SAFETY ANALYSIS REPORT

OUTER PACKAGE–RAW MATERIAL SHIPPING CONTAINER

Docket No. 71-9387
Revision 4
November 2021

Industrial Nuclear Company, Inc.
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(510) 352-6767

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1.0 GENERAL INFORMATION

This chapter of the Outer Package, Raw Material Shipping Container (hereto referred to as the OP-RMSC) Safety Analysis Report presents a general introduction and description of the OP-RMSC package. A detailed description of the major packaging and payload components is presented in the following sections. Detailed drawings are presented in Appendix 1.3.1, *General Arrangement Drawings*.

1.1 Introduction

The OP-RMSC package is a transportation package designed to transport the Raw Material Shipping Container (RMSC) raw material special form capsules containing either iridium-192 (Ir-192) or selenium-75 (Se-75) radioactive material. The RMSC will carry up to four (4) special form capsules that contain the radioactive material. The design is optimized to provide maximum safety during both operations and transport conditions. Both the OP-RMSC and the RMSC consist of a welded cylindrical shell with bolted closure lids. Since the OP-RMSC package does not possess the primary gamma shielding, only the RMSC payload, which utilizes tungsten gamma shields, is relied upon for performing the shielding safety function. Therefore, no shielding credit is assigned to the OP-RMSC package itself.

Authorization is sought for shipment of raw material special form source capsules containing Ir-192 or Se-75 isotopes as a Type B(U)-96, special form material package per the definitions delineated in 10 CFR §71.4[1]. The transport index (TI) for the package, determined in accordance with the definition of 10 CFR §71.4, is determined for each shipment. The TI is based on the radiation dose rate at 1 meter (3.3 feet) from the external surface of the package (method for the transport index is defined in Chapter 7.0, *Package Operations*).

Industrial Nuclear Company has an NRC-approved quality assurance program (Docket Number 71-062), which satisfies the requirements of 10 CFR 71 Subpart H.

1.2 Package Description

1.2.1 Packaging

The OP-RMSC is a Type B(U)-96 package designed for transportation of only special form radioactive materials, which are contained in the RMSC payload. The maximum gross weight of the package is 650 pounds, and its primary components of construction are identified in Figure 1.2-1 and Figure 1.2-2. The radioactive payloads in the RMSC are raw material special form capsules, and are described in Section 1.2.2, *Contents of Packaging*. Primary shielding is provided by tungsten shields in the RMSC payload, which is illustrated in Figure 1.2-3. The tungsten shields are machined, solid sintered shields, and are illustrated in Figure 1.2-4. Detailed drawings of the OP-RMSC packaging are provided in Appendix 1.3.1, *General Arrangement Drawings*.

1.2.2 Contents of Packaging

The OP-RMSC is designed to transport the RMSC payload. The RMSC is designed to carry up to four (4) raw material special form capsules, each containing a maximum of 4,000 Ci (173 TBq) of

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-20 Edition.

Ir-192, or 4,000 Ci (173 TBq) of Se-75. For the total four raw material special form capsules, the maximum radioactive content for the OP-RMSC package is 16,000 Ci (592 TBq).

The maximum decay heat for the OP-RMSC package is 100 W (341 Btu/hr).

1.2.3 Special Requirements for Plutonium

This section does not apply, since plutonium is not transported in the OP-RMSC package.

1.2.4 Operational Features

There are no operationally complex features of the OP-RMSC package. The radioactive material contents (described in Section 1.2.2, *Contents of Packaging*) are confined in special form capsules that are within the RMSC cavity, which is surrounded by tungsten gamma shields. The gamma shields are contained in a welded pipe with a bolted closure lid, as shown in Figure 1.2-4. The RMSC payload is then placed in the OP-RMSC payload cavity and a separate inner closure lid is installed and secured utilizing eight (8) 1/2-13 UNC hex bolts, as shown in Figure 1.2-2. A vented outer closure lid is then secured to the OP-RMSC body by eight (8) 1/2-13 UNC hex bolts. The OP-RMSC package outer closure lid is fitted with a 3/8-16 UNC threaded hole to attach a standard lifting device to facilitate handling. Sequential steps of operation are provided in Chapter 7.0, *Package Operations*.

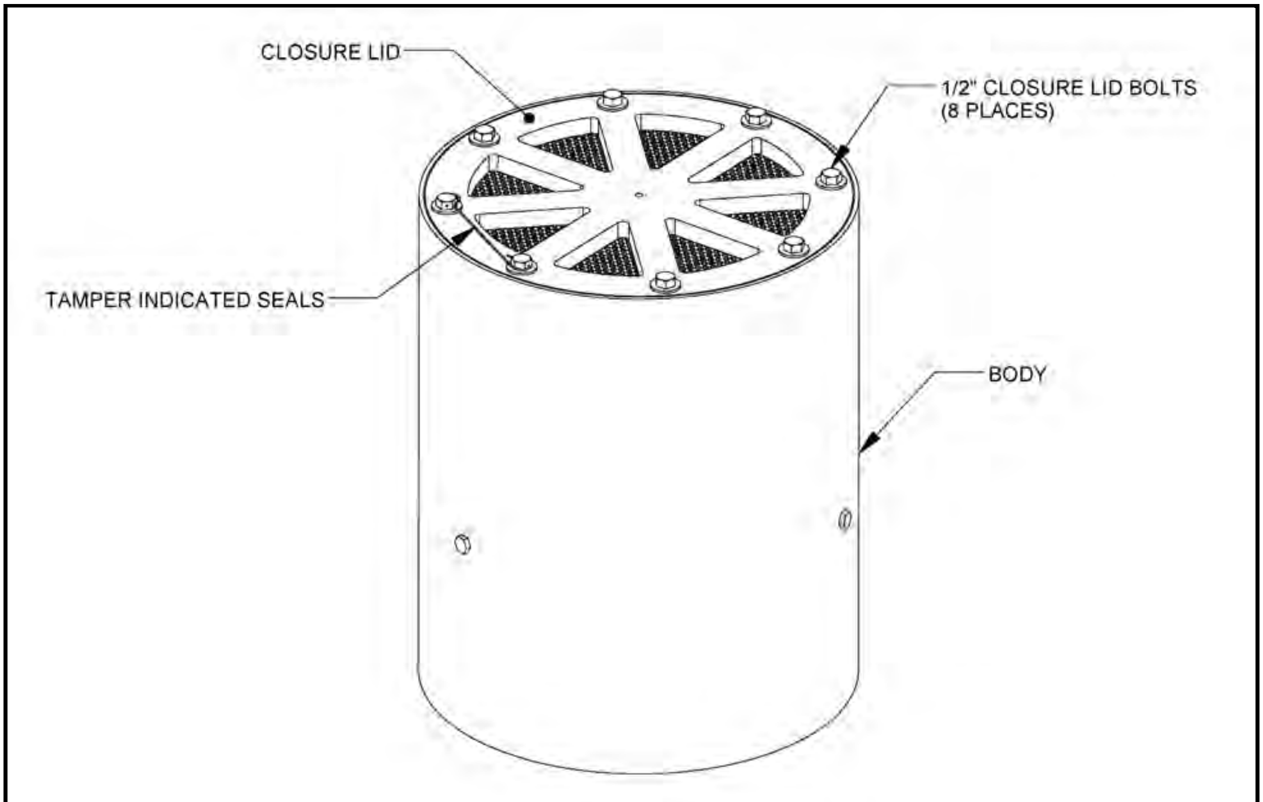


Figure 1.2-1 – Isometric View of the OP-RMSC Packaging

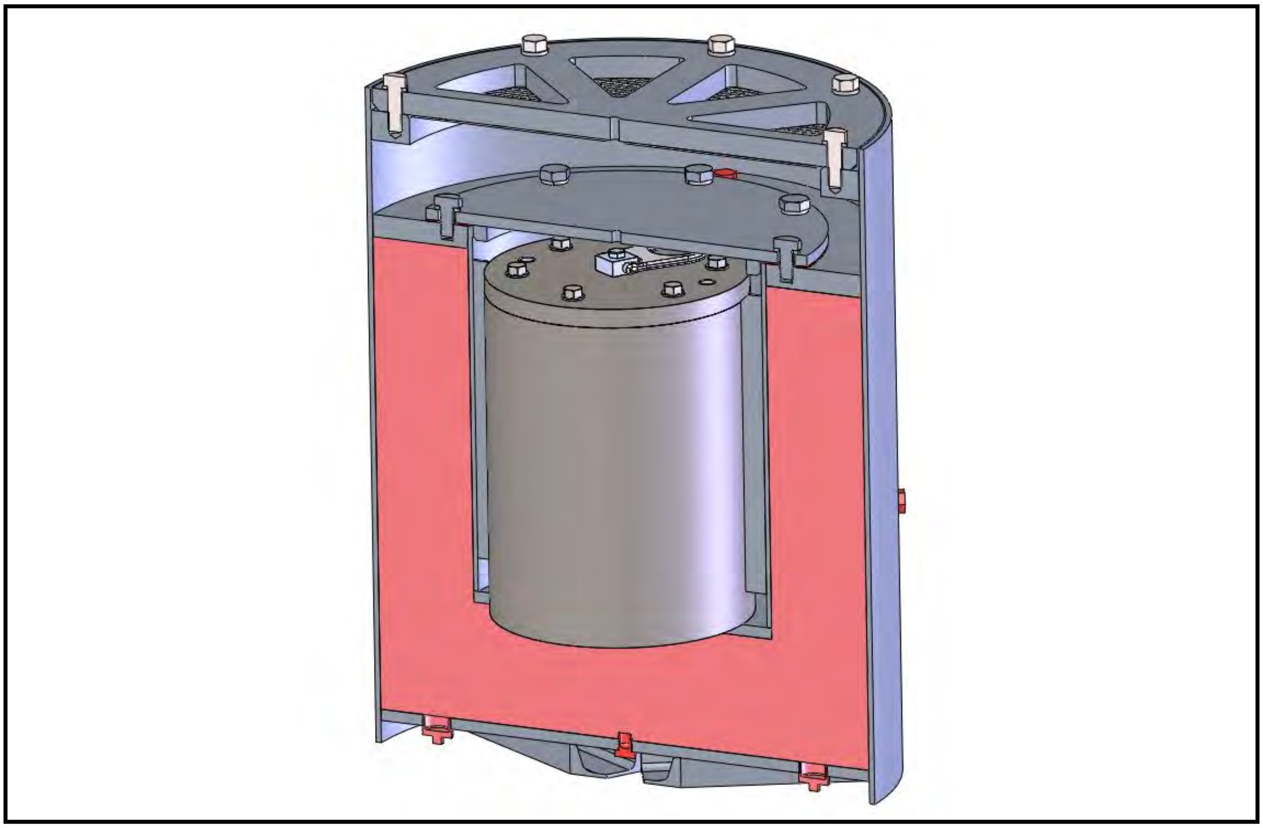


Figure 1.2-2 – Sectional View of the OP-RMSC Packaging

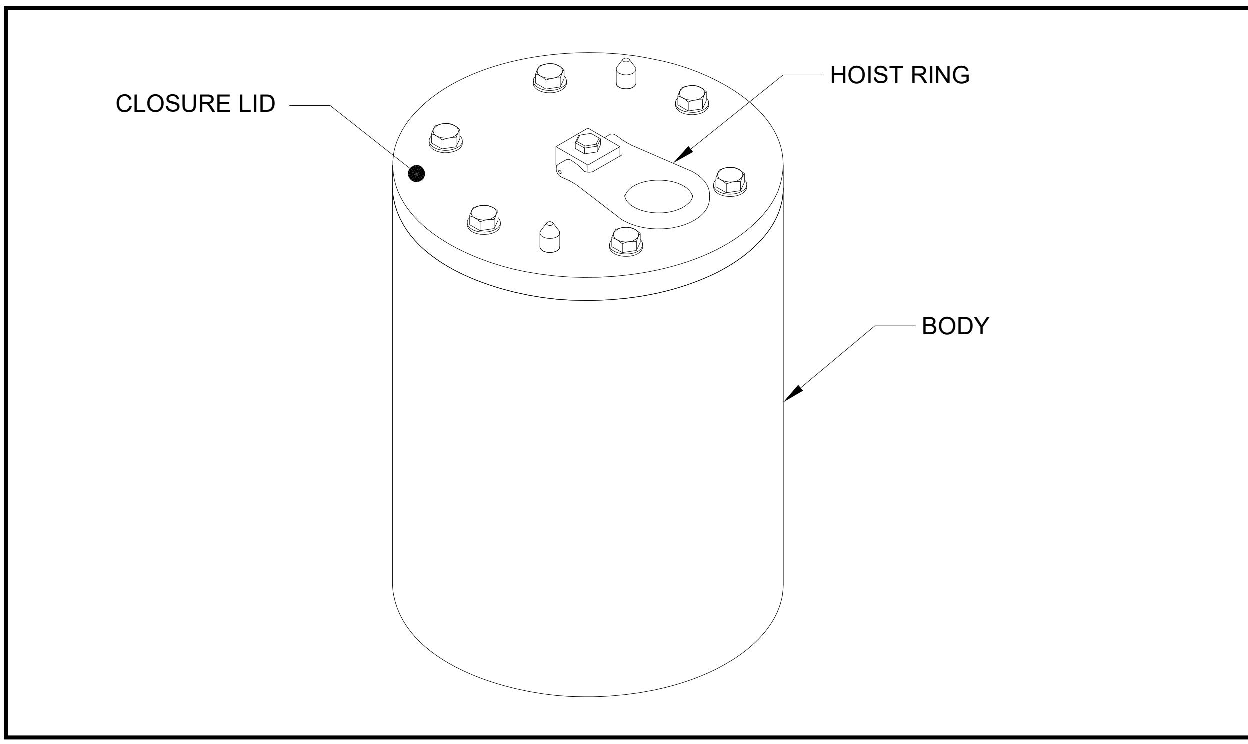


Figure 1.2-3 – Isometric View of the RMSC Payload

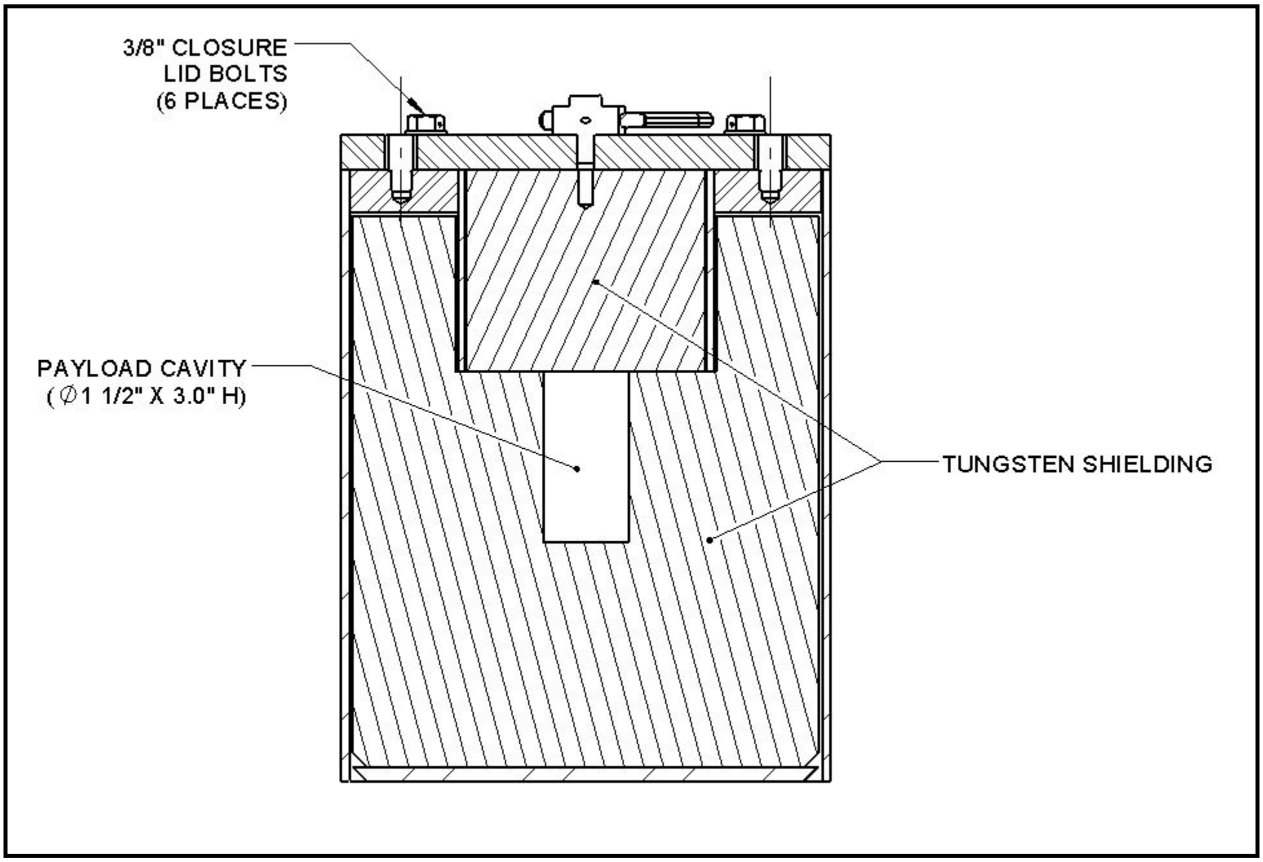


Figure 1.2-4 – Sectional View of the RMSC Payload

1.3 Appendices

1.3.1 General Arrangement Drawings

The following Industrial Nuclear Company drawings are enclosed:

Drawing No. and Revision	Title
OP-RMSC-SAR-TA, Rev. 1	Outer Package, Raw Material Source Container, SAR Drawing
RMSC-SAR-TA, Rev. 2	Inner Package, Raw Material Source Container, SAR Drawing
RMSC-SPFH-SAR, Rev. 0	RMSC Special Form Capsule Holder, SAR Drawing

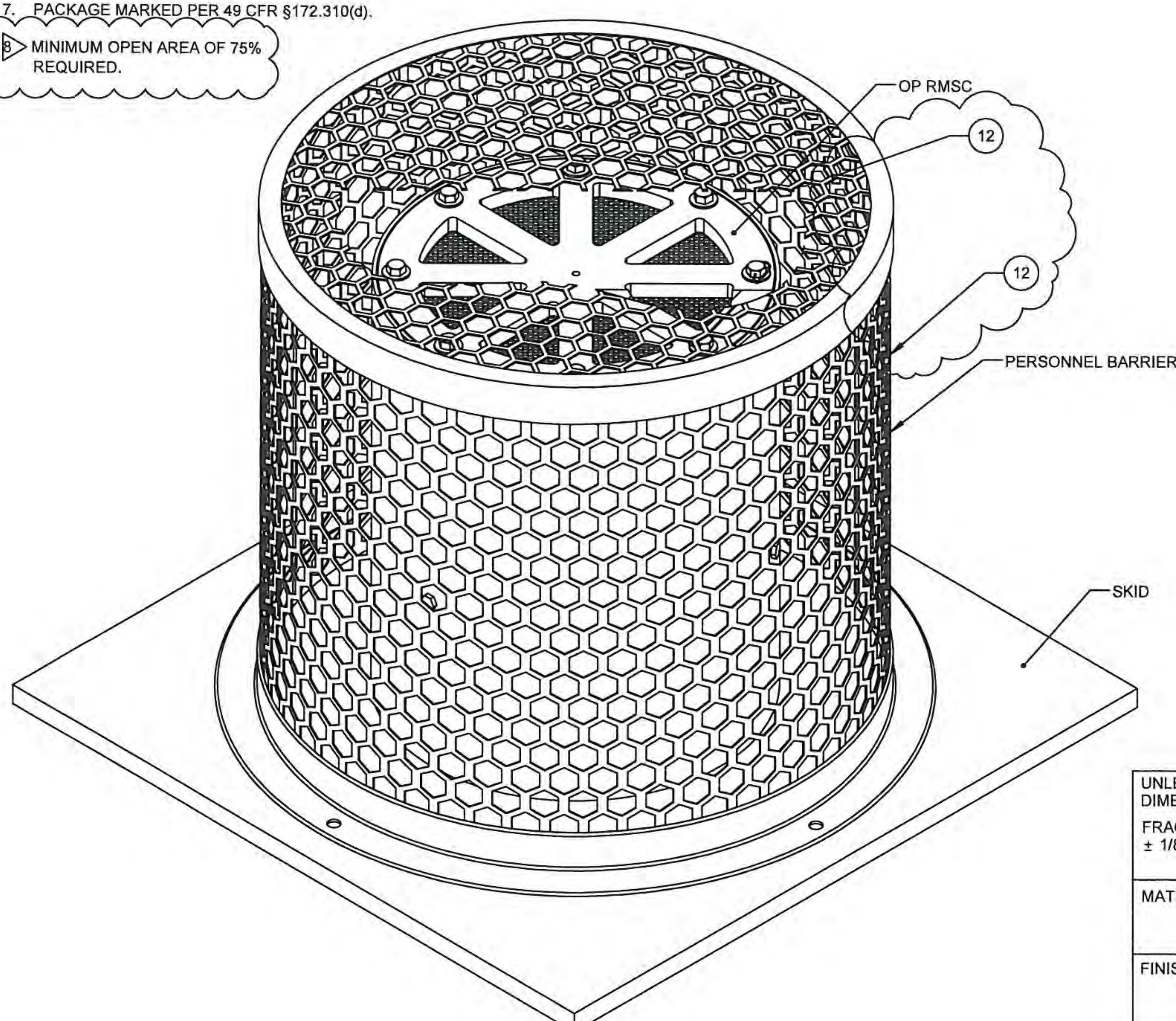
DWG NO.	SH	REV
OP-RMSC-SAR-TA	1	1

REVISIONS

REV	DESCRIPTION	DATE	APPROVED
0	INITIAL RELEASE	09/15/20	M. MARES
1	REVISED	06/16/2021	[signature]

NOTES:

1. INTERPRET DRAWING PER ASME Y14.5M. INTERPRET WELDS PER ASME/AWS A2.4.
2. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH ASME B&PV CODE, SECTION IX.
3. ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH AWS D1.6
4. MAXIMUM WEIGHT OF PACKAGE, INCLUDING CONTENTS: 650 LB.
5. TIGHTEN TO 80± 5 LB-FT TORQUE.
6. TAMPER INDICATING SEALS SHALL BE INSTALLED ON ONE PAIR OF LID BOLTS.
7. PACKAGE MARKED PER 49 CFR §172.310(d).
8. MINIMUM OPEN AREA OF 75% REQUIRED.



Q/C	QTY REQD	ITEM NO.	NOMENCLATURE OR DESCRIPTION	SPECIFICATION
NITS	1	21	SAFETY WIRE, Ø.064 (14AWG)	ASTM A580, TYPE 304
B	16	20	WASHER, FLAT, 1/2	300 SERIES STAINLESS STEEL
B	8	19	HEX BOLT, 1/2-13 UNC-2A X 1.5	ASTM A320, TYPE L43 OR L7
B	8	18	HEX BOLT, 1/2-13 UNC -2A X 1.0	ASTM A320, TYPE L43 OR L7
NITS	1	17	SILICONE, 1/16 THK	
NITS	2	16	CAPLUG, 3/4 NPT, HI-DENSITY POLYETHYLENE	CAPLUG MIL-C-52078
NITS	7	15	CAPLUG, 1/4 NPT HI-DENSITY POLYETHYLENE	CAPLUG MIL-C-52078
NITS	1	14	ADHESIVE, SILICONE OR EQUIVALENT	
NITS	AR	13	RIGID POLYURETHANE FOAM, 20 pcf	
C (8)	1	12	SHEET, EXPANDED METAL, FLATTENED	STAINLESS STEEL, TYPE 304
B	3	11	CHANNEL, 2 X 1 X 1/8 X 7.5	ASTM A276 OR A479, TYPE 304
B	1	10	PIPE, 18-INCH SCH 10S (3/16 WALL) X 22.0	ASTM A312, TYPE 304
B	1	9	PIPE, 10-INCH SCH 10S (.165 WALL) X 12.25	ASTM A312, TYPE 304
C	4	8	BAR, RADIAL SPACER, .25 THK X 0.8 X 10.0	ASTM A240, TYPE 304
B	1	7	PLATE, 1 X Ø17.6 OD X Ø14.8 ID	ASTM A240, TYPE 304
B	1	6	PLATE, 3/4 X Ø17.5	ASTM A240, TYPE 304
B	1	5	PLATE, 1/2 X Ø10.4 OD X Ø9.4 ID	ASTM A240, TYPE 304
B	1	4	PLATE, 3/8 X Ø17.8	ASTM A240, TYPE 304
B	1	3	PLATE, 3/8 X Ø10.8	ASTM A240, TYPE 304
B	1	2	PLATE, 3/8 X Ø13.8	ASTM A240, TYPE 304
B	1	1	PLATE, 3/4 X Ø17.5 OD X Ø10.8 ID	ASTM A240, TYPE 304

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE INCHES
FRACTIONS ± 1/8 | DECIMALS .X ± .2, .XX ± .13 | ANGLES ± 1°

MATERIAL: VARIOUS

FINISH:

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS		DATE
DRAWN	T. MARTIN	06/14/2021
QA REVIEWED	[signature]	6/15/2021
ENG APPROVED	[signature]	06/16/2021

INDUSTRIAL NUCLEAR CO., INC

PARENT COMPONENT: OP-RMSC

TITLE: OUTER PACKAGE RAW MATERIAL SOURCE CONTAINER SAR DRAWING

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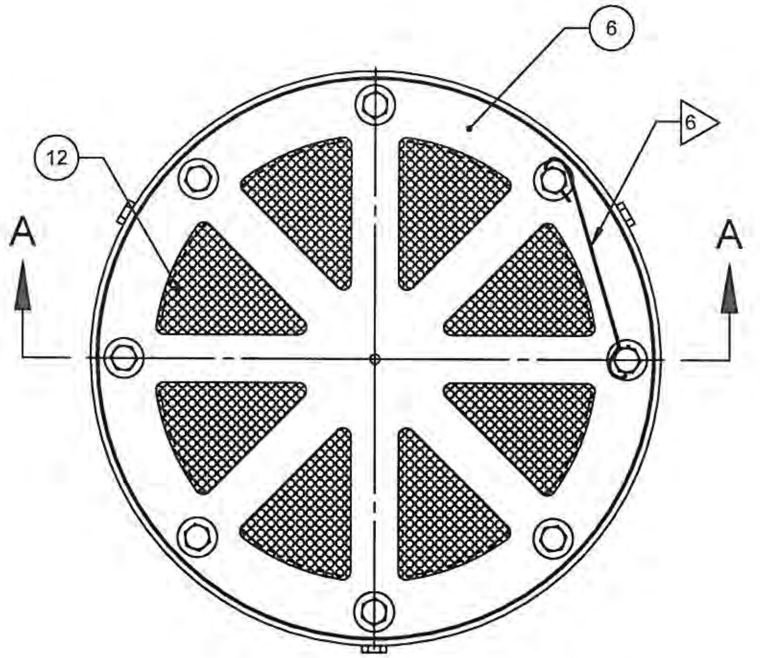

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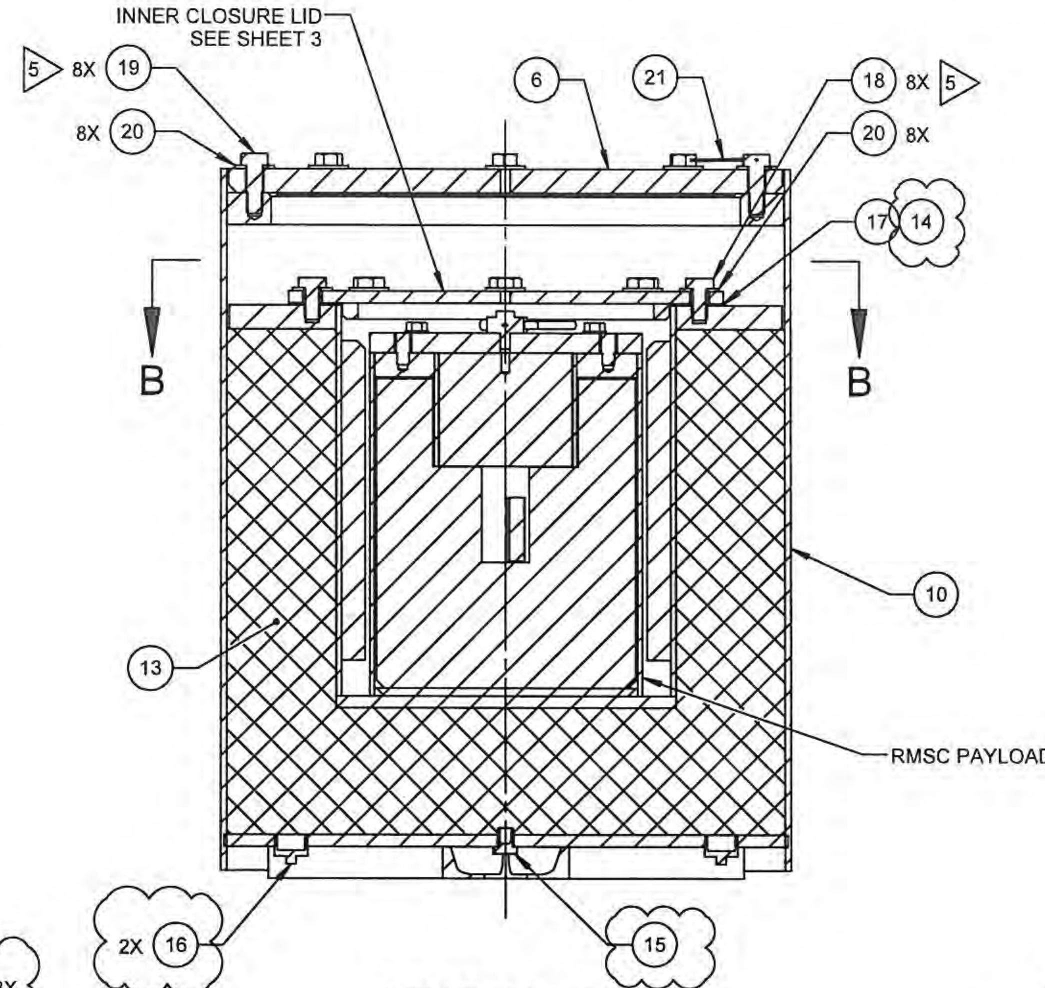

SECTION A-A
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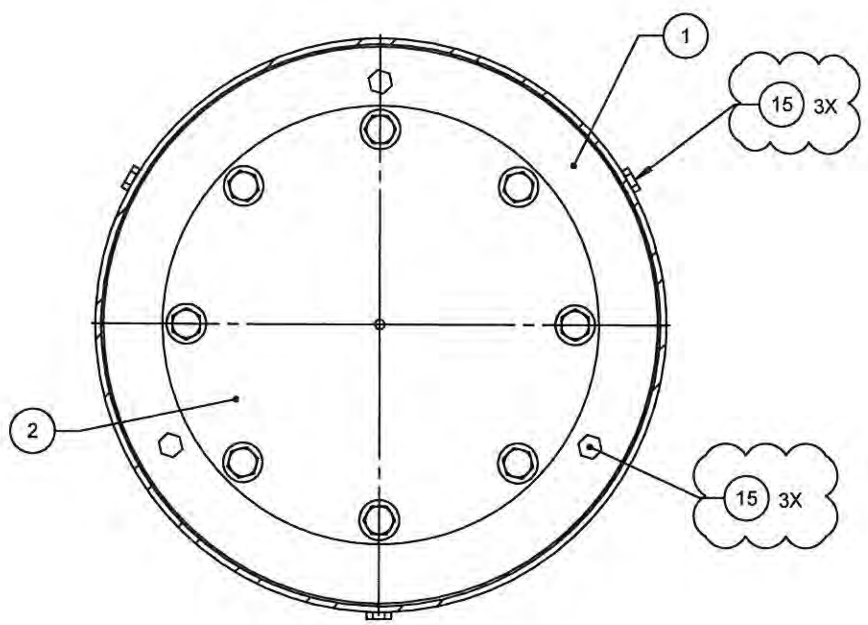

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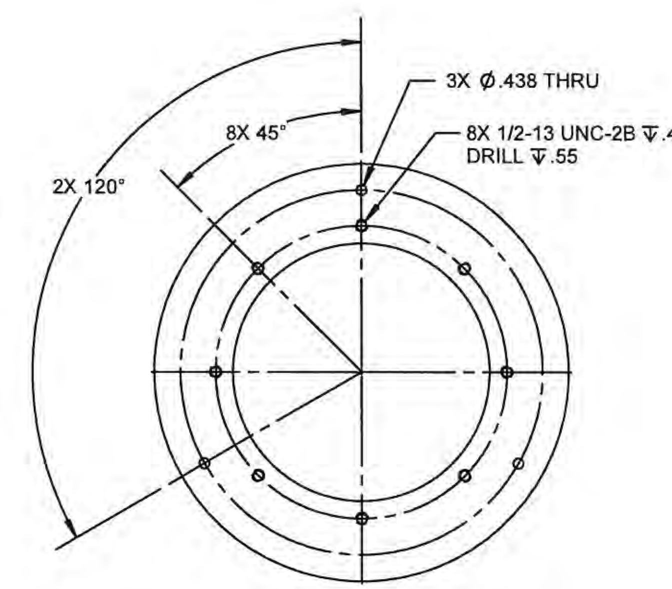

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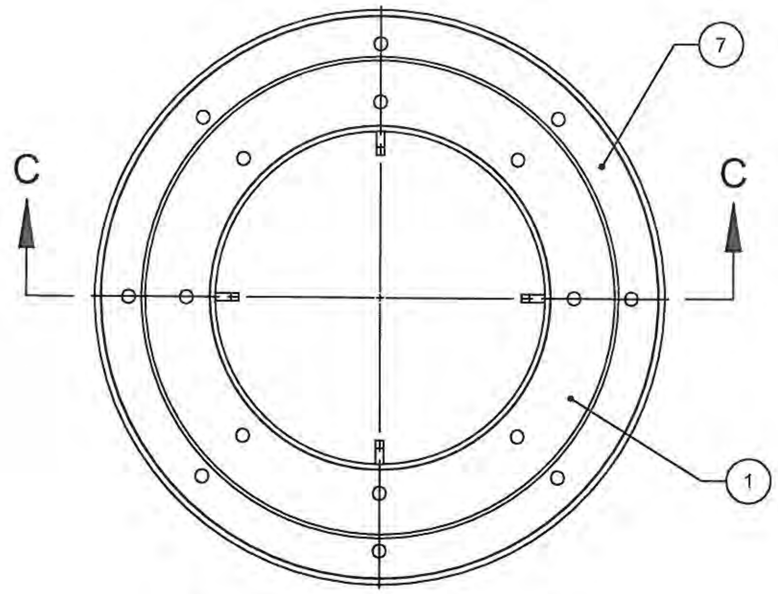

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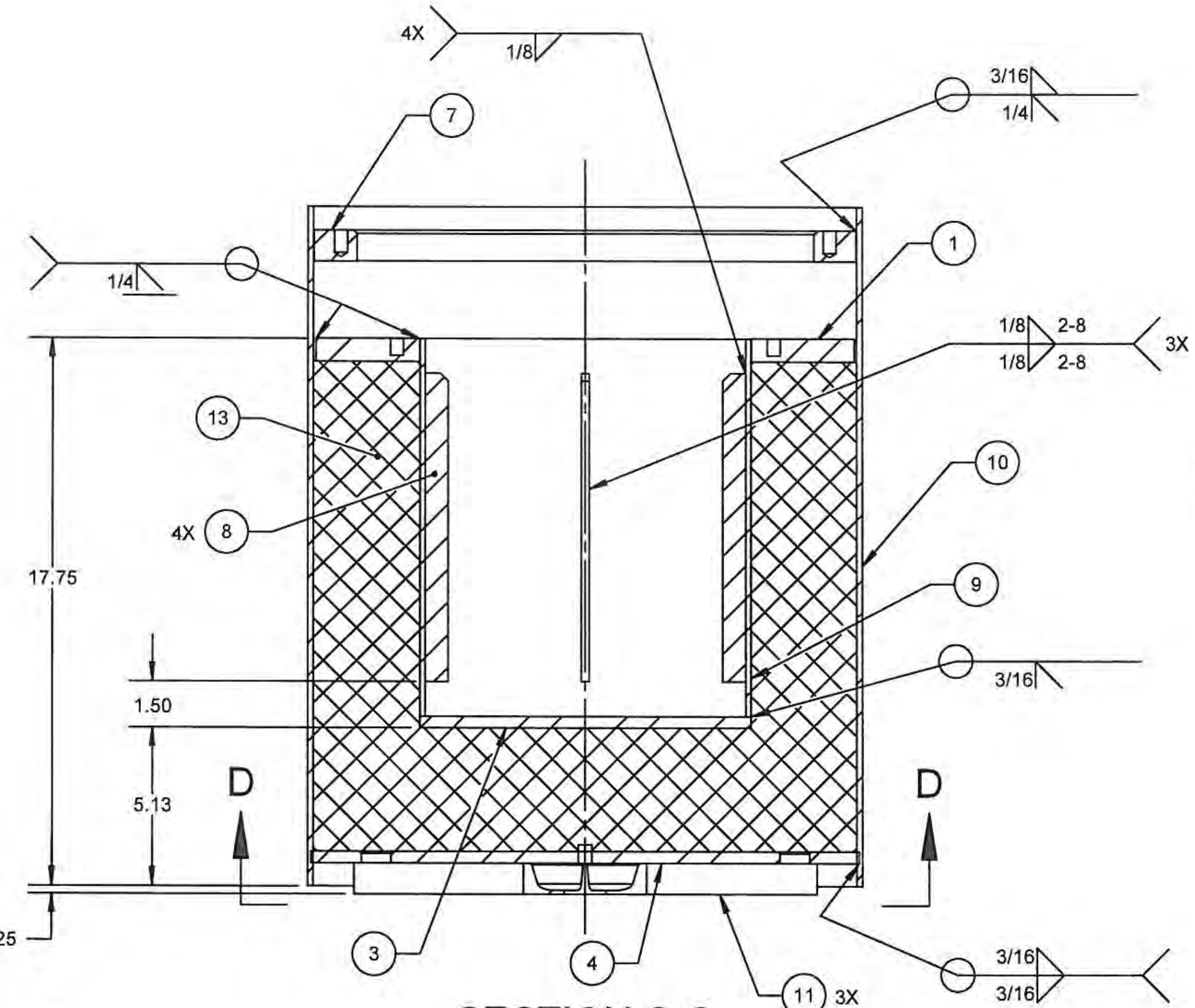

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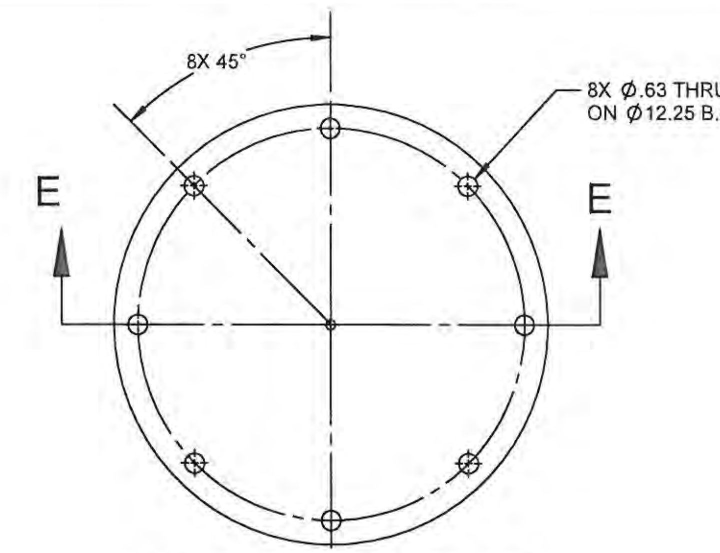

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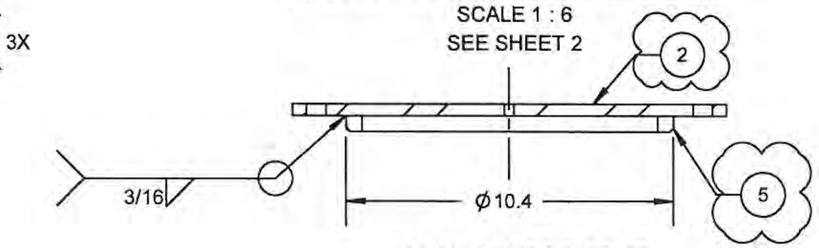

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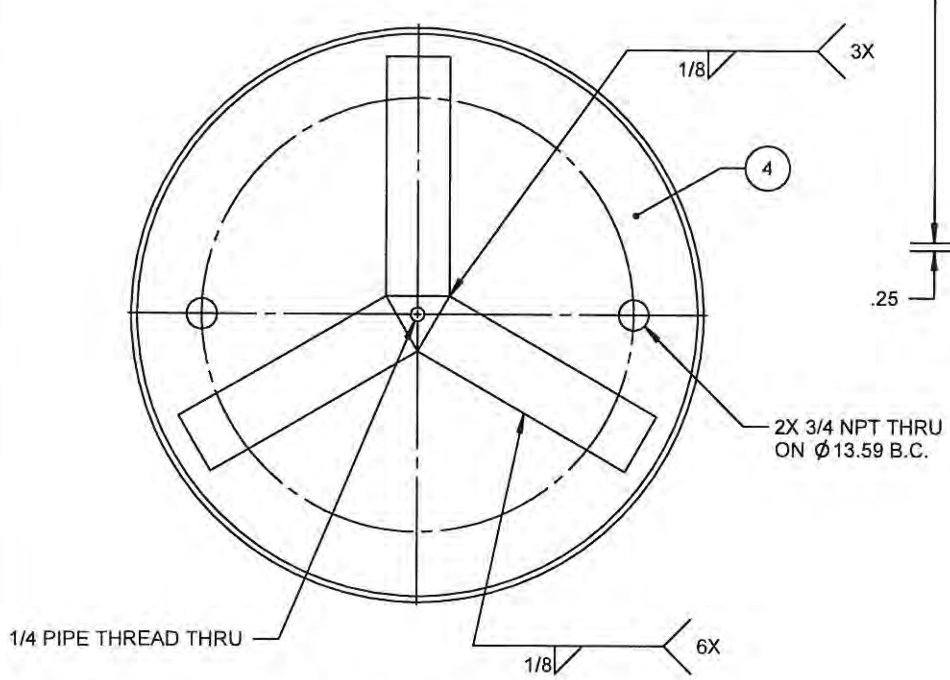

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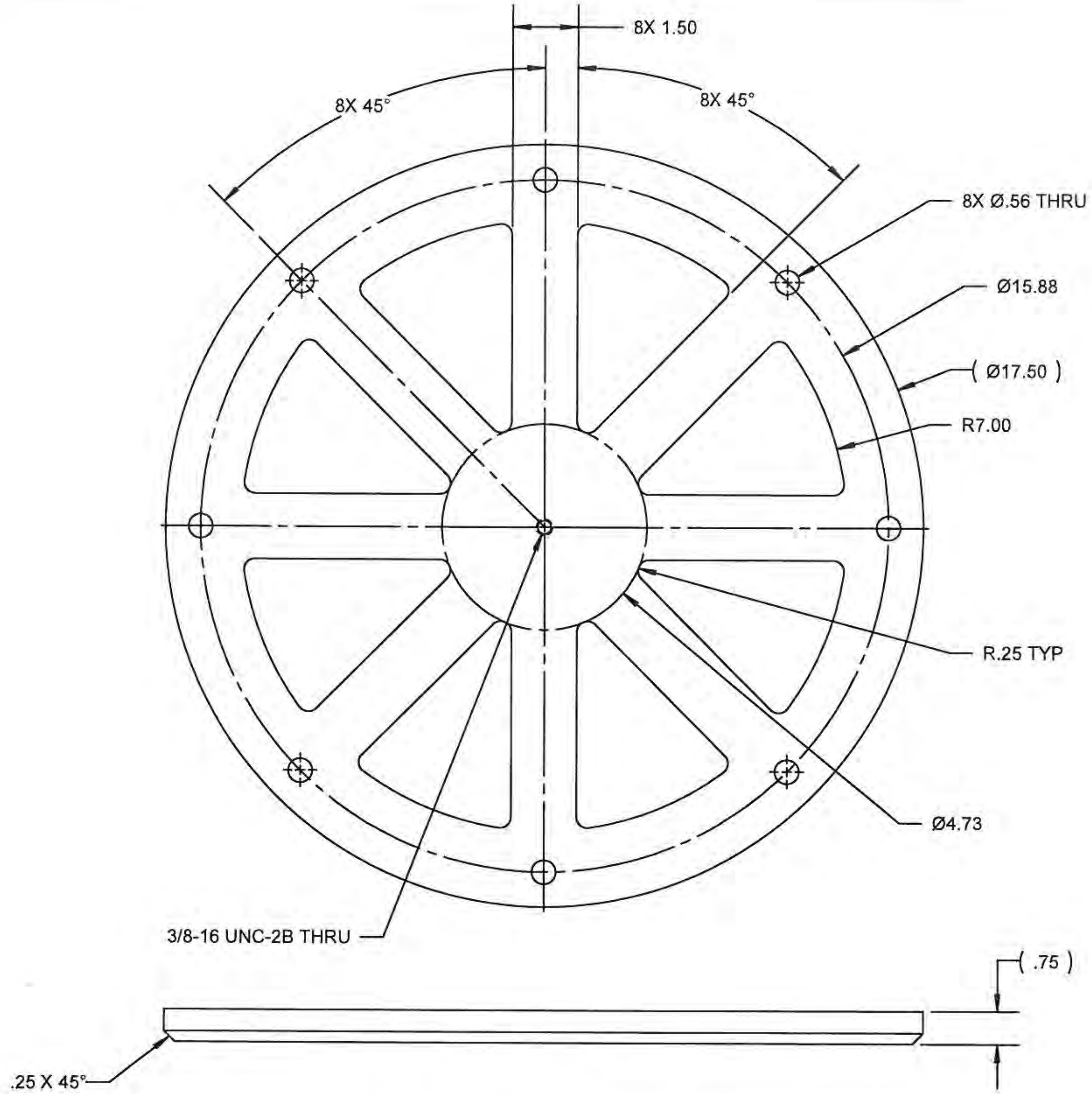

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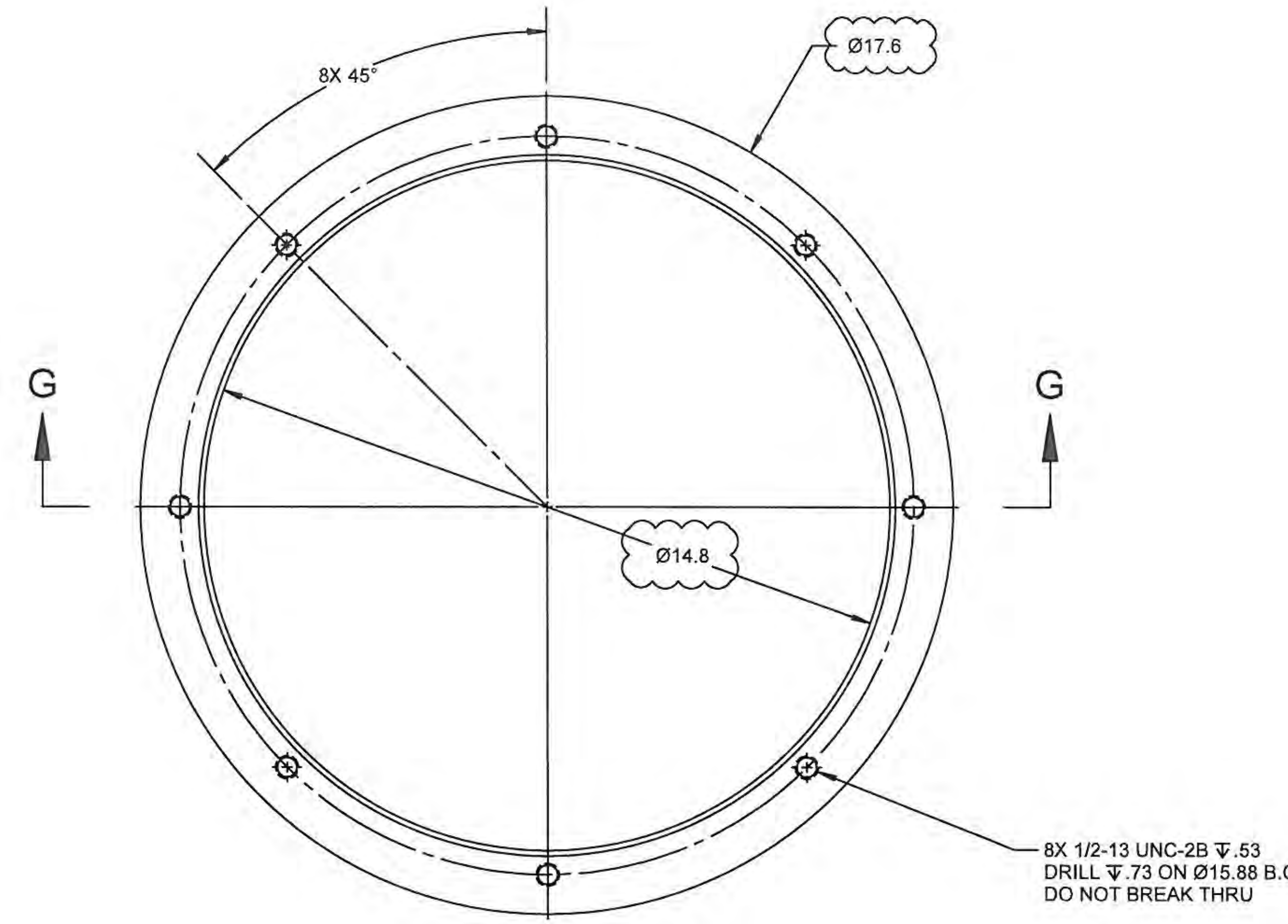

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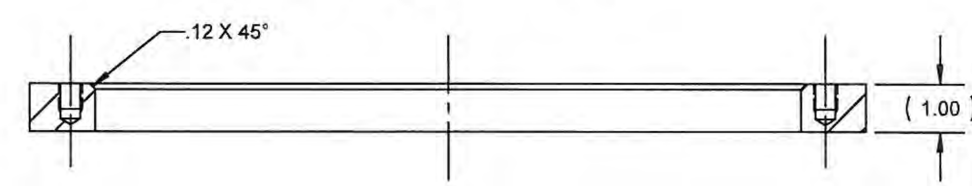


SECTION G-G

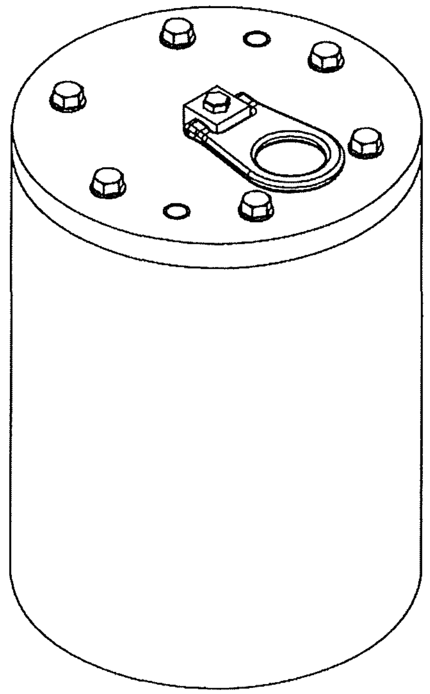
DWG NO.	SH	REV
RMSC-SAR-TA	1	2

NOTES:

1. INTERPRET DRAWING PER ASME Y14.5M.
   INTERPRET WELDS PER ASME/AWS A2.4.
2. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH ASME B&PV CODE, SECTION IX.
3. ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH AWS D1.6
4. TUNGSTEN GAMMA SHIELDS SHALL BE EXAMINED PRIOR TO USE PER SECTION 8.1.6 OF THE REPORT "INC OP-RMSC SAFETY ANALYSIS REPORT"
5. TIGHTEN TO 40± 5 LB-FT TORQUE.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED
0	INITIAL RELEASE	09/15/20	M. MARES
1	REVISED	6/16/2021	M. MARES
2	REVISED TOLERANCES	9/24/21	[signature]



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B	6	10	WASHER, FLAT, 3/8	300 SERIES STAINLESS STEEL
B	6	9	HEX BOLT, 3/8-16 UNC-2A X .88	ASTM A320, TYPE L43 OR L7
B	1	8	TUNGSTEN HEAVY ALLOY, DENSIMET® 185	ASTM B777 CLASS 4
B	1	7	TUNGSTEN CAVITY SHIELD, DENSIMET® 176	ASTM B777 CLASS 2
C	2	6	LID GUIDE PIN	ASTM A276/A479, TYPE 410
B	1	5	PIPE, 4" SCH 10S X 3.6 LG	ASTM A312, TYPE 304
B	1	4	PIPE, 8" SCH 10S X 10.8 LG	ASTM A312, TYPE 304
B	1	3	LID TOP PLATE, 5/8 THK X ∅8.63	ASTM A240, TYPE 304
B	1	2	PLATE, 3/4 THK X 8.3 OD	ASTM A240, TYPE 304
B	1	1	PLATE, 1/4 THK X ∅8.2	ASTM A240, TYPE 304

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE INCHES
FRACTIONS ± 1/8 — DECIMALS .X ± .2, .XX ± .13 — ANGLES ± 1°

MATERIAL: VARIOUS

FINISH:

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN T. MARTIN	09/20/2021
QA REVIEWED M. [signature]	9/20/2021
ENG APPROVED [signature]	9/24/21

INDUSTRIAL NUCLEAR CO., INC

PARENT COMPONENT: OP-RMSC

TITLE: INNER PACKAGE RAW MATERIAL SOURCE CONTAINER SAR DRAWING

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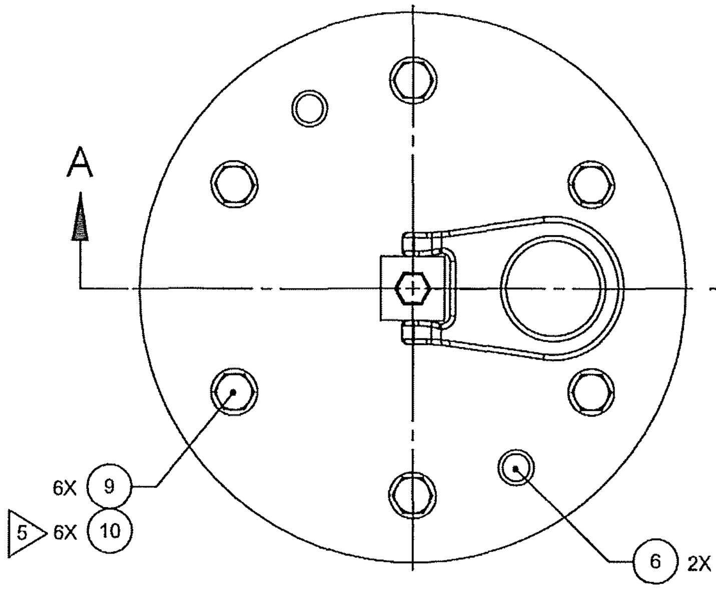

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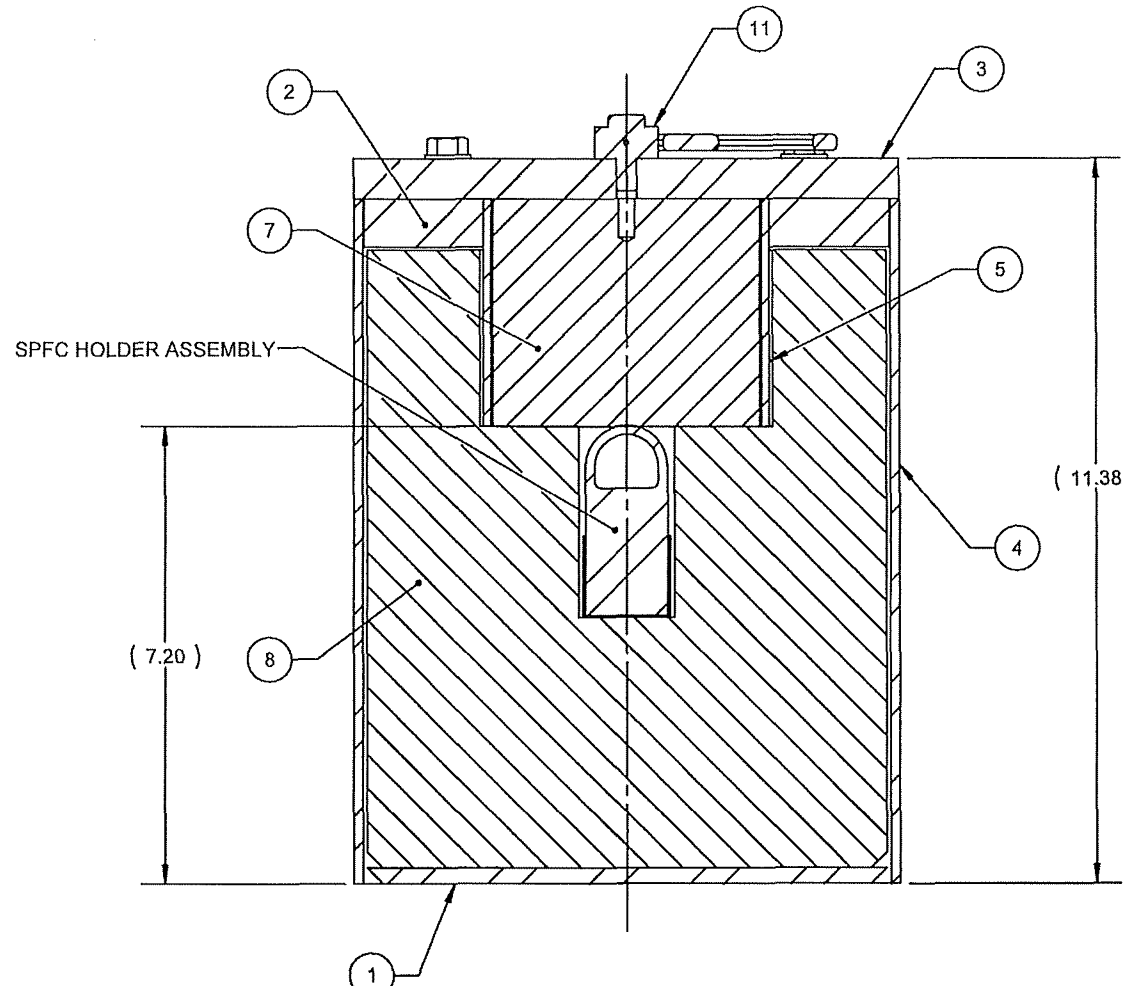

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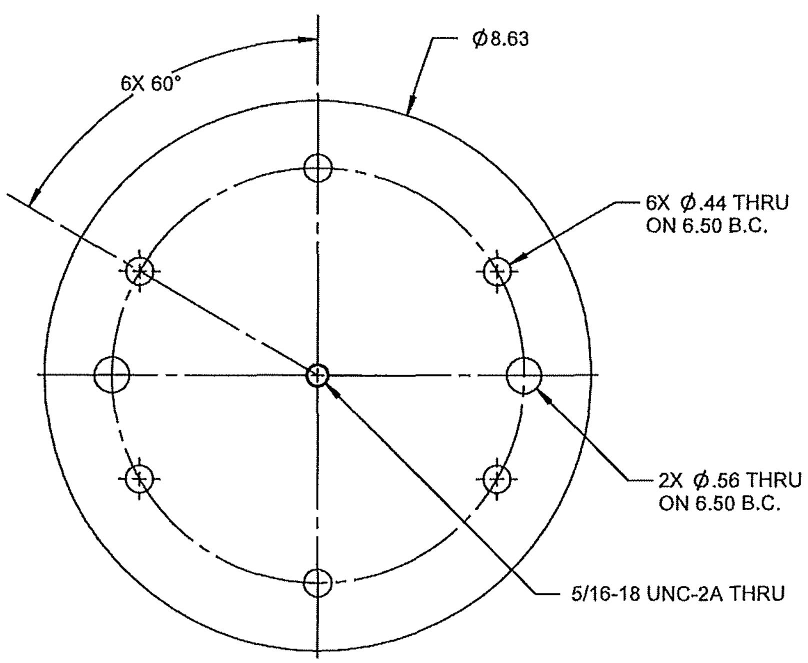

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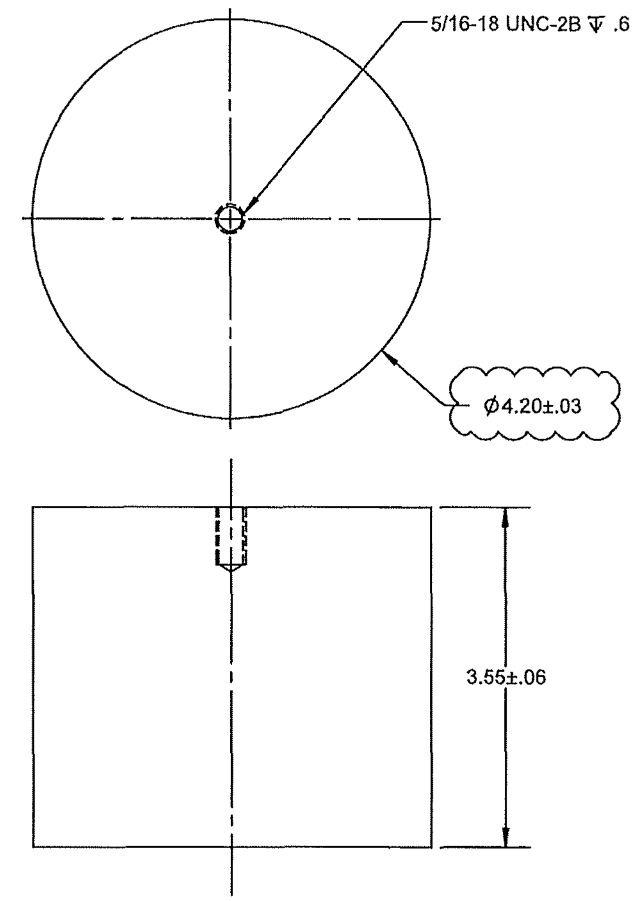

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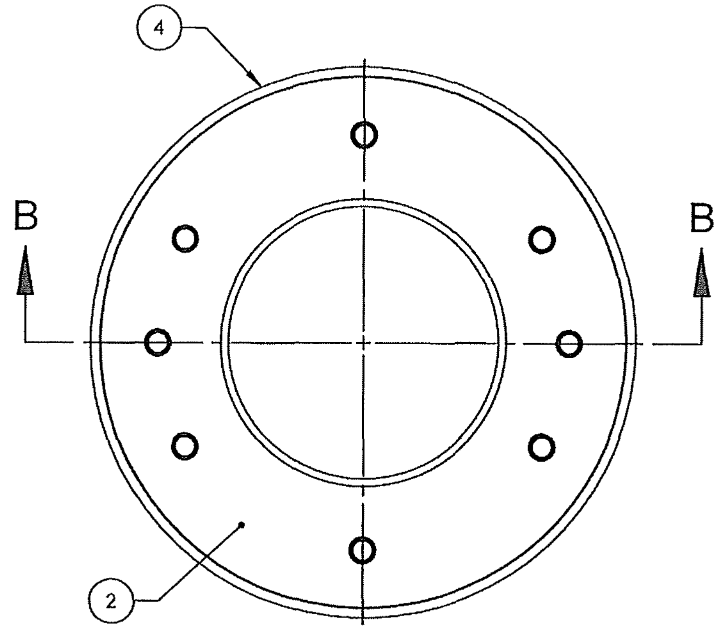

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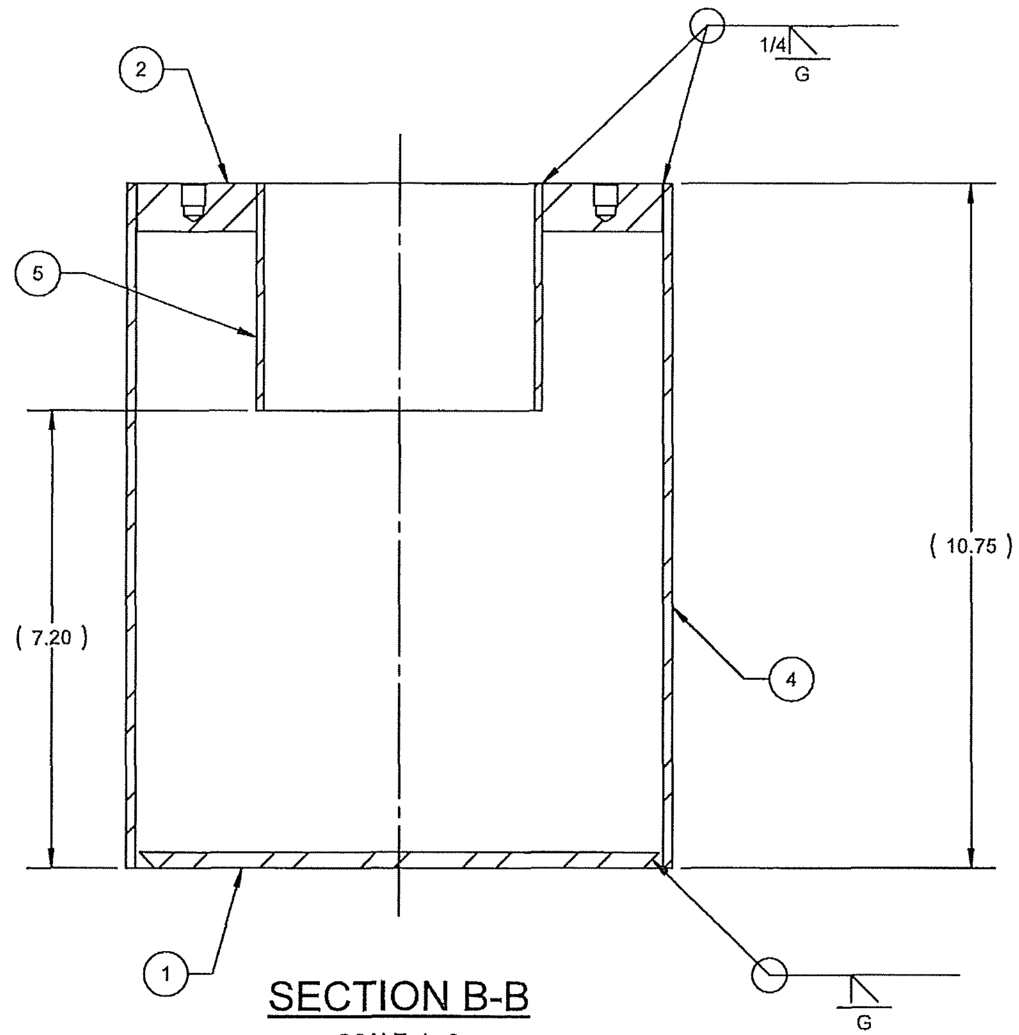

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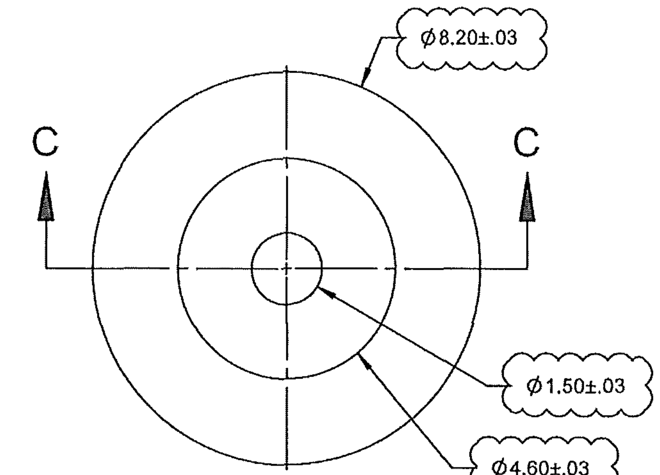
TUNGSTEN SHIELD REMOVED FOR CLARITY



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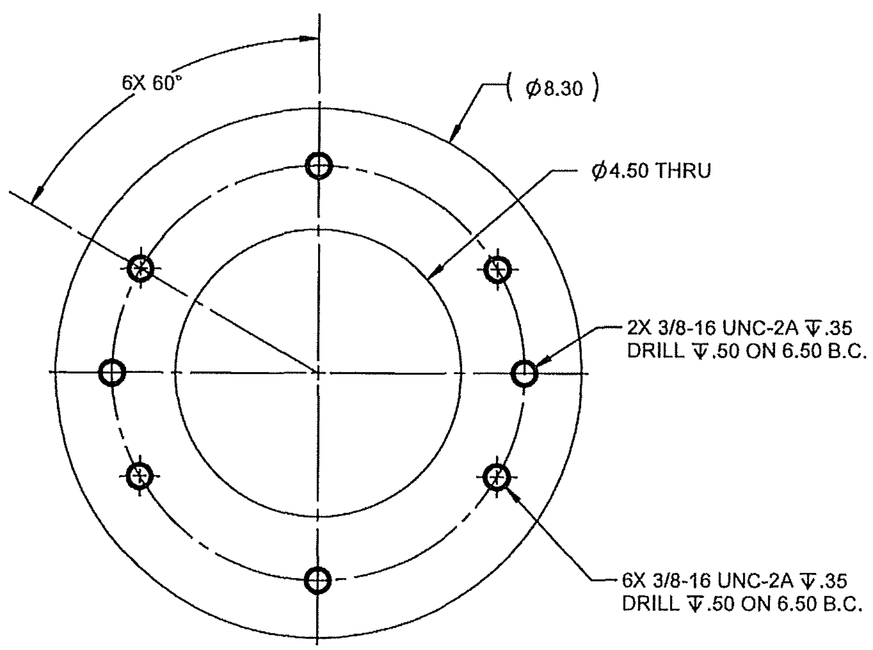

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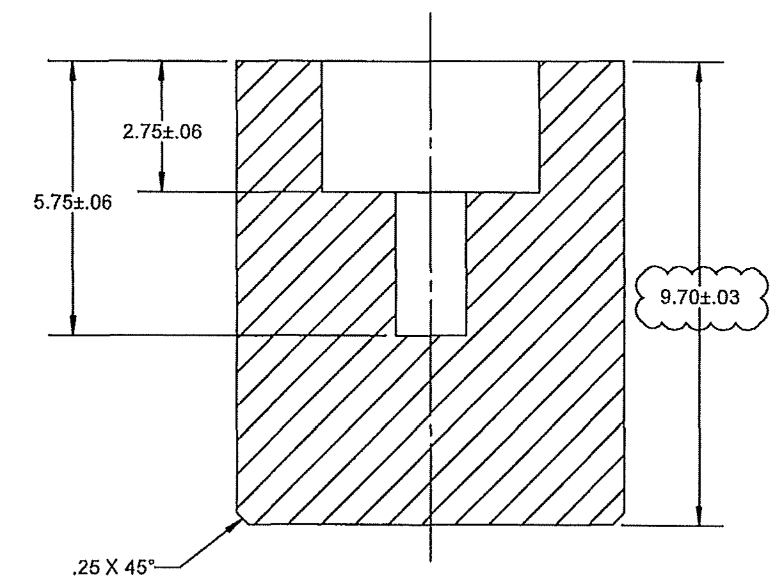

SECTION C-C

SCALE 1 : 4

DWG NO.	SH	REV
RMSC-SPFH-SAR	1	0

NOTES:

1. INTERPRET DRAWING PER ASME Y14.5M.

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
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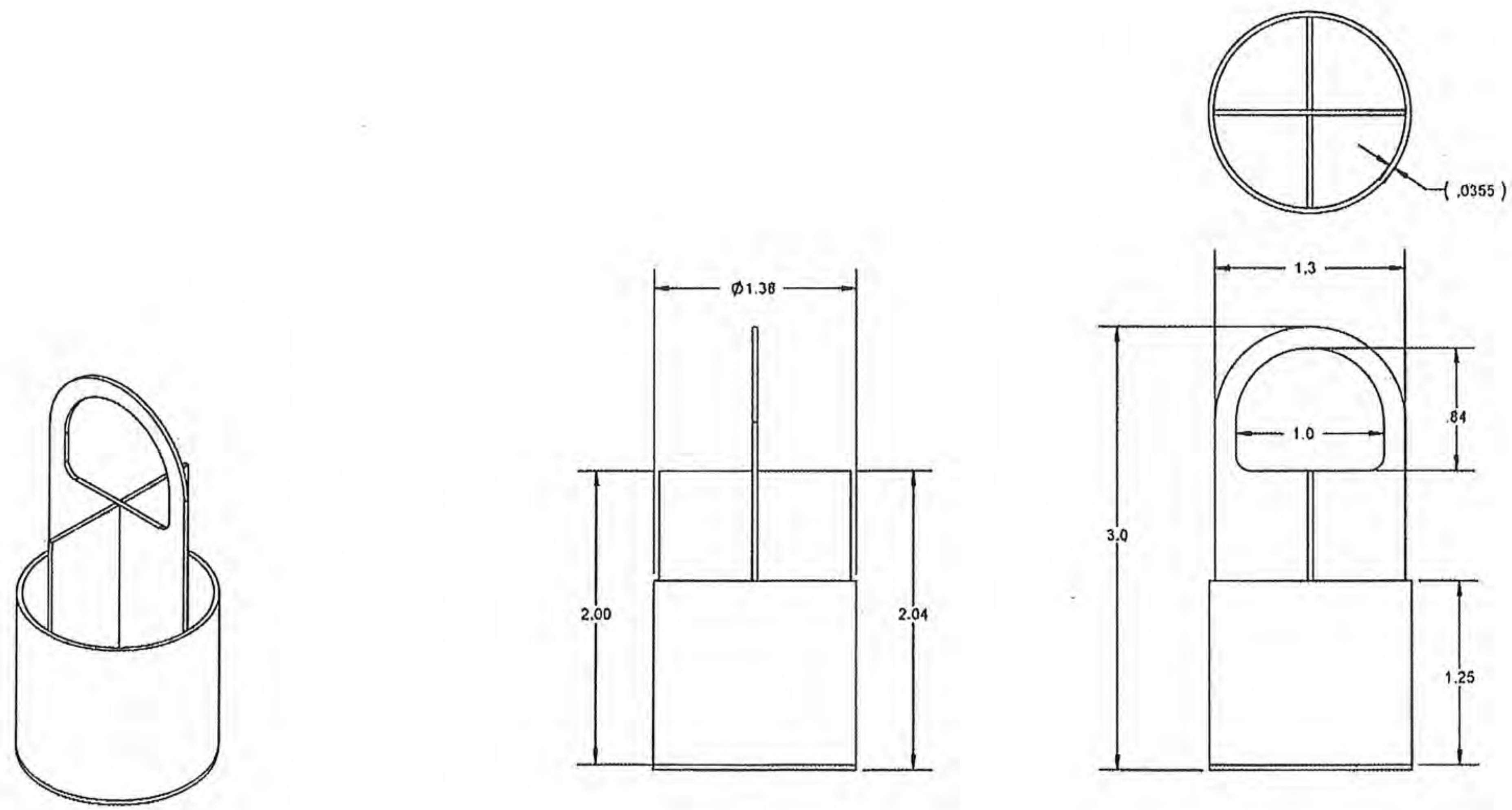

NITS	1	1		SHEET, 20 GA (.0355) THK	ASTM A240, TYPE 304
Q/C	QTY REQD	ITEM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE INCHES FRACTIONS ± 1/8 DECIMALS .X ± .1 .XX ± .03 ANGLES ± 1°	CONTRACT NO		INDUSTRIAL NUCLEAR CO., INC
	APPROVALS	DATE	PARENT COMPONENT RMSC
MATERIAL	DRAWN T. MARTIN	07/28/2021	TITLE RMSC SPECIAL FORM CAPSULE HOLDER SAR DRAWING
FINISH	QA REVIEWED [signature]	7/29/21	SIZE B · FSCM NO. - · DWG NO. RMSC-SPFH-SAR · REV 0
	ENG APPROVED [signature]	7/29/21	
DO NOT SCALE DRAWING			SCALE 1:1 · SHEET 1 OF 1

2.0 STRUCTURAL EVALUATION

This chapter presents the structural design criteria, weights, mechanical properties of material, and structural evaluations that demonstrate that the Outer Package, Raw Material Shipping Container (OP-RMSC) package meets all applicable structural criteria for transportation as defined in 10 CFR 71[2].

2.1 Description of Structural Design

The primary evaluation of the OP-RMSC package is performed with various full-scale tests. The results of the tests are provided in the following sections. Analyses of non-tested structural aspects are also provided.

The OP-RMSC package consists of four major fabricated components: 1) a welded, outer stainless steel pipe assembly that is welded to an inner stainless steel pipe, which forms the payload cavity, 2) a bolted vented closure lid that is secured to the outer pipe, 3) a bolted inner closure lid that covers the payload cavity, and 4) polyurethane foam between the inner and outer pipes.

The RMSC payload consists of four major fabricated components: 1) a welded stainless steel pipe assembly that is welded to a smaller pipe assembly, which forms the payload cavity, 2) a tungsten shield that covers and shields the payload cavity, 3) a bolted closure lid that covers the cavity tungsten shield, and 4) a fixed tungsten shield between the outer pipe and inner pipe assemblies.

2.1.1 Discussion

The OP-RMSC is a welded and bolted assembly that consists of an outer ∅18-inch × 22¾ inch high, Schedule 10S stainless steel pipe and an inner ∅10-inch × 12¼ inch high, Schedule 10S stainless steel pipe. The inner pipe forms the payload cavity. The annular space between the inner and outer pipes is filled with approximately 32 pounds of rigid polyurethane foam that provides some impact and thermal protection of the payload, which is a RMSC. A 3/8-inch thick, 13¾ inch diameter stainless steel plate, which is secured with eight (8) 1/2-inch hex bolts, encloses the payload cavity. Above the inner lid, a 3/4-inch thick, 17½ inch diameter stainless steel closure lid is secured to the outer 18-inch diameter stainless steel pipe body with eight (8) 1/2-13 UNC hex bolts. The outer lid is slotted to dissipate decay heat from the payload cavity via convective heat transfer. Within the payload cavity, there are four (4) 3/8-inch thick stainless steel vertical bars welded to the inner cavity wall. The bars are circumferentially located at 90-degrees to minimize the clearance between the RMSC payload and the cavity wall. The maximum tare and gross weight of the OP-RMSC package is 270 pounds (122 kg) and 650 pounds (295 kg), respectively, and is illustrated in Figure 2.1-1 and Figure 2.1-2.

The RMSC is designed to transport up 16,000 Ci (592 TBq) of Ir-192, or Se-75 isotopes in raw material special form capsules. The RMSC payload consists of a welded outer 8-inch diameter Schedule 10S stainless steel pipe that surrounds a tungsten shield that contains a 1½ inch diameter × 3 inch high payload cavity. Above the payload cavity is a 4.2-inch diameter × 3.6 inch high tungsten gamma shield that is placed over the cavity. The closure lid is then placed over the tungsten shield and secured to the body by six (6) hex head bolts. The RMSC payload weighs approximately 380 pounds (172 kg), and is illustrated in Figure 2.1-3.

[2] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-20 Edition.

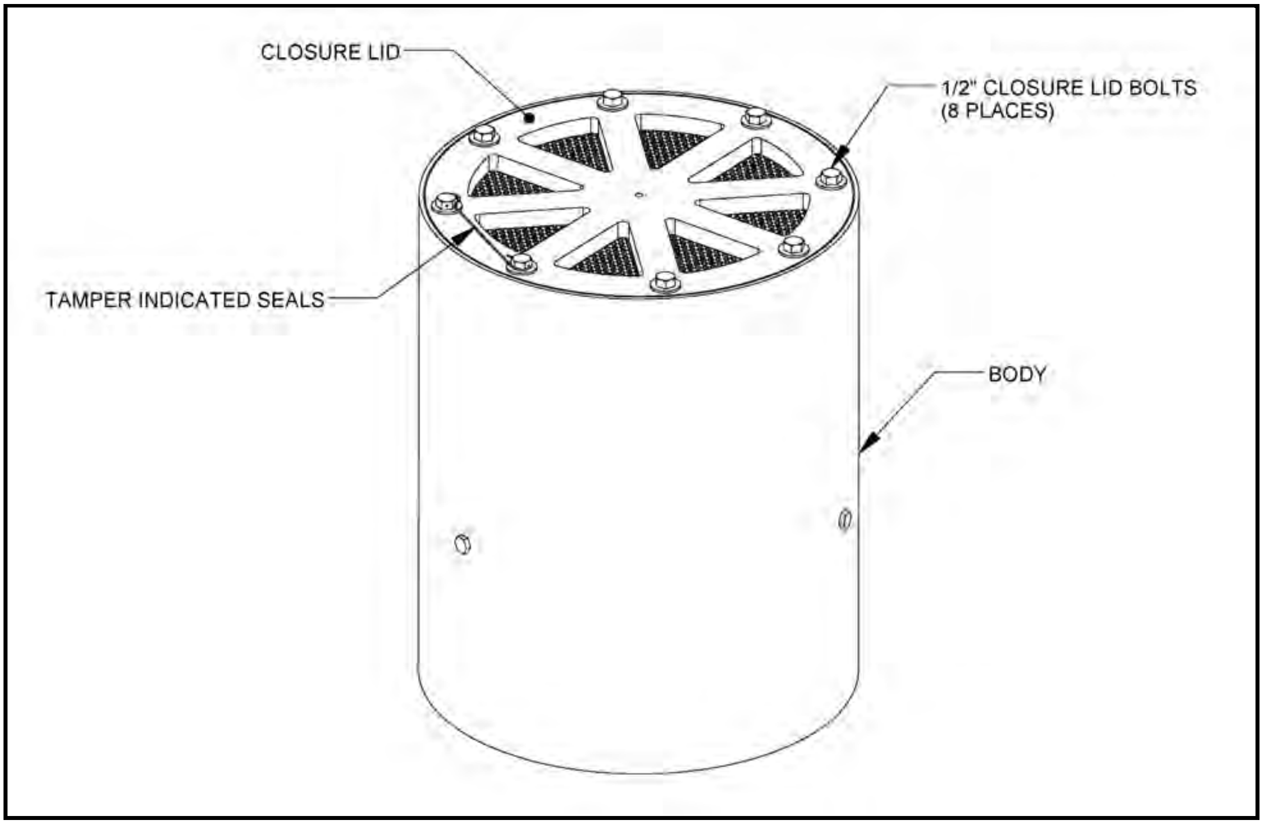

Figure 2.1-1 – Isometric View of the OP-RMSC Packaging

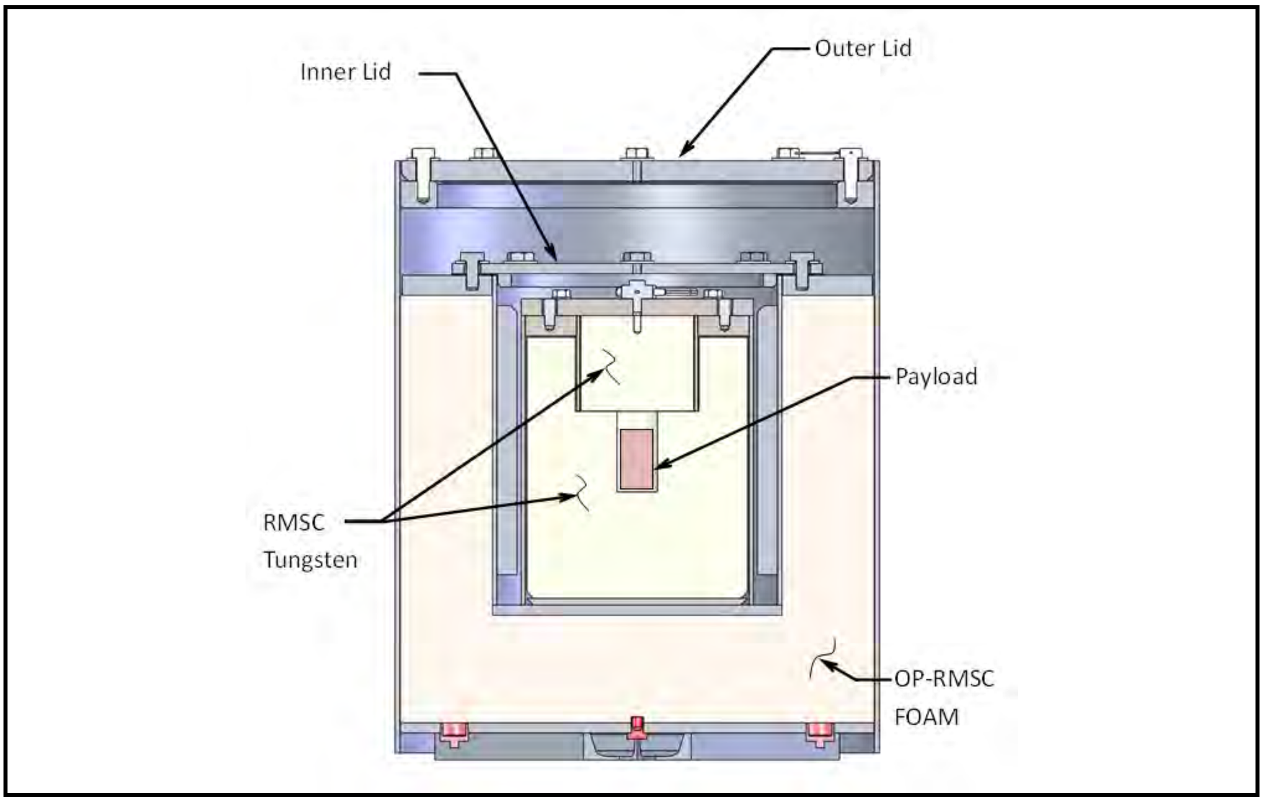

Figure 2.1-2 – Sectional View of the OP-RMSC Packaging

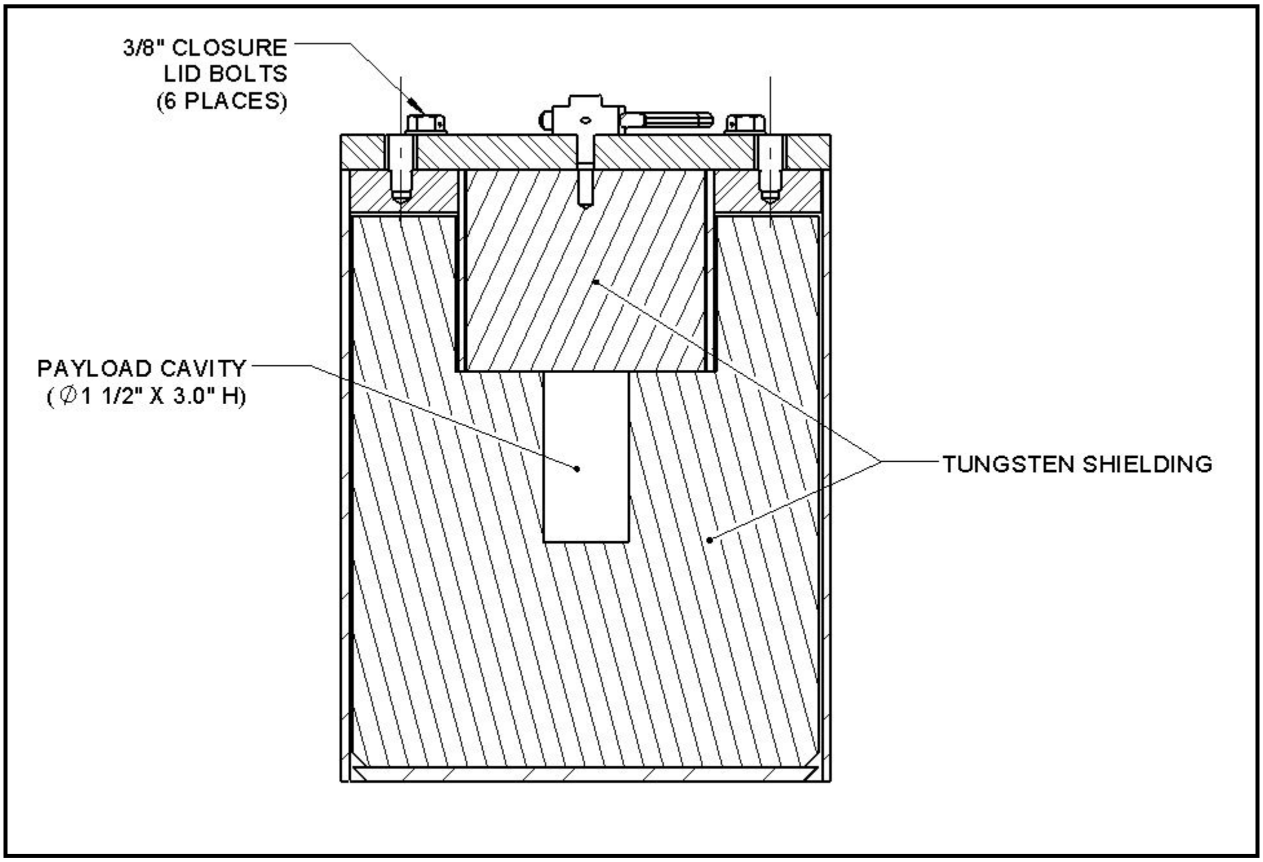

Figure 2.1-3 – Sectional View of the RMSC Payload

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

The OP-RMSC package is primarily demonstrated to satisfy the requirements of 10 CFR 71 via full-scale tests. For evaluation of a lifting attachment, the design criteria is that the structural lifting features do not exceed the material's yield strength when subjected to the requirements of 10 CFR §71.45(a).

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The structural materials of the OP-RMSC packaging include stainless steel and tungsten. Each material is not susceptible to brittle fracture at temperatures as low as -20 ºF (-29 ºC) as described below.

The OP-RMSC packaging and the RMSC payload are fabricated from austenitic stainless steel pipe, plate, and bar. This material does not undergo a ductile-to-brittle transition in the temperature range of interest [i.e., down to -40 ºF (-40 ºC)], and thus does not require evaluation for brittle fracture.

The tungsten shield material, which is enclosed by the welded stainless steel pipe assembly, was free drop and puncture tested at temperatures less than –20 ºF (-29 °C). As documented in the

certification test report[3], the tungsten heavy metal shields in the RMSC payload successfully passed all the free and puncture drop tests, which included cumulative damage effects, with no loss of shielding or confinement capability. In addition to the free drop tests, Plansee performed Charpy impact tests of the Densimet® D176 and D185 materials in accordance with ISO Standards 148-1 and 5754. Three test coupons of each alloy were tested at each temperature: room temperature, -20 °F (-29 °C), and -40 °F (-40 °C). The average Charpy energy values of the three test coupons at each test temperature are provided in Table 2.1-1.

Table 2.1-1 – Densimet® Charpy Impact Test Results[4]

Densimet® Alloy	Test Temperature (°F)	Average Impact Energy ($ft\text{-}lb_f/in^2$)
D176	Room Temperature	21.23
	-20	22.07
	-40	20.81
D185	Room Temperature	4.76
	-20	2.87
	-40	3.01

As shown by these Charpy impact tests, the Densimet® tungsten heavy metal shields are not susceptible to brittle fracture at temperatures as low as -40 °F (-40 °C). Based on the low temperature certification testing and the Charpy impact tests, brittle fracture of the tungsten heavy metal shields in the RMSC payload is not a concern. Additionally, the tungsten heavy metal shields are further protected from brittle fracture by the OP-RMSC outer package.

The closure lid bolts are hex bolts fabricated from ASTM A320, Grade L43 or L7 materials. These materials are specifically intended for low-temperature service applications. The Charpy impact tests for this material are recommended to be performed at -150 °F (-101 °C)[5] for these material grades. Therefore, brittle fracture of the closure lid bolts is not a concern.

2.1.2.2.2 Fatigue

Because the OP-RMSC package is an essentially a rigid body, no structural failures of the confinement boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The OP-RMSC package provides only a confinement boundary. For normal condition and hypothetical accident conditions, the RMSC confinement boundary (i.e., the tungsten gamma shields) will not buckle due to free or puncture drops. This conclusion has been demonstrated via full-scale tests of the OP-RMSC package.

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[3] Orano Federal Services LLC, Document TR-3023626-000, *Certification Test Report for the OP-RMSC Package*, Revision 0, August 17, 2020.

[4] Plansee Composite Materials GmbH, *Results for Charpy Impact Test, Densimet According to ASTM B777*, Inspection Certificate 20210730, dated July 30, 2021.

[5] American Society of Testing and Materials (ASTM) International, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*, A320/A320M-18.

2.1.3 Weights and Center of Gravity

The maximum gross weight of the OP-RMSC package is 650 pounds (295 kg). The center of gravity of the assembled package is along the vertical centerline axis, approximately 13.4 inches above the bottom of the package. Because the overall mass is dominated by the tungsten gamma shields, the package center of gravity is near the center of gravity for the RMSC payload.

2.1.4 Identification of Codes and Standards for Package Design

Since the package contains limited quantities of radioactive material, and does not contain a pressure boundary, the OP-RMSC package is designed only to industrial metal fabrication standards.

2.2 Materials

2.2.1 Material Properties and Specifications

Mechanical properties for the materials utilized for the structural components of the OP-RMSC package are provided in this section. Temperature-dependent material properties for the austenitic stainless steel structural components are obtained from Section II, Part D, of the ASME Boiler and Pressure Vessel (B&PV) Code[6]. Since the evaluation of the OP-RMSC package is primarily via full-scale tests, only the material properties that are used in the analysis portion of the evaluation are given. Table 2.2-1 presents the properties of the structural materials for Type 304 stainless steel utilized in the OP-RMSC package and the RMSC payload.

The tungsten gamma shields that are utilized in the RMSC payload are a tungsten heavy alloy, which is 93% - 97% tungsten alloyed with nickel (Ni) and iron (Fe). The addition of the nickel and iron improves the machinability compared to pure tungsten. Material properties are provided in Table 2.2-2. Since the tungsten gamma shields are not a primary structural material for the RMSC payload, these properties are provided for information and material evaluation related to the shielding safety function that the shields perform.

[6] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, *Materials, Part A – Ferrous Material Specifications*, and *Materials, Part D – Properties*, 2017 Edition.

Table 2.2-1 – Type 304 Stainless Steel Material Properties

Material Specification	Temperature, ºF	Yield Strength (S_y), psi ①	Ultimate Strength (S_u), psi ②	Design Stress Intensity (S_m), psi ③	Elastic Modulus, x 10^6 psi ④	Coefficient of Thermal Expansion, x 10^{-6}, in/in/ºF ⑤
Type 304 Stainless Steel	-40	**30,000**	**75,000**	**20,000**	**28.8**	**8.1**
	-20	30,000	75,000	20,000	**28.7**	**8.2**
	70	30,000	75,000	20,000	28.3	8.5
	100	30,000	75,000	20,000	**28.1**	8.6
	200	25,000	71,000	20,000	27.5	8.9
	300	22,400	66,200	20,000	27.0	9.2
	400	20,700	64,000	18,600	26.4	9.5
	500	19,400	63,400	17,500	25.9	9.7
	600	18,400	63,400	16,600	25.3	9.9
	700	17,600	63,400	15,800	24.8	10.0
	800	16,900	62,800	15,200	24.1	10.1
	900	16,200	60,800	---	23.5	10.2
	1,000	15,500	57,400	---	22.8	10.3
	1,100	---	---	---	22.0	10.4
	1,450	---	---	---	18.9	10.8
	1,500	---	---	---	18.1	10.8

Notes:

① ASME B&PV Code, Section II, Part D, Table Y-1 and ASTM A276 (≤ 100 °F)
② ASME B&PV Code, Section II, Part D, Table U and ASTM A276 (≤ 100 °F)
③ ASME B&PV Code, Section II, Part D, Table 2A
④ ASME B&PV Code, Section II, Part D, Table TM-1, Material Group G
⑤ ASME B&PV Code, Section II, Part D, Table TE-1, Material Group 3, Mean
⑥ When necessary, values are linearly interpolated or extrapolated and given in **bold** text.
⑦ The weight density and Poisson's ratio for stainless steel are 0.285 lb_m/in^3 and 0.29, respectively

Table 2.2-2 – Tungsten Heavy Metal Material Properties*

Alloy	Temperature °F (°C)	Density, lb_m/in^3	Yield Strength, psi	Ultimate Strength, psi	Elastic Modulus, x 10^6, psi	Coefficient of Thermal Expansion x 10^{-6}, in/in/°F
D176	68 (20)	0.636	89,923	127,633	52.2	2.95
	392 (200)	0.632	78,320	110,229	50.8	3.06
	932 (500)	0.629	56,565	82,672	48.3	3.11
	1,472 (800)	0.625	39,160	58,015	46.4	3.17
D185	68 (20)	0.668	87,023	116,030	55.8	2.78
	392 (200)	0.665	75,420	104,427	52.9	2.84
	932 (500)	0.661	60,916	87,023	50.8	2.89
	1,472 (800)	0.658	46,412	69,618	49.3	2.95

* Source: Plansee Brochure, "Refractory Metals for the Foundry Industry", 09.11.

Table 2.2-3 – ASTM A-320 Grade L43/L7 Alloy Bolting Material Properties

Material Specification	Temperature, °F	Yield Strength (S_y), psi ①	Ultimate Strength (S_u), psi ②	Allowable Stress (S), psi ③	Elastic Modulus, x 10^6, psi ④	Coefficient of Thermal Expansion, x 10^{-6}, in/in/°F ⑤
ASTM A320 Grade L43 or L7	-40	**105,000**	**125,000**	**25,000**	**28.3**	**6.2**
	-20	105,000	125,000	25,000	**28.2**	**6.3**
	70	105,000	125,000	25,000	27.8	6.4
	100	105,000	125,000	25,000	**27.6**	6.5
	200	98,000	125,000	25,000	27.1	6.7
	300	94,100	125,000	25,000	26.7	6.9
	400	91,500	125,000	25,000	26.2	7.1
	500	88,500	125,000	25,000	25.7	7.3
	600	84,300	125,000	25,000	25.1	7.4
	700	79,200	119,600	25,000	24.6	7.6
	800	---	---	---	23.9	7.8
	900	---	---	---	23.2	7.9
	1,000	---	---	---	22.4	8.1
	1,300	---	---	---	19.2	8.4

Notes:

① ASME B&PV Code, Section II, Part D, Table Y-1, lower value listed for either grade.
② ASME B&PV Code, Section II, Part D, Table U, lower value listed for either grade.
③ ASME B&PV Code, Section II, Part D, Table 3
④ ASME B&PV Code,, Section II, Part D, Table TM-1, Material Group B (L43) or Group C (L7), lower value listed for either grade.
⑤ ASME B&PV Code,, Section II, Part D, Table TE-1, Material Group 1, Mean
⑥ When necessary, values are linearly interpolated or extrapolated and given in **bold** text.

2.2.2 Chemical, Galvanic, or Other Reactions

The RMSC payload that fully surrounds the tungsten gamma shields is fabricated from Type 304 stainless steel. Since pure tungsten and Type 304 stainless steel materials (either active or passive) may be separated on the chart of electrode potentials of metals, the potential for a composition galvanic cell to form may exist. However, there is no electrolyte present in the welded assembly in the RMSC payload, and the RMSC payload is not wet loaded/unloaded during operations. Therefore, a galvanic corrosive reaction between these two materials will not occur since there is no electrolyte present. Additionally, the stainless steel of the OP-RMSC package does not have significant reactions with the interfacing components, air, or water.

2.2.3 Effects of Radiation on Materials

The gamma radiation associated with the radioactive material will have no effect on the austenitic stainless steel or the tungsten shields comprising the structural and shielding materials of the OP-RMSC package. As discussed in Section 2.1.1, *Discussion*, the polyurethane foam provides minimal protection of the RMSC payload. The effect of the radiation on the polyurethane foam to provide this minimal protection is negligible.

2.3 Fabrication and Examination

2.3.1 Fabrication

Both the OP-RMSC package and RMSC payload are fabricated utilizing conventional metal forming and joining techniques. Materials are procured in accordance with the standards delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*. All welding procedures and welding personnel are qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel (B&PV) Code[7].

2.3.2 Examination

The primary safety function of the OP-RMSC package is to provide protection of the RMSC payload that contains the gamma shielding for the special form radioactive material. To verify this function, each tungsten gamma shield is examined by performing a shielding test, as delineated in Section 8.1.6, *Shielding Tests*, prior to being utilized in the fabrication of a RMSC payload. In addition, all specified welds are visually inspected in accordance with the notes identified in Appendix 1.3.1, *General Arrangement Drawings*.

2.4 General Requirements for All Packages

The OP-RMSC package is evaluated, with respect to the general standards for all packaging specified in 10 CFR §71.43[2]. Results of the evaluations are discussed in the following sections.

2.4.1 Minimum Package Size

The smallest overall dimension of the OP-RMSC package is the 18 inch diameter of the body. This dimension is greater than the minimum dimension of 4 inches (10 cm) specified in 10 CFR §71.43(a). Therefore, the requirements of 10 CFR §71.43(a) are satisfied.

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[7] American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section IX, *Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers, and Welding, Brazing, and Fusing Operators*, 2017 Edition.

2.4.2 Tamper Indicating Device

A tamper indicating seal (wire/lead security seal) is attached to a pair of the closure lid bolts (refer to Figure 2.1-1), which provide visual evidence that the closure lid was not tampered during transportation. Therefore, the requirements of 10 CFR §71.43(b) are satisfied.

2.4.3 Positive Closure

The OP-RMSC package cannot be opened inadvertently. Positive closure of the OP-RMSC package is provided by the bolted closure lid. Therefore, the requirements of 10 CFR §71.43(c) are satisfied.

2.4.4 Valves

Because the OP-RMSC package is a confinement system and designed to transport only special form radioactive materials, there are no valves or other pressure retaining devices on the package. Therefore, the requirements of 10 CFR §71.43(e) are satisfied.

2.4.5 Package Design

As shown in Section 2.6, *Normal Conditions of Transport*, 3.3, *Thermal Evaluation Under Normal Conditions of Transport*, and 5.4, *Shielding Evaluation*, the OP-RMSC package design satisfies the requirements of 10 CFR §71.71. Therefore, the requirements of 10 CFR §71.43(f) are satisfied.

2.4.6 External Temperatures

The maximum decay heat load of the special form capsules is 100 watts (341 Btu/hr) for the maximum radioactive content of 16,000 Ci (592 TBq). With this decay heat, the maximum accessible surface temperature of the package in still air and shade is 152 °F (67 °C), which exceeds the temperature limit of 122 ºF (50 ºC) for a nonexclusive use shipment. With this high surface temperature, an expanded metal personnel barrier is installed over the OP-RMSC package after it is secured to its shipping pallet. The maximum temperature of the accessible surface of the personnel barrier is 100 °F (38 °C). Therefore, the requirements of 10 CFR §71.43(g) are satisfied by the OP-RMSC package with the personnel barrier.

2.4.7 Venting

With special form source capsules encapsulating the radioactive material, the OP-RMSC package does not incorporate any feature that would permit continuous venting during transport. Therefore, the requirements of 10 CFR §71.43(h) are satisfied by the OP-RMSC package.

2.5 Lifting and Tie-down Devices for All Packages

2.5.1 Lifting Devices

The OP-RMSC package is lifted by attaching a standard lift ring or other standard lifting component to the 3/8-16 UNC-2B threaded hole in the center of the 3/4-inch thick closure lid (refer to Figure 2.1-1). For the maximum gross package weight of 650 pounds (295 kg), the threaded hole will support the total weight. For added conservatism, a weight of 700 pounds will be applied to the threaded hole as a tensile load, which results in shear stresses in the internal threads.

The closure lid is a 3/4-inch thick, Type 304 steel plate. A 3/8-16 UNC-2B internal thread has a shear area of 0.8280 in²/in. Conservatively assuming only half the lid thickness for the thread engagement, the developed shear stress in the internal threads will be:

$$\tau_{3/8-16} = \frac{700}{(1/2)(3/4)(0.8280)} = 2{,}254 \text{ psi}$$

From Chapter 3.0, *Thermal Evaluation*, the maximum package surface temperature on the closure lid is 308 ºF (153 °C). For this evaluation, a conservative temperature of 400 °F will be utilized. At this temperature, the minimum tensile yield strength for Type 304 stainless steel is 20,700 psi (from Table 2.3-1). The shear allowable is taken as 0.6 of the tensile yield strength at temperature, or 0.6 (20,700) = 12,420 psi. Therefore, the minimum factor of safety (F.S.) for lifting is:

$$\text{F.S.} = \frac{12{,}420}{2{,}254} = +5.51 > 3.0$$

Additionally, any possible failure of a 3/8 threaded fastener for a lifting component will not impair the ability of the OP-RMSC package to perform its shielding and confinement functions since those safety functions are provided by the RMSC payload. Therefore, the requirements of 10 CFR §71.45(a) are satisfied.

2.5.2 Tie-Down Devices

The OP-RMSC package is secured to a pallet for transport by straps, cargo net, or other standard tie-down equipment that does not attach to the package. The 3/8-16 UNC threaded hole in the closure lid that is utilized for lifting is disabled during transport. Since the design does not contain any tie-down devices that are a structural part of the package, the requirements of 10 CFR §71.45(b) are not applicable to the OP-RMSC package.

2.6 Normal Conditions of Transport

2.6.1 Heat

The maximum steady state temperature of any component in an ambient environment of 100 ºF (38 °C) and full insolation for the OP-RMSC package is 1,122 ºF (606 °C), which occurs in the stainless steel special form capsule payload. For the overall OP-RMSC package, the maximum temperature of the stainless steel structural components for the NCT hot condition is 407 °F (208 °C), which occurs in the center area of the outer shell. However, the temperatures of the top and bottom ends of the OP-RMSC package are at or slightly above 100 °F (38 °C) (refer to Figure 3.3-3). During the certification drop testing, the OP-RMSC package was exposed to a temperature greater than of 200 ºF (93 °C) for several days in an environmental chamber. At the time of the free drop tests, the OP-RMSC CTU was at a temperature greater than 169 °F (76 °C). There was no loss in operational capability or damage to the test units from the free and puncture drop tests performed at the hot test temperature. For the predicted higher NCT hot temperatures with the 100 W (341 Btu/hr) decay heat load, there would also be no loss in operational capability or damage to the package. This conclusion is based on the fact that there is only a slight reduction in the minimum ultimate strength of the stainless steel structural components (~11%) up to 500 °F (260 °C).

2.6.2 Cold

For NCT cold condition, a -40 °F (-40 °C) steady state ambient condition is utilized per 10 CFR §71.71(c)(2), without insulation and any decay heat. This results in a uniform temperature of -40 °F (-40 °C) throughout the package. The OP-RMSC package was exposed to temperatures less than -22 ºF (-30 ºC) for several days in an environmental chamber without negative effects.

2.6.3 Reduced External Pressure

The OP-RMSC package is a confinement boundary for a special form payload and does not have a pressure boundary. Therefore, the effect of reduced external pressure per 10 CFR §71.71(c)(3) is not applicable.

2.6.4 Increased External Pressure

The OP-RMSC package is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of increased external pressure per 10 CFR §71.71(c)(4) is not applicable.

2.6.5 Vibration

The OP-RMSC package is a welded stainless steel package that surrounds the RMSC payload, which contains the gamma shields. The only components of the package that are bolted and removable are the outer and inner closure lids. The closure lids are secured to the body by eight (8) 1/2-13 UNC hex head bolts that are tightened to a minimum of 75 lb_f-ft torque, and fitted with a tamper indicating seal. The closure lid for the RMSC payload is secured by six (6) 3/8-16 UNC hex head cap screws that are tightened to a minimum of 35 lb_f-ft torque. As evidence by the certification drop testing, the package is essentially rigid, and hence, has a very high natural frequency. Based on the certification testing, the OP-RMSC package will not experience any damage or detrimental effects due to vibration normally incident to normal conditions of transport identified in 10 CFR §71.71(c)(5).

2.6.6 Water Spray

The stainless steel materials of construction utilized for the OP-RMSC package are such that the water spray test identified in 10 CFR §71.71(c)(6) will have a negligible effect on the package to satisfy the NCT shielding requirements of 10 CFR §71.51(a)(1).

2.6.7 Free Drop

Since the gross weight of the OP-RMSC package is less than 11,000 pounds (5,000 kg), a 4-foot (1.2 meter) free drop is required per 10 CFR §71.71.(c)(7). As discussed in Appendix 2.12.1, *Certification Tests*, a NCT, 4-foot (1.2-meter) free drop with impact on the package closure lid was performed on a OP-RMSC certification test unit (CTU-1) as an initial condition for the subsequent hypothetical accident condition (HAC) tests. As noted in the appendix, there was no significant visible deformation to the OP-RMSC test unit. A radiation survey following all certification testing demonstrated the ability of the OP-RMSC packaging to maintain the shielding and confinement integrity of the RMSC payload. Therefore, the requirements of 10 CFR §71.71(c)(7) are satisfied.

2.6.8 Corner Drop

This test does not apply, since the materials of construction do not include wood or fiberboard, as delineated in 10 CFR §71.71(c)(8).

2.6.9 Compression

A 3,390-pound (1,538 kg) force, which is greater than five times the gross package weight, was applied to the OP-RMSC package while sitting in its normal upright position for a period of 24 hours (refer to Figure 2.6-2). No observable deformation and damage was detected. Therefore, the requirements of 10 CFR §71.71(c)(9) are satisfied.

Figure 2.6-2 – View of OP-RMSC Package Compression Test After 24 Hours

2.6.10 Penetration

Per 10 CFR §71.71(c)(10), a 1¼ inch (3.2 cm) diameter, 13 pound (6 kg), hemispherical end steel rod is required to be dropped from a height of 40 inches (1 meter) onto the exposed surface of a package that is expected to be most vulnerable to puncture. For the OP-RMSC, the most vulnerable exposed surface is the expanded sheet metal on the outer lid. For this surface, the penetration test is of negligible consequence to the RMSC payload to satisfy the NCT shielding requirements of 10 CFR §71.51(a)(1). This conclusion is based on the fact that the OP-RMSC package is conservatively not considered for any shielding credit for the RMSC payload to satisfy the regulatory dose rates limits. Additionally, the OP-RMSC package was puncture drop tested more severely in accordance with the hypothetical accident conditions (HAC) per §71.73(c)(3). This regulation requires the heavier package to be dropped 40 inches (1 meter) onto a 6-inch (15 cm) diameter bar in the most vulnerable orientation. As noted in Appendix 2.12.1, *Certification*

Tests, there was no visible significant damage from any of the puncture drops to the OP-RMSC package and, no damage to the RMSC payload. Therefore, the requirements of 10 CFR §71.71(c)(10) are satisfied by the HAC puncture drop tests.

2.7 Hypothetical Accident Conditions

When subjected to the hypothetical accident conditions as specified in 10 CFR §71.73, the OP-RMSC package meets the performance requirements specified in Subpart E of 10 CFR 71. This conclusion is demonstrated in the following subsections, where each accident condition is addressed and the package is demonstrated to meet the applicable design criteria. The method of demonstration is primarily by test. The tests specified in 10 CFR §71.73 are applied sequentially, per Regulatory Guide 7.8.

Test results are summarized in Section 2.7.7, *Summary of Damage*, with details provided in Appendix 2.12.1, *Certification Tests*.

2.7.1 Free Drop

Subpart F of 10 CFR 71 requires performing a free drop test in accordance with the requirements of 10 CFR §71.73(c)(1). The free drop test involves performing a 30 foot (9 meter) free drop onto a flat, essentially unyielding, horizontal surface, with the package striking the surface in an orientation for which the maximum damage is expected. For the OP-RMSC, the free drop is addressed by test, in which several orientations are utilized. The free drop precedes both the puncture and thermal tests.

2.7.1.1 Technical Basis for the Free Drop Tests

The drop orientations selected for testing are intended to maximize the damage to the OP-RMSC package and cause a potential separation of the RMSC payload from the inner cavity. Once it separates from the OP-RMSC package, potential damage to the RMSC payload may occur from the subsequent puncture drop event, which could affect the tungsten gamma shielding. Should this condition occur, regulatory radiation limits might be exceeded. Therefore, the primary objective of the 30 foot (9 meter) HAC free drops is to damage the OP-RMSC package that results in the separation of the RMSC payload from the package body.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussion, the OP-RMSC package was tested for three specific, HAC 30 foot (9 meter) free drop orientations: 1) an impact on the top, 2) an impact on the side, and 3) an impact with CG-over-the top corner. Although only a single “worst-case” 30 foot (9 meter) drop is required per 10 CFR §71.73(c)(1), multiple tests were performed on each test unit to ensure that the most vulnerable package features were subjected to “worst-case” impact forces and deformations. The specific conditions selected for the OP-RMSC Certification Test Units (CTUs) are summarized in Table 2.7-1.

2.7.1.3 Summary of Results from the Free Drop Tests

Successful HAC free drop testing of the CTUs indicates that the various OP-RMSC package features are adequately designed to withstand the HAC 30 foot (9 meter) free drop event. The most important result of the testing program was the demonstrated ability of the OP-RMSC package to retain the RMSC payload, which provides the shielding integrity and confinement of

the raw material special form capsules, within the inner cavity. Significant results of the free drop testing are as follows:

- No significant damage to the OP-RMSC package structure from the free drop impacts.
- The RMSC payload did not separate from the OP-RMSC package.

Further details of the free drop test results are provided in Appendix 2.12.1, *Certification Tests*.

2.7.2 Crush

Subpart F of 10 CFR 71 requires performing a free drop test in accordance with the requirements of 10 CFR §71.73(c)(1). The free drop test involves performing a 30 foot (9 meter) free drop onto a flat, essentially unyielding, horizontal surface, with the package striking the surface in an orientation for which the maximum damage is expected. The crush test is required only when the specimen has mass not greater than 1,100 lb_m (500 kg), an overall density not greater than 62.4 lb_m/ft^3 (1,000 kg/m^3), and radioactive contents greater than 1,000 A_2, not as special form. Since the density of the OP-RMSC package is greater than 62.4 lb_m/ft^3 (1,000 kg/m^3), and the radioactive payload is special form, the dynamic crush test is not applicable to the OP-RMSC package.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.73(c)(3). The puncture test involves a 40 inch (1 meter) drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounting on an essentially unyielding, horizontal surface. The bar must be 6 inches (15 cm) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 1/4 inch (6 mm). The minimum length of the bar is to be 8 inches (20 cm). The ability of the OP-RMSC package to adequately withstand this specified drop condition is demonstrated via testing of two full-scale, OP-RMSC CTUs.

2.7.3.1 Technical Basis for the Puncture Drop Tests

The drop orientations selected for testing are intended to maximize the damage to the OP-RMSC package and cause potential separation of the RMSC payload from the inner cavity. Once it separates from the OP-RMSC package, potential damage to the RMSC payload may occur, which could affect the tungsten gamma shielding. Should this condition occur, the regulatory radiation limits might be exceeded. Therefore, the primary objective of the 40 inch (1 meter) HAC puncture drop is to cause further damage from the 30 foot (9 meter) free drop damage to the OP-RMSC package that could cause significant damage to or separation of the RMSC payload.

2.7.3.2 Test Sequence for the Selected Tests

Based on the above general discussion, the CTUs were specifically tested for three HAC puncture drop orientations that attempted to worsen the damage from the 30 foot (9 meter) free drop as part of the certification test program. Although only a single “worst-case” puncture drop is required by 10 CFR §71.73(c)(3), multiple puncture tests were performed to ensure that the most vulnerable package features were subjected to “worst-case” impact forces and deformations. The specific conditions selected for the OP-RMSC Certification Test Units (CTUs) are summarized in Table 2.7-1.

2.7.3.3 Summary of Results from the Puncture Drop Tests

Successful HAC puncture drop testing of the CTUs indicates that the OP-RMSC design features are adequately designed to withstand the HAC puncture drop event. The most important result of the testing program was the demonstrated ability of the OP-RMSC to contain its RMSC payload, which provides the shielding integrity and confinement of the raw material special form capsules, within the inner cavity. Significant results of the puncture drop testing are as follows:

- No evidence of any significant damage to the OP-RMSC body due to the impact with the puncture bar.
- The RMSC payload did not separate from the OP-RMSC package.

Further details of the free drop test results are provided in Appendix 2.12.1, *Certification Tests*.

2.7.4 Thermal

Subpart F of 10 CFR 71 requires performing a thermal test in accordance with the requirements of 10 CFR §71.73(c)(4), which requires a package to be exposed to a hydrocarbon fuel/air fire with a minimum temperature of 1,475 ºF (800 ºC) for 30 minutes. As discussed in Section 2.7.1, *Free Drop*, and Section 2.7.3, *Puncture*, there was no separation of the RMSC payload from the OP-RMSC package. As noted in Appendix 2.12.1, *Certification Tests*, the CTU for the initial temperature condition was heated to greater than 169 °F (76 °C) for the hot 30-foot free drop test. Even considering the maximum temperatures identified in Table 3.3-1, the higher temperatures would not result in the RMSC payload being ejected from the OP-RMSC or affecting the ability of the RMSC payload to maintain its shielding safety function. Since all of the structural and shielding materials, which are Type 304 stainless steel and tungsten heavy alloys for the OP-RMSC package and the RMSC payload have melting temperatures of 2,550 – 2,640 °F (1,400 – 1,450 °C) and 2,732 °F (1,500 °C), respectively, the melting temperatures are significantly higher than the specified fire temperature of 1,475 ºF (800 ºC). The only combustible materials in the OP-RMSC package are the non-structural polyurethane foam, which fills the annulus between the payload cavity and the outer pipe body, and the silicone gasket between the inner closure lid and the payload cavity. The combustion of the foam or the gasket materials, or an increased temperature of the RMSC payload has no effect on the structural or shielding materials of either the OP-RMSC package or the RMSC payload.

The effect of the differential thermal expansion between the alloy bolt material and the stainless steel lid material may be computed for the maximum fire temperature of 1,475 °F (800 °C). For the OP-RMSC inner and outer lid bolted closures, the bolt length-to-lid thickness ratios (2.67 and 2.0, respectively) are greater than the RMSC payload bolt length-to-lid thickness ratio (1.41). Therefore, the RMSC payload is the bounding case for evaluating the effect of differential thermal expansion on a bolted closure.

The lid bolts for the RMSC payload are 3/8-16 UNC × 0.88 inch long. The RMSC lid plate is nominally 5/8 inches thick. From Table 2.2-1, the coefficient of thermal expansion for Type 304 stainless steel at 1,475 °F is 10.8×10^{-6} in/in-°F. From Table 2.2-3, the coefficient of thermal expansion for the A-320 alloy bolt material at 1,300 °F (maximum temperature provided by the ASME material reference) is 8.4×10^{-6} in/in-°F. Assuming an installation temperature of 70 °F (conservative), the thermal expansion of the bolt length and the lid thickness is computed for the thermal transient event as follows:

$$\Delta_{\text{bolt}=\,\alpha}L(T_{1475} - T_{70}) = (8.4 \times 10^{-6})(0.88)(1{,}475 - 70) = 0.010 \text{ inch}$$

$$\Delta_{lid=\alpha}L(T_{1475} - T_{70}) = (10.8 \times 10^{-6})(0.625)(1{,}475 - 70) = 0.009 \text{ inch}$$

Since the lid bolt thermal expansion is greater than the stainless steel lid thermal expansion, there is no additional tensile force applied to the bolts during the peak fire temperature of 1,475 °F (800 °C), and the RMSC payload remains within the OP-RSMC and retains the radioactive capsules.

Therefore, the OP-RMSC package satisfies the external dose rate requirements of 10 CFR §51(a)(2) after exposure to the thermal event per 10 CFR §71.73(c)(4).

2.7.5 Immersion – Fissile Material

The OP-RMSC package does not transport fissile material. Therefore, 10 CFR §71.73(c)(5) does not apply.

2.7.6 Immersion – All Packages

The OP-RMSC package is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of pressure per 10 CFR §71.73(c)(6) is not applicable.

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

The OP-RMSC package contains a maximum of 16,000 Ci (592 TBq) of Ir-192 or Se-75 isotopes, which have A_2 values of 16 Ci (0.6 TBq) and 81 Ci (3.0 TBq), respectively. Since the OP-RMSC package does not contain more than 10^5 A_2 quantities of radioactive material, deep immersion per 10 CFR §71.61 is not applicable.

2.7.8 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of free drop and puncture drop tests were satisfactorily withstood by the full-scale OP-RMSC certification testing. Additionally, the thermal event has no effect on the metallic OP-RMSC package or the RMSC payload. Subsequent radiation post-test surveys of the RMSC CTU payloads confirmed that shielding integrity was maintained throughout the test series. Therefore, the requirements of 10 CFR §71.73 have been adequately demonstrated by the full-scale testing of the OP-RMSC package.

Table 2.7-1 - Summary of OP-RMSC Certification Test Unit (CTU) Tests and Results

Test No.	Test Description (Certification Test Unit No.)	Test Unit Angular Orientation		Test Results
		Longitudinal Axis (0° = upright)	Circumferential Axis (0° = as marked)	
1	4 foot, Top Down (CTU-1)	180°	N/A	No visible damage was observed.
2	30 foot, Top Down (CTU-1)	180°	N/A	Inner lid bolts failed, resulting in lid contacting the closure lid. RMSC remained within the OP-RMSC. No other damaged observed.
3	30 foot, Side Drop (CTU-2)	90°	0°	Impact created ~4 inch wide flat along the side. One closure lid bolt failed. No other damaged observed.
4	30 foot, CG-over-Top Corner (CTU-2)	132°	180°	Impact resulted in a ~1/2-inch fold on outer shell. Five (5) of the closure lid bolts were sheared, with two (2) bolts remaining on opposite side. Closure lid remain attached.
5	Puncture Drop, Top Down, (CTU-1)	180°	N/A	Puncture bar impacted center of closure lid with no observed additional damage.
6	Puncture Drop, Side Drop (CTU-2)	90°	0°	Puncture bar struck side of package, resulting in small deformation of outer shell. No other damaged observed.
7	Puncture Drop, Top Down, CG-over-Corner (CTU-2)	138°	180°	Puncture bar struck outer shell/closure lid interface, resulting in a small “half-moon” deformed area. No other damaged observed.

2.8 Accident Conditions for Air Transport of Plutonium

This section does not apply, since plutonium is not transported in the OP-RMSC package.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since fissile material is not transported in the OP-RMSC package.

2.10 Special Form

The contents of the OP-RMSC package are a maximum of four (4) raw material special form source capsules. All four source capsules are limited to a maximum of 16,000 Ci (592 TBq) per shipment. One certification for an Ir-192 raw material special form capsule that would be transported in OP-RMSC is listed below. Other raw material capsules may be transported in the OP-RMSC provided the capsules are certified as special form, and fit within the capsule holder.

Manufacture	Model Number	Certification Number
Industrial Nuclear Co., Inc.	INC-SFC-1	USA/0798/S-96

2.11 Fuel Rods

This section does not apply, since fuel rods are not transported in the OP-RMSC package.

2.12 Appendix

2.12.1 Certification Tests

2.12.1 Certification Tests

Presented herein are the results of normal conditions of transport (NCT) and hypothetical accident condition (HAC) tests that address free drop, puncture, and thermal test performance requirements of 10 CFR 71[8]. The certification tests are fully documented in the certification test report[9].

2.12.1.1 Introduction

The OP-RMSC, when subjected to the sequence of HAC tests specified in 10 CFR §71.73, subsequent to the NCT tests specified in 10 CFR §71.71, is demonstrated to satisfy the performance requirements specified in Subpart E of 10 CFR 71. As indicated in the introduction to Chapter 2.0, *Structural Evaluation*, the primary proof of performance for the HAC tests is via the use of full-scale testing. In particular, free drop and puncture testing of OP-RMSC CTUs confirms that the packaging will retain its shielding integrity following a worst-case HAC sequence.

2.12.1.2 Summary

As seen in the figures presented in Section 2.12.1.7, *Test Results*, successful testing of the CTUs indicates that the various OP-RMSC packaging design features are adequately designed to withstand the HAC tests specified in 10 CFR §71.73. The most important result of the testing program was the demonstrated ability of the OP-RMSC packaging to maintain its shielding integrity.

Significant results of the free drop tests are as follows:

- No significant damage to the OP-RMSC package structure from the free drop impacts.
- No separation of the RMSC payload from the OP-RMSC package.

Significant results of the puncture drop testing are as follows:

- No evidence of any significant damage to the OP-RMSC body due to the impact with the puncture bar.
- No separation of the RMSC payload from the OP-RMSC package.

2.12.1.3 Test Facilities

The free and puncture drop testing was performed utilizing a horizontal concrete slab, which is approximately 9-12 inches thick × 10 feet × 15 feet. The concrete slab is setting on a parking lot concrete slab that has an approximate thickness of 9½ inches. A 2 inch × 48 inch × 48 inch steel plate was placed on top of the concrete slab, grouted, and secured to the concrete slab by four (4) 5/8-inch anchor bolts. To increase the effective mass of the impact surface, a 5 inch thick steel plate was placed on top of the 2 inch thick plate and welded to the grouted plate. Considering only the concrete directly underneath the steel plates as being effective with a total thickness of 18½ inches for the concrete slabs, the mass of the drop pad (concrete and steel plates) is conservatively estimated to be 8,100 lb_m, which is more than 10 times the mass of the OP-RMSC CTUs. Based on these characteristics, the drop pad satisfied the requirement of 10 CFR §§71.71 and 71.73 for an essentially unyielding, horizontal surface.

[8] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71) *Packaging and Transportation of Radioactive Material*, 1-1-20 Edition.

[9] Orano Federal Services LLC, Document TR-3023626-000, *Certification Test Report for the OP-RMSC Package*, Revision 0, August 17, 2020.

The puncture bar assembly for the puncture tests was a 6-inch (15 cm) diameter × 25½ inch (65 cm) long bar that was welded to a 3/4-inch (19-mm) thick square steel plate. The top circumferential edge of the bar was rounded to a maximum of 1/4-inch (6-mm) radius. The free length of the bar was 25½ inches (65 cm) (i.e., height above the base plate), thus ensuring an adequate length to facilitate maximum damage to the CTU as required by 10 CFR §71.73(c)(3). Following the 30-foot (9-meter) free drop tests, the 3/4-inch (19 mm) thick plate of the puncture bar assembly was welded to the 5-inch (13 cm) thick steel plate on the drop pad. This configuration ensured that the puncture bar assembly was fully restrained for the puncture drop tests.

2.12.1.4 Certification Test Unit Description

The OP-RMSC package is a welded and bolted assembly that consists of an outer ∅18-inch × 22¾ inch high, Schedule 10S stainless steel pipe and an inner ∅10-inch × 12¼ inch high, Schedule 10S stainless steel pipe. The inner pipe forms the payload cavity for the RMSC payload. The annular space between the inner and outer pipes is filled with rigid polyurethane foam that provides limited impact protection of the RMSC payload. A 3/8-inch thick, 13¾ inch diameter stainless steel plate, which is secured with eight (8) 1/2-inch hex bolts, encloses the payload cavity. Above the inner lid, a 3/4-inch thick, 17½ inch diameter stainless steel closure lid is secured to the outer 18-inch diameter stainless steel pipe body with eight (8) 1/2-13 UNC hex head bolts. The outer lid is slotted to dissipate decay heat from the payload cavity via convective heat transfer. Within the payload cavity, there are four (4) 3/8-inch thick stainless steel vertical bars welded to the inner cavity wall. The bars are circumferentially located at 90-degrees to minimize the clearance between the RMSC payload and the cavity wall.

The RMSC payload consists of a welded stainless steel pipe assembly that is welded to a smaller pipe assembly, which forms the payload cavity. A fixed tungsten gamma shield is installed between the outer and inner pipe assemblies. A tungsten gamma shield is installed over the payload cavity to provide shielding of the payload cavity, and then a bolted closure lid is installed to retain the cavity tungsten gamma shield over the cavity.

Prior to free drop and puncture testing, the two RMSC CTUs were loaded with dummy raw material source capsules and a holder to simulate the special form capsules, and then loaded into the OP-RMSC CTUs. The actual pre-test weights of CTU-1 and CTU-2 were 646 pounds and 647 pounds, respectively. Each certification test unit was prototypic of the design delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*. The CTU tungsten shields were nominal, i.e., dimensionally and density in accordance with the ASTM B777 standard. The CTUs differed slightly from the OP-RMSC packaging design as follows:

- A neoprene gasket was utilized under the inner lid rather than the specified silicone gasket.
- The tampering indicating seal/safety wire between two of the closure lid bolts was not installed in the CTUs.

Neither of these minor differences had any effect on the response of the CTUs to the free drop and puncture drop tests.

2.12.1.5 Technical Basis for Tests

For the confinement system to fail, the OP-RMSC package would need to fail and allow the RMSC payload to separate from the package. This potential failure mode may only occur if either of the following conditions occurs:

1. Both the inner and outer lids of the OP-RMSC fail, resulting in the RMSC payload being ejected and sustain significant damage and,
2. The RMSC closure lid fails and the cavity tungsten gamma shield separates from the body.

For either of these potential conditions to occur, the OP-RMSC package would need to sustain significant damage due to the normal and hypothetical accident condition free drops, and then sustain further damage due to the 40-inch (1-meter) drop onto a 6 inch (15 cm) diameter vertical steel bar. Therefore, the primary objective of the 4 foot (1.2 meter) normal condition and the 30-foot (9-meter) hypothetical accident condition (HAC) free drops is to damage the OP-RMSC package that causes the RMSC payload to separate and possibly be damaged by the subsequent puncture drop. A secondary objective of the 9-meter (30-foot) HAC free drops is to attempt to damage the RMSC such that the tungsten gamma shields would become exposed, which could result in a loss of shielding.

The following sections provide the technical basis for the chosen test orientations and sequences for the OP-RMSC CTUs.

2.12.1.5.1 Temperature

Both cold and hot conditions for the free drops were utilized for the OP-RMSC certification testing. To maximize impact decelerations, a CTU was chilled to below -20 °F (-29 °C). To maximize deformations, a CTU was heated to over 160 °F (71 °C). The results of the package testing demonstrated that extreme temperatures had no effect on the shielding integrity of the OP-RMSC package. In addition, the austenitic stainless steel and tungsten materials are not susceptible to brittle fracture, as delineated in Section 2.1.2.2.1, *Brittle Fracture*.

For the puncture tests, ambient temperatures were utilized for the OP-RMSC certification testing.

2.12.1.5.2 Free Drop Tests

The OP-RMSC is qualified primarily by full-scale testing, with acceptance criterion being the ability to demonstrate shield integrity. Per 10 CFR §71.73(c)(1), the package is required to "strike an essentially unyielding surface *in a position for which maximum damage is expected*." Therefore, for determining the drop orientations that satisfy the regulatory "maximum damage" requirement, attention is focused predominately on the issue of shield integrity of the RMSC payload.

To maximize the damage to the OP-RMSC package and potentially separating the RMSC payload, three orientations have been selected for the free drop testing:

1. <u>Vertical, Top</u>: This orientation targets the OP-RMSC closure lid and the inner closure lid. Should this impact be sufficiently severe, both of the OP-RMSC lids may fail and eject the RMSC payload from the cavity. The intent of this drop orientation is also to simulate a probable orientation that could occur in actual use in the field.
2. <u>Side</u>: This orientation again targets both the OP-RMSC closure lid and the inner closure lid. Should this impact be sufficiently severe, the OP-RMSC lid assemblies could become damaged and result in a possible ejection of the RMSC payload. Additionally, should the RMSC outer pipe and/or the closure lid fail, the tungsten gamma shielding would be exposed, which could possibly release or expose the special form radioactive sources.
3. <u>CG-Over-Top Corner</u>: This orientation targets the OP-RMSC closure lid and the inner closure lid. The intent of this orientation is to attempt to damage the tungsten gamma shields of the

RMSC, and the closures of the payload packages. Should this impact be sufficiently severe, the OP-RMSC closure and inner cavity lids may fail and result in the ejection of the RMSC payload package. Additionally, should the RMSC closure lid fail, the special form radioactive sources could be released or exposed, which would result in unshielded radioactive sources.

2.12.1.5.3 Puncture Drop Tests

10 CFR §71.73(c)(3) requires a free drop of the specimen through a distance of 40 inches (1 meter) onto a puncture bar "in a position for which maximum damage is expected." As in Section 2.12.1.5.2, *Free Drop Tests*, the "maximum damage" criterion is evaluated primarily in terms of loss of shielding integrity. Loss of shielding integrity could occur should the RMSC payload be ejected from the OP-RMSC body, and subsequent damage of the tungsten gamma shields occurs.

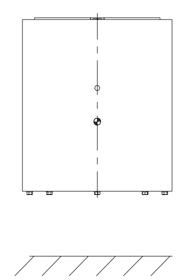
The orientations selected for the puncture tests were the side and CG-over-top corner tests as discussed in Section 2.12.1.5.2, *Free Drop Tests*. The intent of these orientations is to accumulate puncture damage with the damage from the 30-foot free drops for the same orientations.

2.12.1.6 Test Sequence for Selected Free Drop and Puncture Drop Tests

The following sections establish the selected free drop, puncture drop, and thermal test sequence for the OP-RMSC CTUs based on the discussions provided in Section 2.12.1.5, *Technical Basis for Tests*. The tests sequences are summarized in Table 2.12.1-1 and illustrated in Figure 2.12.1-1 and Figure 2.12.1-2.

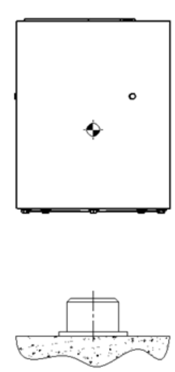
2.12.1.6.1 Certification Test Unit No. 1 (CTU-1)

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the top of the package. The 4 foot (1.2 meter) drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weighing less than 11,000 pounds. The purpose of this test was intended to cause maximum damage to the packaging in its most probable orientation to possibly eject the RMSC payload. This test was performed at a cold temperature.



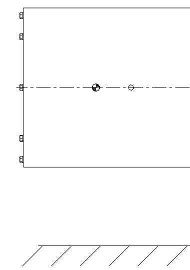
Free Drop No. 2 is a HAC free drop from a height of 30 feet (9 meter), impacting the top of the package, which is the same impact point as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the packaging in its most probable orientation to possibly eject the RMSC payload. This test was performed at a cold temperature.

Puncture Drop No. 5 impacts directly onto the damage created by Free Drop Test 2, directly on the closure lid. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 5 is to cause maximum damage to the closure lid, and possibly result in the ejection of the RMSC payload from the OP-RMSC package.

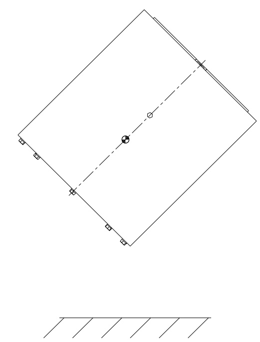


2.12.1.6.2 Certification Test Unit No. 2 (CTU-2)

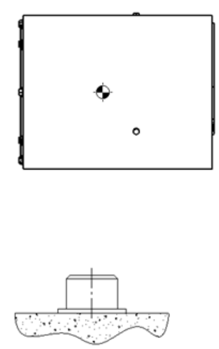
Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the side. The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the closure lid, and possibly damage the RMSC payload. This test was performed at a hot temperature.



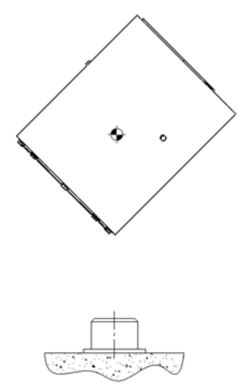
Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the top corner, The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the closure lid and possibly separate the RMSC payload. This test was performed at a hot temperature.



Puncture Drop No. 6 impacts directly onto the damage created by Free Drop Test No. 3, directly on the side of the package. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 6 is to cause maximum damage to the closure lid, and possibly damage the RMSC payload.



Puncture Drop No. 7 impacts directly onto the damage created by Free Drop Test No. 4, directly on the top corner. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 7 is to cause maximum damage to the closure lid, and possibly damage the RMSC payload.



2.12.1.7 Test Results

The following sections report the results of free drop, puncture drop, and thermal tests following the sequence provided in Section 2.12.1.6, *Test Sequence for Selected Free Drop, Puncture Drop, and Thermal Tests*. Results are summarized in Table 2.12.1-2 (refer also to Figures 2.12.1-1 and 2.12.1-2).

Figures 2.12.1-3 through 2.12.1-23 sequentially photo-documents the certification testing process for the OP-RMSC CTUs.

2.12.1.7.1 Certification Test Unit No. 1 (CTU-1)

2.12.1.7.1.1 CTU-1 Free Drop Test No. 1

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the top of the package. As shown in Figure 2.12.1-3, the CTU was oriented vertically with respect to the horizontal impact surface (longitudinal angle 180º). The following list summarizes the test parameters:

- verified longitudinal angle as 180° ±1°
- verified drop height as 4 feet (1.2 meter), +2/-0 inches
- measured surface temperature of inner shell wall as -22 °F at time of test
- conducted test at 6:37 p.m. on Tuesday, 7/7/2020 time of test

The package rebounded (bounced) upon impact off the drop pad, and remained upright. No external damage was noted. The impact and post-test package are shown in Figures 2.12.1-4 and 2.12.1-5, respectively.

2.12.1.7.1.2 CTU-1 Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the top of the package (closure lid). As shown in Figure 2.12.1-6, the CTU was oriented vertically with respect to the horizontal impact surface (longitudinal angle 180º). The following list summarizes the test parameters:

- verified longitudinal angle as 180° ±1°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of inner shell wall as -22 °F at time of test
- conducted test at 6:48 p.m. on Tuesday, 7/7/2020

The package impacted the drop pad and did not rebound (bounce). The package remained upright on drop pad. No external damage was noted. The bolts securing the inner lid failed, allowing the inner lid to contact the closure lid. The RMSC payload remained within the OP-RMSC. The impact damage is shown in Figure 2.12.1-7 and Figure 2.12.1-8.

2.12.1.7.1.3 CTU-1 Puncture Drop Test No. 5

Puncture Drop No. 5 impacted directly onto the damage created by Free Drop Test 2, directly on the closure lid. As shown in Figure 2.12.1-9, the CTU was oriented vertically with the top down with respect to the impact pad so that the puncture bar would strike the damage from the 30-foot free drop. The following list summarizes the test parameters:

- verified longitudinal angle as 180° ±2°
- verified drop height as 40 inches (1 meter), +3/-0 inches

- measured surface temperature of outer shell of OP-RMSC as 92 - 94 °F at time of test
- conducted test at 10:55 a.m. on Wednesday, 7/8/2020

The package rebounded (bounced) off the puncture bar immediately following impact, and fell to its side. The impact struck the previous damage from the 30-foot free drop. No measureable damage was observed from the impact. The post-test condition is shown in Figure 2.12.1-10.

2.12.1.7.1.4 CTU-1 Post-Test Disassembly

Post-test disassembly of CTU-1 was performed on Wednesday, 7/22/20. After removing the OP-RMSC lid, all of the hex bolts securing the inner lid were found to have failed. However, there was no damage to the RMSC payload, as shown in Figures 2.12.1-11 and 2.12.1-12.

2.12.1.7.1.5 CTU-1 Post-Test Radiation Survey

Post-test radiation survey of RMSC CTU-1 was performed on Wednesday, 7/22/20. The post-test radiation survey was performed utilizing Ir-192 special form radioactive capsules. The total radioactive payload on the day of the survey for the post-test survey was 4,297 curies (Ci) [159 TBq]. To account for the maximum design radioactive payload of 16,000 Ci (592 TBq), the measured values were adjusted upward by the ratio of 16,000/4,297 or 3.724 to determine the dose rate for the maximum radioactive content. Utilizing a calibrated INC Model 4 radiation survey meter (Serial No. 900816) that was calibrated to the face of the meter, a qualified technician scanned each surface (side, top, and bottom) to detect the maximum measured reading at the specified distance, i.e., surface, 1-meter and 2-meters. The measured dose rates included the effects of the open threaded hole in the cavity shield. Once the maximum reading from each surface was noted, the maximum post-test dose rate was recorded for the maximum radioactive content of 16,000 Ci (592 TBq) as follows:

Test Unit No.	Maximum Dose Rate [Top/Bottom/Side] (mrem/hr)								
	Surface			1-meter			2-meters		
CTU-1	15	19	123	4	0	4	0	0	0

As indicated above, the radiation dose levels were well below the requirements of 10 CFR §71.47(a) for NCT and 10 CFR §71.51(a)(2) for HAC for a non-exclusive use shipment.

2.12.1.7.2 Certification Test Unit No. 2 (CTU-2)

2.12.1.7.2.1 CTU-2 Free Drop Test No. 3

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the package side. As shown in Figure 2.12.1-13, the CTU was oriented parallel to the horizontal impact surface (longitudinal angle 90º, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 0° ±2°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of inner shell wall as 169+ °F at time of test
- conducted test at 11:01 a.m. on Tuesday, 7/7/2020

The package rebounded (bounced) upon impact off the drop pad, and fell to its side. Impact created a ~4 inch wide flat along the side of the outer shell. One closure lid bolt on the impact side failed. No other external damage was noted. The impact damage is shown in Figure 2.12.1-14.

2.12.1.7.2.2 CTU-2 Free Drop Test No. 4

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the top corner of the package. As shown in Figure 2.12.1-15, the CTU was oriented 48º with respect to the horizontal impact surface (longitudinal angle 132º, circumferential angle 180°). The following list summarizes the test parameters:

- verified longitudinal angle as 132° ±1°
- verified circumferential angle as 180° ±2°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of inner shell wall greater than 171 °F at time of test
- conducted test at 11:25 a.m. on Tuesday, 7/7/2020

The package rebounded (bounced) upon impact off the drop pad, and fell to its side. The impact produced a ~1/2 inch buckle/fold on the outer shell. Five (5) of the remaining seven (7) closure lid bolts failed. However, the closure lid did not separate from the body. No other damage was visible or noted. The impact damage is shown in Figure 2.12.1-16.

2.12.1.7.2.3 CTU-2 Puncture Drop Test No. 6

Puncture Drop No. 6 was intended to impact directly onto the damage created by Free Drop Test 3, directly impacting the side of the package. As shown in Figure 2.12.1-17, the CTU was oriented parallel to the horizontal impact surface (longitudinal angle 90º, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 0° ±2°
- verified drop height as 40 inches (1 meter), +2/-0 inches
- measured surface temperature of outer shell of OP-RMSC as 84 °F at time of test
- conducted test at 11:30 a.m. on Wednesday, 7/8/2020

The package rebounded (bounced) off the puncture bar immediately following impact. The impact struck the previous damage from the 30-foot free drop, resulting in a small deformed area of the outer shell. No other external damage was noted. The impact damage is shown in Figure 2.12.1-18.

2.12.1.7.2.4 CTU-2 Puncture Drop Test No. 7

Puncture Drop No. 7 was intended to impact directly onto the damage created by Free Drop Test 4, directly impacting the top corner of the package. As shown in Figure 2.12.1-19, the CTU was oriented 42º with respect to the horizontal impact surface (longitudinal angle 138º, circumferential angle 180°). The following list summarizes the test parameters:

- verified longitudinal angle as 138° ±1°
- verified circumferential angle as 180° ±2°
- verified drop height as 40 inches (1 meter), +2/-0 inches

- measured surface temperature of outer shell of OP-RMSC as 100 - 103 °F at time of test
- conducted test at 11:58 a.m. on Wednesday, 7/8/2020

The package rebounded (bounced) off the puncture bar immediately following impact. The impact struck the previous damage from the 30-foot free drop with no measureable deformation. No other external damage was noted. The impact damage is shown in Figure 2.12.1-20.

2.12.1.7.2.5 CTU-2 Post-Test Disassembly

Post-test disassembly of CTU-2 was performed on Wednesday, 7/22/20. After removing the OP-RMSC lid, and the hex bolt securing the inner lid, the 1/4-20 hex bolt that attaches the RMSC hoist ring to the lid was sheared. However, the RMSC payload was not damaged from any of the free drop and puncture drop tests. The post-test views of the RMSC payload are shown in Figures 2.12.1-21 thru 2.12.1-23.

2.12.1.7.2.6 CTU-2 Post-Test Radiation Survey

Post-test radiation survey of RMSC CTU-2 was performed on Wednesday, 7/22/20. The post-test radiation survey was performed utilizing Ir-192 special form radioactive capsules. The total radioactive payload on the day of the survey for the post-test survey was 4,297 curies (Ci) [159 TBq]. To account for the maximum design radioactive payload of 16,000 Ci (592 TBq), the measured values were adjusted upward by the ratio of 16,000/4,297 or 3.724 to determine the dose rate for the maximum radioactive content. Utilizing a calibrated INC Model 4 radiation survey meter (Serial No. 900816) that was calibrated to the face of the meter, a qualified technician scanned each surface (side, top, and bottom) to detect the maximum measured reading at the specified distance, i.e., surface, 1-meterm and 2-meters. The measured dose rates included the effects of the open threaded hole in the cavity shield. Once the maximum reading from each surface was noted, the maximum post-test dose rate was recorded for the maximum radioactive content of 16,000 Ci (592 TBq) as follows:

Test Unit No.	Maximum Dose Rate [Top/Bottom/Side] (mrem/hr)								
	Surface			1-meter			2-meters		
CTU-2	11	15	123	4	4	4	0	0	0

As indicated above, the radiation dose levels were below the requirements of 10 CFR §71.47(a) for NCT, and 10 CFR §71.51(a)(2) for HAC for a non-exclusive use shipment.

Based on the test results, the OP-RMSC package design has been demonstrated to satisfy the requirements of Subpart F of 10 CFR 71 for the transportation of special form radioactive material.

Table 2.12.1-1 – Summary of OP-RMSC Certification Tests in Sequential Order[1]

Test No.	Test Description (Certification Test Unit No.)	Test Unit Angular Orientation		Test Unit Temperature (as measured)	Test Results
		Longitudinal Axis[2] (0° = horizontal)	Circumferential Axis[3] (0° = upright)		
1	4 foot, Top Down (CTU-1)	180°	N/A	-22 °F (inner shell)	No visible damage was observed.
2	30 foot, Top Down (CTU-1)	180°	N/A	-22 °F (inner shell)	Inner lid bolts failed, resulting in lid contacting the closure lid. RMSC remained within the OP-RMSC. No other damaged observed.
3	30 foot, Side (CTU-2)	90°	0°	>169 °F (inner shell)	Impact created ~4 inch wide flat along the side. One closure lid bolt failed. No other damaged observed.
4	30 foot, CG-over-Top Corner (CTU-2)	132°	180°	>171 °F (inner shell)	Impact resulted in a ~1/2-inch fold on other shell. Five (5) of the closure lid bolts were sheared, with two (2) bolts remaining on opposite side.
5	Puncture Drop, Top Down (CTU-1)	180°	N/A	92 – 94 °F (outer surface)	Puncture bar impacted center of closure lid with no observed additional damage.
6	Puncture Drop, Side (CTU-2)	90°	0°	84 °F (outer surface)	Puncture bar struck side of package, resulting in small deformation of outer shell. No other damaged observed.
7	Puncture Drop, CG-over-Top Corner (CTU-2)	138°	180°	100 – 103 °F (outer surface)	Puncture bar struck outer shell/closure lid interface, resulting in a small "half-moon" deformed area. No other damaged observed.

Notes:
1. Tested 7/7/2020 and 7/8/2020.
2. Longitudinal angle is relative to vertical axis of packaging (i.e., 0º is upright).
3. Circumferential angle is relative to rotation of package around vertical axis.

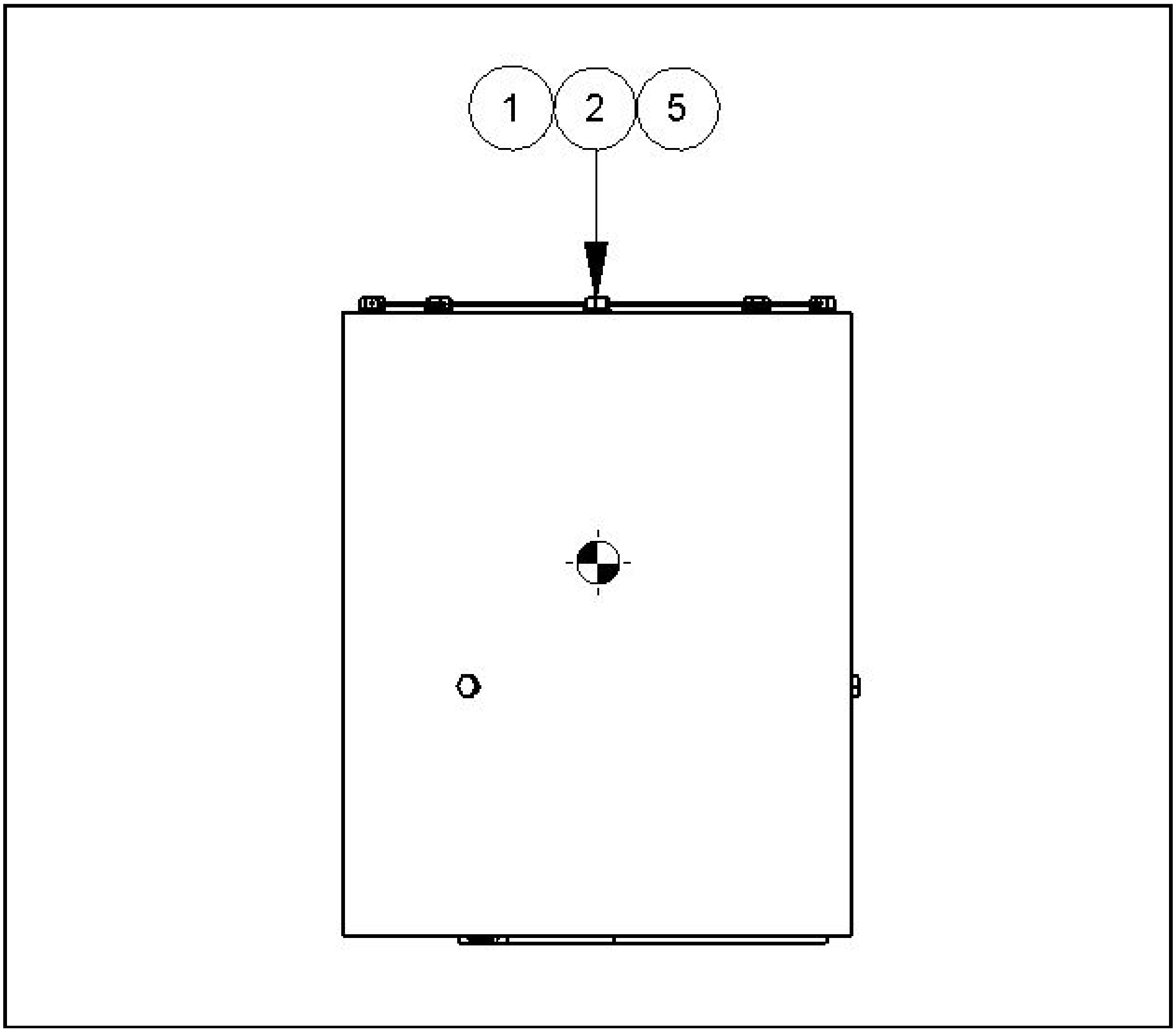


Figure 2.12.1-1 – Schematic Summary of CTU-1 Testing

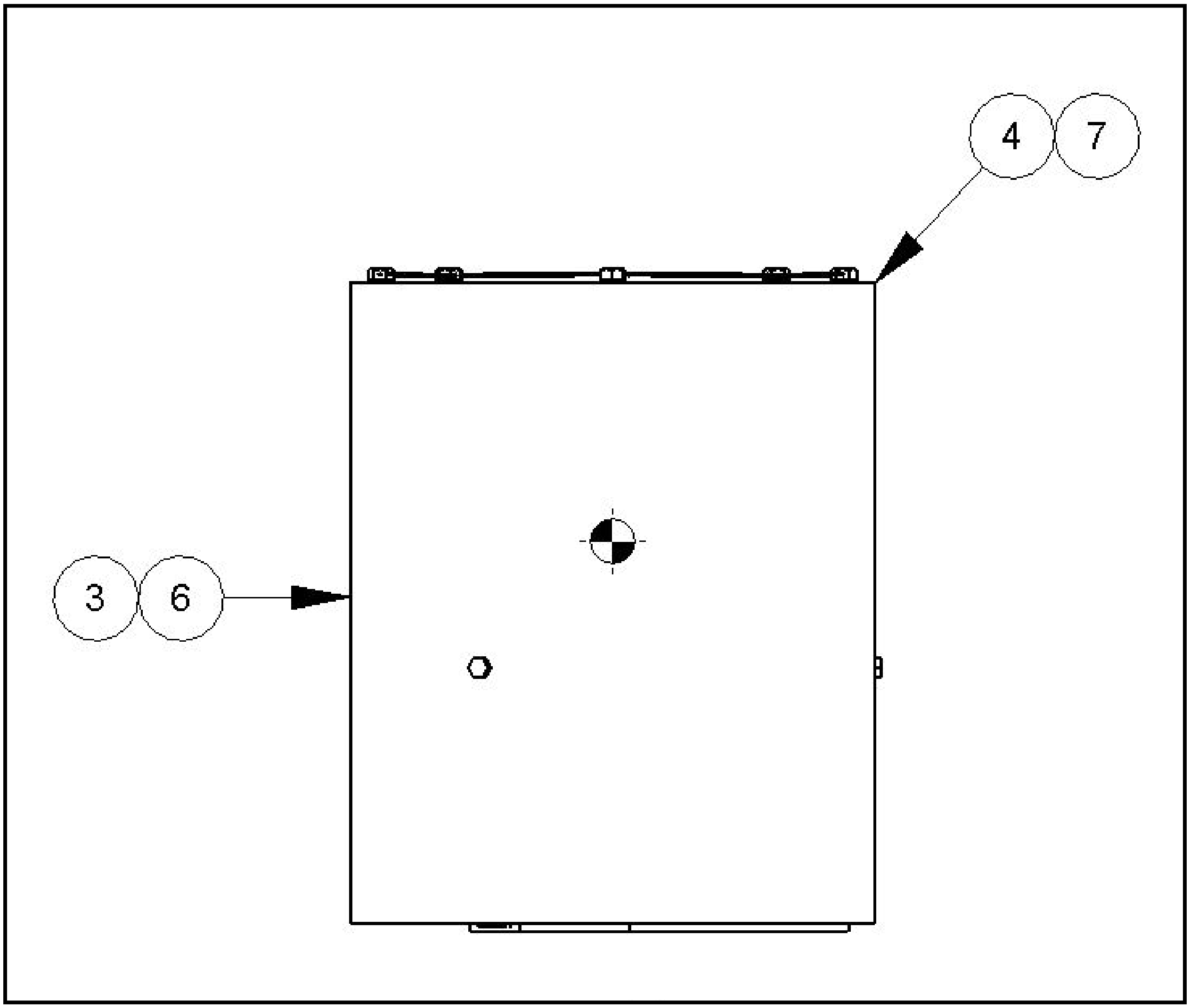


Figure 2.12.1-2 – Schematic Summary of CTU-2 Testing

Figure 2.12.1-3 – CTU-1 Free Drop Test No. 1: View of Test Setup

Figure 2.12.1-4 – CTU-1 Free Drop Test No. 1: View of Test Unit at Impact

Figure 2.12.1-5 – CTU-1 Free Drop Test No. 1: Close-up View of Lid Impact Area

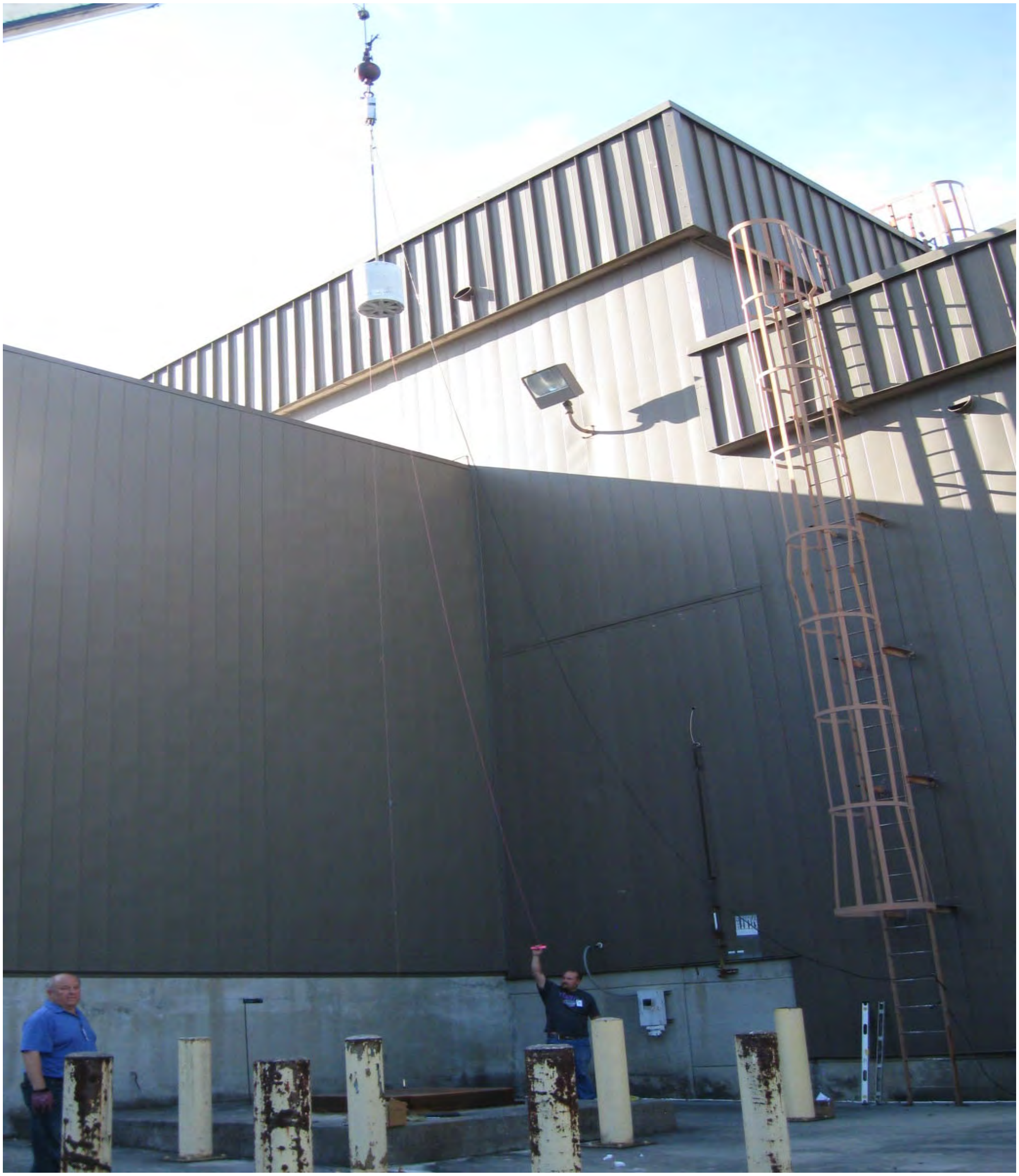


Figure 2.12.1-6 – CTU-1 Free Drop Test No. 2: View of Test Setup

Figure 2.12.1-7 – CTU-1 Free Drop Test No.2: View of Test Unit at Impact

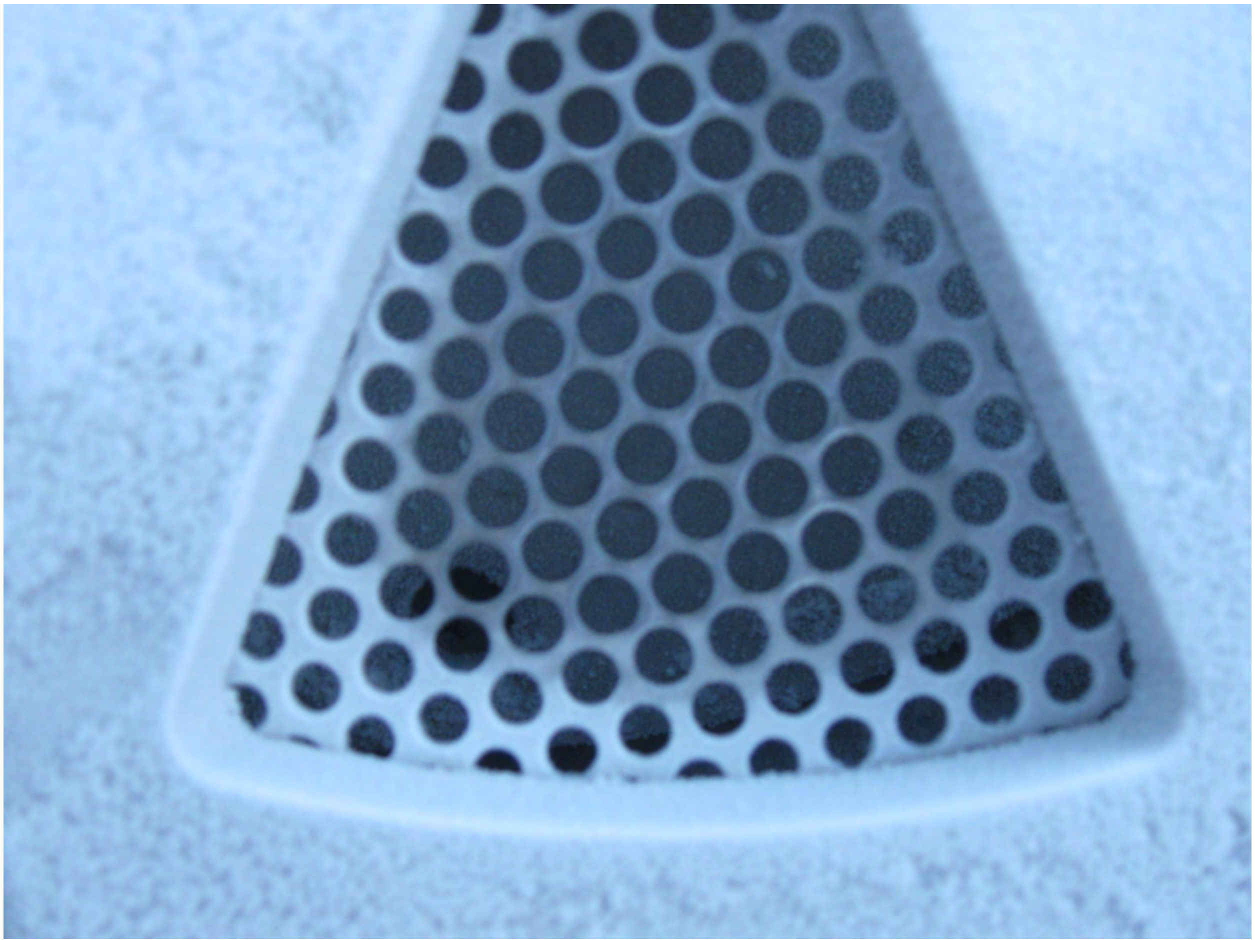


Figure 2.12.1-8 – CTU-1 Free Drop Test No. 2: Close-up View of Failed Inner Lid Bolt

Figure 2.12.1-9 – CTU-1 Puncture Drop Test No. 5: View of Test Setup

Figure 2.12.1-10 – CTU-1 Puncture Drop Test No. 5: Close-up View of Impact Closure Lid

Figure 2.12.1-11 – CTU-1 Post-Test Disassembly: Overall View of RMSC Payload

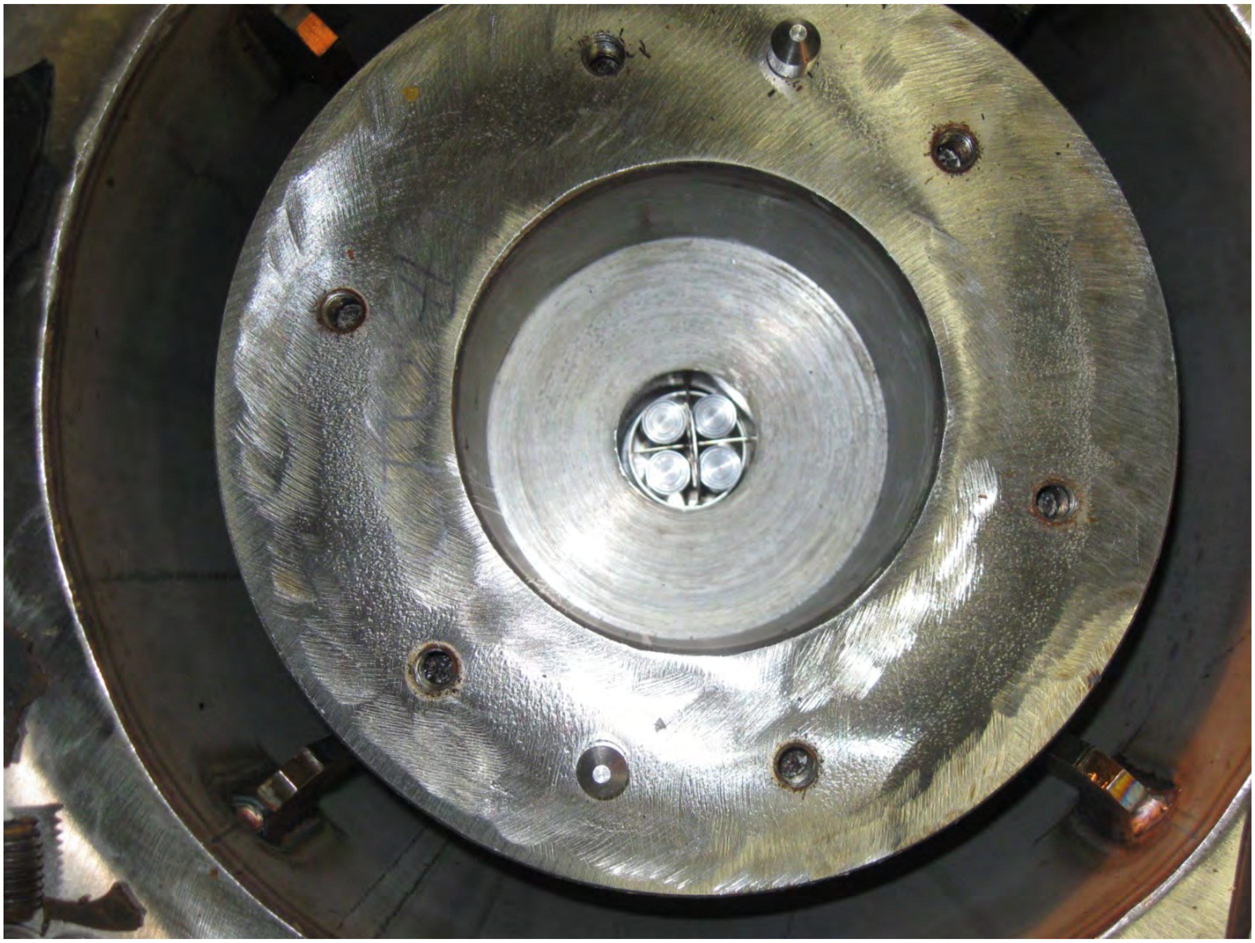


Figure 2.12.1-12 – CTU-1 Post-Test Disassembly: View of Dummy Sources, RMSC Payload

Figure 2.12.1-13– CTU-2 Free Drop Test No. 3: View of Test Setup

Figure 2.12.1-14 – CTU-2 Free Drop Test No. 3: Close-up View of Deformed Side Flat (~4 inch Width), Failed Closure Lid Bolt

Figure 2.12.1-15 – CTU-2 Free Drop Test No. 4: View of Test Setup

Figure 2.12.1-16 – CTU-2 Free Drop Test No. 4: View of Failed Closure Lid Bolts, Deformed Shell/Lid Interface

Figure 2.12.1-17 – CTU-2 Puncture Drop Test No. 6: View of Test Setup

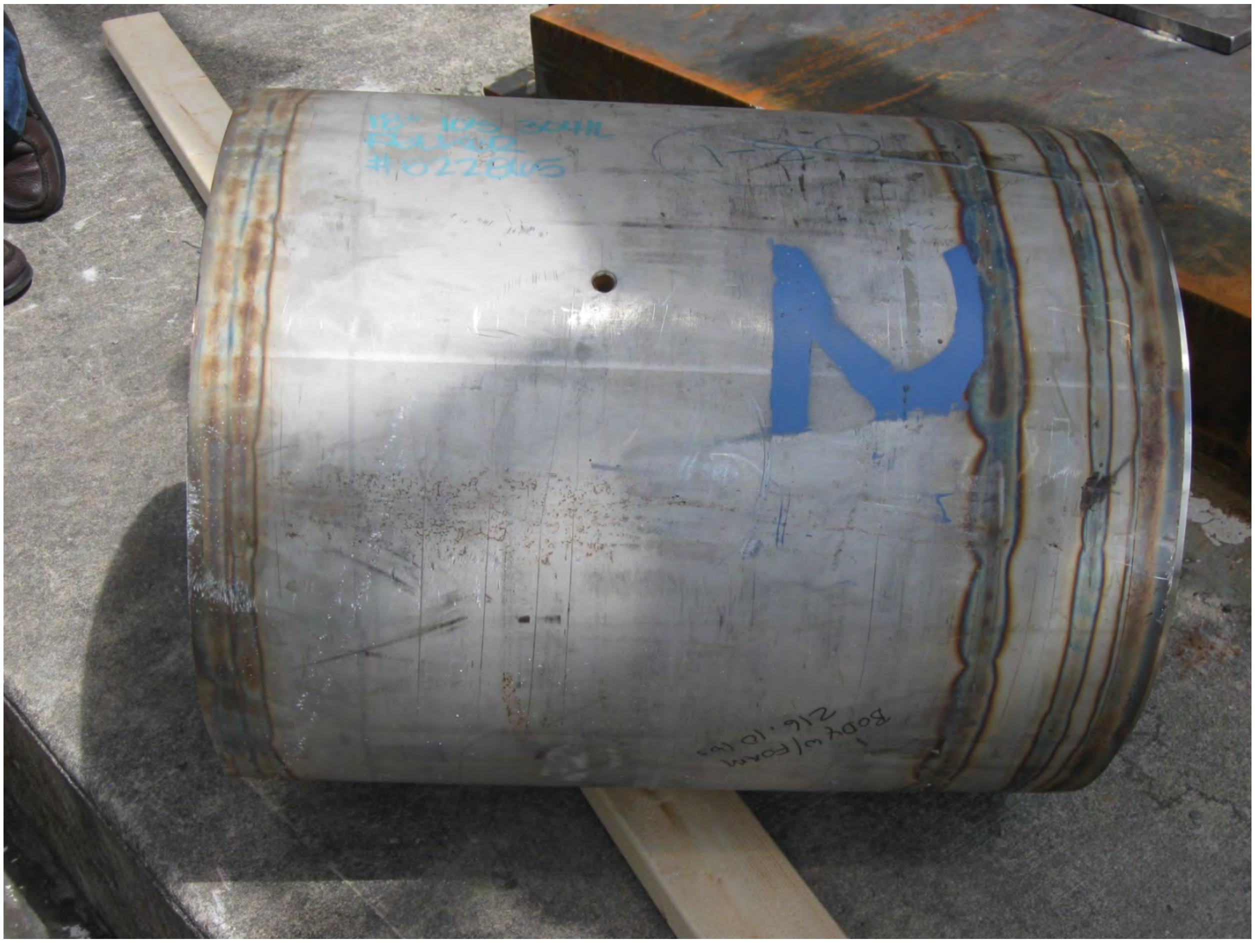


Figure 2.12.1-16 – CTU-2 Puncture Drop Test No. 6: Close-up View of Impact Area

Figure 2.12.1-19 – CTU-2 Puncture Drop Test No. 7: View of Test Setup

Figure 2.12.1-20 – CTU-2 Puncture Drop Test No. 7: Close-up View of Impact Area

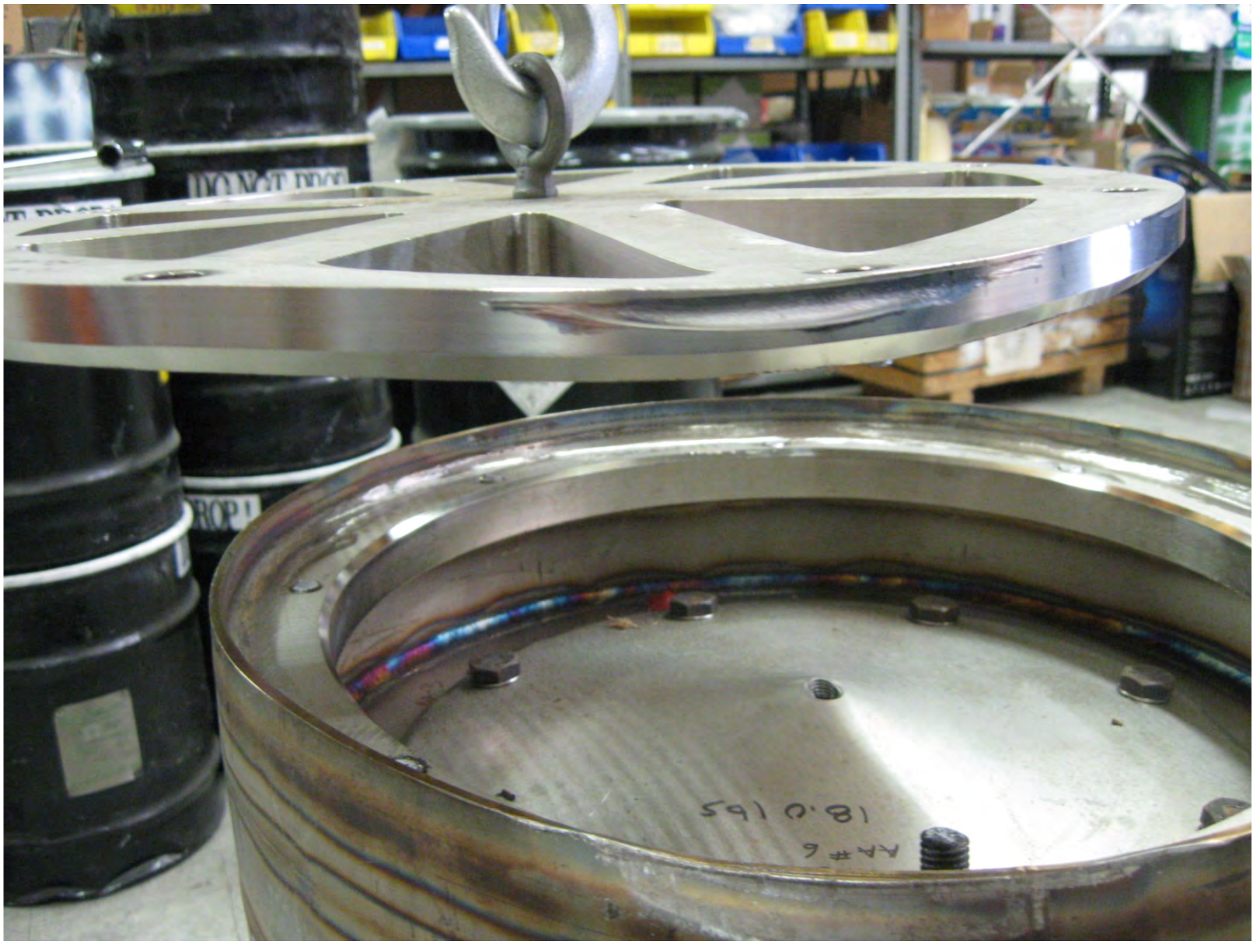


Figure 2.12.1-21 – CTU-2 Post-Test Disassembly: View of OP-RMSC Closure Lid w/ CG-Over-Top Corner Impact Damage

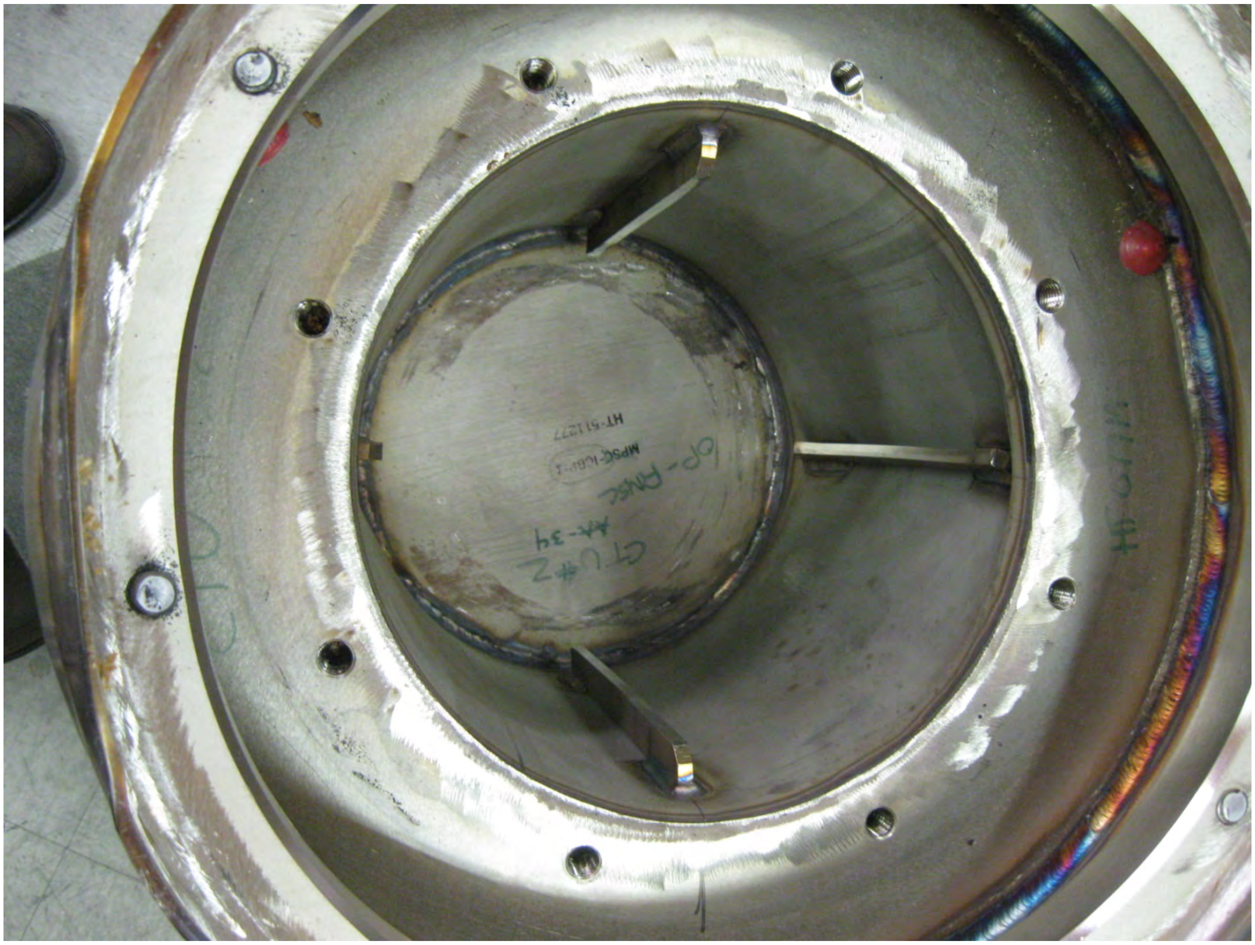


Figure 2.12.1-22 – CTU-2 Post-Test Disassembly: View of OP-RMSC Cavity w/ Side Impact Damage to Inner Wall (Left Side)

Figure 2.12.1-23 – CTU-2 Post-Test Disassembly: Overall View of RMSC Payload

3.0 THERMAL EVALUATION

This chapter establishes the compliance of the OP-RMSC transporting a payload of up to 16,000 Ci (592 TBq) of Ir-192 or Se-75 in special form with the thermal requirements of 10 CFR 71[10].

3.1 Description of Thermal Design

3.1.1 Design Features

The OP-RMSC package does not contain any specific thermal design features. The thermal performance of the package is demonstrated by test. Therefore, this section does not apply.

3.1.2 Content's Decay Heat

The OP-RMSC may contain up to 16,000 Ci (592 TBq) of Ir-192 or Se-75 in special form. The radiolytic decay heat of Ir-192 is 6.14×10^{-3} W/Ci [11]. The radiolytic decay heat of 2.41×10^{-3} W/Ci [9] for Se-75. Since the radiolytic decay heat of Ir-192 is greater than the radiolytic decay heat of Se-75, the heat load of Ir-192 payload bounds the Se-75 payload. Therefore, the maximum decay heat load for the OP-RMSC package is 100 W (341 Btu/hr) from the Ir-192 payload.

3.1.3 Summary Tables of Temperatures

Table 3.1-1 presents a summary of the maximum temperatures determined for the OP-RMSC package under NCT and HAC conditions for the maximum decay heat load of 100 W (341 Btu/hr). Further details of the NCT results are presented in Section 3.3, *Thermal Evaluation under Normal Conditions of Transport*. Similarly, further discussion of the HAC thermal analysis is provided in Section 3.4, *Thermal Evaluation under Hypothetical Accident Conditions*.

3.1.4 Summary Tables of Maximum Pressures

The containment of the OP-RMSC package is provided by the special form payload. Gas can freely move from the internal cavity to the environment during all phases of operation. Therefore, there are no internal pressures to be determined, since the OP-RMSC does not contain any pressure boundaries.

[10] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-20 Edition.

[11] *ORIGEN-S Decay Data Library and Half-Life Uncertainties*, O. W. Hermann, P. R. Daniel, and J. C. Ryman, Oak Ridge National Laboratory, ORNL/TM-13624, September 1998.

Table 3.1-1– Summary of Maximum Package Temperatures

Component	Temperature (°F)			
	NCT Hot [1]	HAC [1]	Maximum Allowable [2]	
			NCT	HAC
OP-RMSC Outer Lid	137	1,465	800	2,800
OP-RMSC Outer Shell	168	1,473	800	2,800
RMSC Lid	535	525	800	2,800
RMSC Body Shell	538	526	800	2,800
Tungsten Shields	555	536	2,732	2,732
Special Form Capsules	1,005	1,005	1,475	1,475
Personnel Barrier	100	N/A	800	N/A

Notes:

1. Peak temperatures determined assuming maximum decay heat load, solar insolation, and a constant ambient temperature of 100 °F (38 °C).
2. Maximum allowable temperatures are established in Section 3.2.2, *Component Specifications*.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The OP-RMSC package is constructed primarily of stainless steel pipe and plate welded assembly that surrounds a tungsten gamma shield. Since the structural integrity of the package is established by testing, the only pertinent temperature limits on the components is established by their melting temperatures for the fire-based Hypothetical Accident Condition (HAC). The melting temperatures for stainless steel and tungsten heavy metal are 2,800 °F (1,538 °C) and 2,732 °F (1,500 °C), respectively.

The payload was qualified per *Qualification of Special Form Radioactive Material,* in 10 CFR §71.75(b)(4).

3.2.2 Component Specifications

The OP-RMSC package does not contain any component or material that is important to the thermal performance of the package. The two primary packaging materials are austenitic stainless steel for structural and the tungsten heavy metal for shielding. As noted in Section 2.1.2.2.1, *Brittle Fracture*, both materials have been tested to temperatures below -20 °F (-29 °C) with no loss of structural or shielding capability. For NCT, the temperature limit for the stainless steel structural materials is limited to the maximum temperature limit of the Section II, Part D of the ASME B&PV Code, which is 800 °F (427 °C). For HAC, the limiting temperatures for the stainless steel structural and tungsten shielding materials are their respective melting temperatures, which are 2,800 °F (1,538 °C) and 2,732 °F (1,500 °C), respectively. For the special form capsules, the maximum allowable temperature is 1,475 °F (800 °C), which is the test temperature for special form qualification per 10 CFR §71.75(b)(4).

3.3 Thermal Evaluation under Normal Conditions of Transport

This section presents the thermal evaluation of the OP-RMSC package under the normal conditions of transport (NCT) per 10 CFR §71.71.

3.3.1 Heat and Cold

Since the total decay heat load of the OP-RMSC package is 100 W (341 Btu/hr), a detailed thermal analysis of the package with the RMSC payload was performed. The internal temperatures will very closely match those on the surface of the package. To determine the NCT maximum package and personnel barrier temperatures with and without insolation, a 3-D, half-symmetry thermal model was created utilizing ANSYS® finite element analysis (FEA) program[12]. To realistically reflect the gamma ray heating in the ANSYS® model, the decay heat was appropriately distributed between the source material, the special form capsules containing the source material, the holder, and the tungsten shields. The distribution of the decay heat within the RMSC components is provided in Table 3.3-1, with a view of the ANSYS® thermal model and the personnel barrier provided in Figure 3.3-1.

Per 10 CFR §71.71(c)(1), the worst-case high temperature condition for the package consists of an ambient temperature of 100 °F (38 °C) with maximum insolation. For this condition, the maximum surface temperature of the OP-RMSC is 168 °F (76 °C). The maximum surface temperature of the OP-RMSC in shade with an ambient temperature of 100 °F (38 °C) is 152 °F (67 °C). This temperature is greater than the maximum acceptable surface temperature of 122 °F (50 °C) for non-exclusive use shipments, as stipulated in 10 CFR §71.43(g). Therefore, a stainless steel expanded metal personnel barrier with a minimum open area of 75% is installed over the OP-RMSC after the package is secured to the transport pallet. With the personnel barrier installed, the maximum accessible surface temperature is 100 °F (38 °C), which allows the package to be shipped as a non-exclusive use shipment. Figure 3.3-2 provides the configuration of the package with the personnel barrier.

The presence of the barrier has negligible effect on heat transfer between the package surface and the environment. Convection is not affected because the distance between the barrier and the package, and the minimum 75% open area of the expanded metal ensures that the airflow around the package is not restricted. Radiant heat transfer to or from the package surface is not significantly affected since the minimum 75% opening of the barrier allows the package to "see" the ambient environment. Thus, approximately 25% of the barrier that the package sees is also very close to the ambient temperature.

The maximum temperature for any structural component in the OP-RMSC package with the 100 W (341 Btu/hr) in an ambient temperature of 100 °F (38 °C) with maximum insolation is 538 °F (281 °C), which occurs in the RMSC stainless steel outer shell. A summary of the maximum component temperatures for NCT is provided in Table 3.3-2.

The ANSYS® NCT thermal model results are illustrated in Figures 3.3-3 and 3.3-4 with and without insolation, respectively.

For the cold condition with zero decay heat, the package surface temperature will be equal to the low temperature ambient conditions of -20 °F (-29 °C) and -40 °F (-40 °C). For the structural

[12] *ANSYS® Finite Element Analysis Program*, Version 19.2, ANSYS Inc.

and shielding materials utilized in the OP-RMSC package, the sub-zero temperature has no effect on the ability of the package to maintain its confinement and shielding safety functions.

Table 3.3-1– Distribution of Gamma Decay Heat in RMSC Components

Maximum Nominal Decay Heat Load		100 W
Actual Decay Heat Load		98.02 W
Decay heat load attributed to gamma heating		77.42 W
Remainder		21.02 W
Component	**Gamma heating distribution (W)**	**Normalized to 100 W**
Ir-192 Source Material	68.7	70.0
Capsule	2.27	2.3
Holder	1.72	1.8
Top	0.40	0.40
Bottom	9.65	9.8
Side	15.4	15.7
Decay heat load from source material, holder, and capsule applied to the special form capsule		74.1 W
Top		0.40 W
Bottom		9.8 W
Side		15.7 W
Sum:		**100 W**

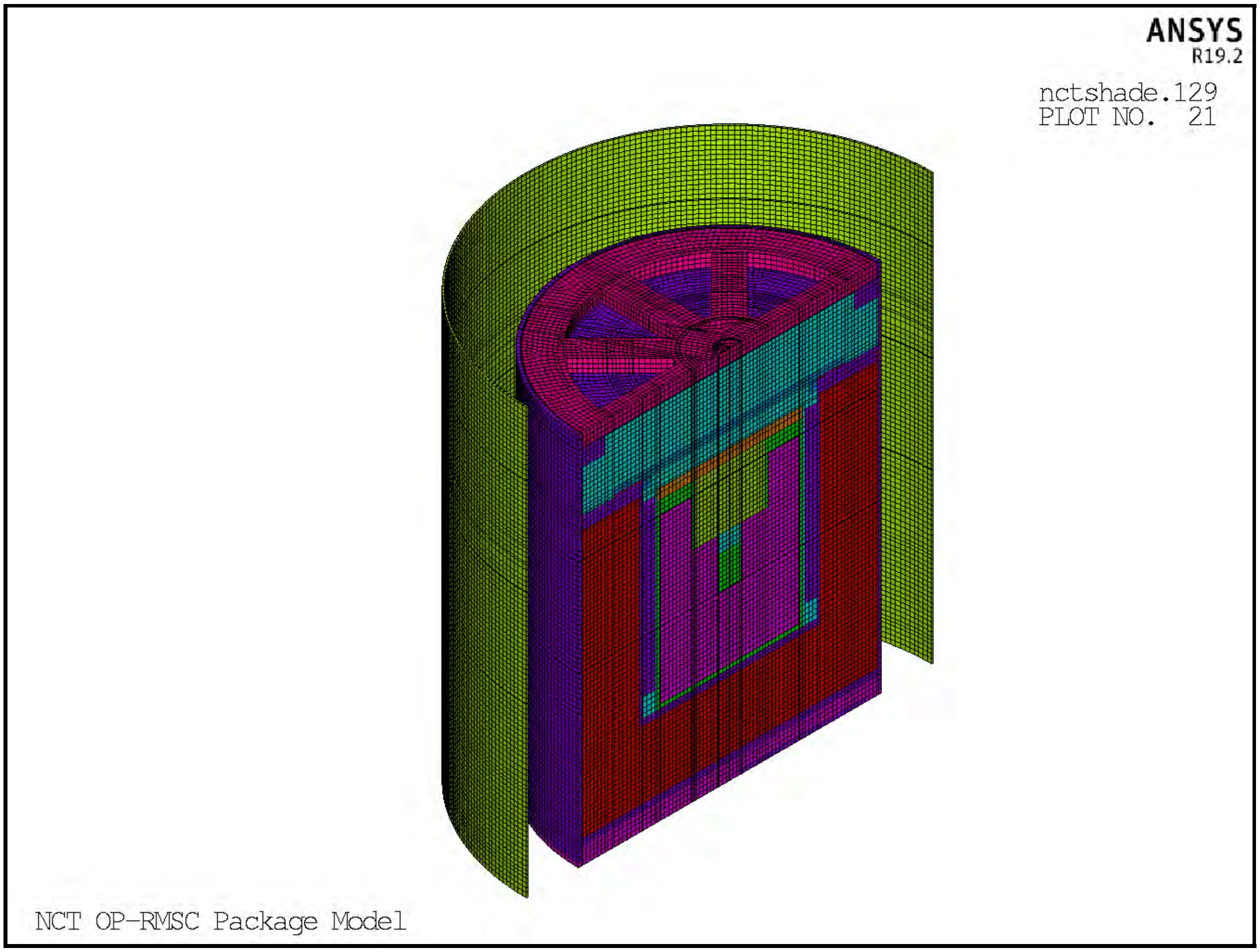


Figure 3.3-1 – ANSYS® Thermal Model of OP-RMSC Package and Personnel Barrier

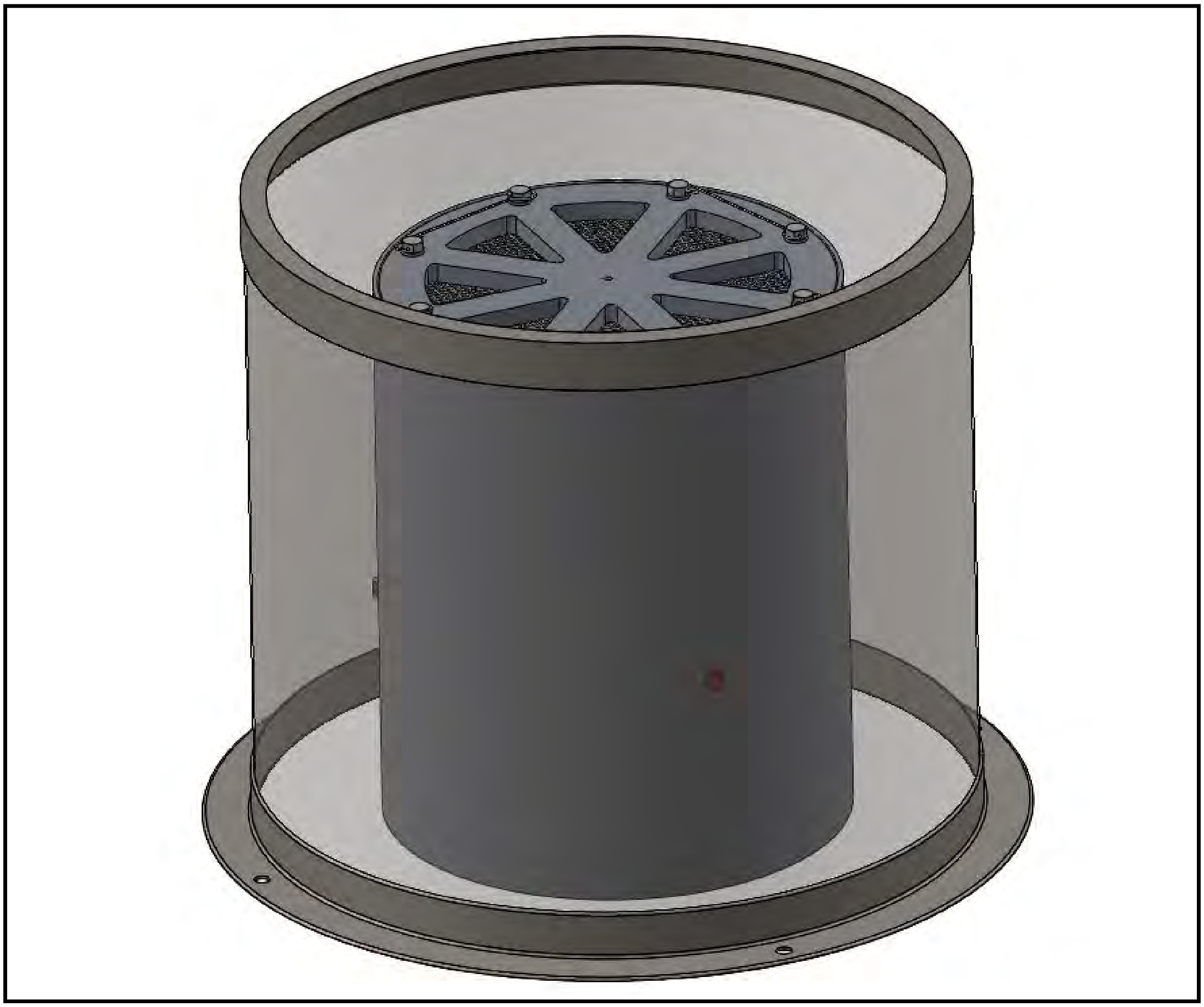


Figure 3.3-2 – View of OP-RMSC Package with Personnel Barrier

Table 3.3-2– Summary of Maximum NCT Component Temperatures

Component	Temperature (°F)	
	NCT, 100 °F, Shade	NCT, 100 °F, Solar
OP-RMSC Outer Lid	119	137
OP-RMSC Outer Shell	152	168
RMSC Lid	523	535
RMSC Body Shell	527	538
Tungsten Shields	543	555
Special Form Capsules	997	1,005
Personnel Barrier	100	N/A

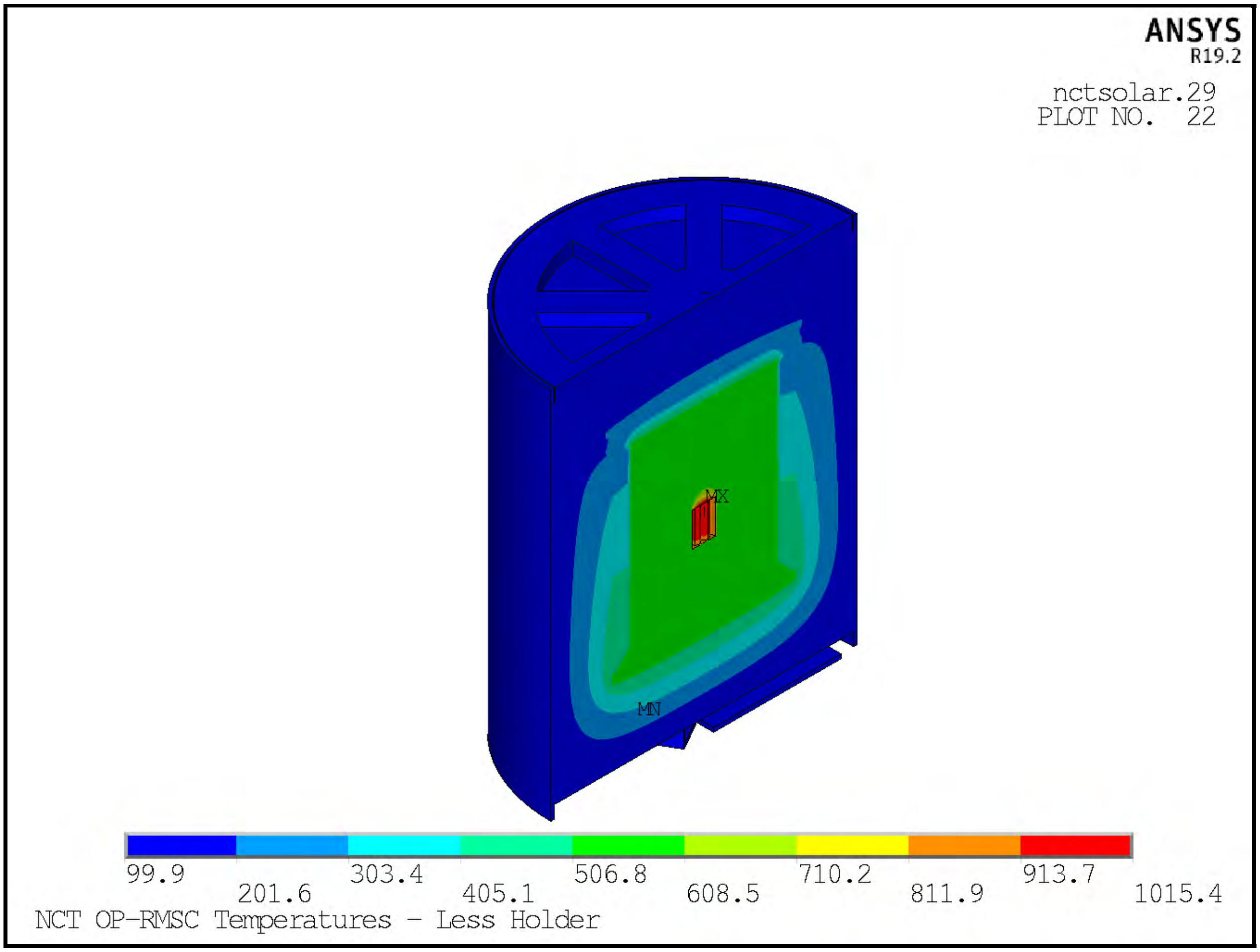


Figure 3.3-3 – OP-RMSC NCT Hot Temperature Profile with Insolation

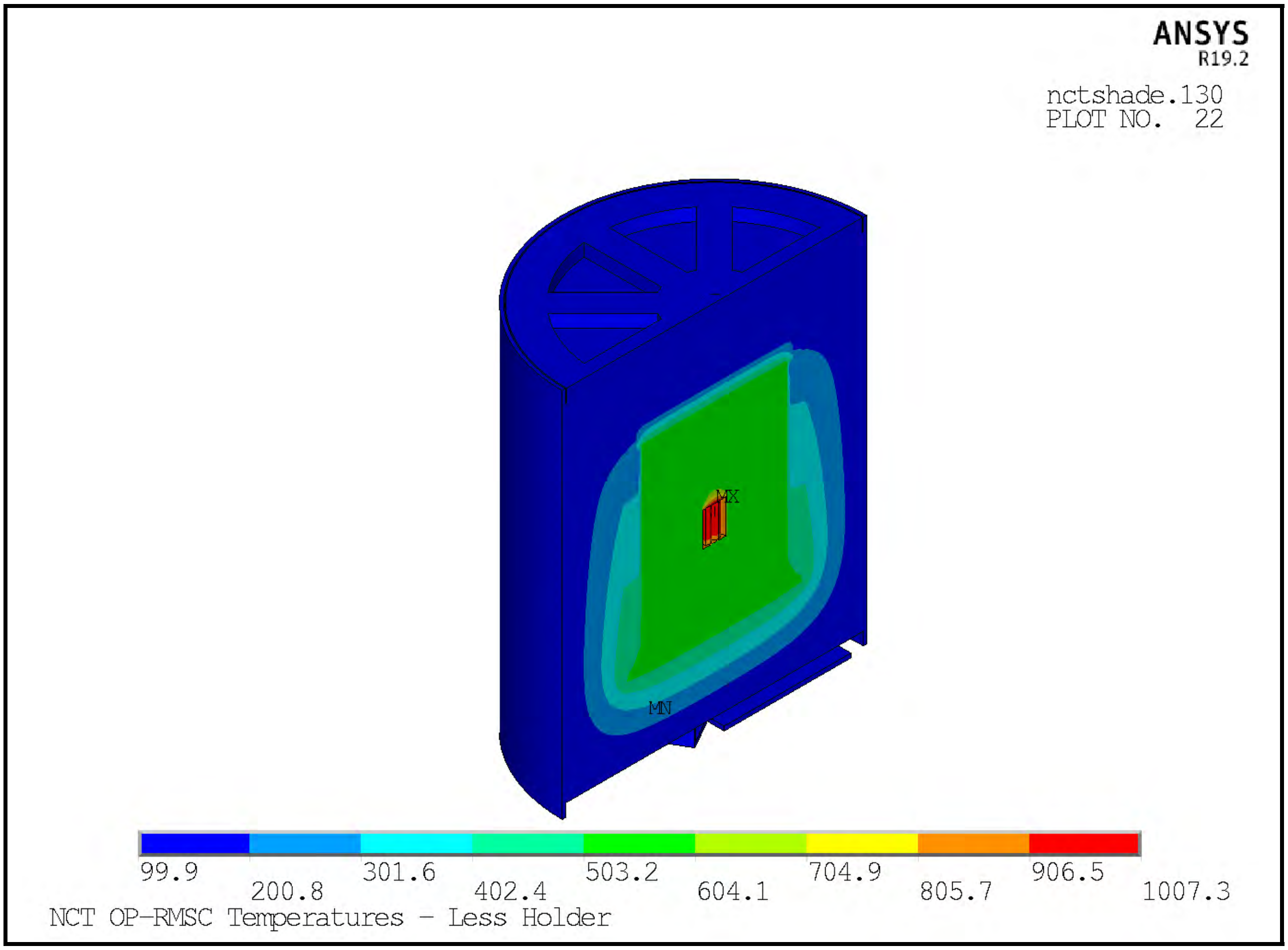


Figure 3.3-4 – OP-RMSC NCT Hot Temperature Profile without Insolation

Note: Maximum temperature of 1,007 °F is for the Special Form Capsule Holder and not the capsules.

3.3.2 Maximum Normal Operating Pressure

This section does not apply, since the OP-RMSC package does not contain any pressure boundaries. Therefore, there is no maximum normal operating pressure (MNOP) for the OP-RMSC package.

3.4 Thermal Evaluation under Hypothetical Accident Conditions

The thermal performance of the OP-RMSC package under Hypothetical Accident Conditions (HAC) in accordance with 10 CFR §71.73 requires that a test specimen must be exposed to a fully engulfing hydrocarbon fuel/air fire with an average flame temperature of 1,475 °F (800 °C) for a period of 30 minutes. The only combustible materials in the OP-RMSC packaging are the polyurethane foam and the silicone gasket, which are not a structural or shielding material. Since all of the structural and shielding materials (stainless steel and tungsten) have melting temperatures of 2,800 °F (1,538 °C) and 2,732 °F (1,500 °C), respectively, the OP-RMSC package is unaffected by the lower 1,475 °F (800 °C) temperature for the HAC fire event. However, a transient analysis of the ANSYS® model was performed to determine the effects of the HAC 30-minute fire event with the maximum 100 W (341 Btu/hr) decay heat load.

3.4.1 Initial Conditions

Thermal conditions prior to the HAC fire event were extracted from the ANSYS® NCT Hot (with insolation) condition, followed by a 30-minute transient with an ambient temperature of 1,475 °F, and then back to a steady-state ambient temperature of 100 °F (38 °C) with maximum decay heat and insolation per 10 CFR §71.71(c)(1). This case evaluated the peak temperature achieved for the various package components under the HAC fire event. The ANSYS® HAC model included forced convection heat transfer during the HAC fire event.

3.4.2 Fire Test Conditions

The fire test conditions analyzed to address the 10 CFR §71.73(c) requirements are as follows:

- The initial ambient conditions are assumed to be 100 °F (38 °C) ambient with insolation,
- At time = 0, a fully engulfing fire environment consisting of a 1,475 °F (800 °C) ambient with an effective emissivity of 1.0 is utilized to simulate the average flame temperature of the hydrocarbon fuel/air fire event. The assumption of an average flame emissivity coefficient of 1.0 conservatively bounds the minimum 0.9 flame emissivity specified by 10 CFR §71.73(c)(4).
- The convection heat transfer coefficients between the package and the ambient during the 30-minute fire event are based on an average gas velocity of 10 m/sec []. Following the 30-minute fire event, the convection coefficients are based on still air.
- The ambient condition of 100 °F with insolation is assumed following the 30-minute fire event. A solar absorptivity of 0.9 is assumed for the exterior surfaces to account for potential soot accumulation on the package surfaces.

The transient analysis is continued for 4.5 hours after the end of the 30-minute fire to capture the peak package temperatures.

3.4.3 Maximum Temperatures and Pressures

The maximum peak temperatures for the OP-RMSC package components with the 100 W (341 Btu/hr) decay heat under HAC conditions are provided in Table 3.4-1. Figures 3.4-1 and 3.4-2 illustrate the temperature profile within the OP-RMSC at the end of the 30-minute fire. Figures 3.4-3 and 3.4-4 illustrate the temperature response for selected package components. As expected, the package surface is demonstrated to reach a peak temperature of 1,473 °F (800 °C). The temperature response of the special form capsules is shown to be very insensitive to the fire heat load; maintaining a temperature of 1,004 °F (540 °C) until the end of the fire with a slight rise to 1,005 °F (541 °C) during the cool down period. The temperature of the special form capsules then return to their steady-state temperature value. Figure 3.4-5 illustrates the temperature profile of the package 24 hours after the fire, which demonstrates that the package rejects the effect of the fire relatively efficiently.

As demonstrated by these temperature results, the special form payload does not exceed the temperature for the special form certification per 10 CFR §71.75(b)(4).

The containment of the OP-RMSC package is provided by the special form payload. Gas can freely move from the internal cavity to the environment during all phases of operation, so determination of internal pressures is not required.

Therefore, the OP-RMSC package satisfies the HAC thermal requirements set forth in 10 CFR §71.73(c).

3.4.4 Maximum Thermal Stresses

The effects of HAC thermal stresses on the OP-RMSC package are minimal for the single event of the HAC fire. The maximum fire temperature for the welded structural package would not exceed 1,475 °F (800 °C), which would not result in any metal fatigue or detrimental condition that affects the shielding and confinement safety functions of the package. As demonstrated in Section 2.7.4, *Thermal*, there is no increase in the bolt tensile stress for any of the lid closures due differential thermal expansion. In addition, the thermal expansion coefficient for stainless steel is over three times the thermal expansion coefficient for tungsten heavy metal. Since the tungsten shields are not rigidly attached to the RMSC stainless steel, no significant thermal stresses will develop within the RMSC payload due to the maximum 1,475 °F (800 °C) fire temperature.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since the OP-RMSC does not contain fissile material.

Table 3.4-1 OP-RMSC HAC Temperatures

Component	Temperature (°F)			
	End of fire	Peak	Post-fire Steady-State	Max. Allowable
OP-RMSC Body	1,473	1,473	520	2,800
OP-RMSC Top Surface	1,465	1,465	136	2,800
OP-RMSC Side Surface	1,473	1,473	163	2,800
Polyurethane Foam (max)	1,470	1,470	520	N/A
Polyurethane Foam (avg)	552	552	229	N/A
OP-RMSC Outer Lid	1,460	1,460	136	2,800
OP-RMSC Inner Lid	830	848	212	2,800
RMSC Body	522	526	522	2,800
RMSC Lid	518	525	518	2,800
RMSC Tungsten Body Shield	536	536	536	2,732
RMSC Tungsten Cavity Shield	522	522	522	2,7,32
Special Form Capsule	1,005	1,005	1,005	1,475

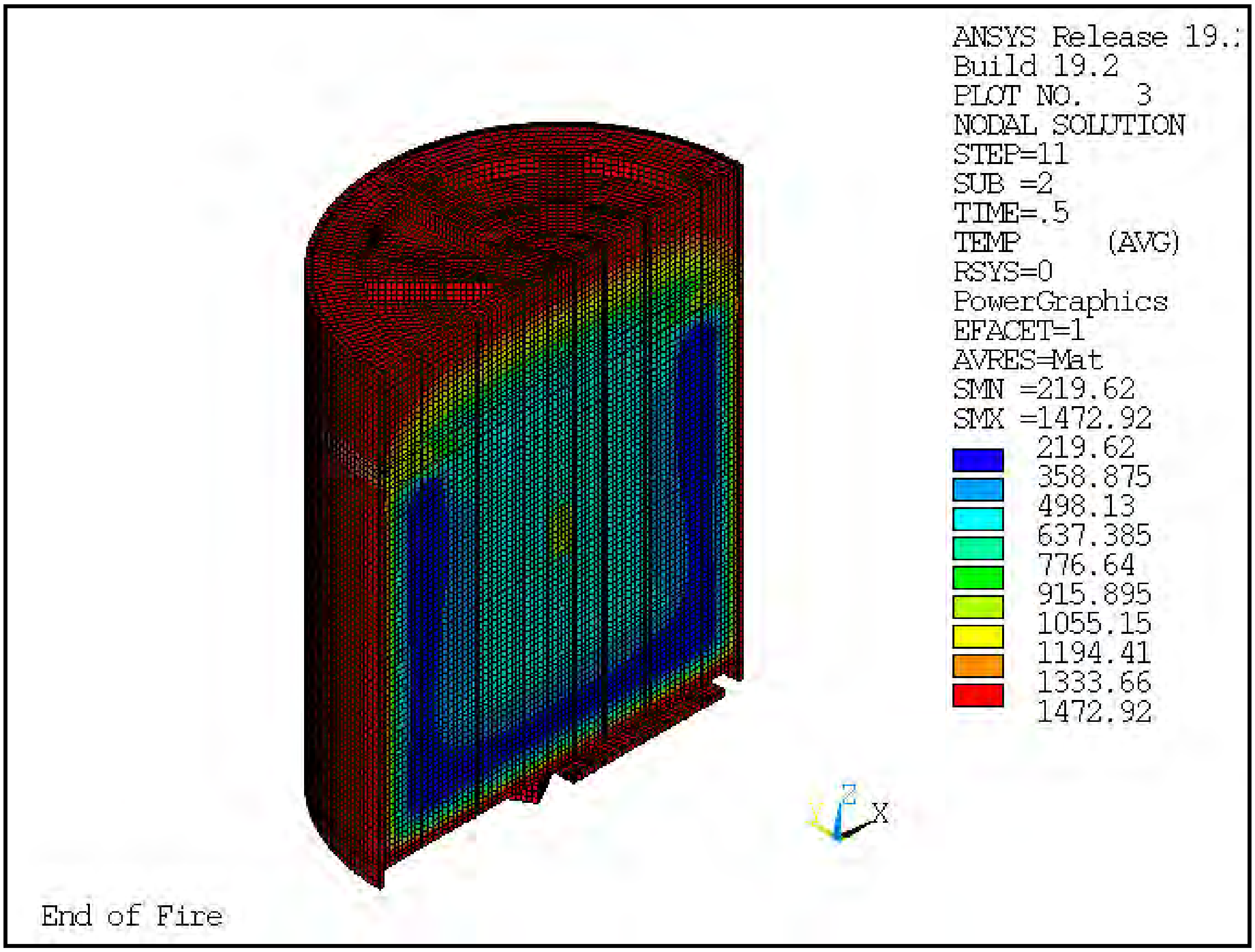


Figure 3.4-1 – OP-RMSC HAC Temperature Distribution at End of 30-minute Fire

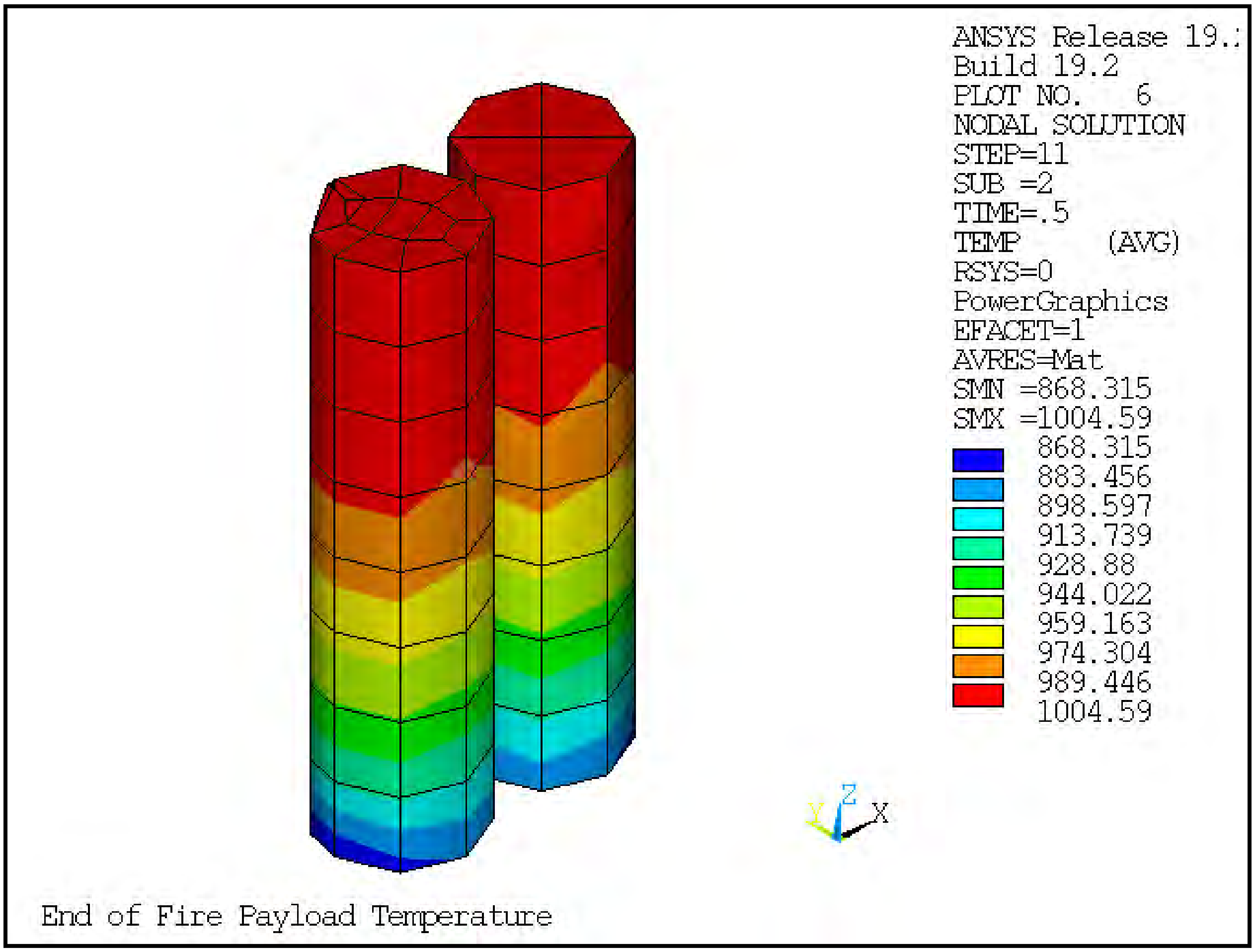


Figure 3.4-2 – Special Form Capsule Temperature Distribution at End of 30-minute Fire

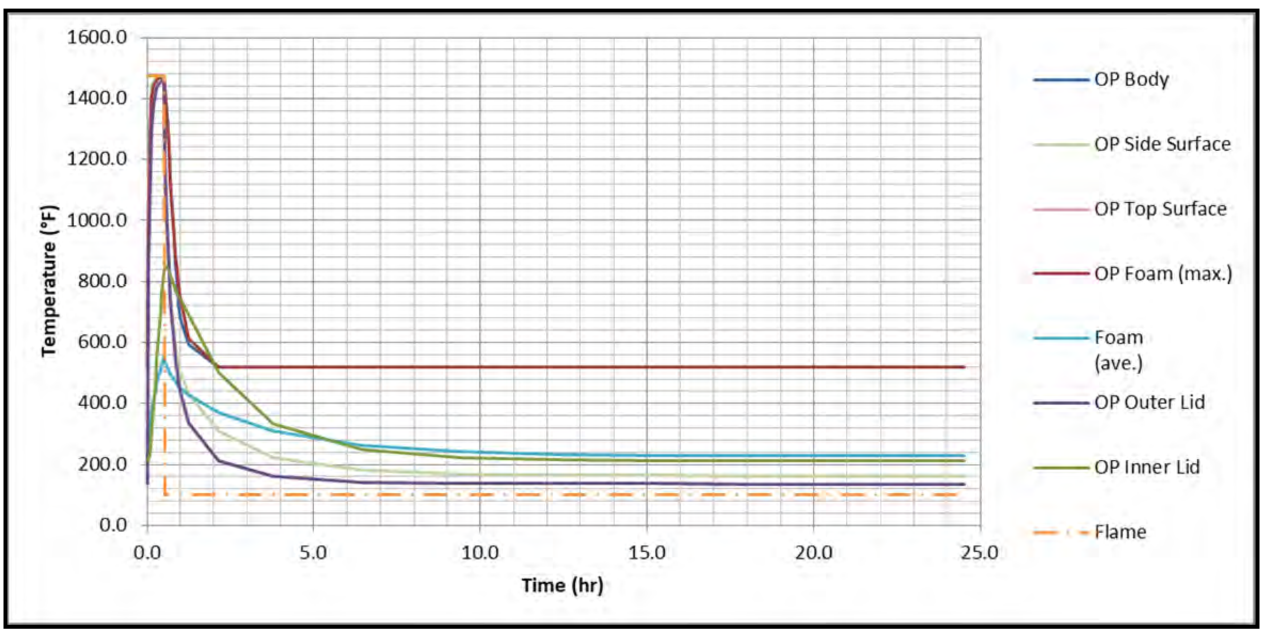


Figure 3.4-3 – OP-RMSC HAC Temperature Response

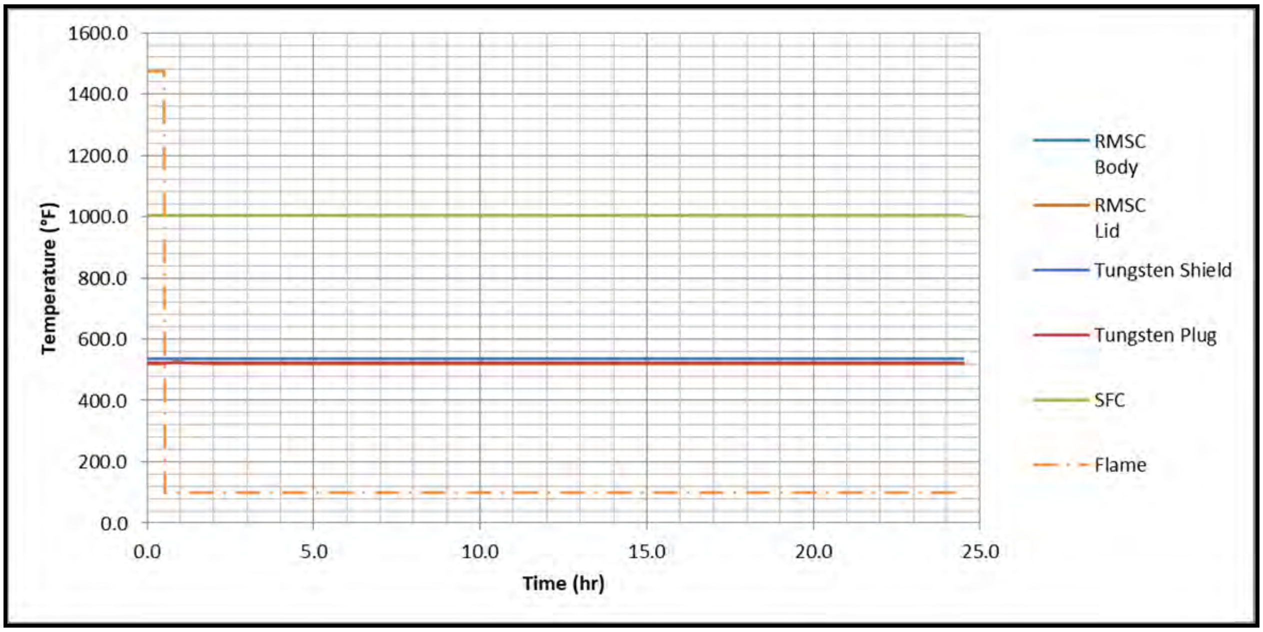


Figure 3.4-4 – RMSC HAC Temperature Response

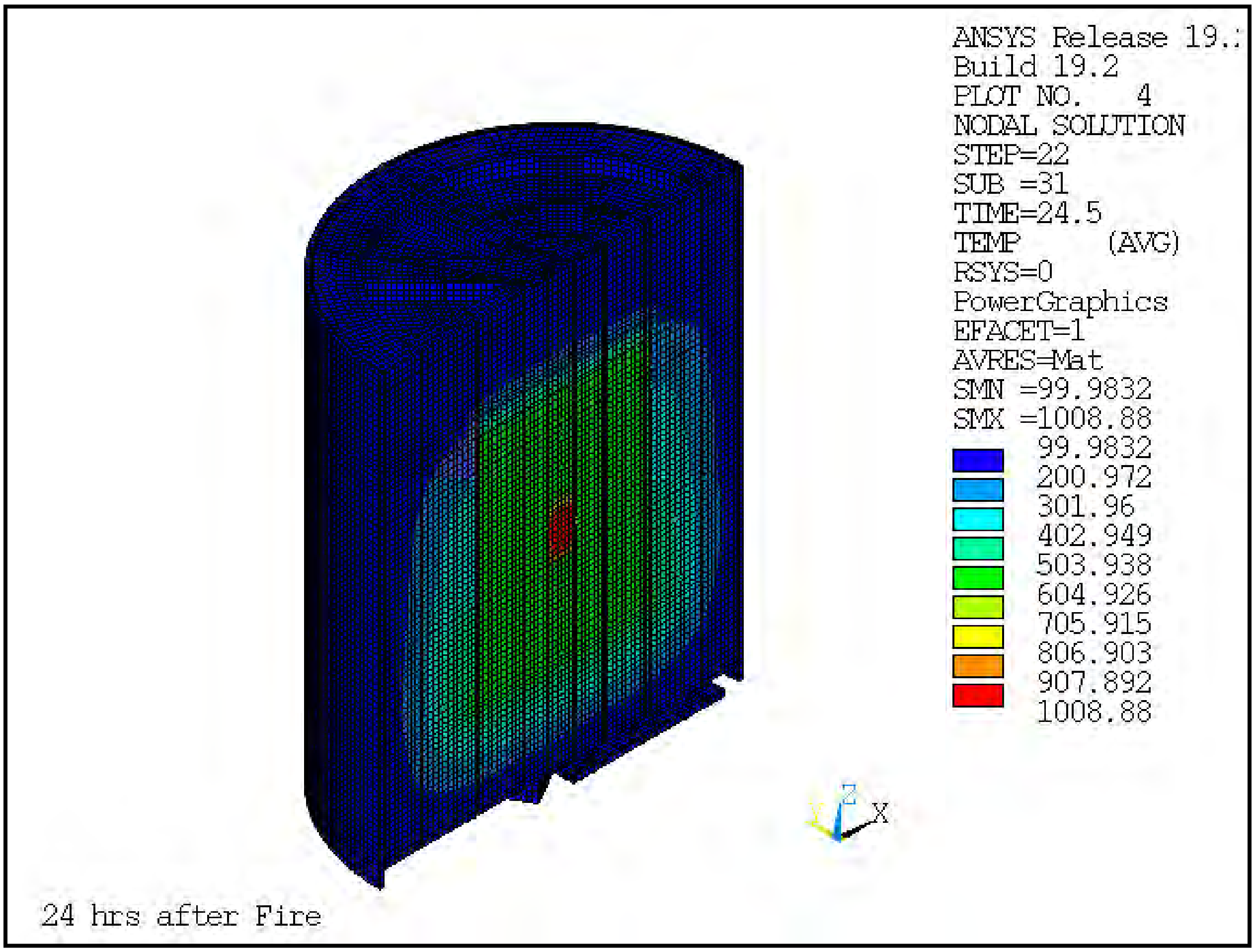


Figure 3.4-5 – OP-RMSC HAC Temperature Distribution at 24 hours After Fire

3.5 Appendix

3.5.1 Sample of ANSYS® Input File for NCT

```
!== DIMENSIONS
==================================================================
/PREP7
! (All dimensions are nominal)
esize1  = 0.5              ! nominal element size
esize2  = 0.25              ! vertical element size
SELTOL,.0001
tol=0.0005                 ! tolerance for merging the nodes
ndiv = 2                  ! multiplication factor on division
! Top Assembly (OP-RMSC-TA-1-2)
h0001 = 22.25              ! height of package from base to top of lid ((22.25) - OP_RMSC-OBA-1)
r0001 = 18.00/2            ! outer radius of package ((18.00) - OP-RMSC-OB-1)
h0002 = 0.125 - 0.013       ! neoprene gasket thickness minus 10% compression (OP-RMSC-TA-1-2,
Item 4)
r0002 = 13.75/2            ! neoprene gasket outer radius (ILA-1 radius) (OP-RMSC-TA-1-2, Item 4)
r0003 = 10.75/2 - 0.165      ! neoprene gasket inner radius (BICA-1 Item #2 IR, Ø 10" sch 10S pipe)
!-- OP RMSC Dimensions -------------------------------------------------------
! Outer Body Assembly
h0801 = 0.75               !  CR offset from OBW top edge
h0802 = 3.50               !  BIP offset from  top of CR
! Body inner cavity assembly (OP-RMSC-BICA-1)
h0901 = 12.63              ! height
h0902 =  1.13              ! RS offset from top of assembly
! Closure Ring (OP-RMSC-CR-1)
h1001 = 1.0                ! height (stock thickness)
r1001 = 17.59/2            ! outer radius
r1002 = 14.84/2            ! inner radius
! Outer Body (OP-RMSC-OB-1
h1101 = 22.00              ! height
r1101 = 18.00/2            ! outer radius, ([1]8" dia. Schedule 10S Pipe)
t1101 = 0.188              ! wall thickness, was .19
r1102 = r1101 - t1101       ! inner radius
! Closure Ring (OP-RMSC-BIP-1)
h1201 = 0.75               ! height (stock thickness)
r1201 = 17.46/2            ! outer radius
r1202 = 10.78/2            ! inner radius
! Inner Plate (OP-RMSC-IP-1)
h1301 = 0.38               ! height (stock thickness)
r1301 = 13.75/2            ! outer radius
```

```
! Inner Lid Ring (OP-RMSC-ILR-1)
h1401 = 0.50            ! height (stock thickness)
r1401 = 10.36/2         ! outer radius
r1402 = 9.36/2          ! inner radius
! Closure Lid (OP-RMSC-CL-1)
h1501 = 0.75            ! height (stock thickness)
r1501 = 17.5/2          ! outer radius
r1502 = 7.00            ! inner radius
! Perforated Sheet (OP-RMSC-PS-1)
r1601 = 14.5/2          ! radius of plate
h1601 = 0.06            ! stock thickness
pct1601 = 58            ! percentage of open area
! Bottom Plate Body (OP-RMSC-BBP-1)
h1701 = 0.38            ! plate stock thickness
r1701 = 17.59/2         ! outer radius
! Bottom Base Channel (OP-RMSC-BBC-3)
L1801 = 7.5             ! length
W1801 = 2.0             ! stock dimension
H1801 = 1.0             ! stock dimension
t1801 = 1/8             ! stock thickness
! Inner Cavity Bottom Plate (OP-RMSC-ICBP-1)
h1901 = 0.38            ! plate stock thickness
r1901 = 10.75/2         ! outer radius
! Inner Cavity Container Body (OP-RMSC-ICC-1)
h2001 = 12.25           ! height
r2001 = 10.75/2         ! outer radius, (10" dia. Schedule 10S Pipe)
t2001 = 0.165           ! wall thickness
r2002 = r2001 - t2001   ! inner radius
! Radial Spacer (OP-RMSC-RS-4)
h2101 = 10.00           ! height
w2101 = 0.75            ! width
t2101 = 0.25            ! stock thickness
! Personnel barrier
r_off_pb = 3                         ! Personnel Barrier radial offset from OP-RMSC shell
h_off_pb = 3                         ! Personnel Barrier vertical offset from OP-RMSC shell
t_pb = .095                          ! Personnel Barrier thickness
ophtdim = 18
*dim,op_ht,,ophtdim
op_ht(18) = h0001 + h_off_pb         ! top edge of personnel barrier 7.6.21 - amr
op_ht(15) = h0001                    ! top surface
op_ht(14) = op_ht(15) - h1501        ! bottom of closure lid
op_ht(16) = op_ht(14) - h1601        ! bottom of perforated plate
```

```
op_ht(13) = op_ht(14) - h1001         ! bottom of closure ring
op_ht(11) = op_ht(14) - h0802         ! top of inner closure ring
op_ht(17) = op_ht(11) + h0002         ! top of neoprene gasket
op_ht(12) = op_ht(17) + h1301         ! top of inner closure plate
op_ht(10) = op_ht(11) - h1401         ! botom of inner lid ring
op_ht(9)  = op_ht(11) - h1201         ! bottom of inner closure ring
op_ht(8)  = op_ht(11) - h0902         ! top of radial spacer
op_ht(7)  = op_ht(8)  - h2101         ! bottom of radial spacer
op_ht(6)  = op_ht(11) - h2001         ! bottom cavity plate top
op_ht(5)  = op_ht(6)  - h1901         ! bottom cavity plate bottom
op_ht(4)  = h1801 + h1701             ! bottom plate top
op_ht(3)  = h1801                     ! bottom plate bottom
op_ht(2)  = h0001 - h1101             ! bottom of body tube
op_ht(1)  = 0.00                      ! bottom of package
raddim1 = 15
          ! 7/6 - amr, personnel barrier addition
*dim,rad_op,,raddim1
rad_op(1) = r2002 - w2101             ! inner edge of radial spacers
rad_op(2) = r1402                     ! inner radius of inner lid ring
rad_op(3) = r1401                     ! outer radius of inner lid ring
rad_op(4) = r2002                     ! inner cavity container body inner radius
rad_op(5) = r2001                     ! inner cavity outer radius
rad_op(6) = r1301                     ! inner lid outer radius
rad_op(7) = r1002                     ! outer lid bolt flange inner radius
rad_op(8) = r1501                     ! outer lid outer radius
rad_op(9) = r1102                     ! outer shell inner radius
rad_op(10)= r1101                     ! outer shell outer radius
rad_op(11)= 7.000                     ! outer radius of lid vents
rad_op(12)= 2.500                     ! approximate inner radius of lid vents
rad_op(13)= r1601                     ! radius of perforated plate
rad_op(14)= r1101 + r_off_pb          ! inner radius of personal barrier
rad_op(15) = r1101 + r_off_pb + t_pb  ! outer radius of personnel barrier
!-- RMSC Dimensions ----------------------------------------------------------
feltg = 0 !0.125          ! felt pad layer
! Stainless Steel Pipe Outer Shell (RMSC-BODY-1)
h0101 = 10.75             ! height
r0101 = 8.63/2            ! outer radius, (8" dia. Schedule 10S Pipe)
t0101 = 0.148             ! wall thickness
r0102 = r0101 - t0101     ! inner radius
! Body Upper Center Pipe (RMSC-BUCP-1)
h0201 = 3.55              ! height
r0201 = 4.50/2            ! outer radius, (4" dia. Schedule 10S Pipe)
```

```
t0201 = 0.120               ! wall thickness
r0202 = r0201 - t0201       ! inner radius
! Body Top Plate (RMSC-BTP-1)
h0301 = 0.75                ! height (stock thickness)
r0301 = 8.30/2              ! outer radius
r0302 = 4.50/2              ! inner radius
! Tungsten body shield (RMSC-TBS-1)
h0401 = 9.70                ! height
h0402 = 5.75                ! cavity depth
h0403 = 2.75                ! cavity shield hole depth
r0401 = 1.50/2              ! inner radius
r0402 = 4.60/2              ! cavity shield hole radius
r0403 = 8.20/2              ! outer radius
! Body Shell Bottom Plate (RMSC-BBP-1)
h0501 = 0.25                ! plate stock thickness
r0501 = 8.20/2              ! outer radius
! Lid Top Plate (RMSC-LTP-1)
h0601 = 0.63                ! height (stock thickness)
r0601 = 8.63/2              ! outer radius
! Tungsten cavity shield (plug) (RMSC-TNGS-1)
h0701 = 3.55                ! height
r0701 = 4.20/2              ! radius
! Special Form Capsule Basket (SPFC Basket)
h2201 = 2.000               ! height
r2201 = 1.375/2             ! outer radius
plgap = 0.010               ! contact from sfc to rmsc - replaced with t2201 - amr
t2201 = .035                            ! thickness of basket base and side = 2.035-2 - amr
! Payload
h3201 = h2201                           ! Height
r3201 = .5/2                            ! payload radius
rmschtdim = 11                          ! added basket bottom plate
*dim,rmsc_ht,,rmschtdim
rmsc_ht(1)  = feltg                 ! felt top/bottom plate bottom surface
rmsc_ht(2)  = h0501  + rmsc_ht(1)       ! bottom plate top surface
rmsc_ht(3)  = rmsc_ht(2) + h0401 - h0402 ! TS cavity bottom
rmsc_ht(4)  = rmsc_ht(3) + plgap        ! bottom of payload basket
rmsc_ht(5)  = rmsc_ht(4) + t2201                    ! bottom of payload - amr
rmsc_ht(6)  = rmsc_ht(4) + h2201        ! top of payload
rmsc_ht(7)  = rmsc_ht(2) + h0401 - h0403 ! TS plug bottom
rmsc_ht(8)  = rmsc_ht(2) + h0401        ! TS top
rmsc_ht(9)  = h0101 - h0301           ! rmsc body top plate bottom
rmsc_ht(10) = h0101                   ! rmsc body top plate top
```

```
rmsc_ht(11) = h0101 + h0601             ! rmsc lid top plate top
raddim2 = 10
*dim,rad_rmsc,,raddim2
rad_rmsc(1)  = r2201 - t2201      ! payload basked inner radius - amr
rad_rmsc(2)  = r2201                ! payload basket outer radius - amr
rad_rmsc(3)  = r0401                ! TBS inner cavity radius
rad_rmsc(4)  = r0701                ! plug radius
rad_rmsc(5)  = r0202                ! BUCP inner radius
rad_rmsc(6)  = r0201                ! BUCP outer radius
rad_rmsc(7)  = r0402                ! TBS shield hole radius
rad_rmsc(8)  = r0403                ! TBS outer radius
rad_rmsc(9)  = r0102                ! Body inner radius
rad_rmsc(10) = r0101                ! BODY/lid outer radius
! offset rmsc to outer package bottom cavity plate top
*do,i,1,rmschtdim
  rmsc_ht(i) = rmsc_ht(i) + op_ht(6)
*enddo
!-- axial meshing array ------------------------------------------------------
heightdim = ophtdim + rmschtdim
*DIM,height,,heightdim
*do,i,1,ophtdim,
  height(i) = op_ht(i)
*enddo
*do,i,ophtdim+1,heightdim
  height(i) = rmsc_ht(i-ophtdim)
*enddo
! .. bubblesort ...............................................................
*do,i,(heightdim),1,-1
  *do,j,2,i,1
    *if,height(j-1),gt,height(j),then
      /COM,heights were out of order - Fixed!
      temp = height(j-1)
      height(j-1)=height(j)
      height(j)=temp
    *endif
  *enddo
*enddo
!-- radial meshing array ------------------------------------------------------
raddim = raddim1 + raddim2
*dim,radius,,raddim
*do,i,1,raddim1,
  radius(i) = rad_op(i)
```

```
*enddo
*do,i,raddim1+1,raddim
  radius(i) = rad_rmsc(i-raddim1)
*enddo
! .. bubblesort (error check/fix)...............................................
*do,i,(raddim),1,-1
  *do,j,2,i,1
    *if,radius(j-1),gt,radius(j),then
      /COM,radii out of order
      temp = radius(j-1)
      radius(j-1)=radius(j)
      radius(j)=temp
    *endif
  *enddo
*enddo
finish
!== MESHING ELEMENT SETTINGS
=========================================================
!           .1 - added insolation shell elements
/prep7
 ET,1,PLANE55                ! 2-D thermal
ET,2,SOLID70                 ! 3-D solid thermal
KEYOPT,2,2,1
KEYOPT,2,4,0
KEYOPT,2,7,0
KEYOPT,2,8,0
ET,3,SURF152
!KEYOPT,3,1,0
!KEYOPT,3,2,0
KEYOPT,3,3,2
KEYOPT,3,4,1
KEYOPT,3,5,0
!KEYOPT,3,6,0
KEYOPT,3,7,0
KEYOPT,3,8,3
KEYOPT,3,9,0
ET,4,SHELL131
KEYOPT,4,2,1
KEYOPT,4,3,2
ET,5,SHELL131
KEYOPT,5,3,2
ET,6,MATRIX50
```

```
KEYOPT,6,1,1
ET,7,SURF152 ! Shell for insolation horizontal flat surfaces
KEYOPT,7,1,0
KEYOPT,7,2,0
KEYOPT,7,3,0
KEYOPT,7,4,1
KEYOPT,7,5,0
KEYOPT,7,6,0
KEYOPT,7,7,0
KEYOPT,7,8,1
KEYOPT,7,9,0
ET,8,SURF152 ! Shell for insolation horizontal perf sheet
KEYOPT,8,1,0
KEYOPT,8,2,0
KEYOPT,8,3,0
KEYOPT,8,4,1
KEYOPT,8,5,0
KEYOPT,8,6,0
KEYOPT,8,7,0
KEYOPT,8,8,1
KEYOPT,8,9,0
ET,9,SURF152 ! Shell for insolation vertical surfaces (outer shell and lid vent surfaces)
KEYOPT,9,1,0
KEYOPT,9,2,0
KEYOPT,9,3,0
KEYOPT,9,4,1
KEYOPT,9,5,0
KEYOPT,9,6,0
KEYOPT,9,7,0
KEYOPT,9,8,1
KEYOPT,9,9,0
ET,10,SURF152        ! Shell for insolation inner lid vertical surfaces
KEYOPT,10,1,0
KEYOPT,10,2,0
KEYOPT,10,3,0
KEYOPT,10,4,1
KEYOPT,10,5,0
KEYOPT,10,6,0
KEYOPT,10,7,0
KEYOPT,10,8,1
KEYOPT,10,9,0
ET,11,SURF152        ! Shell for convection
```

```
KEYOPT,11,4,1
KEYOPT,11,5,0
KEYOPT,11,7,0
KEYOPT,11,8,3           ! evaluates heat flux at surface temp (TS)
KEYOPT,11,9,0
ET,12,SURF152           ! Shell for Heat load horizontal flat surfaces Tungsten Shield
KEYOPT,12,1,0
KEYOPT,12,2,0
KEYOPT,12,3,0
KEYOPT,12,4,1
KEYOPT,12,5,0
KEYOPT,12,6,0
KEYOPT,12,7,0
KEYOPT,12,8,1
KEYOPT,12,9,0
ET,13,SURF152           ! Shell for insolation vertical curved surfaces Tungsten Shield
KEYOPT,13,1,0
KEYOPT,13,2,0
KEYOPT,13,3,0
KEYOPT,13,4,1
KEYOPT,13,5,0
KEYOPT,13,6,0
KEYOPT,13,7,0
KEYOPT,13,8,1
KEYOPT,13,9,0
ET,14,SURF152           ! Shell for insolation horizontal Tungsten Plug
KEYOPT,14,1,0
KEYOPT,14,2,0
KEYOPT,14,3,0
KEYOPT,14,4,1
KEYOPT,14,5,0
KEYOPT,14,6,0
KEYOPT,14,7,0
KEYOPT,14,8,1
KEYOPT,14,9,0
R,1,
R,5,,,,,,
RMORE,.0001 ! dummy thickness for 152 surface elements
finish------------------------------------------------------------------
! ---------------------------------------------------------------------------
```

3.5.2 Sample of ANSYS® Input File for HAC

```
!!!! = Initial Setup ================================================================
! Orano Federal Services 9-07-2021
finish
/clear,start
! - load model file ------------------------------------------------------------
RESUME,..\mesh\package.f1,db
! - define run descriptors ------------------------------------------------------
/title, OP-RMSC HAC Fire
/filnam,hacfire.f1,db
! - define loads and key temperatures ------------------------------------------
/PREP7
Q=100        ! Watts
Tambt=100    ! Ambient temperature
Tfire=1475   ! Fire temperature
Q=Q*3.412    ! Decay heat load, change Watts to BTU/hr
PI=3.14159   ! approximate ratio of the circumference of a circle to its diameter
! - Define number of load steps
nstpf=10      ! no. of steps during 0.5 hr fire
nstcd=10      ! no. of steps in initial 0.5 hr of cooldown
duration = 24  ! duration of cooldown in hours
! = Calculate Loads ===================================================================
! calculate internal heat load per unit area/volume - capsule
esel,s,mat,,10
*get,Emin,elem,0,num,min
*get,Emax,elem,,num,max
*get,Ecnt,elem,,count
! determine modeled payload volume
VTot_sfc=0
Enum=Emin
*do,Vcnt,1,Ecnt,1
   *get,Evol,elem,Enum,volu
   VTot_sfc=VTot_sfc+Evol
   *get,Enum,elem,Enum,NXTH
*enddo
dhflx_sfc = Q*0.741/(2*Vtot_sfc)
! calculate dispersed heat loads - basket
dhflx_top = (Q* 0.4/100)/(PI*rad_rmsc(3)**2)
dhflx_bot = (Q* 9.8/100)/(PI*rad_rmsc(3)**2)
dhflx_side= (Q*15.7/100)/(2*PI*rad_rmsc(3)*h2201)
! - Define surface emissivities ------------------------------------------------
emis_ws=0.45    ! Emissivity of weathered stainless
```

```
emis_st=0.8     ! Emissivity of soot
emis_fr=1.0     ! Emissivity of fire
abs_ws =0.52    ! Solar absorptivity of stainless steel
abs_st= 0.90    ! Solar absorptivity of sooted surface
! - Define initial surface convective heat flux (radiation and convection) -----
HTOT_HFPU,Tambt,r0001*2,41,emis_ws          ! Top flat surface of package
HTOT_VCYL,Tambt,r0001*2,42,emis_ws,h0001     ! Vertical cylinder (body)
HTOT_HFPU,Tambt,3.0,43,emis_ws              ! Top flat surface of vents
HTOT_VP,Tambt,h1501,44,emis_ws              ! edge surface of lid vent holes
HTOT_HFPD,Tambt,r0001*2,45,emis_ws          ! bottom edge of outer shell
HTOT_HFPD,Tambt,r0001*2,47,emis_ws          ! bottom surfaces of package
! - Fire surface properties set at fire temperature ---------------------------
HTOT_FIRE,Tfire,emis_fr,500,emis_st
! - Define cooldown surface convective heat flux (radiation and convection)
HTOT_HFPU,Tambt,r0001*2,401,emis_st          ! Top flat surface of package
HTOT_VCYL,Tambt,r0001*2,402,emis_st,h0001     ! Vertical cylinder (body)
HTOT_HFPU,Tambt,3.0,403,emis_st              ! Top flat surface of vents
HTOT_VP,Tambt,h1501,404,emis_st              ! edge surface of lid vent holes
HTOT_HFPD,Tambt,r0001*2,405,emis_st          ! bottom edge of outer shell
HTOT_HFPD,Tambt,r0001*2,407,emis_st          ! bottom surfaces of package
! - Define insolation heat fluxes on package ----------------------------------
!Insolation Heat Load per 10CFR71.71(c)(1)
!cask has 12 hour heat load averaged over the entire 24 hour period
! The inner cover has limited view for solar.  Insolation is multiplied by 1/2 X
! 1/3 X .58 = 10% where 1/2 accounts for 90° is the range of the sun shining
! through the outer lid slots, 1/3 is the proportional area of the slots in the
! outer lid and 58% is the open area in the perforated sheet in the outer lid
! vents.
vf = 0.10
pf = .58               ! inner lid view factor
! Initial state insolation
!UNITS: Btu/hr-in^2
solhfpu   =(800*(2.54**2)/252/24)*abs_ws       ! top plate - sst
solhfpu_p =(800*(2.54**2)/252/24)*abs_ws*pf    ! top plate - sst perf. sheet
solvcyl   =(400*(2.54**2)/252/24)*abs_ws       ! outer cylinder - sst
solhfpu_i =(800*(2.54**2)/252/24)*abs_ws*vf    ! inner lid - sst
! Sooted package insolation
!UNITS: Btu/hr-in^2
solhfpu2  =(800*(2.54**2)/252/24)*abs_st       ! top plate - sst
solhfpu_p2=(800*(2.54**2)/252/24)*abs_st*pf    ! top plate - sst perf. sheet
solvcyl2  =(400*(2.54**2)/252/24)*abs_st       ! outer cylinder - sst
solhfpu_i2=(800*(2.54**2)/252/24)*abs_st*vf    ! inner lid - sst
```

```
! = Assign Heat Load Groups ====================================================
! define nodal groups for payload heat flux ------------------------------------
csys,1
esel,s,mat,,10
nsle,s
cm,heatload,node
! define nodal groups for insolation ------------------------------------------
! top flat surface of package
esel,s,mat,,41
nsle,s
cm,sh41,node
! outer curved surfaces of package
esel,s,mat,,42
nsle,s
cm,sh42,node
! flat horizontal vent surfaces of lid
esel,s,mat,,43
nsle,s
cm,sh43,node
! vertical vent surfaces of lid
esel,s,mat,,44
nsle,s
cm,sh44,node
! bottom edge surface of package
esel,s,mat,,45
nsle,s
cm,sh45,node
! inner closure lid top surface
esel,s,mat,,46
nsle,s
cm,sh46,node
! bottom surfaces of package
esel,s,mat,,47
nsle,s
cm,sh47,node
! inner surfaces of upper cavity of package
esel,s,mat,,48
nsle,s
cm,sh48,node
! = Radiation Matrix Setup ======================================================
/prep7
TYPE,6
```

```
se,..\mesh\radzone1.rad,,
/prep7
TYPE,6
se,..\mesh\radzone2.rad,,
/prep7
TYPE,6
se,..\mesh\radzone3.rad,,
/prep7
TYPE,6
se,..\mesh\radzone4.rad,,
esel,s,type,,4
edele,all
alls
save
! = Initial Conditions Load Step =================================================
tunif,Tambt
timint,off,all
alls
time,0.00001
deltim,1e-5,1e-5,1e-5
kbc,1
eqslv,pcg,1e-6
csys,0
! - decay heat load  ----------------------------------------------------------
alls
esel,s,mat,,10
nsle
bfe,all,HGEN,,dhflx_sfc
!bottom TS cavity
ESEL,s,type, ,12
NSLE,s
SF,all,hflux,dhflx_bot
!Side TS Cavity
ESEL,s,type, ,13
NSLE,s
SF,all,hflux,dhflx_side
!Bottom Tungsten Plug
ESEL,s,type, ,14
NSLE,s
SF,all,hflux,dhflx_top
! - radiation + Convection to ambient ------------------------------------------
esel,s,type,,2
```

```
nsle,s
sf, sh41,conv,-41,Tambt
sf, sh42,conv,-42,Tambt
sf, sh43,conv,-43,Tambt
sf, sh44,conv,-44,Tambt
sf, sh45,conv,-45,Tambt
!sf, sh47,conv,-47,Tambt
! - base boundary condition for isothermal to ambient
alls
nsel,s,loc,z,0
d,all,temp,Tambt
! - Insolation ---------------------------------------------------------------
!Outer Lid
ESEL,s,type, ,7
NSLE,s
SF,all,hflux,solhfpu
!Outer Lid vent - Perf sheet
ESEL,s,type, ,8
NSLE,s
SF,all,hflux,solhfpu_p
!Outer cylinder
ESEL,s,type, ,9
NSLE,s
SF,all,hflux,solvcyl
!Inner lid
ESEL,s,type, ,10
NSLE,s
SF,all,hflux,solhfpu_i
! - Write loadstep ------------------------------------------------------------
alls
save
lswrite,1
! = Transient for Fire ========================================================
/prep7
antype,trans,new
timint,on,all
deltim,0.03,0.01,0.1
alls
ddele,all,all
sfdele,,all,all
sfedele,all,all,all
kbc,1
```

```
outres,basic,last
! apply decay heat loads -------------------------------------------------------
alls
esel,s,mat,,10
nsle
bfe,all,HGEN,,dhflx_sfc
!bottom TS cavity
ESEL,s,type, ,12
NSLE,s
SF,all,hflux,dhflx_bot
!Side TS Cavity
ESEL,s,type, ,13
NSLE,s
SF,all,hflux,dhflx_side
!Bottom Tungsten Plug
ESEL,s,type, ,14
NSLE,s
SF,all,hflux,dhflx_top
! apply radiation + convection to fire ------------------------------------------
! (all surfaces exposed, including upper cavity of package & inner closure lid)
esel,s,type,,2
nsle,s
sf, sh41,conv,-500,Tfire
sf, sh42,conv,-500,Tfire
sf, sh43,conv,-500,Tfire
sf, sh44,conv,-500,Tfire
sf, sh45,conv,-500,Tfire
sf, sh46,conv,-500,Tfire
sf, sh47,conv,-500,Tfire
sf, sh48,conv,-500,Tfire
! write load steps ------------------------------------------------------------
alls
csys,0
*do,i,1,nstpf
time,(0.5/nstpf)*i
lswrite,(i+1)
*enddo
! = Transient for Cooldown ===================================================
alls
ddele,all,all
sfdele,,all,all
sfedele,all,all,all
```

```
kbc,1
outres,basic,last
! apply decay heat loads ------------------------------------------------------
alls
esel,s,mat,,10
nsle
bfe,all,HGEN,,dhflx_sfc
!bottom TS cavity
ESEL,s,type, ,12
NSLE,s
SF,all,hflux,dhflx_bot
!Side TS Cavity
ESEL,s,type, ,13
NSLE,s
SF,all,hflux,dhflx_side
!Bottom Tungsten Plug
ESEL,s,type, ,14
NSLE,s
SF,all,hflux,dhflx_top
! apply radiation + convection to fire ------------------------------------------
esel,s,type,,2
nsle,s
sf, sh41,conv,-401,Tambt
sf, sh42,conv,-402,Tambt
sf, sh43,conv,-403,Tambt
sf, sh44,conv,-404,Tambt
sf, sh45,conv,-405,Tambt
!sf, sh47,conv,-407,Tambt
! - base boundary condition for isothermal to ambient
alls
nsel,s,loc,z,0
d,all,temp,Tambt
! - Insolation ------------------------------------------------------------------
!Outer Lid
ESEL,s,type, ,7
NSLE,s
SF,all,hflux,solhfpu2
!Outer Lid vent - Perf sheet
ESEL,s,type, ,8
NSLE,s
SF,all,hflux,solhfpu_p2
!Outer cylinder
```

```
ESEL,s,type, ,9
NSLE,s
SF,all,hflux,solvcyl2
!Inner lid
ESEL,s,type, ,10
NSLE,s
SF,all,hflux,solhfpu_i2
! write load steps -----------------------------------------------------------
alls
csys,0
*do,i,nstpf+1,nstpf+nstcd
  time,(0.5/nstcd)*i
  lswrite,(i+1)
*enddo
! remainder of cooldown
deltim,0.05,0.01,1
alls
kbc,1
outres,basic,3
! write load step ------------------------------------------------------------
time,duration+0.5
lswrite,(nstpf+nstcd+2)
! = Run Solution ==============================================================
/solu
csys,0
antype,trans,new
solcontrol,on,1
eqslv,pcg,1e-6
scopt,yes
alls
lssolve,1,1,1
lssolve,2,(nstpf+1),1
lssolve,(nstpf+2),(nstpf+nstcd+1),1
lssolve,(nstpf+nstcd+2)
save
! = Post Process ==============================================================
/input,hacpost.f1,inp
```

4.0 CONTAINMENT

The OP-RMSC package is designed as a confinement boundary for raw material special form source capsules. Containment of radioactive material is provided by the special form construction of the payloads. The DOT-IAEA Certification Number for one raw material special form capsule that would be transported in OP-RMSC is as follows:

Manufacture	Model Number	Certification Number
Industrial Nuclear Co., Inc.	INC-SFC-1*	USA/0798/S-96

* Limited to 4,000 Ci (148 TBq) of Ir-192 per capsule.

Other raw material special form capsules may be transported in the OP-RMSC provided the capsules comply with the radioactive content limits specified in 1.2.2, *Contents of Packaging*.

Since the OP-RMSC package does not provide containment, subsequent sections of this chapter are not applicable.

5.0 SHIELDING EVALUATION

This section demonstrates the shielding capability of the OP-RMSC package design for the authorized special form contents. For the Ir-192 and Se-75 payloads, the shielding evaluation is demonstrated via prototypic testing in lieu of an analytical evaluation.

5.1 Description of Shielding Design

5.1.1 Design Features

The OP-RMSC package is a welded stainless steel structure that contains the RMSC payload, which contains the tungsten gamma shields and the radioactive content. Four (4) stainless steel raw material special form capsules, which each contain a maximum of 4,000 Ci (148 TBq) of Ir-192 or Se-75 isotope, are placed in the cavity of the RMSC payload. The RMSC payload cavity that is surrounded by the tungsten gamma shields provides the maximum attenuation of the gamma radiation.

5.1.2 Summary Table of Maximum Radiation Levels

Table 5.1-1 provides the maximum measured external radiation levels for the RMSC payload with the maximum payload content of Ir-192 (16,000 Ci [592 TBq]) for a non–exclusive use shipment, as documented in Appendix 2.12.1, *Certification Tests*.

Table 5.1-1 – Maximum Measured External Radiation Levels for Ir-192 (Non–Exclusive Use)

Measurement Location	Normal Conditions of Transport		Hypothetical Accident Conditions	
	Measured* mrem/hr (mSv/hr)	10 CFR §71.47(a) Limit mrem/hr (mSv/hr)	Measured mrem/hr (mSv/hr)	10 CFR §71.51(a)(2) Limit mrem/hr (mSv/hr)
Side Surface	123 (1.2)[1,2]	200 (2)	N/A	N/A
Top Surface	15[1]	200 (2)	N/A	N/A
Bottom Surface	19[1]	200 (2)	N/A	N/A
40 inches (1 Meter) from Top, Side, or Bottom Surfaces	4 (0.0)[2]	10 (0.1)	4 (0.0)	1000 (10)

* Note: Normal condition maximum measured values were for CTU-1[1] and/or CTU-2[2] (as noted) with 4,297 Ci (159 TBq) of Ir-192, and are adjusted by a factor of 16,000/4,297 = 3.724 to account for the maximum 16,000 Ci (592 TBq) radioactive content. Utilizing a calibrated INC Model 4[13] radiation survey meter (Serial No. 900816) that was calibrated to the face of the meter, measurements were performed post-test following the hypothetical accident conditions (HAC) tests per 10 CFR §71.73. Since the survey meter is calibrated to the face of the meter, no correction of the measured dose is required to compensate for a gap between package surface and point of the radiation measurement (i.e., detector geometry adjustment).

5.2 Source Specification

5.2.1 Gamma Source

The radioactive content of the OP-RMSC package is limited to either 16,000 Ci (592 TBq) of Ir-192 or Se-75 isotopes. Since the photon energy of Ir-192 (0.380 MeV average) is greater than Se-75 (0.280 MeV average), Ir-192 results in a higher unit dose than Se-75 per curie of activity, as

[13] Refer to Industrial Nuclear Company's website (i.e., www.ir100.com/products/radiation-survey-meters).

tabulated in Table 5.2-1. Therefore, the Ir-192 payload bounds Se-75 payload for the maximum 16,000 Ci (592 TBq) content. Because actual Ir-192 special form capsules are utilized to determine the acceptance of the tungsten gamma shields, the tabulation of gamma decay source strengths for the raw material special form capsules for Ir-192 or Se-75 is not required for the RMSC payload.

Table 5.2-1 – Specific Gamma Ray Constants for Raw Material Isotopes[14]

Radionuclide	Specific Gamma Ray Constant ($R\text{-}m^2/hr\text{-}Ci$)
Iridium-192	0.460
Selenium-75	0.203

5.2.2 Neutron Source

This section does not apply, since the OP-RMSC package does not contain neutron sources.

5.3 Shielding Model

The shielding capability of the RMSC payload for the OP-RMSC package design is primarily demonstrated by physical tests of prototypic packages for the maximum curie content for the Ir-192 isotope. Therefore, no analytical shielding model of the package is performed.

5.4 Shielding Evaluation

5.4.1 Methods

The method utilized to demonstrate the shielding performance of the OP-RMSC package for the Ir-192 and Se-75 isotopes is primarily via prototypic testing utilizing special form capsules containing radioactive Ir-192 material, which bounds the Se-75 isotope.

5.4.2 Input and Output Data

This section does not apply, since shielding performance of the RMSC payload is not performed analytically.

5.4.3 Flux-to-Dose-Rate Conversions

This section does not apply, since shielding performance of the RMSC payload is not performed analytically.

5.4.4 External Radiation Levels

Following the specified tests of two prototypic packages with 16,000 Ci (592 TBq) of Ir-192 payload per 2.6, *Normal Conditions of Transport*, and 2.7, *Hypothetical Accident Conditions*, the adjusted maximum measured radiation level on the surface and at 1-meter of the RMSC payloads is 123 mrem/hr (1.23 mSv/hr) and 4 mrem/hr (0.0 mSv/hr), respectively. As noted in Table 5.1-1, these levels are significantly below the regulatory limits of 10 CFR §71.47(a) and 10 CFR §71.51(a)(2).

[14] "Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides", David S. Smith and Michael G. Stabin, Department of Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, Health Physics Society Journal, March 2012 issue.

As noted in Section 2.12.1.4, *Certification Test Unit Description*, each certification test unit, CTU-1 and CTU-2, was prototypic of the license package design delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*. The CTU tungsten shields were nominal, i.e., dimensionally and density in accordance with the ATSM B777 standard. Utilizing the calibrated radiation meter, a qualified technician scanned each surface of the CTU, i.e., side, top, and bottom, to detect the maximum dose rate reading at the specified distance (surface, 1-meter, and 2-meters). Once the maximum reading from each surface was noted, the maximum dose rate reading was recorded on the appropriate test data sheet. Note that the measured dose rates included the effects of the open thread hole in the cavity shield.

6.0 CRITICALITY EVALUATION

The OP-RMSC package does not transport fissile material; therefore, this section does not apply.

7.0 PACKAGE OPERATIONS

7.1 Package Loading

This section delineates the procedures for loading the RMSC payload into the OP-RMSC package. Hereafter, reference to specific OP-RMSC components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

7.1.1 Preparation of the OP-RMSC for Loading

1) Visually inspect the OP-RMSC package for damage and/or missing parts.
2) Remove the eight (8) hex bolts/washers and the closure lid from the OP-RMSC package body.
3) Remove the eight (8) hex bolts/washers and the inner closure lid. Visually inspect the silicone gasket for damage.
4) Attach appropriate rigging to the hoist ring and remove the RMSC from the OP-RMSC cavity.
5) Visually inspect the OP-RMSC cavity and RMSC for damage and/or missing parts.

7.1.2 Loading the Special Form Contents into the RMSC

1) Loosen the six (6) hex bolts/washers so that they may be easily removed in a remote handling operation.
2) Place the RMSC in an appropriate hot cell or shielded cell.
3) Remove the six (6) hex bolts/washers. Using an appropriate lifting device, remove the closure lid from the RMSC body, and place it in a secure location in the cell.
4) Thread an appropriate lift device into the threaded hole in the cavity tungsten shield and remove it from the payload cavity. Store the tungsten shield in a secure location in the cell.
5) Insert up to four (4) raw material source capsules and holder into the RMSC cavity.
6) Re-install the cavity tungsten shield over the payload cavity. Remove the lifting device from the shield, and place it in a secure location.
7) Install the closure lid and the hex bolts/washers. Tighten the hex bolts to a hand tight condition.
8) Remove the RMSC from the hot cell or shielded cell.
9) Perform a radiation survey and smear test of the RMSC exterior to ensure that the dose rates and surface contamination levels are within the regulatory limits of 10 CFR §71.47(a)[15] and 49 CFR §173.443[16], respectively.
10) Tighten the six (6) closure lid hex bolts to 40 ±5 lb_f-ft torque.

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[15] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-20 Edition.

[16] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers-General Requirements for Shipments and Packagings*, 10-1-20 Edition.

7.1.3 Preparation for Transport

1) Prior to loading the RMSC payload, visually inspect the OP-RMSC for damage and/or missing parts, include the gasket and the lid bolts/washers.
2) Attach appropriate rigging to the hoist ring, lift the RMSC payload and insert it into the OP-RMSC payload cavity. Remove the rigging from the hoist ring.
3) Install the inner lid and the eight (8) hex bolts/washers. Tighten the hex bolts to 80 ±5 lb_f-ft torque.
4) Install the closure lid and the eight (8) hex bolts/washers to the OP-RMSC package body. Tighten the closure lid bolts to 80 ±5 lb_f-ft torque.
5) Install a tamper-indicating seal (security wire/lead seals) to a pair of the closure lid bolts.
6) Install an appropriate lifting device into the 3/8-16 UNC threaded hole, lift and place the OP-RMSC package onto the transport skid. Secure the package utilizing nylon straps or other securement system.
7) Remove the lifting device from the threaded hole, and install a threaded fastener to prevent the hole from being utilized as a tie-down. Tighten the fastener to a snug-tight condition.
8) Monitor external radiation per the guidelines of 49 CFR §173.441.
9) Determine the shielding transport index for the loaded OP-RMSC package per the guidelines of 49 CFR §173.403.
10) Install the personnel barrier over the OP-RMSC package, and secure it to the transport skid with the fasteners.
11) Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172[17].
12) OP-RMSC package marking shall be in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Packaging placarding shall be in accordance with Subpart F of 49 CFR 172.

7.2 Package Unloading

This section delineates the procedures for unloading the RMSC payload from the OP-RMSC package. Hereafter, reference to specific OP-RMSC components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

7.2.1 Receipt of OP-RMSC Package from Carrier

1) Remove the fasteners that secure the personnel barrier to the skid, and remove the barrier from the conveyance.
2) Remove the straps or system that secures the OP-RMSC package to the transport conveyance.
3) Monitor the external radiation to ensure that the OP-RMSC package was not damaged during shipment.
4) Remove the fastener from the 3/8-16 threaded hole, and install an appropriate lifting device.

[17] Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 10-1-20 Edition.

5) Utilizing appropriate rigging equipment, lift the OP-RMSC package from the transport conveyance, and place in a secure position for unloading the RMSC payload.

7.2.2 Removal of Special Form Contents from the RMSC

1) Remove the tamper-indicating seal from the closure lid bolts.
2) Remove the closure lid bolts/washers and the closure lid.
3) Remove the inner closure lid bolts/washers and the inner closure lid.
4) Attach appropriate rigging to the hoist ring, and lift the RMSC payload from the OP-RMSC cavity.
5) Perform a radiation survey and smear test in accordance with 49 CFR §173.443(a) of the RMSC payload to ensure that the package is acceptable for unloading in a hot cell.
6) Loosen the six (6) hex bolts/washers so that they may be easily removed in a remote handling operation.
7) Place the RMSC payload in an appropriate hot cell or shielded cell.
8) Remove the six (6) hex bolts/washers. Using an appropriate lifting device, remove the closure lid from the RMSC body, and place it in a secure location in the cell.
9) Thread an appropriate lift device into the threaded hole in the cavity tungsten shield and remove it from the payload cavity. Store the tungsten shield in a secure location in the cell.
10) Utilizing appropriate remote handling tools, remove the raw material special form capsules and holder from the RMSC cavity, and place the capsules/holder in a secure location.
11) Re-insert the cavity tungsten shield into the RMSC body. Remove the lifting device from the cavity tungsten shield.
12) Install the closure lid and the hex bolts/washers. Tighten the hex bolts to a hand tight condition.
13) Remove the RMSC from the hot cell or shielded cell. Tighten the hex bolts to a snug-tight condition.
14) Perform a radiation survey and smear test in accordance with 49 CFR §173.428 of the RMSC payload to ensure that the empty payload is acceptable for loading into the OP-RMSC.
15) Attach appropriate rigging to the hoist ring, lift the RMSC payload, and insert it into the OP-RMSC payload cavity. Remove the rigging from the hoist ring.
16) Install the inner closure lid and the eight (8) hex bolts/washers. Tighten the hex bolts to a snug-tight condition.
17) Install the closure lid and the eight (8) hex bolts/washers to the OP-RMSC package body. Tighten the closure lid bolts to a snug-tight condition.

7.3 Preparation of Empty OP-RMSC Package for Transport

Previously used and empty OP-RMSC packages shall be prepared and transported per the requirements of 49 CFR §173.428.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85(c), this section discusses the inspections and tests to be performed prior to first use of the OP-RMSC package.

8.1.1 Visual Inspections and Measurements

All materials of construction for the OP-RMSC package shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a). This examination includes, but is not limited to, such items as materials, physical arrangement of components, quantities, dimensions, welds, measurements, and verification that there are no surface defects (e.g., cracks, pin holes) in the observable surfaces of the tungsten shields.

8.1.2 Weld Examinations

All OP-RMSC package welds shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

8.1.3 Structural and Pressure Tests

The OP-RMSC package does not contain any lifting/tie-down devices or pressure boundaries that require testing. Therefore, this section does not apply.

8.1.4 Leakage Tests

The OP-RMSC package does not contain any seals or containment boundaries that require leakage testing. Therefore, this section does not apply.

8.1.5 Component and Material Tests

The OP-RMSC package does not contain any additional components or materials that require acceptance testing. Therefore, this section does not apply.

8.1.6 Shielding Tests

A radiation profile shall be performed on each tungsten gamma shield assembly prior to being utilized in the fabrication of a RMSC payload. These measured survey results are ratioed to determine the expected radiation levels for the maximum authorize source strength of 16,000 Ci (592 TBq) for the Ir-192 isotope. Any radiation profile of a tungsten gamma shield assembly that results in a dose rate that exceeds the requirements of 49 CFR §173.441(a) for non-exclusive use for the maximum authorized payload shall not be utilized in the manufacture of a RMSC payload.

8.1.7 Thermal Tests

The OP-RMSC package does not contain any thermal features or systems that require testing. Therefore, this section does not apply.

8.1.8 Miscellaneous Tests

There are no additional tests required to utilize the OP-RMSC package. Therefore, this section does not apply.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the OP-RMSC package.

8.2.1 Structural and Pressure Tests

The OP-RMSC package does not contain any lifting/tie-down devices or pressure boundaries that require load testing. Therefore, this section does not apply.

8.2.2 Leakage Tests

The OP-RMSC package does not contain any seals or containment boundaries that require testing. Therefore, this section does not apply.

8.2.3 Component and Material Tests

All threaded components shall be inspected quarterly for deformed or stripped threads. Damaged components shall be repaired or replaced prior to further use.

The silicone gasket on the inner closure lid shall be inspected quarterly for damage and/or excessive wear. A damaged gasket shall be replacement prior to further use.

8.2.4 Thermal Tests

No thermal tests are necessary to ensure continued performance of the OP-RMSC package.

8.2.5 Miscellaneous Tests

No additional tests are necessary to ensure continued performance of the OP-RMSC package.