AOS
Alpha-Omega Services, Inc.

August 17, 2009

Mr. Eric Benner, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike: MS: EBB-3D-02M
Rockville, MD 20852-2738

Ref: Docket No. 71-9316

Dear Mr. Benner:

In response to your letters dated July 31, 2009; "Application for Certification of Compliance No. 9316 for the Models No. AOS-025, AOS-050, AOS-100 and AOS-165 Packages, Docket No. 71-9316- Request For Supplemental Information" and August 6, 2009; "Application for the Model No. AOS-165 – Not Accepted For Review", please find attached the supplemental information for Models AOS-025, AOS-050 and AOS-100.

Sincerely,

Troy Hedger, CEO
Alpha-Omega Services, Inc.
9156 Rose Street
Bellflower, CA 90706

Chapter 1: General Information

RSI 1-1: *Provide key dimensions and tolerances in the Drawings. For example, dimensions and tolerances of the shielding does not appear to be present (see RSI 5-2). Also, staff was not able to find the bottom plate thickness, among other dimensions, for the AOS-050 package.*

The drawings should be consistent with the guidance in NUREG/CR5502 :Engineering Drawings for 10 CFR Part 71 Package Approvals."

A summary materials data sheet or Bill of Materials should be included in the Drawings, which will be included as reference in the Certificate of Compliance.

This information is needed to determine compliance with 10 CFR 71.31.

Response:

The requested dimensions and a Bill of Materials Chart have been added to the Drawings. The AOS Certification drawings listed below are proprietary information and not for general public distribution. A copy of the Affidavit filed with the NRC is attached.

AOS-025

105E9722, Rev A,MARK-UP, IMPACT LIMITER

166D8143, Rev A,MARK-UP, CASK

AOS-050

166D8138, Rev A, MARK-UP, IMPACT LIMITER

166D8137, Rev A, MARK-UP, CASK

AOS-100

105E9713, Rev A, MARK-UP, IMPACT LIMITER

105E9712, Rev A, MARK-UP, CASK, AOS-100A and AOS-100B

105E9719, Rev A, MARK-UP, CASK, AOS-100A-S

RSI 1-2: *The description of the contents should be more detailed and include the chemical composition, type, size and shape of solid, e.g. large ball or shredded matter, etc.*

This information is needed to determine compliance with 10 CFR 71.33(b)(3).

Response:
The AOS Transport Packaging System is a multi-purpose, multi-user package. The content is defined for all Models as: Solid, activation product material in metallic form, meeting "normal" or "special" definitions. The content can be shaped as a rod, pellet, disk or powder. The quantity of material is limited by either the assigned decay heat or the shielding characteristic of the design, which could be augmented by the use of removable shielding devices. Because these shielding devices perform a "safety function," they are defined in the SAR, which also describes their usage. Typically, the content is placed in the cask cavity, in a basket or rack device. This device provides shoring to the content, to ensure that its loading arrangement is maintained during transportation. Selection of the type of material for fabrication of this device is based upon the temperature environment within the cask cavity. A cavity temperature of less than 400°F will allow the use of aluminum. For temperatures of 400°F or greater, the choice is stainless steel material, although this material could be used in either case.

The cavity temperature within all AOS Transport System Models is less than 300°F under NCT; therefore, the use of either material is acceptable.

The following documents show some of the proposed content for the AOS Transport Packaging System.

Special Form Example

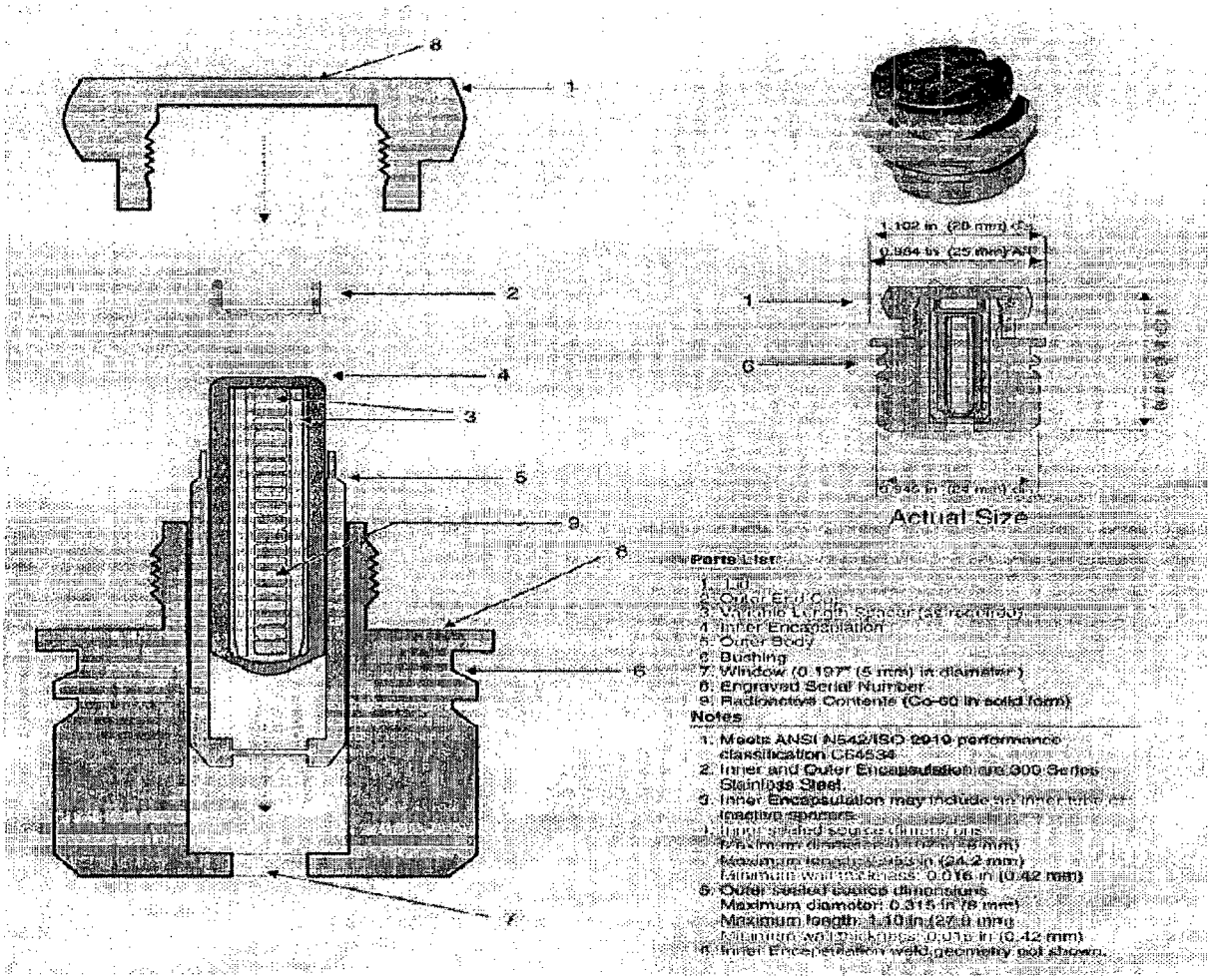
The Elekta Models 43047, 43685 **and 1000029** are doubly encapsulated welded sealed sources. The inner and outer capsules are fabricated from 300-series stainless steel and have identical dimensions as detailed in Table 1, later in this section. The only differences between the two models are that (1) the models use different series of stainless steel, and (2) the shape of the bottom of the inner capsules and tubes have been modified to facilitate manufacturing improvements. When in use, the sealed source is retained in a source holder consisting of an aluminum bushing and a stainless steel threaded lid. The assembled source in its source holder is included as Attachment 1.

The active volume of the sealed source contains cobalt-60, normally in pellet form, nominally 1 mm (0.039 inch) in diameter with a length of 1 mm (0.039 inch). **Other forms of Cobalt-60 ranging from powder to solid rod may also be used.**

Table 1 – Critical Source Component Dimensions

	Attribute	Nominal Dimension	
		(inches)	(mm)
Inner capsule	outer diameter	0.1965	4.991
	spacer inner diameter **(models 43047 and 43685)**	0.0465	1.181
	length	0.945	24.0
	minimum material thickness, At weld	0.016	0.42
Outer capsule	outer diameter	0.3146	7.991
	inner diameter	0.1975	5.016
	length	1.07	27.2
	minimum material thickness		
	At end cap	0.018	0.4575
	Body, at counterbore of cap	0.019	0.496
	At weld	0.016	0.42

Assembled Source Capsule and Source Holder (Bushing)



Typical Shipments

192 to 201 Sources In-bushing OR **192 to 201 Sources without bushing**

Approx. 244.2 TBq/shipment

Approx. 244.2 TBq/shipment

Normal Form Iridium-192 Example

Pre-Irradiated Material

Iridium 191 range	37% to 88%
Iridium 193 range	12% to 63%

Ir-192, Solid Metal Rod

Range Activity per rods: 0.037 to 1.0 TBq

Dimensional Range:

Diameter 0.30 to 1.0 mm

Length 1.0 to 4.0 mm

Sealed Quartz Tubing

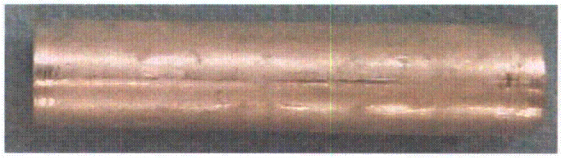
No. of rods per Tube: 1 – 6 stacked

Dimensional Range:

Outer Diameter 1.0 to 1.8 mm

Inner Diameter 0.5 to 1.4mm

Length 12 to 25 mm



Holder: 1100 Series Aluminum Can

Holds 1 to 30 Quartz Tubes

Inside Packed with Glass Wool

Dimensional Range:

Outer Diameter	6.0 to 25 mm
Inner Diameter	3.0 to 20 mm
Length	15 to 40 mm

Prior to irradiation, Iridium rods are sealed in quartz tubes. Upon irradiation completion, the Iridium rods in quartz tubes are placed in an aluminum can with glass wool, then placed in the shipping cask with shoring, as required.

Normal Form Cobalt-60 Example

Co-60, Solid Metal, Pellets

Dim: 1 mm diameter by 1 mm in height

Activity Range: 250 to 350 Ci/g

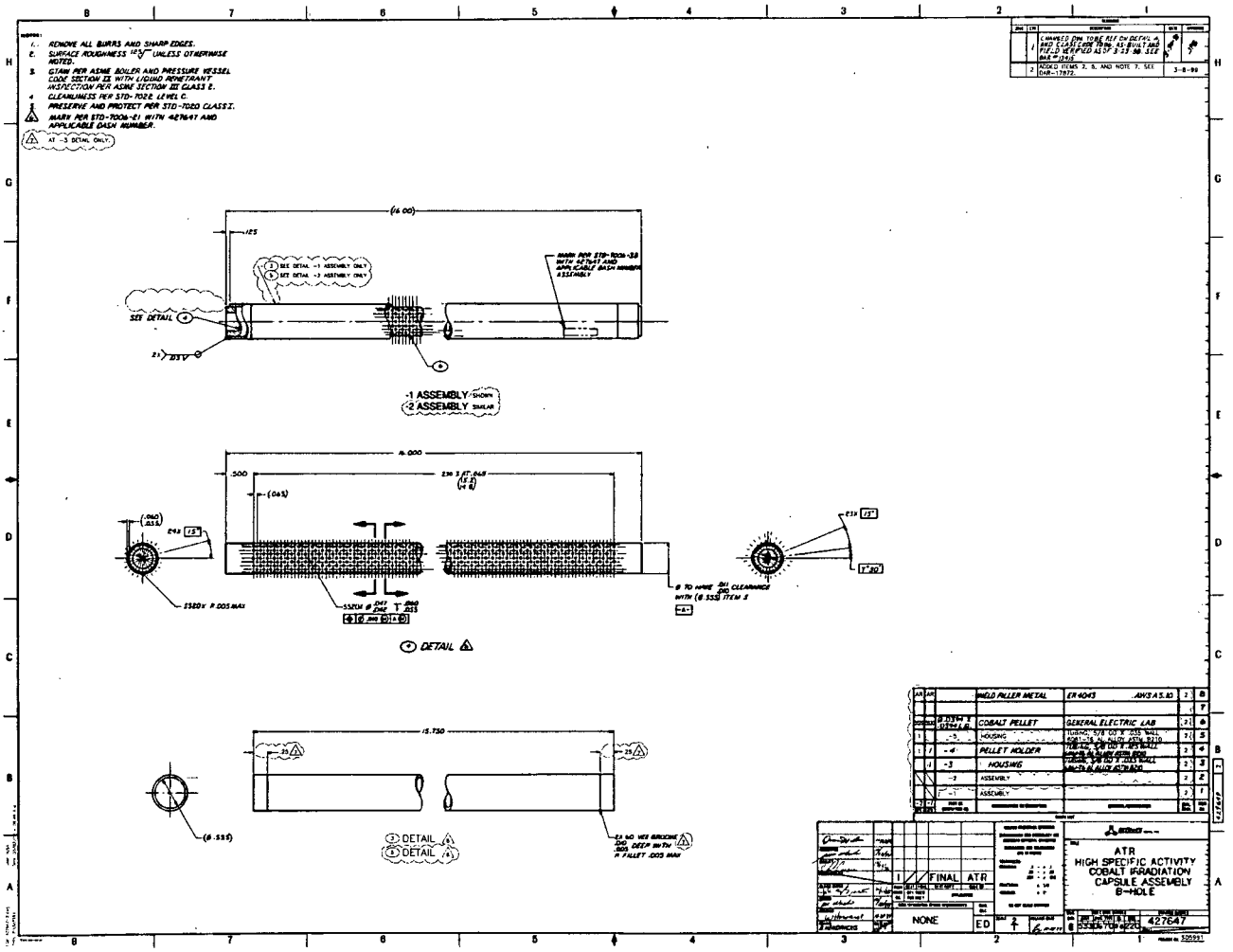
Co-60 Mass per target

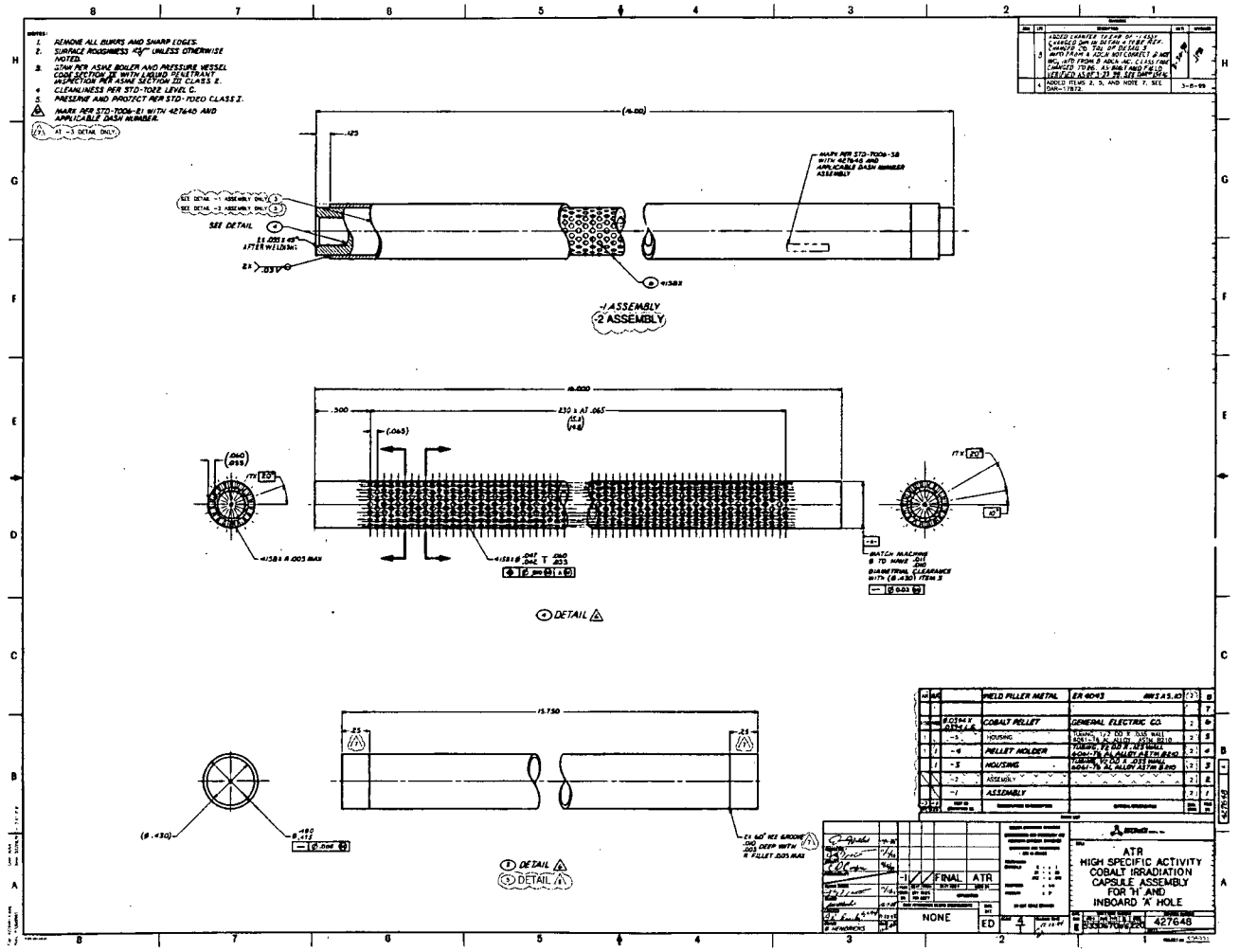
½" dia. target holder: 29.5 to 32.5 grams

5/8" target holder: 38.5 to 40.5 grams

Target Holders: 5/8" in diameter and ½" diameter.

Both are 16 inches in length and consist of two aluminum tubes. The inner tube contains dimples that are just over 1 mm in diameter and 1 mm in depth. The Co-60 pellets are placed in the dimples and the second aluminum tube slides over the inner tube, acting as a sheath. The ends are then seal-welded and leak-tested.


-1 ASSEMBLY SHOWN
-2 ASSEMBLY SIMILAR
DETAIL A
DETAIL A
ATR
HIGH SPECIFIC ACTIVITY
COBALT IRRADIATION
CAPSULE ASSEMBLY
B-HOLE
427647
NONE
FINAL
COBALT PELLET
PELLET HOLDER
HOUSING
ER 4043


NOTES:
1. REMOVE ALL BURRS AND SHARP EDGES.
2. SURFACE ROUGHNESS 125µ" UNLESS OTHERWISE NOTED.
3. STAMP PER ASME BOILER AND PRESSURE VESSEL CODE SECTION IX WITH LIQUID PENETRANT INSPECTION PER ASME SECTION III CLASS 2.
4. CLEANLINESS PER STD-7002 LEVEL C.
5. PRESERVE AND PROTECT PER STD-7060 CLASS I.
6. MARK PER STD-7006-B1 WITH 427648 AND APPLICABLE DASH NUMBER.
A1 -3 DETAIL ONLY
SEE DETAIL
-1 ASSEMBLY
-2 ASSEMBLY
DETAIL A
FIELD FILLER METAL
ER 4043
COBALT PELLET
GENERAL ELECTRIC CO.
HOUSING
PELLET HOLDER
HOUSING
ASSEMBLY
ASSEMBLY
FINAL
ATR
NONE
ED
ATR
HIGH SPECIFIC ACTIVITY
COBALT IRRADIATION
CAPSULE ASSEMBLY
FOR 'H' AND
INBOARD 'A' HOLE
427648

AGR-1 Compacts [Exemption from Classification as Fissile Material, 10CFR 71.15 (a) or (b)]

Description: A typical Advanced Gas Reactor (AGR) compact is shown in Figure 1. Currently, each fuel compact is a right circular cylinder nominally 25 mm in length and 12.3 mm in diameter and weighs approximately 5.5 grams per compact. Each compact contains approximately 4,200 coated fuel particles that are slightly less than 1 mm in diameter. These particles are bound together with a carbonaceous (graphite) matrix material. Each particle consists of a uranium oxycarbide (~75% $U0_2$, and the remainder UC and UC_2) fuel kernel surrounded by the following layers (as depicted in Figure 2):

- Porous carbon buffer layer
- Inner pyrolytic carbon (PyC) layer
- Silicon Carbide (SiC) barrier coating
- Outer PyC layer

(**Note:** Some future compacts will be up to 51 mm in length, with a 12.3 mm diameter.)

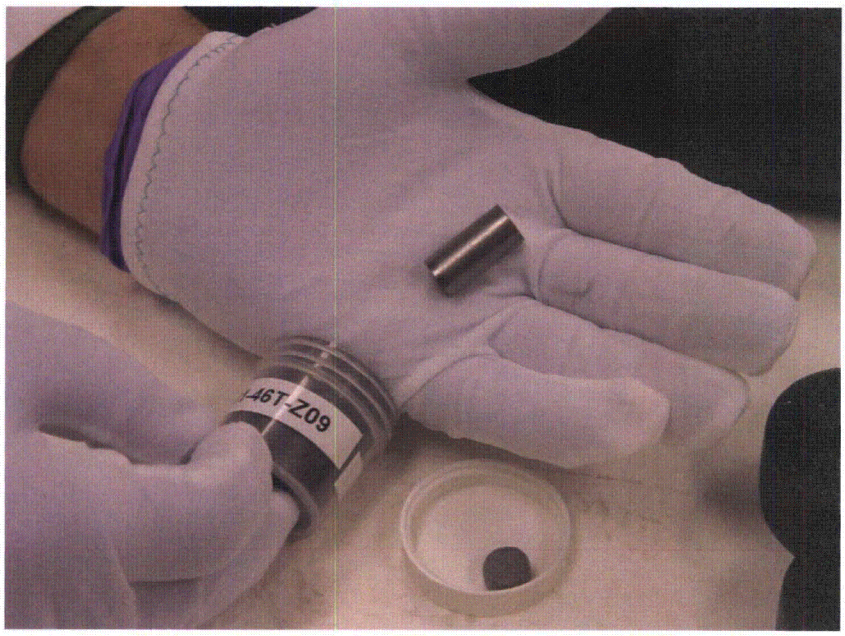


Figure 1. Typical AGR-1 fuel compact and its storage bottle

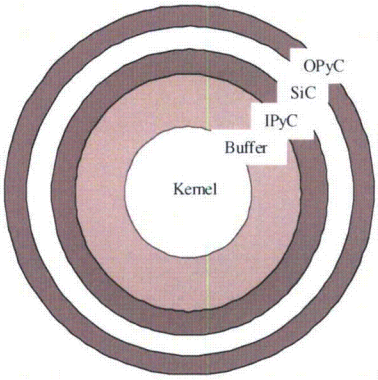


Figure 2. Schematic of a typical AGR-1 coated fuel particle

The compacts are not encapsulated during irradiation, but are placed into a modified Swagelok container in the hot cell after irradiation. A picture of the compact and container is provided below (Figure 3). The compacts are approximately 0.5" diameter x 1" long, and the container is approximately 1" diameter x 3" long. The container is an aluminum Swagelok bulkhead fitting, with the threads and center hex nut turned off. In future tests, some compacts will have a 0.5" diameter and be 2" long. A similar container will be used for the longer compacts, but adjusted dimensionally, to accommodate the longer length.

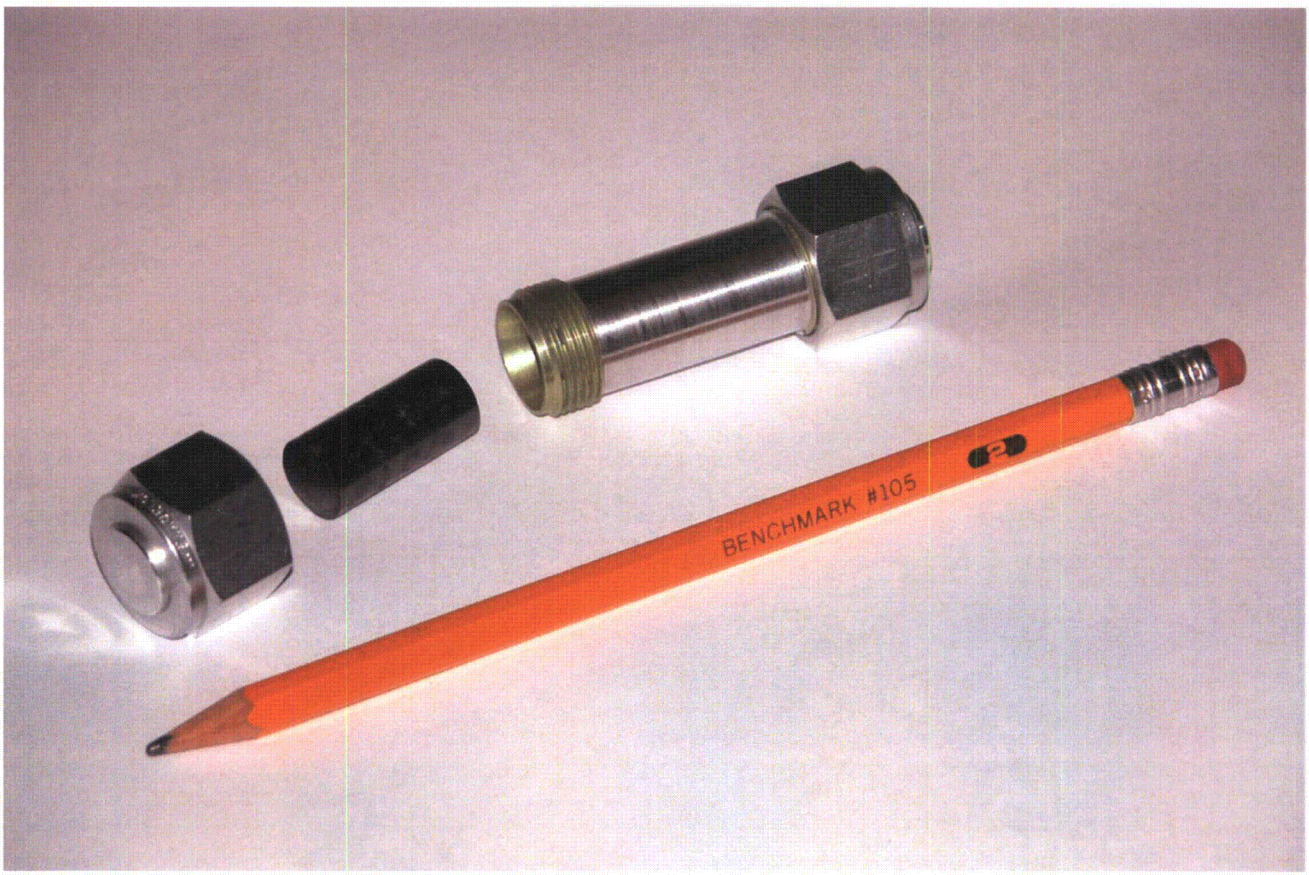


Figure 3. Compact and Container (shown with pencil, for size aspect/visualization)

Chapter 2: Structural Evaluation

RSI 2-1: *Re-evaluate all load combinations, to ensure that Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," is being properly applied to determine the load combinations. Justify the evaluation and selection of load combinations.*

For example, to create the hot environment load combination for NCT, from the applicant's load cases, the staff should see a combination that includes Load Cases 102, 201, and 211. The staff does not specifically see this load combination in Tables 2-159, 2-226, nor 2-292.

The staff also notes that Load Case 102 includes maximum solar insolation, whereas Load Case 101 does not.

This information is needed to determine compliance with 10 CFR 71.33(b)(3) and 71.43(d).

Response:
Load Cases used in the Model AOS-025, AOS-050 and AOS-100 analyses are listed below in Table 1, and Load Combinations are listed in Table 2. From these two tables, it can be seen that the Hot Environment, Load Combination 101, now includes Load Case 102 (Maximum Decay Heat, Maximum Insolation), Load Case 201 (Maximum Internal Pressure), and Load Case 211 (Fabrication Stress). Previously, Load Combination 101 had incorrectly used Load Case 101 instead of 102. This error has been corrected, and the updated combined stress tables for Models AOS-025, AOS-050, and AOS-100, respectively, are listed below. Corrected stresses show only a slight change in Q stress values, and no change in minimum margins of safety.

Table 1. Load Case Descriptions

Load Case Number	Description
101	100F Ambient, Maximum Decay Heat
102	100F Ambient, Maximum Decay Heat, Maximum Insolation
103	-20F Ambient, Zero Decay Heat, Zero Insolation
104	-40F Ambient, Zero Decay Heat, Zero Insolation
105	-40F Ambient, Maximum Decay Heat
111	Fire @ 30 Minutes, 1,475F Ambient, Max Decay Heat
112	Fire @60 Minutes, 100F, Maximum Decay Heat, Maximum Insolation
113	Fire @90 Minutes, 100F, Maximum Decay Heat, Maximum Insolation
114	Fire @120 Minutes, 100F, Maximum Decay Heat, Maximum Insolation
115	Fire @150 Minutes, 100F, Maximum Decay Heat, Maximum Insolation
116	Fire @180 Minutes, 100F, Maximum Decay Heat, Maximum Insolation
201	Maximum Internal Pressure, 30 psi (AOS-025)
	Maximum Internal Pressure, 60 psi (AOS-050)
	Maximum Internal Pressure, 280 psi (AOS-100)
202	Minimum External Pressure, 3.5 psia
203	Maximum Increased External Pressure, 20 psia
204	Additional Increased External Pressure, 290 psi
211	Fabrication Stress
215	Compression Load (5x weight)
216	Rod Drop onto Cask
221	Forward 5g Vibration Inertia Load
222	Lateral 5g Vibration Inertia Load
223	Vertical 10g Vibration Inertia Load
231	4-ft Head-on Drop
232	30-ft Head-on Drop Impact Test, Normal Conditions
301	30-ft Head-on Drop
302	30-ft Side Drop + Slap-down
303	Cg/Corner Drop
304	30-ft Head-on Drop at -40F, Low Temperature
305	30-ft Side Drop + Slap-down at -40F, Low Temperature
306	30-ft Cg/Corner Drop at -40F, Low Temperature
311	4-ft Drop onto Rod

Table 2. Load Combination Descriptions

Load Combination Number	Load Case Numbers	Description
101	102,201,211	Hot Environment
102	104,201,211	Cold Environment
103	103,201,211	Increased External Pressure
104	101,201,202,211	Minimum External Pressure
105	105,201,202,211	Cold Environment with Maximum Decay Heat
106	101,201,203,211	Maximum Pressure, Hot Environment
107	105,201,203,211	Maximum Pressure, Cold Environment
215	215,101,201,211	Compression Load
216	216,101,201,211	Rod Drop
217	216,104,201,211	Rod Drop, Cold Environment
221	221,101,201,211	Forward Vibration
222	222,101,201,211	Lateral Vibration
223	223,101,201,211	Vertical Vibration
231	231,102,201,211	4-ft Head-on Drop, Normal Conditions
232	232,102,201,211	30-ft Head-on Drop, Normal Conditions (Impact Test)
301	301,102,201,211	Head-on Drop Orientation
302	302,102,201,211	Side Drop Orientation
303	303,102,201,211	Cg/corner Drop Orientation
304	304,105,202,211	Head-on Drop Orientation at -40F, Cold Environment
305	305,105,202,211	Side Drop Orientation at -40F, Cold Environment
306	306,105,202,211	Cg/Corner Drop Orientation at -40F, Cold environment
310	204,101,211	Additional Increased External Pressure (290 psi)
311	311,101,201,211	4-ft Drop onto Rod
312	311,104,201,211	4-ft Drop onto Rod at -40F, Cold Environment
350	111,201,211	Fire @ 30 Minutes
351	112,201,211	Fire @ 60 Minutes
352	113,201,211	Fire @ 90 Minutes
353	114,201,211	Fire @ 120 Minutes
354	115,201,211	Fire @ 150 Minutes
355	116,201,211	Fire @ 180 Minutes

Model AOS-025

Normal Load Combination 101

Load Cases: 102 201 211
100F Ambient, Max Decay Heat, Max Insolation
Maximum Internal Pressure - 30 Psia
Fabrication Stress

Stress (ksi/MPa)

Loc	Pm	Pb	Q	Pm+Pb	Pm+Pb+Q	Sm	Su	MS
1	0.75	1.10	0.03	1.85	1.88	20.00	70.00	>10
	5.16	7.60	0.24	12.75	12.99	137.90	482.63	
2	0.14	0.20	0.05	0.34	0.38	20.00	70.00	>10
	0.96	1.35	0.33	2.31	2.64	137.90	482.63	
3	0.08	0.08	0.04	0.16	0.20	20.00	70.00	>10
	0.58	0.54	0.25	1.12	1.38	137.90	482.63	
4	1.16	1.78	0.26	2.94	3.20	20.00	70.00	9.20
	8.00	12.28	1.80	20.28	22.08	137.90	482.63	
5	1.18	1.00	0.29	2.18	2.47	20.00	70.00	>10
	8.17	6.88	2.01	15.05	17.05	137.90	482.63	
6	0.78	1.17	0.12	1.95	2.07	20.00	70.00	>10
	5.40	8.05	0.83	13.44	14.28	137.90	482.63	
7	0.34	0.07	0.05	0.40	0.45	20.00	70.00	>10
	2.34	0.45	0.33	2.79	3.13	137.90	482.63	
8	0.32	0.04	0.05	0.36	0.41	20.00	70.00	>10
	2.21	0.27	0.33	2.48	2.82	137.90	482.63	
9	0.36	0.07	0.05	0.43	0.48	20.00	70.00	>10
	2.48	0.48	0.33	2.97	3.30	137.90	482.63	
10	1.23	0.15	0.06	1.38	1.44	20.00	70.00	>10
	8.49	1.03	0.39	9.52	9.91	137.90	482.63	
11	0.93	1.23	0.09	2.17	2.25	20.00	70.00	>10
	6.44	8.51	0.59	14.95	15.53	137.90	482.63	
12	1.01	1.49	0.13	2.50	2.63	20.00	70.00	>10
	6.95	10.27	0.87	17.23	18.10	137.90	482.63	

13	1.19	1.05	0.17	2.24	2.41	20.00	70.00	>10
	8.21	7.23	1.16	15.44	16.60	137.90	482.63	
14	1.21	1.54	0.15	2.75	2.90	20.00	70.00	9.91
	8.36	10.61	1.01	18.97	19.98	137.90	482.63	
15	1.70	1.94	1.29	3.64	4.93	20.00	70.00	7.25
	11.69	13.38	8.89	25.07	33.96	137.90	482.63	
16	1.70	2.69	0.71	4.39	5.10	20.00	70.00	5.83
	11.72	18.55	4.91	30.27	35.17	137.90	482.63	
17	1.12	1.79	0.43	2.90	3.33	20.00	70.00	9.33
	7.71	12.31	2.95	20.02	22.96	137.90	482.63	
18	0.87	1.40	0.20	2.27	2.47	20.00	70.00	>10
	5.99	9.65	1.40	15.64	17.04	137.90	482.63	
19	1.46	2.17	0.36	3.63	4.00	20.00	70.00	7.26
	10.09	14.96	2.49	25.05	27.54	137.90	482.63	
20	1.82	2.90	0.46	4.72	5.18	20.00	70.00	5.35
	12.58	19.99	3.16	32.57	35.73	137.90	482.63	
21	0.32	0.44	0.01	0.76	0.77	20.00	70.00	>10
	2.24	3.00	0.09	5.24	5.33	137.90	482.63	
22	0.46	0.47	0.04	0.93	0.97	20.00	70.00	>10
	3.20	3.23	0.26	6.43	6.69	137.90	482.63	

Min MS: 5.350, Location: 20, Combination: Pm+Pb

Model AOS-050

Normal Load Combination 101

Load Cases: 102 201 211
100F Ambient, Max Decay Heat, Max Insolation
Maximum Internal Pressure - 60 Psia
Fabrication Stress

	Stress (ksi/MPa)							
Loc	Pm	Pb	Q	Pm+Pb	Pm+Pb+Q	Sm	Su	MS
1	1.19	1.70	0.15	2.90	3.04	20.00	70.00	9.36
	8.23	11.73	1.01	19.97	20.97	137.90	482.63	
2	0.08	0.05	0.21	0.13	0.34	20.00	70.00	>10
	0.53	0.37	1.47	0.90	2.37	137.90	482.63	
3	0.04	0.01	0.15	0.05	0.20	20.00	70.00	>10
	0.24	0.09	1.05	0.33	1.39	137.90	482.63	
4	1.71	2.69	1.20	4.40	5.60	20.00	70.00	5.82
	11.78	18.56	8.26	30.33	38.59	137.90	482.63	
5	1.65	2.53	1.08	4.18	5.26	20.00	70.00	6.18
	11.36	17.47	7.44	28.83	36.27	137.90	482.63	
6	0.61	1.02	0.57	1.63	2.20	20.00	70.00	>10
	4.21	7.03	3.95	11.24	15.19	137.90	482.63	
7	0.34	0.00	0.18	0.34	0.52	20.00	70.00	>10
	2.35	0.01	1.25	2.36	3.61	137.90	482.63	
8	0.34	0.00	0.18	0.34	0.52	20.00	70.00	>10
	2.35	0.00	1.22	2.35	3.57	137.90	482.63	
9	0.34	0.00	0.18	0.34	0.52	20.00	70.00	>10
	2.35	0.01	1.24	2.36	3.60	137.90	482.63	
10	0.49	0.21	0.63	0.71	1.33	20.00	70.00	>10
	3.40	1.48	4.31	4.88	9.19	137.90	482.63	
11	0.27	0.16	0.54	0.43	0.97	20.00	70.00	>10
	1.85	1.12	3.74	2.97	6.71	137.90	482.63	
12	0.23	0.11	0.75	0.34	1.09	20.00	70.00	>10
	1.61	0.76	5.15	2.37	7.52	137.90	482.63	

13	0.82	0.89	0.60	1.71	2.31	20.00	70.00	>10
	5.65	6.15	4.15	11.81	15.95	137.90	482.63	
14	0.81	0.64	0.48	1.45	1.94	20.00	70.00	>10
	5.58	4.45	3.33	10.03	13.36	137.90	482.63	
15	1.35	0.65	1.78	2.00	3.79	20.00	70.00	>10
	9.34	4.46	12.30	13.80	26.10	137.90	482.63	
16	0.36	0.47	0.63	0.83	1.47	20.00	70.00	>10
	2.51	3.23	4.37	5.74	10.11	137.90	482.63	
17	0.28	0.35	0.37	0.63	1.00	20.00	70.00	>10
	1.95	2.40	2.55	4.36	6.91	137.90	482.63	
18	0.51	0.81	0.12	1.33	1.45	20.00	70.00	>10
	3.53	5.62	0.85	9.15	10.00	137.90	482.63	
19	0.74	0.97	0.21	1.71	1.92	20.00	70.00	>10
	5.13	6.65	1.43	11.78	13.21	137.90	482.63	
20	0.73	1.01	0.34	1.74	2.09	20.00	70.00	>10
	5.04	6.97	2.38	12.01	14.39	137.90	482.63	
21	0.17	0.29	0.03	0.46	0.49	20.00	70.00	>10
	1.19	1.98	0.22	3.17	3.39	137.90	482.63	
22	0.72	0.36	0.09	1.08	1.17	20.00	70.00	>10
	4.97	2.48	0.59	7.46	8.05	137.90	482.63	

Min MS: 5.819, Location: 4, Combination: Pm+Pb

Model AOS-100

Normal Load Combination 101

Load Cases: 102 201 211
100F Ambient, Max Decay Heat, Max Insolation
Maximum Internal Pressure - 280 Psia
Fabrication Stress

Stress (ksi/MPa)

Loc	Pm	Pb	Q	Pm+Pb	Pm+Pb+Q	Sm	Su	MS
1	0.60	0.86	0.28	1.46	1.74	20.00	70.00	>10
	4.14	5.93	1.95	10.07	12.02	137.90	482.63	
2	0.04	0.03	0.42	0.07	0.49	20.00	70.00	>10
	0.28	0.19	2.91	0.47	3.38	137.90	482.63	
3	0.03	0.02	0.28	0.05	0.32	20.00	70.00	>10
	0.17	0.16	1.91	0.33	2.24	137.90	482.63	
4	4.94	8.72	2.84	13.66	16.50	20.00	70.00	1.20
	34.09	60.09	19.60	94.18	113.78	137.90	482.63	
5	4.28	6.97	2.96	11.24	14.20	20.00	70.00	1.67
	29.48	48.05	20.41	77.52	97.93	137.90	482.63	
6	1.66	2.27	1.30	3.93	5.23	20.00	70.00	6.63
	11.45	15.65	8.93	27.10	36.03	137.90	482.63	
7	0.29	0.01	0.34	0.29	0.63	20.00	70.00	>10
	1.97	0.05	2.36	2.02	4.38	137.90	482.63	
8	0.28	0.00	0.34	0.28	0.62	20.00	70.00	>10
	1.96	0.00	2.33	1.96	4.29	137.90	482.63	
9	0.28	0.01	0.34	0.30	0.63	20.00	70.00	>10
	1.96	0.08	2.32	2.04	4.37	137.90	482.63	
10	0.98	1.01	0.54	1.99	2.53	20.00	70.00	>10
	6.76	6.95	3.73	13.72	17.44	137.90	482.63	
11	0.61	0.28	0.64	0.90	1.54	20.00	70.00	>10
	4.22	1.96	4.43	6.18	10.62	137.90	482.63	
12	0.52	0.41	0.93	0.93	1.86	20.00	70.00	>10
	3.55	2.83	6.45	6.39	12.83	137.90	482.63	
13	1.04	0.92	1.13	1.96	3.08	20.00	70.00	>10
	7.17	6.32	7.76	13.50	21.26	137.90	482.63	

14	0.98	0.98	0.97	1.96	2.93	20.00	70.00	>10
	6.76	6.78	6.68	13.53	20.22	137.90	482.63	
15	3.84	5.45	0.80	9.29	10.09	20.00	70.00	2.23
	26.44	37.58	5.54	64.02	69.56	137.90	482.63	
16	2.32	3.39	0.31	5.72	6.03	20.00	70.00	4.25
	16.01	23.40	2.16	39.41	41.58	137.90	482.63	
17	1.64	2.46	0.19	4.10	4.29	20.00	70.00	6.32
	11.32	16.94	1.32	28.26	29.58	137.90	482.63	
18	1.94	3.00	0.15	4.94	5.09	20.00	70.00	5.07
	13.41	20.68	1.02	34.09	35.11	137.90	482.63	
19	3.11	4.80	0.22	7.92	8.13	20.00	70.00	2.79
	21.47	33.11	1.51	54.57	56.08	137.90	482.63	
20	2.54	4.71	0.49	7.25	7.74	20.00	70.00	3.14
	17.53	32.47	3.39	50.00	53.39	137.90	482.63	
21	0.22	0.47	0.09	0.69	0.78	20.00	70.00	>10
	1.55	3.21	0.61	4.76	5.37	137.90	482.63	
22	1.97	2.34	0.10	4.31	4.41	20.00	70.00	5.96
	13.59	16.13	0.67	29.72	30.39	137.90	482.63	

Min MS: 1.196, Location: 4, Combination: Pm+Pb

Chapter 3: Thermal Evaluation

RSI 3-1: *Provide impact limiter foam temperatures and the associated temperature limit for all models in Table 3-4 of the application.*

It appears that the temperature limit during NCT may be exceeded considering the glass transition temperature of 279°F (137°C), as reported in the "Design Guide for LAST-A-FOAM FR-3700 for Crash & Fire Protection of Radioactive Material Shipping Containers." This could affect the performance of the package in HAC and NCT drop conditions.

This information is needed to determine compliance with 10 CFR 71.71 and 71.73.

Response:

Table 3-4 will be revised to change the component name from "Overpack Inside Surface" to "Impact Limiter Foam Material" and the associated Regulatory/Component Criteria will also be changed from "400°C (752°F)" to "137°C (279°F)." The temperature values currently listed in Table 3-4 for this component, Impact Limiter Foam Material, under NCT (Conditions 1 and 2) already meets the 137°C (279°F) criteria for Models AOS-025, AOS-050, and AOS-100. The locations listed in Table 3-4 are the maximum values for the monitoring locations, Figure 3-6, Location Points 23 through 28. In addition, all tables listed in Tables 3-18, 3-45, and 3-53 for Models AOS-100, AOS-025, and AOS-050, respectively, provide, as the last item in the table, a list of the maximum temperature values for each material/component type, anywhere within the particular material/component. The values posted in these tables also meet the temperature criteria.

The updated Table 3-4 is presented below. In addition to the changes cited above, the temperature values for the Model AOS-100B are changed. Because of an error found in the thermal models, all analyses were re-run.

Table 3-4. Transport Package Temperature Summary – All Models

Model	Component	Thermal Temperatures, by Condition														Regulatory/Component Criteria[a]
		1		2		3[b]		4		5		6		7		
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-025A	Cask Cavity	99	210	60	141	149	300	-15	5	-40	-40	-4	24	-29	-20	400°C (752°F)
	Shielding Material	98	209	60	140	149	299	-16	3	-40	-40	-5	23	-29	-20	400°C (752°F)
	Cask Seal Area	98	208	59	139	149	300	-16	3	-40	-40	-5	22	-29	-20	300°C (572°F) Metallic Seal
	Cask Test Port	98	208	59	139	148	299	-16	2	-40	-40	-6	22	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Drain Port	98	208	59	138	147	297	-17	2	-40	-40	-6	22	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Vent Port	98	208	59	139	149	300	-16	2	-40	-40	-6	22	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Outside Surface	98	208	59	138	147	297	-16	2	-40	-40	-6	22	-29	-20	400°C (752°F)
	Impact Limiter Foam Material	98	208	59	139	214	417	-16	2	-40	-40	-6	22	-29	-20	137°C (279°F) Conditions 1 and 2
	Overpack Accessible Outside Surface[c]	87	188	43	110	797	1,467	-34	-29	-40	-40	-23	-9	-29	-20	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use – Condition 2

[a] *The Vendor Literature provided in Appendix 3.5.7, "Properties of Materials References," supports these temperature limits.*

[b] *Temperature listed is the maximum value obtained throughout Fire conditions of transport.*

[c] *Listed temperatures are on the overpack and cask surfaces, and not at the personnel barrier surface.*

Model	Component	Thermal Temperatures, by Condition														Regulatory/Component Criteria[a]
		1		2		3[b]		4		5		6		7		
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-050A	Cask Cavity	128	263	92	198	205	401	18	65	-40	-40	29	84	-29	-20	400°C (752°F)
	Shielding Material	125	257	89	193	218	425	15	60	-40	-40	26	79	-29	-20	400°C (752°F)
	Cask Seal Area	123	254	88	190	200	392	13	56	-40	-40	24	76	-29	-20	300°C (572°F) Metallic Seal
	Cask Test Port	123	253	87	188	200	393	13	55	-40	-40	24	74	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Drain Port	124	254	87	189	201	393	13	55	-40	-40	24	75	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Vent Port	123	254	88	190	199	391	13	56	-40	-40	24	76	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Outside Surface	122	252	86	187	374	706	12	53	-40	-40	22	72	-29	-20	400°C (752°F) Conditions 1 and 2
	Impact Limiter Foam Material	124	255	88	190	289	553	14	57	-40	-40	24	76	-29	-20	137°C (279°F) Conditions 1 and 2
	Overpack Accessible Outside Surface[c]	96	202	41	106	799	1,471	-36	-33	-40	-40	-26	-14	-29	-20	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use – Condition 2

Model	Component	Thermal Temperatures, by Condition														Regulatory/Component Criteria[a]
		1		2		3[b]		4		5		6		7		
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-100A, AOS-100A-S	Cask Cavity	126	258	90	195	185	365	12	54	-40	-40	25	78	-29	-20	400°C (752°F)
	Shielding Material	121	250	86	186	204	400	8	46	-40	-40	21	69	-29	-20	400°C (752°F)
	Cask Seal Area	118	245	82	180	185	365	4	39	-40	-40	17	63	-29	-20	300°C (572°F) Metallic Seal
	Cask Test Port	116	241	81	177	175	346	2	36	-40	-40	15	59	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Drain Port	116	242	81	177	175	346	2	36	-40	-40	15	60	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Vent Port	118	245	82	180	174	345	4	39	-40	-40	17	63	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Outside Surface	115	239	79	174	426	799	0	31	-40	-40	13	55	-29	-20	400°C (752°F) Conditions 1 and 2
	Impact Limiter Foam Material	119	246	83	182	618	1,145	5	40	-40	-40	118	64	-29	-20	137°C (279°F) Conditions 1 and 2
	Overpack Accessible Outside Surface[c]	79	174	39	102	799	1,471	-39	-38	-40	-40	-28	-18	-29	-20	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use – Condition 2

Model	Component	Thermal Temperatures, by Condition														Regulatory/Component Criteria[a]
		1		2		3[b]		4		5		6		7		
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-100B	Cask Cavity	126	259	90	195	183	360	13	55	-40	-40	26	78	-29	-20	400°C (752°F)
	Shielding Material	122	251	86	187	202	396	8	46	-40	-40	21	69	-29	-20	400°C (752°F)
	Cask Seal Area	118	245	82	180	172	341	4	39	-40	-40	17	63	-29	-20	300°C (572°F) Metallic Seal
	Cask Test Port	116	241	81	177	172	342	2	36	-40	-40	15	59	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Drain Port	116	242	81	178	172	342	2	36	-40	-40	15	60	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Vent Port	118	245	82	180	171	340	4	39	-40	-40	17	63	-29	-20	232°C (450°F) Elastomeric Seal
	Cask Outside Surface	115	239	79	174	426	799	0	31	-40	-40	13	55	-29	-20	400°C (752°F) Conditions 1 and 2
	Impact Limiter Foam Material	119	246	83	182	618	1,145	5	40	-40	-40	18	64	-29	-20	137°C (279°F) Conditions 1 and 2
	Overpack Accessible Outside Surface[c]	79	174	39	102	799	1,471	-39	-38	-40	-40	-28	-18	-29	-20	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use – Condition 2

RSI 3-2: *Provide information justifying the Ci/Watt values for all nuclides, the energy and type of emissions for each nuclide, as well as a reference for the values.*

Based on preliminary calculations performed to verify the Ci/Watt values for certain nuclides, the staff believes that many of the Ci/Watt values used by the applicant may be non-conservative, including (but not limited to) Zr/Nb-95, Ho-166, Se-75, Sm-153, and Yb-169.

The staff compared the applicant's Ci/Watt values to those in ICRP Publication 38, Radionuclide Transformations Energy and Intensity of Emissions, 1983, as well as those from the Microshield 5 Code (Grove Engineering).

This information is needed to determine compliance with 10 CFR 71.31 and 71.33.

Response:

Table 1-6 will be corrected and updated in the SAR. Other locations within the SAR, in which this data appears, will be corrected and updated as well.

The following is an **UNVERIFIED** copy of Table 1-6, provided as an example of the changes made to the table.

Note: Please note that in the SAR, the footnote will be identified as "a", not "d". It is appearing as "d" due to constraints within Microsoft Word.

Table 1-6. Activity Limits – All Models

Isotope[d]	Ci/Watt	Model							
		AOS-025		AOS-050		AOS-100			
		A (10W)		A (100W)		A, A-S (400W)		B (400W)	
		TBq	Ci	TBq	Ci	TBq	Ci	TBq	Ci
Co-60	6.49E+01	2.40E+01	6.49E+02	2.40E+02	6.49E+03	7.48E+02	2.02E+04	6.00E+00	1.62E+02
Cs-137	1.99E+02	1.28E+00	3.45E+01	1.28E+01	3.46E+02	2.95E+03	7.96E+04	1.84E+01	4.97E+02
Hf-181	2.28E+02	–		8.44E+02	2.28E+04	3.38E+03	9.12E+04	3.38E+03	9.12E+04
Ir-192	1.63E+02	5.48E+00	1.48E+02	3.63E+01	9.81E+02	2.41E+03	6.52E+04	5.78E+01	1.56E+03
Zr/Nb-95	6.02E+01	–		2.10E+00	5.66E+01	8.92E+02	2.41E+04	3.74E+00	1.01E+02
C-14	3.41E+03	1.26E+03	3.41E+04	1.26E+04	3.41E+05	–		–	
Fe-59	1.29E+02	2.02E-01	5.46E+00	–		–		–	
Ho-166	2.33E+02	8.63E+01	2.33E+03	8.63E+02	2.33E+04	–		–	
Na-24	3.61E+01	2.58E-03	6.97E-02	1.55E-02	4.19E-01	–		–	
P-32	2.43E+02	8.48E+01	2.29E+03	9.00E+01	2.43E+03	–		–	
P-33	2.21E+03	8.15E+01	2.20E+03	8.19E+03	2.21E+05	–		–	
Sb-124	7.52E+01	1.16E-02	3.13E-01	1.62E-02	4.38E-01	–		–	

[d] *Encapsulated solid material or solid metal that meets Normal or Special form criteria.*

Isotope[d]	Ci/Watt	Model							
		AOS-025		AOS-050		AOS-100			
		A (10W)		A (100W)		A, A-S (400W)		B (400W)	
		TBq	Ci	TBq	Ci	TBq	Ci	TBq	Ci
Sc-46	7.94E+01	1.05E-01	2.84E+00	–		–		–	
Se-75	4.41E+02	5.44E+02	1.47E+04	1.05E+02	2.84E+03	–		–	
Sm-153	5.15E+02	5.04E+03	1.36E+05	8.74E+02	2.36E+04	–		–	
Sr/Y-90	1.49E+02	5.52E+00	1.49E+02	5.52E+02	1.49E+04	–		–	
Sr-89	2.89E+02	1.07E+02	2.88E+03	1.07E+02	2.88E+03	–		–	
Yb-169	7.94E+02	1.09E+03	2.94E+04	2.10E+02	5.67E+03	–		–	
Yb-175	1.00E+03	1.38E+04	3.74E+05	2.67E+04	7.21E+05	–		–	
Shipping Configuration		Use of Liner 183C8485 is required		No additional shielding is required		Use of Axial Shielding Plates 183C8491 is required for shipments of 7.34E+02 TBq (1.98+04 Ci) Co-60		No additional shielding is required	

RSI 3-3: *Correct discrepancies noted, in particular between the decay heat appendix of the application which mentions that 200 Watts were analyzed for the Model No. AOS-050, while Table 3-4 of the application reports that the analysis was performed for 100 Watts.*

Correct also the analysis results and ensure that such errors do not appear in the analysis of other AOS package models.

This information is needed to determine compliance with 10 CFR 71.31.

Response:

The Decay Heat value applied to each of the Models – AOS-025, AOS-050, and AOS-100 – were verified and found to be correct. The particular calculation presented in the Appendix (see below) is a typographical error. The decay heat for the AOS-050 is 100 Watts, and its corresponding Heat Flux value of 2.875 Btu/hr-in^2 is shown at the last sentence in this paragraph.

Model AOS-050 Cask

Decay Heat = 200W

200W = 3.4121 * 200 = 682.4 Btu/hr

Cavity Area

$2\pi\ (1.62424^2 + 1.62424 * (14.0 - 4.0))$

= 118.63 in^2

Heat Flux

682.4 / 118.63 = 5.75 Btu/hr-in^2

2.875 (100W)

RSI 3-4: *Justify the validation of information provided for the LIBRA code.*

Table 3-94 of the SAR, "Comparison of Heat Test GE Model 2000 and LIBRA Results," shows that the LIBRA code consistently and significantly underpredicts the cask cavity temperature compared to the results of the heat test. It is not clear how these temperature differences are justified and addressed in the validation of the code.

This information is needed to determine compliance with 10 CFR 71.31.

Response:

The GE Model 2000 heat tests were performed to verify thermal properties used in the analytical model, In particular, the Model 2000 heat tests were used to validate thermal conduction properties for cask structural and shielding materials. The Libra program accuracy is demonstrated by a number of verification problems described below, and by the Model AOS-165A tests.

The GE Model 2000 heat tests were conducted outside, using a test structure only partially enclosed by plywood. In addition, tests were conducted over an extended time period, during which the ambient temperature varied by over 20°F. Consequently, test convective values could not be accurately identified. However, thermal conduction values can be evaluated without accurate convection properties, by matching test and analytical temperature patterns. To this end, approximate ambient temperature and convection values were applied in the analysis of the test event. While the approximate convection properties produced the consistently low temperature correlation, the calculated temperature patterns correlated well with test results validating the model.

The Model AOS-165A test was performed under a more controlled environment, and the correlation between analytical and test temperatures are very good. Accuracy of the LIBRA code is further demonstrated by the following eight solutions, presented in the LIBRA program verification documentation. These problems were chosen to exercise the LIBRA program elements and features used in the AOS thermal analyses. The LIBRA input models for these problems are contained on the **LIBRA** program CD, **Libra64** folder, **verification** sub-folder.

<u>ver_prob.1 (Main 12, Elements 34 & 32)</u>

Axisymmetric, steady-state heat transfer of Carbon resistor, graphite core and michanite conductor, model 1. Solution from Denny, "Transfer Processes," 2nd Ed., p. 27.

```
graphite temperature = 368.8
Libra node 15 temperature = 368.5
```

ver_prob.2 (Main 12, Elements 34 & 32)

Axisymmetric, steady-state heat transfer of Carbon resistor, graphite core and michanite conductor, model 2. Solution from Denny, "Transfer Processes," 2nd Ed., p. 27.

```
graphite temperature = 368.8
Libra node 39 temperature = 368.5
```

ver_prob.3 (Main 12, Elements 34 & 32)

Axisymmetric, steady-state heat transfer of Carbon resistor, graphite core and michanite conductor, model 3. Solution from Denny, "Transfer Processes," 2nd Ed., p. 27.

```
graphite temperature = 368.8
Libra node 39 temperature = 368.5
```

ver_prob.4 (Main 12, Elements 34 & 32)

Axisymmetric, steady-state heat transfer of Carbon resistor, graphite core and michanite conductor, model 4. Solution from Denny, "Transfer Processes," 2nd Ed., p. 27.

```
core temperature = 434.8
Libra node 6 temperature = 434.8
```

ver_prob.5 (Main 12, Elements 34 & 32)

Axisymmetric, transient heat transfer of copper wire initially at 300 deg immersed in water. Solution from Kreith, "Principals of Heat Transfer," 2nd Ed., p. 131.

Item	Theory	Libra
time step 16 temp	173.7	175.2
time step 32 temp	127.1	128.3
time step 48 temp	110.0	110.6
time step 64 temp	103.7	104.0
time step 90 temp	101.4	101.5

ver_prob.6 (Main 12, Elements 34 & 32)
Axisymmetric, transient heat transfer of copper wire initially at 300 deg, immersed in air. Solution from Kreith, "Principals of Heat Transfer," 2nd Ed., p. 131.

Item	Theory	Libra
temperature @ time step 32	217.5	217.3
temperature @ time step 64	169.0	168.8
temperature @ time step 96	140.5	140.3
temperature @ time step 128	123.8	123.7
temperature @ time step 160	114.0	113.9

ver_prob.7 (Main 12, Elements 34 & 32)

Transient heat transfer of concrete wall initially at 100 deg exposed to gas at 1,600 deg. Solution from Kreith, "Principals of Heat Transfer," 2nd Ed., p. 151.

Item	Theory	Libra
temperature @ x/L 0.0	500.8578	500.5
temperature @ x/L 0.2	543.3878	543.1
temperature @ x/L 0.4	668.5285	668.5
temperature @ x/L 0.6	868.4861	868.7
temperature @ x/L 0.8	1129.25	1130.0
temperature @ x/L 1.0	1430.378	1431.1

ver_prob.8 (Main 12, Element 34)

Steady-state heat transfer of two-layer furnace wall. Solution from Kreith, "Principals of Heat Transfer," 2nd Ed., p. 34.

```
temperature @ inside surface  = 2957.0, Libra node  1 = 2957.3
temperature @ outside surface =  336.0, Libra node 50 =  335.8
```

RSI 3-5: *Review all unit conversions in the application and associated analysis files and correct and report any discrepancies found.*

Table 3-7 has an incorrect unit conversion for thermal conductivity, an incorrect unit conversion for specific heat as well as an incorrect unit label.

This information is needed to determine compliance with 10 CFR 71.31.

Response:
In Table 3-7, the specific heat (Cp) should be 0.111 Btu/lb instead of 0.222 Btu/lb. Also, the tabulated values for K are off by a factor of 10, that is, 550 should be 55.0, and so forth. Also, "thermal differential" should be "thermal diffusivity". Paragraph 3.2.1.3 and Appendix 3.5.4 are changed, as shown below.

In addition the following errors are found throughout Chapter 3:

Section 3.1, pg 3-4 – In Table 3-4 change "lists the maximum" to "list selected nodal".

Page 3-6, Pressure Calculation –
Under Initial Condition, P_1 should be 14.7 psia, not 30 psia;
P_2 calculation result is erroneous, P_2 should be 19.56 psia, not 21 psia.

Paragraph 3.2.1.3, pg 3-16 – Redo write-up to reflect updated carbon steel material properties.

Sub-section 3.3.3, pg 3-45 – First paragraph, change "minimum" to "maximum".

also pages 3-70, 3-86, 3-114, 3-143, 3-168, 3-193

Section 3.4, pg 3-83 – 1st paragraph, should "5 to 10 ms" be "5 to 10 w/m^2-°C"?

Sub-section 3.4.5, pg 3-85, change "Flssle" to "Fissile".

Sub-section 3.4.7, pg 3-114 – Remove data and reference to LC102 and add LC116?

Also under ***Notes***, the last two paragraphs may be removed after the change.

Sub-section 3.4.7, pg 3-115 – Table 3-41, remove reference to LC102.

Also noticed that contour plots have been supplied in this section, but not in Sub-section 3.3.3, pages 3-70 through 3-82.

It was noticed that there is no description of the boundary conditions during the 30-minute fire condition. Paragraph 3.3.1.3.x will be added, as provided below.

3.2.1.3 Carbon Steel

Table 3-7 lists the thermophysical properties of carbon steel SA105, as they apply to the transport packages (3-13) AOS-100B. Figure 3-2 illustrates the relationship between conductivity and temperature for the carbon steel material.

Table 3-7. Carbon Steel Properties

Material: SA-105, Carbon Steel Forging			
Temperature °C	Conductivity W/m-°C	Thermal Diffusivity m^2/hr	Specific Heat kJ/kg-°C
21.1	60.75	0.06457	0.4324
37.8	60.06	0.06262	0.4408
65.6	59.02	0.05992	0.4527
93.3	58.15	0.05695	0.4693
121.1	56.94	0.05435	0.4815
148.9	55.90	0.05212	0.4930
204.4	53.48	0.04757	0.5167
260.0	51.06	0.04385	0.5351
315.6	48.46	0.04023	0.5537
343.3	47.25	0.03846	0.5646
371.1	46.04	0.03660	0.5780
398.9	44.83	0.03475	0.5929
426.7	43.61	0.03298	0.6078
454.4	42.40	0.03112	0.6262
482.2	41.19	0.02945	0.6483

Density = 7832.8 kg/m^3

= 0.283 lb/in^3

The conductivity property as a function of temperature is defined as:

$$K = 3.003 - 1.027E\text{-}3\ T - 1.249E\text{-}7\ T^2$$

where:

K = Conductivity - Btu/hr-in-°F

T = Temperature - °F

The specific heat property as a function of temperature is defined as:

$$Cp = 0.1009 + 4.847E\text{-}5\ T + 9.493E\text{-}9\ T^2$$

where:

Cp = Specific heat - Btu/lb-°F

T = Temperature, °F

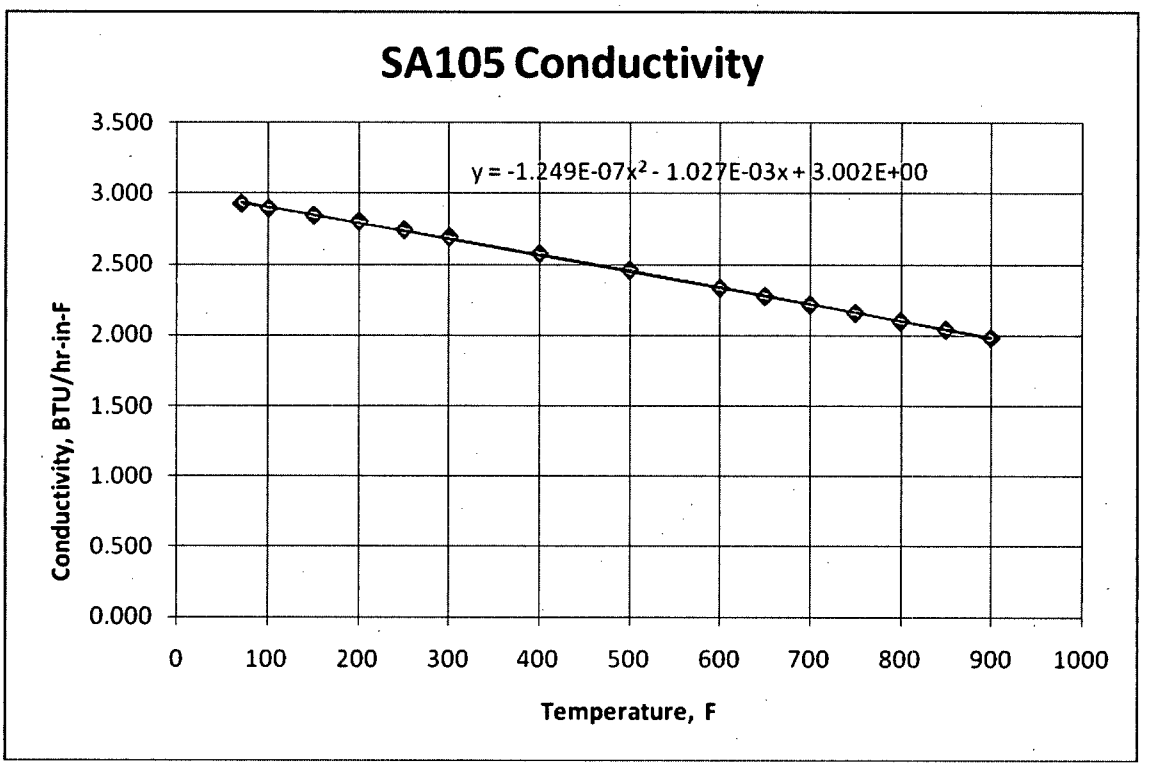


Figure 3-2. Carbon Steel Conductivity versus Temperature Used in Model AOS-100B

Appendix 3.5.4 Tungsten Alloy versus Carbon Steel Materials Comparison

(Only the results are presented here)

Table 3-96. Carbon Steel Properties

Material: SA-105, Carbon Steel Forging			
Temperature °C	Conductivity W/m-°C	Thermal Diffusivity m^2/hr	Specific Heat kJ/kg-°C
21.1	60.75	.06457	.4324
37.8	60.06	.06262	.4408
65.6	59.02	.05992	.4527
93.3	58.15	.05695	.4693
121.1	56.94	.05435	.4815
148.9	55.90	.05212	.4930
204.4	53.48	.04757	.5167
260.0	51.06	.04385	.5351
315.6	48.46	.04023	.5537
343.3	47.25	.03846	.5646
371.1	46.04	.03660	.5780
398.9	44.83	.03475	.5929
426.7	43.61	.03298	.6078
454.4	42.40	.03112	.6262
482.2	41.19	.02945	.6483

Density = 7832.8 kg/m^3
= 0.283 lb/in^3

The conductivity property as a function of temperature is defined as:

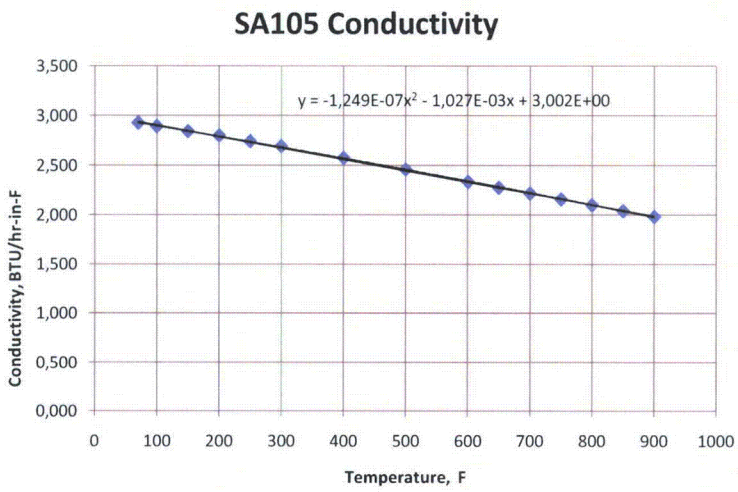
$$K = 3.003 - 1.027e\text{-}3\ T - 1.249e\text{-}7\ T^2$$

where, K = conductivity - BTU/hr-in-°F
T = temperature - °F

The specific heat property as a function of temperature is defined as:

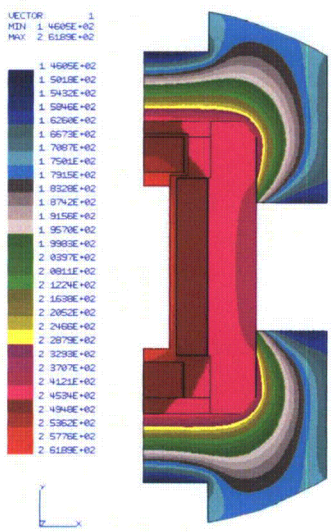
$$Cp = 0.1009 + 4.847e\text{-}5\ T + 9.493e\text{-}9\ T^2$$

where, Cp = specific heat – BTU/lb-°F
T = temperature, °F

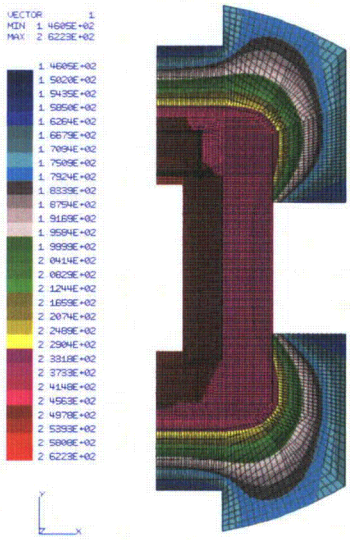


AOS-100, 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy

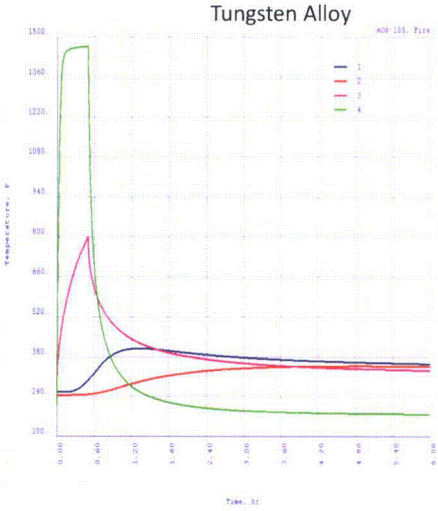


Carbon Steel

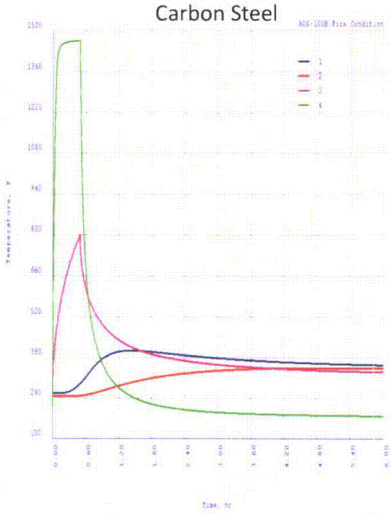


AOS-100, 5 Hour Fire Transient
30 minutes Fire @ 1475°F, 4.5 Hour Cool Down @ 100°F

Tungsten Alloy

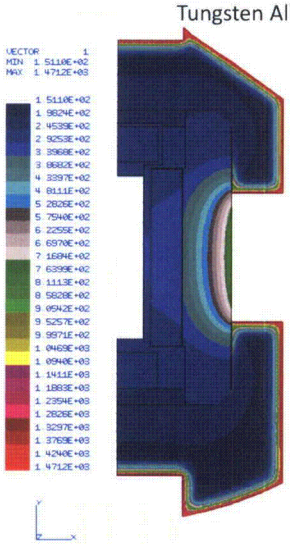


Carbon Steel

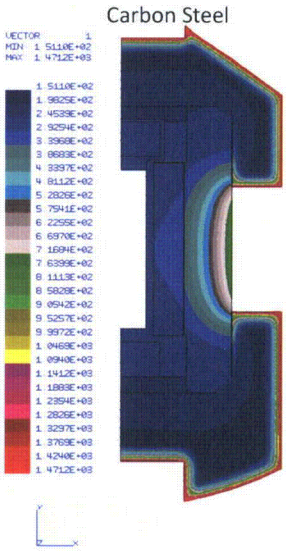


AOS-100, 30 Min Fire – 1475°F Ambient, 400 W Decay Heat

Tungsten Alloy

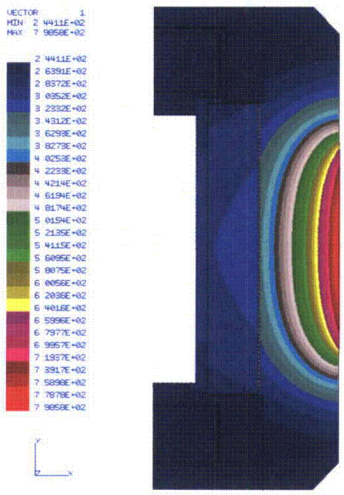


Carbon Steel

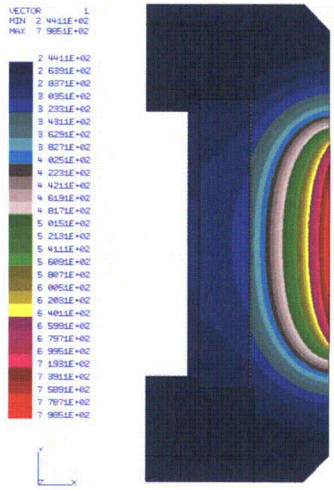


AOS-100, 30 Min Fire – 1475°F Ambient, 400 W Decay Heat

Tungsten Alloy

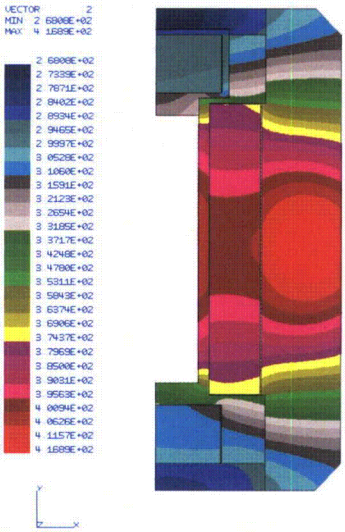


Carbon Steel

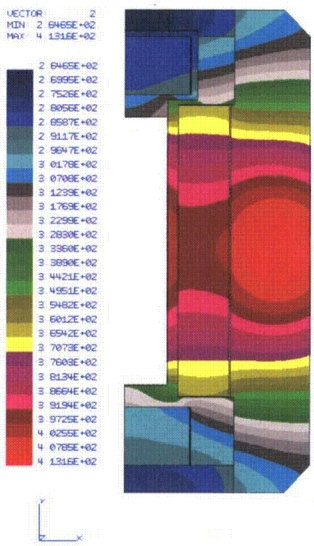


AOS-100, 90 Min Fire – 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy

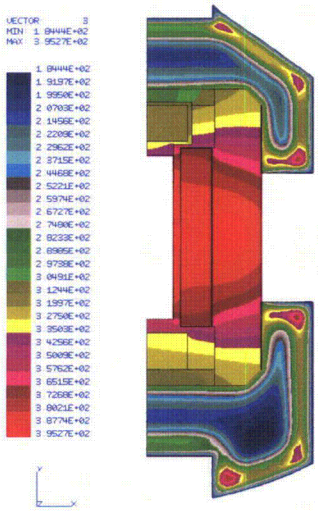


Carbon Steel

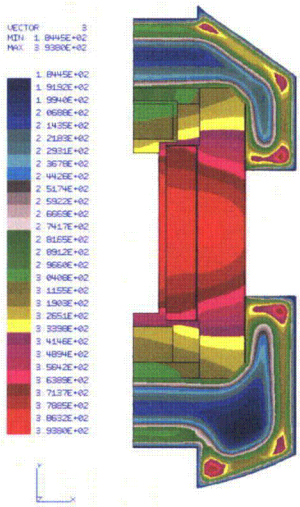


AOS-100, 120 Min Fire – 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy

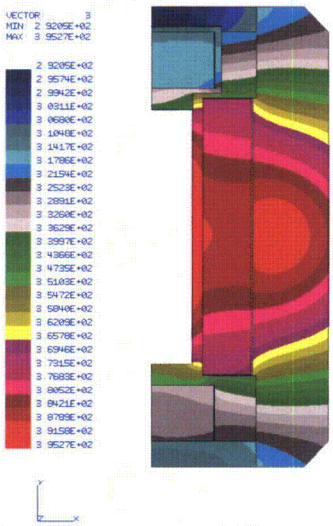


Carbon Steel

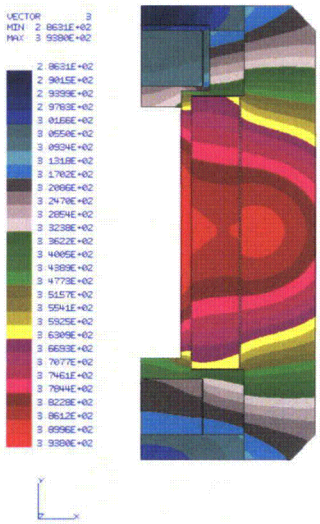


AOS-100, 120 Min Fire – 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy

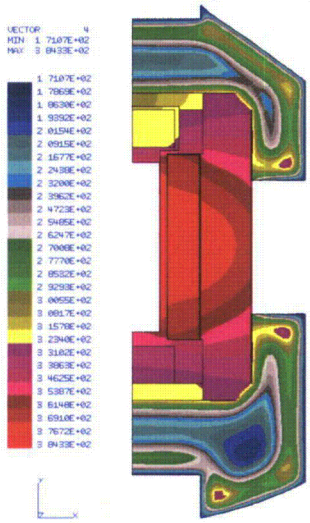


Carbon Steel

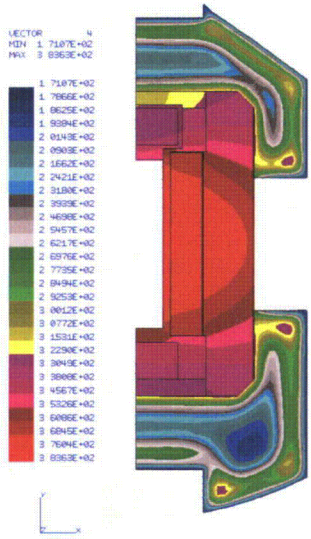


AOS-100, 150 Min Fire – 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy

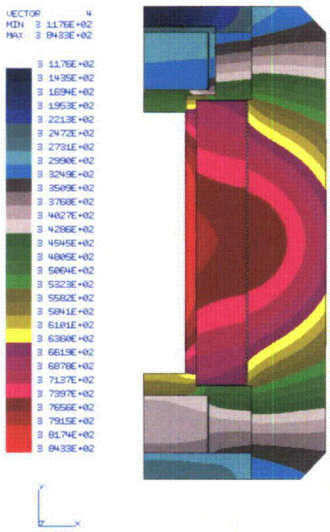


Carbon Steel

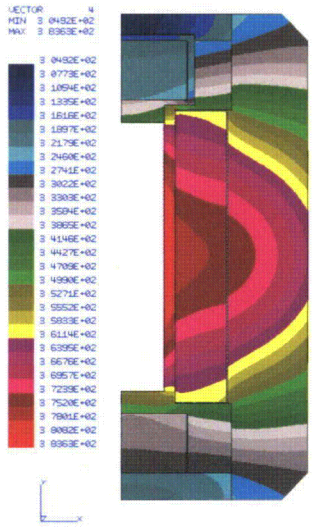


AOS-100, 150 Min Fire – 100°F Ambient, 400 W Decay Heat + Insolation

Tungsten Alloy



Carbon Steel



3.3.1.3.x Cask Boundary Surfaces at 1,475°F Environment

During the 30-minute fire condition, the ambient air is 1,475°F. Using the relationship provided in Paragraph 3.3.1.1 for convection due to radiation, the surface convective coefficient is:

$$h_r = S * F * (T_1^2 + 1{,}935^2) * (T_1 + 1{,}935)$$

where:

S = Stefan-Boltzmann constant = 1.1944E-11 Btu/hr-in^2-°R^4

F = Gray body shape factor

using emissivity value of 0.9 and absorptivity = 0.8

F = 0.7347

T1 = Surface temperature, °R

Then:

$$h_r = 0.87753E\text{-}11 * (T_1^3 + 1{,}935 * T_1^2 + 1{,}935^2 * T_1 + 1{,}935^3)$$

A convective heat transfer is also present during the fire condition:

$$h_c = 10 \text{ w/m}^2\text{-°C } (0.01223 \text{ Btu/hr-in}^2\text{-°F})$$

Combining the effects of both radiation and convection, total surface convection during the fire condition defined as a function of temperature is:

$$h_t = 9.722E\text{-}2 + 3.999E\text{-}5 * T + 4.998E\text{-}8 * T^2$$

where:

T = Surface temperature, °F

RSI 3-6: *Provide descriptions, including drawings, of the internal basket assemblies used in the various designs in Section 3.3.1 of the application. Describe the thermal interactions of the payload with the internal surfaces of the inner canister. Demonstrate that the decay heat generated by the contents is appropriately modeled in relation to the interior of the package*

The assumption that the heat on internal surfaces is evenly distributed may not be conservative. The temperature distribution within the inner cavity will be dependent on the arrangement of the contents. While the overall decay heat generated may be represented, the distribution of this heat load is not captured by applying it uniformly on the inner surface of the canister.

The demonstration that the decay heat is appropriately modeled is required so that softening of the basket does not occur if an aluminum basket is used in some AOS models.

This information is needed to determine compliance with 10 CFR 71.33(a)(5)(v).

Response:
Typically, the content is placed in the cask cavity in a basket or rack device. This device provides shoring to the content, to ensure that its loading arrangement is maintained during transportation. Selection of the type of material for fabrication of this device is based upon the temperature environment within the cask cavity. A cavity temperature of less than 400°F will allow the use of aluminum. For temperatures of 400°F or greater, the choice is stainless steel material, although this material could be used in either case.

The cavity temperature within all AOS Transport System Models is less than 300°F under NCT; therefore, the use of either material in the fabrication of the shoring devices is acceptable.

In the AOS cask analyses, the decay heat is assumed to be uniformly distributed throughout the cask cavity. The effect of this assumption is examined here, by comparing cask stress and temperatures corresponding to three assumed distributions of decay heat over the surface of the cask cavity. The three assumed distributions represent usual, assumed decay heat distributions over the cask cavity cylinder, top and bottom.

Case 1. Decay heat uniformly distributed over the cask cavity cylindrical surface, top surface, and bottom surface (as in the AOS analyses).

Case 2. Decay heat distributed over the cask cavity cylindrical surface, top surface, and bottom surface, such that the cylindrical surface receives twice the heat intensity as the top and bottom surfaces.

Case 3. Decay heat distributed over only cask cavity cylindrical surface, with the top and bottom surfaces receiving no heat.

Cask temperatures and thermal stress were determined for each of the three distributions. The maximum component temperatures are presented in Tables 1 through 3, and cask temperature distributions are illustrated in Figures 1 through 3. Pm and Pb stress at the critical cask cross-sections are presented in Tables 4 through 6, and plots of maximum principal stress in the cask dog-leg region are illustrated in Figures 4 through 6.

A comparison of Tables 1 through 3 shows little variation in maximum temperature for the three heat distributions. Figures 1 through 3 show that Case 1, uniformly distributed decay heat, provides maximum temperature in the seal region. From Tables 1 through 3, the maximum temperature difference is less than 6°F .

A comparison of Tables 4 through 6 shows little variation in stress due to heat distribution. Maximum thermal bending stress occurs at Location 4, and the maximum stress difference due to heat distribution is 0.5 ksi. Figures 4 through 6 also show only a small stress difference in the cask dog-leg region due to the heat distribution.

In the AOS cask analyses, thermal stress due to maximum decay heat represents only a small portion of total stress in all load combinations. As a result, the small stress change in the three cases shows that a change in assumed decay heat distribution would have negligible effect upon overall stress evaluations. In addition, maximum change in the corresponding temperatures for the three cases is less than 6°F, with the uniform decay heat distribution producing maximum temperature in the seal region.

Table 1. Case 1, Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp
Outside Shell	101	2894	606	1.8090E+02
Bottom Plate	3001	3232	3120	1.8160E+02
Lid	3233	3424	3233	1.8210E+02
Shell Cavity	4001	4998	4227	1.9420E+02
Plug	5001	5404	5001	1.9820E+02
Tungsten	6001	7656	7377	1.8620E+02
LAST-A-FOAM	8001	10791	9501	1.8160E+02

Table 2. Case 2, Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp
Outside Shell	101	2894	620	1.7830E+02
Bottom Plate	3001	3232	3120	1.7850E+02
Lid	3233	3424	3233	1.7680E+02
Shell Cavity	4001	4998	4482	1.8920E+02
Plug	5001	5404	5012	1.8000E+02
Tungsten	6001	7656	6392	1.8120E+02
LAST-A-FOAM	8001	10791	8197	1.7810E+02

Table 3. Case 3, Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp
Outside Shell	101	2894	634	1.8120E+02
Bottom Plate	3001	3232	3120	1.8060E+02
Lid	3233	3424	3233	1.8000E+02
Shell Cavity	4001	4998	4497	1.9310E+02
Plug	5001	5404	5012	1.8350E+02
Tungsten	6001	7656	6432	1.8450E+02
LAST-A-FOAM	8001	10791	8197	1.8030E+02

Table 4. Case 1, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.0456E+02	-1.8983E+02	-2.8034E+01	2.9439E+02	4.2926E+02
	7.2091E-01	-1.3088E+00	-1.9329E-01	2.0297E+00	2.9597E+00
2	1.3149E+02	-2.9406E+02	-8.4539E+01	4.2555E+02	8.7203E+02
	9.0661E-01	-2.0275E+00	-5.8288E-01	2.9341E+00	6.0124E+00
3	1.0021E+02	-1.8730E+02	-2.2414E+01	2.8752E+02	4.2741E+02
	6.9094E-01	-1.2914E+00	-1.5454E-01	1.9823E+00	2.9469E+00
4	6.3127E+02	-2.1814E+03	-4.4076E+02	2.8126E+03	5.5355E+03
	4.3524E+00	-1.5040E+01	-3.0390E+00	1.9392E+01	3.8166E+01
5	6.2466E+02	-2.4329E+03	-9.8919E+02	3.0575E+03	4.8291E+03
	4.3069E+00	-1.6774E+01	-6.8202E+00	2.1081E+01	3.3295E+01
6	9.6377E+01	-1.2090E+03	-1.3048E+03	1.3054E+03	1.5833E+03
	6.6450E-01	-8.3357E+00	-8.9960E+00	9.0002E+00	1.0916E+01
7	-1.9217E+01	-4.1327E+02	2.4598E+01	3.9406E+02	4.2739E+02
	-1.3249E-01	-2.8494E+00	1.6960E-01	2.7169E+00	2.9468E+00
8	-1.9485E+01	-4.1288E+02	-1.5849E-01	3.9339E+02	4.2023E+02
	-1.3434E-01	-2.8467E+00	-1.0927E-03	2.7123E+00	2.8974E+00
9	-1.9384E+01	-4.1271E+02	-1.5390E+00	3.9333E+02	4.1618E+02
	-1.3364E-01	-2.8456E+00	-1.0611E-02	2.7119E+00	2.8695E+00
10	-7.2193E+01	-5.3770E+02	6.2101E+01	4.6550E+02	9.5760E+02
	-4.9775E-01	-3.7073E+00	4.2817E-01	3.2095E+00	6.6024E+00
11	-1.2200E+02	-6.7410E+02	-3.2254E+02	5.5211E+02	1.2549E+02
	-8.4114E-01	-4.6478E+00	-2.2238E+00	3.8066E+00	8.6522E-01
12	2.5799E+00	-8.1753E+02	-8.1351E+02	8.2011E+02	1.7232E+02
	1.7788E-02	-5.6367E+00	-5.6090E+00	5.6545E+00	1.1881E+00
13	-8.6733E+01	-1.2094E+03	-1.2100E+02	1.1227E+03	8.1844E+02
	-5.9800E-01	-8.3386E+00	-8.3430E-01	7.7406E+00	5.6430E+00
14	-6.9338E+01	-1.0534E+03	5.7286E+01	9.8411E+02	6.6719E+02
	-4.7807E-01	-7.2632E+00	3.9497E-01	6.7852E+00	4.6001E+00
15	2.1678E+02	-2.8099E+02	-3.4633E+01	4.9777E+02	8.3966E+02
	1.4946E+00	-1.9374E+00	-2.3879E-01	3.4320E+00	5.7893E+00
16	6.5964E+01	-1.3093E+02	-3.3301E+01	1.9689E+02	3.3071E+02
	4.5480E-01	-9.0271E-01	-2.2960E-01	1.3575E+00	2.2802E+00

17	3.0783E+01	-9.2873E+01	-1.1470E+01	1.2366E+02	2.1759E+02
	2.1224E-01	-6.4034E-01	-7.9082E-02	8.5258E-01	1.5002E+00
18	4.5328E+01	-9.9979E+01	5.5228E+02	1.4531E+02	6.1413E+01
	3.1252E-01	-6.8933E-01	3.8078E+00	1.0019E+00	4.2343E-01
19	-1.8918E+01	-2.1523E+02	6.9267E+02	1.9631E+02	2.1305E+02
	-1.3043E-01	-1.4840E+00	4.7758E+00	1.3535E+00	1.4689E+00
20	-3.7965E+01	-5.4220E+02	1.6813E+02	5.0423E+02	2.4979E+02
	-2.6176E-01	-3.7383E+00	1.1592E+00	3.4765E+00	1.7222E+00
21	3.1481E+00	-8.6388E+01	-8.2724E+01	8.9536E+01	1.2184E+02
	2.1705E-02	-5.9563E-01	-5.7036E-01	6.1733E-01	8.4008E-01
22	-2.8719E+01	-1.4109E+02	-1.3557E+02	1.1237E+02	1.3962E+02
	-1.9801E-01	-9.7277E-01	-9.3474E-01	7.7476E-01	9.6264E-01

Table 5. Case 2, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.0626E+02	-1.8898E+02	-1.7071E+01	2.9524E+02	4.2317E+02
	7.3263E-01	-1.3029E+00	-1.1770E-01	2.0356E+00	2.9176E+00
2	1.3586E+02	-3.0081E+02	-9.1768E+01	4.3667E+02	8.9696E+02
	9.3669E-01	-2.0740E+00	-6.3272E-01	3.0107E+00	6.1843E+00
3	1.0306E+02	-1.8881E+02	-1.6976E+01	2.9187E+02	4.2935E+02
	7.1056E-01	-1.3018E+00	-1.1704E-01	2.0124E+00	2.9603E+00
4	6.8554E+02	-2.0418E+03	-4.0530E+02	2.7273E+03	5.3361E+03
	4.7267E+00	-1.4077E+01	-2.7944E+00	1.8804E+01	3.6791E+01
5	7.1795E+02	-2.3302E+03	-7.5061E+02	3.0481E+03	4.8219E+03
	4.9501E+00	-1.6066E+01	-5.1752E+00	2.1016E+01	3.3246E+01
6	1.0763E+02	-1.1763E+03	-9.7713E+02	1.2839E+03	1.6656E+03
	7.4210E-01	-8.1103E+00	-6.7371E+00	8.8524E+00	1.1484E+01
7	-2.0446E+01	-4.0750E+02	2.8551E+01	3.8706E+02	4.7858E+02
	-1.4097E-01	-2.8096E+00	1.9685E-01	2.6687E+00	3.2997E+00
8	-2.0978E+01	-4.0600E+02	-4.8058E-01	3.8502E+02	4.5443E+02
	-1.4464E-01	-2.7992E+00	-3.3135E-03	2.6546E+00	3.1332E+00
9	-2.0912E+01	-4.0664E+02	9.9173E+00	3.8573E+02	4.6822E+02
	-1.4418E-01	-2.8037E+00	6.8378E-02	2.6595E+00	3.2283E+00
10	-5.2623E+01	-4.2684E+02	-1.1668E+02	3.7421E+02	5.2219E+02
	-3.6282E-01	-2.9429E+00	-8.0447E-01	2.5801E+00	3.6003E+00
11	-4.6965E+01	-4.3616E+02	-2.8320E+02	3.8919E+02	1.9263E+01
	-3.2381E-01	-3.0072E+00	-1.9526E+00	2.6834E+00	1.3281E-01
12	1.4280E+00	-4.9718E+02	-4.9572E+02	4.9861E+02	7.6981E+00
	9.8457E-03	-3.4279E+00	-3.4179E+00	3.4378E+00	5.3076E-02
13	-6.2872E+01	-1.0239E+03	-1.9446E+02	9.6098E+02	8.5804E+02
	-4.3349E-01	-7.0592E+00	-1.3407E+00	6.6258E+00	5.9160E+00
14	-3.7412E+01	-8.9557E+02	-3.3335E+01	8.5816E+02	6.0010E+02
	-2.5795E-01	-6.1747E+00	-2.2984E-01	5.9168E+00	4.1376E+00
15	2.1957E+02	-2.7300E+02	-2.5945E+01	4.9258E+02	8.3463E+02
	1.5139E+00	-1.8823E+00	-1.7889E-01	3.3962E+00	5.7545E+00
16	6.4300E+01	-1.2668E+02	-3.6108E+01	1.9097E+02	3.1495E+02
	4.4333E-01	-8.7340E-01	-2.4895E-01	1.3167E+00	2.1715E+00

17	2.8317E+01	-8.6767E+01	1.9932E+00	1.1508E+02	2.0063E+02
	1.9524E-01	-5.9824E-01	1.3742E-02	7.9347E-01	1.3833E+00
18	7.6299E+00	-4.6973E+01	1.0789E+02	5.4603E+01	6.5954E+01
	5.2606E-02	-3.2387E-01	7.4391E-01	3.7647E-01	4.5473E-01
19	1.4607E+01	-8.9408E+01	8.3077E+01	1.0401E+02	1.6972E+02
	1.0071E-01	-6.1645E-01	5.7280E-01	7.1716E-01	1.1702E+00
20	2.8480E+00	-1.0012E+02	-6.3027E+01	1.0297E+02	1.9318E+02
	1.9636E-02	-6.9030E-01	-4.3456E-01	7.0994E-01	1.3319E+00
21	5.8399E+00	-7.5225E+01	-6.8959E+01	8.1065E+01	1.2310E+02
	4.0265E-02	-5.1866E-01	-4.7546E-01	5.5892E-01	8.4872E-01
22	-2.2860E+01	-5.5165E+01	-4.5433E+01	3.2305E+01	5.0119E+01
	-1.5761E-01	-3.8035E-01	-3.1325E-01	2.2273E-01	3.4556E-01

Table 6. Case 3, Stress (psi/MPa)

Location	Sigma_1	Sigma_2	Sigma_3	Pm	Pb
1	1.1332E+02	-2.0167E+02	-1.7830E+01	3.1499E+02	4.5244E+02
	7.8130E-01	-1.3904E+00	-1.2294E-01	2.1717E+00	3.1195E+00
2	1.4456E+02	-3.1945E+02	-9.9536E+01	4.6401E+02	9.5345E+02
	9.9670E-01	-2.2025E+00	-6.8628E-01	3.1992E+00	6.5738E+00
3	1.0883E+02	-1.9587E+02	-1.1934E+01	3.0470E+02	4.4224E+02
	7.5036E-01	-1.3504E+00	-8.2283E-02	2.1008E+00	3.0492E+00
4	6.9648E+02	-2.1058E+03	-4.1724E+02	2.8022E+03	5.4835E+03
	4.8021E+00	-1.4519E+01	-2.8768E+00	1.9321E+01	3.7807E+01
5	7.3302E+02	-2.4089E+03	-7.8913E+02	3.1419E+03	4.9727E+03
	5.0540E+00	-1.6609E+01	-5.4409E+00	2.1663E+01	3.4285E+01
6	1.1040E+02	-1.2142E+03	-1.0213E+03	1.3246E+03	1.7067E+03
	7.6121E-01	-8.3716E+00	-7.0419E+00	9.1328E+00	1.1767E+01
7	-2.1151E+01	-4.2187E+02	3.0050E+01	4.0072E+02	5.1802E+02
	-1.4583E-01	-2.9087E+00	2.0719E-01	2.7629E+00	3.5716E+00
8	-2.2697E+01	-4.1929E+02	-8.1965E-01	3.9660E+02	4.9239E+02
	-1.5649E-01	-2.8909E+00	-5.6513E-03	2.7344E+00	3.3949E+00
9	-2.0069E+01	-4.2351E+02	2.3821E+01	4.0344E+02	5.2751E+02
	-1.3837E-01	-2.9200E+00	1.6424E-01	2.7816E+00	3.6370E+00
10	1.0335E+02	-4.4853E+02	-3.3947E+02	5.5188E+02	1.1988E+00
	7.1255E-01	-3.0925E+00	-2.3405E+00	3.8050E+00	8.2654E-03
11	1.0720E+02	-2.2665E+02	-2.4470E+02	3.3385E+02	1.8718E+02
	7.3910E-01	-1.5627E+00	-1.6871E+00	2.3018E+00	1.2906E+00
12	1.2235E+01	-1.3838E+02	-1.2779E+02	1.5061E+02	2.1751E+02
	8.4356E-02	-9.5409E-01	-8.8110E-01	1.0384E+00	1.4996E+00
13	3.8109E+00	-8.7929E+02	-2.9444E+02	8.8310E+02	9.4655E+02
	2.6275E-02	-6.0625E+00	-2.0301E+00	6.0887E+00	6.5262E+00
14	1.4413E+01	-7.5512E+02	-1.5131E+02	7.6954E+02	5.5921E+02
	9.9376E-02	-5.2064E+00	-1.0432E+00	5.3058E+00	3.8556E+00
15	2.3622E+02	-2.9365E+02	-2.7933E+01	5.2987E+02	8.9787E+02
	1.6287E+00	-2.0246E+00	-1.9259E-01	3.6533E+00	6.1906E+00
16	6.9144E+01	-1.3625E+02	-3.8755E+01	2.0539E+02	3.3867E+02
	4.7673E-01	-9.3939E-01	-2.6721E-01	1.4161E+00	2.3350E+00

17	3.0430E+01	-9.3259E+01	2.3069E+00	1.2369E+02	2.1560E+02
	2.0981E-01	-6.4300E-01	1.5906E-02	8.5281E-01	1.4865E+00
18	8.1408E+00	-5.0305E+01	1.1570E+02	5.8446E+01	7.0571E+01
	5.6129E-02	-3.4684E-01	7.9773E-01	4.0297E-01	4.8657E-01
19	1.5492E+01	-9.5652E+01	8.9411E+01	1.1114E+02	1.8136E+02
	1.0681E-01	-6.5950E-01	6.1647E-01	7.6631E-01	1.2505E+00
20	2.8083E+00	-1.0699E+02	-6.7307E+01	1.0980E+02	2.0545E+02
	1.9362E-02	-7.3769E-01	-4.6406E-01	7.5706E-01	1.4165E+00
21	1.1268E+01	-6.6794E+01	-5.5199E+01	7.8062E+01	1.3120E+02
	7.7691E-02	-4.6053E-01	-3.8058E-01	5.3822E-01	9.0459E-01
22	-2.4790E+01	-5.9183E+01	-4.8922E+01	3.4393E+01	5.6968E+01
	-1.7092E-01	-4.0805E-01	-3.3730E-01	2.3713E-01	3.9278E-01

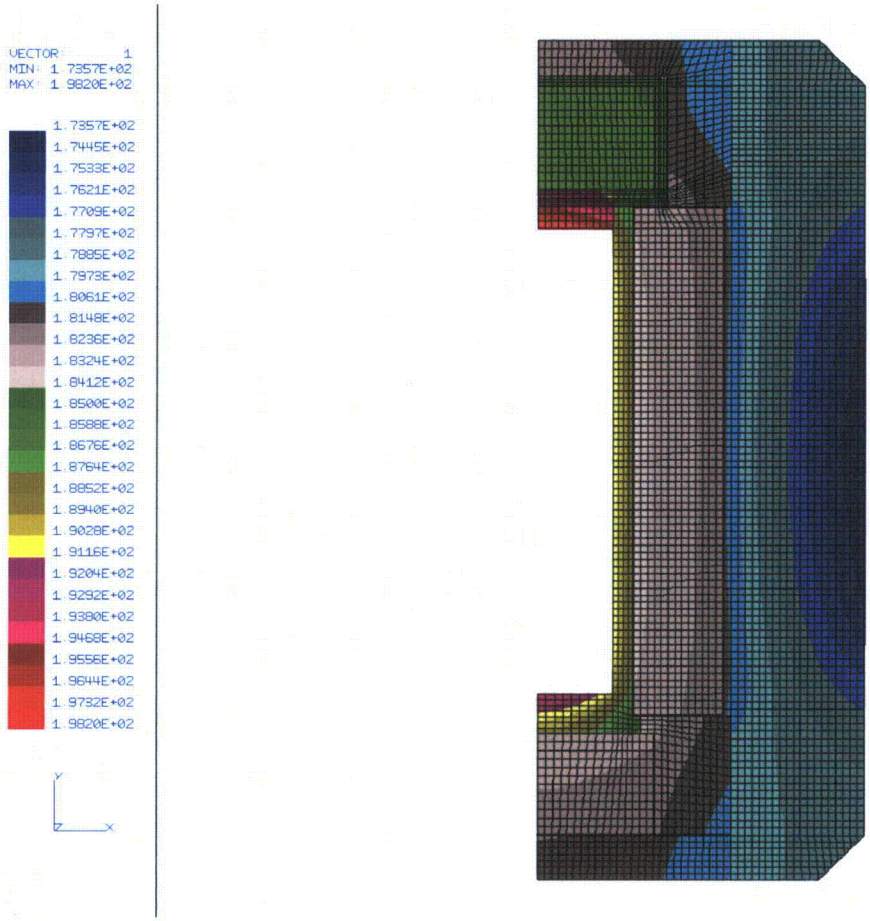
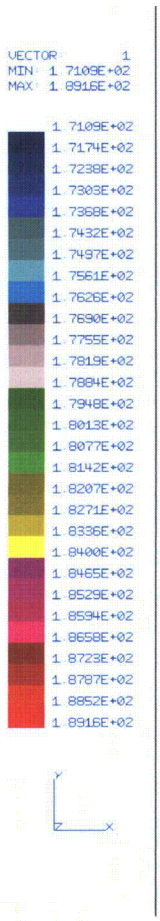


Figure 1. Case 1 Temperatures



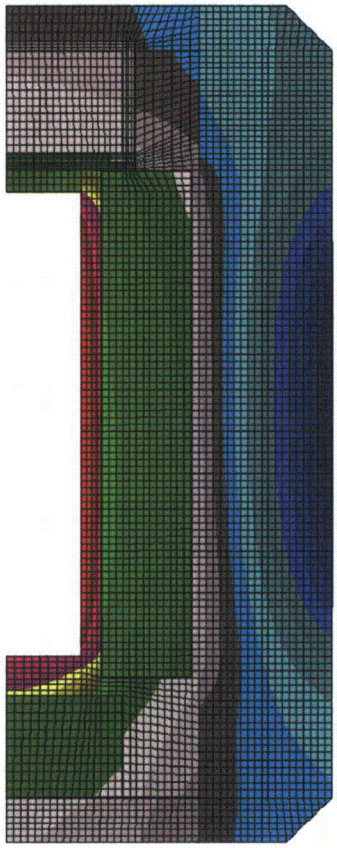


Figure 2. Case 2 Temperatures

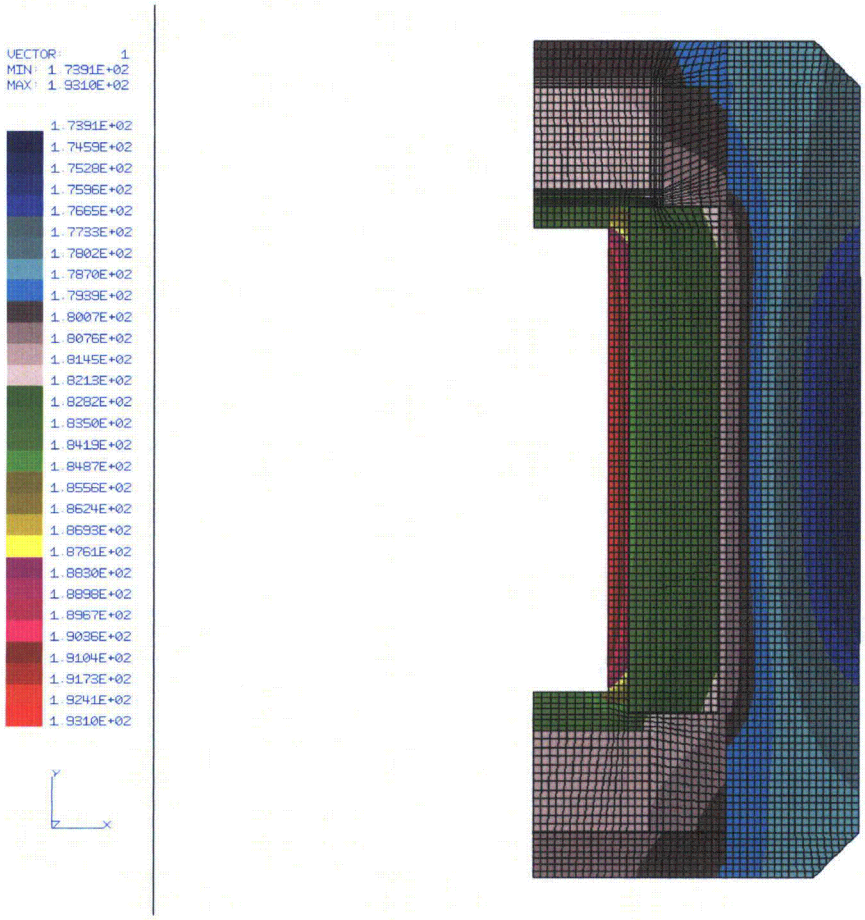


Figure 3. Case 3 Temperatures

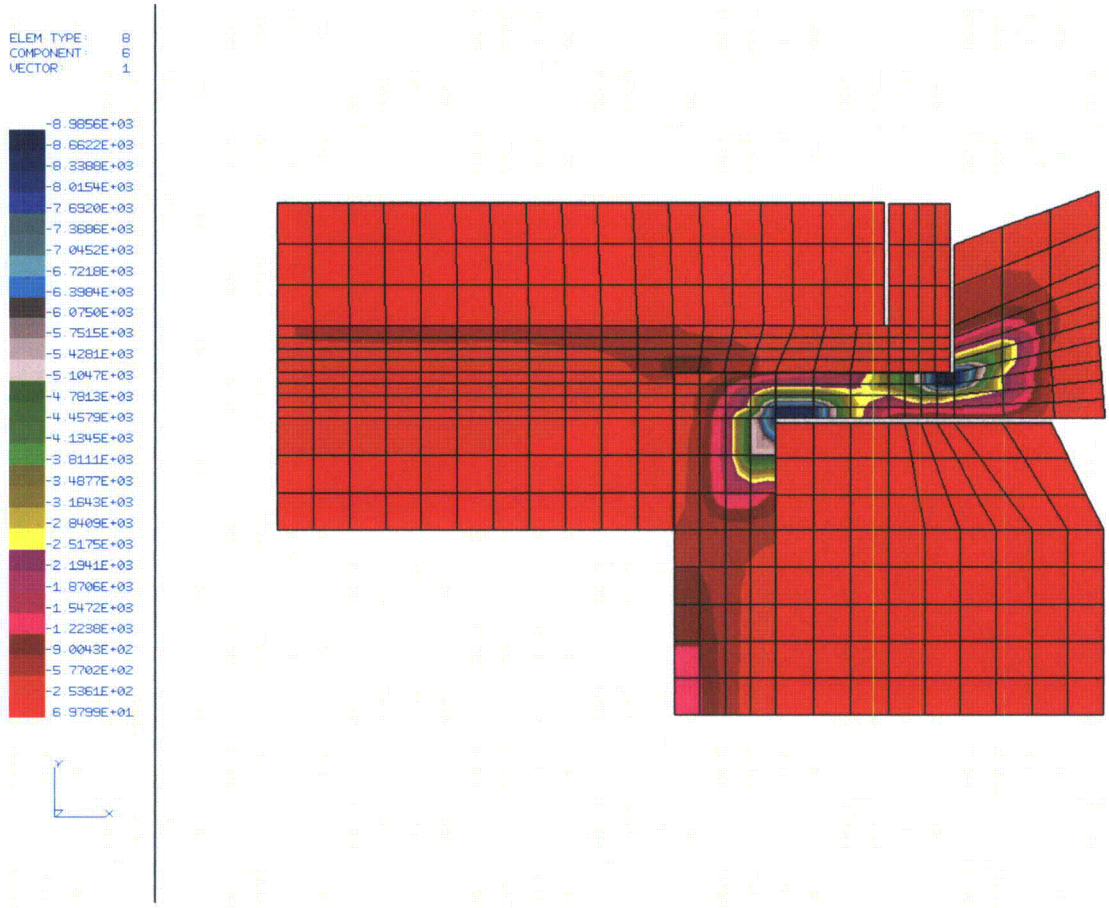


Figure 4. Case 1, Maximum Principal Stress at Lid Corner

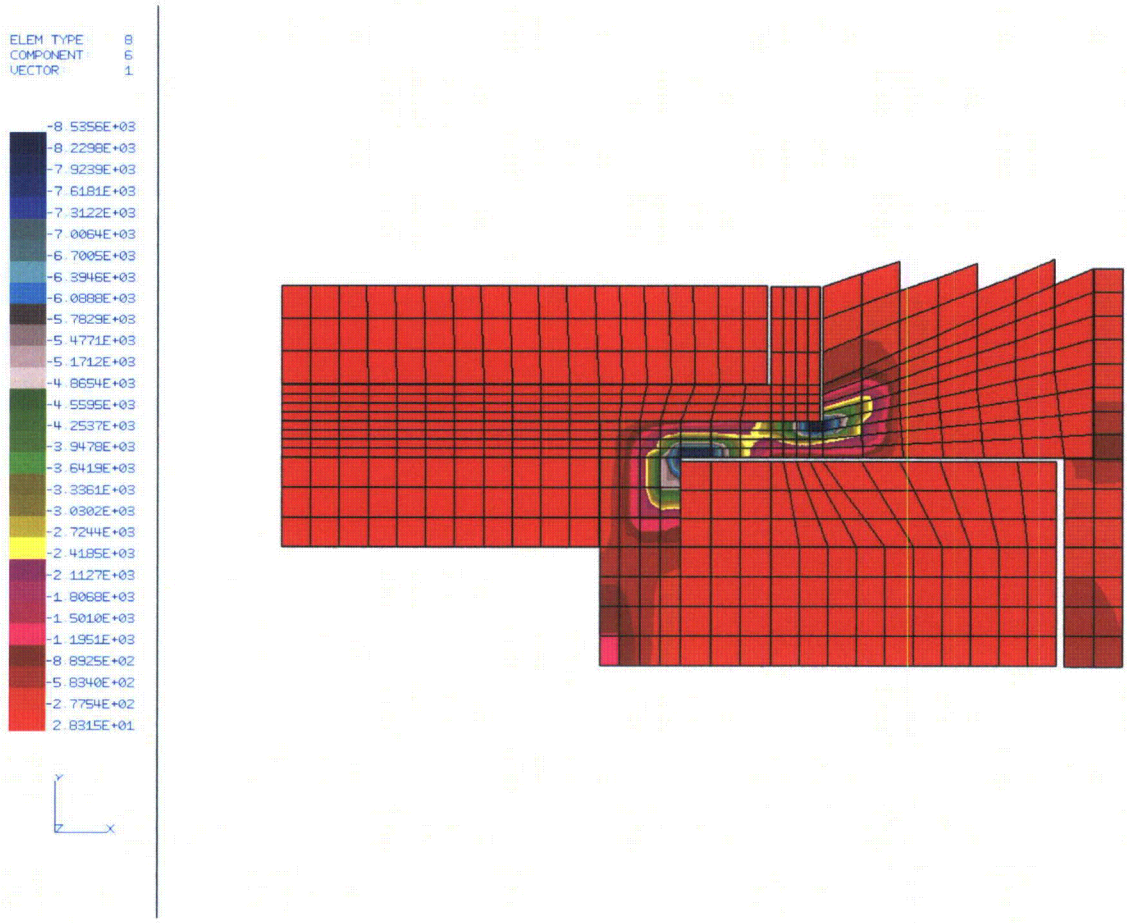


Figure 2. Case 2, Maximum Principal Stress at Lid Corner

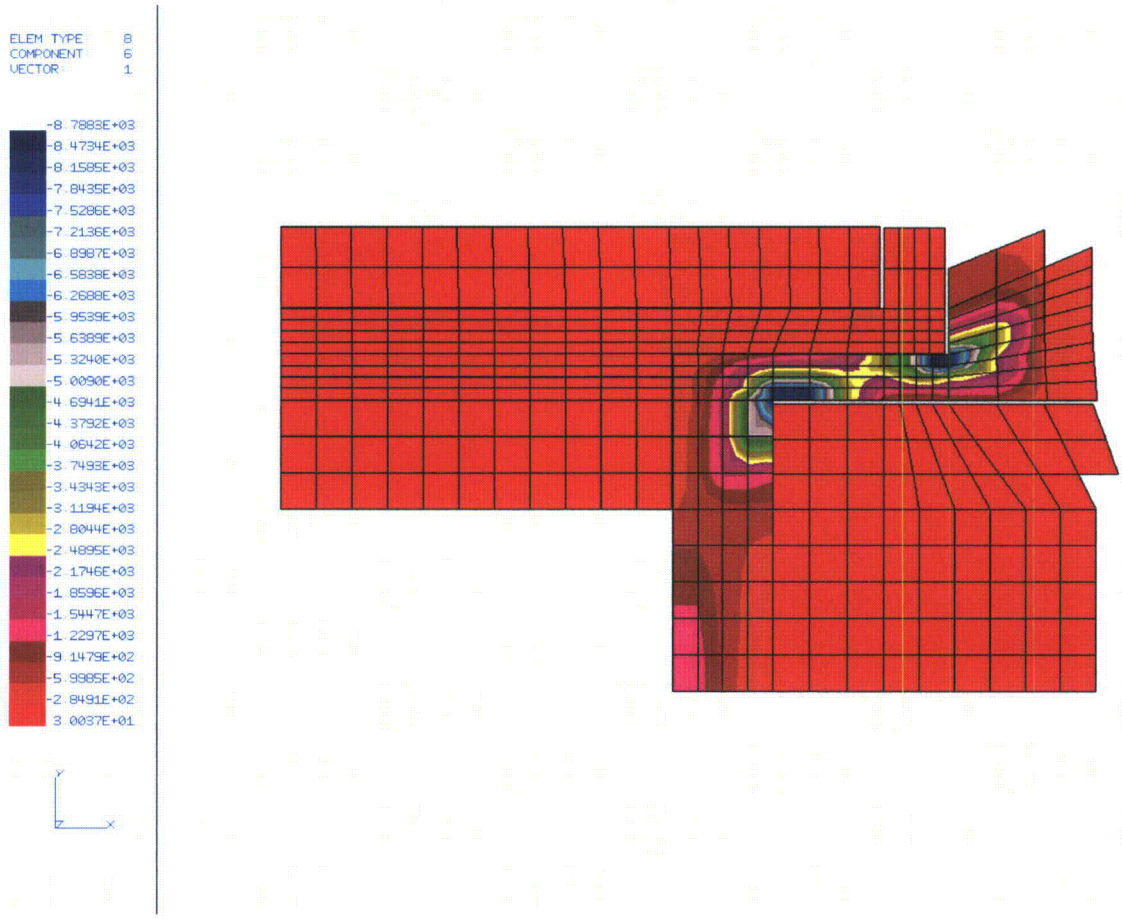


Figure 6. Case 3, Maximum Principal Stress at Lid Corner

RSI 3-7: *Justify that the maximum temperatures have been provided in Table 3-4 for all AOS models. Demonstrate that maximum temperatures have been provided for package components based upon the entire set of nodes in the analysis.*

It appears that samples of nodes were chosen from the thermal analysis, and then the temperature of those nodes was monitored to provide maximum temperatures.

This information is needed to determine compliance with 10 CFR 71.35.

Response:

In addition to the monitoring node temperatures reported in Table 3-4, all tables listed in Tables 3-18, 3-45, and 3-53 for Models AOS-100, AOS-025, and AOS-050 respectively, provide, as the last item in the table, a list of the maximum temperature values for each material/component type, anywhere within the particular material/component.

The following table is excerpted from Table 3-21 for Condition: 100°F Ambient Temperature, Maximum Decay Heat, and Maximum Insolation.

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Outside Shell	101	2894	620	1.1850E+02	2.4530E+02
Bottom Plate	3001	3232	3120	1.1878E+02	2.4580E+02
Lid	3233	3424	3233	1.1900E+02	2.4620E+02
Shell Cavity	4001	4998	4227	1.2561E+02	2.5810E+02
Plug	5001	5404	5001	1.2772E+02	2.6190E+02
Tungsten Alloy	6001	7656	7377	1.2122E+02	2.5020E+02
LAST-A-FOAM	8001	10791	9501	1.1878E+02	2.4580E+02

RSI 3-8: *Include a summary of the results of thermal stress evaluation under NCT and HAC in Sections 3.3 and 3.4, respectively. Include an evaluation of thermal stresses caused by constrained interfaces among package components resulting from temperature gradients and differential thermal expansion.*

This evaluation should be provided for both NCT and HAC.

This information is needed to determine compliance with 10 CFR 71.71 and 71.73.

Response:

Subsection 3.4.4 will be revised to read as follows:

"Thermal stresses resulting from temperature gradients and differential thermal expansion are provided in Chapter 2, Tables 2-26 through 2-31 for Normal conditions of transportation, and Tables 2-131 through 2-136 for Hypothetical Accident conditions of transportation."

RSI 3-9: *Clarify the inconsistency between the elastomeric seal temperature limit on page 2-20 and the value provided in Table 3-4. Clarify if there are two different types of metallic seals regarding footnote No. 1 in Table 2-3. Provide all seal NCT limits if these limits are different from HAC limits, as it appears to be the case in Table 2-3 of the application.*

This information is needed to determine compliance with 10 CFR 71.33, 71.73 and 71.7.

Response:

The inconsistency between the elastomeric seal temperature limit on page 2-20 and the value provided in Table 3-4 is due to an error. The metal seal material is the same for the Model AOS-025, AOS-050, and AOS-100 lid seals. The seal is rated to 300°C (572°F) for continuous operations, and 427°C (800°F) is a limiting temperature. For the elastomeric seal (Silicone), the temperature limit is 232°C (450°F) The write-up on page 2-20 and Table 2-3 will be revised to reflect these temperature values, under NCT and HAC, respectively.

RSI 3-10: *Provide the maximum initial pressure and temperature conditions for each of the AOS model configurations in Table 3-3 and Table 2-63 of the application.*

Section 7.3.5.3 step a. of the application states that the cask cavity will be pressurized with 104 kPa (15.1 psia) or 208 kPa (15.5 psig). The staff notes that the design pressure for the AOS-025 is 30 psia, which would be exceeded during NCT and HAC if an initial pressure of 208 kPa (15.5 psig) were used. It appears that an initial condition of 30 psia and 78°F was given on page 3-6, but it is not clear what initial pressure and temperature were used to calculate pressures in Table 3-3 and Table 2-63.

This information is needed to determine compliance with 10 CFR 71.71 and 71.73.

Response:

The maximum initial temperature and pressure is one atmosphere (14.7 psia) at 78°F. The following tables are updated – Tables 2-3, 2-22, 2-63, and 3-3.

RSI 3-11: *Justify the discrepancy between the thermal conductivity values for foam in Table 3-8 of the SAR in comparison with the thermal conductivity values in the "Design Guide for LAST-A-FOAM FR-3700 for Crash & Fire Protection of Radioactive Material Shipping Containers."*

This information is needed to determine compliance with 10 CFR 71.71 and 71

Response:

The values used in the SAR analyses were taken from General Plastics Manufacturing Company data sheet for LAST-A-FOAM FR-3700. The latest thermal conduction data published by General Plastics differs from the data available when the SAR was prepared.

Product	Old K Value (Btu/hr-ft^2/°F)	New K Value (Btu/hr-ft^2/°F)
FR-3710	0.279	0.213
FR-3718	0.356	0.324
FR-3720	0.376	0.349

The largest change is in FR-3710, where the new value is 76% of the old value. FR-3710 is closest to the product used in the Model AOS-050, which uses 12-lb. foam. The effect of the change in conductivity is evaluated by recalculating temperatures and thermal stress in the Model AOS-050, using thermal conductivity values reduced by a 0.75 factor, and comparing the resulting margins of safety and maximum component temperatures to the SAR values.

Tables 1 and 2 show the Model AOS-050 margins of safety for normal loading conditions. Table 1 presents values corresponding to the reduced K, while Table 2 contains the values provided in the SAR. A comparison of these two tables shows that the reduced K values produce no change in margins of safety for normal conditions.

Tables 3 and 4 show the Model AOS-050 margins of safety for accident loading conditions. Table 3 presents values corresponding to the reduced K, while Table 4 contains the values provided in the SAR. A comparison of these two tables shows that the reduced K values produce small changes in margins of safety for accident conditions where margins of safety are high, but no change where accident margins of safety are less than 1.0.

Finally, Tables 5 and 6 show the Model AOS-050 maximum component temperature for the fire accident condition. Table 5 presents values corresponding to the reduced K, while Table 6 contains the values provided in the SAR. A comparison of these two tables shows that the reduced K values produce small changes in maximum component temperature. The maximum temperature change is a 16°F reduction in foam temperature, from 563°F to 547°F. Other maximum component temperatures increase by less than 3°F.

This information will be updated, as appropriate, in the SAR.

Table 1. Reduced K Min MS for Normal Conditions of Transport

Ld_Cmb	Load_Cases	Min_MS	Loc	Str_Cmb
101	102 201 211 0 0	5.819E+00	4	Pm+Pb
102	104 201 211 0 0	2.164E+00	5	Pm+Pb+Q
103	103 201 211 0 0	2.686E+00	5	Pm+Pb+Q
104	101 201 202 211 0	5.535E+00	4	Pm+Pb
105	105 201 202 211 0	5.535E+00	4	Pm+Pb
106	101 201 203 211 0	4.918E+00	4	Pm+Pb
107	105 201 203 211 0	4.918E+00	4	Pm+Pb
215	215 101 201 211 0	5.145E+00	4	Pm+Pb
216	216 101 201 211 0	1.285E+00	15	Pm
217	216 104 201 211 0	1.285E+00	15	Pm
221	221 101 201 211 0	5.812E+00	4	Pm+Pb
222	222 101 201 211 0	5.607E+00	4	Pm+Pb
223	223 101 201 211 0	5.408E+00	4	Pm+Pb
231	231 102 201 211 0	3.034E+00	4	Pm+Pb
232	232 102 201 211 0	1.032E+00	4	Pm+Pb

Table 2. SAR Min MS for Normal Conditions of Transport

Ld_Cmb	Load_Cases	Min_MS	Loc	Str_Cmb
101	102 201 211 0 0	5.819E+00	4	Pm+Pb
102	104 201 211 0 0	2.164E+00	5	Pm+Pb+Q
103	103 201 211 0 0	2.686E+00	5	Pm+Pb+Q
104	101 201 202 211 0	5.535E+00	4	Pm+Pb
105	105 201 202 211 0	5.535E+00	4	Pm+Pb
106	101 201 203 211 0	4.918E+00	4	Pm+Pb
107	105 201 203 211 0	4.918E+00	4	Pm+Pb
215	215 101 201 211 0	5.145E+00	4	Pm+Pb
216	216 101 201 211 0	1.285E+00	15	Pm
217	216 104 201 211 0	1.285E+00	15	Pm
221	221 101 201 211 0	5.812E+00	4	Pm+Pb
222	222 101 201 211 0	5.607E+00	4	Pm+Pb
223	223 101 201 211 0	5.408E+00	4	Pm+Pb
231	231 102 201 211 0	3.034E+00	4	Pm+Pb
232	232 102 201 211 0	1.032E+00	4	Pm+Pb

Table 3. Reduced K Min MS for Hypothetical Accident Conditions of Transport

Ld_Cmb	Load_Cases					Min_MS	Loc	Str_Cmb
301	301	102	201	211	0	3.491E+00	4	Pm+Pb
302	302	102	201	211	0	8.885E+00	4	Pm+Pb
303	303	102	201	211	0	3.318E+00	1	Pm
304	304	105	202	211	0	2.818E+00	4	Pm+Pb
305	305	105	202	211	0	7.495E+00	1	Pm+Pb
306	306	105	202	211	0	2.537E+00	1	Pm
310	204	101	211	0	0	3.028E+00	4	Pm+Pb
311	311	101	201	211	0	5.885E-01	15	Pm
312	311	104	201	211	0	5.885E-01	15	Pm
350	111	201	211	0	0	1.305E+01	4	Pm+Pb
351	112	201	211	0	0	1.305E+01	4	Pm+Pb
352	113	201	211	0	0	1.305E+01	4	Pm+Pb
353	114	201	211	0	0	1.305E+01	4	Pm+Pb
354	115	201	211	0	0	1.305E+01	4	Pm+Pb
355	116	201	211	0	0	1.305E+01	4	Pm+Pb

Table 4. SAR Min MS for Hypothetical Accident Conditions of Transport

Ld_Cmb	Load_Cases					Min_MS	Loc	Str_Cmb
301	301	102	201	211	0	3.741E+00	4	Pm+Pb
302	302	102	201	211	0	9.436E+00	4	Pm+Pb
303	303	102	201	211	0	3.466E+00	1	Pm
304	304	105	202	211	0	2.818E+00	4	Pm+Pb
305	305	105	202	211	0	7.495E+00	1	Pm+Pb
306	306	105	202	211	0	2.537E+00	1	Pm
310	204	101	211	0	0	3.028E+00	4	Pm+Pb
311	311	101	201	211	0	5.885E-01	15	Pm
312	311	104	201	211	0	5.885E-01	15	Pm
350	111	201	211	0	0	1.491E+01	4	Pm+Pb
351	112	201	211	0	0	1.491E+01	4	Pm+Pb
352	113	201	211	0	0	1.491E+01	4	Pm+Pb
353	114	201	211	0	0	1.491E+01	4	Pm+Pb
354	115	201	211	0	0	1.491E+01	4	Pm+Pb
355	116	201	211	0	0	1.491E+01	4	Pm+Pb

Table 5. Reduced K Fire Condition Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp
Outside Shell	101	2894	1107	4.2400E+02
Bottom Plate	3001	3232	3120	3.9480E+02
Lid	3233	3424	3233	3.9330E+02
Shell Cavity	4001	4998	4527	4.2570E+02
Plug	5001	5404	5001	4.0310E+02
Tungsten	6001	7656	6436	4.2210E+02
LAST-A-FOAM	8001	10791	10035	5.4670E+02

Table 6. SAR Fire Condition Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp
Outside Shell	101	2894	1117	4.2140E+02
Bottom Plate	3001	3232	3120	3.9210E+02
Lid	3233	3424	3233	3.9160E+02
Shell Cavity	4001	4998	4522	4.2290E+02
Plug	5001	5404	5001	4.0080E+02
Tungsten	6001	7656	6440	4.1940E+02
LAST-A-FOAM	8001	10791	10034	5.6270E+02

RSI 3-12: *Ensure each of the isotope activity limits is not exceeding the analyzed decay heat. Confirm if each isotope will be transported individually in a package or if more than one type of isotope could be transported in the same package.*

The activity limits for some of the isotopes in Table 1-6 appear to exceed the analyzed decay heat. This includes (but may not be limited to) Co-60, Zr/Nb-95, Se-75, Sm-153, Yb-169, Yb-175.

This information is needed to determine compliance with 10 CFR 71.31, 71.33, and 71.51.

Response:

Table 1-6 will be revised to correct any errors or inconsistencies. Other locations within the SAR, in which this data appears, will be corrected and updated as well.

An **UNVERIFIED** copy of Table 1-6, provided as an example of the changes made to the table, is submitted under RSI 3-2.

RSI 3-13: *Provide all thermal input/output files and all AutoCAD inventor files on DVDs or CDs, rather than referencing the ftp site.*

This information is needed to determine compliance with 10 CFR 71.31 and 71.33.

Response:

All thermal input/output files, as well as all Autodesk Inventor files, are attached on the CDs, as listed below:

CDs 1, 2, and 3 – All analytical files, including the LIBRA FE program.

CD 4 – Autodesk Inventor files.

Chapter 4: Containment Evaluation

RSI 4-1: *Justify the selection and the use of the seals for the AOS packages.*

It appears that seals, used in certain AOS configurations, exceed their rated temperatures for NCT and/or HAC conditions.

This information is needed to determine compliance with 10 CFR 71.51 (a)(1) and 10 CFR 71.51 (a)(2).

Response:

The AOS Transport Packaging System Models use a double "C" profile, metallic seal for their **lid closure seal**, with a temperature limit of 427°C (800°F), and an elastomeric, silicon material, O-Ring for the **port cover closure**, with a temperature limit of 232°C (450°F). A review of Table 3-4 shows that the provided temperatures are within these limits; therefore, their use is acceptable. A copy of the updated Table 3-4 is submitted under RSI 3-1.

RSI 4-2: *Provide a detailed description of the leakage tests performed on the AOS packages.*

The general description, included in Section 4.4 of the application, provides only an overview of the testing that is planned to be done, but a more detailed discussion is needed to ensure that the package can be effectively tested by the package user.

This information is needed to determine compliance with 10 CFR 71.71.

Response:

The description of the leakage test procedure will be expanded to include additional details – adding the steps to care for the sealing surface, installation of the seal, test equipment setup, seal calibration, and recording the resulting data.

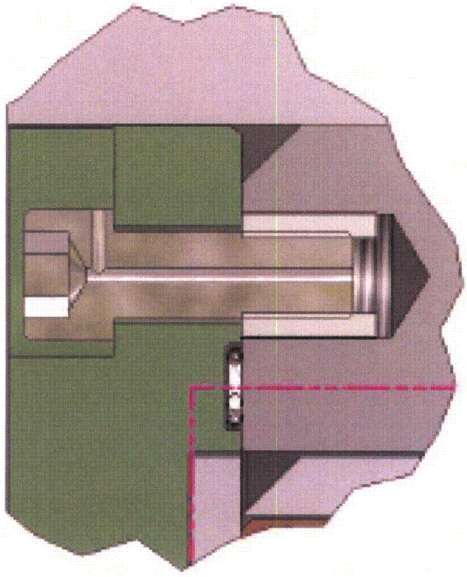
RSI 4-3: *Define the seals that are considered as primary seals to be relied upon for the containment of the package contents.*

The containment boundary of the AOS series of packages is described and illustrated in Section 4.1.1. The illustration of the containment boundary does not clearly define which seals are considered as primary seals to be relied upon for containment of the package contents. Such clarification is required for the evaluation of the containment performance and leak testing of the package.

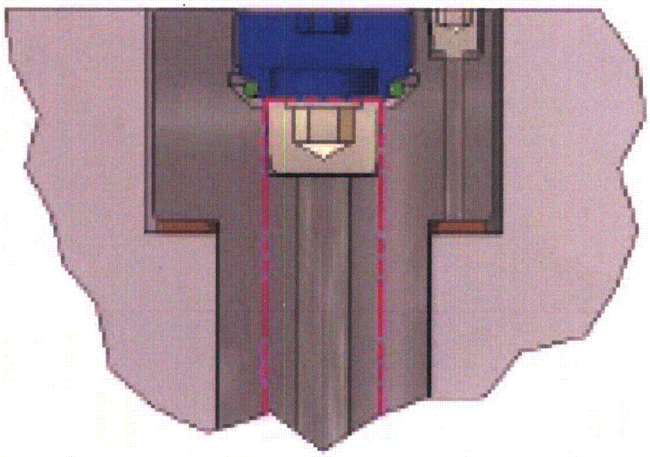
This information is needed to determine compliance with 10 CFR 71.51.

Response:

Figure 4-1 will be revised to clearly show that the lid seal inner "C" cross-section of the double seal is the primary seal and the outside seal is the secondary Seal. In the case of port seals, the threaded pipe is the primary seal and the elastomeric O-Ring is the secondary seal.



DETAIL A



DETAIL C

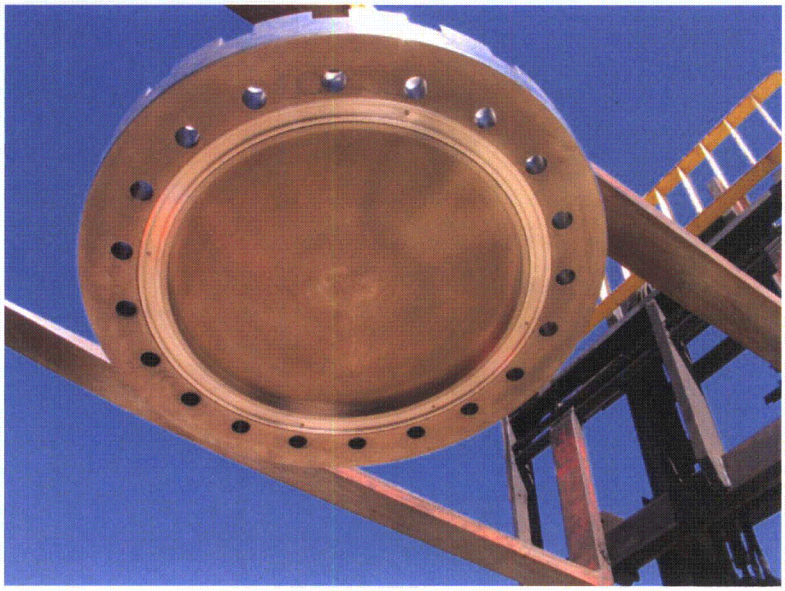
RSI 4-4: *Provide an additional explanation of the placement of the seals using four small screws, as mentioned on page 4-9 of the application.*

It is unclear from the application whether or not the use of screws is a standard configuration for securing the seals.

This information is needed to determine compliance with 10 CFR 71.31 (b) and 71.51.

Response:

The attached photo illustrates how the seal is attached to the lid by the four screws. Located between the two "C" cross-sections of the seal, the screws are sized and installed in such a way as to prevent the screws from interfering with the deformation of the "C" cross-sections when the lid bolts are being tightened.



RSI 4-5: *Include a description of the test provided for the seals in Appendix 4.5 and demonstrate that the seals installed on the AOS packages meet the ANSI N14.5 leak-tight criteria.*

It is not clear how the test flange used in the helium leak test is indicative of the AOS cask design closure, and if the seals tested are indicative of the seals that will be utilized for the AOS packages.

This information is needed to determine compliance with 10 CFR 71.31 (b) and 71.51.

Response:

The test described in Appendix 4.5 was performed to demonstrate that the selected materials for the seal are able to perform at their temperature limits. This test was not used to qualify the seal joint. The seal joint qualification test is performed with the actual joint using the cask, seal, lid, and bolting installed, as prescribed, in the Acceptance Test and Annual Test procedures.

Chapter 5: Shielding Evaluation

RSI 5-1: *Verify which values in Table 1-6 were used in the shielding evaluations, as well as which values were used to determine the decay heat for each nuclide. Identify the maximum radioactivity of radioactive constituents.*

The activity values for TBq and Curies (Ci) are not equivalent in Table 1-6 when using the conversion factor $3.7x10^{10}$ Bq/Ci. The staff notes also that if the values are converted to equivalent units, then the values listed for Ci are higher than those for TBq.

This information is needed to determine compliance with 10 CFR 71.33(b)(1).

Response:

Table 1-6 will be updated, as requested, as part of the final RSI Response Package. Other locations within the SAR, in which this data appears, will be corrected as well.

An **UNVERIFIED** copy of Table 1-6, provided as an example of the changes made to the table, is submitted under RSI 3-2.

RSI 5-2: *Justify the use of the point source method for shielding calculations. Provide limiting dimensions for the source material.*

The staff notes that there can be deficiencies associated with using a point source method. These are discussed in NUREG/CR-6802 "Recommendations for Shielding Evaluations for Transport and Storage Packages."

The staff does not have any information about the geometry of the source material, and therefore cannot determine if the distance between the point source and the detector points is sufficient to justify a point source approximation.

This information is needed to determine compliance with 10 CFR 71.33(b)(3) 10 CFR 71.47(a).

Response:

The following justifications for the use of a point source as a conservative representation of any source geometry are provided in Paragraph 5.2.2.1 of the AOS SAR:

- Point sources do not account for the self-shielding effects provided by the actual source geometry and density, nor for the shielding provided by internal components, such as source racks.
- The location of the point source at the edge of the cavity wall, and as close to the dose point as possible, minimizes the distance to the dose point.
- The location of the point source at the edge of the cavity wall, and as close to the dose point as possible, minimizes the attenuation from shielding materials.

Additional justifications, particularly with respect to the use of point sources as opposed to line sources, are listed below:

- The path between the source point and detector point penetrates the shield body at a normal angle, eliminating any possible concerns due to angular approximations and minimizing shielding between source and receptor.
- For dose points very close to the source, the error associated with the use of a point source, as opposed to a line source to represent long source geometries can be large, but it will always be in the conservative direction. This is true because the contribution from any given emission point to the total dose at a location on the mid-plane of a line source decreases as the distance of the emission point from the center of the line source increases. In other words, because the activity is assumed to be spread evenly throughout a line source, the dose at a location on the mid-plane of the line source will increase as the length of the line source decreases. The maximum possible dose will occur when the length of the line source approaches zero, which is equivalent to the point source approximation used.

As any source geometry is bounded by the use of a point source, no dimensions for source materials will be provided.

RSI 5-3: *Ensure that the dimensions for the cask cavity, cask cavity shell, and radial and axial shields along with tolerances are included in the following drawings: 166D8143, (AOS-025A) 166D8137, (AOS-050A) 105E9719, (AOS-100A-S), 105E9708, and 105E9712 (AOS-100A/ AOS-100B). Drawings must include appropriate dimensions and acceptance criteria for all design parameters.*

This information is needed to determine compliance with 10 CFR 71.7(a) and 10 CFR 71.111.

Response:

The dimensions and tolerances requested are provided in the attached revised drawings, submitted under RSI 1-1, with exception to 105E9708, which is for the AOS-165, which will not be included in the resubmission of the SAR.

Chapter 7 – Package Operations

RSI 7-1: *Provide key steps of the leakage tests performed on the AOS packages in the Operating Procedures (see RSI 4-2).*

This information is needed to determine compliance with 10 CFR 71.71.

Response:

The description of the leakage test procedure will be expanded to include additional details – adding the steps to care for the sealing surface, installation of the seal, test equipment setup, seal calibration, and recording the resulting data.

Chapter 8 – Acceptance Tests and Maintenance Program

RSI 8-1: *Provide additional explanations on the placement and installation of the seals during maintenance operations.*

This information is needed to determine compliance with 10 CFR 71.31 (b).

Response:

Additional explanation regarding the placement and installation of the seals during maintenance operations will be added to the Maintenance Program description. The expansion will consist of adding instructions for cleaning the sealing surfaces, inspecting the seals for damage such as scratches (scratches could create a leak path), inspecting the threads where the screws that hold the seal are installed, inspecting the seal surfaces, and installing the seal in the lid groove.

Observations

Observation 1: *The location of the center of gravity shown in Table 1-1 is in contradiction with the locations shown in Figure 1-2.*

Response:

The Table 1-1 (and Tables 2-10, 4-1, and 8-1) Cg location values are corrected. The discrepancy is because the previous values did not account for the package pallet nor cradle devices.

Note: Please note that in the SAR, the footnotes will be identified as "a" and "b", not "e" and "f". They are appearing as "e" and "f" due to constraints within Microsoft Word.

Table 1-1. AOS Transport Packaging System Dimensions and Cg Location – All Models

Model	Category	Dimensions (cm / in.)						Packaging Weight[e] (kg / lbs.)	Cg Location[f]		
		Packaging		Cask		Cavity					
		OD	Height	OD	Height	OD	Height		X	Y	Z
AOS-025A	III	28.96	39.62	17.78	22.86	4.14	12.70	71.4	19.05	19.05	26.34
		11.40	15.60	7.00	9.00	1.63	5.00	157	7.50	7.51	10.37
AOS-050A	III	57.96	79.25	35.56	45.72	8.26	25.40	511	41.91	41.91	46.28
		22.82	31.20	14.00	18.00	3.25	10.00	1,126	16.50	16.50	18.22
AOS-100A	II	115.93	158.50	71.12	91.44	16.51	50.80	3,950	91.44	89.15	80.03
		45.64	62.40	28.00	36.00	6.50	20.00	8,700	36.00	35.10	31.51
AOS-100B	III	115.93	158.50	71.12	91.44	16.51	50.80	3,232	91.44	89.15	80.03
		45.64	62.40	28.00	36.00	6.50	20.00	7,125	36.00	35.10	31.51
AOS-100A-S	II	115.93	158.50	71.12	91.44	16.51	50.80	3,901	91.44	89.15	80.03
		45.64	62.40	28.00	36.00	6.50	20.00	8,600	36.00	35.10	31.51

[e] *All AOS Transport Packaging System models have dimensions greater than 10 cm (4 in.).*

[f] *Refer to Figure 1-2.*

Observation 2: *Handbooks supplied for tungsten and the impact limiter foam contain a lot of irrelevant material to this review. Direction to selected parts of the handbooks where relevant information can be found would save review time.*

Response:

Non-pertinent data will be removed from the referenced appendices.

Observation 3: *Provide clear documentation to indicate that the impact limiter and the personnel barrier will remain intact for NCT. Justify and clarify if the dose points at the personnel barrier are appropriate for NCT.*

Response:

An analysis will be presented in Chapter 2, to demonstrate that these devices will remain intact by the NCT loadings.

Observation 4: *The drawing in Figure 5-4 appears inconsistent with the description in Paragraph 5.4.4.2 in the application. Figure 5-4 shows the dose points at the personnel barrier surface and at 1 meter from the personnel barrier surface. Paragraph 5.4.4.2 states that the dose points used are at the personnel barrier and 1 meter from the cask surface.*

Response:

Figure 5-4 will be updated, as requested, as part of the final RSI Response package.