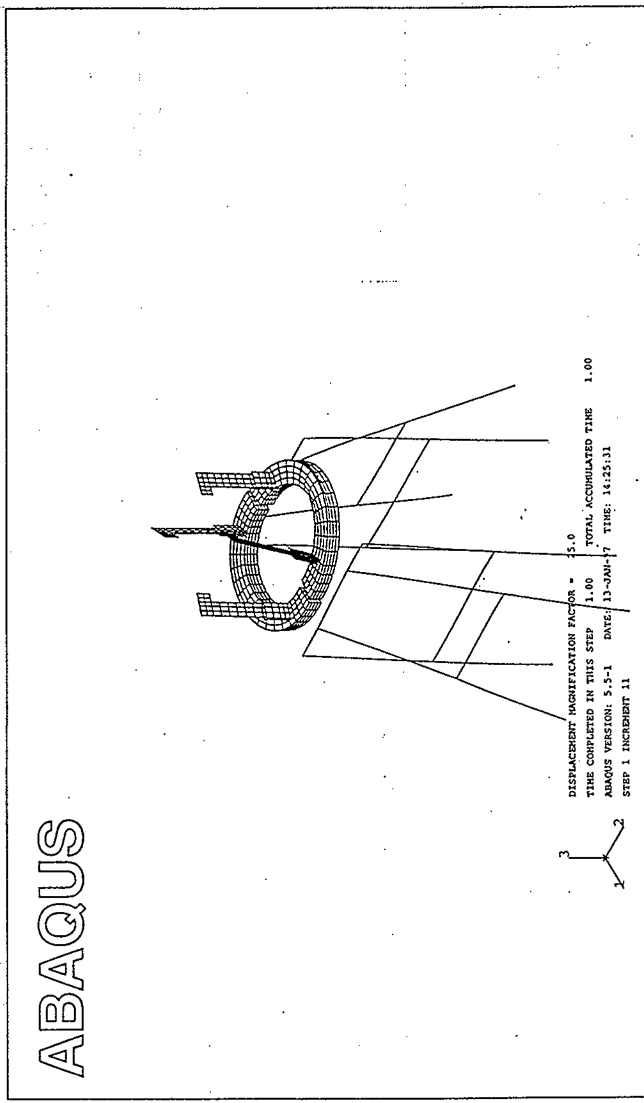

Fig. 3.0-1. Deformed Shape - Lateral Load

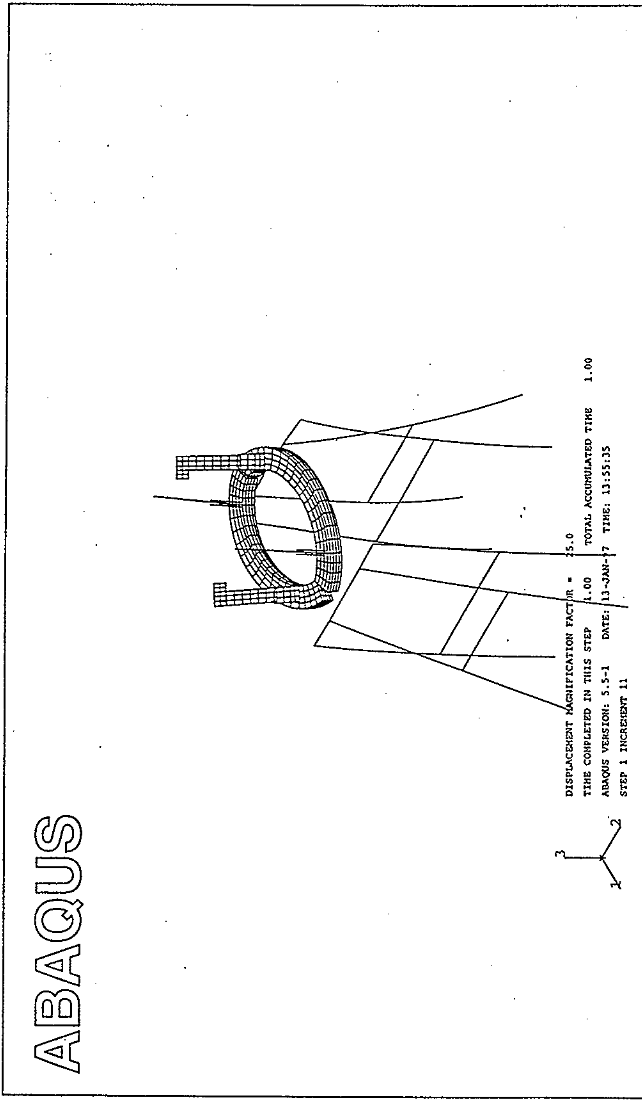

Fig. 3.0-2. Deformed Shape - Longitudinal Load

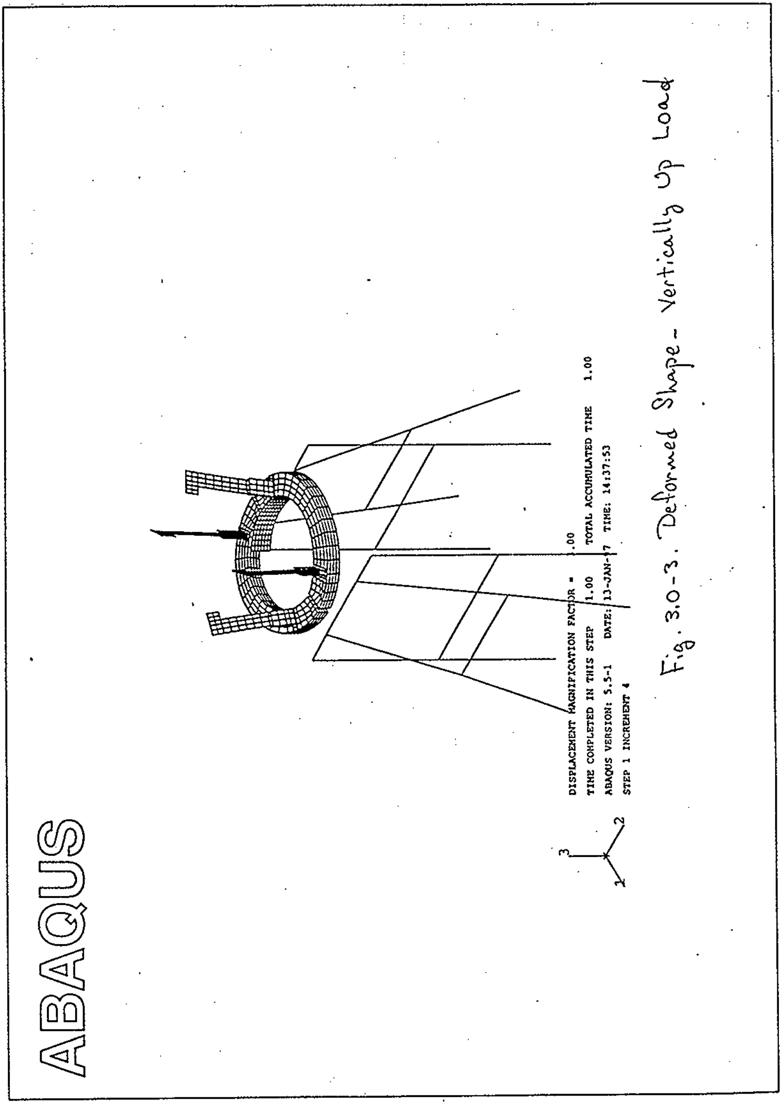

Fig. 3.0-3. Deformed Shape - Vertically Up Load

Attachment A. ABAQUS/Standard Input File For Longitudinal Load Case

Ellipsis denotes the omission of lengthy node or element definitions.

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...
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...
5116,4.0000,0.81000,7.0000
*system
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765,774
*elset,elset=leg2,generate
715,724
775,784
*elset,elset=leg3,generate
725,734
*elset,elset=leg4,generate
735,744
785,794
*elset,elset=leg5,generate
745,754
795,804
*elset,elset=leg6,generate
755,764
*elset,elset=leg7,generate
815,824
865,874
*elset,elset=leg8,generate
805,814
845,854
*elset,elset=leg11,generate
885,894
*elset,elset=leg12,generate
825,834
875,884
*elset,elset=leg13,generate
835,844
855,864
*elset,elset=leg16,generate
895,904
*elset,elset=leg17,generate
909,912
921,924
905,908
*elset,elset=leg18,generate
913,916
925,928
917,920
*beamsection,elset=leg1,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
0.4338,-0.9010,0.0
*beamsection,elset=leg2,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
-0.4338,-0.9010,0.0
```
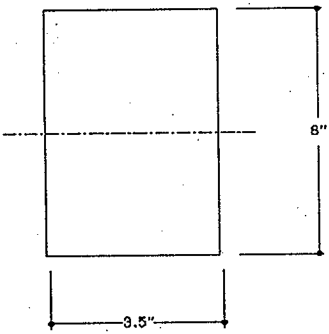

```
*beamsection,elset=leg3,material=steel,section=box
4.0,4.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg4,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
0.4338,0.9010,0.0
*beamsection,elset=leg5,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
-0.4338,0.9010,0.0
*beamsection,elset=leg6,material=steel,section=box
4.0,4.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg7,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg8,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg11,material=steel,section=box
4.0,4.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg12,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg13,material=steel,section=box
7.0,7.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg16,material=steel,section=box
4.0,4.0,0.5,0.5,0.5,0.5
1.0,0.0,0.0
*beamsection,elset=leg17,material=steel,section=box
8.0,8.0,1.25,0.625,0.625,0.625
0.0,0.0,-1.0
*beamsection,elset=leg18,material=steel,section=box
8.0,8.0,1.25,0.625,0.625,0.625
0.0,0.0,-1.0
*nset,nset=fix
709,720,811,822
844,833,740,751
*boundary
99999,2,6
fix,encastre
*nset,nset=junk
123,98,209,20
*ncopy,old set=junk,shift,change number=30000
0.0,0.0,0.0

*element,type=b31,elset=cbolt1
85001,333,30123
85002,308,30098
*element,type=b31,elset=cbolt2
85003,419,30209
85004,230,30020
*beamsection,elset=cbolt1,material=steel,sect=circ
1.25
1.,0.,0.
*beamsection,elset=cbolt2,material=steel,sect=circ
1.06
1.,0.,0.
*mpc
beam,333,123
beam,308,98
beam,30098,925
beam,30123,927
beam,419,209
beam,230,20
beam,30209,930
beam,30020,928
beam,5073,272
beam,5064,272
beam,5086,266
beam,5083,266
beam,7083,220
beam,7086,220
beam,7064,216
beam,7073,216
beam,8083,371
beam,8086,371
beam,8064,377
beam,8073,377
beam,6086,317
beam,6083,317
beam,6073,321
beam,6064,321
beam,5004,5002
beam,5001,5002
beam,6004,6002
beam,6001,6002
beam,8004,8002
beam,8001,8002
beam,7004,7002
beam,7001,7002
beam,5100,5026
beam,5115,5026
beam,6100,6026
beam,6115,6026
beam,7100,7026
beam,7115,7026
beam,8100,8026
beam,8115,8026
*nset,nset=asurf,generate
106,110
439,441
484,486
487,489
490,492
481,483
316,320
56,56
86,89
424,426
592,594
589,591
586,588
568,570
266,266
296,299
*contact node set,name=asurf
asurf,
*surface definition,name=bsurf
cask,spos
*surface interaction,name=rough
*contact pair,interaction=rough,small sliding
asurf,bsurf
*restart,write
*step,inc=9999,nlgeom
*static
0.01,1.
*boundary
99999,1,1,-0.815
*elprint,freq=0
*nodeprint,freq=0
*end step
```

ENGINEERING SAFETY EVALUATION

Subject: MCO Tiedown Analysis — Page: 1 of 3
Originator: R. S. Marlow — Date: 1/17/97
Checker: S. S. Shiraga — Date: 1/23/97

Hold Down Bracket Weld:

The hold down bracket weld is analyzed for the 2 *g* up load case.



Axial load: $\frac{2\cdot(60000\,lbf)}{4} = 30000\cdot lbf$

Moment: $30000\,lbf(1.5\cdot in + 4\cdot in) = 165000\cdot lbf\cdot in$

$$f_b := \frac{165000\,lbf\cdot in}{(3.5\cdot in)\cdot(8\cdot in) + \frac{(8\cdot in)^2}{3}} \qquad f_b = 3345\cdot\frac{lbf}{in}$$

$$f_a := \frac{30000\,lbf}{2\cdot(8\cdot in + 3.5\cdot in)} \qquad f_a = 1304\cdot\frac{lbf}{in}$$

$$f_t := \sqrt{f_b^{\,2} + f_a^{\,2}} \qquad f_t = 3590\cdot\frac{lbf}{in}$$

Required weld size: $\frac{f_t}{0.7\cdot 40000\,psi} = 0.13\cdot in$

Margin against yield: $\frac{0.31}{0.13} - 1 = 1.4$

Weld yield is assumed at yield of 6061 T6

ENGINEERING SAFETY EVALUATION

Subject: MCO Tiedown Analysis Page: 2 of 3
Originator: R. S. Marlow Date: 1/17/97
Checker: S. S. Shiraga Date: 1/23/97

Hold Down Device Hex Bolts:

The hex bolts are analyzed for the 2g upload case. Assume bolts carry total vertical load.

Shear Stress: $\dfrac{30000\,\text{lbf}}{(1.41\cdot\text{in})\cdot(2\cdot\text{in})} = 10638\cdot\text{psi}$

Shear stress is acceptable. (Bolts are A-479 XM-19 (Hot Rolled), which a yield of 105 ksi.

Clamp Bolts and Pins:

The clamp bolts and pins are analyzed for the 2g longitudinal case.

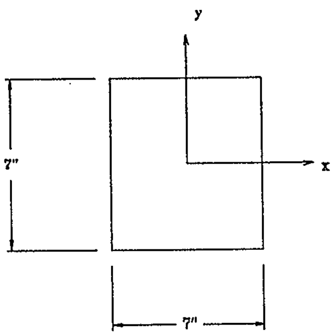
Shear area: $2\cdot\left(\dfrac{\pi}{4}\right)\cdot(1.995\,\text{in})^2 + (2)\cdot\left(1.41\cdot\text{in}^2\right) = 9.07\cdot\text{in}^2$

Shear stress: $\dfrac{120000\,\text{lbf}}{9.07\cdot\text{in}^2} = 13230\cdot\text{psi}$

Shear stress is acceptable. (Bolts are A-479 XM-19 (Hot Rolled), which a yield of 105 ksi.

Weld Between Frame and Trailer:

The welds are analyzed under the maximum moments and forces from all three load cases. Forces and moments are from the finite-element calculation.



$M_x := 103890\,\text{in}\cdot\text{lbf}$

$M_y := 264800\,\text{in}\cdot\text{lbf}$

$T := 2062\cdot\text{in}\cdot\text{lbf}$

$P := 146900\,\text{in}\cdot\text{lbf}$

$V_x := 1414\,\text{lbf}$

$V_y := 1279\,\text{lbf}$

ENGINEERING SAFETY EVALUATION

Subject: MCO Tiedown Analysis Page: 3 of 3
Originator: R. S. Marlow Date: 1/17/97
Checker: S. S. Shiraga Date: 1/23/97

$$f_{bx} := \frac{M_x}{(7\cdot in)^2 + \frac{(7\cdot in)^2}{3}} \qquad f_{bx} = 1590\cdot\frac{lbf}{in}$$

$$f_{by} := \frac{M_y}{(7\cdot in)^2 + \frac{(7\cdot in)^2}{3}} \qquad f_{by} = 4053\cdot\frac{lbf}{in}$$

$$f_t := \frac{T\cdot\sqrt{(3.5\cdot in)^2 + (3.5\cdot in)^2}}{\left[\frac{(7\cdot in + 7\cdot in)^3}{6}\right]} \qquad f_t = 22\cdot\frac{lbf}{in}$$

$$f_a := \frac{P}{(4\cdot in)\cdot(7\cdot in)} \qquad f_a = 5246\cdot\frac{lbf}{in}$$

$$f_{sx} := \frac{V_x}{4\cdot(7\cdot in)} \qquad f_{sx} = 51\cdot\frac{lbf}{in}$$

$$f_{sy} := \frac{V_y}{4\cdot(7\cdot in)} \qquad f_{sy} = 46\cdot\frac{lbf}{in}$$

Neglect Shear and Torsion: $f_t := f_{by} + f_{bx} + f_a$ $\qquad f_t = 10890\cdot\frac{lbf}{in}$

Required weld size: $\frac{f_t}{0.7\cdot(46000\,psi)} = 0.34\cdot in$

Margin against yield: $\frac{0.5}{0.33} - 1 = 0.52$

(Weld yield is assumed as yield of ASTM A500, Grade B.)

LONG.XLS

705	264810	10892.34	
705	-103890		
705	-2062		
705	-146890		
705	-1414		-50.5
705	1279		45.67857
715	264810	10892.34	
715	103890		
715	2062		
715	-146890		
715	-1414		-50.5
715	-1279		-45.6786
735	-91844	4236.884	
735	-37015		
735	-3328		
735	63375		
735	-478		-17.0786
735	1073		38.32143
745	-91844	4236.884	
745	37015		
745	3328		
745	63375		
745	-478		-17.0786
745	-1073		-38.3214
805	33722	10764.09	
805	-343650		
805	8577		
805	139570		
805	-2961		-105.75
805	-3055		-109.107
815	-33722	10764.09	
815	-343650		
815	-8577		
815	139570		
815	2961		105.75
815	-3055		-109.107
825	14269	4150.592	
825	-119620		
825	-3986		
825	-58800		
825	-1246		-44.5
825	-473		-16.8893
835	-14269	4150.592	
835	-119620		
835	3986		
835	-58800		
835	1246		44.5
835	-473		-16.8893

LAT.XLS

705	-1.09E+05	6759.693	
705	-1.87E+05		
705	-1.35E+04		
705	6.22E+04		
705	2029		72.46429
705	-4850		-173.214
715	3.77E+04	4628.828	
715	-2.16E+05		
715	-1.34E+04		
715	-2.07E+04		
715	-1537		-54.8929
715	-4577		-163.464
735	-7.36E+04	6177.675	
735	1.90E+05		
735	1.82E+04		
735	5.97E+04		
735	587.6		20.98571
735	5367		191.6786
745	2.39E+04	4352.871	
745	2.11E+05		
745	1.96E+04		
745	-2.11E+04		
745	-1067		-38.1071
745	4653		166.1786
805	-2.08E+05	3898.458	
805	1.37E+04		
805	-1.63E+04		
805	-1.38E+04		
805	4919		175.6786
805	-209.9		-7.49643
815	-2.00E+05	5098.042	
815	7.27E+04		
815	-1.28E+04		
815	-2.59E+04		
815	4144		148
815	730.9		26.10357
825	-1.77E+05	4564.41	
825	-6.41E+04		
825	1.29E+04		
825	-2.42E+04		
825	3664		130.8571
825	-607.5		-21.6964
835	-1.85E+05	3357.393	
835	-4194		
835	1.61E+04		
835	-1.26E+04		
835	4374		156.2143
835	371.6		13.27143

705	-3.04E+04	1166.238	
705	1.73E+04		
705	-1954		
705	1.22E+04		
705	1033		36.89286
705	700.8		25.02857
715	-3.04E+04	1166.238	
715	-1.73E+04		
715	1954		
715	1.22E+04		
715	1033		36.89286
715	-700.8		-25.0286
735	-7357	723.5791	
735	-7847		
735	1980		
735	1.37E+04		
735	379.5		13.55357
735	-554.5		-19.8036
745	-7357	723.5791	
745	7847		
745	-1980		
745	1.37E+04		
745	379.5		13.55357
745	554.5		19.80357
805	2585	721.9667	
805	2.21E+04		
805	-1318		
805	9611		
805	-226.4		-8.08571
805	900.8		32.17143
815	-2585	721.9667	
815	2.21E+04		
815	1318		
815	9611		
815	226.4		8.085714
815	900.8		32.17143
825	-3570	602.6757	
825	-8832		
825	-1061		
825	1.16E+04		
825	312.6		11.16429
825	-598.5		-21.375
835	3570	602.6757	
835	-8832		
835	1061		
835	1.16E+04		
835	-312.6		-11.1643
835	-598.5		-21.375

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	Packaging Engineering	Date 07/10/97
Project Title/Work Order		EDT No. 618195
Safety Analysis Report for Packaging (Onsite) Mulitcanister Overpack Cask (HNF-SD-TP-SARP-017)		ECN No. NA

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
D. W. Claussen	S7-55	X			
R. L. Clawson	H1-14	X			
W. S. Edwards	H1-15	X			
J. G. Field	H1-15	X			
L. M. Hay	H1-15	X			
C. R. Hoover	H1-15	X			
A. T. Kee	R3-86	X			
P. G. Leroy	R3-15	X			
R. W. Rasmussen	R3-86	X			
NS Information Center (DOE-HQ-5)		X			
Central Files	A3-88	X			