3 THERMAL EVALUATION

This chapter identifies, describes, discusses, and evaluates the principal thermal engineering design of the packaging, components, and systems important to safety, and describes how the package complies with the performance requirements specified by *10 CFR 71* **[3.1]** and *IAEA TS-R-1* **[3.2]**.

The evaluation accomplishes this objective by determining the temperature distributions within the transport package during Normal Accident conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport. Additionally, the thermal results are compared against the performance requirements and temperature limits of the materials used. The approach taken assures the safe operation of the package.

3.1 DESCRIPTION OF THERMAL DESIGN

The AOS Transport Packaging System is designed with a thermally passive system to provide adequate thermal performance under Normal and Hypothetical Accident conditions of transport relying solely upon the design capacity to transmit and dissipate heat to the outside environment. The cask component is enclosed at both ends by an impact limiter structure, which functions as a thermal shield and mitigates regulatory impact loads, per regulatory requirements. In the case of the Model AOS-025, the impact limiter component of the AOS Transport Packaging System completely encloses the cask.

3.1.1 Design Features

The AOS Transport Packaging System consists of three (3) main components: (a) cask; (b) impact limiters; and (c) cask lid seal. Materials of construction are 300 series stainless steel (SS300) for structural members of the packaging; tungsten alloy or carbon steel for shielding material inserts; polyurethane foam for thermal shielding and impact load mitigation; and selected silicone/SS300 series for the cask lid elastomeric seal and silver/nickel-chromium alloy/SS304L combination for the Helicoflex® cask lid metallic seal. Refer to Section 1.2, "Package Description," for further details regarding these main and other minor components. Principal packaging dimensions are presented in Table 1-1, "AOS Transport Packaging System Dimensions and Maximum Authorized Package Weight – All Models."

Due to fabrication dimension tolerances, there is a series of gaps throughout the cask body. To minimize their impact upon the heat transfer characteristics of this component, the largest gaps are either packed with stainless steel wool or shim stock. The conservative approaches taken for the treatment of these gaps within the analytical model are discussed further in this chapter.

The temperature distributions for the AOS Transport Packaging System models are determined for the thermal environments listed in Table 3-1.

All thermal conditions were analyzed using the LIBRA Finite Element program, with the exception of Thermal Conditions 5 and 7, where uniform temperature fields of -40°C and -29°C (-40°F and -20°F, respectively) were assigned. A description of the LIBRA Finite Element program heat transfer module is provided in Appendix 3.5.3, which also includes the qualifications and verification program conducted by GE to support the modeling techniques and assumptions taken throughout the thermal evaluation. To further verify the thermal model, a heat test was conducted, using a 165%-scaled geometry of the Model AOS-100A transport package. In this test, a 7-kW electrical heat source was placed inside the cask cavity. The cask was then closed and placed within a pit. Placing the cask inside the pit helped to maintain the environment temperature constant. Temperatures inside and outside of the cask, and the ambient temperature inside the pit, were recorded during the cask heating and cooling cycles. Refer to Appendix 3.5.7 for a detailed account of the heat test and its results.

The maximum decay heat for each AOS Transport Packaging System model is distributed across the cask cavity surface. Condition 3 (fire transient) analysis is initiated at the steady-state Condition 1, in which the maximum solar load is applied.

Table 3-1. Transport Package Thermal Environment Conditions – All Models

Condition	Conditions of Transport	Thermal Environment
1	Normal	38°C (100°F) ambient with maximum decay heat and maximum solar load.
2	Normal	38°C (100°F) ambient with maximum decay heat.
3	Hypothetical Accident (Fire)	Fire transient, t = 0 to 8.0 hours.
4	Normal	-40°C (-40°F) ambient with maximum decay heat.
5	Normal	-40°C (-40°F) ambient.
6	Normal	-29°C (-20°F) ambient with maximum decay heat.
7	Normal	-29°C (-20°F) ambient.

3.1.2 Contents' Decay Heat

Table 1-2, "Activity Limits – All Models," provides the maximum decay heat and radioactivity for the contents of the AOS Transport Packaging System. This includes Decay Heat (Ci/W) values for each radioisotope listed, showing that the decay heat is consistent with the maximum quantity of radioactivity contents. A summary of the Decay Heat values is shown in Table 3-2.

Table 3-2. Contents' Decay Heat – All Models

Model	Contents' Decay Heat (W)
AOS-025A	10
AOS-050A	100
AOS-100A	400
AOS-100B	400
AOS-100A-S	400

3.1.3 Summary Tables of Temperatures

Table 3-3. Maximum Temperature Summary, Normal Conditions of Transport – All Models

Model	Component[a]	Thermal Temperatures, by Condition[b]												Regulatory/ Component Criteria (Temperature Range)
		1		2		4		5		6		7		°C °F
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-025A	Cask Outer Shell	124	256	77	170	3	37	-40	-40	13	56	-29	-20	-40 to 538 -40 to 1,000
	Cask Cavity	125	257	78	172	4	39	-40	-40	14	58	-29	-20	
	Cask Lid	124	255	77	170	2	36	-40	-40	13	55	-29	-20	
	Cask Lid Plug	126	258	78	173	4	40	-40	-40	15	59	-29	-20	
	Bottom Plate	124	255	76	169	2	36	-40	-40	13	55	-29	-20	
	Shielding	124	256	77	171	3	37	-40	-40	13	56	-29	-20	
	Cask Lid Seal Area	124	255	77	170	2	36	-40	-40	13	56	-29	-20	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	124	255	77	170	2	36	-40	-40	13	55	-29	-20	-40 to 232 -40 to 450
	Cask Drain Port	124	255	76	170	2	36	-40	-40	13	55	-29	-20	
	Test Port	124	255	76	170	2	36	-40	-40	13	55	-29	-20	
	Cask Vent Port Pipe Plug	124	255	77	170	2	36	-40	-40	13	55	-29	-20	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	124	255	76	170	2	36	-40	-40	13	55	-29	-20	
	Cask Vent Port Conical Seal	124	255	77	170	2	36	-40	-40	13	56	-29	-20	
	Cask Drain Port Conical Seal	124	255	77	170	3	37	-40	-40	13	56	-29	-20	
	Cavity Bottom	125	257	78	172	4	39	-40	-40	14	58	-29	-20	-40 to 538 -40 to 1,000
	Cavity Side	125	257	77	171	3	38	-40	-40	14	57	-29	-20	
	Cavity Top	126	258	78	173	4	40	-40	-40	15	59	-29	-20	
	Impact Limiter, Foam	94[d]	202[d]	73	163	-2	29	-40	-40	9	48	-29	-20	-40 to 127 -40 to 260
	Accessible Outside Surface[e]	–	–	48	119	–	–	–	–	–	–	–	–	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use

Table 3-3. Maximum Temperature Summary,
Normal Conditions of Transport – All Models (Continued)

Model	Component[a]	Thermal Temperatures, by Condition[b]												Regulatory/ Component Criteria (Temperature Range)
		1		2		4		5		6		7		°C °F
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-050A	Cask Outer Shell	142	287	102	216	30	86	-40	-40	40	105	-29	-20	-40 to 538 -40 to 1,000
	Cask Cavity	147	296	107	225	35	96	-40	-40	46	114	-29	-20	
	Cask Lid	141	286	102	216	30	85	-40	-40	40	104	-29	-20	
	Cask Lid Plug	148	298	109	229	38	100	-40	-40	48	119	-29	-20	
	Bottom Plate	141	286	102	215	29	85	-40	-40	40	104	-29	-20	
	Shielding	142	288	103	218	31	88	-40	-40	41	107	-29	-20	
	Cask Lid Seal Area	141	286	102	215	30	85	-40	-40	40	104	-29	-20	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	140	284	101	214	29	84	-40	-40	39	103	-29	-20	-40 to 232 -40 to 450
	Cask Drain Port	141	286	101	214	29	84	-40	-40	39	103	-29	-20	
	Test Port	141	286	102	215	29	85	-40	-40	40	104	-29	-20	
	Cask Vent Port Pipe Plug	140	285	101	214	29	84	-40	-40	39	103	-29	-20	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	141	286	101	214	29	84	-40	-40	39	103	-29	-20	
	Cask Vent Port Conical Seal	141	286	102	216	30	85	-40	-40	40	104	-29	-20	
	Cask Drain Port Conical Seal	142	288	103	217	30	87	-40	-40	41	106	-29	-20	
	Cavity Bottom	147	296	107	225	35	96	-40	-40	46	114	-29	-20	-40 to 538 -40 to 1,000
	Cavity Side	144	292	105	221	33	91	-40	-40	43	110	-29	-20	
	Cavity Top	148	298	109	229	38	100	-40	-40	48	119	-29	-20	
	Impact Limiter, Foam	117[d]	242[d]	94	201	21	71	-40	-40	32	90	-29	-20	-40 to 127 -40 to 260
	Accessible Outside Surface[e]	–	–	45	113	–	–	–	–	–	–	–	–	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use

Table 3-3. Maximum Temperature Summary,
Normal Conditions of Transport – All Models (Continued)

Model	Component[a]	Thermal Temperatures, by Condition[b]												Regulatory/ Component Criteria (Temperature Range)
		1		2		4		5		6		7		°C °F
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
AOS-100A, AOS-100A-S	Cask Outer Shell	146	295	101	214	30	86	-40	-40	41	105	-29	-20	-40 to 538 -40 to 1,000
	Cask Cavity	155	312	111	232	41	105	-40	-40	51	124	-29	-20	
	Cask Lid	145	294	101	214	30	86	-40	-40	41	105	-29	-20	
	Cask Lid Plug	158	317	115	239	45	113	-40	-40	55	132	-29	-20	
	Bottom Plate	146	294	101	213	29	85	-40	-40	40	104	-29	-20	
	Shielding	148	298	103	218	33	91	-40	-40	43	110	-29	-20	
	Cask Lid Seal Area	145	293	101	214	30	86	-40	-40	40	104	-29	-20	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	143	290	99	210	28	82	-40	-40	38	101	-29	-20	-40 to 232 -40 to 450
	Cask Drain Port	144	291	99	210	28	82	-40	-40	38	101	-29	-20	
	Test Port	145	293	101	213	30	85	-40	-40	40	104	-29	-20	
	Cask Vent Port Pipe Plug	143	290	99	211	28	83	-40	-40	39	101	-29	-20	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	144	292	99	210	28	82	-40	-40	38	101	-29	-20	
	Cask Vent Port Conical Seal	145	293	101	214	30	86	-40	-40	41	105	-29	-20	
	Cask Drain Port Conical Seal	147	296	102	216	31	88	-40	-40	41	107	-29	-20	
	Cavity Bottom	155	312	111	232	41	105	-40	-40	51	124	-29	-20	-40 to 538 -40 to 1,000
	Cavity Side	151	305	107	225	36	98	-40	-40	47	116	-29	-20	
	Cavity Top	158	317	115	239	45	113	-40	-40	55	132	-29	-20	
	Impact Limiter, Foam	111[d]	231[d]	93	199	21	70	-40	-40	32	89	-29	-20	-40 to 127 -40 to 260
	Accessible Outside Surface[e]	–	–	41	106	–	–	–	–	–	–	–	–	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use

Table 3-3. Maximum Temperature Summary,
Normal Conditions of Transport – All Models (Continued)

Model	Component[a]	Thermal Temperatures, by Condition[b]												Regulatory/ Component Criteria (Temperature Range)
		1		2		4		5		6		7		°C
		°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°F
AOS-100B	Cask Outer Shell	146	295	101	214	30	86	-40	-40	41	105	-29	-20	-40 to 538 -40 to 1,000
	Cask Cavity	156	312	111	232	41	106	-40	-40	51	124	-29	-20	
	Cask Lid	145	294	101	214	30	86	-40	-40	41	105	-29	-20	
	Cask Lid Plug	158	317	115	239	45	114	-40	-40	56	132	-29	-20	
	Bottom Plate	146	294	101	213	29	85	-40	-40	40	104	-29	-20	
	Shielding	148	298	103	218	33	91	-40	-40	43	110	-29	-20	
	Cask Lid Seal Area	145	293	101	214	30	86	-40	-40	40	105	-29	-20	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	143	290	99	210	28	82	-40	-40	38	101	-29	-20	-40 to 232 -40 to 450
	Cask Drain Port	144	291	99	210	28	82	-40	-40	38	101	-29	-20	
	Test Port	145	293	101	213	30	85	-40	-40	40	104	-29	-20	
	Cask Vent Port Pipe Plug	143	290	99	211	28	83	-40	-40	39	101	-29	-20	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	144	292	99	210	28	82	-40	-40	38	101	-29	-20	
	Cask Vent Port Conical Seal	145	293	101	214	30	86	-40	-40	41	105	-29	-20	
	Cask Drain Port Conical Seal	147	297	102	216	31	88	-40	-40	41	107	-29	-20	
	Cavity Bottom	156	312	111	232	41	106	-40	-40	51	124	-29	-20	-40 to 538 -40 to 1,000
	Cavity Side	151	305	107	225	37	98	-40	-40	47	117	-29	-20	
	Cavity Top	158	317	115	239	45	114	-40	-40	56	132	-29	-20	
	Impact Limiter, Foam	111[d]	231[d]	93	199	21	70	-40	-40	32	89	-29	-20	-40 to 127 -40 to 260
	Accessible Outside Surface[e]	–	–	41	106	–	–	–	–	–	–	–	–	50°C (122°F) Non-Exclusive Use 85°C (185°F) Exclusive Use

a. Refer to Appendix 3.5.9 for locations of nodes representing copper seal locations within the analytical model.

b. Refer to Table 3-1 for Condition descriptions.

c. Refer to Appendix 3.5.10.

d. Refer to Appendix 3.5.4.7.

e. Maximum temperature on the impact limiter surfaces, "Insolation Heat Load Analysis for FR-3700 Series Foam Under Condition 1 for Table 3-3".

Table 3-4. Maximum Temperature Summary, Hypothetical Accident Conditions of Transport (Condition 3) – All Models

Model	Component[a]	Thermal Temperatures and Time: During Fire Temperature °C	During Fire Temperature °F	During Fire Time hr	Post Fire Temperature °C	Post Fire Temperature °F	Post Fire Time[b] hr	Regulatory/Component Criteria (Temperature Range) °C / °F
AOS-025A	Cask Outer Shell	145	294	0.5	145	294	0.5	-40 to 538 -40 to 1,000
	Cask Cavity	134	273	0.5	136	277	1.0	
	Cask Lid	128	263	0.5	134	274	3.0	
	Cask Lid Plug	130	267	0.5	136	277	2.8	
	Bottom Plate	132	269	0.5	137	279	0.8	
	Shielding	133	272	0.5	135	276	1.0	
	Cask Lid Seal Area	128	263	0.5	134	274	3.0	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	129	264	0.5	134	274	2.8	-40 to 232 -40 to 450
	Cask Drain Port	133	272	0.5	135	276	0.6	
	Test Port	128	262	0.5	134	274	2.8	
	Cask Vent Port Pipe Plug	129	264	0.5	134	274	2.8	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	133	272	0.5	135	276	0.6	
	Cask Vent Port Conical Seal	129	265	0.5	134	274	2.8	
	Cask Drain Port Conical Seal	132	270	0.5	135	276	1.0	
	Cavity Bottom	133	272	0.5	136	277	1.0	-40 to 538 -40 to 1,000
	Cavity Side	134	273	0.5	135	275	1.0	
	Cavity Top	130	267	0.0	136	277	2.9	

Table 3-4. Maximum Temperature Summary,
Hypothetical Accident Conditions of Transport (Condition 3) – All Models (Continued)

Model	Component[a]	Thermal Temperatures and Time						Regulatory/Component Criteria (Temperature Range)
		During Fire			Post Fire			
		Temperature		Time	Temperature		Time[b]	°C
		°C	°F	hr	°C	°F	hr	°F
AOS-050A	Cask Outer Shell	414	777	0.5	414	777	0.5	-40 to 538 -40 to 1,000
	Cask Cavity	241	465	0.5	259	499	0.7	
	Cask Lid	170	338	0.5	223	433	2.3	
	Cask Lid Plug	196	385	0.5	230	446	2.0	
	Bottom Plate	175	347	0.5	224	435	2.4	
	Shielding	250	483	0.5	262	504	0.6	
	Cask Lid Seal Area	170	337	0.5	223	434	1.9	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	197	386	0.5	225	437	1.2	-40 to 232 -40 to 450
	Cask Drain Port	195	384	0.5	227	440	1.2	
	Test Port	166	330	0.5	223	433	2.2	
	Cask Vent Port Pipe Plug	196	386	0.5	225	437	1.2	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	195	384	0.5	227	441	1.2	
	Cask Vent Port Conical Seal	194	382	0.5	224	435	1.8	
	Cask Drain Port Conical Seal	195	384	0.5	224	436	2.2	
	Cavity Bottom	201	395	0.5	231	447	0.8	-40 to 538 -40 to 1,000
	Cavity Side	240	465	0.5	259	499	0.7	
	Cavity Top	196	385	0.0	230	446	2.0	

Table 3-4. Maximum Temperature Summary,
Hypothetical Accident Conditions of Transport (Condition 3) – All Models (Continued)

Model	Component[a]	Thermal Temperatures and Time						Regulatory/Component Criteria (Temperature Range)
		During Fire			Post Fire			
		Temperature		Time	Temperature		Time[b]	°C
		°C	°F	hr	°C	°F	hr	°F
AOS-100A, AOS-100A-S	Cask Outer Shell	463	866	0.5	463	866	0.5	-40 to 538 -40 to 1,000
	Cask Cavity	179	354	0.5	246	476	1.4	
	Cask Lid	147	297	0.5	206	403	6.8	
	Cask Lid Plug	159	318	0.5	219	426	5.4	
	Bottom Plate	149	300	0.5	207	405	7.1	
	Shielding	191	375	0.5	246	475	1.2	
	Cask Lid Seal Area	147	297	0.5	207	404	5.4	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	195	383	0.5	208	407	2.6	-40 to 232 -40 to 450
	Cask Drain Port	193	379	0.5	210	410	2.6	
	Test Port	146	295	0.5	206	402	6.4	
	Cask Vent Port Pipe Plug	192	378	0.5	209	407	2.6	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	190	374	0.5	211	411	2.6	
	Cask Vent Port Conical Seal	160	321	0.5	207	405	4.8	
	Cask Drain Port Conical Seal	162	323	0.5	208	407	6.1	
	Cavity Bottom	160	321	0.5	218	424	4.0	-40 to 538 -40 to 1,000
	Cavity Side	178	352	0.5	246	476	1.4	
	Cavity Top	159	318	0.0	219	426	5.4	

Table 3-4. Maximum Temperature Summary, Hypothetical Accident Conditions of Transport (Condition 3) – All Models (Continued)

Model	Component[a]	Thermal Temperatures and Time						Regulatory/Component Criteria (Temperature Range)
		During Fire			Post Fire			
		Temperature		Time	Temperature		Time[b]	
		°C	°F	hr	°C	°F	hr	°C °F
AOS-100B	Cask Outer Shell	463	866	0.5	463	866	0.5	-40 to 538 -40 to 1,000
	Cask Cavity	173	343	0.5	241	467	1.5	
	Cask Lid	147	297	0.5	203	398	7.2	
	Cask Lid Plug	158	317	0.5	216	421	5.8	
	Bottom Plate	148	298	0.5	205	401	7.4	
	Shielding	189	372	0.5	242	467	1.2	
	Cask Lid Seal Area	147	296	0.5	204	399	5.7	Elastomeric: -40 to 232 -40 to 450 Metallic: -40 to 300 -40 to 572[c]
	Cask Vent Port	195	383	0.5	206	403	0.8	-40 to 232 -40 to 450
	Cask Drain Port	193	379	0.5	207	405	2.8	
	Test Port	146	295	0.5	203	397	6.8	
	Cask Vent Port Pipe Plug	192	378	0.5	206	402	2.8	-40 to 360 -40 to 680
	Cask Drain Port Pipe Plug	190	374	0.5	208	406	2.6	
	Cask Vent Port Conical Seal	159	317	0.5	205	400	5.0	
	Cask Drain Port Conical Seal	160	320	0.5	206	402	6.5	
	Cavity Bottom	157	315	0.5	215	420	4.6	-40 to 538 -40 to 1,000
	Cavity Side	172	342	0.5	241	467	1.5	
	Cavity Top	158	317	0.0	216	421	5.8	

a. *Refer to Appendix 3.5.9 for locations of nodes representing copper seal locations within the analytical model.*

b. *Temperatures are computed every 0.001 hours. Time is the time at which the maximum temperature occurs, to the nearest 0.1 hour.*

c. *Refer to Appendix 3.5.10.*

3.1.4 Summary Tables of Maximum Pressures

The maximum cask cavity pressures due to Normal and Hypothetical Accident conditions of transport are provided in Table 4-6, "Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models," and Table 4-7, "Maximum Cask Cavity Pressure Due to Fire Condition – All Models," respectively, by model.

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

The thermal properties of each material are provided in the following subsections. The curve fit functions, which provide the property variations with temperature, are also provided. These property functions are used in all analyses, to update the material properties as the temperature changes.

Selected material properties are also provided in Appendix 2.12.5, "Selected Material Properties References."

3.2.1 Material Properties

The transport packages consist of four (4) materials:

- Stainless Steel, 300 Series (SS300)
- Tungsten Alloy or SA-105 Carbon Steel
- Air
- LAST-A-FOAM FR-3700 Series Foams

Each is described in the paragraphs that follow.

3.2.1.1 Stainless Steel, 300 Series (SS300)

Table 3-5 lists the thermophysical properties of Type 304 Stainless Steel (SS304), as they apply to the transport packages. Refer to Appendix 3.5.4.1.1 for English units and values of the properties that are used in the analyses, and plots of the equations that represent them. Appendix 3.5.5 shows how these properties are entered into the LIBRA input files.

Table 3-5. Type 304 Stainless Steel (SS304) Thermophysical Properties (Reference [3.16])[a]

Temperature (°C)	Diffusivity α (m^2/hr.)	Specific Heat C_p (KJ/kg-°C)	Conductivity K (W/m-°C)
21.1	0.0140	0.477	14.88
37.8	0.0141	0.479	15.06
93.3	0.0145	0.498	16.10
148.9	0.0149	0.510	16.96
204.4	0.0153	0.528	18.00
260.0	0.0158	0.535	18.86
315.6	0.0162	0.542	19.56
371.1	0.0166	0.552	20.42
426.7	0.0171	0.554	21.11
482.2	0.0176	0.560	21.98
537.8	0.0180	0.569	22.85
593.3	0.0184	0.574	23.54
648.9	0.0189	0.575	24.23
704.4	0.0193	0.583	25.10
760.0	0.0197	0.587	25.79
815.6	0.0201	0.591	26.48

a. *"Table TCD," Material Group J, page 663 (Reference* [3.16]*).*

Specific Heat, C_p (Btu/lb-°F)

$$C_p(T) = K(T) / \alpha(T)(\rho)$$

$$= 1.120 \times 10^{-1} + 3.504 \times 10^{-5}T - 1.080 \times 10^{-8}T^2$$

Conductivity, K (Btu/hr-in-°F)

$$K(T) = 6.851 \times 10^{-1} + 4.544 \times 10^{-4}T - 4.126 \times 10^{-8}T^2$$

Density, ρ(lb/in^3)

$$\rho = 0.29$$

3.2.1.2 Tungsten Alloy

Table 3-6 lists the thermophysical properties of the tungsten alloy used for shielding, as they apply to the transport packages that include suffix A in their model numbers. Refer to Appendix 3.5.4.1.2 for English units and values of the properties that are used in the analyses, and plots of the equations that represent them. Refer also to Appendix 2.12.5, "Selected Material Properties References," for further details.

Table 3-6. Tungsten Alloy Thermophysical Properties (Reference [3.3])[a] – Models AOS-025A, AOS-050A, AOS-100A, and AOS-100A-S

Temperature (°C)	Density ρ (g/cc)	Diffusivity α (cm^2/sec.)	Specific Heat C_p (J/kg-°K)	Conductivity K (W/m-°K)
25	18.11	0.2742	154.7	76.8
97		0.2700	159.2	77.8
206		0.2624	163.4	77.6
316		0.2553	170.3	78.8
427		0.2451	173.9	77.2

a. *All table values were obtained by testing.*

Density, ρ (lb/in^3)

$$\rho = 0.654$$

Specific Heat, C_p (Btu/lb-°F)

$$C_p(T) = 3.631 \times 10^{-2} + 8.017 \times 10^{-6}T - 1.807 \times 10^{-9}T^2$$

Conductivity, K (Btu/hr-in-°F)

$$K(T) = 3.673 + 4.028 \times 10^{-4}T - 4.167 \times 10^{-7}T^2$$

3.2.1.3 SA-105 Carbon Steel

Table 3-7 lists the thermophysical properties of SA-105 carbon steel (used for shielding), as they apply to the Model AOS-100B transport package. Refer to Appendix 3.5.4.1.3 for English units and values of the properties that are used in the analyses, and plots of the equations that represent them.

Table 3-7. Carbon Steel Properties – Model AOS-100B (Reference [3.16])[a]

Temperature (°C)	Conductivity (W/m-°C)	Thermal Diffusivity (m^2/hr)	Specific Heat (KJ/kg-°C)
Material: SA-105, Carbon Steel Forging			
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

a. "Table TCD," Material Group A, page 662 (Reference [3.16]).

Density = 7,832.8 kg/m^3 (0.283 lb/in^3)

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

$$K = 3.002 - 1.027 \times 10^{-3}T - 1.249 \times 10^{-7}T^2$$

where:

K = Conductivity, Btu/hr-in-°F

T = Temperature, °F

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

$$Cp = 0.1009 + 4.847 \times 10^{-5}T + 9.493 \times 10^{-9}T^2$$

where:

Cp = Specific heat, Btu/lb-°F

T = Temperature, °F

3.2.1.4 Air

Table 3-8 lists the thermophysical properties of air, as they apply to the transport packages. Refer to Appendix 3.5.4.1.4 for English units and values of the properties that are used in the analyses, and plots of the equations that represent them.

Table 3-8. Air Thermophysical Properties (Reference [3.4])[a]

Temperature		Density	Dynamic Viscosity	Specific Heat	Conductivity	Prandtl Number
°C	°F	ρ (kg/m³)	$\mu \times 10^{-7}$ (N-sec/m²)	C_p (KJ/kg-°K)	$K \times 10^{-3}$ (W/m-°K)	(Pr)
27	80.6	1.1614	184.6	1.007	26.3	0.707
77	170.6	0.9950	208.2	1.009	30.0	0.700
127	260.6	0.8711	230.1	1.014	33.8	0.690
177	350.6	0.7740	250.7	1.021	37.3	0.686
227	440.6	0.6964	270.1	1.030	40.7	0.684
277	530.6	0.6329	288.4	1.040	43.9	0.683
327	620.6	0.5804	305.8	1.051	46.9	0.685
377	710.6	0.5356	322.5	1.063	49.7	0.690
427	800.6	0.4975	338.8	1.075	52.4	0.695
477	890.6	0.4643	354.6	1.087	54.9	0.702
527	980.6	0.4354	369.8	1.099	57.3	0.709
577	1,070.6	0.4097	384.3	1.110	59.6	0.716
627	1,160.6	0.3868	398.1	1.121	62.0	0.720
677	1,250.6	0.3666	411.3	1.131	64.3	0.723
727	1,340.6	0.3482	424.4	1.141	66.7	0.726

a. *Table A.4, page 839.*

Note: *The temperature unit used in the following equations is °F.*

Density, ρ(lb/in³)

$$\rho(T) = 4.684 \times 10^{-5} - 7.150 \times 10^{-8}T + 5.869 \times 10^{-11}T^2 - 1.834 \times 10^{-14}T^3$$

Specific Heat, C_p (Btu/lb-°F)

$$C_p(T) = 0.2402 - 1.401 \times 10^{-6}T + 3.995 \times 10^{-8}T^2 - 1.570 \times 10^{-11}T^3$$

Conductivity, K (Btu/hr-in-°F)

$$K(T) = 1.110 \times 10^{-3} + 2.083 \times 10^{-6}T - 3.956 \times 10^{-10}T^2$$

3.2.1.5 LAST-A-FOAM FR-3700 Series Foams

Table 3-9 lists the thermophysical properties of the General Plastics LAST-A-FOAM FR-3700 series foam used by each transport package model. Refer also to Appendix 2.12.5, "Selected Material Properties References," for further details.

Table 3-9. LAST-A-FOAM FR-3700 Series Foam Thermophysical Properties – All Models (Reference [3.19])[a, b]

Model	Load Conditions of Transport	Density (lb/ft^3)	Conductivity		Specific Heat	
			Btu/hr-in-°F	W/m-°C	Btu/lb-°F	KJ/kg-°C
AOS-025	Normal	20	0.00242	0.0503	0.353	1.477
	Fire Condition, Upper Impact Limiter	25	0.00288	0.0597		
	Fire Condition, Lower Impact Limiter	20	0.00242	0.0503		
AOS-050	Normal	10	0.00148	0.0307	0.353	1.477
	Fire Condition, Upper Impact Limiter	12.5	0.00172	0.0357		
	Fire Condition, Lower Impact Limiter	10	0.00148	0.0307		
AOS-100	Normal	12	0.00167	0.0347	0.353	1.477
	Fire Condition, Upper Impact Limiter	14.6	0.00192	0.0399		
	Fire Condition, Lower Impact Limiter	12	0.00167	0.0347		

a. *Reference* **[3.19]** *applies only to Normal conditions of transport. For Hypothetical Accident conditions of transport, the property values provided in Table 3-9 were arrived at using the same procedures as shown in Appendix 3.5.4.2.5.*

b. *The foam properties presented are those used for the analyses within this chapter, for both Normal and Hypothetical Accident conditions of transport. Newer foam values are now in use (18, 8, and 11 pcf, for the Model AOS-025, AOS-050, and AOS-100, respectively). There is no significant variation of the property values listed above, and the new foam values.*

3.2.2 Component Specifications

The component material within the transport package that is considered to be temperature-sensitive is the elastomeric material used in the cask lid elastomeric seal and port plug O-Rings. The elastomeric material is a silicone-based compound (Parker O-Ring Division, S1224-70 compound), with a recommended temperature limit of 232°C (450°F) (Reference [3.20]). The following containment boundary components are not explicitly modeled within the analysis; only the temperature at their locations is monitored:

- Cask lid metallic seal (Jacket: Silver, ASTM B742; Spring: Nickel-chromium alloy 90 UNS N07090; Lining: SS304L UNS S30403)
- Conical copper alloy seal (C10100, C10200, or C11000 copper, foil or strip, chemical composition per ASTM B152 or ASTM F68 and mechanical properties per AMS 4500)

3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

The thermal evaluation of the AOS Transport Packaging System is conducted by analysis, using finite element methods. The computer program applied in the analysis, LIBRA, is a multi-purpose finite element program applicable to static and dynamic analyses of linear and non-linear structural systems, as well as thermal analysis. A thermal test is also conducted to verify that the cask's temperature distribution is similar to the one predicted by the analytical model.

3.3.1 Heat and Cold

In the thermal evaluation, the following conditions and assumptions were applied to all transport package models:

- For Normal conditions of transport, existing gaps were increased over nominal values by drawing tolerance, 0.01 in. In addition, for surface interfaces with null gap, heat transfer was assumed by contact resistance, and contact resistance values increased by a factor of 10 over nominal values. The contact resistance was set to 0.30 hr-ft^2-°F/Btu, where nominal contact resistance is 0.03 hr-ft^2-°F/Btu **[3.10]**.
- For Hypothetical Accident conditions of transport, all gaps were assumed closed. Interface heat transfer was by contact resistance, and nominal contact resistance values were decreased by a factor of 10, to 0.003 hr-ft^2-°F/Btu. For the Fire event's Cool-Down cycle, the analysis proceeded with gaps open to expanded values, and the contact resistance was increased to 0.30 hr-ft^2-°F/Btu. This procedure was found to be the most conservative.
- All cask component conduction and convection properties were modeled with temperature-dependent properties, except for the impact limiter foam. During the Fire event's Cool-Down cycle, foam properties were replaced with air properties.
- For Fire events, impact limiter geometries were modified to reflect deformations due to 30-ft. Head-On Drop events.
- Ribs inside the impact limiter are not included in the analysis models. A study has been performed that shows for Normal conditions of transport, temperatures are slightly higher without the ribs modeled. Under Normal conditions of transport, neglecting the ribs is conservative. Under Hypothetical Accident conditions of transport, temperatures at some areas are slightly higher with the ribs included, and do not significantly impact the final temperatures. Details are provided in Appendix 3.5.4.8.
- Foam thermal property values used in the analyses were the nominal values provided in the manufacturer's (General Plastics) literature. The property values variation listed in Table 8-5, "LAST-A-FOAM FR-3700 Series Foams – Testing Program," provides the acceptance criteria for the foam. Using the ranges from the table, sensitivity analyses were performed. The analyses used a ±15% variation in density, and a ±20% variation in specific heat. The analyses results demonstrated a temperature change of less than 1°F. Further details are provided in Appendix 3.5.4.9.

3.3.2 Maximum Normal Operating Pressure

The maximum operating pressure, based upon steady state temperatures for Normal conditions of transport are 20 psia, 21 psia, and 21 psia for Models AOS-025, AOS-050, and AOS-100, respectively. The calculation is applied by using the Ideal Gas Law, a relationship of temperature and pressure. The volume parameter does not enter into the calculation, because it is constant. Refer to Table 4-6, "Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models," for pressure calculation details.

The AOS Transport Packaging System can be loaded dry or wet; however, if loaded wet, the cask cavity must be vacuum-dried to remove all water or other moisture. Subsequently, only the relative humidity in the loading environment is trapped within the cavity. None of the contents undergo alpha decay in any appreciable amount, neither neutron emitters nor boron systems, that could generate helium gas.

3.3.3 Thermal Finite Element Model

The thermal evaluation of the AOS Transport Packaging System is conducted using the thermal analysis modulus of the LIBRA computer program, **MAIN12**. This heat conduction solution determines both steady-state and transient temperature fields. For transient thermal problems, the user can control the integration scheme by specifying the integration parameter. A zero (0) value for this parameter provides an explicit integration scheme; while between zero (0) and one (1) provide implicit schemes. A value of one (1) is used in the evaluation, corresponding to a backward difference integration technique. Temperature-dependent properties are either incorporated into an algorithm or implemented by a user-written subroutine. In this evaluation, the temperature-dependent properties are provided by an algorithm, and are shown in Subsection 3.2.1, "Material Properties."

The thick stainless steel cask outer shell, which comprises the bulk of the cask, defines the outside dimensions of the cask. The cask cavity is defined by the cask cavity shell, which is secured to the cask outer shell. The cask lid plug shell is secured by the cask lid and cask cavity shell. Four-node quadrilateral conduction elements are used to model the cask outer shell, cask cavity shell, and cask lid plug shell. Also, the bottom plate and cask lid are modeled with four-node quadrilateral conduction elements. Figure 3-1 shows the analytical model used in the evaluation of Normal conditions of transport. Refer to Appendix 3.5.4.2 and Appendix 3.5.4.3 for descriptions of the analytical model used in this evaluation.

The side tungsten alloy or carbon steel shielding is encapsulated by the cask outer shell and cask cavity shell. The vertical wall between the shielding and cask outer shell is packed with stainless steel wool on one side, and between the shielding and cask cavity shell, an air gap exists on the other. At the top and bottom horizontal surfaces, existing gaps within the cask cavity shell are filled with stainless steel shim plates. Two-node conduction elements are used in the model for the surface contact resistance and conduction through the stainless steel wool. Other surface interfaces, between cask components, are assembled with zero (0) gap, and are modeled with two-node conduction elements that have pressure surface-contact resistance properties.

The analytical FEA methodology and model are validated by a thermal test, the details of which are provided in Appendix 3.5.7.

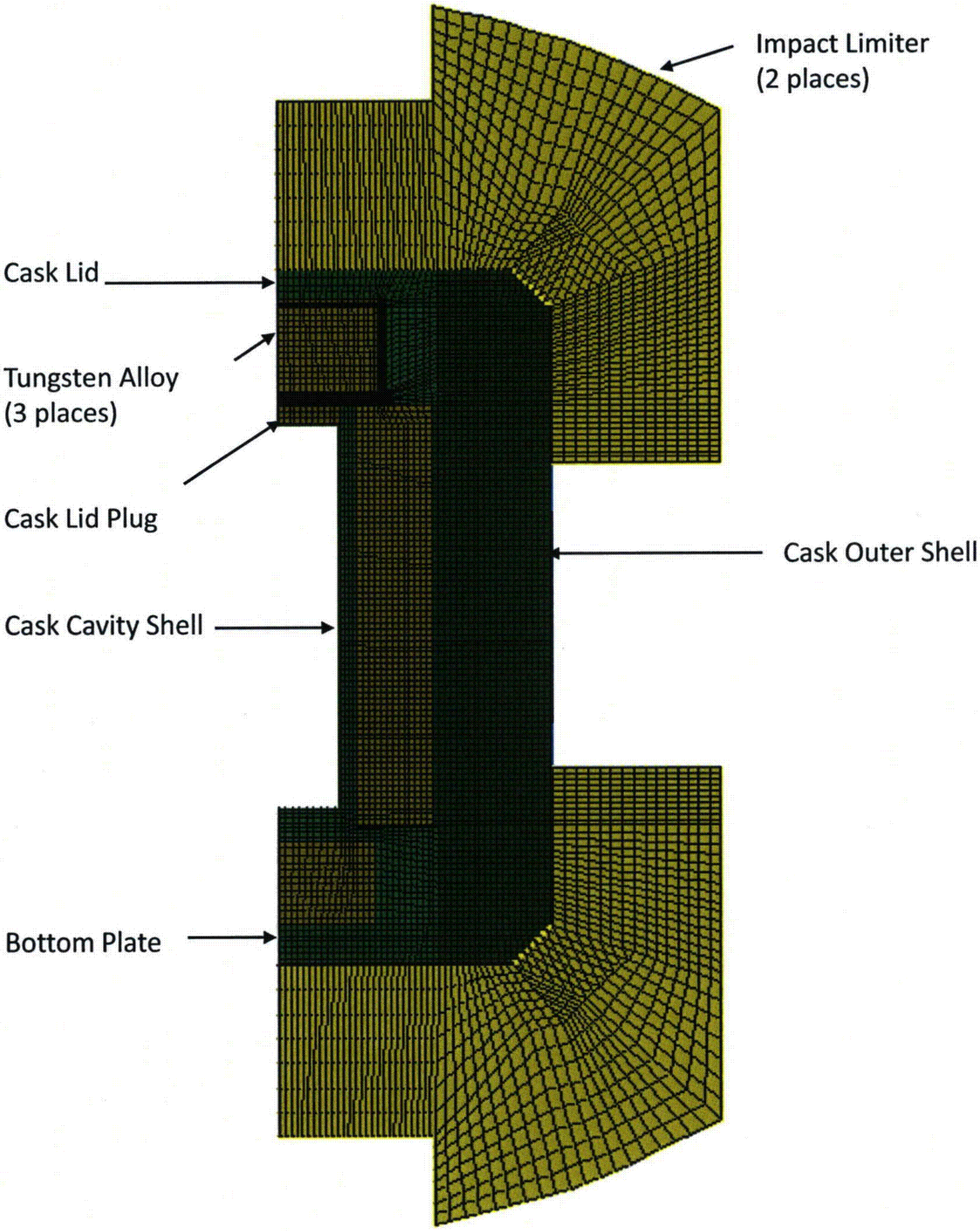

Figure 3-1. Analytical FEA Model – Normal Conditions of Transport

The bottom tungsten alloy or carbon steel shielding is encapsulated by the cask cavity shell and bottom plate. The top and bottom horizontal surfaces have zero (0) gaps, and heat transfer across these interfaces by a low-pressure, surface-contact resistance. The gap between the shielding vertical side wall and cask cavity shell is packed with stainless steel wool.

The top shielding is completely encapsulated by the cask lid plug shell. In a manner similar to the bottom shielding, the shielding top and bottom horizontal surfaces have zero (0) gaps, and heat transfers through these interfaces by a low-pressure, surface-contact resistance. A gap between the vertical side wall and cask lid plug shell is packed with stainless steel wool. Two-node conduction elements are used in the model for the surface contact resistance and conduction through the stainless steel wool.

A zero-gap surface thermal contact resistance, $1/h_c$, a value of 0.03 hr-ft^2-°F/Btu (refer to Appendix 2.12.5, "Selected Material Properties References," and Reference **[3.10]**) represents a low-contact pressure of less than 50 psi. In thermal situations, where lower resistance would provide higher temperatures, a resistance value of 0.003 hr-ft^2-°F/Btu is used at all pressure contact interfaces. This situation occurs during Thermal Condition 3, the 30-minute Fire event. The other six (6) thermal events use a higher resistance of 0.30 hr-ft^2-°F/Btu, at all contact interfaces, which provides for higher temperatures within the cask.

Packed steel wool conductive and density thermal properties are assumed to be approximately 10% that of the SS304 material, and its specific heat is approximated to that of air.

K = 0.068 Btu/hr-in-°F

Cp = 0.24 Btu/lb-°F

Density = 0.029 lb/in^3

Several interface surfaces have air gaps. Air gaps are modeled with two-node conduction elements, with conduction and radiation properties. The six (6) air gaps are located between the:

1. Cask outer shell and upper section of the cask cavity shell and cask lid.
2. Cask cavity shell and cask lid plug shell lower section.
3. Cask cavity shell and cask lid plug shell upper section.
4. Cask lid plug shell top horizontal surface and cask lid.
5. Cask outer shell corner and side, impact limiter.
6. Cask cavity shell and shielding (tungsten alloy or carbon steel).

In thermal situations, where a smaller gap would provide higher temperatures, all gaps are closed, and at the interface, a low-contact resistance value of 0.003 hr-ft^2-°F/Btu is used. This situation occurs during Thermal Condition 3, the 30-minute Fire event. The other six (6) thermal conditions use gaps that are increased by 0.01 inches over their nominal values, which allows dimensional tolerance to be considered. Table 3-11 lists the analyses values for the six (6) gaps used in all models.

The impact limiter structure is a spherical head, axisymmetric (2D) structure. The impact limiter's stainless steel outer shell is modeled by two-node conduction/convection elements. The interior is filled with General Plastics LAST-A-FOAM FR-3700 series foam, and modeled by four-node quadrilateral elements.

The decay heat of the cask contents is introduced in the model by two-node convective boundary elements, along the cask cavity surface. In the model, it is assumed that the load is uniformly distributed across the entire surface.

Boundary elements define the convective and radiative properties at the interface located between the impact limiter outside surface and regulatory-required environments. A second convective surface is located on the exposed cask outer shell, between the impact limiters. In addition to convective and radiative properties, these boundary two-node elements have the capability to include required solar heat flux loads.

Figure 3-4 illustrates all thermal model components and interfaces. The dimensions of all AOS Transport Packaging System models are provided in Appendix 3.5.4.

3.3.3.1 Heat Flux Property Set

Convective boundary elements, located within the model's cask cavity, define the prescribed heat flux due to decay heat. The Model AOS-100 transport package's maximum heat load is 400W. This load is applied as a uniform surface heat flux to the entire cavity surface area. Its value is calculated, as follows:

$$q = \frac{Q}{A} = \frac{(400)}{(2\pi)\left[(0.08255)^2 + (0.08255)(0.508)\right]}$$

$$= 1{,}305.9 \text{ W/m}^2$$

The justification for this approach is presented in Appendix 3.5.6.

Uniform decay heat flux values for all models are provided in Table 3-10.

Table 3-10. Heat Flux Values – All Models

Model	Decay Heat (W)	Cavity Area (in^2)	Heat Flux (Btu/hr-in^2)
AOS-025	10	29.65	1.15
AOS-050	100	118.63	2.88
AOS-100	400	474.77	2.88

3.3.3.2 Enclosed Air Space Property Sets

Six element property sets represent the previously described enclosed air spaces.

For convective heat transfer in an enclosed vertical air space, Gebhart **[3.5]** provides the following:

$$Nu = 0.18 \sqrt[4]{Gr}\ (H/S)^{(-1/9)} \qquad \text{For } 2 \times 10^4 < Gr < 2 \times 10^5$$

$$Nu = 0.065 \sqrt[3]{Gr}\ (H/S)^{(-1/9)} \qquad \text{For } 2 \times 10^5 < Gr < 11 \times 10^6$$

where:

Nu = Nusselt Number

Gr = Grashof Number, based upon S

S = Distance across enclosed space

H = Height of enclosed space

For Gr less than 2,000, the process is simple conduction, Nu = 1.0. The Grashof Number is defined, as follows:

$$Gr = \frac{\rho^2 g \beta S^3 \Delta T}{\mu^2} = \frac{g S^3 \Delta T}{T \nu^2}$$

where:

ρ = Density, kg/m^3

g = Acceleration of gravity ($9.8\ m/s^2$)

β = Coefficient of the thermal expansion (°C) = $\frac{1}{T}$ for ideal gases

ΔT = Temperature difference across enclosure (°C)

μ = Dynamic viscosity (kg/m-s)

ν = Kinematic viscosity (m^2/s) = μ/ρ

T = Absolute temperature (°K)

The convective heat transfer in an enclosed horizontal air space depends upon the temperatures of the upper and lower plates. From Gebhart **[3.7]**, when the upper plate's temperature is higher than the lower plate's temperature, the process is simple conduction:

$$Nu = 1.0$$

From Gebhart **[3.7]**, when the lower plate's temperature is higher than the upper plate's temperature, then:

$$Nu = 0.195 \sqrt[4]{Gr} \qquad 10^4 < Gr < 4 \times 10^5$$

$$Nu = 0.068 \sqrt[3]{Gr} \qquad 4 \times 10^5 < Gr$$

For values of Gr below 1,700, pure conduction is observed and Nu = 1.0. Therefore, the heat transfer process is simple conduction.

The Grashof Number, Gr, is evaluated at each gap, for the Model AOS-025, AOS-050, and AOS-100 transport packages. Enclosed gaps are small and in all cases, Gr is less than 1,700. It is concluded that convection is not a mode of heat transfer across all gaps. Details for this evaluation are provided in Appendix 3.5.4.4.3.

After Nu is known, the convective heat transfer coefficient, h_c, can be determined by the following expression in both cases, vertical and horizontal air spaces:

$$h_c = \frac{Nu * k}{S}$$

where:

k = Thermal conductivity (W/m-°C)

S = Distance across the space (m)

For radiative heat transfer:

$$h_r = \sigma F \left(T_1^2 + T_2^2\right)\left(T_1 + T_2\right)$$

where:

T_1, T_2 = Temperatures on either side of air space (°K)

σ = 5.669×10^{-8} (W/m^2-°K^4)

F = Gray body shape factor

The gray body shape factor, F, is defined as follows:

$$F = \frac{1}{\left(\frac{1}{\varepsilon_1} - 1\right) + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right) + \frac{1}{F_{12}}}$$

where:

A_1 = Area of smaller surface

A_2 = Area of larger surface

$\varepsilon_1, \varepsilon_2$ = Emissivities

F_{12} = Shape factor

The gray body shape factor, F, is a geometric function of the system. When body A is completely enclosed by body A_2 and A_1, it cannot see itself, as is the case here, F_{12} = 1.0 (Reference [3.8]).

From Reference [3.9], for oxidized SS304, $\varepsilon_1 = \varepsilon_2 = 0.52$ and assuming $A_1 = A_2$, then:

F = 0.351

for all material sets that have SS304 matching interface surface materials.

For Model AOS-100A, at Gap 6, the interface materials are SS304 to tungsten alloy. The emissivity for tungsten is 0.27 (Reference [3.17]), resulting in a gray body shape factor of:

F = 0.216

For the Model AOS-100B transport package, at Gap 6, the interface materials are SS304 to carbon steel. The emissivity for carbon steel is 0.58 (Reference [3.18]), resulting in a gray body shape factor of:

F = 0.378

The finite element model represents these air spaces with conductive elements. The conversions from h to k are as follows:

k = h * S

where:

k = Conduction

h = Convection

S = Distance across the air space

In general, the effective conductivity across the air gap, k_a, is due to conduction plus radiation, because it was previously proven that convection does not influence the heat transfer across the gaps (Gr ≤ 1,700). Therefore, k_a can be as follows:

k_a = $k + h_r * S$

Table 3-11 lists the thermal properties used in the analysis as a function of temperature, for the six (6) air gaps located within each AOS Transport Packaging System model. Appendix 3.5.4.4 provides information regarding curve-fitting data for all air gaps.

Table 3-11. Thermal Properties Used in Analysis as Function of Temperature, with Respect to the Air Gaps – All Models

Model	Air Gap	Effective Conductivity (Btu/hr-in-°F), Including Radiation	
		S^a (in.)	$k_a(T)^b$
AOS-025	1	0.0118	1.122E-3 + 2.085E-6T + 2.527E-10T^2
	2	0.0124	1.122E-3 + 2.085E-6T + 2.527E-10T^2
	3	0.0176	1.132E-3 + 2.070E-6T + 5.343E-10T^2
	4	0.0147	1.122E-3 + 2.085E-6T + 2.527E-10T^2
	5	0.0403	1.178E-3 + 2.005E-6T + 1.763E-9T^2
	6	0.0108	1.111E-3 + 2.101E-6T - 5.217E-11T^2
AOS-050	1	0.0140	1.127E-3 + 2.077E-6T + 3.935E-10T^2
	2	0.0150	1.127E-3 + 2.077E-6T + 3.935E-10T^2
	3	0.0250	1.147E-3 + 2.049E-6T + 9.350E-10T^2
	4	0.0190	1.127E-3 + 2.077E-6T + 3.935E-10T^2
	5	0.0710	1.239E-3 + 1.916E-6T + 3.426E-9T^2
	6	0.0120	1.112E-3 + 2.099E-6T - 1.885E-11T^2
AOS-100A	1	0.0170	1.131E-3 + 2.072E-6T + 5.018E-10T^2
	2	0.0200	1.137E-3 + 2.063E-6T + 6.642E-10T^2
	3	0.0400	1.177E-3 + 2.005E-6T + 1.747E-9T^2
	4	0.0290	1.155E-3 + 2.037E-6T + 1.152E-9T^2
	5	0.1310	1.359E-3 + 1.743E-6T + 6.675E-9T^2
	6	0.0130	1.113E-3 + 2.097E-6T + 1.447E-11T^2
AOS-100B	1	0.0170	1.131E-3 + 2.072E-6T + 5.018E-10T^2
	2	0.0200	1.137E-3 + 2.063E-6T + 6.642E-10T^2
	3	0.0400	1.177E-3 + 2.005E-6T + 1.747E-9T^2
	4	0.0290	1.155E-3 + 2.037E-6T + 1.152E-9T^2
	5	0.1310	1.359E-3 + 1.743E-6T + 6.675E-9T^2
	6	0.0130	1.125E-3 + 2.080E-6T + 3.393E-10T^2

a. S = Distance across the air space.

b. Temperature unit is °F.

3.3.3.3 Boundary Property Sets

The transport packages are transported in a vertical position. Eleven (11) material property sets define the outside cask surface and link the transport package with the external environment. These sets also define the film coefficient, ambient temperature, and solar heat flux values. All models are evaluated with Surfaces 1, 2, and 3 having no convection nor solar loads. However, during the Fire event, all surfaces are exposed to the fire environment.

In addition, each property set specifies the free convective coefficient, ambient temperature, and solar heat flux value for a portion of the cask boundary. Free convective coefficients are determined in accordance with empirical equations provided in Reference **[3.4]**. In general, convection coefficients are determined by finding the Nusselt Number, and then using the following equation to solve for h:

$$Nu = h * L / k$$

where:

h = Convective film coefficient

L = Characteristic length

k = Air conductive coefficient

The empirical formulations used to determine the Nusselt Numbers used in the vertical and horizontal surface cask analyses are presented in Paragraph 3.3.3.4 and Paragraph 3.3.3.5, respectively.

Convective film coefficient values are dependent upon the plate shape, size, and orientation. The film temperature is assumed to be the average between the transport package surface and required regulatory ambient temperatures. The film coefficient is then evaluated with air properties defined at the film temperature. Detailed information regarding the surface convective coefficient is provided in Appendix 3.5.4.5.

For all models, Table 3-12 (Normal conditions of transport) and Table 3-13 (Fire condition) list the orientation, shape, and size of the cask assembly's external surfaces. (Refer also to Table 3-14 and Table 3-15.) Appendix 3.5.4.5 provides additional information regarding the dimensional values used in all models. Figure 3-2 and Figure 3-3 illustrate the external surface locations for Normal and Hypothetical Accident conditions of transport, respectively.

All transport packages have several curved vertical surfaces that are considered flat vertical plates, in their evaluations for surface convection. In the analyses, a vertical cylinder is treated as a flat vertical plate when it meets the criterion, $D/L \geq 35 / Gr^{1/4}$. It is shown in Appendix 3.5.4.6 that this criterion is met for all curved vertical surfaces.

Table 3-12. Cask Assembly External Surface Orientation and Size, Normal Conditions of Transport – All Models

Model	Surface	Orientation	Length (m)	Width (m)
AOS-025 (Transported Vertically)	1	Bottom Horizontal	0.091	0.091
	2	Vertical	0.030	0.030
	3	Bottom Horizontal	0.290	0.290
	4	Vertical	0.343	0.343
	9	Top Horizontal	0.290	0.290
	10	Vertical	0.030	0.030
	11	Top Horizontal	0.091	0.091
AOS-050 (Transported Vertically)	1	Bottom Horizontal	0.183	0.183
	2	Vertical	0.061	0.061
	3	Bottom Horizontal	0.579	0.579
	4	Vertical	0.282	0.282
	5	Top Horizontal	0.579	0.579
	6	Vertical	0.099	0.099
	7	Bottom Horizontal	0.579	0.579
	8	Vertical	0.282	0.282
	9	Top Horizontal	0.579	0.579
	10	Vertical	0.061	0.061
	11	Top Horizontal	0.183	0.183
AOS-100 (Transported Vertically)	1	Bottom Horizontal	0.364	0.364
	2	Vertical	0.190	0.190
	3	Bottom Horizontal	1.159	1.159
	4	Vertical	0.464	0.464
	5	Top Horizontal	1.159	1.159
	6	Vertical	0.400	0.400
	7	Bottom Horizontal	1.159	1.159
	8	Vertical	0.464	0.464
	9	Top Horizontal	1.159	1.159
	10	Vertical	0.190	0.190
	11	Top Horizontal	0.364	0.364

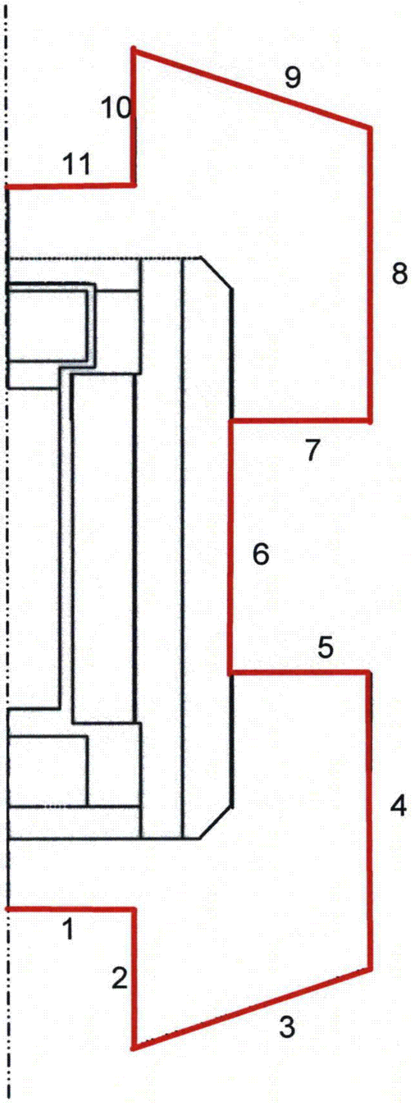

Figure 3-2. Cask Assembly External Surface Identification, Normal Conditions of Transport – All Models (Typical; Surfaces 5, 6, 7, and 8 are not used on Model AOS-025)

Note: *The figure depicts the package orientation during transport.*

Table 3-13. Cask Assembly External Surface Orientation and Size, Fire Condition – All Models

Model	Surface	Orientation	Length (m)	Width (m)
AOS-025 Fire Model (Transported Vertically)	1	Bottom Horizontal	0.091	0.091
	2	Vertical	0.030	0.030
	3	Bottom Horizontal	0.290	0.290
	4	Vertical	0.343	0.343
	11	Top Horizontal	0.257	0.257
AOS-050 Fire Model (Transported Vertically)	1	Bottom Horizontal	0.183	0.183
	2	Vertical	0.061	0.061
	3	Bottom Horizontal	0.579	0.579
	4	Vertical	0.282	0.282
	5	Top Horizontal	0.503	0.503
	6	Vertical	0.099	0.099
	7	Bottom Horizontal	0.579	0.579
	8	Vertical	0.264	0.264
	11	Top Horizontal	0.513	0.513
AOS-100 Fire Model (Transported Vertically)	1	Bottom Horizontal	0.364	0.364
	2	Vertical	0.190	0.190
	3	Bottom Horizontal	1.159	1.159
	4	Vertical	0.464	0.464
	5	Top Horizontal	1.159	1.159
	6	Vertical	0.400	0.400
	7	Bottom Horizontal	1.159	1.159
	8	Vertical	0.452	0.452
	11	Top Horizontal	1.027	1.027

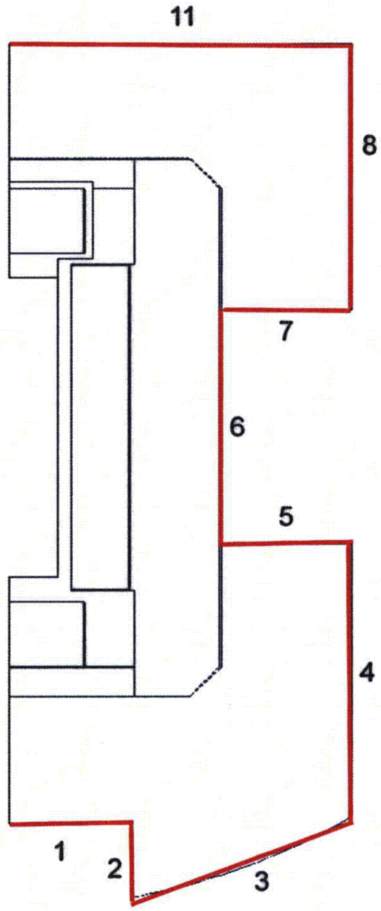

Figure 3-3. Cask Assembly External Surface Identification, Fire Condition – All Models (Typical; Surfaces 5, 6, 7, and 8 are not used on Model AOS-025)

Note: *The figure depicts the package orientation during transport.*

In addition to convection, the cask surface interacts radiatively with its surroundings. The radiative heat transfer coefficient, h_r, is calculated, using the equations provided in Paragraph 3.3.3.2. Regulatory environments place the transport package in an outside environment. Therefore, in evaluating the equation for the gray body shape factor, it is assumed that A_1 is negligible, when compared with A_2, and F_{12} = 1.0. The impact limiter outside surface is oxidized SS304, and the surface emissivity is 0.52. The cask outside surface is polished, and an emissivity of 0.20. Both of these values can be found in Reference **[3.9]**.

The effective film coefficient, h (Btu/hr-in^2-°F), is as follows:

$$h = h_c + h_r$$

The three (3) regulatory required ambient temperatures are 38°C, -29°C, and -40°C (100°F, -20°F, and -40°F, respectively). Convective properties, including radiation, used in the analysis as a function of temperature have a form:

$$h(T) = a_0 + a_1T + a_2T^2 + a_3T^3$$

where:

h(T) = Btu/hr-in^2-°F

T = Surface temperature, °F

Table 3-14 (Normal conditions of transport) defines the polynomial coefficients used in the equivalent convective property of each ambient temperature and external surface, for each AOS Transport Packaging System model.

Two sets of convective properties are used due to the change in geometry for the Hypothetical Accident conditions of transport:

- One set of properties (defined in Table 3-15) is used for the steady-state analysis that leads into the fire transient. This set of properties is also used for the cool-down transient analysis. A sample calculation is included in Appendix 3.5.4.5.3, which provides the computation for the effective film coefficient of a vertical plate within the Model AOS-100. Appendix 3.5.4 also includes curve-fitting data for all models and environments.
- The second set of properties is used only for the Fire event, which is defined in Paragraph 3.3.3.8.

Table 3-14. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Normal Conditions of Transport – All Models

Model	Ambient Temperature		Surface	Polynomial Coefficient			
	°C	°F		a_0	a_1	a_2	a_3
AOS-025	37.78	100	4	2.149E-03	4.387E-05	-2.977E-08	2.231E-11
			9	1.405E-03	6.306E-05	-5.279E-08	3.117E-11
			10	7.659E-04	8.122E-05	-7.456E-08	3.957E-11
			11	7.659E-04	8.122E-05	-7.456E-08	3.957E-11
	-28.89	-20	4	4.988E-03	3.463E-05	-2.796E-08	2.399E-11
			9	6.394E-03	4.944E-05	-4.937E-08	3.367E-11
			10	7.787E-03	6.350E-05	-6.974E-08	4.291E-11
			11	7.787E-03	6.350E-05	-6.974E-08	4.291E-11
	-40	-40	4	5.452E-03	3.314E-05	-2.772E-08	2.439E-11
			9	7.193E-03	4.723E-05	-4.890E-08	3.425E-11
			10	8.902E-03	6.062E-05	-6.907E-08	4.369E-11
			11	8.902E-03	6.062E-05	-6.907E-08	4.369E-11

Table 3-14. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Normal Conditions of Transport – All Models (Continued)

Model	Ambient Temperature		Surface	Polynomial Coefficient			
	°C	°F		a_0	a_1	a_2	a_3
AOS-050	37.78	100	4	2.101E-03	4.562E-05	-3.187E-08	2.312E-11
			5	2.101E-03	4.562E-05	-3.187E-08	2.312E-11
			6	-1.782E-04	5.110E-05	-5.237E-08	2.439E-11
			7	2.506E-03	3.176E-05	-1.526E-08	1.669E-11
			8	2.101E-03	4.562E-05	-3.187E-08	2.312E-11
			9	2.101E-03	4.562E-05	-3.187E-08	2.312E-11
			10	1.774E-03	6.288E-05	-5.234E-08	3.101E-11
			11	1.774E-03	6.288E-05	-5.234E-08	3.101E-11
	-28.89	-20	4	5.034E-03	3.803E-05	-3.569E-08	2.885E-11
			5	6.114E-03	5.269E-05	-6.023E-08	4.052E-11
			6	4.585E-03	4.254E-05	-5.666E-08	3.182E-11
			7	3.993E-03	2.521E-05	-1.425E-08	1.774E-11
			8	5.034E-03	3.803E-05	-3.569E-08	2.885E-11
			9	6.114E-03	5.269E-05	-6.023E-08	4.052E-11
			10	6.688E-03	4.944E-05	-4.915E-08	3.360E-11
			11	6.688E-03	4.944E-05	-4.915E-08	3.360E-11
	-40	-40	4	5.628E-03	3.444E-05	-2.967E-08	2.529E-11
			5	7.165E-03	4.791E-05	-5.230E-08	3.581E-11
			6	5.487E-03	3.808E-05	-4.872E-08	2.720E-11
			7	4.246E-03	2.415E-05	-1.412E-08	1.799E-11
			8	5.628E-03	3.444E-05	-2.967E-08	2.529E-11
			9	7.165E-03	4.791E-05	-5.230E-08	3.581E-11
			10	7.477E-03	4.725E-05	-4.871E-08	3.420E-11
			11	7.477E-03	4.725E-05	-4.871E-08	3.420E-11

Table 3-14. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Normal Conditions of Transport – All Models (Continued)

Model	Ambient Temperature		Surface	Polynomial Coefficient			
	°C	°F		a_0	a_1	a_2	a_3
AOS-100	37.78	100	4	2.222E-03	4.132E-05	-2.673E-08	2.113E-11
			5	1.265E-03	5.985E-05	-4.941E-08	2.965E-11
			6	1.521E-04	3.699E-05	-3.557E-08	1.790E-11
			7	2.634E-03	2.814E-05	-1.092E-08	1.502E-11
			8	2.222E-03	4.132E-05	-2.673E-08	2.113E-11
			9	1.265E-03	5.985E-05	-4.941E-08	2.965E-11
			10	1.265E-03	5.985E-05	-4.941E-08	2.965E-11
			11	1.265E-03	5.985E-05	-4.941E-08	2.965E-11
	-28.89	-20	4	5.405E-03	3.722E-05	-3.825E-08	3.034E-11
			5	6.261E-03	4.969E-05	-5.170E-08	3.465E-11
			6	3.493E-03	2.892E-05	-3.340E-08	1.951E-11
			7	3.715E-03	2.240E-05	-1.019E-08	1.590E-11
			8	5.405E-03	3.722E-05	-3.825E-08	3.034E-11
			9	6.261E-03	4.969E-05	-5.170E-08	3.465E-11
			10	5.458E-03	3.897E-05	-3.420E-08	2.682E-11
			11	6.261E-03	4.969E-05	-5.170E-08	3.465E-11
	-40	-40	4	6.442E-03	3.974E-05	-4.914E-08	3.711E-11
			5	6.912E-03	4.503E-05	-4.558E-08	3.270E-11
			6	4.024E-03	2.761E-05	-3.310E-08	1.988E-11
			7	3.848E-03	2.316E-05	-1.524E-08	1.980E-11
			8	6.442E-03	3.974E-05	-4.914E-08	3.711E-11
			9	6.912E-03	4.503E-05	-4.558E-08	3.270E-11
			10	6.019E-03	3.727E-05	-3.390E-08	2.727E-11
			11	6.912E-03	4.503E-05	-4.558E-08	3.270E-11

Table 3-15. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Steady-State Leading to the Fire and Cool-Down Conditions – All Models

Model	Ambient Temperature		Surface	Polynomial Coefficient			
	°C	°F		a_0	a_1	a_2	a_3
AOS-025	37.78	100	4	2.149E-03	4.387E-05	-2.977E-08	2.231E-11
			11	1.346E-03	6.472E-05	-5.477E-08	3.193E-11
AOS-050	37.78	100	4	2.150E-03	4.597E-05	-3.272E-08	2.364E-11
			5	1.657E-03	5.588E-05	-4.418E-08	2.785E-11
			6	-1.782E-04	5.110E-05	-5.237E-08	2.438E-11
			7	2.506E-03	3.176E-05	-1.526E-08	1.669E-11
			8	2.150E-03	4.597E-05	-3.272E-08	2.364E-11
			11	1.657E-03	5.588E-05	-4.418E-08	2.785E-11
AOS-100	37.78	100	4	2.216E-03	4.153E-05	-2.698E-08	2.123E-11
			5	1.265E-03	5.985E-05	-4.941E-08	2.965E-11
			6	1.521E-04	3.699E-05	-3.557E-08	1.790E-11
			7	2.606E-03	2.837E-05	-1.138E-08	1.527E-11
			8	2.216E-03	4.153E-05	-2.698E-08	2.123E-11
			11	1.265E-03	5.985E-05	-4.941E-08	2.965E-11

3.3.3.4 Vertical Surface

The Nusselt Number used for convection from a vertical surface under laminar flow, $Ra \leq 10^9$, is determined from Reference [3.4], Equation 9.27:

$$Nu = 0.68 + A / B$$

$$A = 0.670 * Ra^{1/4}$$

$$B = [1 + (0.492 / Pr)^{9/16}]^{4/9}$$

where:

Pr = Prandtl Number

The Nusselt Number for turbulent flow, $Ra \geq 10^9$, is determined from Reference [3.4], Equation 9.26:

$$Nu = \{0.825 + A / B\}^2$$

$$A = 0.387 * Ra^{1/6}$$

$$B = [1 + (0.492 / Pr)^{9/16}]^{8/27}$$

where:

Ra = Pr * Gr, Rayleigh Number

3.3.3.5 Horizontal Surface

The Nusselt Number used for convection from a horizontal, upper surface under laminar flow, $10^4 \le Ra \le 10^7$, is determined from Reference [3.4], Equation 9.30:

$$Nu = 0.54 * Ra^{1/4}$$

The Nusselt Number for turbulent flow, $10^7 \le Ra \le 10^{11}$, is determined from Reference [3.4], Equation 9.31:

$$Nu = 0.15 * Ra^{1/3}$$

The Nusselt Number used for convection from a horizontal, lower surface, $10^5 \le Ra \le 10^{10}$, is determined from Reference [3.4], Equation 9.32:

$$Nu = 0.27 * Ra^{1/4}$$

3.3.3.6 Horizontal Cylinder

The Nusselt Number used for convection from a horizontal cylinder with $Ra \le 10^{12}$ is determined from Reference [3.4], Equation 9.34:

$$Nu = \{0.60 + A / B\}^2$$

$$A = 0.387 * Ra^{1/6}$$

$$B = [1 + (0.559 / Pr)^{9/16}]^{8/27}$$

where:

Pr = Prandtl Number

3.3.3.7 Solar Heat Load

The total heat load per unit area is defined by the surface type and orientation, over a 12-hour period. For steady-state and fire-transient solutions, the heat load is divided by 12 hours, to determine the heat flow rate. (Refer also to Appendix 3.5.4.7 for FR-3700 Series foam materials, under Thermal Condition 1 of Table 3-3.)

Table 3-16 defines the solar heat applied to the cask's outside surfaces for Thermal Conditions 1 and 3.

Table 3-16. Solar Heat Application to Cask Outside Surfaces – All Models

Model	Surface	Total Insolation		Heat Rate
		Cal/cm2	Btu/in^2	Btu/hr-in^2
AOS-025	1, 2, 3	0	0	0
	4	400	10.24	0.8533
	5, 6, 7, 8	–	–	–
	9	800	20.48	1.7070
	10	400	10.24	0.8533
	11	800	20.48	1.7070
AOS-050	1, 2, 3	0	0	0
	4, 8	400	10.24	0.8533
	5	800	20.48	1.7070
	6	400	10.24	0.8533
	7	200	5.12	0.4267
	9	800	20.48	1.7070
	10	400	10.24	0.8533
	11	800	20.48	1.7070
AOS-100	1, 2, 3	0	0	0
	4	400	10.24	0.8533
	5	800	20.48	1.7070
	6	400	10.24	0.8533
	7	200	5.12	0.4267
	8	400	10.24	0.8533
	9	800	20.48	1.7070
	10	400	10.24	0.8533
	11	800	20.48	1.7070

3.3.3.8 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 3.3.3.2 for convection due to radiation, h_r, 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

= 0.8

T_1 = Surface temperature, °R

Then:

$$h_r = 9.5552\text{E-}12 * (T_1^3 + 1{,}935 * T_1^2 + 1{,}935^2 * T_1 + 1{,}935^3)$$

A convective heat transfer, h_c 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:

$$h_t = h_c + h_r$$

$$h_t = 1.051\text{E-}1 + 4.370\text{E-}5 * T + 5.461\text{E-}8 * T^2$$

where:

T = Surface temperature, °F

Additional information is provided in Appendix 3.5.4.5.2.4.

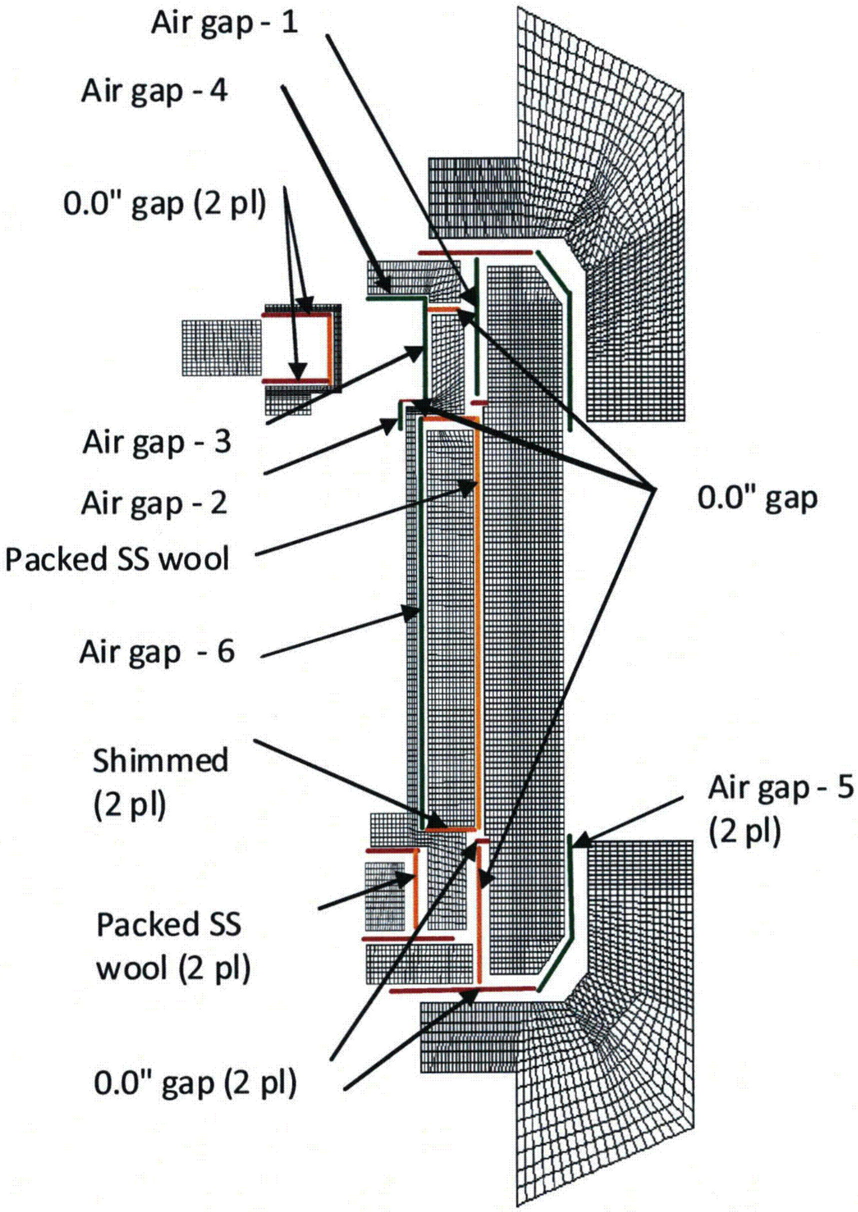

Figure 3-4. Expanded View of Thermal Model Defining Component Interfaces

3.3.4 Normal Conditions of Transport Thermal Results

The tables and figures provided in Appendix 3.5.2, "Thermal Evaluation Results – Models AOS-025, AOS-050, and AOS-100," contain the nodal temperatures determined for all Normal conditions of transport thermal conditions specified in *Regulatory Guide 7.8* (Reference **[3.21]**). The maximum component temperatures summarized in Table 3-3 show that all component temperatures meet their regulatory/ component criteria.

3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS

The AOS Transport Packaging System models are analyzed for the Hypothetical Accident conditions of transport Fire event – a 1/2-hour fire engulfing the entire cask, after a 30-ft. free drop, followed by a natural cool-down. The transport package's impact limiters are assumed to be deformed as a result of the free drop. Thermal analysis of the Fire event is conducted using the LIBRA Finite Element program, using an axisymmetric model. In the LIBRA analyses, model element thermal properties are updated every tenth time step, to account for the changes in material properties during the Fire event.

AOS considered the Head-On Drop condition the more damaging condition under the Fire event. This is supported by the analysis provided in Appendix 3.5.4.2.5. In this analysis, the model includes the combined deformation of all three (3) drop orientations – Head-On, Side and Slap Down. The results show little change in the maximum cask component temperature when compared with the uncrushed configuration results. Furthermore, the maximum cask component temperatures usually occur during the cool-down period of the Hypothetical Accident conditions of transport. During this period, the impact limiter foam is assumed to be gone (destroyed) and replaced with air. Therefore, the geometry due to a puncture deformation is not a significant factor in the resulting temperatures.

Figure 3-5 illustrates the LIBRA Finite Element thermal model used in this analysis. The analytical model shown in Figure 3-5 is that of the Model AOS-100A transport package. Similar models are developed to represent the Model AOS-025 and AOS-050 transport packages. In this LIBRA model, the impact limiter is conservatively modeled to reflect deformations due to a hypothetical 30-ft. Head-On Drop. The impact limiter model height is reduced by 5.9 in. for the Head-On Drop, reflecting 100% of the computed deformation. In the analytical model, this deformation is applied to the axisymmetric model. Further details on this approach are provided in Appendix 3.5.4.2.

The impact limiter foam thermal properties are adjusted to account for the change in volume resulting from the free drop. The value adjustment is proportional to the volume reduction.

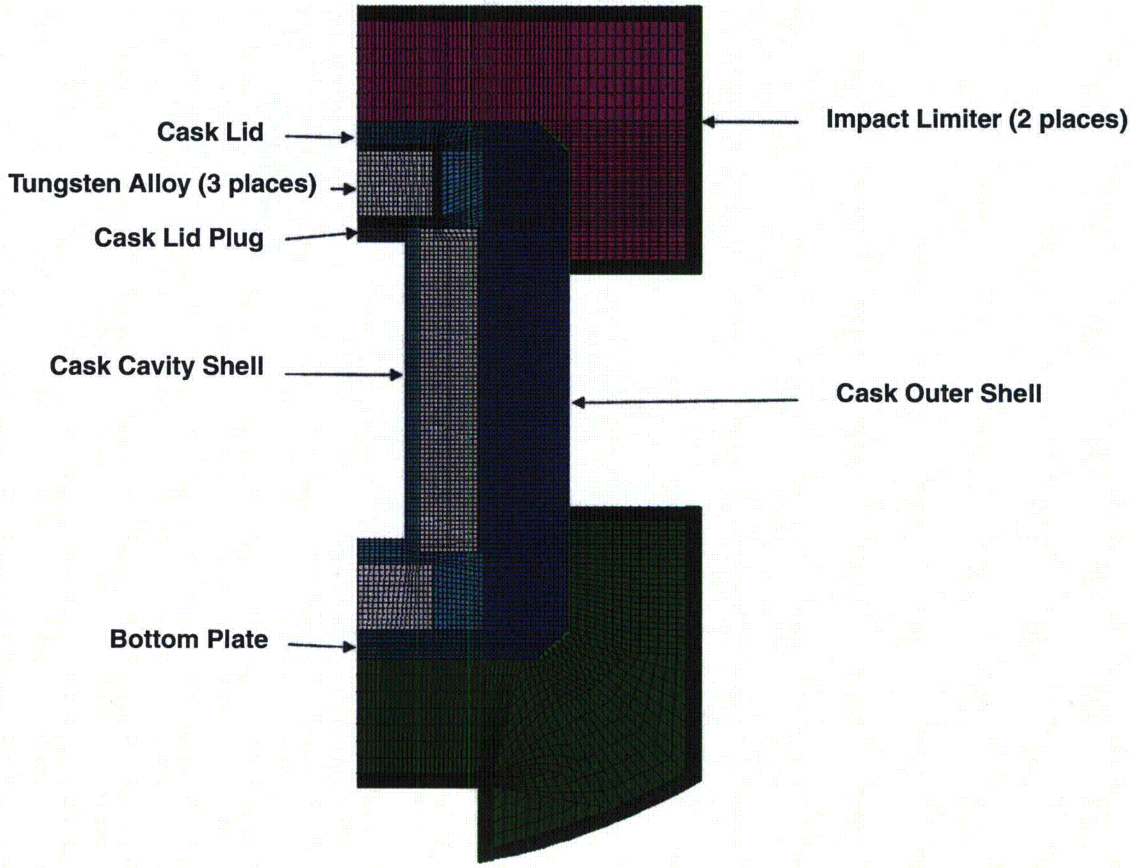

Figure 3-5. Thermal Finite Element Model – Fire Conditions

3.4.1 Initial Conditions

The package is subjected to two (2) free drops – one from a height of 914.4 cm (30 ft.), and another from a height of 121.92 cm (4 ft.) onto a cylindrical punch. The orientation of the package during the drops is selected to provide the greatest damage potential by aiming for the weakest point along the containment boundary. However, because the impact limiter encloses all of these areas, the critical factor becomes how much energy the impact limiter can absorb. The initial condition for the Fire event is the Normal condition of transport – 38°C (100°F) ambient temperature – with maximum decay heat and solar load. The analytical model used in the evaluation is the same as the one used to evaluate the Normal condition, with the section representing the impact limiter modified to represent the deformed geometry of this structure because of the free-drop condition.

3.4.2 Fire Test Conditions

As discussed in Subsection 3.4.1, the Fire condition analysis begins at the 38°C (100°F) ambient temperature, with maximum decay heat and solar load solution. At time zero, an ambient temperature of 800°C (1,475°F) is applied to the model. Also, all gaps are closed, and conduction across all interfacing surfaces are assumed to be by contact resistance. Contact resistance is reduced for the fire's duration. This ambient temperature is maintained for 0.5 hours. At this time, the ambient condition is reversed to the initial condition and all gaps are reopened and contact resistance is increased by a factor of 100. The post fire phase of this analysis assumes the foam is gone and in its place air properties are used. The analysis continues until eight (8) hours elapse.

3.4.3 Maximum Temperatures and Pressures

The maximum temperatures are reported in Table 3-4. Temperature tables and contour plots of the Fire condition follows. The maximum pressures are reported in Table 4-7, "Maximum Cask Cavity Pressure Due to Fire Condition – All Models."

3.4.4 Maximum Thermal Stresses

Thermal stresses resulting from temperature gradients and differential thermal expansion for all transport package models are provided in Appendix 2.12.2, "Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100."

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

Not applicable. Fissile material is not an authorized content for the AOS Transport Packaging System.

3.4.6 Hypothetical Accident Conditions of Transport Thermal Results

The tables and figures provided in Appendix 3.5.2 contain the nodal temperatures determined for the Fire event, as specified in References **[3.1]** and **[3.2]**. The maximum component temperatures summarized in Table 3-4 show that all component temperatures meet their regulatory/component criteria.

During the 30-minute Fire condition, conductivity is increased across all gaps and contact surfaces. During the initial start of this event, temperatures briefly decrease within the interior region of the cask. This phenomenon is caused by increased conductivity due to gap closures for this fire condition. The closed gap is a conservative assumption during the fire period, to increase heat flow. There is a brief period following gap closure when conductivity is increased and the fire heat has not yet reached the plug.

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3.5 APPENDIX

This appendix presents the following information:

- Data CDs
- Thermal Evaluation Results – Models AOS-025, AOS-050, and AOS-100
  - Thermal Evaluation Results – Model AOS-025A
  - Thermal Evaluation Results – Model AOS-050A
  - Thermal Evaluation Results – Models AOS-100A and AOS-100A-S
  - Thermal Evaluation Results – Model AOS-100B
- LIBRA Finite Element Program Heat Transfer Module
- Analysis Modeling Data
  - Material Properties
  - Model Dimensions
  - Analysis FEA Models
  - Enclosed Gaps, Equivalent Conductivity
  - Surface Convective Coefficients
  - Curved Vertical Plates Used as Flat Vertical Plates, Criteria Check
  - Insolation Heat Load Analysis for FR-3700 Series Foam under Condition 1 of Table 3-3
  - Impact Limiter Rib Study
- LIBRA File Input Showing Material Property Assignation
- Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity
- Thermal Tests
- Heat Test Report – AOS-165A Prototype
- Copper Seal Locations with Analytical Model (with Cask Lid Metallic Seal)
- Garlock Helicoflex Report, Helicoflex Seal Temperature Limit – Cask Lid Metallic Seal

3.5.1 Data CDs

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

- **CDs 1, 2, and 3** – All analytical files, including the LIBRA FEA program
- **CD 4** – Autodesk Inventor files

3.5.2 Thermal Evaluation Results – Models AOS-025, AOS-050, and AOS-100

This appendix presents Load Case thermal evaluations for each AOS Transport Packaging System model:

- Thermal Evaluation Results – Model AOS-025A
- Thermal Evaluation Results – Model AOS-050A
- Thermal Evaluation Results – Models AOS-100A and AOS-100A-S
- Thermal Evaluation Results – Model AOS-100B

3.5.2.1 Thermal Evaluation Results – Model AOS-025A

This appendix presents the following information, specific to the Model AOS-025A transport package:

- Normal Conditions of Transport Thermal Evaluation Results – Model AOS-025A
- Fire Condition Thermal Evaluation Results – Model AOS-025A

Table 3-17 lists the temperature monitoring points (nodes) for the Model AOS-025A transport package, under Normal conditions of transport and the Fire condition.

Table 3-17. Temperature Monitoring Points by Condition – Model AOS-025A

Nodal Location	LIBRA Model Nodal Number, by Condition	
	Normal Conditions of Transport	Fire Condition
1	5001	5001
2	4532	4532
3	4227	4227
4	4752	4752
5	4838	4838
6	4993	4993
7	3309	3309
8	3351	3351
9	678	678
10	2537	2537
11	2533	2533
12	4828	4828
13	1888	1888
14	583	583
15	579	579
16	4313	4313
17	3148	3148
18	3001	3001
19	7533	7533
20	7377	7377
21	7371	7371
22	6942	6942
23	6267	6267
24	6121	6121
25	6001	6001
26	9501	12481
27	9950	12941
28	10014	13260
29	10781	17060
30	9091	17008
31	8463	9785
32	8462	9571
33	8197	8197
34	9711	12451
35	9821	13160

Table 3-17. Temperature Monitoring Points by Condition – Model AOS-025A (Continued)

Nodal Location	LIBRA Model Nodal Number, by Condition	
	Normal Conditions of Transport	Fire Condition
36	10158	14272
37	10605	14943
38	9102	14891
39	8578	9900
40	8225	8673
41	8001	8225

3.5.2.1.1 Normal Conditions of Transport Thermal Evaluation Results – Model AOS-025A

Table 3-18 lists the tables and figures in this appendix that present the Model AOS-025A transport package results under Normal conditions of transport, for Load Cases 101 through 106. Each table provides a list of temperatures at each monitoring node. The tables for Load Cases 101, 102, 105, and 106 also include a list of maximum temperatures within each transport package component.

Figure 3-6 illustrates the location of each node on the transport package, under Normal conditions of transport. (The node locations are listed in Table 3-17.)

Table 3-18. Normal Conditions of Transport Thermal Evaluation Results – Model AOS-025A

Load Case	Description	Results Table	Entire Model	Cask Model
101	100°F Ambient, Maximum Decay Heat	Table 3-19	Figure 3-7	Figure 3-8
102	100°F Ambient, Maximum Decay Heat, Maximum Insolation	Table 3-20	Figure 3-9	Figure 3-10
103	-20°F Ambient, Zero Decay Heat, Zero Insolation	Table 3-21	Figure 3-11	–
104	-40°F Ambient, Zero Decay Heat, Zero Insolation	Table 3-22	Figure 3-12	–
105	-40°F Ambient, Maximum Decay Heat	Table 3-23	Figure 3-13	Figure 3-14
106	-20°F Ambient, Maximum Decay Heat	Table 3-24	Figure 3-15	Figure 3-16

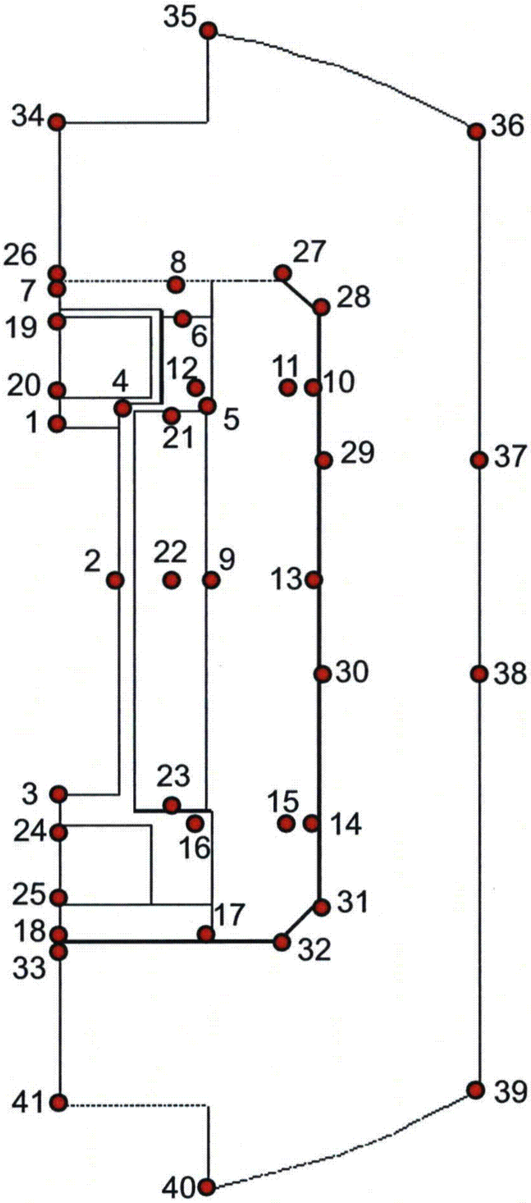

Figure 3-6. Selected Nodal Locations for Normal Conditions of Transport – Model AOS-025A

Table 3-19. Load Case 101, 100°F Ambient, Maximum Decay Heat – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	78.22	172.80
2	4532	77.39	171.30
3	4227	77.78	172.00
4	4752	77.28	171.10
5	4838	76.67	170.00
6	4993	76.61	169.90
7	3309	76.44	169.60
8	3351	76.44	169.60
9	678	76.83	170.30
10	2537	76.50	169.70
11	2533	76.50	169.70
12	4828	76.67	170.00
13	1888	76.50	169.70
14	583	76.39	169.50
15	579	76.44	169.60
16	4313	76.78	170.20
17	3148	76.33	169.40
18	3001	76.22	169.20
19	7533	76.78	170.20
20	7377	76.83	170.30
21	7371	76.89	170.40
22	6942	76.89	170.40
23	6267	76.83	170.30
24	6121	76.78	170.20
25	6001	76.78	170.20
26	9501	75.06	167.10
27	9950	75.06	167.10
28	10014	75.22	167.40
29	10781	75.61	168.10
30	9091	74.89	166.80
31	8463	75.11	167.20
32	8462	75.11	167.20
33	8197	75.11	167.20
34	9711	40.83	105.50
35	9821	39.50	103.10
36	10158	39.61	103.30
37	10605	43.00	109.40
38	9102	45.22	113.40
39	8578	43.00	109.40
40	8225	48.00	118.40
41	8001	50.83	123.50

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	674	7.6833E+01	1.7030E+02
Bottom Plate	3001	3232	3148	7.6333E+01	1.6940E+02
Cask Lid	3233	3424	3233	7.6500E+01	1.6970E+02
Shell Cavity	4001	4998	4227	7.7778E+01	1.7200E+02
Cask Lid Plug	5001	5404	5001	7.8222E+01	1.7280E+02
Tungsten Alloy	6001	7656	6340	7.6944E+01	1.7050E+02
Bottom Cavity	4227	4236	4227	7.7778E+01	1.7200E+02
Side Cavity	4372	4702	4482	7.7389E+01	1.7130E+02
Top Cavity	5001	5012	5001	7.8222E+01	1.7280E+02
Lid Seal	4993	4993	4993	7.6611E+01	1.6990E+02
Cask Vent Port	2537	2537	2537	7.6500E+01	1.6970E+02
Cask Vent Port Seal	2533	2533	2533	7.6500E+01	1.6970E+02
Vt.Conic.Seal	4828	4828	4828	7.6667E+01	1.7000E+02
Cask Drain Port	583	583	583	7.6389E+01	1.6950E+02
Cask Drain Port Seal	579	579	579	7.6444E+01	1.6960E+02
Drn.Conic.Seal	4313	4313	4313	7.6778E+01	1.7020E+02
Test Port	3351	3351	3351	7.6444E+01	1.6960E+02

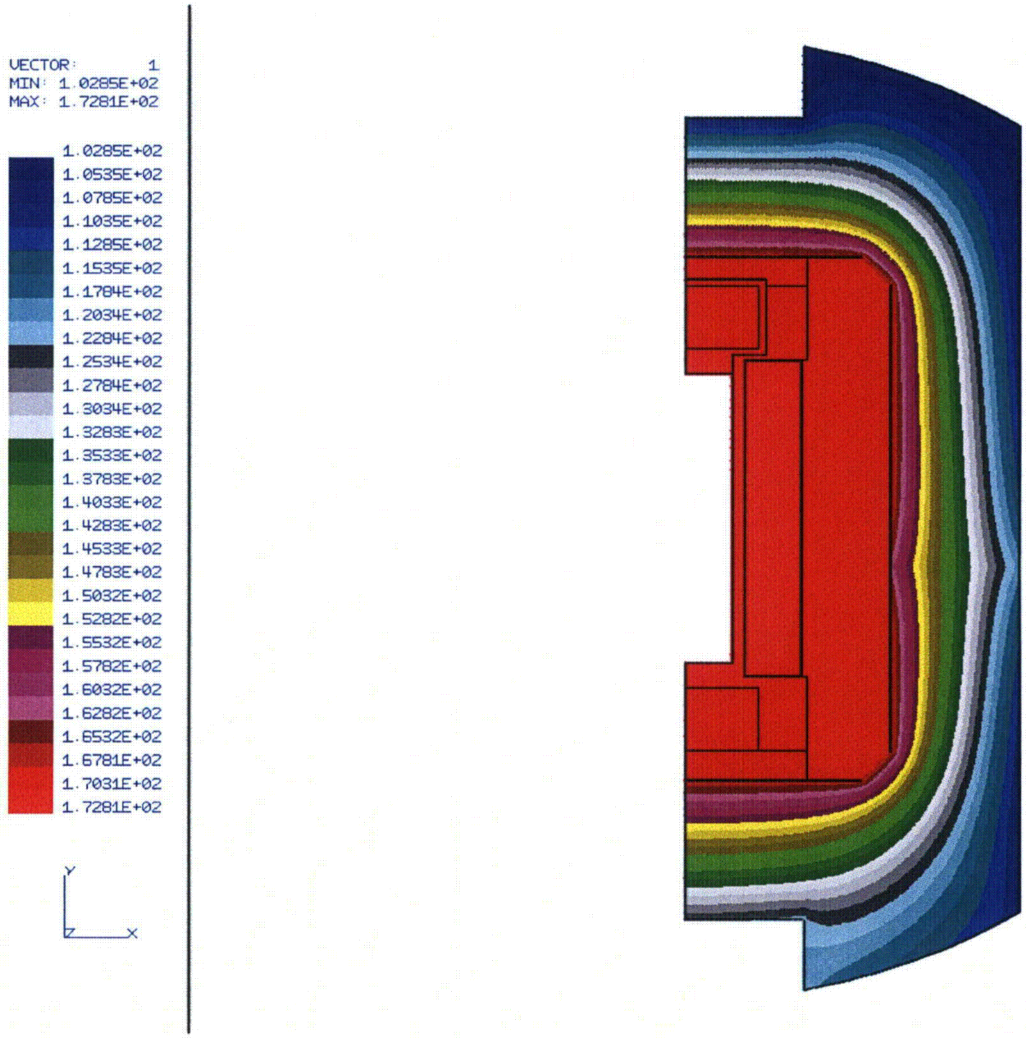

Figure 3-7. Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A

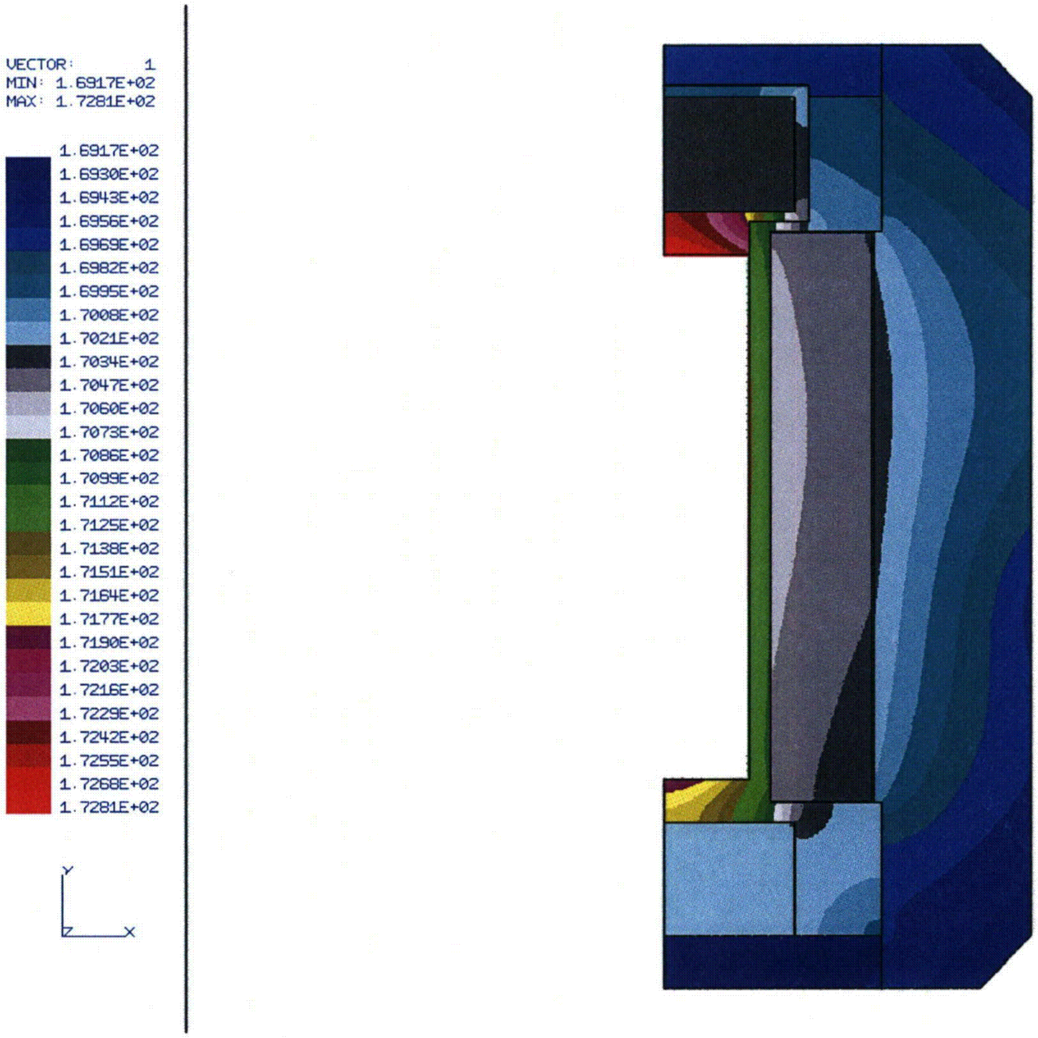

Figure 3-8. Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A

Table 3-20. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	125.56	258.00
2	4532	124.67	256.40
3	4227	125.06	257.10
4	4752	124.61	256.30
5	4838	124.06	255.30
6	4993	124.00	255.20
7	3309	123.94	255.10
8	3351	123.94	255.10
9	678	124.17	255.50
10	2537	123.94	255.10
11	2533	123.94	255.10
12	4828	124.06	255.30
13	1888	123.83	254.90
14	583	123.72	254.70
15	579	123.78	254.80
16	4313	124.11	255.40
17	3148	123.67	254.60
18	3001	123.56	254.40
19	7533	124.22	255.60
20	7377	124.22	255.60
21	7371	124.28	255.70
22	6942	124.28	255.70
23	6267	124.17	255.50
24	6121	124.11	255.40
25	6001	124.11	255.40
26	9501	122.89	253.20
27	9950	122.89	253.20
28	10014	123.00	253.40
29	10781	123.17	253.70
30	9091	122.39	252.30
31	8463	122.61	252.70
32	8462	122.56	252.60
33	8197	122.50	252.50
34	9711	98.72	209.70
35	9821	97.56	207.60
36	10158	98.89	210.00
37	10605	90.50	194.90
38	9102	91.83	197.30
39	8578	90.39	194.70
40	8225	95.22	203.40
41	8001	97.94	208.30

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	662	1.2417E+02	2.5550E+02
Bottom Plate	3001	3232	3148	1.2367E+02	2.5460E+02
Cask Lid	3233	3424	3233	1.2394E+02	2.5510E+02
Shell Cavity	4001	4998	4227	1.2506E+02	2.5710E+02
Cask Lid Plug	5001	5404	5001	1.2556E+02	2.5800E+02
Tungsten Alloy	6001	7656	6424	1.2433E+02	2.5580E+02
Bottom Cavity	4227	4236	4227	1.2506E+02	2.5710E+02
Side Cavity	4372	4702	4537	1.2472E+02	2.5650E+02
Top Cavity	5001	5012	5001	1.2556E+02	2.5800E+02
Lid Seal	4993	4993	4993	1.2400E+02	2.5520E+02
Cask Vent Port	2537	2537	2537	1.2394E+02	2.5510E+02
Cask Vent Port Seal	2533	2533	2533	1.2394E+02	2.5510E+02
Vt.Conic.Seal	4828	4828	4828	1.2406E+02	2.5530E+02
Cask Drain Port	583	583	583	1.2372E+02	2.5470E+02
Cask Drain Port Seal	579	579	579	1.2378E+02	2.5480E+02
Drn.Conic.Seal	4313	4313	4313	1.2411E+02	2.5540E+02
Test Port	3351	3351	3351	1.2394E+02	2.5510E+02

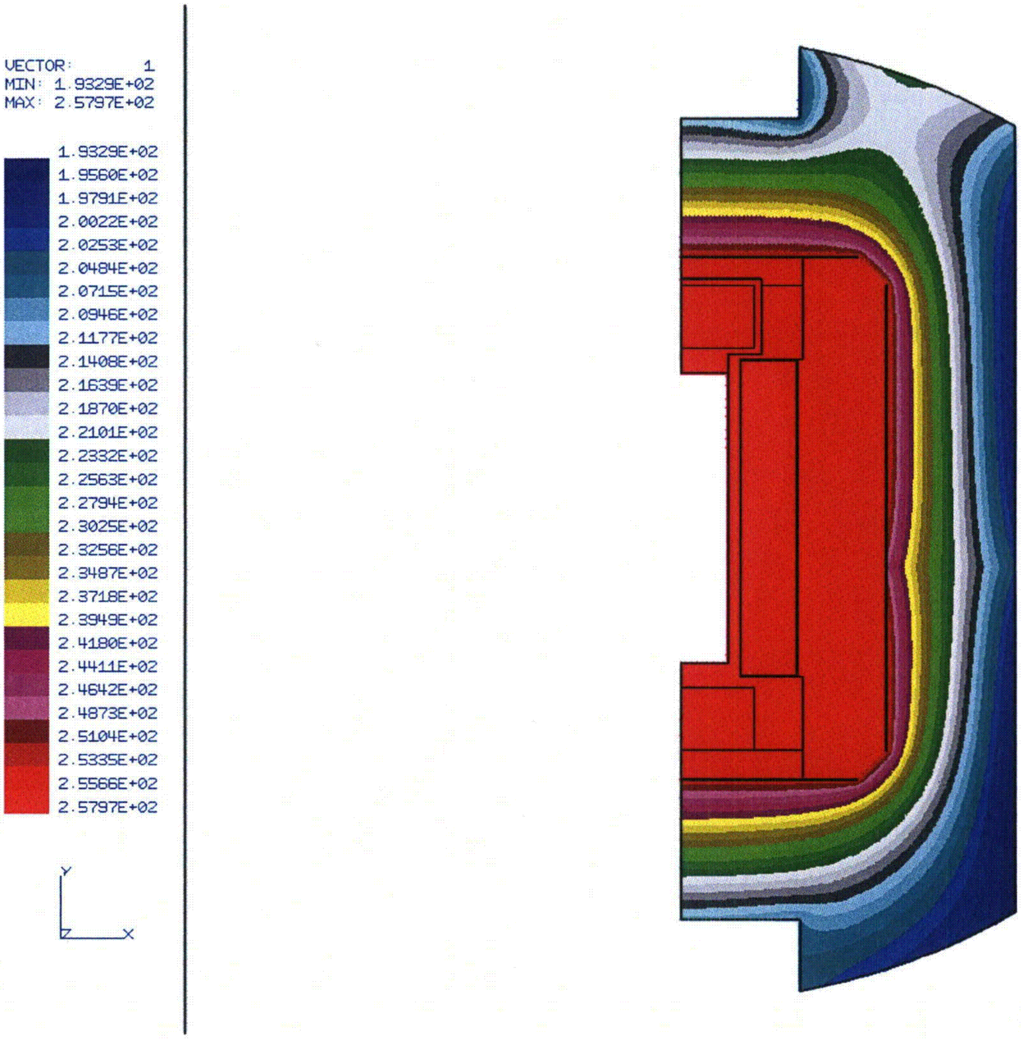

Figure 3-9. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

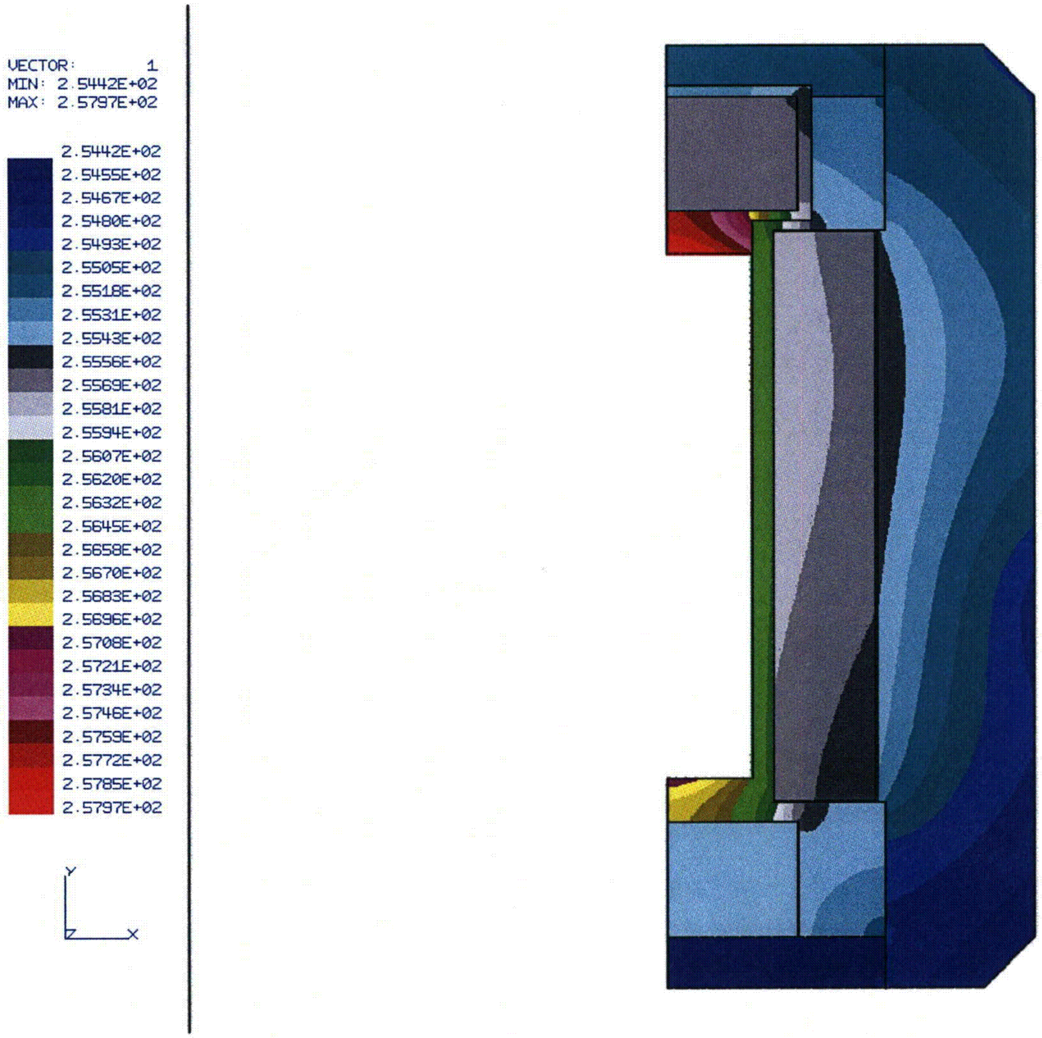

Figure 3-10. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

Table 3-21. Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	-28.89	-20.00
2	4532	-28.89	-20.00
3	4227	-28.89	-20.00
4	4752	-28.89	-20.00
5	4838	-28.89	-20.00
6	4993	-28.89	-20.00
7	3309	-28.89	-20.00
8	3351	-28.89	-20.00
9	678	-28.89	-20.00
10	2537	-28.89	-20.00
11	2533	-28.89	-20.00
12	4828	-28.89	-20.00
13	1888	-28.89	-20.00
14	583	-28.89	-20.00
15	579	-28.89	-20.00
16	4313	-28.89	-20.00
17	3148	-28.89	-20.00
18	3001	-28.89	-20.00
19	7533	-28.89	-20.00
20	7377	-28.89	-20.00
21	7371	-28.89	-20.00
22	6942	-28.89	-20.00
23	6267	-28.89	-20.00
24	6121	-28.89	-20.00
25	6001	-28.89	-20.00
26	9501	-28.89	-20.00
27	9950	-28.89	-20.00
28	10014	-28.89	-20.00
29	10781	-28.89	-20.00
30	9091	-28.89	-20.00
31	8463	-28.89	-20.00
32	8462	-28.89	-20.00
33	8197	-28.89	-20.00
34	9711	-28.89	-20.00
35	9821	-28.89	-20.00
36	10158	-28.89	-20.00
37	10605	-28.89	-20.00
38	9102	-28.89	-20.00
39	8578	-28.89	-20.00
40	8225	-28.89	-20.00
41	8001	-28.89	-20.00

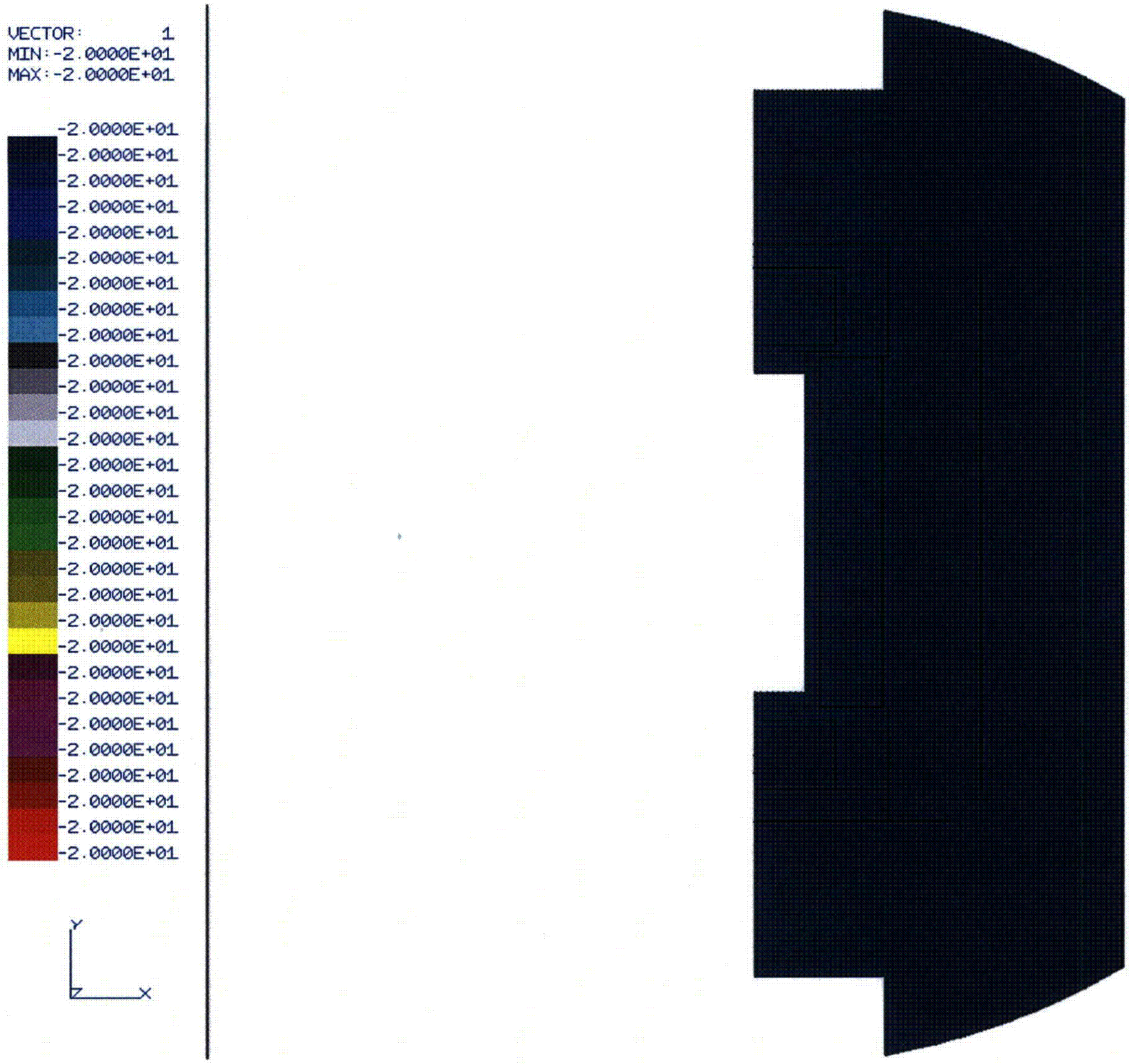

Figure 3-11. Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025A

Table 3-22. Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	-40.00	-40.00
2	4532	-40.00	-40.00
3	4227	-40.00	-40.00
4	4752	-40.00	-40.00
5	4838	-40.00	-40.00
6	4993	-40.00	-40.00
7	3309	-40.00	-40.00
8	3351	-40.00	-40.00
9	678	-40.00	-40.00
10	2537	-40.00	-40.00
11	2533	-40.00	-40.00
12	4828	-40.00	-40.00
13	1888	-40.00	-40.00
14	583	-40.00	-40.00
15	579	-40.00	-40.00
16	4313	-40.00	-40.00
17	3148	-40.00	-40.00
18	3001	-40.00	-40.00
19	7533	-40.00	-40.00
20	7377	-40.00	-40.00
21	7371	-40.00	-40.00
22	6942	-40.00	-40.00
23	6267	-40.00	-40.00
24	6121	-40.00	-40.00
25	6001	-40.00	-40.00
26	9501	-40.00	-40.00
27	9950	-40.00	-40.00
28	10014	-40.00	-40.00
29	10781	-40.00	-40.00
30	9091	-40.00	-40.00
31	8463	-40.00	-40.00
32	8462	-40.00	-40.00
33	8197	-40.00	-40.00
34	9711	-40.00	-40.00
35	9821	-40.00	-40.00
36	10158	-40.00	-40.00
37	10605	-40.00	-40.00
38	9102	-40.00	-40.00
39	8578	-40.00	-40.00
40	8225	-40.00	-40.00
41	8001	-40.00	-40.00

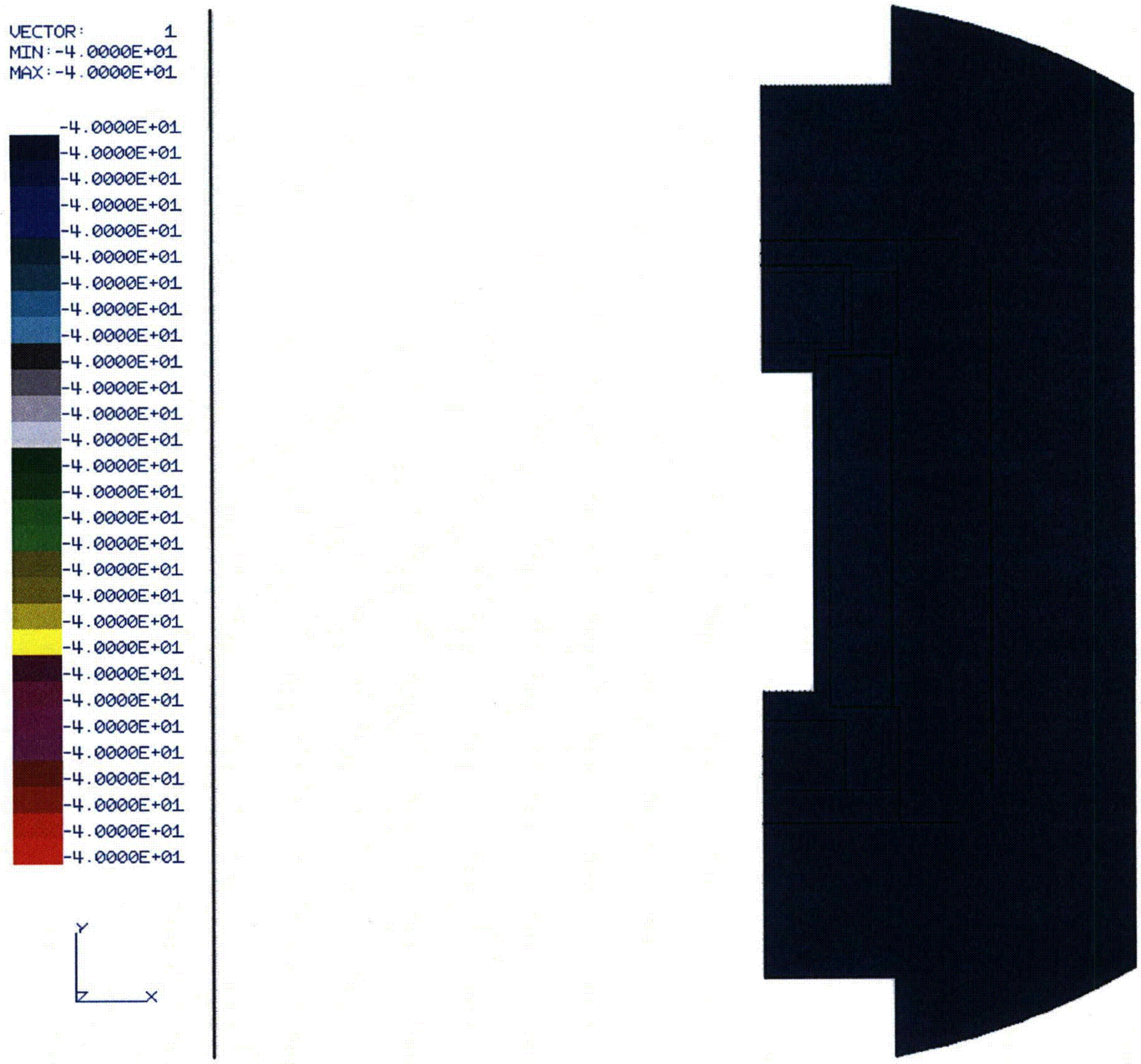

Figure 3-12. Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025A

Table 3-23. Load Case 105, -40°F Ambient, Maximum Decay Heat – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	4.24	39.63
2	4532	3.30	37.94
3	4227	3.72	38.69
4	4752	3.14	37.66
5	4838	2.48	36.47
6	4993	2.42	36.35
7	3309	2.21	35.98
8	3351	2.24	36.03
9	678	2.67	36.80
10	2537	2.30	36.14
11	2533	2.33	36.20
12	4828	2.48	36.47
13	1888	2.34	36.21
14	583	2.22	35.99
15	579	2.24	36.04
16	4313	2.61	36.69
17	3148	2.11	35.80
18	3001	1.99	35.59
19	7533	2.67	36.80
20	7377	2.68	36.83
21	7371	2.73	36.92
22	6942	2.76	36.97
23	6267	2.70	36.86
24	6121	2.62	36.71
25	6001	2.61	36.69
26	9501	0.72	33.29
27	9950	0.61	33.09
28	10014	0.73	33.31
29	10781	1.14	34.06
30	9091	0.32	32.58
31	8463	0.62	33.12
32	8462	0.70	33.26
33	8197	0.83	33.49
34	9711	-35.94	-32.69
35	9821	-37.49	-35.49
36	10158	-37.03	-34.65
37	10605	-32.46	-26.42
38	9102	-29.89	-21.80
39	8578	-32.42	-26.36
40	8225	-26.98	-16.56
41	8001	-23.90	-11.02

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	686	2.6722E+00	3.6810E+01
Bottom Plate	3001	3232	3148	2.1111E+00	3.5800E+01
Cask Lid	3233	3424	3233	2.2778E+00	3.6100E+01
Shell Cavity	4001	4998	4227	3.7167E+00	3.8690E+01
Cask Lid Plug	5001	5404	5001	4.2389E+00	3.9630E+01
Tungsten Alloy	6001	7656	6452	2.8167E+00	3.7070E+01
Bottom Cavity	4227	4236	4227	3.7167E+00	3.8690E+01
Side Cavity	4372	4702	4552	3.3056E+00	3.7950E+01
Top Cavity	5001	5012	5001	4.2389E+00	3.9630E+01
Lid Seal	4993	4993	4993	2.4167E+00	3.6350E+01
Cask Vent Port	2537	2537	2537	2.3000E+00	3.6140E+01
Cask Vent Port Seal	2533	2533	2533	2.3333E+00	3.6200E+01
Vt.Conic.Seal	4828	4828	4828	2.4833E+00	3.6470E+01
Cask Drain Port	583	583	583	2.2167E+00	3.5990E+01
Cask Drain Port Seal	579	579	579	2.2444E+00	3.6040E+01
Drn.Conic.Seal	4313	4313	4313	2.6056E+00	3.6690E+01
Test Port	3351	3351	3351	2.2389E+00	3.6030E+01

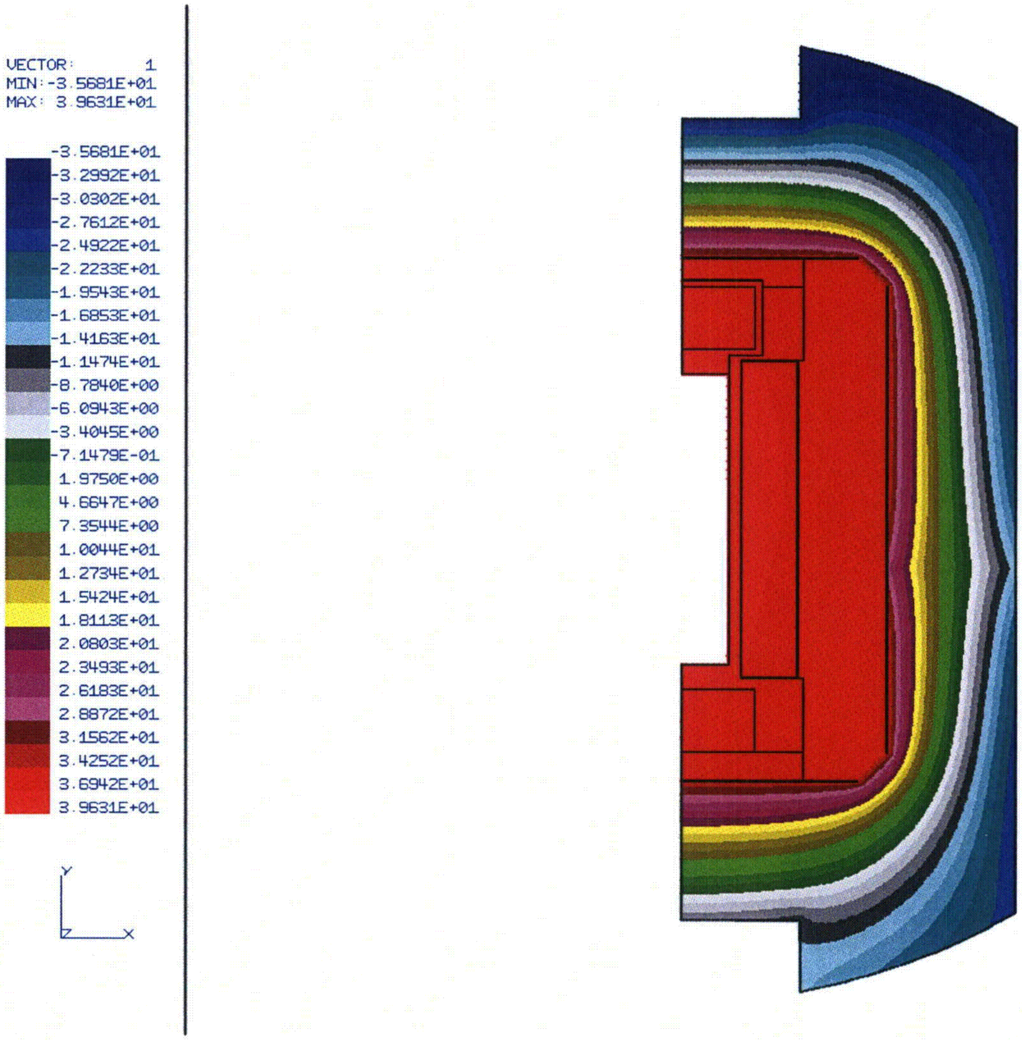

Figure 3-13. Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A

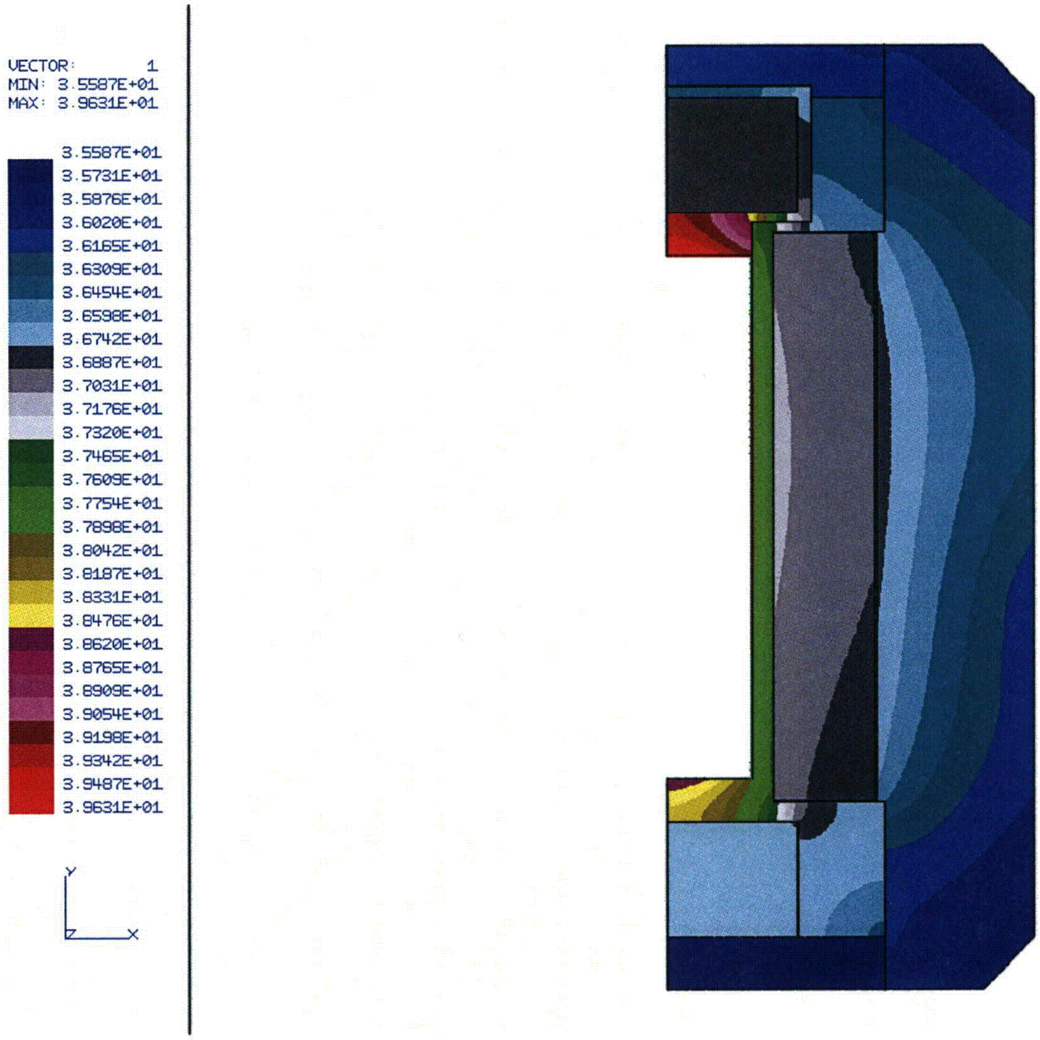

Figure 3-14. Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A

Table 3-24. Load Case 106, -20°F Ambient, Maximum Decay Heat – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	14.85	58.73
2	4532	13.92	57.06
3	4227	14.34	57.81
4	4752	13.77	56.79
5	4838	13.12	55.62
6	4993	13.06	55.50
7	3309	12.86	55.14
8	3351	12.88	55.19
9	678	13.30	55.94
10	2537	12.94	55.30
11	2533	12.97	55.35
12	4828	13.12	55.62
13	1888	12.98	55.36
14	583	12.86	55.14
15	579	12.88	55.19
16	4313	13.24	55.83
17	3148	12.76	54.96
18	3001	12.64	54.75
19	7533	13.29	55.93
20	7377	13.31	55.96
21	7371	13.37	56.07
22	6942	13.39	56.11
23	6267	13.34	56.01
24	6121	13.25	55.85
25	6001	13.24	55.83
26	9501	11.38	52.48
27	9950	11.29	52.33
28	10014	11.42	52.55
29	10781	11.83	53.30
30	9091	11.02	51.84
31	8463	11.31	52.36
32	8462	11.37	52.47
33	8197	11.48	52.67
34	9711	-24.94	-12.89
35	9821	-26.47	-15.65
36	10158	-26.06	-14.90
37	10605	-21.63	-6.94
38	9102	-19.10	-2.38
39	8578	-21.61	-6.89
40	8225	-16.24	2.77
41	8001	-13.19	8.25

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	696	1.3311E+01	5.5960E+01
Bottom Plate	3001	3232	3148	1.2756E+01	5.4960E+01
Cask Lid	3233	3424	3233	1.2922E+01	5.5260E+01
Shell Cavity	4001	4998	4227	1.4339E+01	5.7810E+01
Cask Lid Plug	5001	5404	5001	1.4850E+01	5.8730E+01
Tungsten Alloy	6001	7656	6444	1.3450E+01	5.6210E+01
Bottom Cavity	4227	4236	4227	1.4339E+01	5.7810E+01
Side Cavity	4372	4702	4552	1.3928E+01	5.7070E+01
Top Cavity	5001	5012	5001	1.4850E+01	5.8730E+01
Lid Seal	4993	4993	4993	1.3056E+01	5.5500E+01
Cask Vent Port	2537	2537	2537	1.2944E+01	5.5300E+01
Cask Vent Port Seal	2533	2533	2533	1.2972E+01	5.5350E+01
Vt.Conic.Seal	4828	4828	4828	1.3122E+01	5.5620E+01
Cask Drain Port	583	583	583	1.2856E+01	5.5140E+01
Cask Drain Port Seal	579	579	579	1.2883E+01	5.5190E+01
Drn.Conic.Seal	4313	4313	4313	1.3239E+01	5.5830E+01
Test Port	3351	3351	3351	1.2883E+01	5.5190E+01

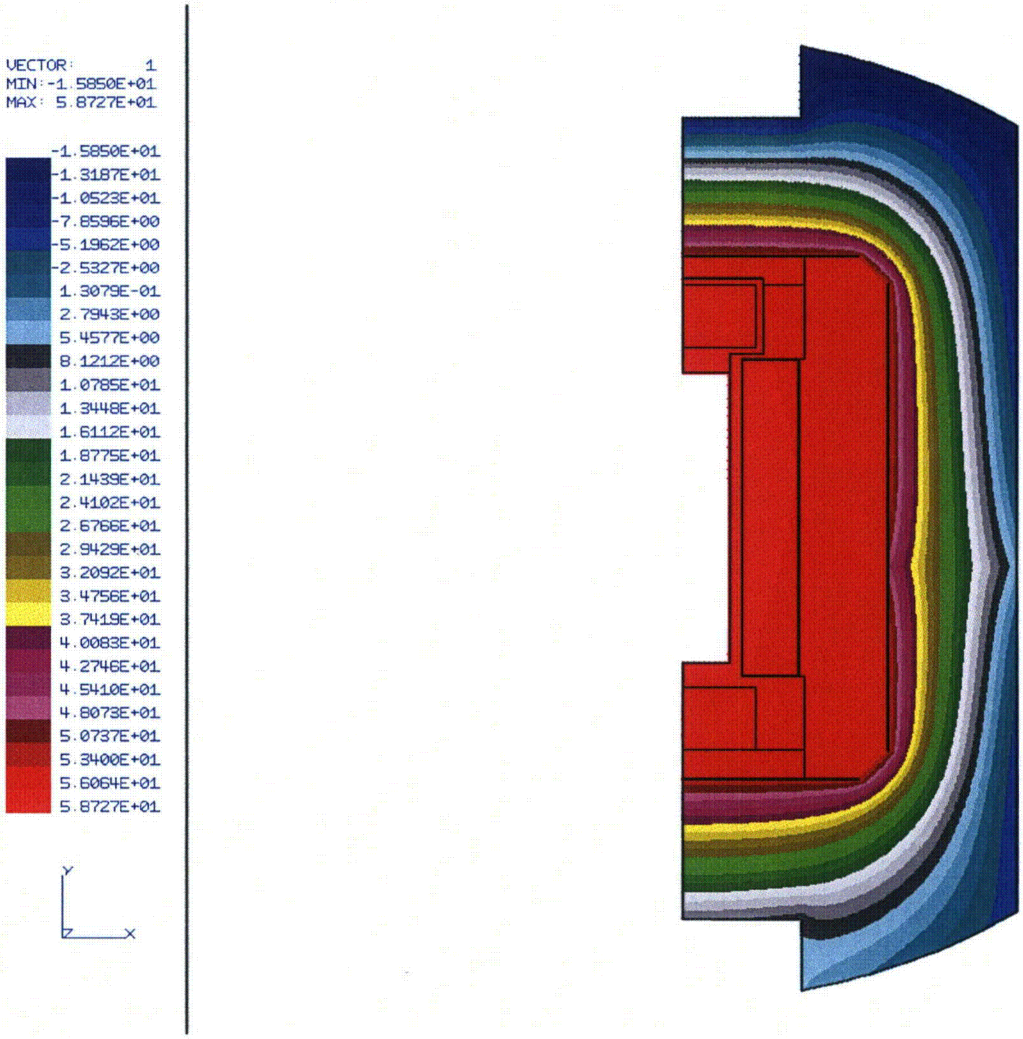

Figure 3-15. Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A

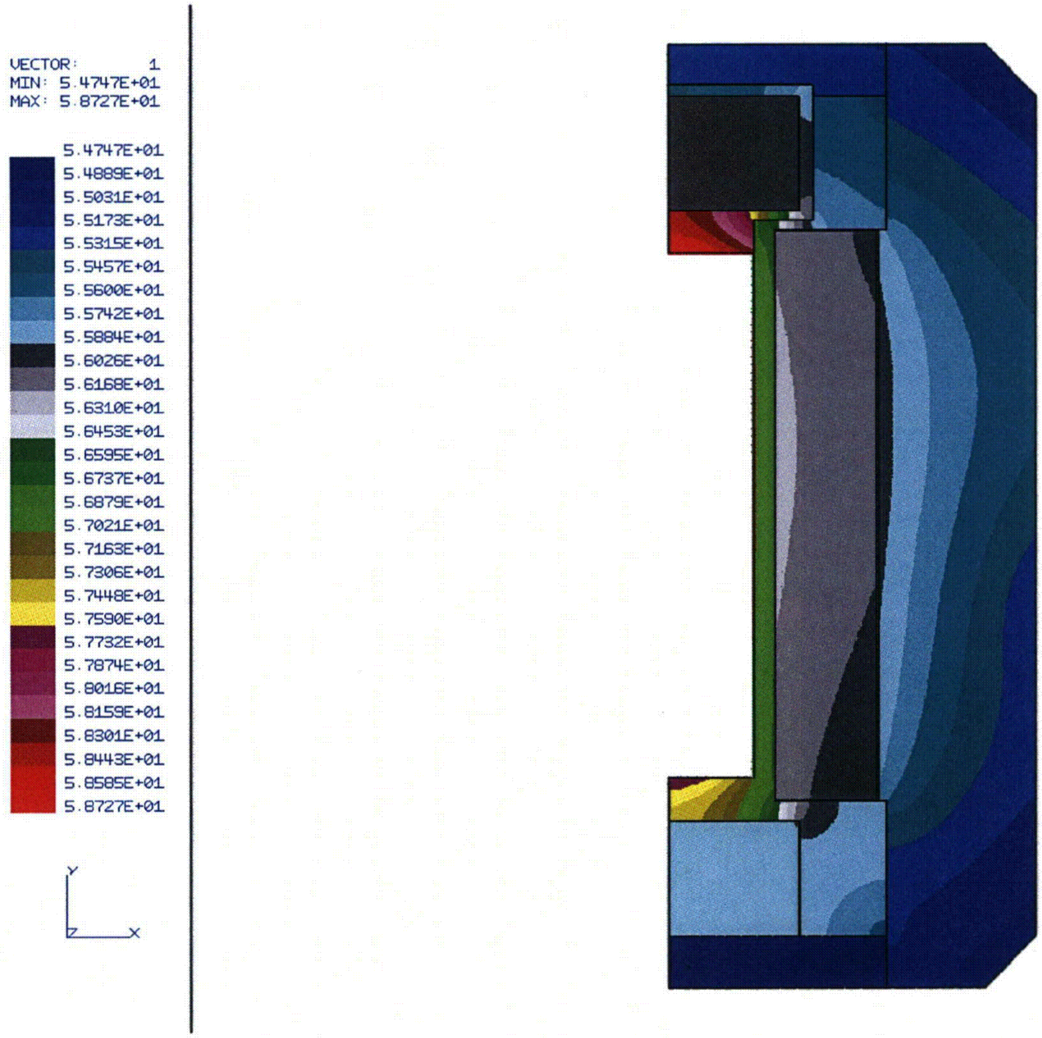

Figure 3-16. Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A

3.5.2.1.2 Fire Condition Thermal Evaluation Results – Model AOS-025A

Table 3-25 lists the tables and figures in this appendix that present the Model AOS-025A transport package results under the Fire condition, for Load Cases 111 and 112. Each table provides a list of temperatures at each monitoring node. Also listed are the maximum temperatures within each transport package component.

Figure 3-17 illustrates the location of each node on the transport package, under the Fire condition. (The node locations are listed in Table 3-17.)

Table 3-25. Fire Condition Thermal Evaluation Results – Model AOS-025A

<table>
<tr><th>Load Case</th><th>Description</th><th>Temperature versus Time</th><th>Results Table</th><th>Entire Model</th><th>Cask Model</th></tr>
<tr><td>111</td><td>Fire at 30 Minutes,
1,475°F Ambient,
Maximum Decay Heat</td><td rowspan="6">Figure 3-18
Figure 3-19
Figure 3-20</td><td>Table 3-26</td><td>Figure 3-21</td><td>Figure 3-22</td></tr>
<tr><td rowspan="5">112</td><td>Post Fire at 60 Minutes,
100°F, Maximum Decay Heat,
Maximum Insolation</td><td>Table 3-27</td><td>Figure 3-23</td><td>Figure 3-24</td></tr>
<tr><td>Post Fire at 90 Minutes,
100°F, Maximum Decay Heat,
Maximum Insolation</td><td>Table 3-28</td><td>Figure 3-25</td><td>Figure 3-26</td></tr>
<tr><td>Post Fire at 120 Minutes,
100°F, Maximum Decay Heat,
Maximum Insolation</td><td>Table 3-29</td><td>Figure 3-27</td><td>Figure 3-28</td></tr>
<tr><td>Post Fire at 150 Minutes,
100°F, Maximum Decay Heat,
Maximum Insolation</td><td>Table 3-30</td><td>Figure 3-29</td><td>Figure 3-30</td></tr>
<tr><td>Post Fire at 180 Minutes,
100°F, Maximum Decay Heat,
Maximum Insolation</td><td>Table 3-31</td><td>Figure 3-31</td><td>Figure 3-32</td></tr>
</table>

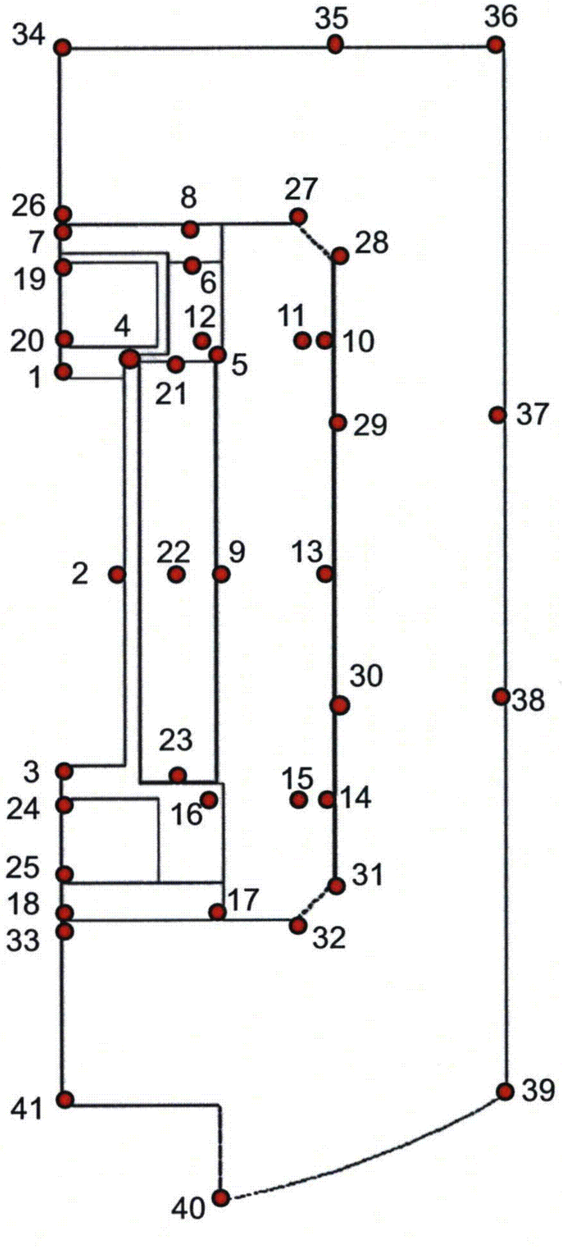

Figure 3-17. Selected Nodal Locations for Fire Condition – Model AOS-025A

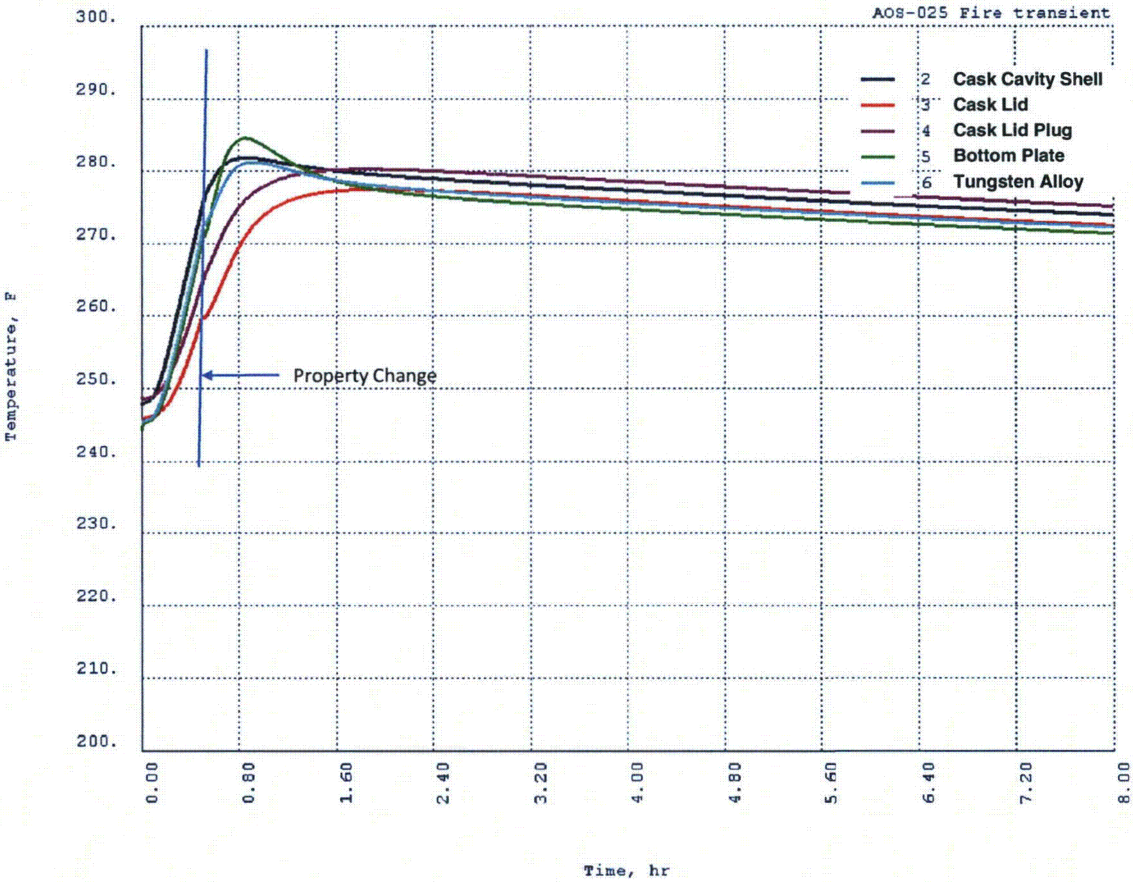

Figure 3-18. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Tungsten Alloy – Model AOS-025A

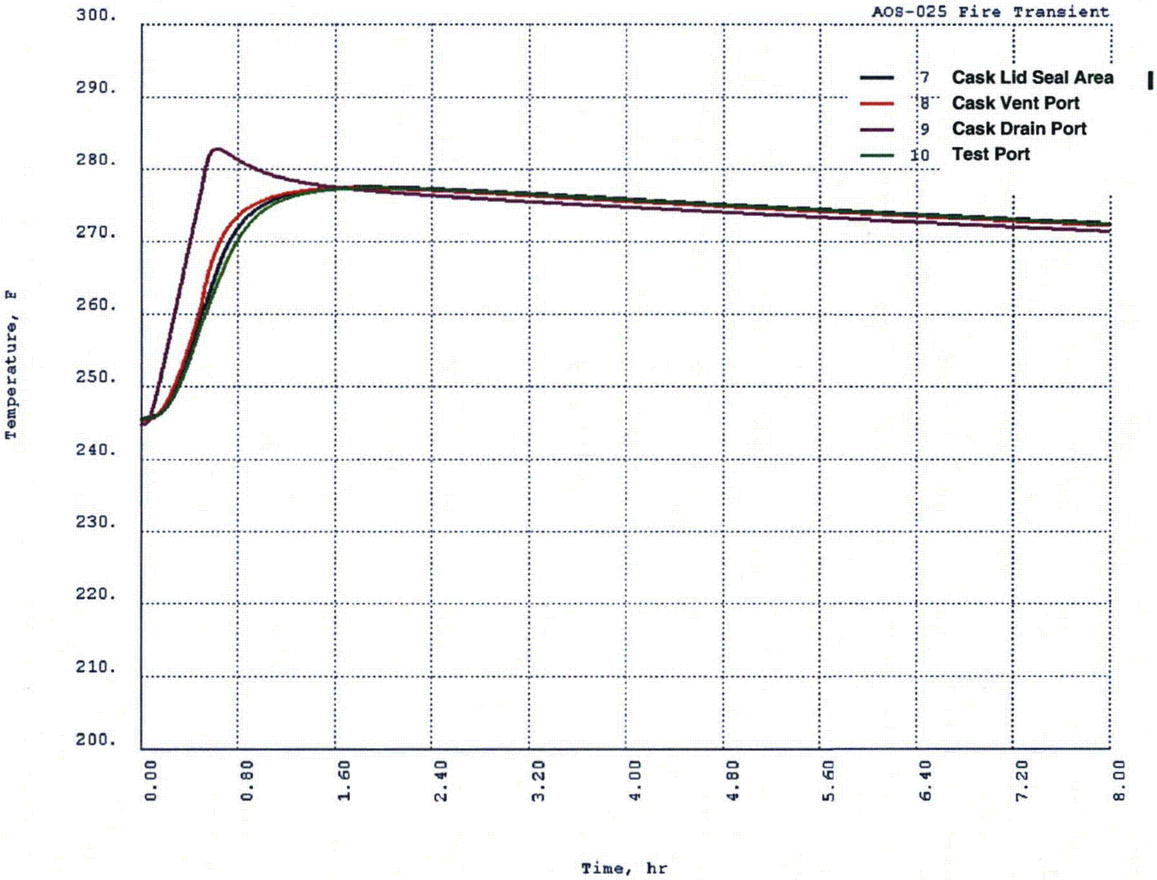

Figure 3-19. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Lid Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Model AOS-025A

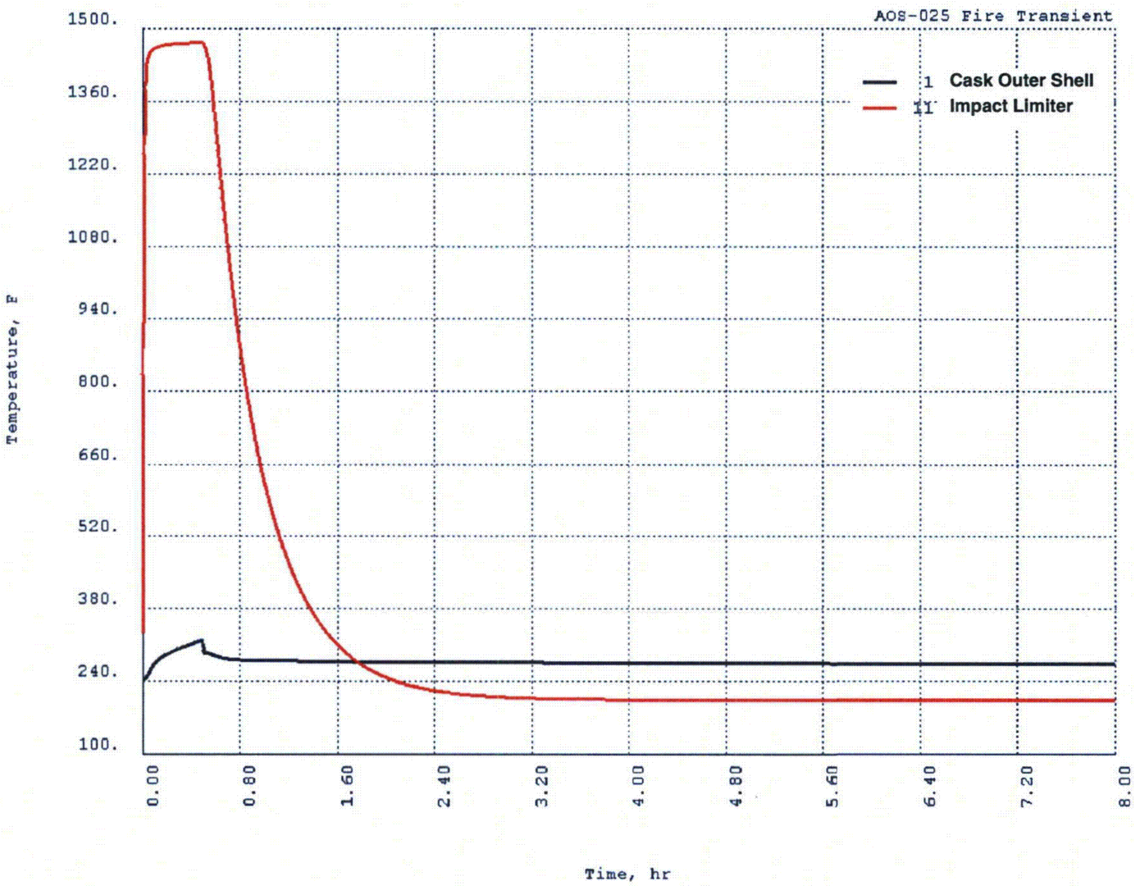

Figure 3-20. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Model AOS-025A

Table 3-26. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	130.39	266.70
2	4532	133.44	272.20
3	4227	133.33	272.00
4	4752	129.89	265.80
5	4838	129.33	264.80
6	4993	128.22	262.80
7	3309	128.11	262.60
8	3351	127.94	262.30
9	678	132.78	271.00
10	2537	128.61	263.50
11	2533	128.61	263.50
12	4828	129.17	264.50
13	1888	134.06	273.30
14	583	133.11	271.60
15	579	133.11	271.60
16	4313	132.44	270.40
17	3148	131.22	268.20
18	3001	131.22	268.20
19	7533	128.61	263.50
20	7377	129.00	264.20
21	7371	130.33	266.60
22	6942	132.56	270.60
23	6267	133.06	271.50
24	6121	132.00	269.60
25	6001	131.67	269.00
26	12481	128.11	262.60
27	12941	127.67	261.80
28	13260	127.78	262.00
29	17060	129.67	265.40
30	17008	136.61	277.90
31	9785	131.56	268.80
32	9571	131.22	268.20
33	8197	131.22	268.20
34	12451	794.44	1462.00
35	13160	794.44	1462.00
36	14272	799.44	1471.00
37	14943	796.11	1465.00
38	14891	792.78	1459.00
39	9900	798.89	1470.00
40	8673	800.00	1472.00
41	8225	795.56	1464.00

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.4539E+02	2.9370E+02
Bottom Plate	3001	3232	3120	1.3156E+02	2.6880E+02
Cask Lid	3233	3424	3233	1.2828E+02	2.6290E+02
Shell Cavity	4001	4998	4417	1.3411E+02	2.7340E+02
Cask Lid Plug	5001	5404	5011	1.3044E+02	2.6680E+02
Tungsten Alloy	6001	7656	6696	1.3344E+02	2.7220E+02
Bottom Cavity	4227	4236	4227	1.3333E+02	2.7200E+02
Side Cavity	4372	4702	4417	1.3411E+02	2.7340E+02
Top Cavity	5001	5012	5011	1.3044E+02	2.6680E+02
Lid Seal	4993	4993	4993	1.2822E+02	2.6280E+02
Cask Vent Port	2537	2537	2537	1.2861E+02	2.6350E+02
Cask Vent Port Seal	2533	2533	2533	1.2861E+02	2.6350E+02
Vt.Conic.Seal	4828	4828	4828	1.2917E+02	2.6450E+02
Cask Drain Port	583	583	583	1.3311E+02	2.7160E+02
Cask Drain Port Seal	579	579	579	1.3311E+02	2.7160E+02
Drn.Conic.Seal	4313	4313	4313	1.3244E+02	2.7040E+02
Test Port	3351	3351	3351	1.2794E+02	2.6230E+02

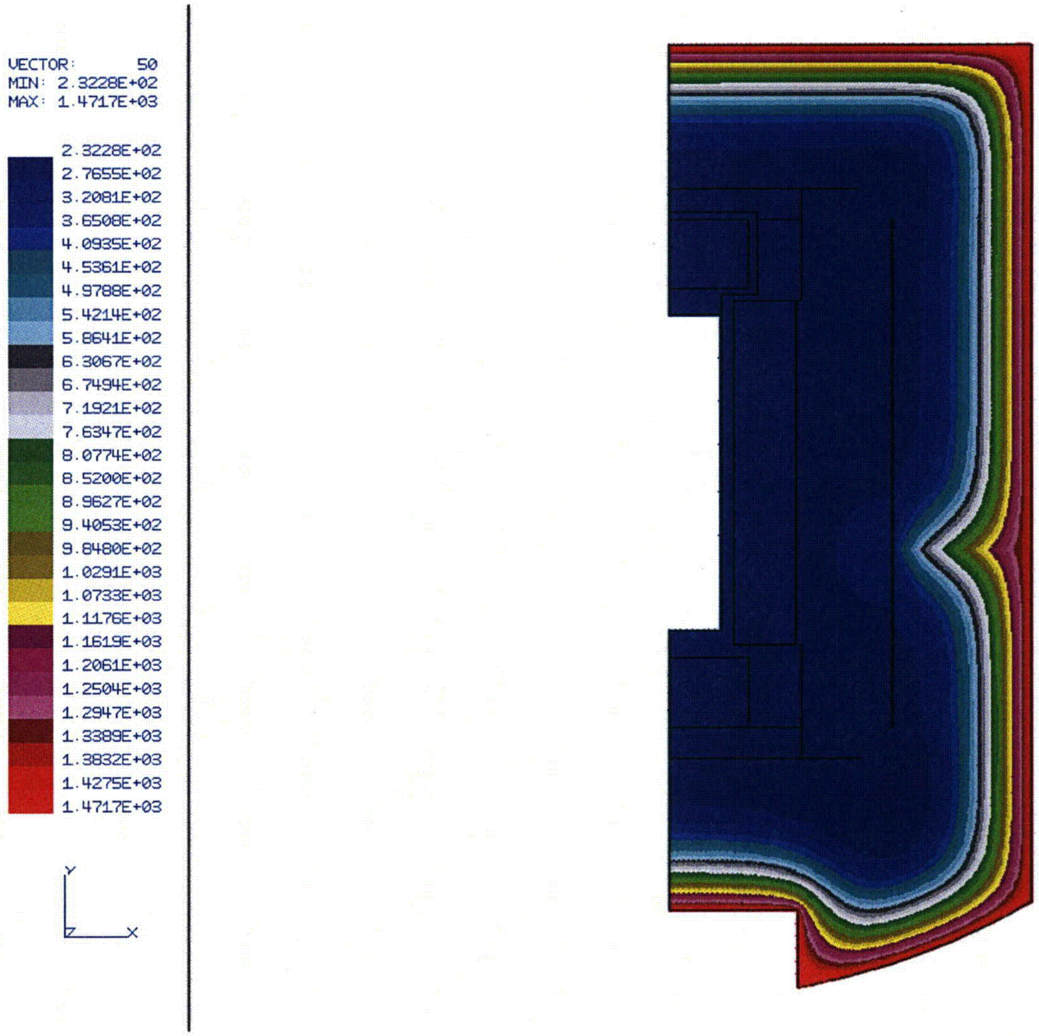

Figure 3-21. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A

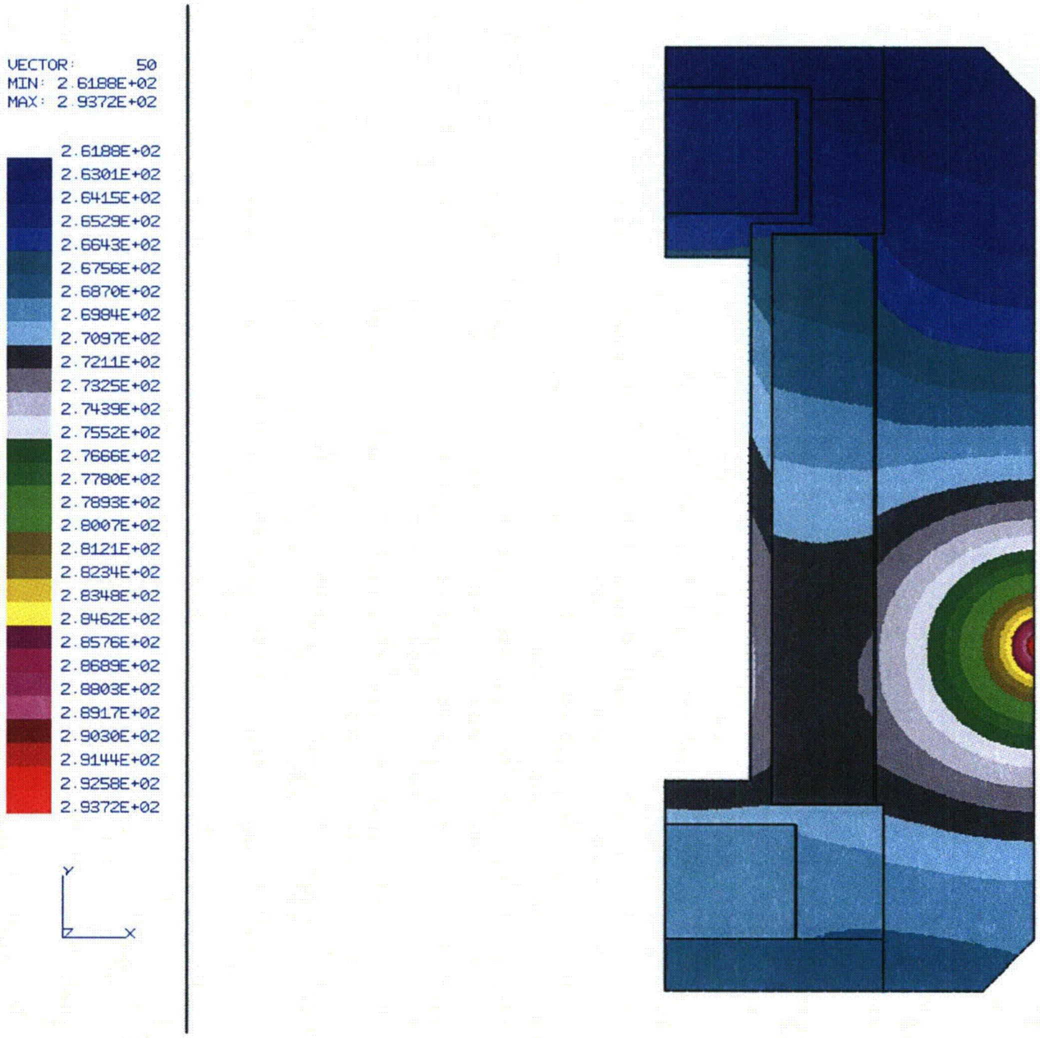

Figure 3-22. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A

Table 3-27. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	134.67	274.40
2	4532	134.78	274.60
3	4227	135.83	276.50
4	4752	134.00	273.20
5	4838	133.33	272.00
6	4993	133.11	271.60
7	3309	132.67	270.80
8	3351	132.78	271.00
9	678	134.22	273.60
10	2537	133.28	271.90
11	2533	133.33	272.00
12	4828	133.28	271.90
13	1888	133.94	273.10
14	583	134.78	274.60
15	579	134.78	274.60
16	4313	135.33	275.60
17	3148	135.78	276.40
18	3001	136.61	277.90
19	7533	133.00	271.40
20	7377	133.06	271.50
21	7371	134.00	273.20
22	6942	134.33	273.80
23	6267	134.67	274.40
24	6121	135.33	275.60
25	6001	135.33	275.60
26	12481	131.83	269.30
27	12941	132.11	269.80
28	13260	132.28	270.10
29	17060	132.83	271.10
30	17008	132.50	270.50
31	9785	135.78	276.40
32	9571	137.83	280.10
33	8197	141.72	287.10
34	12451	108.22	226.80
35	13160	106.44	223.60
36	14272	98.39	209.10
37	14943	89.94	193.90
38	14891	95.72	204.30
39	9900	158.83	317.90
40	8673	329.39	624.90
41	8225	368.50	695.30

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.3839E+02	2.8110E+02
Bottom Plate	3001	3232	3001	1.3711E+02	2.7880E+02
Cask Lid	3233	3424	3233	1.3439E+02	2.7390E+02
Shell Cavity	4001	4998	4227	1.3583E+02	2.7650E+02
Cask Lid Plug	5001	5404	5001	1.3594E+02	2.7670E+02
Tungsten Alloy	6001	7656	6001	1.3533E+02	2.7560E+02
Bottom Cavity	4227	4236	4227	1.3583E+02	2.7650E+02
Side Cavity	4372	4702	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	5012	5001	1.3594E+02	2.7670E+02
Lid Seal	4993	4993	4993	1.3444E+02	2.7400E+02
Cask Vent Port	2537	2537	2537	1.3433E+02	2.7380E+02
Cask Vent Port Seal	2533	2533	2533	1.3433E+02	2.7380E+02
Vt.Conic.Seal	4828	4828	4828	1.3450E+02	2.7410E+02
Cask Drain Port	583	583	583	1.3544E+02	2.7580E+02
Cask Drain Port Seal	579	579	579	1.3539E+02	2.7570E+02
Drn.Conic.Seal	4313	4313	4313	1.3533E+02	2.7560E+02
Test Port	3351	3351	3351	1.3439E+02	2.7390E+02

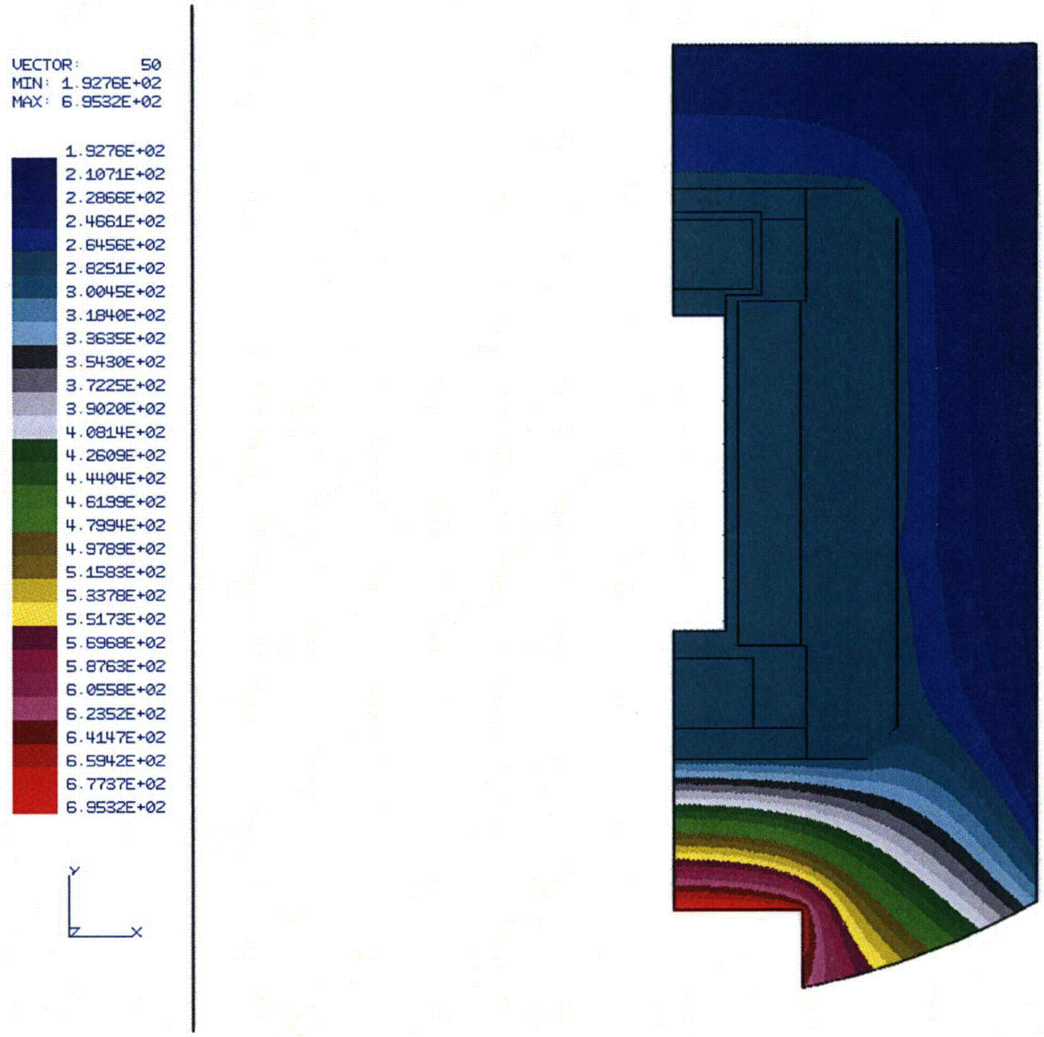

Figure 3-23. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

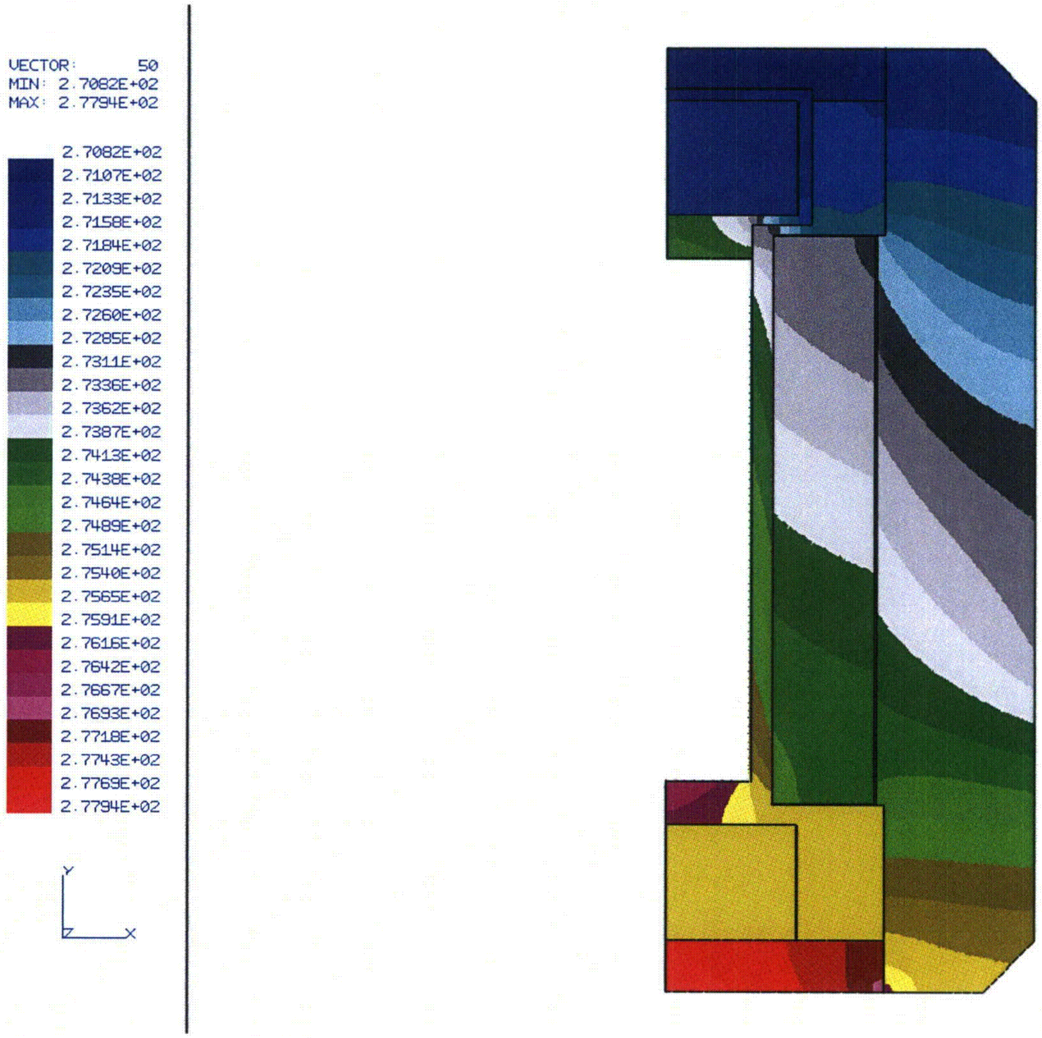

Figure 3-24. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

Table 3-28. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	135.61	276.10
2	4532	135.00	275.00
3	4227	135.61	276.10
4	4752	134.78	274.60
5	4838	134.17	273.50
6	4993	134.11	273.40
7	3309	133.89	273.00
8	3351	133.94	273.10
9	678	134.44	274.00
10	2537	134.06	273.30
11	2533	134.06	273.30
12	4828	134.17	273.50
13	1888	134.17	273.50
14	583	134.33	273.80
15	579	134.33	273.80
16	4313	134.83	274.70
17	3148	134.67	274.40
18	3001	134.89	274.80
19	7533	134.22	273.60
20	7377	134.22	273.60
21	7371	134.50	274.10
22	6942	134.56	274.20
23	6267	134.61	274.30
24	6121	134.89	274.80
25	6001	134.83	274.70
26	12481	133.11	271.60
27	12941	133.11	271.60
28	13260	133.17	271.70
29	17060	133.44	272.20
30	17008	132.11	269.80
31	9785	133.89	273.00
32	9571	134.44	274.00
33	8197	135.50	275.90
34	12451	108.22	226.80
35	13160	106.44	223.60
36	14272	98.33	209.00
37	14943	89.78	193.60
38	14891	93.89	201.00
39	9900	111.11	232.00
40	8673	168.33	335.00
41	8225	184.06	363.30

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.3839E+02	2.8110E+02
Bottom Plate	3001	3232	3001	1.3711E+02	2.7880E+02
Cask Lid	3233	3424	3233	1.3439E+02	2.7390E+02
Shell Cavity	4001	4998	4227	1.3583E+02	2.7650E+02
Cask Lid Plug	5001	5404	5001	1.3594E+02	2.7670E+02
Tungsten Alloy	6001	7656	6001	1.3533E+02	2.7560E+02
Bottom Cavity	4227	4236	4227	1.3583E+02	2.7650E+02
Side Cavity	4372	4702	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	5012	5001	1.3594E+02	2.7670E+02
Lid Seal	4993	4993	4993	1.3444E+02	2.7400E+02
Cask Vent Port	2537	2537	2537	1.3433E+02	2.7380E+02
Cask Vent Port Seal	2533	2533	2533	1.3433E+02	2.7380E+02
Vt.Conic.Seal	4828	4828	4828	1.3450E+02	2.7410E+02
Cask Drain Port	583	583	583	1.3544E+02	2.7580E+02
Cask Drain Port Seal	579	579	579	1.3539E+02	2.7570E+02
Drn.Conic.Seal	4313	4313	4313	1.3533E+02	2.7560E+02
Test Port	3351	3351	3351	1.3439E+02	2.7390E+02

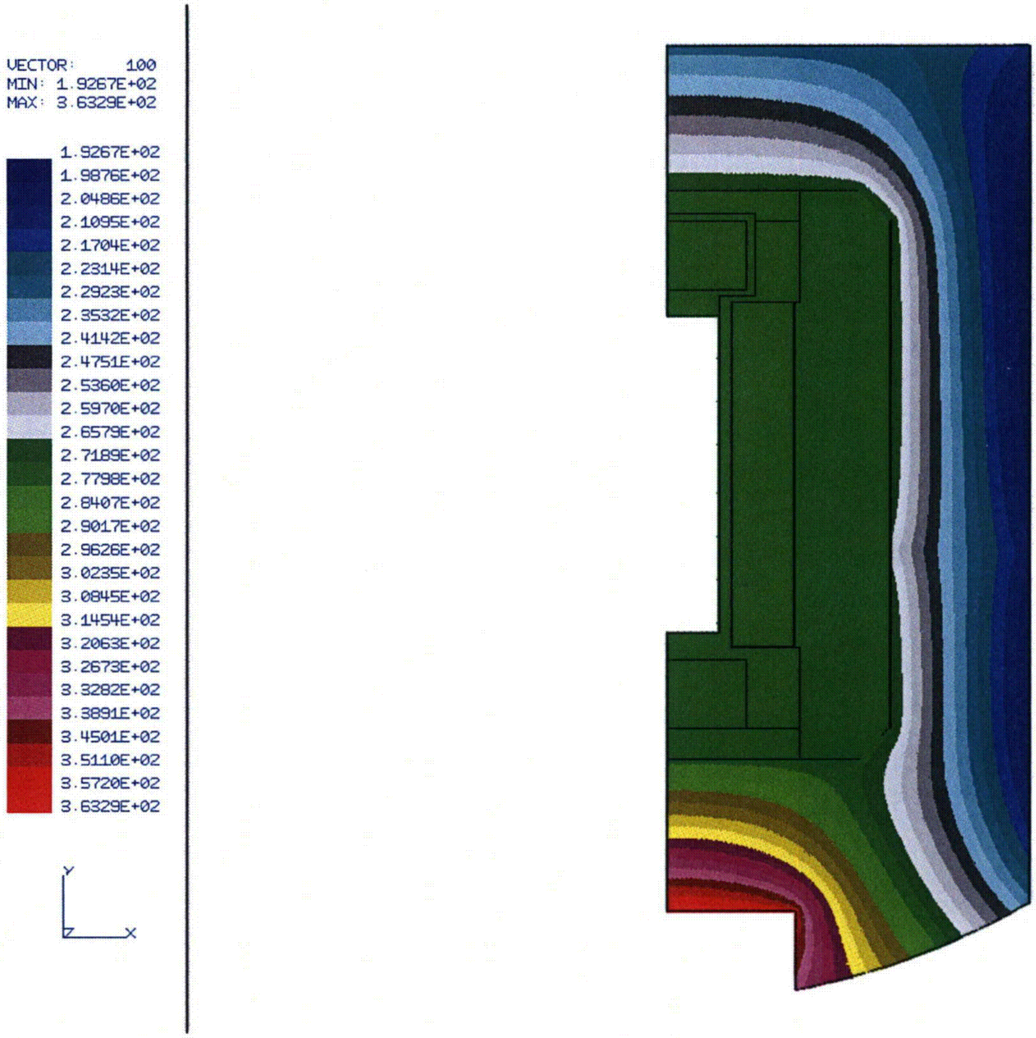

Figure 3-25. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

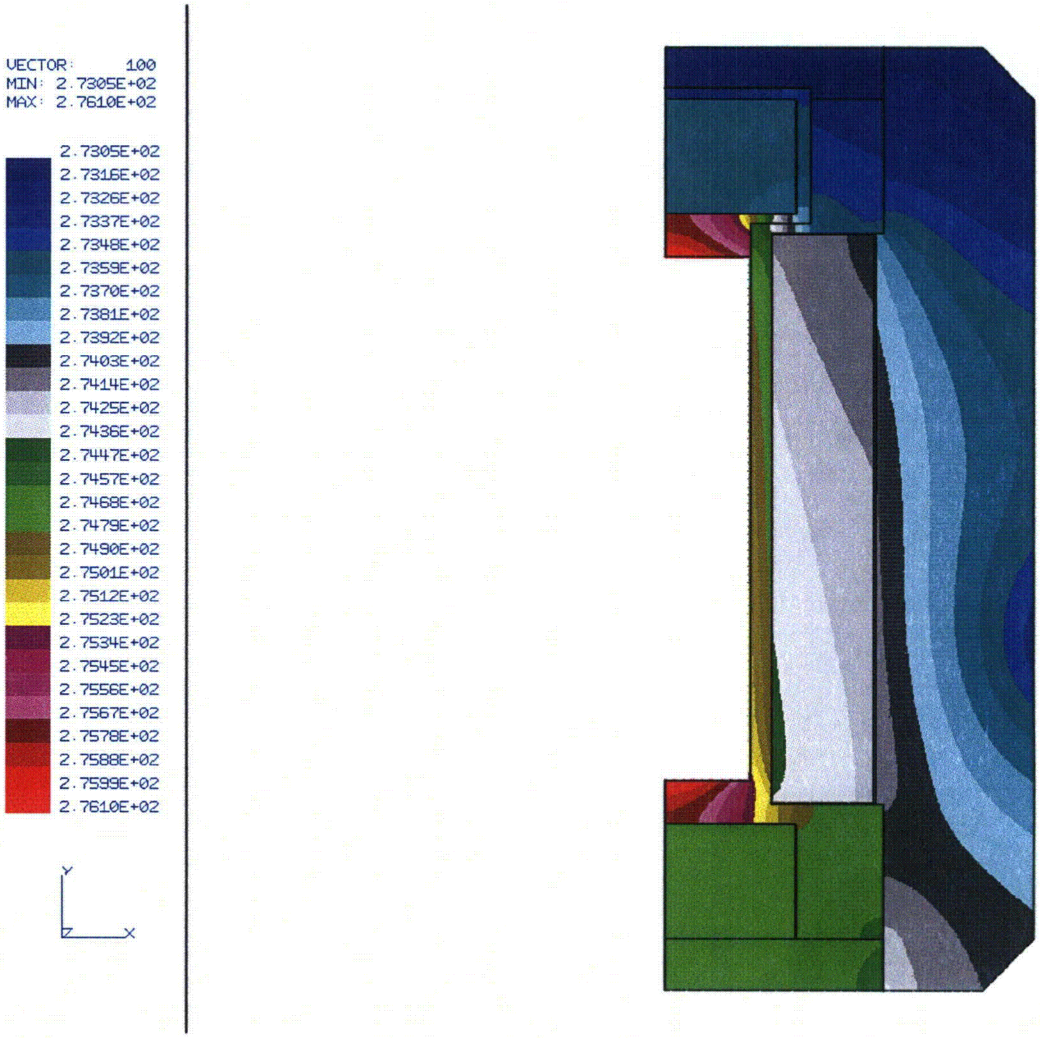

Figure 3-26. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

Table 3-29. Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	135.83	276.50
2	4532	135.06	275.10
3	4227	135.50	275.90
4	4752	134.94	274.90
5	4838	134.44	274.00
6	4993	134.39	273.90
7	3309	134.28	273.70
8	3351	134.28	273.70
9	678	134.56	274.20
10	2537	134.28	273.70
11	2533	134.28	273.70
12	4828	134.44	274.00
13	1888	134.22	273.60
14	583	134.17	273.50
15	579	134.17	273.50
16	4313	134.56	274.20
17	3148	134.22	273.60
18	3001	134.22	273.60
19	7533	134.56	274.20
20	7377	134.56	274.20
21	7371	134.61	274.30
22	6942	134.61	274.30
23	6267	134.56	274.20
24	6121	134.61	274.30
25	6001	134.61	274.30
26	12481	133.44	272.20
27	12941	133.39	272.10
28	13260	133.44	272.20
29	17060	133.61	272.50
30	17008	132.00	269.60
31	9785	133.33	272.00
32	9571	133.50	272.30
33	8197	133.78	272.80
34	12451	108.22	226.80
35	13160	106.44	223.60
36	14272	98.33	209.00
37	14943	89.72	193.50
38	14891	93.44	200.20
39	9900	96.89	206.40
40	8673	118.67	245.60
41	8225	125.83	258.50

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.3839E+02	2.8110E+02
Bottom Plate	3001	3232	3001	1.3711E+02	2.7880E+02
Cask Lid	3233	3424	3233	1.3439E+02	2.7390E+02
Shell Cavity	4001	4998	4227	1.3583E+02	2.7650E+02
Cask Lid Plug	5001	5404	5001	1.3594E+02	2.7670E+02
Tungsten Alloy	6001	7656	6001	1.3533E+02	2.7560E+02
Bottom Cavity	4227	4236	4227	1.3583E+02	2.7650E+02
Side Cavity	4372	4702	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	5012	5001	1.3594E+02	2.7670E+02
Lid Seal	4993	4993	4993	1.3444E+02	2.7400E+02
Cask Vent Port	2537	2537	2537	1.3433E+02	2.7380E+02
Cask Vent Port Seal	2533	2533	2533	1.3433E+02	2.7380E+02
Vt.Conic.Seal	4828	4828	4828	1.3450E+02	2.7410E+02
Cask Drain Port	583	583	583	1.3544E+02	2.7580E+02
Cask Drain Port Seal	579	579	579	1.3539E+02	2.7570E+02
Drn.Conic.Seal	4313	4313	4313	1.3533E+02	2.7560E+02
Test Port	3351	3351	3351	1.3439E+02	2.7390E+02

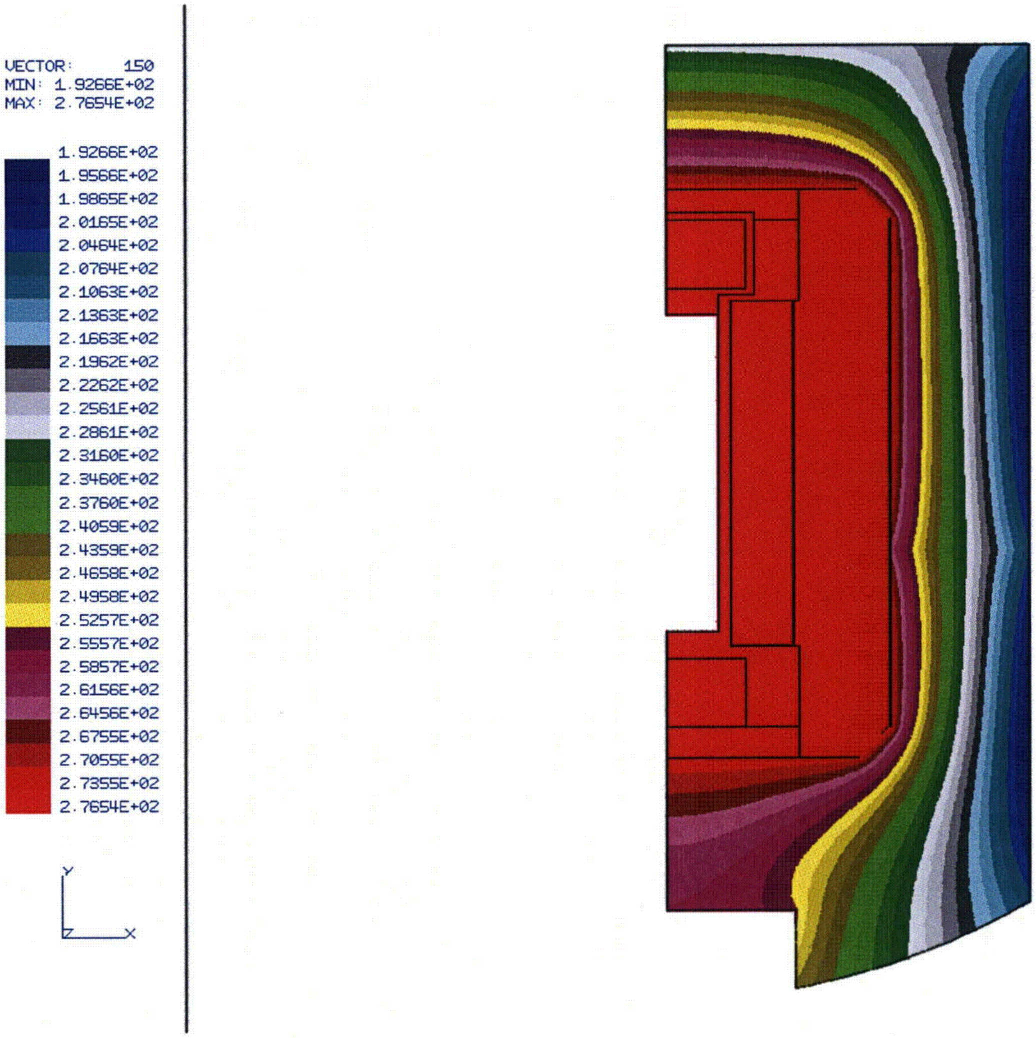

Figure 3-27. Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

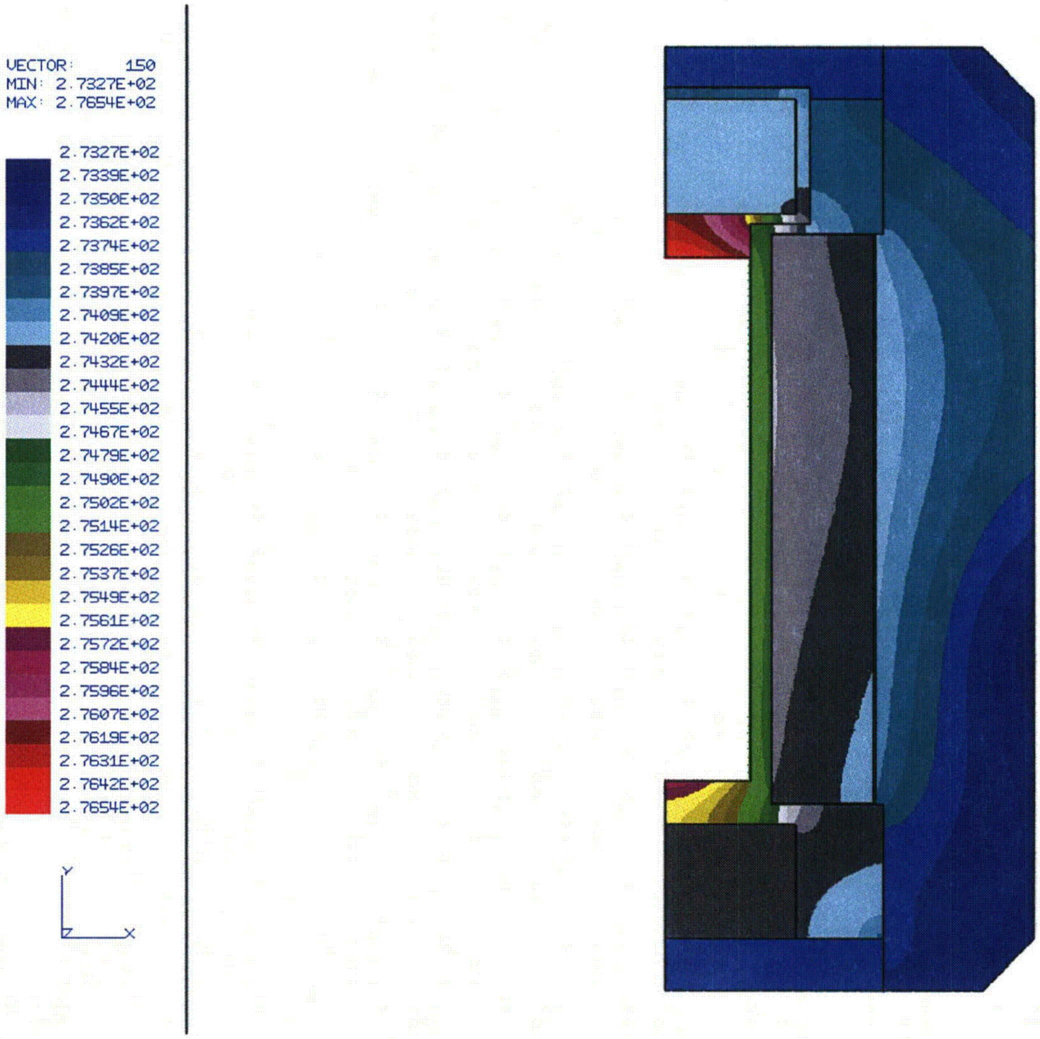

Figure 3-28. Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

Table 3-30. Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	135.94	276.70
2	4532	135.06	275.10
3	4227	135.44	275.80
4	4752	135.00	275.00
5	4838	134.50	274.10
6	4993	134.44	274.00
7	3309	134.33	273.80
8	3351	134.33	273.80
9	678	134.56	274.20
10	2537	134.33	273.80
11	2533	134.33	273.80
12	4828	134.50	274.10
13	1888	134.22	273.60
14	583	134.11	273.40
15	579	134.11	273.40
16	4313	134.50	274.10
17	3148	134.11	273.40
18	3001	134.06	273.30
19	7533	134.61	274.30
20	7377	134.61	274.30
21	7371	134.67	274.40
22	6942	134.61	274.30
23	6267	134.56	274.20
24	6121	134.50	274.10
25	6001	134.50	274.10
26	12481	133.56	272.40
27	12941	133.44	272.20
28	13260	133.50	272.30
29	17060	133.67	272.60
30	17008	131.94	269.50
31	9785	133.17	271.70
32	9571	133.17	271.70
33	8197	133.22	271.80
34	12451	108.22	226.80
35	13160	106.44	223.60
36	14272	98.33	209.00
37	14943	89.72	193.50
38	14891	93.28	199.90
39	9900	92.33	198.20
40	8673	102.67	216.80
41	8225	106.94	224.50

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.3839E+02	2.8110E+02
Bottom Plate	3001	3232	3001	1.3711E+02	2.7880E+02
Cask Lid	3233	3424	3233	1.3439E+02	2.7390E+02
Shell Cavity	4001	4998	4227	1.3583E+02	2.7650E+02
Cask Lid Plug	5001	5404	5001	1.3594E+02	2.7670E+02
Tungsten Alloy	6001	7656	6001	1.3533E+02	2.7560E+02
Bottom Cavity	4227	4236	4227	1.3583E+02	2.7650E+02
Side Cavity	4372	4702	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	5012	5001	1.3594E+02	2.7670E+02
Lid Seal	4993	4993	4993	1.3444E+02	2.7400E+02
Cask Vent Port	2537	2537	2537	1.3433E+02	2.7380E+02
Cask Vent Port Seal	2533	2533	2533	1.3433E+02	2.7380E+02
Vt.Conic.Seal	4828	4828	4828	1.3450E+02	2.7410E+02
Cask Drain Port	583	583	583	1.3544E+02	2.7580E+02
Cask Drain Port Seal	579	579	579	1.3539E+02	2.7570E+02
Drn.Conic.Seal	4313	4313	4313	1.3533E+02	2.7560E+02
Test Port	3351	3351	3351	1.3439E+02	2.7390E+02

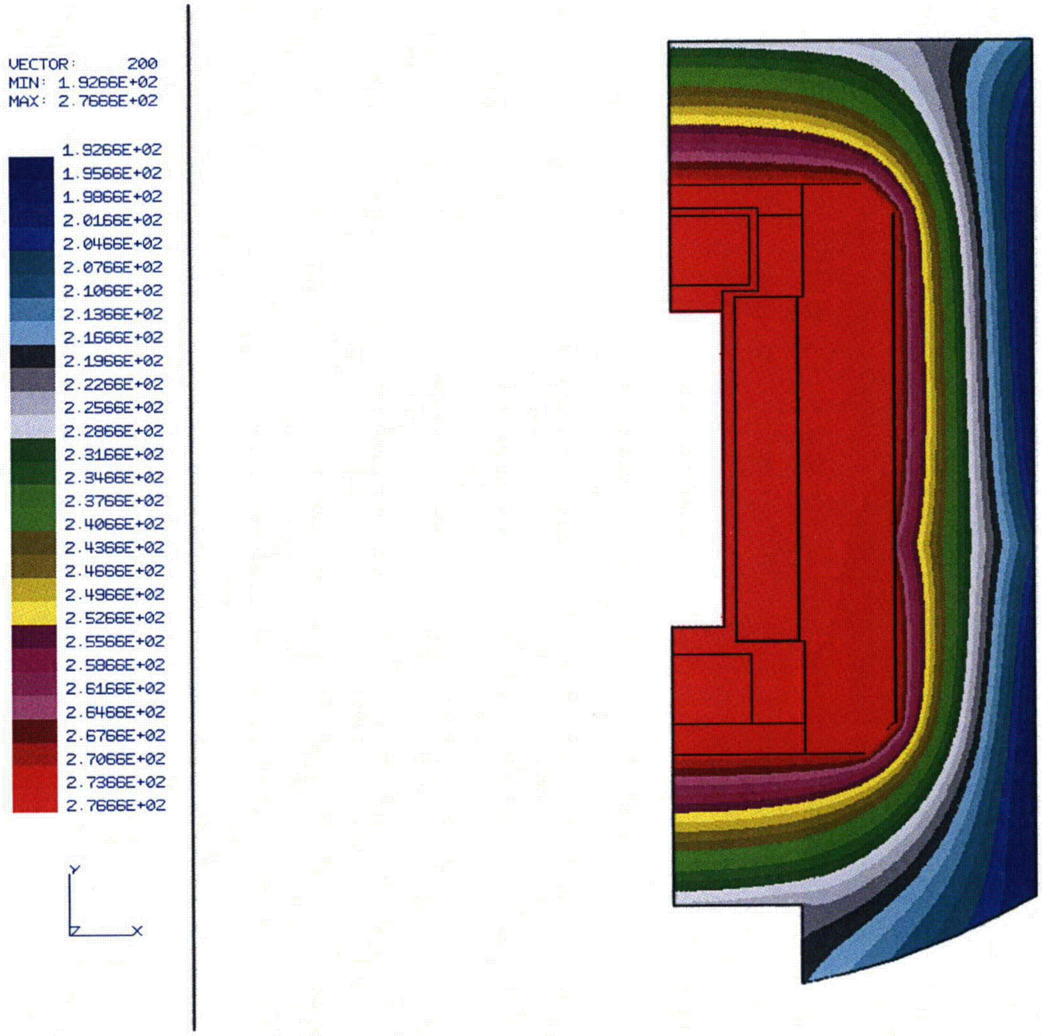

Figure 3-29. Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

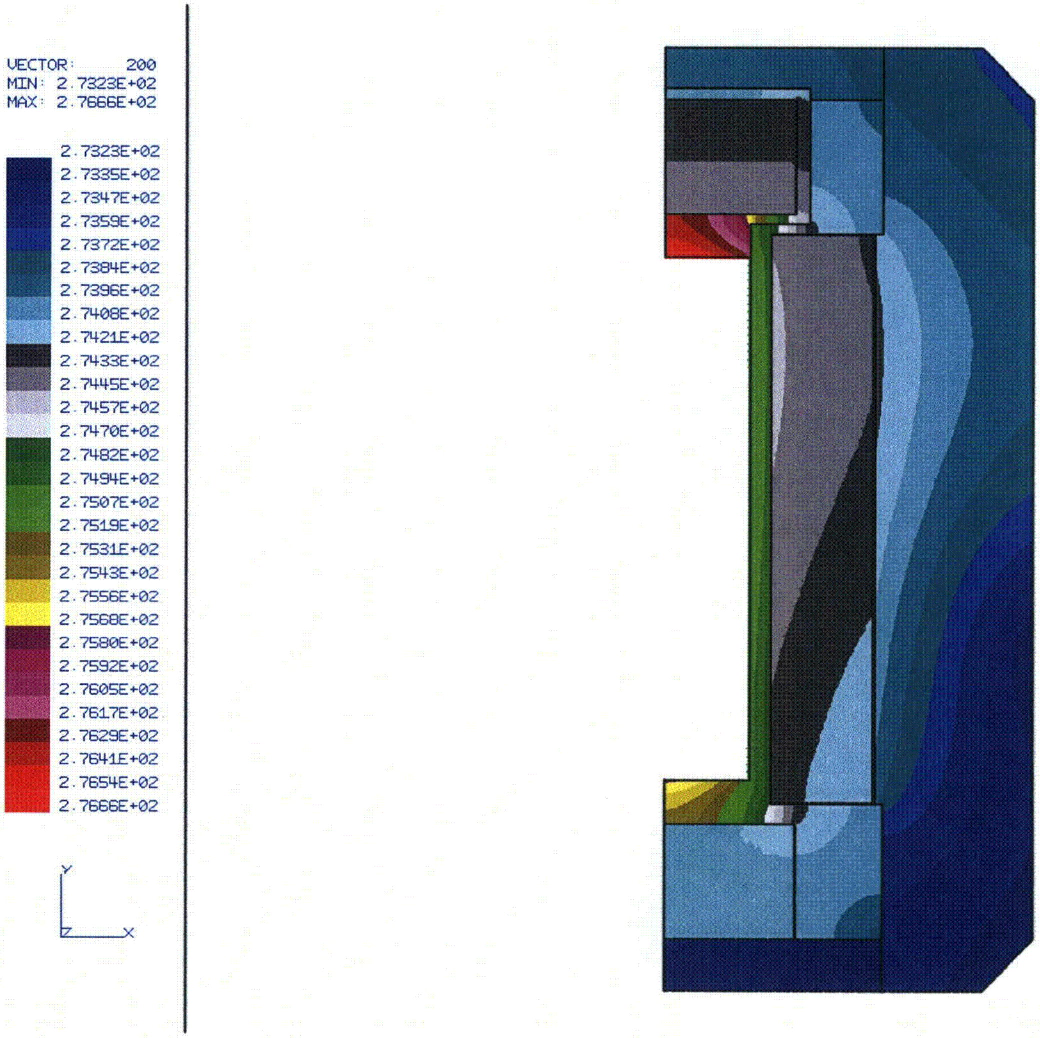

Figure 3-30. Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

Table 3-31. Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A

Location	Node	Temp(C)	Temp(F)
1	5001	135.94	276.70
2	4532	135.06	275.10
3	4227	135.39	275.70
4	4752	135.00	275.00
5	4838	134.50	274.10
6	4993	134.44	274.00
7	3309	134.39	273.90
8	3351	134.39	273.90
9	678	134.50	274.10
10	2537	134.33	273.80
11	2533	134.33	273.80
12	4828	134.50	274.10
13	1888	134.22	273.60
14	583	134.06	273.30
15	579	134.06	273.30
16	4313	134.44	274.00
17	3148	134.00	273.20
18	3001	133.94	273.10
19	7533	134.61	274.30
20	7377	134.67	274.40
21	7371	134.67	274.40
22	6942	134.61	274.30
23	6267	134.50	274.10
24	6121	134.44	274.00
25	6001	134.44	274.00
26	12481	133.56	272.40
27	12941	133.44	272.20
28	13260	133.56	272.40
29	17060	133.67	272.60
30	17008	131.89	269.40
31	9785	133.06	271.50
32	9571	133.06	271.50
33	8197	133.00	271.40
34	12451	108.22	226.80
35	13160	106.44	223.60
36	14272	98.33	209.00
37	14943	89.72	193.50
38	14891	93.22	199.80
39	9900	90.83	195.50
40	8673	97.50	207.50
41	8225	100.72	213.30

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1712	1.3839E+02	2.8110E+02
Bottom Plate	3001	3232	3001	1.3711E+02	2.7880E+02
Cask Lid	3233	3424	3233	1.3439E+02	2.7390E+02
Shell Cavity	4001	4998	4227	1.3583E+02	2.7650E+02
Cask Lid Plug	5001	5404	5001	1.3594E+02	2.7670E+02
Tungsten Alloy	6001	7656	6001	1.3533E+02	2.7560E+02
Bottom Cavity	4227	4236	4227	1.3583E+02	2.7650E+02
Side Cavity	4372	4702	4372	1.3522E+02	2.7540E+02
Top Cavity	5001	5012	5001	1.3594E+02	2.7670E+02
Lid Seal	4993	4993	4993	1.3444E+02	2.7400E+02
Cask Vent Port	2537	2537	2537	1.3433E+02	2.7380E+02
Cask Vent Port Seal	2533	2533	2533	1.3433E+02	2.7380E+02
Vt.Conic.Seal	4828	4828	4828	1.3450E+02	2.7410E+02
Cask Drain Port	583	583	583	1.3544E+02	2.7580E+02
Cask Drain Port Seal	579	579	579	1.3539E+02	2.7570E+02
Drn.Conic.Seal	4313	4313	4313	1.3533E+02	2.7560E+02
Test Port	3351	3351	3351	1.3439E+02	2.7390E+02

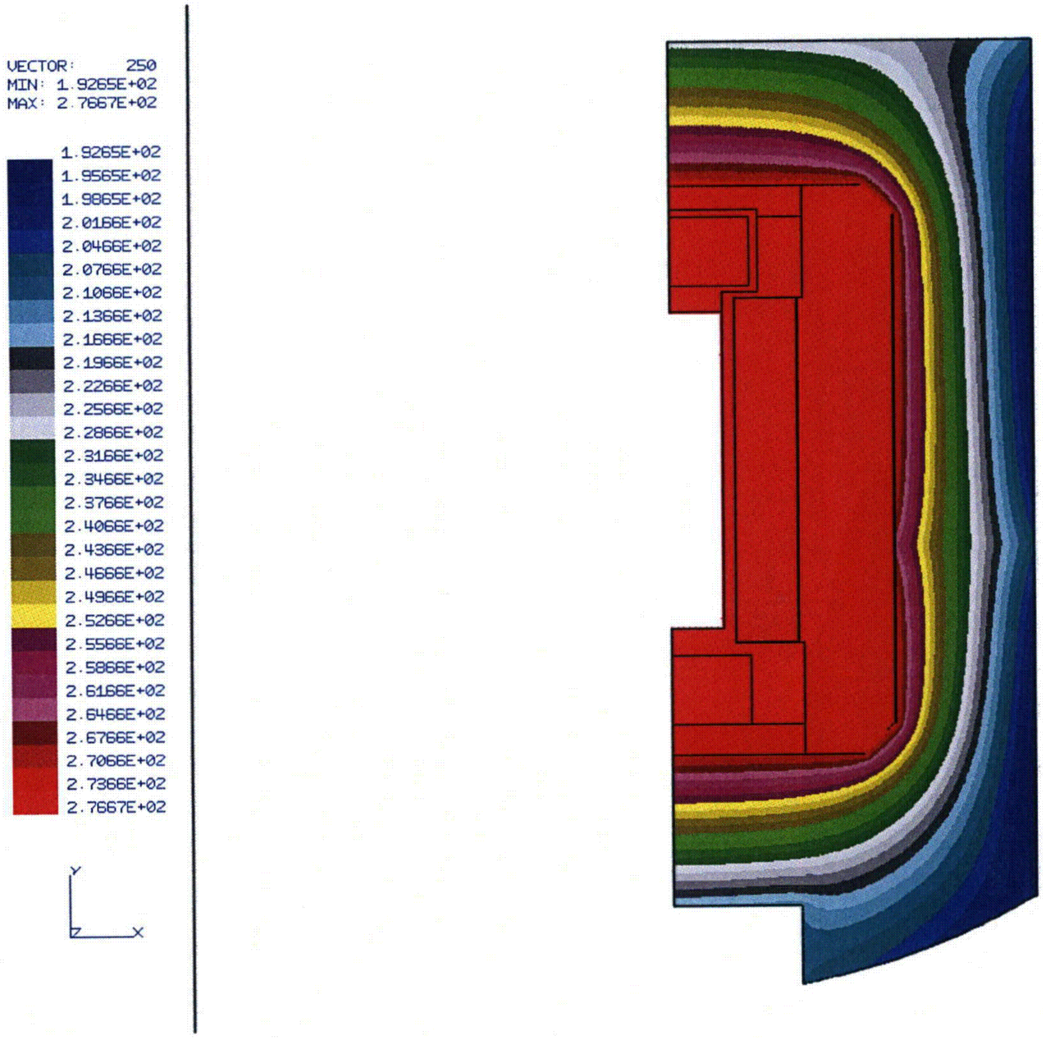

Figure 3-31. Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A

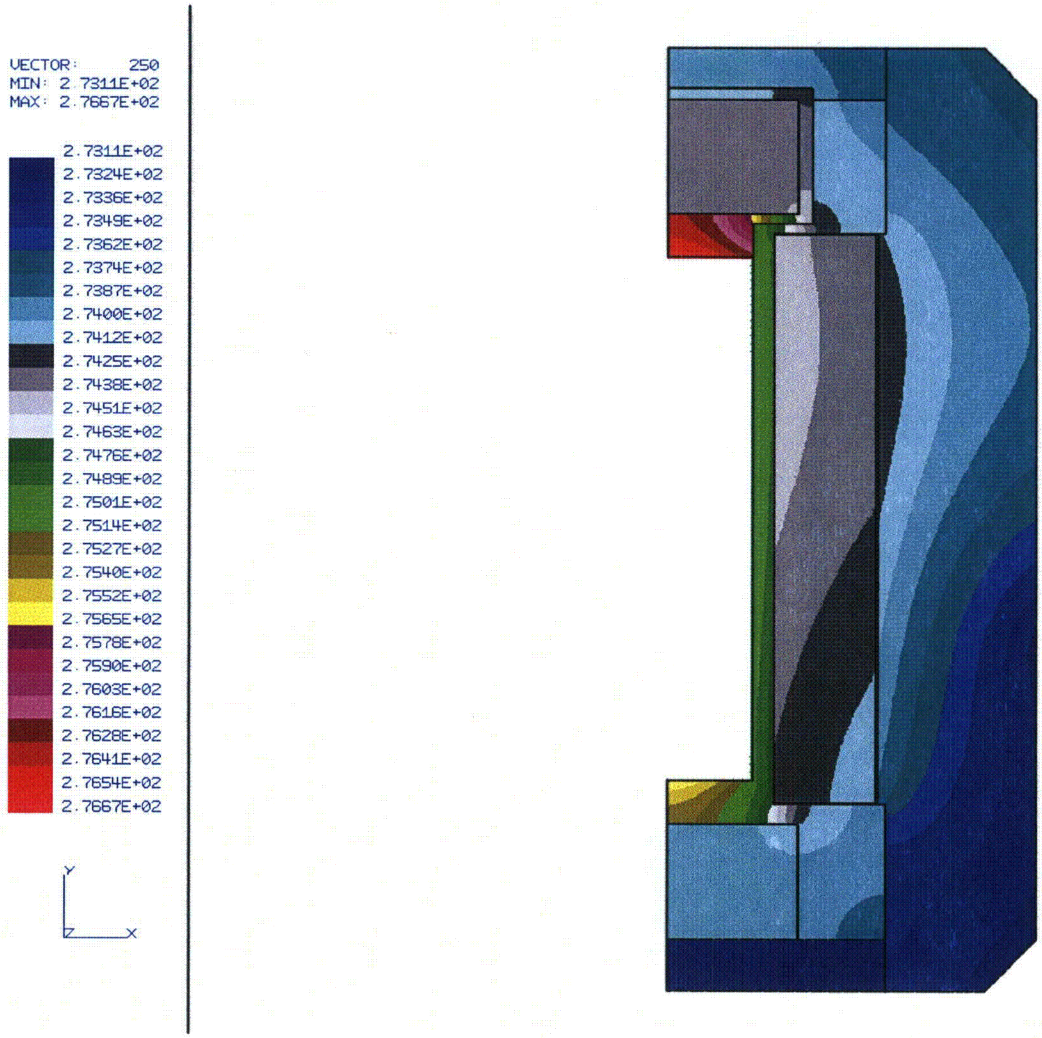

Figure 3-32. Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A

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3.5.2.2 Thermal Evaluation Results – Model AOS-050A

This appendix presents the following information, specific to the Model AOS-050A transport package:

- Normal Conditions of Transport Thermal Evaluation Results – Model AOS-050A
- Fire Condition Thermal Evaluation Results – Model AOS-050A

Table 3-32 lists the temperature monitoring points (nodes) for the Model AOS-050A transport package, under Normal conditions of transport and the Fire condition.

Table 3-32. Temperature Monitoring Points, by Condition – Model AOS-050A

Nodal Location	LIBRA Model Nodal Number, by Condition	
	Normal Conditions of Transport	Fire Condition
1	5001	5001
2	4532	4532
3	4227	4227
4	4752	4752
5	4838	4838
6	4993	4993
7	3309	3309
8	3351	3351
9	678	678
10	2537	2537
11	2533	2533
12	4828	4828
13	1888	1888
14	583	583
15	579	579
16	4313	4313
17	3148	3148
18	3001	3001
19	7533	7533
20	7377	7377
21	7371	7371
22	6942	6942
23	6267	6267
24	6121	6121
25	6001	6001
26	9501	15481
27	9950	15941
28	10014	16260
29	11016	17311
30	9428	11965
31	8463	9785
32	8462	9571
33	8197	8197
34	9711	15451
35	9821	16160

Table 3-32. Temperature Monitoring Points, by Condition – Model AOS-050A (Continued)

Nodal Location	LIBRA Model Nodal Number, by Condition	
	Normal Conditions of Transport	Fire Condition
36	10158	17790
37	10792	18750
38	9204	11485
39	8578	9900
40	8225	8673
41	8001	8225

3.5.2.2.1 Normal Conditions of Transport Thermal Evaluation Results – Model AOS-050A

Table 3-33 lists the tables and figures in this appendix that present the Model AOS-050A transport package results under Normal conditions of transport, for Load Cases 101 through 106. Each table provides a list of temperatures at each monitoring node. The tables for Load Cases 101, 102, 105, and 106 also include a list of maximum temperatures within each transport package component.

Figure 3-33 illustrates the location of each node on the transport package, under Normal conditions of transport. (The node locations are listed in Table 3-32.)

Table 3-33. Normal Conditions of Transport Thermal Evaluation Results – Model AOS-050A

Load Case	Description	Results Table	Entire Model	Cask Model
101	100°F Ambient, Maximum Decay Heat	Table 3-34	Figure 3-34	Figure 3-35
102	100°F Ambient, Maximum Decay Heat, Maximum Insolation	Table 3-35	Figure 3-36	Figure 3-37
103	-20°F Ambient, Zero Decay Heat, Zero Insolation	Table 3-36	Figure 3-38	–
104	-40°F Ambient, Zero Decay Heat, Zero Insolation	Table 3-37	Figure 3-39	–
105	-40°F Ambient, Maximum Decay Heat	Table 3-38	Figure 3-40	Figure 3-41
106	-20°F Ambient, Maximum Decay Heat	Table 3-39	Figure 3-42	Figure 3-43

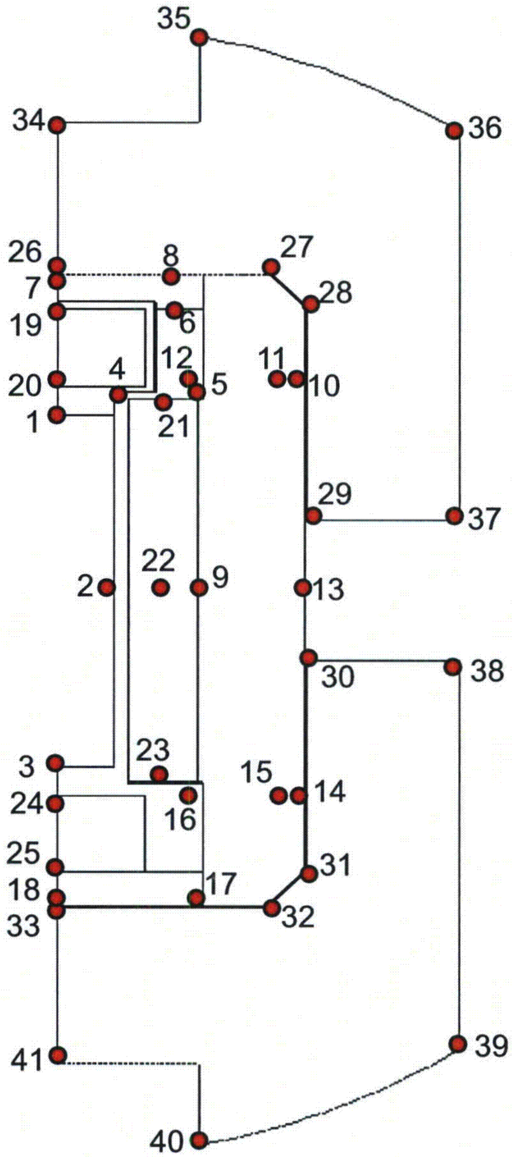

Figure 3-33. Selected Nodal Locations for Normal Conditions of Transport – Model AOS-050A

Table 3-34. Load Case 101, 100°F Ambient, Maximum Decay Heat – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	109.22	228.60
2	4532	104.78	220.60
3	4227	107.22	225.00
4	4752	104.56	220.20
5	4838	101.89	215.40
6	4993	101.83	215.30
7	3309	101.83	215.30
8	3351	101.72	215.10
9	678	101.94	215.50
10	2537	101.11	214.00
11	2533	101.17	214.10
12	4828	101.94	215.50
13	1888	99.72	211.50
14	583	101.17	214.10
15	579	101.22	214.20
16	4313	102.72	216.90
17	3148	101.50	214.70
18	3001	101.56	214.80
19	7533	102.89	217.20
20	7377	103.00	217.40
21	7371	102.50	216.50
22	6942	102.56	216.60
23	6267	102.61	216.70
24	6121	102.78	217.00
25	6001	102.78	217.00
26	9501	100.83	213.50
27	9950	100.22	212.40
28	10014	100.00	212.00
29	11016	82.94	181.30
30	9428	78.17	172.70
31	8463	100.00	212.00
32	8462	100.33	212.60
33	8197	100.72	213.30
34	9711	40.11	104.20
35	9821	38.78	101.80
36	10158	38.72	101.70
37	10792	45.00	113.00
38	9204	43.89	111.00
39	8578	41.39	106.50
40	8225	49.11	120.40
41	8001	53.61	128.50

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	614	1.0211E+02	2.1580E+02
Bottom Plate	3001	3232	3120	1.0161E+02	2.1490E+02
Cask Lid	3233	3424	3233	1.0194E+02	2.1550E+02
Shell Cavity	4001	4998	4227	1.0722E+02	2.2500E+02
Cask Lid Plug	5001	5404	5001	1.0922E+02	2.2860E+02
Tungsten Alloy	6001	7656	7552	1.0306E+02	2.1750E+02
Bottom Cavity	4227	4236	4227	1.0722E+02	2.2500E+02
Side Cavity	4372	4702	4372	1.0506E+02	2.2110E+02
Top Cavity	5001	5012	5001	1.0922E+02	2.2860E+02
Lid Seal	4993	4993	4993	1.0183E+02	2.1530E+02
Cask Vent Port	2537	2537	2537	1.0111E+02	2.1400E+02
Cask Vent Port Seal	2533	2533	2533	1.0117E+02	2.1410E+02
Vt.Conic.Seal	4828	4828	4828	1.0194E+02	2.1550E+02
Cask Drain Port	583	583	583	1.0117E+02	2.1410E+02
Cask Drain Port Seal	579	579	579	1.0122E+02	2.1420E+02
Drn.Conic.Seal	4313	4313	4313	1.0272E+02	2.1690E+02
Test Port	3351	3351	3351	1.0172E+02	2.1510E+02

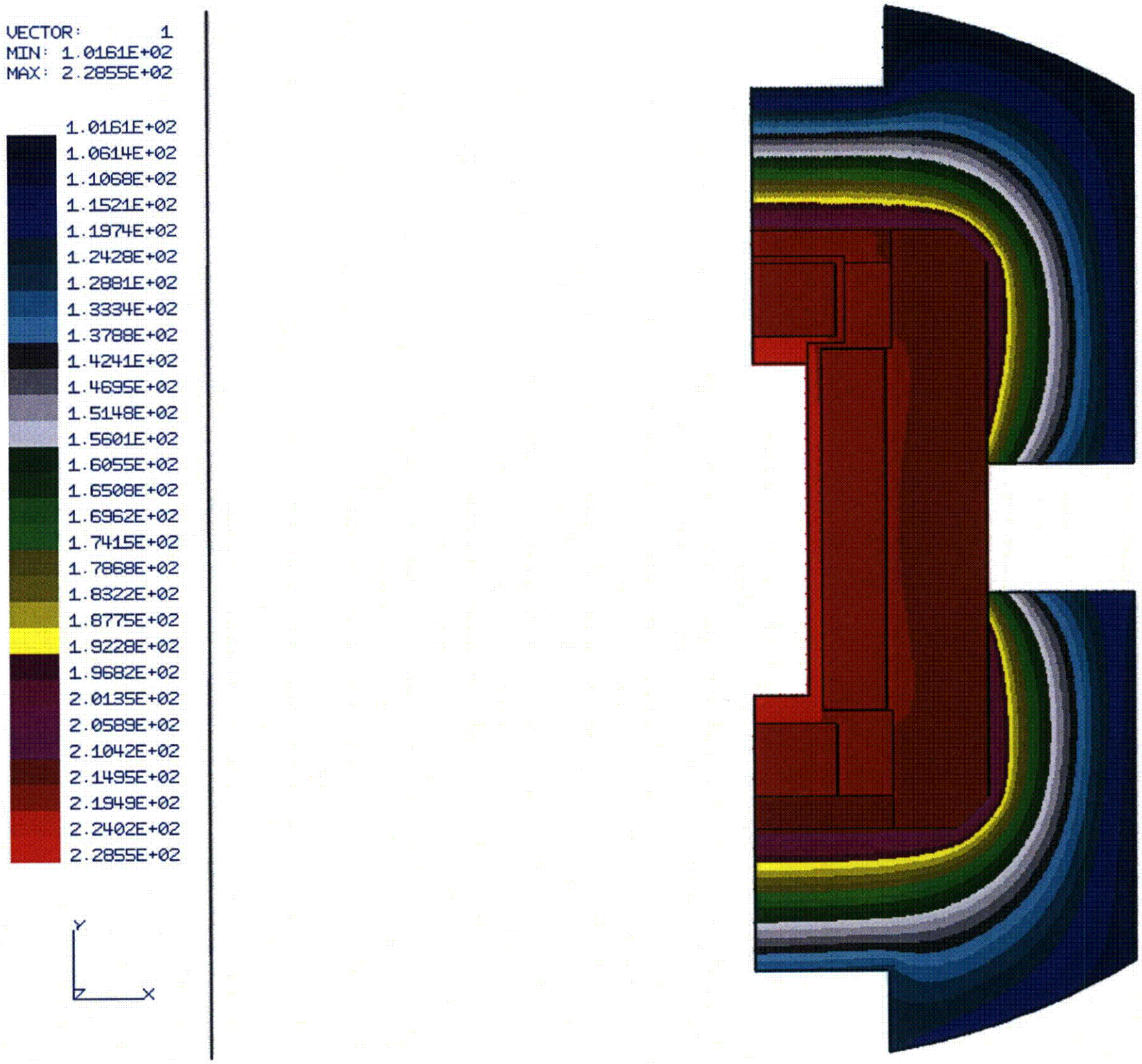

Figure 3-34. Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A

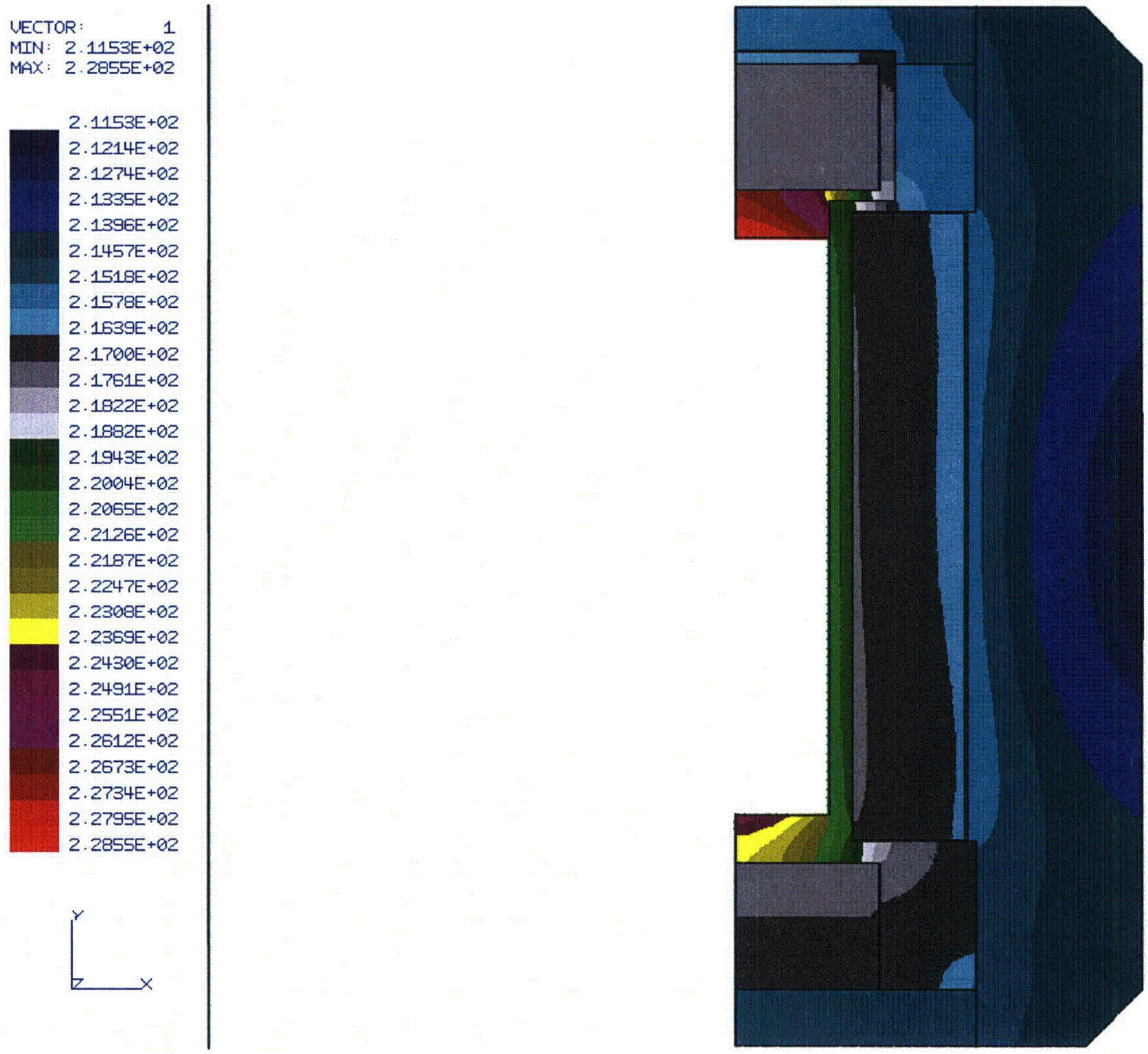

Figure 3-35. Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A

Table 3-35. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	148.00	298.40
2	4532	143.94	291.10
3	4227	146.50	295.70
4	4752	143.61	290.50
5	4838	141.06	285.90
6	4993	141.00	285.80
7	3309	141.06	285.90
8	3351	140.94	285.70
9	678	141.22	286.20
10	2537	140.22	284.40
11	2533	140.28	284.50
12	4828	141.11	286.00
13	1888	138.94	282.10
14	583	140.89	285.60
15	579	140.94	285.70
16	4313	142.28	288.10
17	3148	141.17	286.10
18	3001	141.22	286.20
19	7533	142.00	287.60
20	7377	142.06	287.70
21	7371	141.67	287.00
22	6942	141.83	287.30
23	6267	142.06	287.70
24	6121	142.33	288.20
25	6001	142.28	288.10
26	9501	140.39	284.70
27	9950	139.83	283.70
28	10014	139.56	283.20
29	11016	119.39	246.90
30	9428	130.06	266.10
31	8463	140.06	284.10
32	8462	140.22	284.40
33	8197	140.50	284.90
34	9711	105.44	221.80
35	9821	103.11	217.60
36	10158	102.89	217.20
37	10792	84.28	183.70
38	9204	103.67	218.60
39	8578	88.61	191.50
40	8225	95.11	203.20
41	8001	98.94	210.10

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	606	1.4161E+02	2.8690E+02
Bottom Plate	3001	3232	3120	1.4128E+02	2.8630E+02
Cask Lid	3233	3424	3233	1.4111E+02	2.8600E+02
Shell Cavity	4001	4998	4227	1.4650E+02	2.9570E+02
Cask Lid Plug	5001	5404	5001	1.4800E+02	2.9840E+02
Tungsten Alloy	6001	7656	6247	1.4244E+02	2.8840E+02
Bottom Cavity	4227	4236	4227	1.4650E+02	2.9570E+02
Side Cavity	4372	4702	4372	1.4439E+02	2.9190E+02
Top Cavity	5001	5012	5001	1.4800E+02	2.9840E+02
Lid Seal	4993	4993	4993	1.4100E+02	2.8580E+02
Cask Vent Port	2537	2537	2537	1.4022E+02	2.8440E+02
Cask Vent Port Seal	2533	2533	2533	1.4028E+02	2.8450E+02
Vt.Conic.Seal	4828	4828	4828	1.4111E+02	2.8600E+02
Cask Drain Port	583	583	583	1.4089E+02	2.8560E+02
Cask Drain Port Seal	579	579	579	1.4094E+02	2.8570E+02
Drn.Conic.Seal	4313	4313	4313	1.4228E+02	2.8810E+02
Test Port	3351	3351	3351	1.4094E+02	2.8570E+02

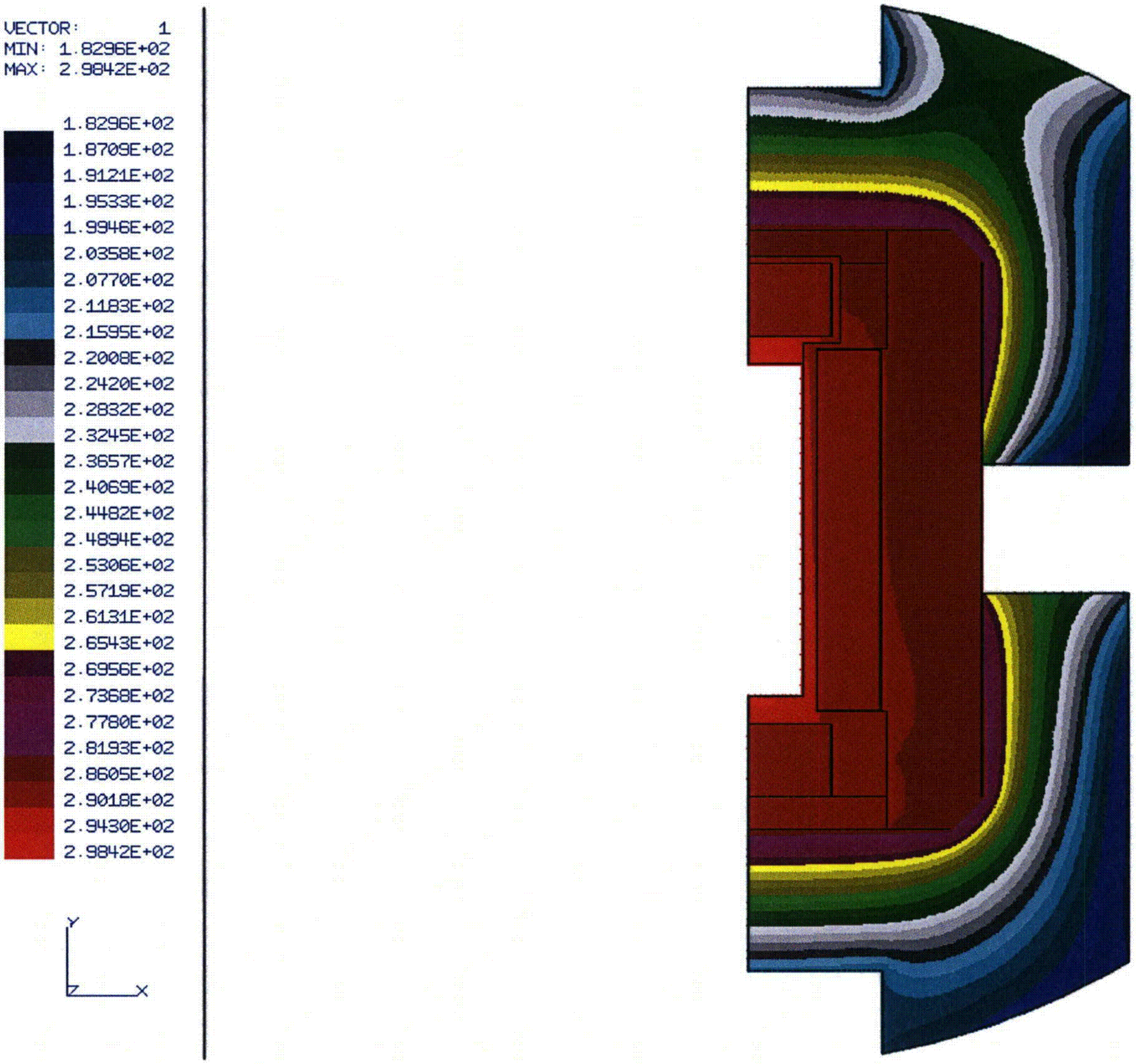

Figure 3-36. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A

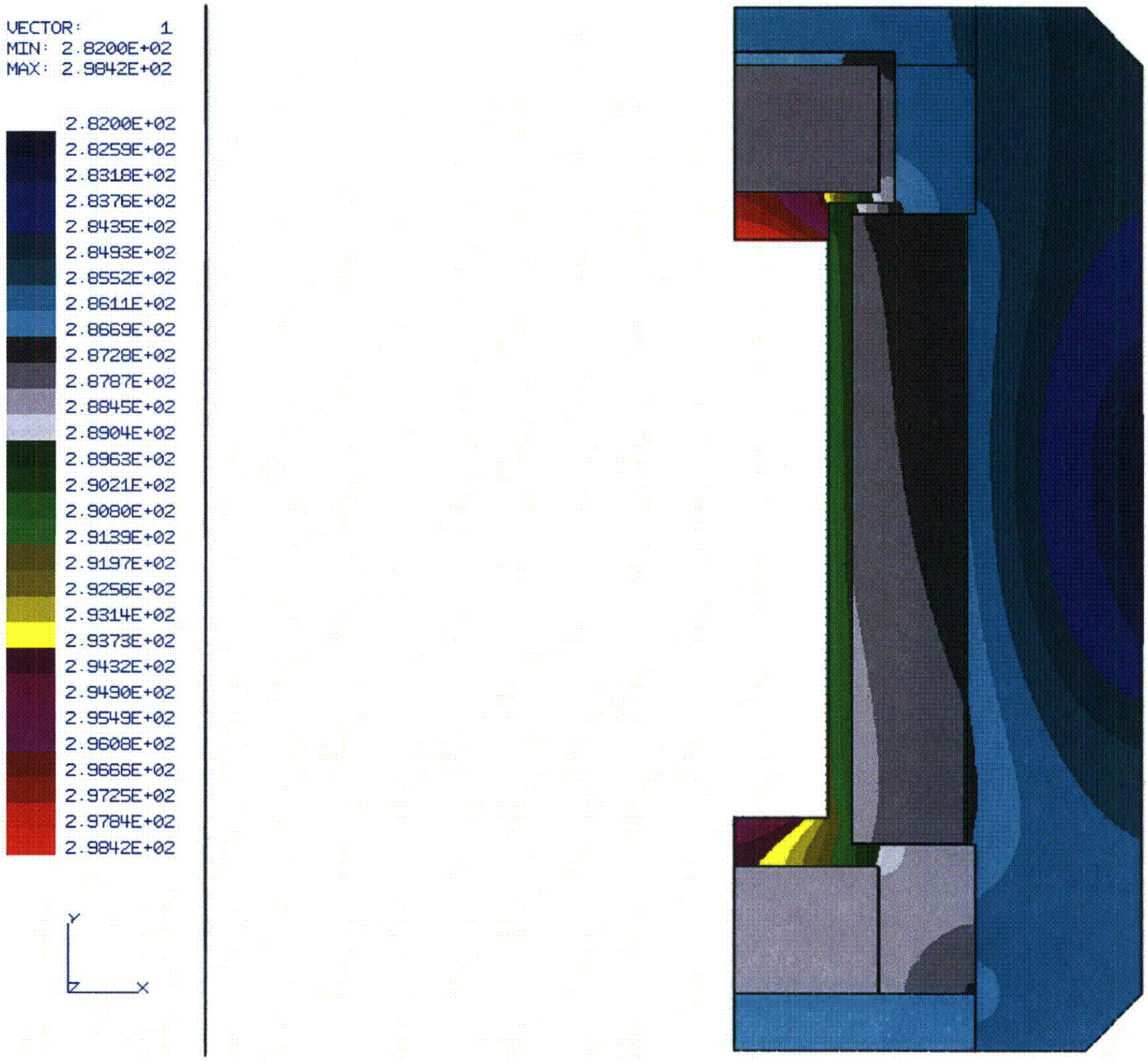

Figure 3-37. Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A

Table 3-36. Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	-28.89	-20.00
2	4532	-28.89	-20.00
3	4227	-28.89	-20.00
4	4752	-28.89	-20.00
5	4838	-28.89	-20.00
6	4993	-28.89	-20.00
7	3309	-28.89	-20.00
8	3351	-28.89	-20.00
9	678	-28.89	-20.00
10	2537	-28.89	-20.00
11	2533	-28.89	-20.00
12	4828	-28.89	-20.00
13	1888	-28.89	-20.00
14	583	-28.89	-20.00
15	579	-28.89	-20.00
16	4313	-28.89	-20.00
17	3148	-28.89	-20.00
18	3001	-28.89	-20.00
19	7533	-28.89	-20.00
20	7377	-28.89	-20.00
21	7371	-28.89	-20.00
22	6942	-28.89	-20.00
23	6267	-28.89	-20.00
24	6121	-28.89	-20.00
25	6001	-28.89	-20.00
26	9501	-28.89	-20.00
27	9950	-28.89	-20.00
28	10014	-28.89	-20.00
29	11016	-28.89	-20.00
30	9428	-28.89	-20.00
31	8463	-28.89	-20.00
32	8462	-28.89	-20.00
33	8197	-28.89	-20.00
34	9711	-28.89	-20.00
35	9821	-28.89	-20.00
36	10158	-28.89	-20.00
37	10792	-28.89	-20.00
38	9204	-28.89	-20.00
39	8578	-28.89	-20.00
40	8225	-28.89	-20.00
41	8001	-28.89	-20.00

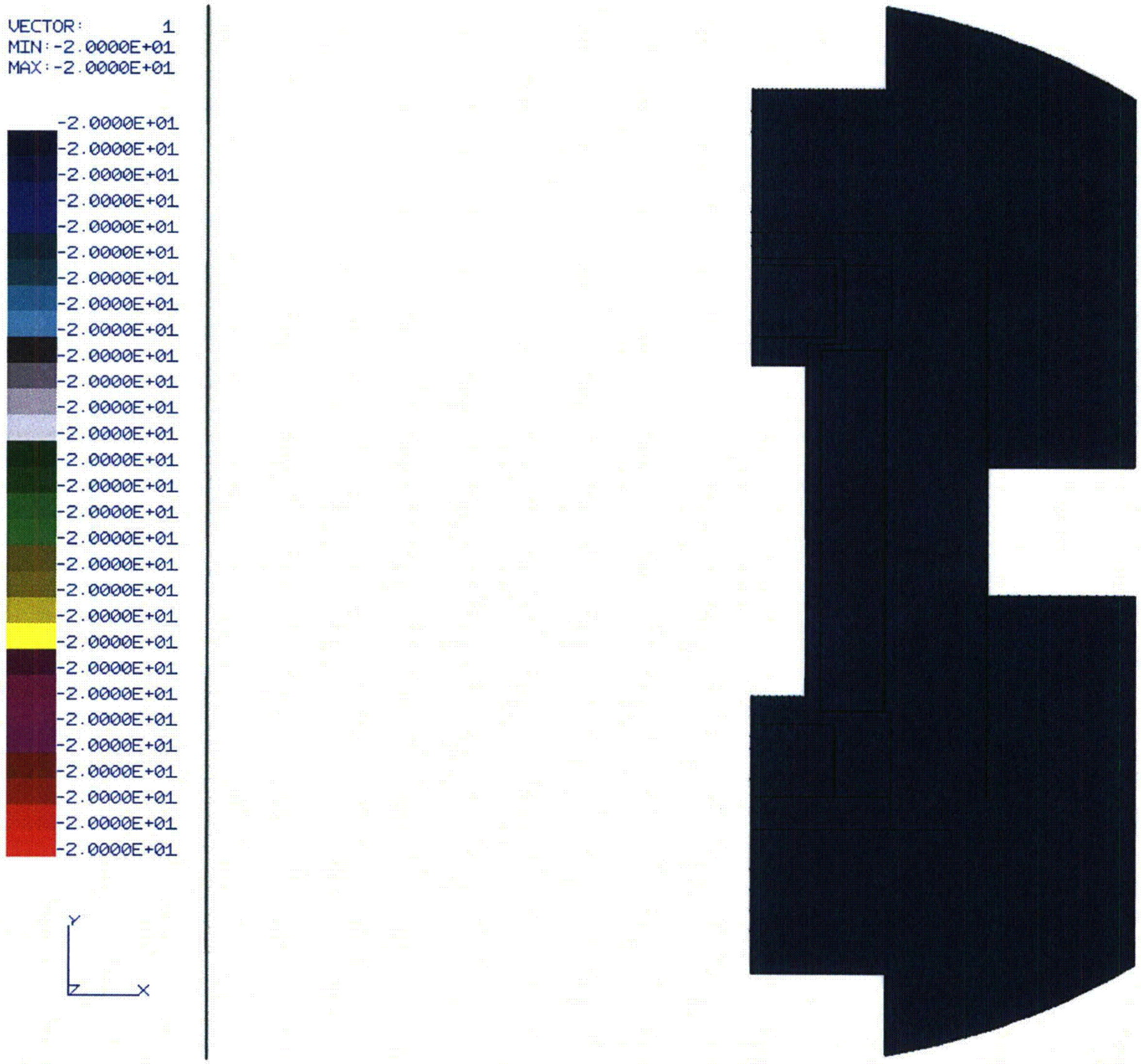

Figure 3-38. Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-050A

Table 3-37. Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	-40.00	-40.00
2	4532	-40.00	-40.00
3	4227	-40.00	-40.00
4	4752	-40.00	-40.00
5	4838	-40.00	-40.00
6	4993	-40.00	-40.00
7	3309	-40.00	-40.00
8	3351	-40.00	-40.00
9	678	-40.00	-40.00
10	2537	-40.00	-40.00
11	2533	-40.00	-40.00
12	4828	-40.00	-40.00
13	1888	-40.00	-40.00
14	583	-40.00	-40.00
15	579	-40.00	-40.00
16	4313	-40.00	-40.00
17	3148	-40.00	-40.00
18	3001	-40.00	-40.00
19	7533	-40.00	-40.00
20	7377	-40.00	-40.00
21	7371	-40.00	-40.00
22	6942	-40.00	-40.00
23	6267	-40.00	-40.00
24	6121	-40.00	-40.00
25	6001	-40.00	-40.00
26	9501	-40.00	-40.00
27	9950	-40.00	-40.00
28	10014	-40.00	-40.00
29	11016	-40.00	-40.00
30	9428	-40.00	-40.00
31	8463	-40.00	-40.00
32	8462	-40.00	-40.00
33	8197	-40.00	-40.00
34	9711	-40.00	-40.00
35	9821	-40.00	-40.00
36	10158	-40.00	-40.00
37	10792	-40.00	-40.00
38	9204	-40.00	-40.00
39	8578	-40.00	-40.00
40	8225	-40.00	-40.00
41	8001	-40.00	-40.00

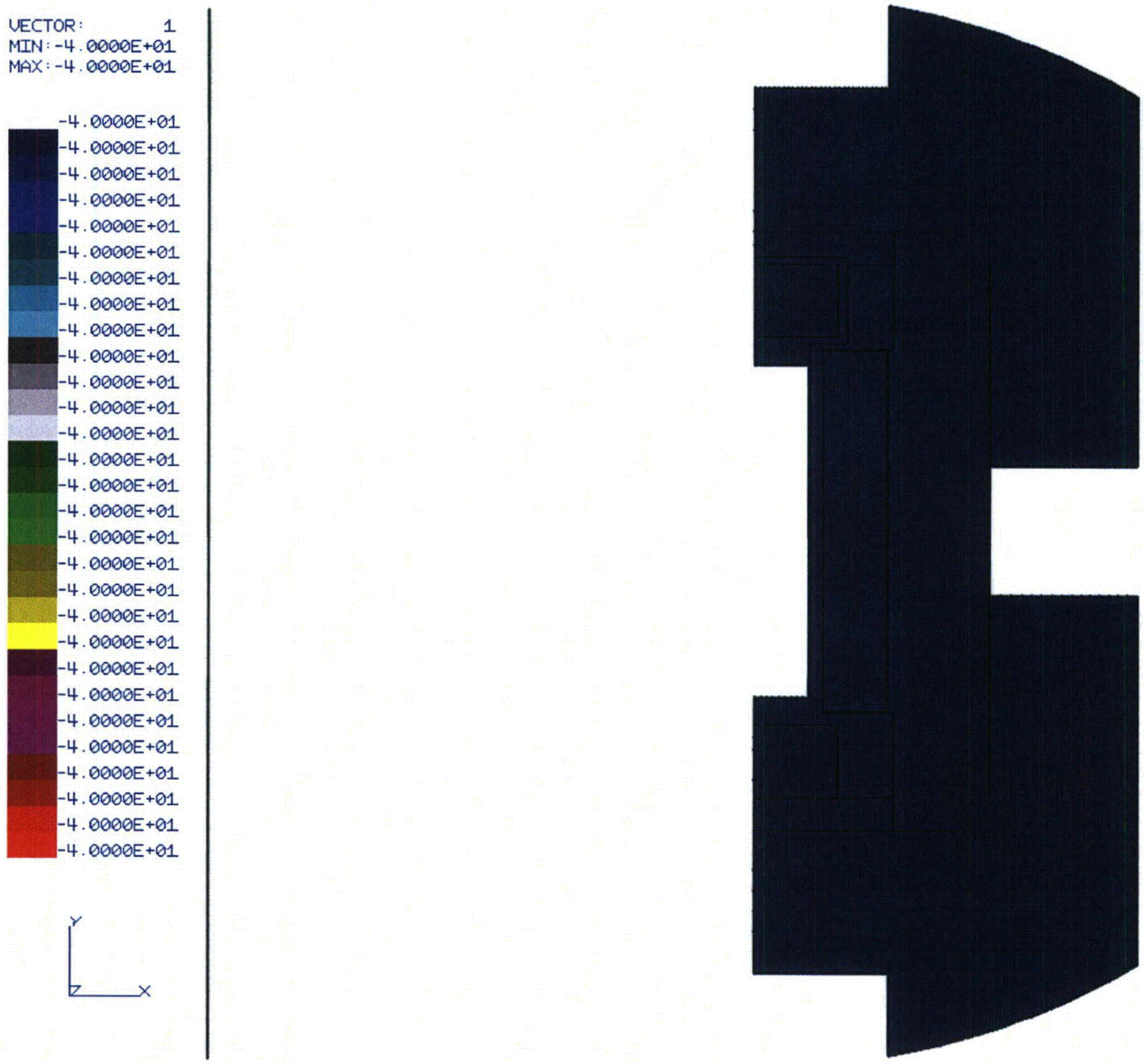

Figure 3-39. Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-050A

Table 3-38. Load Case 105, -40°F Ambient, Maximum Decay Heat – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	37.74	99.94
2	4532	32.84	91.11
3	4227	35.36	95.64
4	4752	32.51	90.51
5	4838	29.66	85.39
6	4993	29.58	85.24
7	3309	29.61	85.29
8	3351	29.44	85.00
9	678	29.65	85.37
10	2537	28.76	83.77
11	2533	28.84	83.92
12	4828	29.71	85.48
13	1888	27.22	80.99
14	583	28.77	83.79
15	579	28.84	83.92
16	4313	30.44	86.80
17	3148	29.09	84.36
18	3001	29.15	84.47
19	7533	30.87	87.57
20	7377	30.96	87.72
21	7371	30.23	86.42
22	6942	30.27	86.48
23	6267	30.28	86.50
24	6121	30.54	86.98
25	6001	30.49	86.88
26	9501	28.49	83.28
27	9950	27.66	81.79
28	10014	27.30	81.14
29	11016	9.86	49.75
30	9428	2.55	36.59
31	8463	27.16	80.89
32	8462	27.67	81.81
33	8197	28.28	82.90
34	9711	-36.76	-34.16
35	9821	-38.56	-37.41
36	10158	-38.50	-37.30
37	10792	-29.39	-20.90
38	9204	-32.64	-26.75
39	8578	-34.81	-30.66
40	8225	-26.09	-14.96
41	8001	-21.03	-5.85

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	622	2.9794E+01	8.5630E+01
Bottom Plate	3001	3232	3120	2.9228E+01	8.4610E+01
Cask Lid	3233	3424	3233	2.9694E+01	8.5450E+01
Shell Cavity	4001	4998	4227	3.5356E+01	9.5640E+01
Cask Lid Plug	5001	5404	5001	3.7744E+01	9.9940E+01
Tungsten Alloy	6001	7656	7552	3.1039E+01	8.7870E+01
Bottom Cavity	4227	4236	4227	3.5356E+01	9.5640E+01
Side Cavity	4372	4702	4372	3.3044E+01	9.1480E+01
Top Cavity	5001	5012	5001	3.7744E+01	9.9940E+01
Lid Seal	4993	4993	4993	2.9578E+01	8.5240E+01
Cask Vent Port	2537	2537	2537	2.8761E+01	8.3770E+01
Cask Vent Port Seal	2533	2533	2533	2.8844E+01	8.3920E+01
Vt.Conic.Seal	4828	4828	4828	2.9711E+01	8.5480E+01
Cask Drain Port	583	583	583	2.8772E+01	8.3790E+01
Cask Drain Port Seal	579	579	579	2.8844E+01	8.3920E+01
Drn.Conic.Seal	4313	4313	4313	3.0444E+01	8.6800E+01
Test Port	3351	3351	3351	2.9444E+01	8.5000E+01

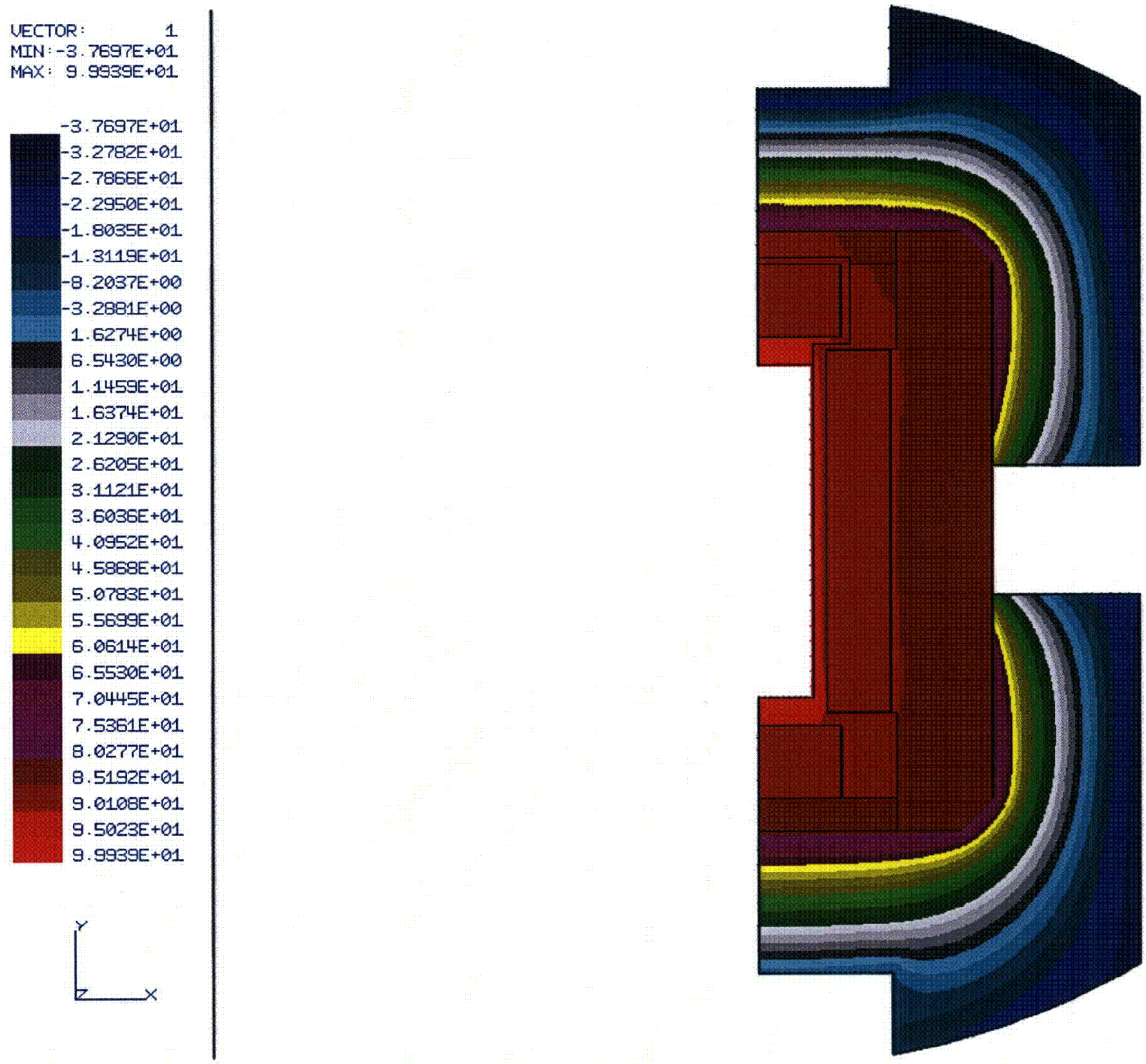

Figure 3-40. Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A

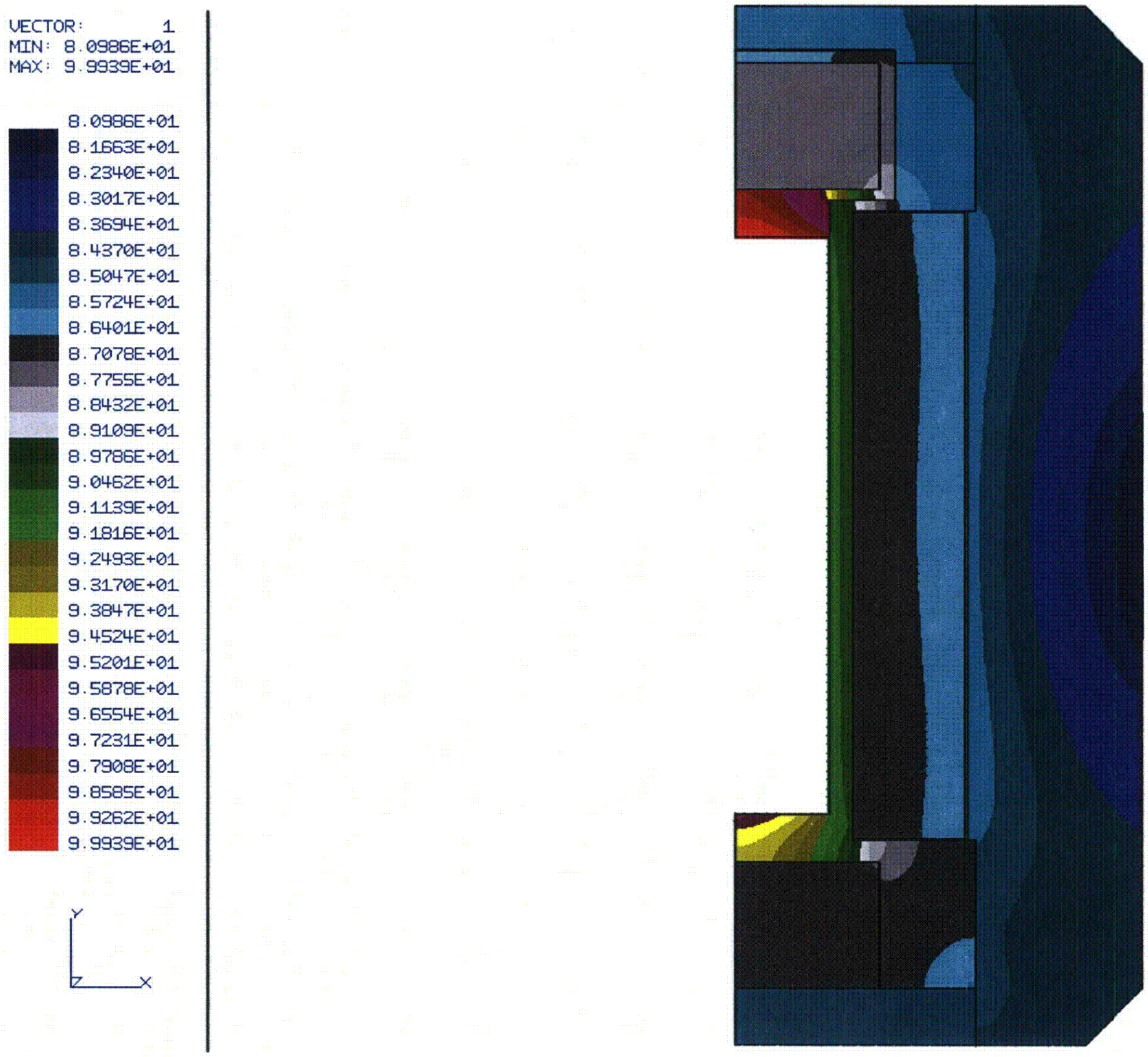

Figure 3-41. Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A

Table 3-39. Load Case 106, -20°F Ambient, Maximum Decay Heat – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	48.11	118.60
2	4532	43.28	109.90
3	4227	45.78	114.40
4	4752	42.94	109.30
5	4838	40.11	104.20
6	4993	40.06	104.10
7	3309	40.06	104.10
8	3351	39.89	103.80
9	678	40.11	104.20
10	2537	39.22	102.60
11	2533	39.33	102.80
12	4828	40.17	104.30
13	1888	37.72	99.90
14	583	39.28	102.70
15	579	39.33	102.80
16	4313	40.89	105.60
17	3148	39.56	103.20
18	3001	39.61	103.30
19	7533	41.28	106.30
20	7377	41.39	106.50
21	7371	40.72	105.30
22	6942	40.72	105.30
23	6267	40.78	105.40
24	6121	41.00	105.80
25	6001	40.94	105.70
26	9501	38.94	102.10
27	9950	38.17	100.70
28	10014	37.83	100.10
29	11016	20.44	68.80
30	9428	13.51	56.31
31	8463	37.72	99.89
32	8462	38.22	100.80
33	8197	38.78	101.80
34	9711	-25.74	-14.34
35	9821	-27.47	-17.45
36	10158	-27.41	-17.33
37	10792	-18.63	-1.54
38	9204	-21.52	-6.74
39	8578	-23.81	-10.85
40	8225	-15.24	4.57
41	8001	-10.26	13.53

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	614	4.0278E+01	1.0450E+02
Bottom Plate	3001	3232	3120	3.9722E+01	1.0350E+02
Cask Lid	3233	3424	3233	4.0167E+01	1.0430E+02
Shell Cavity	4001	4998	4227	4.5778E+01	1.1440E+02
Cask Lid Plug	5001	5404	5001	4.8111E+01	1.1860E+02
Tungsten Alloy	6001	7656	7551	4.1444E+01	1.0660E+02
Bottom Cavity	4227	4236	4227	4.5778E+01	1.1440E+02
Side Cavity	4372	4702	4372	4.3444E+01	1.1020E+02
Top Cavity	5001	5012	5001	4.8111E+01	1.1860E+02
Lid Seal	4993	4993	4993	4.0056E+01	1.0410E+02
Cask Vent Port	2537	2537	2537	3.9222E+01	1.0260E+02
Cask Vent Port Seal	2533	2533	2533	3.9333E+01	1.0280E+02
Vt.Conic.Seal	4828	4828	4828	4.0167E+01	1.0430E+02
Cask Drain Port	583	583	583	3.9278E+01	1.0270E+02
Cask Drain Port Seal	579	579	579	3.9333E+01	1.0280E+02
Drn.Conic.Seal	4313	4313	4313	4.0889E+01	1.0560E+02
Test Port	3351	3351	3351	3.9889E+01	1.0380E+02

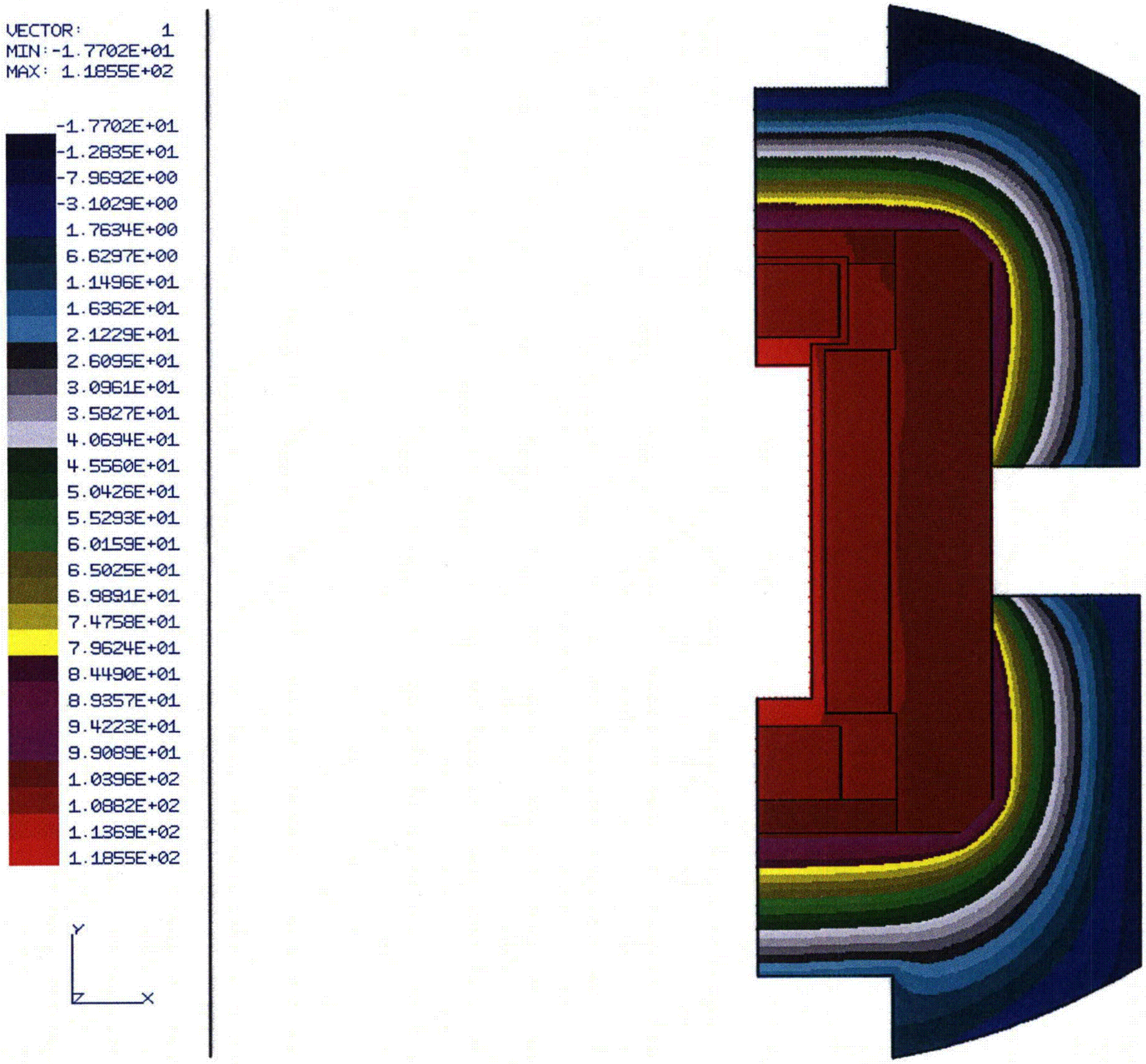

Figure 3-42. Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A

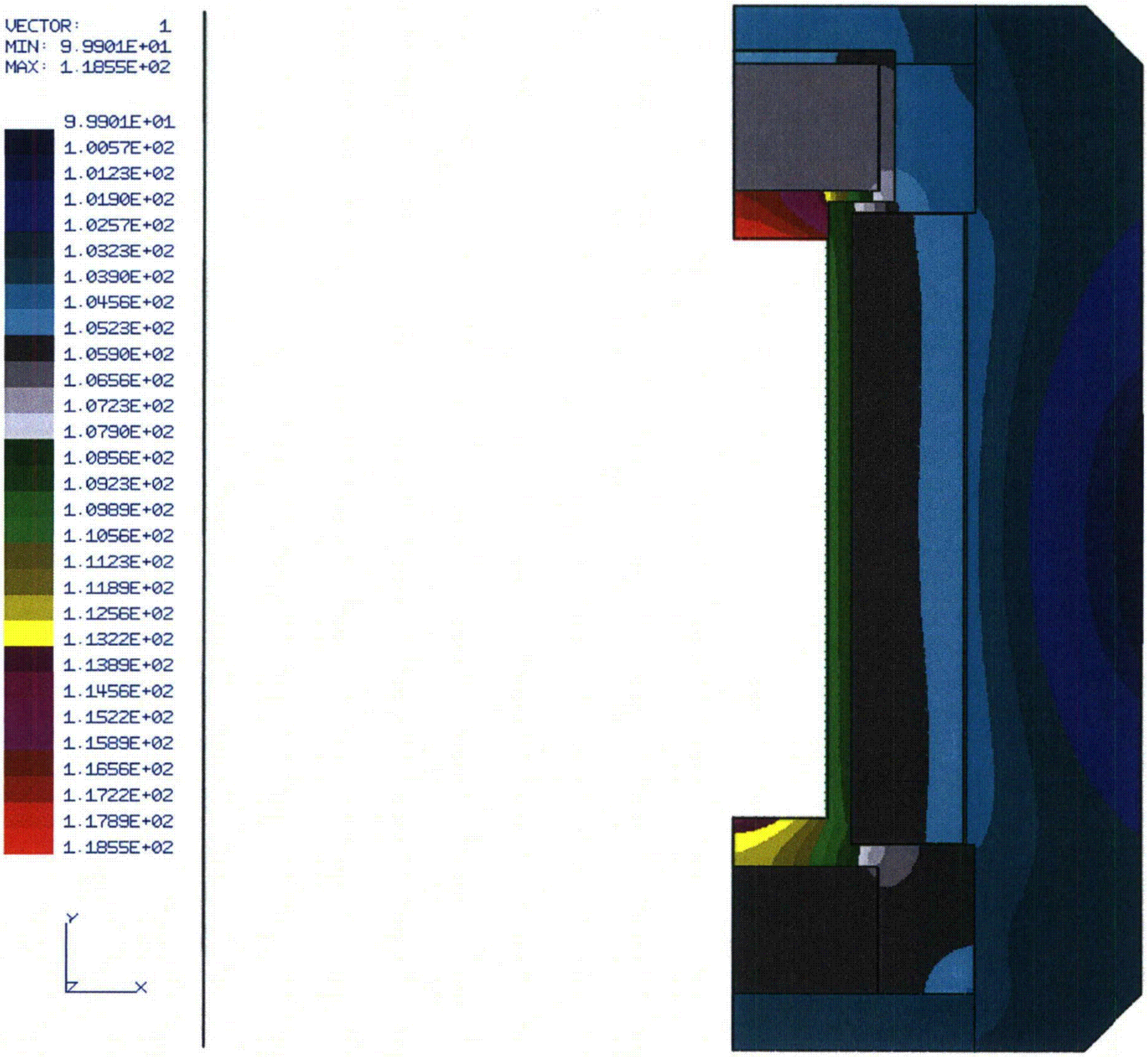

Figure 3-43. Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A

3.5.2.2.2 Fire Condition Thermal Evaluation Results – Model AOS-050A

Table 3-40 lists the tables and figures in this appendix that present the Model AOS-050A transport package results under the Fire condition, for Load Cases 111 and 112. Each table provides a list of temperatures at each monitoring node. Also listed are the maximum temperatures within each transport package component.

Figure 3-44 illustrates the location of each node on the transport package, under the Fire condition. (The node locations are listed in Table 3-32.)

Table 3-40. Fire Condition Thermal Evaluation Results – Model AOS-050A

Load Case	Description	Temperature versus Time	Results Table	Entire Model	Cask Model
111	Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat	Figure 3-45 Figure 3-46 Figure 3-47	Table 3-41	Figure 3-48	Figure 3-49
112	Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation		Table 3-42	Figure 3-50	Figure 3-51
	Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation		Table 3-43	Figure 3-52	Figure 3-53
	Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation		Table 3-44	Figure 3-54	Figure 3-55
	Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation		Table 3-45	Figure 3-56	Figure 3-57
	Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation		Table 3-46	Figure 3-58	Figure 3-59

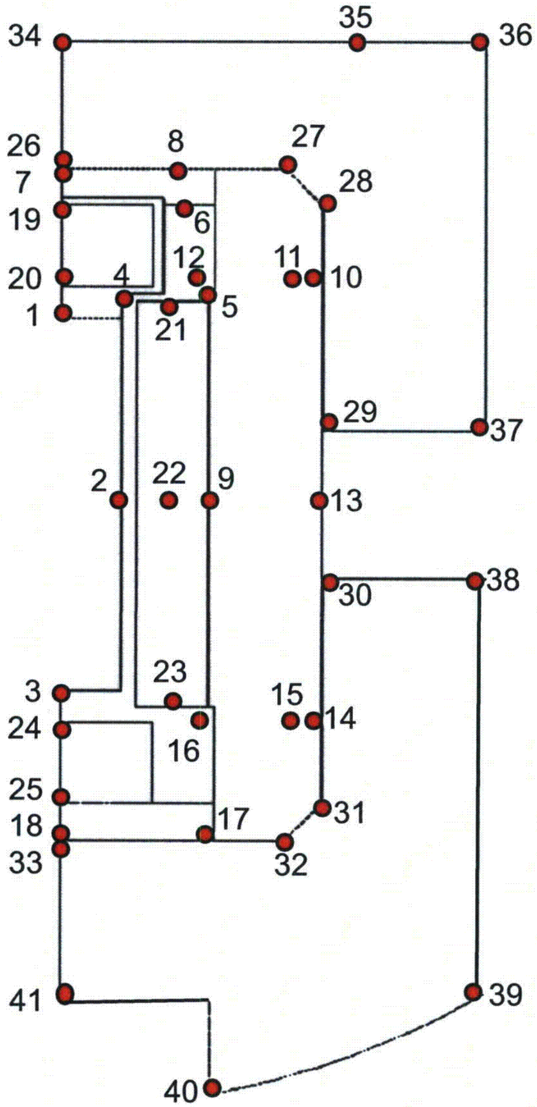

Figure 3-44. Selected Nodal Locations for Fire Condition – Model AOS-050A

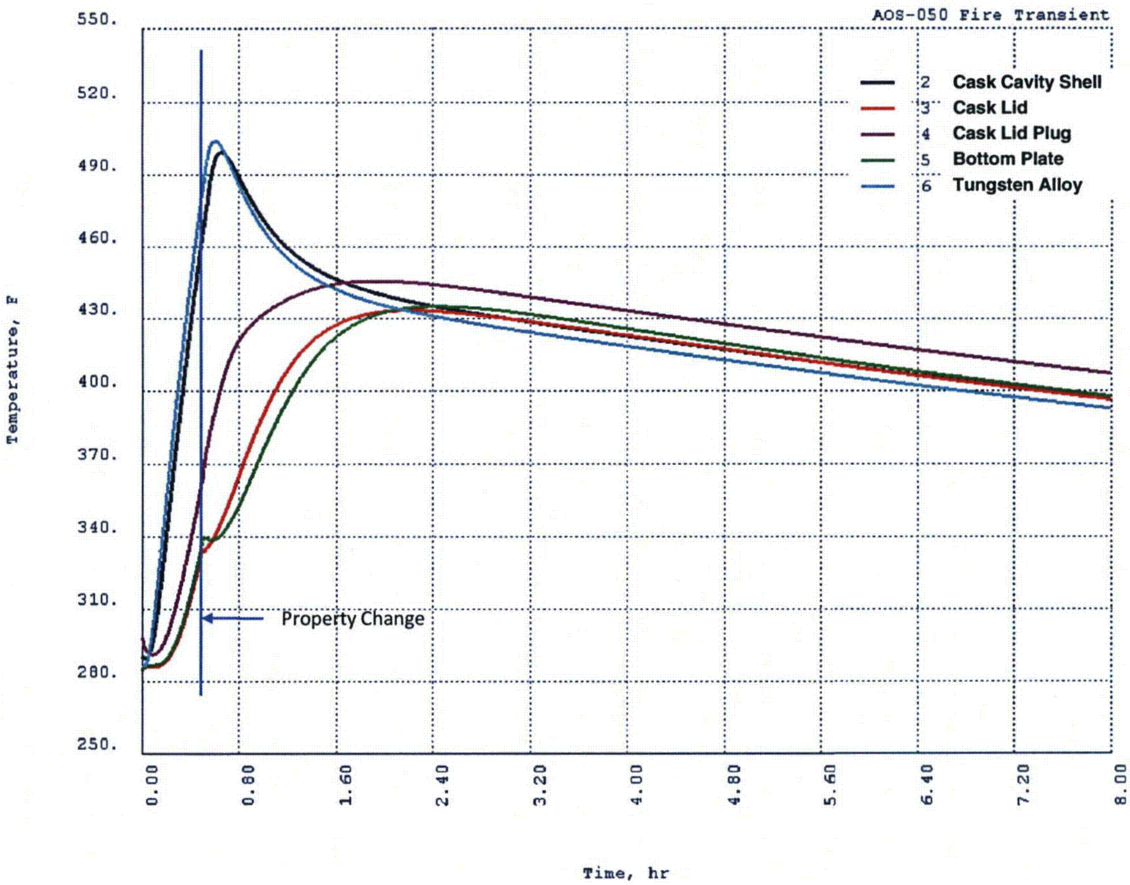

Figure 3-45. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Tungsten Alloy – Model AOS-050A

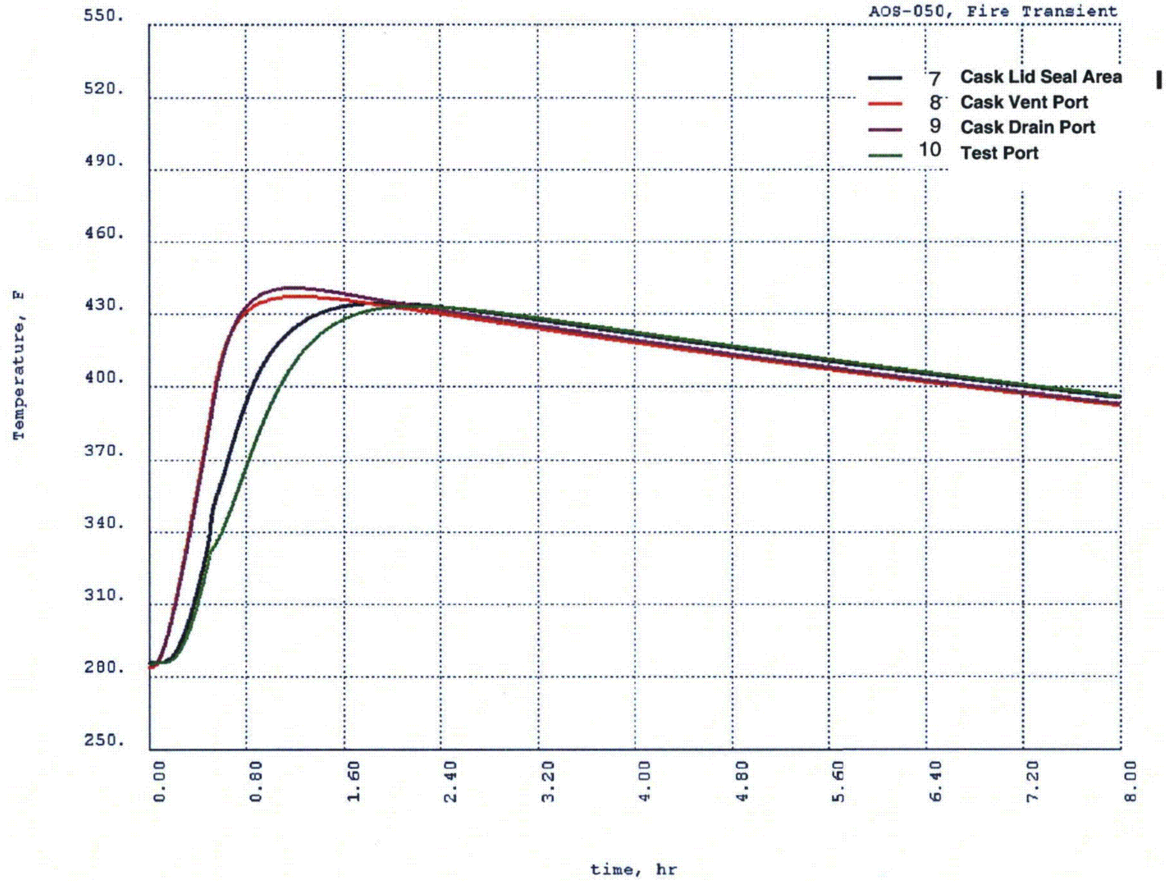

Figure 3-46. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Lid Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Model AOS-050A

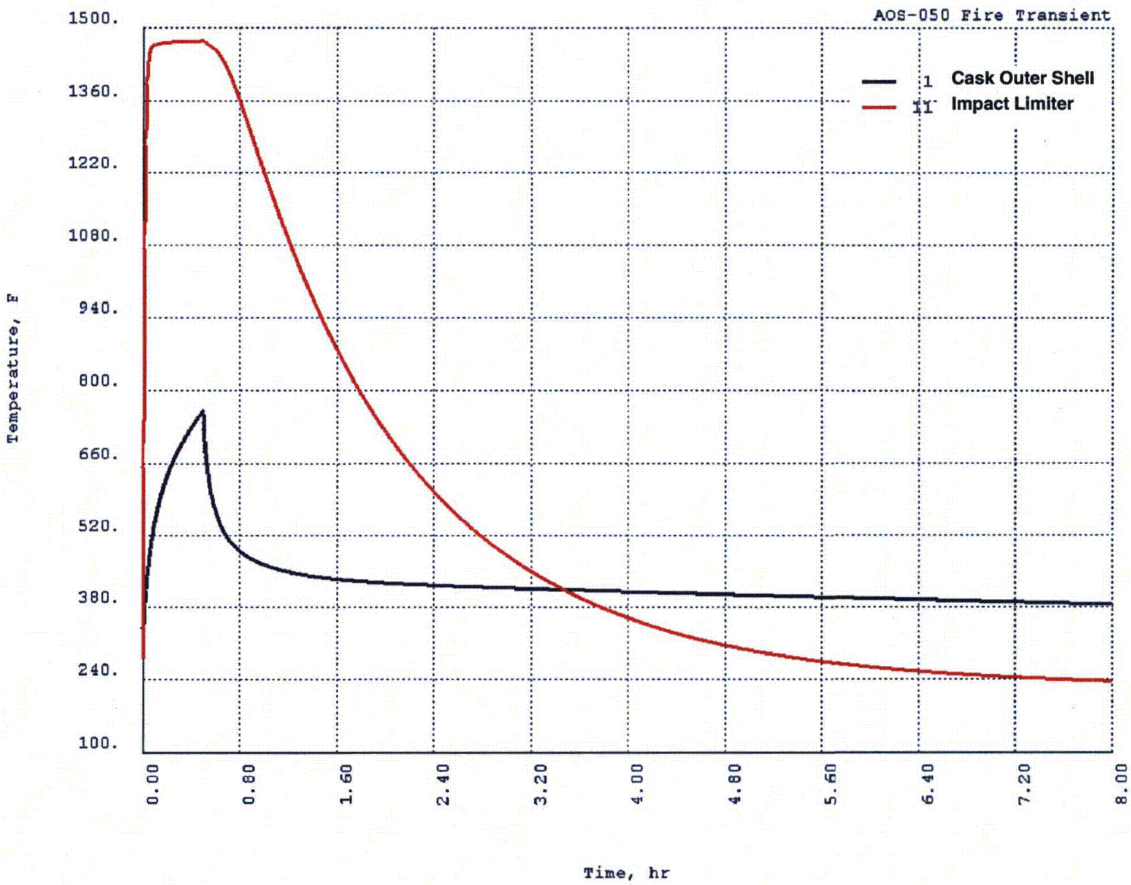

Figure 3-47. Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Model AOS-050A

Table 3-41. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	184.17	363.50
2	4532	240.33	464.60
3	4227	187.06	368.70
4	4752	191.94	377.50
5	4838	199.78	391.60
6	4993	169.67	337.40
7	3309	166.72	332.10
8	3351	165.56	330.00
9	678	267.83	514.10
10	2537	196.50	385.70
11	2533	196.44	385.60
12	4828	194.44	382.00
13	1888	413.94	777.10
14	583	195.39	383.70
15	579	195.33	383.60
16	4313	195.39	383.70
17	3001	169.67	337.40
18	3148	166.17	331.10
19	7533	174.33	345.80
20	7377	178.83	353.90
21	7371	210.61	411.10
22	6942	244.00	471.20
23	6267	209.61	409.30
24	6121	181.06	357.90
25	6001	175.94	348.70
26	15481	166.67	332.00
27	15941	166.06	330.90
28	16260	170.00	338.00
29	17311	446.22	835.20
30	11965	446.56	835.80
31	9785	170.50	338.90
32	9571	166.67	332.00
33	8197	169.56	337.20
34	15451	797.78	1468.00
35	16160	797.78	1468.00
36	17790	800.00	1472.00
37	18750	800.00	1472.00
38	11485	800.56	1473.00
39	9900	800.00	1472.00
40	8673	800.56	1473.00
41	8225	798.33	1469.00

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1888	4.1394E+02	7.7710E+02
Bottom Plate	3001	3232	3120	1.7489E+02	3.4680E+02
Cask Lid	3233	3424	3233	1.6972E+02	3.3750E+02
Shell Cavity	4001	4998	4536	2.4056E+02	4.6500E+02
Cask Lid Plug	5001	5404	5012	1.9583E+02	3.8450E+02
Tungsten Alloy	6001	7656	6949	2.5039E+02	4.8270E+02
Bottom Cavity	4227	4236	4236	2.0144E+02	3.9460E+02
Side Cavity	4372	4702	4532	2.4033E+02	4.6460E+02
Top Cavity	5001	5012	5012	1.9583E+02	3.8450E+02
Lid Seal	4993	4993	4993	1.6967E+02	3.3740E+02
Cask Vent Port	2537	2537	2537	1.9650E+02	3.8570E+02
Cask Vent Port Seal	2533	2533	2533	1.9644E+02	3.8560E+02
Vt.Conic.Seal	4828	4828	4828	1.9444E+02	3.8200E+02
Cask Drain Port	583	583	583	1.9539E+02	3.8370E+02
Cask Drain Port Seal	579	579	579	1.9533E+02	3.8360E+02
Drn.Conic.Seal	4313	4313	4313	1.9539E+02	3.8370E+02
Test Port	3351	3351	3351	1.6556E+02	3.3000E+02

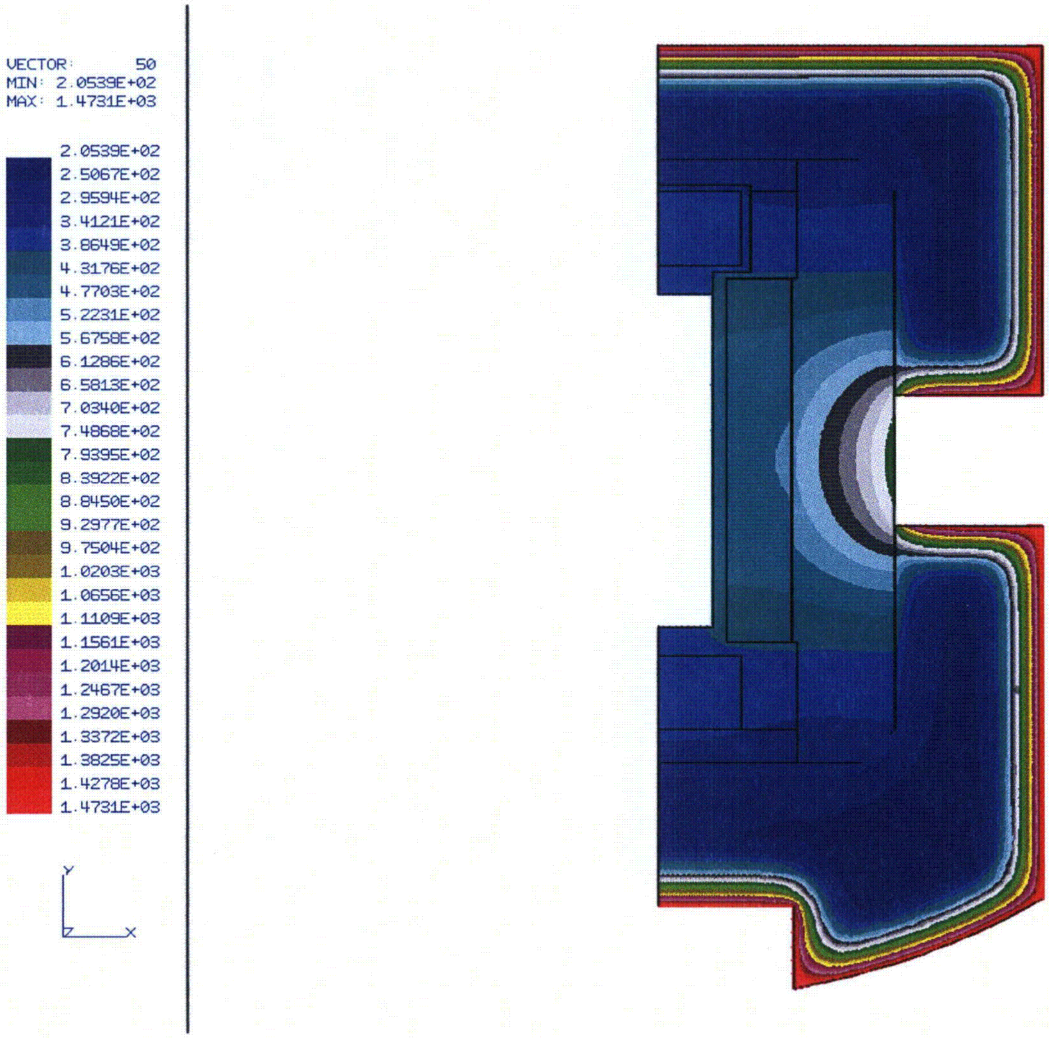

Figure 3-48. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A

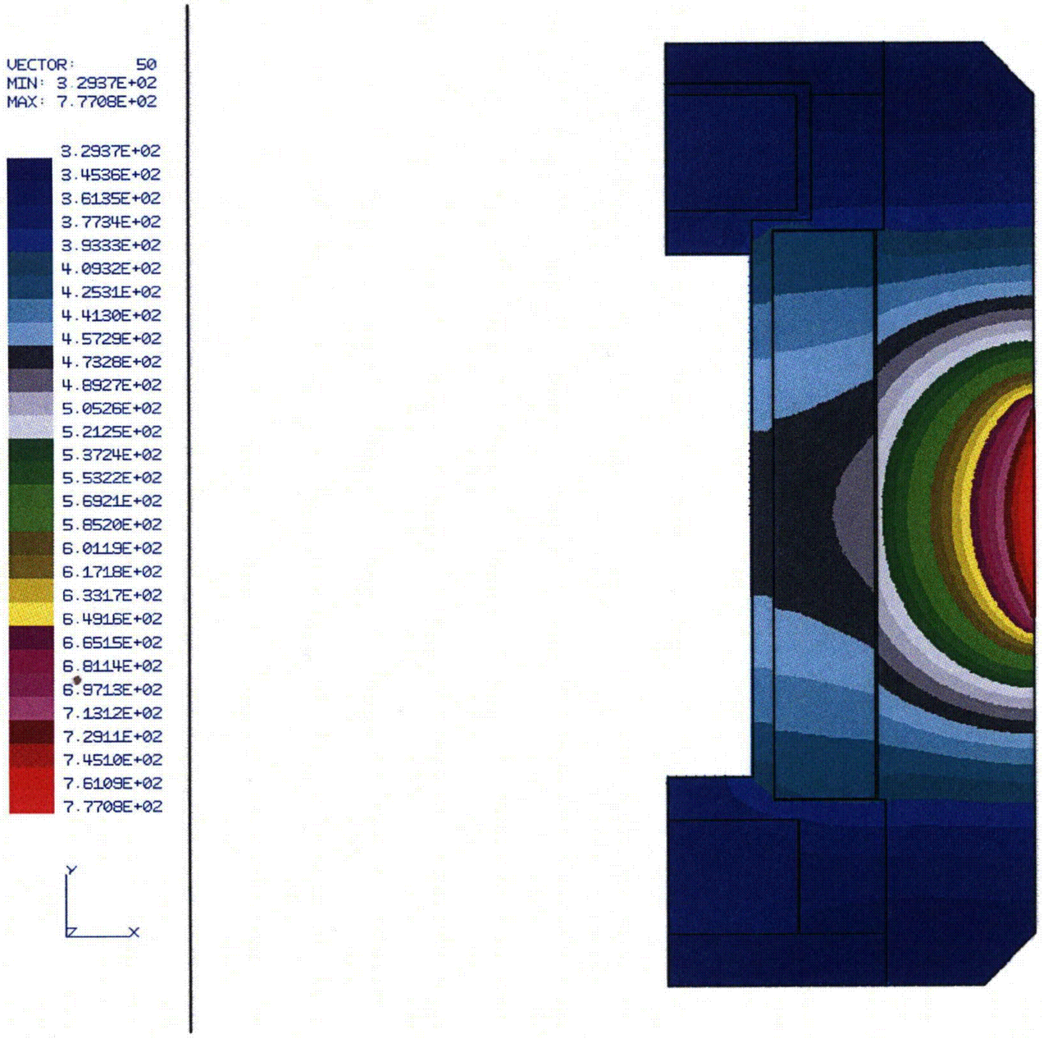

Figure 3-49. Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A

Table 3-42. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	221.94	431.50
2	4532	243.89	471.00
3	4227	227.78	442.00
4	4752	227.22	441.00
5	4838	219.39	426.90
6	4993	211.78	413.20
7	3309	194.22	381.60
8	3351	199.83	391.70
9	678	241.78	467.20
10	2537	224.28	435.70
11	2533	224.44	436.00
12	4828	217.00	422.60
13	1888	237.89	460.20
14	583	226.22	439.20
15	579	226.33	439.40
16	4313	206.50	403.70
17	3001	190.61	375.10
18	3148	205.44	401.80
19	7533	200.89	393.60
20	7377	201.28	394.30
21	7371	237.06	458.70
22	6942	241.61	466.90
23	6267	237.50	459.50
24	6121	204.94	400.90
25	6001	204.44	400.00
26	15481	191.28	376.30
27	15941	208.06	406.50
28	16260	213.22	415.80
29	17311	180.56	357.00
30	11965	186.56	367.80
31	9785	217.89	424.20
32	9571	215.44	419.80
33	8197	200.72	393.30
34	15451	115.50	239.90
35	16160	114.22	237.60
36	17790	102.72	216.90
37	18750	93.83	200.90
38	11485	106.61	223.90
39	9900	236.33	457.40
40	8673	660.00	1220.00
41	8225	698.33	1289.00

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1887	3.7294E+02	7.0330E+02
Bottom Plate	3001	3232	3001	2.2383E+02	4.3490E+02
Cask Lid	3233	3424	3329	2.2289E+02	4.3320E+02
Shell Cavity	4001	4998	4532	2.5939E+02	4.9890E+02
Cask Lid Plug	5001	5404	5001	2.2972E+02	4.4550E+02
Tungsten Alloy	6001	7656	6938	2.6200E+02	5.0360E+02
Bottom Cavity	4227	4236	4236	2.3072E+02	4.4730E+02
Side Cavity	4372	4702	4532	2.5939E+02	4.9890E+02
Top Cavity	5001	5012	5001	2.2972E+02	4.4550E+02
Lid Seal	4993	4993	4993	2.2344E+02	4.3420E+02
Cask Vent Port	2537	2537	2537	2.2494E+02	4.3690E+02
Cask Vent Port Seal	2533	2533	2533	2.2511E+02	4.3720E+02
Vt.Conic.Seal	4828	4828	4828	2.2389E+02	4.3500E+02
Cask Drain Port	583	583	583	2.2689E+02	4.4040E+02
Cask Drain Port Seal	579	579	579	2.2700E+02	4.4060E+02
Drn.Conic.Seal	4313	4313	4313	2.2428E+02	4.3570E+02
Test Port	3351	3351	3351	2.2278E+02	4.3300E+02

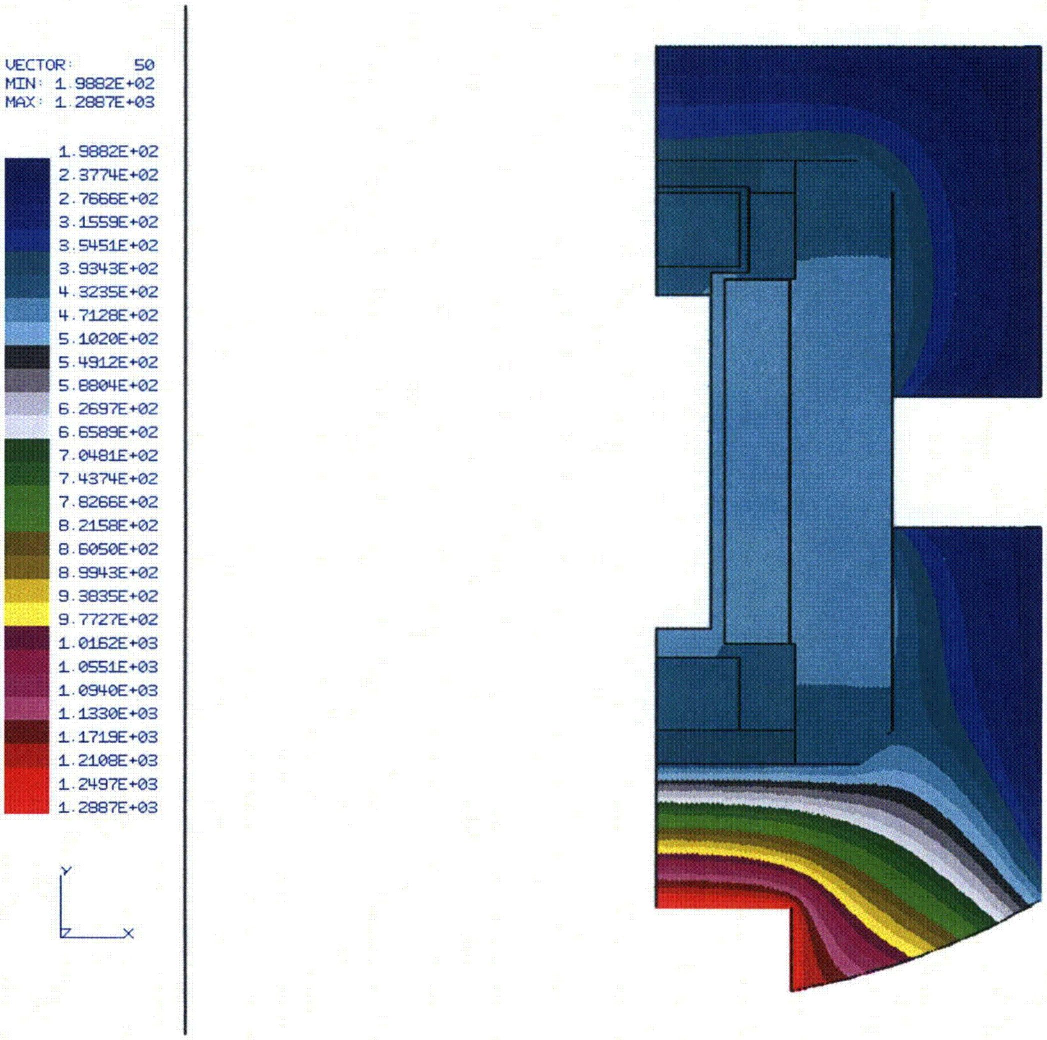

Figure 3-50. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A

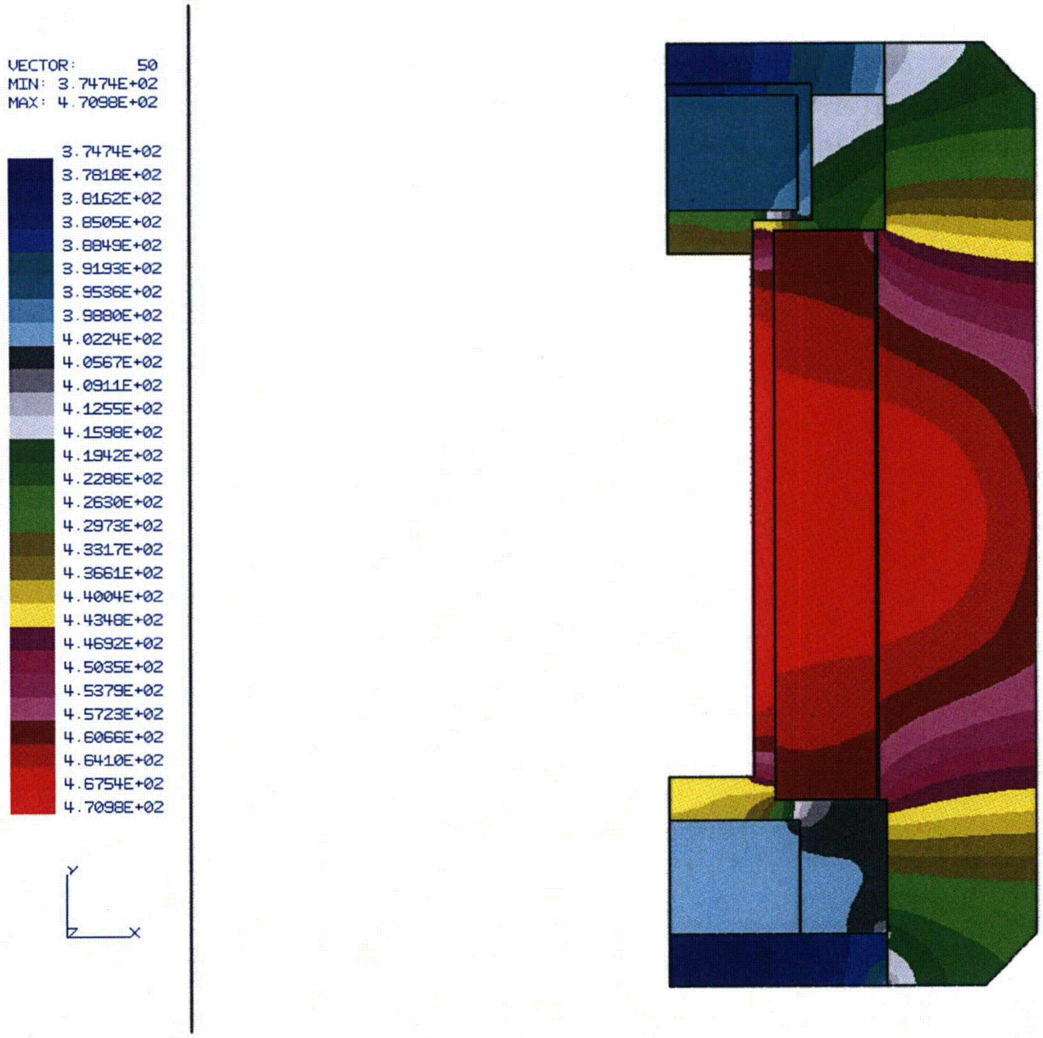

Figure 3-51. Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A

Table 3-43. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A

Location	Node	Temp(C)	Temp(F)
1	5001	228.50	443.30
2	4532	231.50	448.70
3	4227	228.94	444.10
4	4752	227.17	440.90
5	4838	223.94	435.10
6	4993	222.06	431.70
7	3309	216.17	421.10
8	3351	218.17	424.70
9	678	228.61	443.50
10	2537	224.50	436.10
11	2533	224.61	436.30
12	4828	223.39	434.10
13	1888	223.44	434.20
14	583	226.06	438.90
15	579	226.11	439.00
16	4313	220.11	428.20
17	3001	214.06	417.30
18	3148	220.06	428.10
19	7533	218.61	425.50
20	7377	218.78	425.80
21	7371	228.39	443.10
22	6942	229.39	444.90
23	6267	228.89	444.00
24	6121	219.56	427.20
25	6001	219.39	426.90
26	15481	213.83	416.90
27	15941	219.56	427.20
28	16260	220.89	429.60
29	17311	172.11	341.80
30	11965	179.39	354.90
31	9785	223.94	435.10
32	9571	224.61	436.30
33	8197	220.50	428.90
34	15451	115.17	239.30
35	16160	113.22	235.80
36	17790	100.56	213.00
37	18750	89.56	193.20
38	11485	104.44	220.00
39	9900	178.61	353.50
40	8673	496.44	925.60
41	8225	556.67	1034.00

Maximum Component Temperatures

Component	Node_1	Node_2	Node	Max_Temp(C)	Max_Temp(F)
Cask Outer Shell	101	2894	1887	3.7294E+02	7.0330E+02
Bottom Plate	3001	3232	3001	2.2383E+02	4.3490E+02
Cask Lid	3233	3424	3329	2.2289E+02	4.3320E+02
Shell Cavity	4001	4998	4532	2.5939E+02	4.9890E+02
Cask Lid Plug	5001	5404	5001	2.2972E+02	4.4550E+02
Tungsten Alloy	6001	7656	6938	2.6200E+02	5.0360E+02
Bottom Cavity	4227	4236	4236	2.3072E+02	4.4730E+02
Side Cavity	4372	4702	4532	2.5939E+02	4.9890E+02
Top Cavity	5001	5012	5001	2.2972E+02	4.4550E+02
Lid Seal	4993	4993	4993	2.2344E+02	4.3420E+02
Cask Vent Port	2537	2537	2537	2.2494E+02	4.3690E+02
Cask Vent Port Seal	2533	2533	2533	2.2511E+02	4.3720E+02
Vt.Conic.Seal	4828	4828	4828	2.2389E+02	4.3500E+02
Cask Drain Port	583	583	583	2.2689E+02	4.4040E+02
Cask Drain Port Seal	579	579	579	2.2700E+02	4.4060E+02
Drn.Conic.Seal	4313	4313	4313	2.2428E+02	4.3570E+02
Test Port	3351	3351	3351	2.2278E+02	4.3300E+02

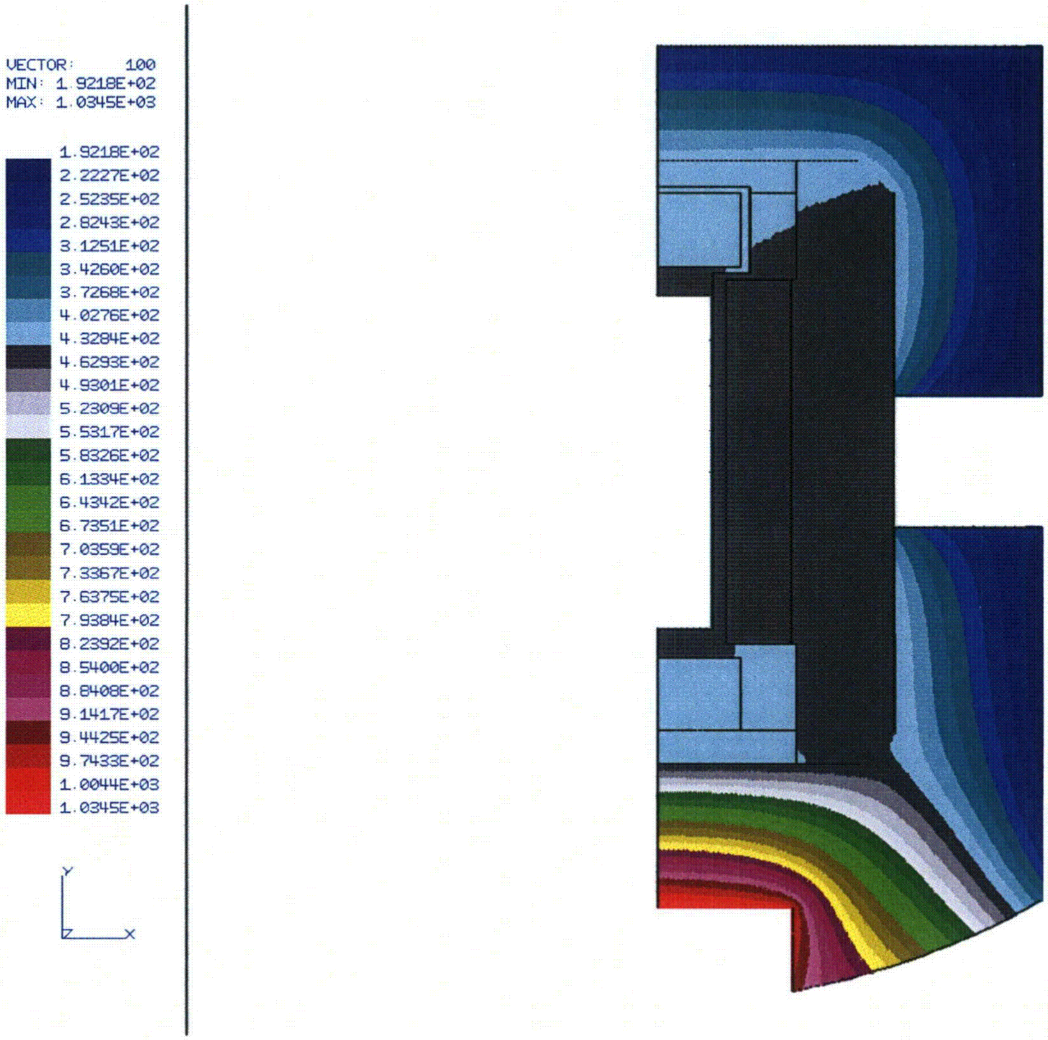

Figure 3-52. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A

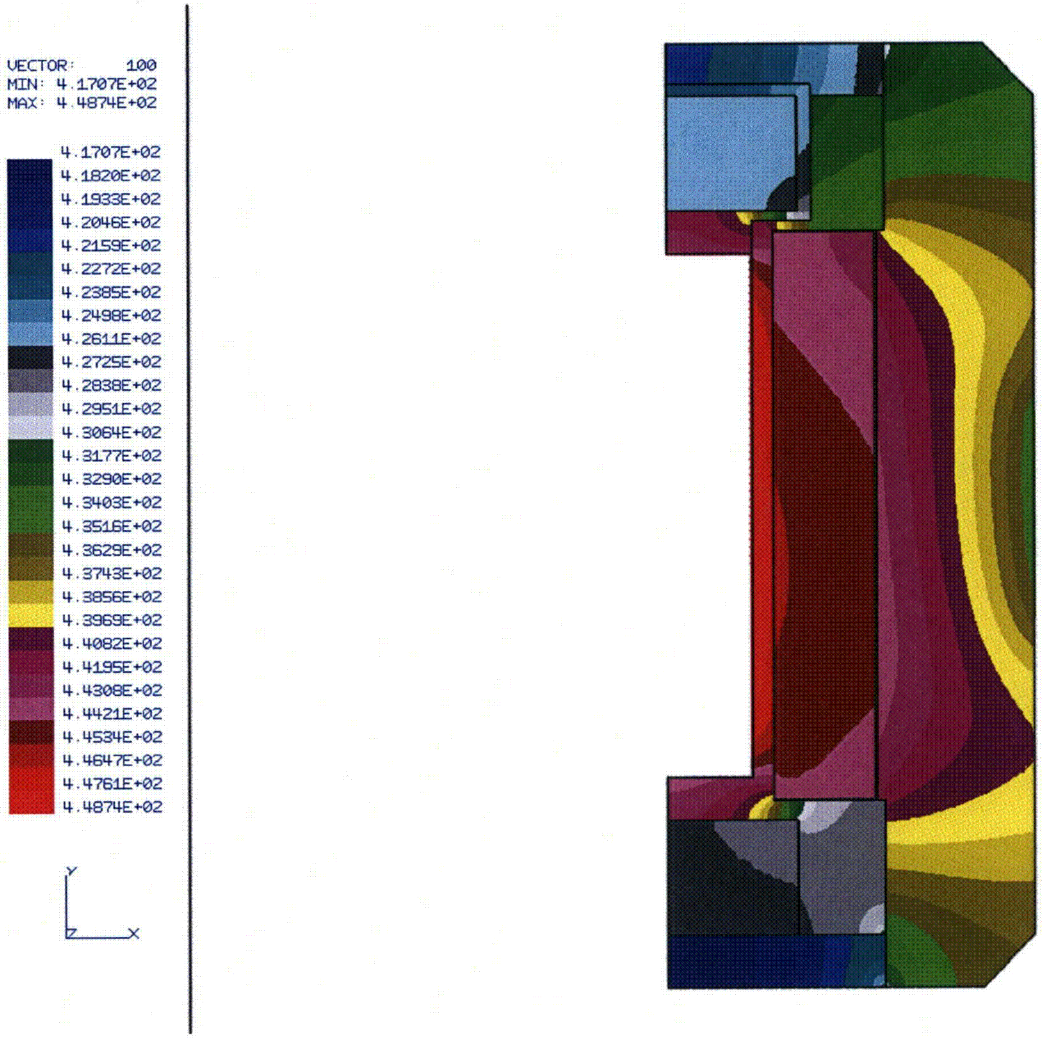

Figure 3-53. Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A