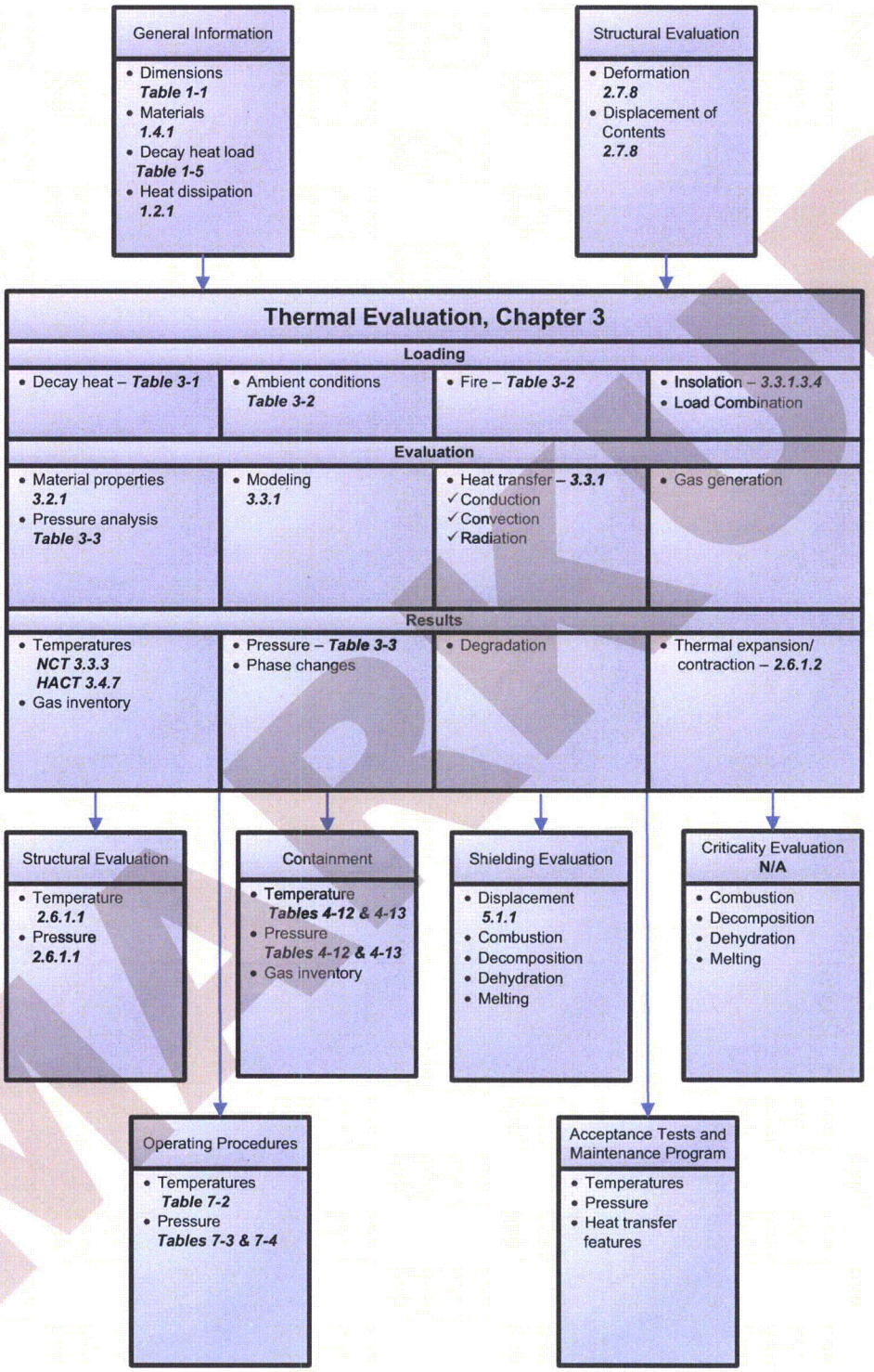
# 3 THERMAL EVALUATION

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***Note:*** *Unless indicated otherwise, all information related to the Model AOS-100A is also applicable to the Model AOS-100A-S.*

The objective of the thermal evaluation is to determine the temperature distribution in the transport package, which occurs during Normal and Hypothetical Accident conditions of transport. Additionally, the thermal evaluation verifies that the transport packages meet the performance requirements specified by *10 CFR 71* **[3.1]** and *IAEA TS-R-1* **[3.2]**, and establishes the temperature effects on the package components and their performance, because these effects relate to the safe transport of radioactive material.

## 3.1 DESCRIPTION OF THERMAL DESIGN

The AOS Transport Packaging System is designed with a thermally passive system. The cask component is enclosed at both ends by an overpack or impact limiter structure, which functions as a thermal shield and mitigates regulatory impact loads. Table 3-1 summarizes the dimensions and typical contents of each AOS Transport Packaging System model. The impact limiter consists of a thin-walled cylindrical shell, with a flat disk at one end and a dish head at the other end. On the flat disk side, there is cylindrical recess, with an internal profile identical to that of the cask profile, which accommodates the cask during transport. Twelve (12) squared ribs are attached to the inside wall cylindrical resection. Eight (8) of these ribs extend beyond the flat disk plate, to be used as turnbuckle attachment points. At the dish head end, there is also a resection, created to reduce the area available for impact during a head-on drop. The impact limiter shell is filled with rigid, closed-cell, polyurethane foam material.

Figure 3-1 presents an isometric view of the Model AOS-100A/AOS-100A-S packaging. This impact limiter design applies to Models AOS-050, AOS-100, and AOS-165. For the Model AOS-025, the impact limiter is extended to the center of the package, enclosing the cask component completely, and the turnbuckles are replaced by eight (8) hook connectors.

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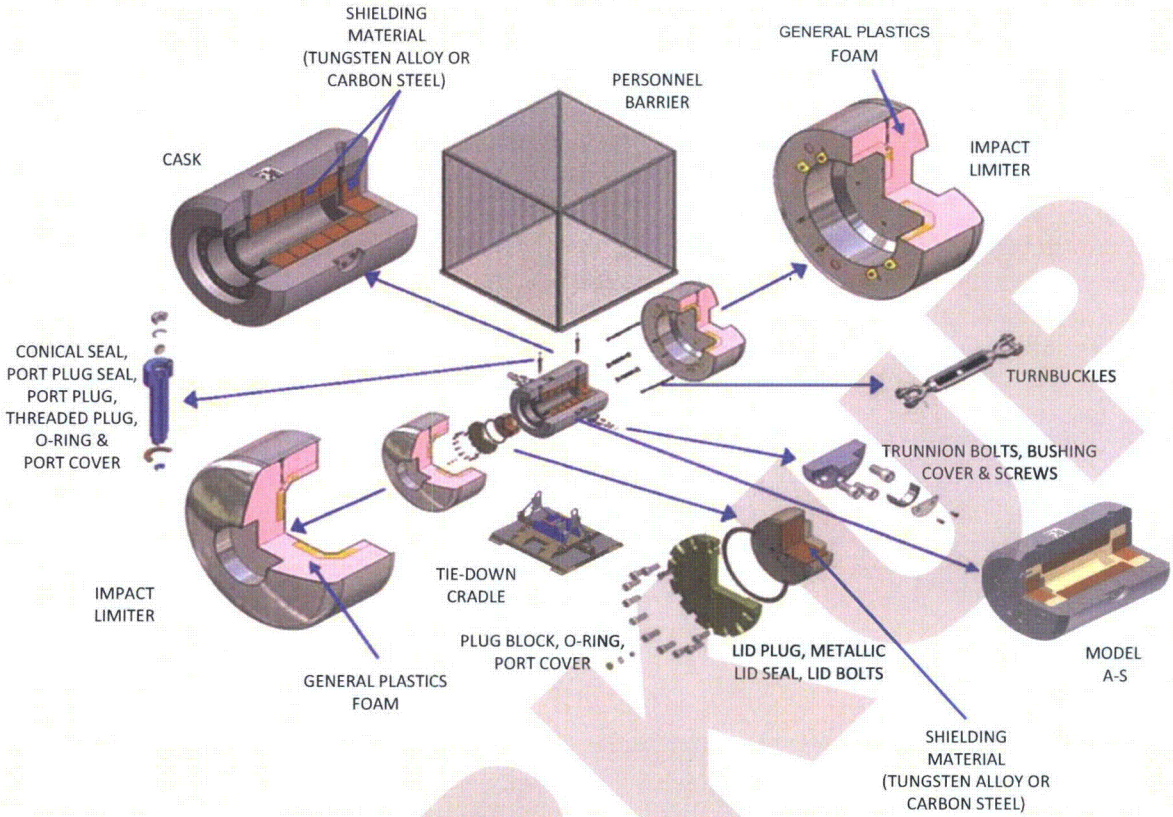


**Figure 3-1. Transport Package, Isometric View – Models AOS-100A and AOS-100A-S**

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The temperature distributions for the AOS Transport Packaging System models are determined for the thermal environments listed in Table 3-2.

All conditions were analyzed using the LIBRA Finite Element program, with the exception of Conditions 5 and 7, where uniform temperature fields of -40°C (-40°F) and -28.9°C (-20°F) 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 performed 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 the Model AOS-165A transport package. In this test, a 7-kW electrical heat source was placed in the cask cavity. The cask was then closed and placed into a pit. Placing the cask inside the pit helped to maintain the environment temperature as constant as possible. Temperatures inside and outside of the cask, as well as the ambient temperature inside the pit, were recorded during the cask's heating and cooling cycle. Refer to Chapter 8, Appendix 8.3.1, "Heat Test Report," for a detailed account of the heat test and its results.

Condition 3, fire transient, analysis is initiated at the steady-state Condition 1, in which the maximum solar load is applied. The maximum decay heat of each of the AOS Transport Packaging System models is distributed across the cask cavity surface. Table 3-3 presents the resulting pressure due to thermal load compared to design pressure, for each AOS Transport Packaging System model. Table 3-4 lists selected nodal temperatures determined by each analyses within a regulatory environment, as well as each component's thermal criteria, by model.

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## Table 3-1. AOS Transport Packaging System Summary – All Models

| Model | Category | Dimensions (cm / in.) | | | | | | Content | | | | Weight (kg / lbs.) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Packaging | | Cask | | Cavity | | | | | | | | | |
| | | OD | Height | OD | Height | OD | Height | Radioisotope[a], TBq / Ci | | Fissile Materials, U-235 eq/Bup/ Cool | Decay Heat, Watts | Packaging[b] | Cask | Limiters | Content |
| AOS-025A | III | 28.96 | 39.62 | 17.78 | 22.86 | 4.14 | 12.70 | 5.3 | Ir-192 | – | 10 | 71.4 | 53.6 | 11 | 6.8 |
| | | 11.40 | 15.60 | 7.00 | 9.00 | 1.63 | 5.00 | 148 | | | | 157 | 118 | 24 | 15 |
| AOS-050A | III | 57.96 | 79.25 | 35.56 | 45.72 | 8.26 | 25.40 | 555 | Ir-192 | – | 100 | 511 | 431.2 | 52.6 | 27.2 |
| | | 22.82 | 31.20 | 14.00 | 18.00 | 3.25 | 10.00 | 981 | | | | 1,126 | 950 | 116 | 60 |
| AOS-100A | II | 115.93 | 158.50 | 71.12 | 91.44 | 16.51 | 50.80 | 720 | Co-60 | – | 400 | 3,950 | 3,451 | 272 | 227 |
| | | 45.64 | 62.40 | 28.00 | 36.00 | 6.50 | 20.00 | 20,000 | | | | 8,700 | 7,601 | 599 | 500 |
| AOS-100B | III | 115.93 | 158.50 | 71.12 | 91.44 | 16.51 | 50.80 | 6 | Co-60 | – | 400 | 3,232 | 2,823 | 272 | 227 |
| | | 45.64 | 62.40 | 28.00 | 36.00 | 6.50 | 20.00 | 162 | | | | 7,125 | 6,218 | 600 | 500 |
| AOS-100A-S | II | 115.93 | 158.50 | 71.12 | 91.44 | 16.51 | 50.80 | 720 | Co-60 | – | 400 | 3,901 | 3,402 | 272 | 227 |
| | | 45.64 | 62.40 | 28.00 | 36.00 | 6.50 | 20.00 | 20,000 | | | | 8,600 | 7,500 | 600 | 500 |
| AOS-165A | I | 191.26 | 264.16 | 117.35 | 150.88 | 27.23 | 83.82 | 16,200 | Co-60 | – | 7,000 | 18,234 | 14,968 | 2,268 | 998 |
| | | 75.30 | 104.00 | 46.20 | 59.40 | 10.72 | 33.00 | 450,000 | | | | 40,200 | 33,000 | 5,000 | 2,200 |
| AOS-165B | I | 191.26 | 264.16 | 117.35 | 150.88 | 27.23 | 83.82 | 5,910 | Co-60 | – | 2,500 | 15,535 | 12,270 | 2,268 | 998 |
| | | 75.30 | 104.00 | 46.20 | 59.40 | 10.72 | 33.00 | 16,300 | | | | 34,250 | 27,050 | 5,000 | 2,200 |

*a. Representative isotope. Additional isotopes are authorized for shipment in the AOS Transport Packaging System.*

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

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**Table 3-2. *Transport Package Thermal Environment Conditions – All Models***

| Condition | Thermal Environment |
|---|---|
| 1 | 37.8°C (100°F) ambient with maximum decay heat and maximum solar load. |
| 2 | 37.8°C (100°F) ambient with maximum decay heat. |
| 3 | Fire transient, t = 0 to 3.0 hours. |
| 4 | -40°C (-40°F) ambient with maximum decay heat. |
| 5 | -40°C (-40°F) ambient. |
| 6 | -28.9°C (-20°F) ambient with maximum decay heat. |
| 7 | -28.9°C (-20°F) ambient. |

**Table 3-3. Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models**

| Model | Volume | | Temperature (T)[a] | | Pressure (P)[b] | | | Design Pressure[c] | |
|---|---|---|---|---|---|---|---|---|---|
| | l | in³ | °C | °F | kPa | psia | | kPa | psia |
| AOS-025 | 0.17 | 10 | 99 | 210 | 126 | 18 | < | 207 | 30 |
| AOS-050 | 1.36 | 83 | 128 | 263 | 136 | 20 | < | 414 | 60 |
| AOS-100A<br>AOS-100A-S | 11.21 | 684 | 126 | 258 | 135 | 20 | < | 1,931 | 280 |
| AOS-100B | 11.21 | 684 | 126 | 259 | 135 | 20 | < | 1,931 | 280 |
| AOS-165A | 49 | 2,978 | 365 | 689 | 209 | 30 | < | 1,517 | 220 |
| AOS-165B | 49 | 2,978 | 202 | 395 | 209 | 30 | < | 1,517 | 220 |

*a. Temperatures listed are the maximum values obtained throughout Normal conditions of transport events.*

*b. Pressure calculation is based upon the ideal gas law, where:*

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

**Initial Condition**

$P_1 = 14.7$ psia

$T_1 = 78°F$

**Final Condition**

$P_2 = ?$

$T_2 = 256°F$

$$P_2 = \frac{(256 + 460)}{(78 + 460)} * 14.7 = 19.56 \text{ psia}$$

*c. **Model AOS-100 and AOS-165 transport packages** – Pressure value is based upon projected operating conditions.*

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

| Model | Component[a] | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[c] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-025A | Cask Cavity | 99 | 210 | 60 | 141 | 149 | 300 | -15 | 5 | -40 | -40 | -4 | 24 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 98 | 209 | 60 | 140 | 149 | 299 | -16 | 3 | -40 | -40 | -5 | 23 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 98 | 208 | 59 | 139 | 148 | 299 | -16 | 3 | -40 | -40 | -5 | 22 | -29 | -20 | 300°C (572°F) Metallic Seal |
| | Cask Test Port | 98 | 208 | 59 | 139 | 148 | 299 | -16 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Drain Port | 98 | 208 | 59 | 138 | 147 | 297 | -17 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Vent Port | 98 | 208 | 59 | 139 | 149 | 300 | -16 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Outside Surface | 98 | 208 | 59 | 138 | 147 | 297 | -16 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 400°C (752°F) |
| | Impact Limiter Foam Material | 98 | 208 | 59 | 139 | 214 | 417 | -16 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 137°C (279°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[d] | 87 | 189 | 43 | 110 | 797 | 1,467 | -34 | -29 | -40 | -40 | -23 | -9 | -29 | -20 | 50°C (122°F) Non-Exclusive Use<br>85°C (185°F) Exclusive Use – Condition 2 |

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**Table 3-4. Transport Package Temperature Summary – All Models (Continued)**

| Model | Component[a] | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[c] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-050A | Cask Cavity | 128 | 263 | 92 | 198 | 205 | 401 | 18 | 65 | -40 | -40 | 29 | 84 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 125 | 257 | 89 | 193 | 218 | 425 | 15 | 60 | -40 | -40 | 26 | 79 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 123 | 254 | 88 | 190 | 200 | 392 | 13 | 56 | -40 | -40 | 24 | 76 | -29 | -20 | 300°C (572°F) Metallic Seal |
| | Cask Test Port | 123 | 253 | 87 | 188 | 200 | 393 | 13 | 55 | -40 | -40 | 24 | 74 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Drain Port | 124 | 254 | 87 | 189 | 201 | 393 | 13 | 55 | -40 | -40 | 24 | 75 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Vent Port | 123 | 254 | 88 | 190 | 199 | 391 | 13 | 56 | -40 | -40 | 24 | 76 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Outside Surface | 122 | 252 | 86 | 187 | 374 | 706 | 12 | 53 | -40 | -40 | 22 | 72 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Impact Limiter Foam Material | 124 | 255 | 88 | 190 | 289 | 553 | 14 | 57 | -40 | -40 | 24 | 76 | -29 | -20 | 137°C (279°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[d] | 95 | 202 | 41 | 106 | 799 | 1,471 | -36 | -33 | -40 | -40 | -26 | -14 | -29 | -20 | 50°C (122°F) Non-Exclusive Use<br>85°C (185°F) Exclusive Use – Condition 2 |

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**Table 3-4. Transport Package Temperature Summary – All Models (Continued)**

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

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**Table 3-4. Transport Package Temperature Summary – All Models (Continued)**

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

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**Table 3-4. Transport Package Temperature Summary – All Models (Continued)**

| Model | Component[a] | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[c] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-165A (7 kW Maximum Decay Heat) | Cask Cavity | 365 | 689 | 344 | 652 | 375 | 707 | 277 | 531 | -40 | -40 | 288 | 550 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 329 | 623 | 307 | 585 | 348 | 658 | 239 | 462 | -40 | -40 | 250 | 482 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 304 | 580 | 283 | 541 | 326 | 619 | 212 | 414 | -40 | -40 | 224 | 435 | -29 | -20 | 427°C (800°F) Metallic Seal |
| | Cask Test Port | 289 | 553 | 268 | 514 | 314 | 597 | 197 | 386 | -40 | -40 | 208 | 406 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Drain Port | 290 | 555 | 269 | 516 | 315 | 598 | 198 | 388 | -40 | -40 | 209 | 408 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Vent Port | 305 | 580 | 283 | 541 | 326 | 619 | 213 | 415 | -40 | -40 | 224 | 435 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Outside Surface | 266 | 510 | 243 | 470 | 522 | 972 | 170 | 338 | -40 | -40 | 182 | 359 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Inside Surface | 311 | 592 | 290 | 554 | 652 | 1,206 | 220 | 428 | -40 | -40 | 231 | 448 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[d] | 80 | 176 | 42 | 108 | 798 | 1,469 | -36 | -32 | -40 | -40 | -24 | -12 | -29 | -20 | 50°C (122°F) Non-Exclusive Use<br>85°C (185°F) Exclusive Use – Condition 2 |

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**Table 3-4. Transport Package Temperature Summary – All Models (Continued)**

| Model | Component[a] | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[c] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-165B (2.5 kW Maximum Decay Heat) | Cask Cavity | 202 | 395 | 172 | 341 | 232 | 449 | 95 | 203 | -40 | -40 | 106 | 123 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 187 | 369 | 157 | 315 | 227 | 441 | 79 | 175 | -40 | -40 | 91 | 196 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 177 | 350 | 146 | 296 | 204 | 400 | 67 | 153 | -40 | -40 | 79 | 175 | -29 | -20 | 204°C (400°F) |
| | Cask Test Port | 171 | 339 | 140 | 285 | 202 | 395 | 61 | 142 | -40 | -40 | 73 | 163 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Drain Port | 171 | 340 | 141 | 285 | 200 | 393 | 61 | 143 | -40 | -40 | 73 | 164 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Vent Port | 177 | 350 | 146 | 296 | 204 | 399 | 67 | 153 | -40 | -40 | 79 | 175 | -29 | -20 | 232°C (450°F) Elastomeric Seal |
| | Cask Outside Surface | 162 | 324 | 131 | 268 | 452 | 846 | 50 | 122 | -40 | -40 | 62 | 144 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Inside Surface | 180 | 355 | 149 | 301 | 631 | 1,167 | 70 | 159 | -40 | -40 | 82 | 180 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[d] | 80 | 176 | 40 | 103 | 798 | 1,469 | -38 | -37 | -40 | -40 | -27 | -16 | -29 | -20 | 50°C (122°F) Non-Exclusive Use<br>85°C (185°F) Exclusive Use – Condition 2 |

a. *Maximum temperature for these components anywhere in the Transport Packaging System model are provided in all Load Case tables, located throughout this chapter.*

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

c. *Temperature listed is the maximum value obtained throughout Fire conditions of transport.*

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

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## 3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

The thermal properties of each material are provided in the following sections. 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.

### 3.2.1 Material Properties

The transport packages consist of four materials:

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

Each is described in the paragraphs that follow.

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### 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.

**Table 3-5. Type 304 Stainless Steel (SS304) Thermophysical Properties – All Models**

| Temperature (°C) | Diffusivity $\alpha$ ($m^2$/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 |

Specific Heat, $C_p$ (Btu/lb-°F)

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

$$C_p(T) = 1.120 * 10^{-1} + 3.504 * 10^{-5}T - 1.080 * 10^{-8}T^2$$

Conductivity, K (Btu/hr-in-°F)

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

Density, $\rho$(lb/in$^3$)

$$\rho = 0.29$$

***Note:*** *Refer also to Appendix 3.5.5, "Material Properties Correlation between the Equations Provided in the Test and the LIBRA Input File."*

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### 3.2.1.2 Tungsten Alloy

Table 3-6 lists the thermophysical properties of tungsten alloy, as they apply to the transport packages.

**Table 3-6. Tungsten Alloy Thermophysical Properties – All Models**

| Temperature (°C) | Density $\rho$(g/cc) | Diffusivity $\alpha$ ($cm^2$/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 |

Density, $\rho$ (lb/in$^3$)

$$\rho = 0.654$$

Specific Heat, $C_p$ (Btu/lb-°F)

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

Conductivity, K (Btu/hr-in-°F)

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

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### 3.2.1.3 Carbon Steel

Table 3-7 lists the thermophysical properties of carbon steel SA105, as they apply to the Model AOS-100B and AOS-165B transport packages. Figure 3-2 illustrates the relationship between conductivity and temperature for the carbon steel material.

**Table 3-7. Carbon Steel Properties**

| 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 |

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Density = 7,832.8 kg/m$^3$

= 0.283 lb/in$^3$

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

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

*where:*

K = Conductivity - Btu/hr-in-°F

T = Temperature - °F

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

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

*where:*

Cp = Specific heat - Btu/lb-°F

T = Temperature, °F

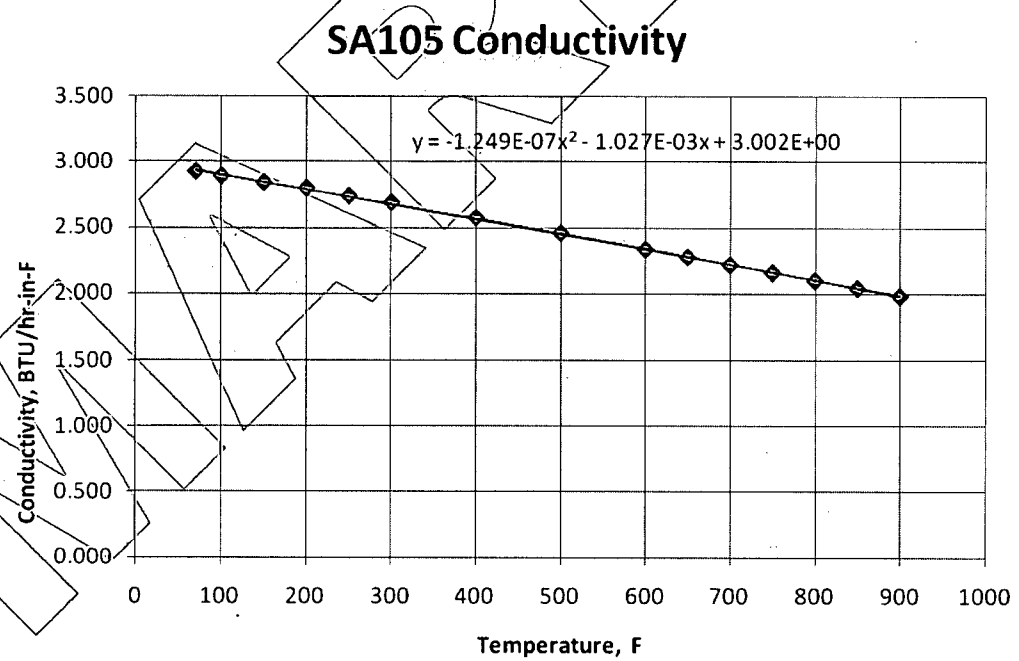


**Figure 3-2. Carbon Steel Conductivity (~ 0.5% Carbon) – Model AOS-100B**

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### 3.2.1.4 LAST-A-FOAM FR-3700

Table 3-8 lists the thermophysical properties of each General Plastics LAST-A-FOAM type used within the FR-3700 family. Table 3-9 lists the foam density used for each transport package model.

Justification for the use of these properties is presented in Appendix 3.5.10, "Justification for Use of LAST-A-FOAM 3700 Thermal Properties."

**Table 3-8. LAST-A-FOAM Thermophysical Properties – All Models**

| LAST-A-FOAM | Density ($kg/m^3$) | Conductivity (W/m-°C) | Specific Heat (KJ/kg-°C) |
|---|---|---|---|
| FR-3710 | 160.18 | 0.0402 | – |
| FR-3712 | 192.22 | – | 1.477 |
| FR-3718 | 288.32 | 0.0513 | – |
| FR-3720 | 320.36 | 0.0542 | – |

**Table 3-9. Transport Package Foam Density – All Models**

| Model | Density ($kg/m^3$) |
|---|---|
| AOS-025 | 320.36 |
| AOS-050 | 160.18 |
| AOS-100 | 192.22 |
| AOS-165 | 288.32 |

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### 3.2.1.5 Air

Table 3-10 lists the thermophysical properties of air, as they apply to the transport packages.

**Table 3-10. Air Thermophysical Properties – All Models**

| Temperature | | Density | Dynamic Viscosity | Specific Heat | Conductivity | Prandtl Number |
|---|---|---|---|---|---|---|
| °C | °F | $\rho$(kg/m$^3$) | $\mu * 10^{-7}$ (N-sec/m$^2$) | $C_p$ (KJ/kg-K) | K * $10^{-3}$ (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 |

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

Density, $\rho$(lb/in$^3$)

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

Specific Heat, $C_p$ (Btu/lb-°F)

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

Conductivity, K (Btu/hr-in-°F)

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

Prandtl Number, Pr

$$Pr(T) = 0.7232 - 1.954 * 10^{-4}T + 2.820 * 10^{-7}T^2 - 1.002 * 10^{-10}T^3$$

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### 3.2.2 Component Technical Specifications

The component material within the transport package, considered to be temperature-sensitive, is the elastomeric material used in the port plug O-Rings. The elastomeric material is a silicone-based compound (Parker Silicon, 51224-70 compound, or equivalent), with a recommended temperature limit of 232°C (450°F).

Other package materials used are stainless steel and tungsten alloy. The melting points of these materials are 1,430°C (2,606°F) and 3,370°C (6,098°F), respectively. All temperatures resulting from Normal and Hypothetical Accident thermal conditions are well below these temperature limits; therefore, melting of these metals will not occur.

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## 3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

Figure 3-3 illustrates the LIBRA Finite Element model of the Model AOS-100 transport package, which consists of 8,368 nodes and 7,820 elements. This model is used for all Normal conditions of transport, and includes the cask and impact limiter structures. The encapsulated tungsten alloy shielding material is included in the cask model. Because an axisymmetric (2D) solution is used, only a cross-section of the package must be modeled. The model includes both conductive two-node axial and four-node quadrilateral elements. Also, the boundary two-node element type is used. Air is represented to account not only for temperature variation, but also for different heat transfer modes. The mode of heat transfer across an air space varies, depending upon whether the air space is:

- Enclosed or open
- Vertically or horizontally oriented

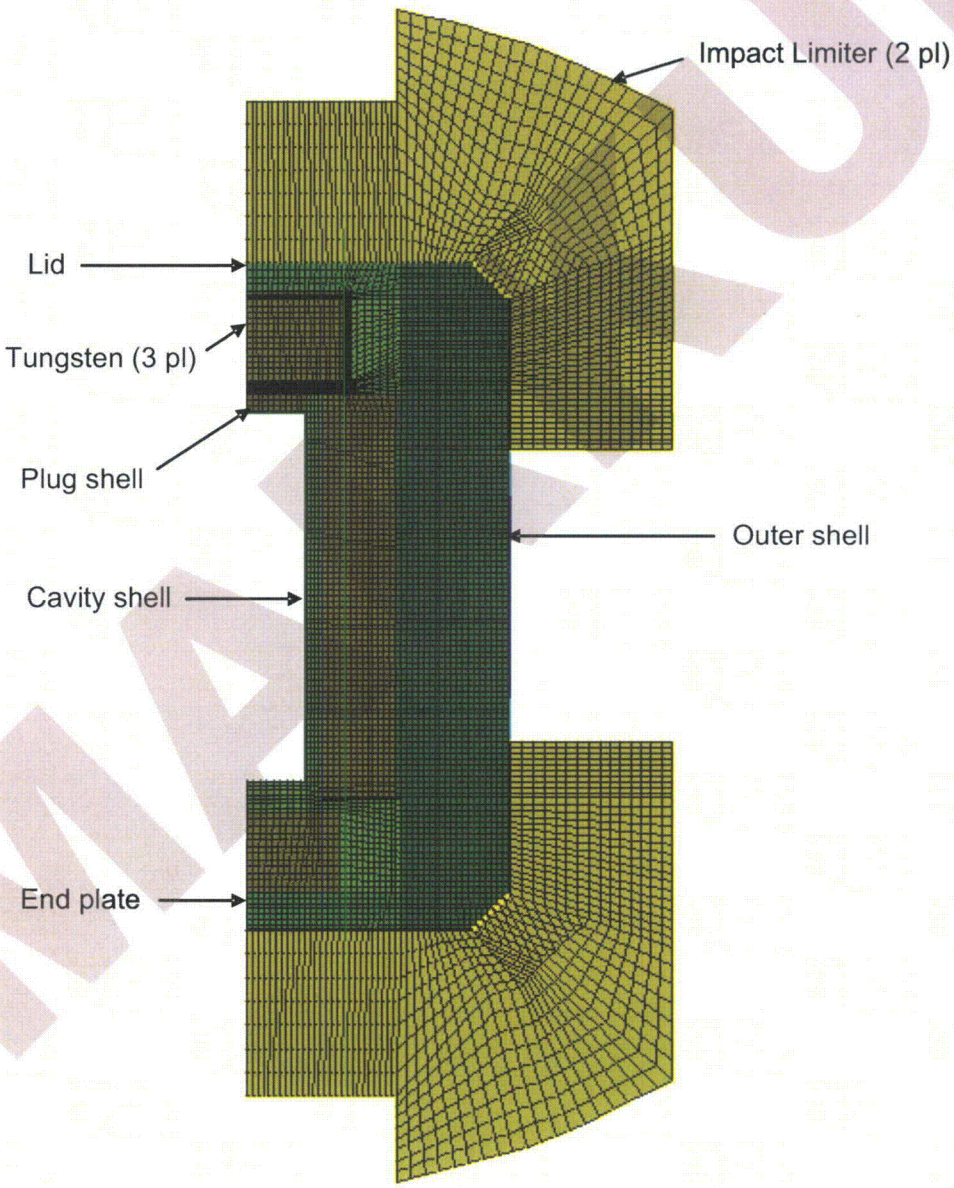


**Figure 3-3. Thermal Finite Element Model – Normal Conditions of Transport**

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### 3.3.1 Analytical Model

The thick stainless steel outside shell, which comprises the bulk of the cask, defines the outside dimensions of the cask. The cask cavity is defined by the cavity shell, which is secured to the outside shell. The cavity shell defines the surface of the cask cavity. The plug shell is secured by the cask lid and cavity shell. Four-node quadrilateral conduction elements are used to model the outside shell, cavity shell, and plug shell. Also, the end plate and lid are modeled with four-node quadrilateral conduction elements.

The side tungsten alloy shielding is encapsulated by the outside and cavity shells. The vertical wall between the tungsten alloy and outside shell is packed with stainless steel wool, and between the tungsten alloy and cavity shell, an air gap exists. At the top and bottom horizontal surfaces, existing gaps with the 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.

The bottom tungsten alloy shielding is encapsulated by the cavity shell and end plate. The top and bottom horizontal surfaces have zero gaps, and heat transfer across these interfaces by a low-pressure, surface-contact resistance. The gap between the shielding vertical side wall and the cavity shell is packed with stainless steel wool. The top tungsten alloy shielding is completely encapsulated by the plug shell. In a manner similar to the bottom shielding, the shielding top and bottom horizontal surfaces have zero gaps, and heat transfer through these interfaces by a low-pressure, surface-contact resistance. A gap between the vertical side wall and 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. All zero-gap surface thermal contact resistances, $1/h_c$, use a value of 0.03 hr-in$^2$-°F/Btu (Reference **[3.10]**). 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 |
| 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. Outside shell, and upper section of the cavity shell and lid.
2. Cavity shell and plug shell lower section.
3. Cavity shell and plug shell upper section.
4. Plug shell top horizontal surface and lid.
5. Outside shell corner and side, impact limiter.
6. Cavity shell and tungsten alloy.

All air gaps are vertical, with the exception of air gap No. 4, which is horizontal. (Refer to Paragraph 3.3.1.2.)

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The impact limiter structure is a doughnut-shaped axisymmetric (2D) structure. Its stainless steel outside shell is modeled with two-node conduction elements. The interior is filled with General Plastics LAST-A-FOAM material and modeled with four-node quadrilateral elements.

Other surface interfaces, between cask components, are assembled with zero gap and are modeled with two-node conduction elements that have pressure surface-contact resistance properties of 0.03 hr-in$^2$°F/Btu (Reference **[3.10]**).

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

Convective boundary elements define the convective and radiative properties at the interface between the impact limiter outside surface and the regulatory environments. Another convective surface is located on the side of the cask's outside shell, between the upper and lower impact limiter structures. 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.

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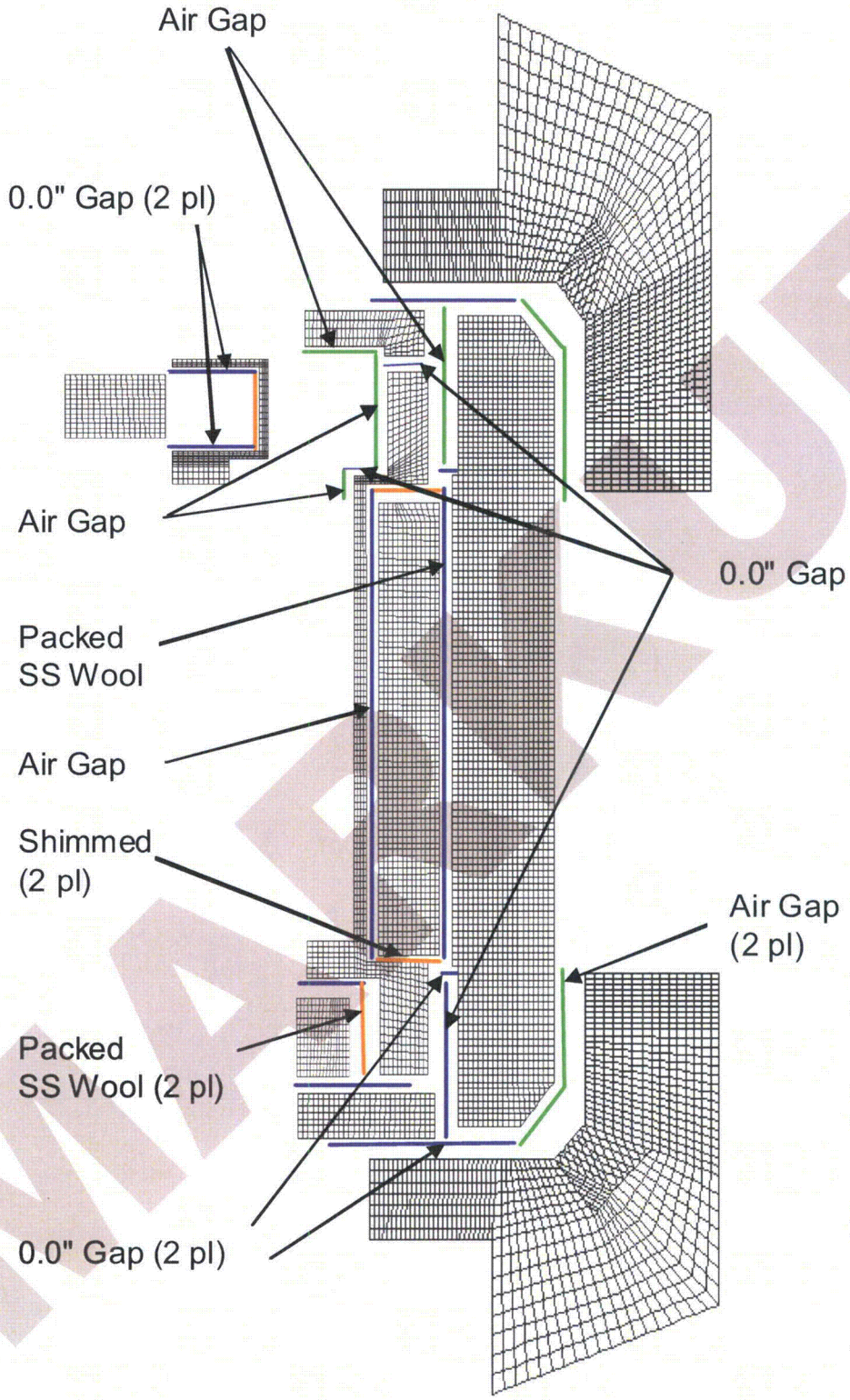


**Figure 3-4. Expanded View of Thermal Model Defining Component Interfaces**

### 3.3.1.1 Heat Flux Property Set

Convective boundary elements, located in the model's cask cavity, define the prescribed heat flux due to decay heat. The maximum heat load for the Model AOS-100 transport package is 400W. As discussed in Subsection 3.3.1, this load is applied as a uniform surface heat flux to the entire cavity surface area. Its value is calculated as follows:

$$q = \frac{Q}{A} = \frac{(400)}{(2\pi)\left[(0.0838)^2 + (0.0838)(0.508)\right]}$$

$$= 1{,}283.69 \text{ W/m}^2$$

The justification for this approach is presented in Appendix 3.5.9, "Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity."

### 3.3.1.2 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:

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

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

*where:*

Nu = Nusselt Number

Gr = Grashof Number, based upon S

S = Distance across enclosed space

H = Height of enclosed space

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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:*

$\rho$ = Density, kg/m$^3$

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

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

$\Delta T$ = Temperature difference across enclosure (°C)

$\mu$ = Dynamic viscosity (kg/m-s)

$\nu$ = Kinematic viscosity (m$^2$/s) = μ/ρ

T = Absolute temperature (°K)

The above correlation between Nu and Gr applies to an air space enclosed between plates. In general, a curved surface can be considered flat without significant error, if according to Gebhart **[3.6]**:

$$\frac{D}{L} \geq \frac{35}{\sqrt[4]{Gr_L}}$$

*where:*

D = Diameter

L = Height

$Gr_L$ = Grashof Number, based upon height

Table 3-11 lists air gaps 1, 2, 3, 5, and 6, with a temperature of 300°K (26.85°C; 80.33°F), and a $\Delta T$ = 5.6°C (42.08°F). These values indicate the correlation applicable to the vertical air gap geometries.

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**Table 3-11. Correlation Applicable to Vertical Air Gap Geometries – Model AOS-165[a]**

| Air Gap | Air Gap (mm) | D (m) | L (m) | $\frac{D}{L} \geq \frac{35}{\sqrt[4]{Gr_L}}$ |
|---|---|---|---|---|
| 1 | 0.3 | 0.70 | 0.30 | 2.10 ≥ 0.52 |
| 2 | 0.4 | 0.27 | 0.05 | 5.10 ≥ 1.99 |
| 3 | 1.3 | 0.46 | 0.22 | 2.20 ≥ 0.65 |
| 5 | 5.1 | 1.17 | 0.42 | 2.80 ≥ 0.40 |
| 6 | 0.1 | 0.34 | 0.91 | 0.38 ≥ 0.23 |

a. *Values used in Table 3-11 are for the Model AOS-165 transport package. Results show the assumption that simple conduction should be adequate for this geometry.*

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:

$$Nu = 1.0 \qquad Gr < 2 * 10^4$$

$$Nu = 0.195 \sqrt[4]{Gr} \qquad 2 * 10^4 < Gr < 4 * 10^5$$

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

Properties are evaluated at the average of the two surface temperatures.

Regions of enclosed air space have small gaps, from 0.1 to 5.1 mm (0.005 to 0.200 in.). As a result, in all cases, Gr is less than 2,000 for temperatures less than 700°C (1,292°F). Therefore, the heat transfer process is simple conduction.

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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)

$\sigma$ = $5.669 * 10^{-8}$ ($W/m^2$-$K^4$)

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

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The 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 six material sets.

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 = Convective

S = Distance across the air space

In general, the effective conductivity across the air space, $k_a$, is due to conduction plus radiation. However, as previously discussed, a convective mode can arise, depending upon the Gr and/or the plates' temperatures. Therefore, $k_a$ can be as follows:

$$k_a = (k + h_r) * S$$

or

$$k_a = (h_c + h_r) * S$$

Table 3-12 lists the thermal properties used in the analysis as a function of temperature, for each AOS Transport Packaging System model.

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**Table 3-12. Thermal Properties Used in Analysis as Function of Temperature – All Models**

| Model | Air Gap | Effective Conductivity (Btu/hr-in-°F), Including Radiation | |
|---|---|---|---|
| | | S (in.) | k(T)[a] |
| AOS-025 | 1 | 0.0018 | $1.115E-3 + 2.072E-6T - 2.940E-10T^2$ |
| | 2 | 0.0024 | $1.116E-3 + 2.069E-6T - 2.601E-10T^2$ |
| | 3 | 0.0076 | $1.131E-3 + 2.037E-6T + 3.353E-11T^2$ |
| | 4 | 0.0047 | $1.123E-3 + 2.055E-6T - 1.302E-10T^2$ |
| | 5 | 0.0303 | $1.197E-3 + 1.899E-6T + 1.315E-9T^2$ |
| | 6 | 0.0008 | $1.112E-3 + 2.078E-6T - 3.505E-10T^2$ |
| AOS-050 | 1 | 0.0040 | $1.121E-3 + 2.059E-6T - 1.698E-10T^2$ |
| | 2 | 0.0050 | $1.124E-3 + 2.053E-6T - 1.133E-10T^2$ |
| | 3 | 0.0150 | $1.153E-3 + 1.992E-6T + 4.514E-10T^2$ |
| | 4 | 0.0090 | $1.135E-3 + 2.028E-6T + 1.126E-10T^2$ |
| | 5 | 0.0610 | $1.285E-3 + 1.712E-6T + 3.049E-9T^2$ |
| | 6 | 0.0020 | $1.115E-3 + 2.071E-6T - 2.827E-10T^2$ |
| AOS-100 | 1 | 0.0070 | $1.130E-3 + 2.041E-6T - 3.541E-13T^2$ |
| | 2 | 0.0100 | $1.138E-3 + 2.022E-6T + 1.691E-10T^2$ |
| | 3 | 0.0300 | $1.196E-3 + 1.900E-6T + 1.298E-9T^2$ |
| | 4 | 0.0190 | $1.164E-3 + 1.967E-6T + 6.773E-10T^2$ |
| | 5 | 0.1210 | $1.458E-3 + 1.346E-6T + 6.437E-9T^2$ |
| | 6 | 0.0030 | $1.118E-3 + 2.065E-6T - 2.262E-10T^2$ |
| AOS-165 | 1 | 0.0120 | $1.096E-3 + 2.455E-6T - 5.362E-10T^2 + 3.974E-13T^3$ |
| | 2 | 0.0160 | $1.103E-3 + 2.497E-6T - 4.437E-10T^2 + 4.645E-13T^3$ |
| | 3 | 0.0500 | $1.158E-3 + 2.859E-6T + 3.425E-10T^2 + 1.035E-12T^3$ |
| | 4 | 0.0310 | $1.127E-3 + 2.657E-6T - 9.688E-11T^2 + 7.160E-13T^3$ |
| | 5 | 0.2000 | $8.659E-4 + 6.990E-6T + 3.992E-10T^2 + 4.927E-12T^2$ |
| | 6 | 0.0050 | $1.684E-3 + 7.550E-7T + 7.256E-9T^2$ |

a. *Temperature unit is °F.*

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### 3.3.1.3 Boundary Property Sets

Transport packages are transported in a horizontal position, with the center axis of the package aligned in the direction of travel. Eleven (11) material property sets surround the cask assembly. These sets link the transport package with the external environment. Each set contains the film coefficient, ambient temperature, and solar heat flux values.

These eleven (11) material property sets define the cask thermal boundary. Each 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 given in Reference **[3.4]**. In general, convection coefficients are determined by finding the Nusselt Number, and then solving for h from the equation:

$$Nu = h * L / k$$

*where:*

h = Convective film coefficient

L = Characteristic length

k = Air conductive coefficient

The empirical formulations used to determine the Nusselt Numbers used in the cask analyses for the vertical and horizontal surfaces are presented in Paragraph 3.3.1.3.1 and Paragraph 3.3.1.3.2.

Convective film coefficient values are dependent upon the plate shape, size, and orientation. The film temperature is assumed as 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. The transport package horizontal surfaces are curved; however, lengths are relatively short compared to its radius. Therefore, it is assumed that these plates are flat and horizontal. For all models, Table 3-13 (Normal conditions of transport) and Table 3-14 (Fire conditions of transport) list, and Figure 3-5 illustrates, the assumed orientation, shape, and size of the cask assembly's eleven (11) external surfaces. (Refer also to Table 3-15 and Table 3-16.)

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**Table 3-13. Cask Assembly External Surface Orientation and Size, Normal Conditions of Transport – All Models**

| Model | Surface | Orientation | Length (m) | Width (m) |
|---|---|---|---|---|
| AOS-025 (Transported Vertical) | 1 | Bottom Horizontal | 0.091 | 0.091 |
| | 2 | Vertical | 0.051 | 0.030 |
| | 3 | Bottom Horizontal | 0.099 | 0.102 |
| | 4 | Vertical | 0.343 | 0.145 |
| | 9 | Top Horizontal | 0.099 | 0.102 |
| | 10 | Vertical | 0.051 | 0.030 |
| | 11 | Top Horizontal | 0.091 | 0.091 |
| AOS-050 (Transported Vertical) | 1 | Bottom Horizontal | 0.183 | 0.183 |
| | 2 | Vertical | 0.102 | 0.064 |
| | 3 | Bottom Horizontal | 0.198 | 0.196 |
| | 4 | Vertical | 0.290 | 0.282 |
| | 5 | Top Horizontal | 0.234 | 0.109 |
| | 6 | Vertical | 0.178 | 0.099 |
| | 7 | Bottom Horizontal | 0.234 | 0.109 |
| | 8 | Vertical | 0.290 | 0.282 |
| | 9 | Top Horizontal | 0.198 | 0.196 |
| | 10 | Vertical | 0.102 | 0.064 |
| | 11 | Top Horizontal | 0.183 | 0.183 |
| AOS-100 (Transported Horizontal) | 1 | Vertical | 0.360 | 0.360 |
| | 2 | Bottom Horizontal | 0.203 | 0.127 |
| | 3 | Vertical | 0.406 | 0.406 |
| | 4 | Top Horizontal | 0.584 | 0.457 |
| | 5 | Vertical | 0.457 | 0.229 |
| | 6 | Top Horizontal | 0.406 | 0.356 |
| | 7 | Vertical | 0.457 | 0.229 |
| | 8 | Top Horizontal | 0.584 | 0.457 |
| | 9 | Vertical | 0.406 | 0.406 |
| | 10 | Bottom Horizontal | 0.203 | 0.127 |
| | 11 | Vertical | 0.360 | 0.360 |

**Table 3-13. Cask Assembly External Surface Orientation and Size, Normal Conditions of Transport – All Models (Continued)**

| Model | Surface | Orientation | Length (m) | Width (m) |
|---|---|---|---|---|
| AOS-165 (Transported Horizontal) | 1 | Vertical | 0.597 | 0.597 |
| | 2 | Bottom Horizontal | 0.340 | 0.208 |
| | 3 | Vertical | 0.660 | 0.660 |
| | 4 | Top Horizontal | 0.958 | 0.765 |
| | 5 | Vertical | 0.775 | 0.366 |
| | 6 | Top Horizontal | 0.660 | 0.592 |
| | 7 | Vertical | 0.775 | 0.366 |
| | 8 | Top Horizontal | 0.958 | 0.765 |
| | 9 | Vertical | 0.660 | 0.660 |
| | 10 | Bottom Horizontal | 0.340 | 0.208 |
| | 11 | Vertical | 0.597 | 0.597 |

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**Table 3-14. *Cask Assembly External Surface Orientation and Size,* Fire Conditions of Transport – All Models**

| Model | Surface | Orientation | Length (m) | Width (m) |
|---|---|---|---|---|
| AOS-025 Fire Model (Transported Vertical) | 1 | Bottom Horizontal | 0.091 | 0.091 |
| | 2 | Vertical | 0.051 | 0.030 |
| | 3 | Bottom Horizontal | 0.091 | 0.084 |
| | 4 | Vertical | 0.294 | 0.130 |
| | 9 | Top Horizontal | 0.109 | 0.091 |
| | 10 | Vertical | 0.051 | 0.010 |
| | 11 | Top Horizontal | 0.091 | 0.091 |
| AOS-050 Fire Model (Transported Vertical) | 1 | Bottom Horizontal | 0.183 | 0.183 |
| | 2 | Vertical | 0.104 | 0.064 |
| | 3 | Bottom Horizontal | 0.180 | 0.165 |
| | 4 | Vertical | 0.300 | 0.259 |
| | 5 | Top Horizontal | 0.218 | 0.079 |
| | 6 | Vertical | 0.178 | 0.102 |
| | 7 | Bottom Horizontal | 0.218 | 0.079 |
| | 8 | Vertical | 0.259 | 0.196 |
| | 9 | Top Horizontal | 0.191 | 0.180 |
| | 10 | Vertical | 0.104 | 0.020 |
| | 11 | Top Horizontal | 0.183 | 0.183 |
| AOS-100 Fire Model (Transported Horizontal) | 1 | Vertical | 0.360 | 0.360 |
| | 2 | Bottom Horizontal | 0.200 | 0.130 |
| | 3 | Vertical | 0.360 | 0.330 |
| | 4 | Top Horizontal | 0.520 | 0.500 |
| | 5 | Vertical | 0.440 | 0.160 |
| | 6 | Top Horizontal | 0.410 | 0.360 |
| | 7 | Vertical | 0.440 | 0.160 |
| | 8 | Top Horizontal | 0.520 | 0.290 |
| | 9 | Vertical | 0.360 | 0.380 |
| | 10 | Bottom Horizontal | 0.200 | 0.040 |
| | 11 | Vertical | 0.360 | 0.360 |

**Table 3-14. Cask Assembly External Surface Orientation and Size, Fire Conditions of Transport – All Models (Continued)**

| Model | Surface | Orientation | Length (m) | Width (m) |
|---|---|---|---|---|
| AOS-165 Fire Model (Transported Horizontal) | 1 | Vertical | 0.597 | 0.597 |
| | 2 | Bottom Horizontal | 0.340 | 0.208 |
| | 3 | Vertical | 0.597 | 0.541 |
| | 4 | Top Horizontal | 0.853 | 0.823 |
| | 5 | Vertical | 0.721 | 0.262 |
| | 6 | Top Horizontal | 0.660 | 0.587 |
| | 7 | Vertical | 0.721 | 0.262 |
| | 8 | Top Horizontal | 0.853 | 0.485 |
| | 9 | Vertical | 0.597 | 0.630 |
| | 10 | Bottom Horizontal | 0.340 | 0.066 |
| | 11 | Vertical | 0.597 | 0.597 |

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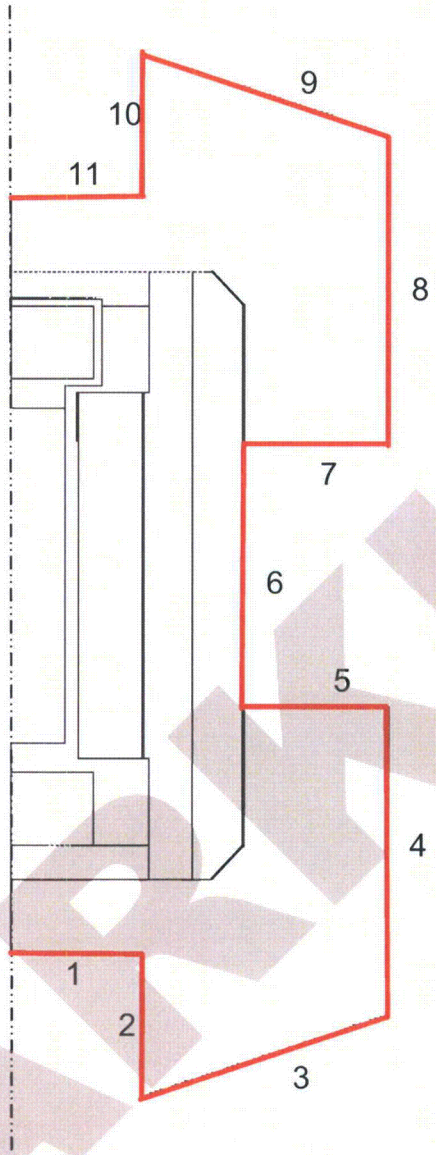


**Figure 3-5. Cask Assembly External Surface Identification**

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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 3.3.1.2. 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 compared with $A_2$, and $F_{12} = 1$. The impact limiter outside surface is oxidized SS304, and the surface emissivity is 0.52. The cask's outside surface is polished, and an emissivity of 0.20 is used.

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 37.8°C (100°F), -28.9°C (-20°F), and -40°C (-40°F). 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 3-15 (Normal conditions of transport) and Table 3-16 (Fire conditions of transport) define the polynomial coefficients used in the equivalent convective property of each ambient temperature and external surface, for each AOS Transport Packaging System model.

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**Table 3-15. 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 | | $a_0$ | $a_1$ | $a_2$ |
| AOS-025 | 37.78 | 100 | 1 | 9.438E-3 | 6.940E-6 | 2.288E-8 |
| | | | 2 | 1.254E-2 | 1.139E-5 | 2.105E-8 |
| | | | 3 | 9.438E-3 | 6.940E-6 | 2.288E-8 |
| | | | 4 | 9.438E-3 | 6.940E-6 | 2.288E-8 |
| | | | 9 | 1.420E-2 | 1.434E-5 | 1.965E-8 |
| | | | 10 | 1.254E-2 | 1.139E-5 | 2.105E-8 |
| | | | 11 | 1.420E-2 | 1.434E-5 | 1.965E-8 |
| | -28.89 | -20 | 1 | 8.920E-3 | 7.161E-6 | 2.024E-8 |
| | | | 2 | 1.286E-2 | 1.077E-5 | 1.860E-8 |
| | | | 3 | 8.920E-3 | 7.161E-6 | 2.024E-8 |
| | | | 4 | 8.920E-3 | 7.161E-6 | 2.024E-8 |
| | | | 9 | 1.519E-2 | 1.315E-3 | 1.730E-8 |
| | | | 10 | 1.286E-2 | 1.077E-5 | 1.860E-8 |
| | | | 11 | 1.519E-2 | 1.315E-3 | 1.730E-8 |
| | -40 | -40 | 1 | 8.931E-3 | 7.069E-6 | 1.986E-8 |
| | | | 2 | 1.304E-2 | 1.048E-5 | 1.829E-8 |
| | | | 3 | 8.931E-3 | 7.069E-6 | 1.986E-8 |
| | | | 4 | 8.931E-3 | 7.069E-6 | 1.986E-8 |
| | | | 9 | 1.567E-2 | 1.286E-5 | 1.696E-8 |
| | | | 10 | 1.304E-2 | 1.048E-5 | 1.829E-8 |
| | | | 11 | 1.567E-2 | 1.286E-5 | 1.696E-8 |

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**Table 3-15. 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 | | $a_0$ | $a_1$ | $a_2$ |
| AOS-050 | 37.78 | 100 | 1 | 8.715E-3 | 5.909E-6 | 2.332E-8 |
| | | | 2 | 1.119E-2 | 9.418E-6 | 2.186E-8 |
| | | | 3 | 8.715E-3 | 5.909E-6 | 2.332E-8 |
| | | | 4 | 9.807E-3 | 7.488E-6 | 2.241E-8 |
| | | | 5 | 1.313E-2 | 1.263E-5 | 2.040E-8 |
| | | | 6 | 7.320E-3 | 8.110E-6 | 6.487E-9 |
| | | | 7 | 8.715E-3 | 5.909E-6 | 2.332E-8 |
| | | | 8 | 9.807E-3 | 7.488E-6 | 2.241E-8 |
| | | | 9 | 1.257E-2 | 1.178E-5 | 2.077E-8 |
| | | | 10 | 1.119E-2 | 9.418E-6 | 2.186E-8 |
| | | | 11 | 1.257E-2 | 1.178E-5 | 2.077E-8 |
| | -28.89 | -20 | 1 | 7.975E-3 | 6.408E-6 | 2.059E-8 |
| | | | 2 | 1.116E-2 | 9.166E-6 | 1.933E-8 |
| | | | 3 | 7.975E-3 | 6.408E-6 | 2.059E-8 |
| | | | 4 | 9.185E-3 | 7.393E-6 | 2.014E-8 |
| | | | 5 | 1.377E-2 | 1.182E-5 | 1.795E-8 |
| | | | 6 | 8.236E-3 | 7.135E-6 | 5.691E-9 |
| | | | 7 | 7.975E-3 | 6.408E-6 | 2.059E-8 |
| | | | 8 | 9.185E-3 | 7.393E-6 | 2.014E-8 |
| | | | 9 | 1.322E-2 | 1.130E-5 | 1.821E-8 |
| | | | 10 | 1.119E-2 | 9.166E-6 | 1.933E-8 |
| | | | 11 | 1.322E-2 | 1.130E-5 | 1.821E-8 |
| | -40 | -40 | 1 | 8.330E-3 | 6.690E-6 | 2.003E-8 |
| | | | 2 | 1.126E-2 | 8.987E-6 | 1.896E-8 |
| | | | 3 | 8.330E-3 | 6.690E-6 | 2.003E-8 |
| | | | 4 | 9.207E-3 | 7.299E-6 | 1.975E-8 |
| | | | 5 | 1.402E-2 | 1.143E-5 | 1.768E-8 |
| | | | 6 | 8.454E-3 | 6.845E-6 | 5.624E-9 |
| | | | 7 | 8.330E-3 | 6.690E-6 | 2.003E-8 |
| | | | 8 | 9.207E-3 | 7.299E-6 | 1.975E-8 |
| | | | 9 | 1.324E-2 | 1.081E-5 | 1.798E-8 |
| | | | 10 | 1.126E-2 | 8.987E-6 | 1.896E-8 |
| | | | 11 | 1.324E-2 | 1.081E-5 | 1.798E-8 |

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**Table 3-15. 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 | | $a_0$ | $a_1$ | $a_2$ |
| AOS-100 | 37.78 | 100 | 1 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 2 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 3 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 4 | 1.093E-2 | 9.279E-6 | 2.186E-8 |
| | | | 5 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 6 | 8.395E-3 | 9.959E-6 | 5.634E-9 |
| | | | 7 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 8 | 1.093E-2 | 9.279E-6 | 2.186E-8 |
| | | | 9 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 10 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | | | 11 | 9.141E-3 | 6.264E-6 | 2.323E-8 |
| | -28.89 | -20 | 1 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | | | 2 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | | | 3 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | | | 4 | 1.198E-2 | 1.012E-5 | 1.744E-8 |
| | | | 5 | 1.027E-2 | 2.872E-6 | 2.246E-8 |
| | | | 6 | 9.689E-3 | 8.641E-6 | 4.912E-9 |
| | | | 7 | 1.027E-2 | 2.872E-6 | 2.246E-8 |
| | | | 8 | 1.198E-2 | 1.012E-5 | 1.744E-8 |
| | | | 9 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | | | 10 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | | | 11 | 8.264E-3 | 6.672E-6 | 2.046E-8 |
| | -40 | -40 | 1 | 8.826E-3 | 5.616E-6 | 2.132E-8 |
| | | | 2 | 8.826E-3 | 5.616E-6 | 2.132E-8 |
| | | | 3 | 8.826E-3 | 5.616E-6 | 2.132E-8 |
| | | | 4 | 1.227E-2 | 1.002E-5 | 1.686E-8 |
| | | | 5 | 1.053E-2 | 2.881E-6 | 2.171E-8 |
| | | | 6 | 1.065E-2 | 6.986E-6 | 5.460E-9 |
| | | | 7 | 1.053E-2 | 2.881E-6 | 2.171E-8 |
| | | | 8 | 1.227E-2 | 1.002E-5 | 1.686E-8 |
| | | | 9 | 8.826E-3 | 5.616E-6 | 2.132E-8 |
| | | | 10 | 8.826E-3 | 5.616E-6 | 2.132E-8 |
| | | | 11 | 8.826E-3 | 5.616E-6 | 2.132E-8 |

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**Table 3-15. 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 | | $a_0$ | $a_1$ | $a_2$ |
| AOS-165 | 37.78 | 100 | 1 | 8.842E-3 | 5.958E-6 | 2.332E-8 |
| | | | 2 | 8.460E-3 | 5.531E-6 | 2.348E-8 |
| | | | 3 | 1.017E-2 | 6.810E-6 | 2.144E-8 |
| | | | 4 | 1.095E-2 | 1.076E-5 | 2.059E-8 |
| | | | 5 | 8.840E-3 | 1.269E-5 | 1.823E-8 |
| | | | 6 | 7.614E-3 | 1.195E-5 | 3.583E-9 |
| | | | 7 | 8.840E-3 | 1.269E-5 | 1.823E-8 |
| | | | 8 | 1.095E-2 | 1.076E-5 | 2.059E-8 |
| | | | 9 | 1.017E-2 | 6.810E-6 | 2.144E-8 |
| | | | 10 | 8.460E-3 | 5.531E-6 | 2.348E-8 |
| | | | 11 | 8.842E-3 | 5.958E-6 | 2.332E-8 |
| | -28.89 | -20 | 1 | 9.960E-3 | 1.079E-5 | 1.520E-8 |
| | | | 2 | 7.648E-3 | 6.076E-6 | 2.075E-8 |
| | | | 3 | 9.612E-3 | 1.181E-5 | 1.531E-8 |
| | | | 4 | 1.199E-2 | 9.857E-6 | 1.803E-8 |
| | | | 5 | 1.028E-2 | 6.960E-6 | 2.010E-8 |
| | | | 6 | 1.019E-2 | 8.825E-6 | 3.944E-9 |
| | | | 7 | 1.028E-2 | 6.960E-6 | 2.010E-8 |
| | | | 8 | 1.199E-2 | 9.857E-6 | 1.803E-8 |
| | | | 9 | 9.612E-3 | 1.181E-5 | 1.531E-8 |
| | | | 10 | 7.648E-3 | 6.076E-6 | 2.075E-8 |
| | | | 11 | 9.960E-3 | 1.079E-5 | 1.520E-8 |
| | -40 | -40 | 1 | 9.990E-3 | 1.144E-5 | 1.421E-8 |
| | | | 2 | 7.602E-3 | 6.066E-6 | 2.034E-8 |
| | | | 3 | 1.003E-2 | 1.015E-5 | 1.645E-8 |
| | | | 4 | 1.233E-2 | 9.411E-6 | 1.775E-8 |
| | | | 5 | 1.031E-2 | 7.737E-6 | 1.896E-8 |
| | | | 6 | 1.070E-2 | 8.232E-6 | 3.962E-9 |
| | | | 7 | 1.031E-2 | 7.737E-6 | 1.896E-8 |
| | | | 8 | 1.233E-2 | 9.411E-6 | 1.775E-8 |
| | | | 9 | 1.003E-2 | 1.015E-5 | 1.645E-8 |
| | | | 10 | 7.602E-3 | 6.066E-6 | 2.034E-8 |
| | | | 11 | 9.990E-3 | 1.144E-5 | 1.421E-8 |

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**Table 3-16. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Fire Conditions of Transport – All Models**

| Model | Ambient Temperature | | Surface | Polynomial Coefficient | | |
|---|---|---|---|---|---|---|
| | °C | °F | | $a_0$ | $a_1$ | $a_2$ |
| AOS-025 | 37.78 | 100 | 1 | 9.624E-3 | 7.201E-6 | 2.277E-8 |
| | | | 2 | 1.255E-2 | 1.139E-5 | 2.106E-8 |
| | | | 3 | 9.624E-3 | 7.201E-6 | 2.277E-8 |
| | | | 4 | 9.624E-3 | 7.201E-6 | 2.277E-8 |
| | | | 9 | 1.420E-2 | 1.434E-5 | 1.965E-8 |
| | | | 10 | 1.255E-2 | 1.139E-5 | 2.106E-8 |
| | | | 11 | 1.420E-2 | 1.434E-5 | 1.965E-8 |
| AOS-050 | 37.78 | 100 | 1 | 8.848E-3 | 6.110E-6 | 2.323E-8 |
| | | | 2 | 1.116E-2 | 9.371E-6 | 2.188E-8 |
| | | | 3 | 8.848E-3 | 6.110E-6 | 2.323E-8 |
| | | | 4 | 9.968E-3 | 6.641E-6 | 2.321E-8 |
| | | | 5 | 1.337E-2 | 1.465E-5 | 1.906E-8 |
| | | | 6 | 7.319E-3 | 8.112E-6 | 6.484E-9 |
| | | | 7 | 8.848E-3 | 6.110E-6 | 2.323E-8 |
| | | | 8 | 9.968E-3 | 6.641E-6 | 2.321E-8 |
| | | | 9 | 1.271E-2 | 1.201E-5 | 2.067E-8 |
| | | | 10 | 1.116E-2 | 9.371E-6 | 2.188E-8 |
| | | | 11 | 1.271E-2 | 1.201E-5 | 2.067E-8 |

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**Table 3-16. Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Fire Conditions of Transport – All Models (Continued)**

| Model | Ambient Temperature | | Surface | Polynomial Coefficient | | |
|---|---|---|---|---|---|---|
| | °C | °F | | $a_0$ | $a_1$ | $a_2$ |
| AOS-100 | 37.78 | 100 | 1 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 2 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 3 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 4 | 1.094E-2 | 9.294E-6 | 2.185E-8 |
| | | | 5 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 6 | 8.395E-3 | 9.959E-6 | 5.634E-9 |
| | | | 7 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 8 | 1.094E-2 | 9.294E-6 | 2.185E-8 |
| | | | 9 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| | | | 10 | 9.916E-3 | 7.736E-6 | 2.252E-8 |
| | | | 11 | 9.326E-3 | 6.712E-6 | 2.299E-8 |
| AOS-165 | 37.78 | 100 | 1 | 8.842E-3 | 5.964E-6 | 2.331E-8 |
| | | | 2 | 8.460E-3 | 5.531E-6 | 2.348E-8 |
| | | | 3 | 8.842E-3 | 5.964E-6 | 2.331E-8 |
| | | | 4 | 1.095E-2 | 1.073E-5 | 2.061E-8 |
| | | | 5 | 8.273E-3 | 1.430E-5 | 1.667E-8 |
| | | | 6 | 7.614E-3 | 1.196E-5 | 3.583E-9 |
| | | | 7 | 8.273E-3 | 1.430E-5 | 1.667E-8 |
| | | | 8 | 1.063E-2 | 1.191E-5 | 1.955E-8 |
| | | | 9 | 9.926E-3 | 5.561E-6 | 2.274E-8 |
| | | | 10 | 9.315E-3 | 6.817E-6 | 2.293E-8 |
| | | | 11 | 8.842E-3 | 5.964E-6 | 2.331E-8 |

MAPS

#### 3.3.1.3.1 Vertical Surface

The Nusselt Number used for convection from a vertical surface under laminar flow, $10^4 < Ra < 10^9$, 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, $Ra > 10^9$, 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 = Rayleigh Number

#### 3.3.1.3.2 Horizontal Surface

The Nusselt Number used for convection from a horizontal, upper surface under laminar flow, $10^4 < Ra < 10^9$, is determined from Reference **[3.4]**, Equation 9.30:

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

The Nusselt Number for turbulent flow, $Ra > 10^9$, 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, $10^5 < Ra < 10^{10}$, is determined from Reference **[3.4]**, Equation 9.32:

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

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### 3.3.1.3.3 Horizontal Cylinder

The Nusselt Number used for convection from a horizontal cylinder with $Ra < 10^{12}$ 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

### 3.3.1.3.4 Solar Heat Load

Table 3-17 defines the solar heat applied to the cask's outside surfaces, with an ambient temperature of 37.8°C (100°F). In the evaluation, the solar load is applied using a steady-state analytical solution, for a 12-hour period.

**Table 3-17. Solar Heat Application to Cask Outside Surfaces – All Models**

| Surface Form and Location | Total Insolation for a 12-Hour Period (g cal/cm$^2$) |
|---|---|
| Flat surfaces transported horizontally: | |
| • Base | None |
| • Other surfaces | 800 |
| Flat surfaces not transported horizontally | 200 |
| Curved surface | 400 |

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### 3.3.1.3.5 Cask Boundary Surfaces at 1,475°F Environment

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

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

*where:*

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

$F$ = Gray body shape factor, using emissivity value of 0.9 and absorptivity = 0.8
= 0.7347

$T_1$ = Surface temperature, °R

Then:

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

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

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

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

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

*where:*

$T$ = Surface temperature, °F

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## 3.3.2 Normal Conditions of Transport Results – Models AOS-100A and AOS-100A-S

Table 3-18 lists the tables and figures in this subsection that present the Model AOS-100A and AOS-100A-S 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. Also listed are the maximum temperatures within each transport package component.

Table 3-19 lists the temperature monitoring points (nodes) for the Model AOS-100 (A, B, and A-S) transport packages, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-6 illustrates the location of each node on the transport packages, under Normal conditions.

***Note:*** *Results for the Model AOS-100B transport package are provided in Subsection 3.3.3. Results for the Model AOS-025, AOS-050, and AOS-165 transport packages are provided in Appendix 3.5.*

**Table 3-18. Normal Conditions of Transport Results – Models AOS-100A and AOS-100A-S**

| Load Case | Description | Results Table | Entire Model | Cask Model |
|---|---|---|---|---|
| 101 | 100°F Ambient, Maximum Decay Heat | Table 3-20 | Figure 3-7 | Figure 3-8 |
| 102 | 100°F Ambient, Maximum Decay Heat, Maximum Insolation | Table 3-21 | Figure 3-9 | Figure 3-10 |
| 103 | -20°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-22 | Figure 3-11 | – |
| 104 | -40°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-23 | Figure 3-12 | – |
| 105 | -40°F Ambient, Maximum Decay Heat | Table 3-24 | Figure 3-13 | Figure 3-14 |
| 106 | -20°F Ambient, Maximum Decay Heat | Table 3-25 | Figure 3-15 | Figure 3-16 |

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**Table 3-19. Temperature Monitoring Points, All Conditions of Transport – Model AOS-100**

| Nodal Location | LIBRA Model Nodal Number | |
|---|---|---|
| | Normal Conditions | Fire Conditions |
| 1 | 5001 | 5001 |
| 2 | 4532 | 4532 |
| 3 | 4227 | 4227 |
| 4 | 4752 | 4752 |
| 5 | 4838 | 4838 |
| 6 | 4995 | 4995 |
| 7 | 3309 | 3309 |
| 8 | 3419 | 3419 |
| 9 | 678 | 678 |
| 10 | 2537 | 2537 |
| 11 | 1888 | 1888 |
| 12 | 583 | 583 |
| 13 | 3001 | 3001 |
| 14 | 3148 | 3148 |
| 15 | 7533 | 7533 |
| 16 | 7377 | 7377 |
| 17 | 7371 | 7371 |
| 18 | 6942 | 6942 |
| 19 | 6267 | 6267 |
| 20 | 6121 | 6121 |
| 21 | 6001 | 6001 |
| 22 | 9501 | 15481 |
| 23 | 9950 | 16630 |
| 24 | 10014 | 16694 |
| 25 | 10781 | 18111 |
| 26 | 9091 | 1153 |
| 27 | 8463 | 9785 |
| 28 | 8462 | 9571 |
| 29 | 8197 | 8197 |
| 30 | 9711 | 15451 |
| 31 | 9821 | 15961 |
| 32 | 10158 | 17022 |
| 33 | 10605 | 17743 |
| 34 | 9102 | 11051 |
| 35 | 8578 | 9900 |
| 36 | 8225 | 8673 |
| 37 | 8001 | 8225 |

INTERIM

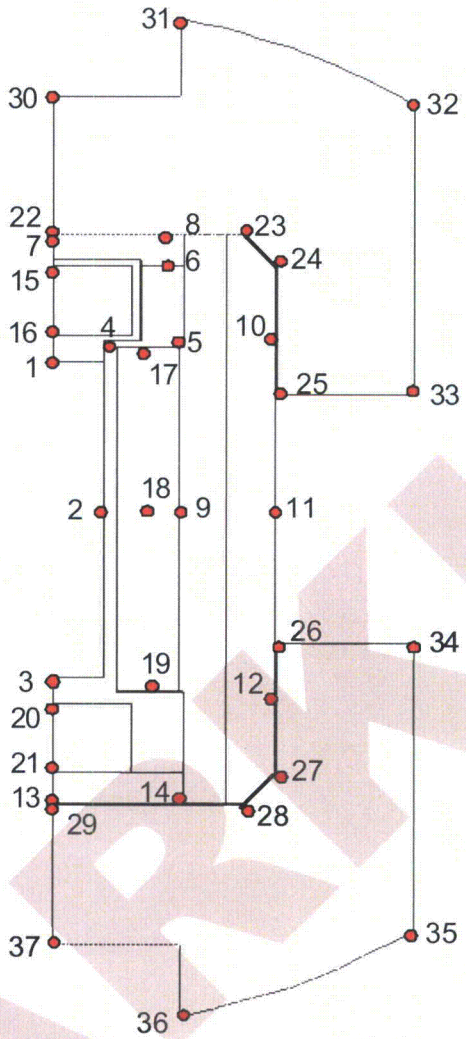


**Figure 3-6. Selected Nodal Locations for Normal Conditions of Transport – Models AOS-100**

MARKUP

**Table 3-20. Load Case 101 – 100°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 92.33 | 198.20 |
| 2 | 4532 | 88.39 | 191.10 |
| 3 | 4227 | 90.11 | 194.20 |
| 4 | 4752 | 86.61 | 187.90 |
| 5 | 4838 | 82.67 | 180.80 |
| 6 | 4995 | 82.39 | 180.30 |
| 7 | 3309 | 83.22 | 181.80 |
| 8 | 3419 | 82.39 | 180.30 |
| 9 | 678 | 82.61 | 180.70 |
| 10 | 2537 | 80.67 | 177.20 |
| 11 | 1888 | 78.67 | 173.60 |
| 12 | 583 | 80.78 | 177.40 |
| 13 | 3001 | 82.94 | 181.30 |
| 14 | 3148 | 82.00 | 179.60 |
| 15 | 7533 | 85.11 | 185.20 |
| 16 | 7377 | 85.67 | 186.20 |
| 17 | 7371 | 83.61 | 182.50 |
| 18 | 6942 | 83.72 | 182.70 |
| 19 | 6267 | 83.61 | 182.50 |
| 20 | 6121 | 83.89 | 183.00 |
| 21 | 6001 | 83.44 | 182.20 |
| 22 | 9501 | 83.11 | 181.60 |
| 23 | 9950 | 81.11 | 178.00 |
| 24 | 10014 | 79.94 | 175.90 |
| 25 | 10781 | 61.00 | 141.80 |
| 26 | 9091 | 60.89 | 141.60 |
| 27 | 8463 | 79.78 | 175.60 |
| 28 | 8462 | 81.17 | 178.10 |
| 29 | 8197 | 82.83 | 181.10 |
| 30 | 9711 | 38.78 | 101.80 |
| 31 | 9821 | 38.00 | 100.40 |
| 32 | 10158 | 37.94 | 100.30 |
| 33 | 10605 | 38.78 | 101.80 |
| 34 | 9102 | 38.78 | 101.80 |
| 35 | 8578 | 37.94 | 100.30 |
| 36 | 8225 | 38.00 | 100.40 |
| 37 | 8001 | 38.78 | 101.80 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 8.2722E+01 | 1.8090E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 8.3111E+01 | 1.8160E+02 |
| Lid | 3233 | 3424 | 3233 | 8.3389E+01 | 1.8210E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 9.0111E+01 | 1.9420E+02 |
| Plug | 5001 | 5404 | 5001 | 9.2333E+01 | 1.9820E+02 |
| Tungsten Alloy | 6001 | 7656 | 7377 | 8.5667E+01 | 1.8620E+02 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 8.3111E+01 | 1.8160E+02 |

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

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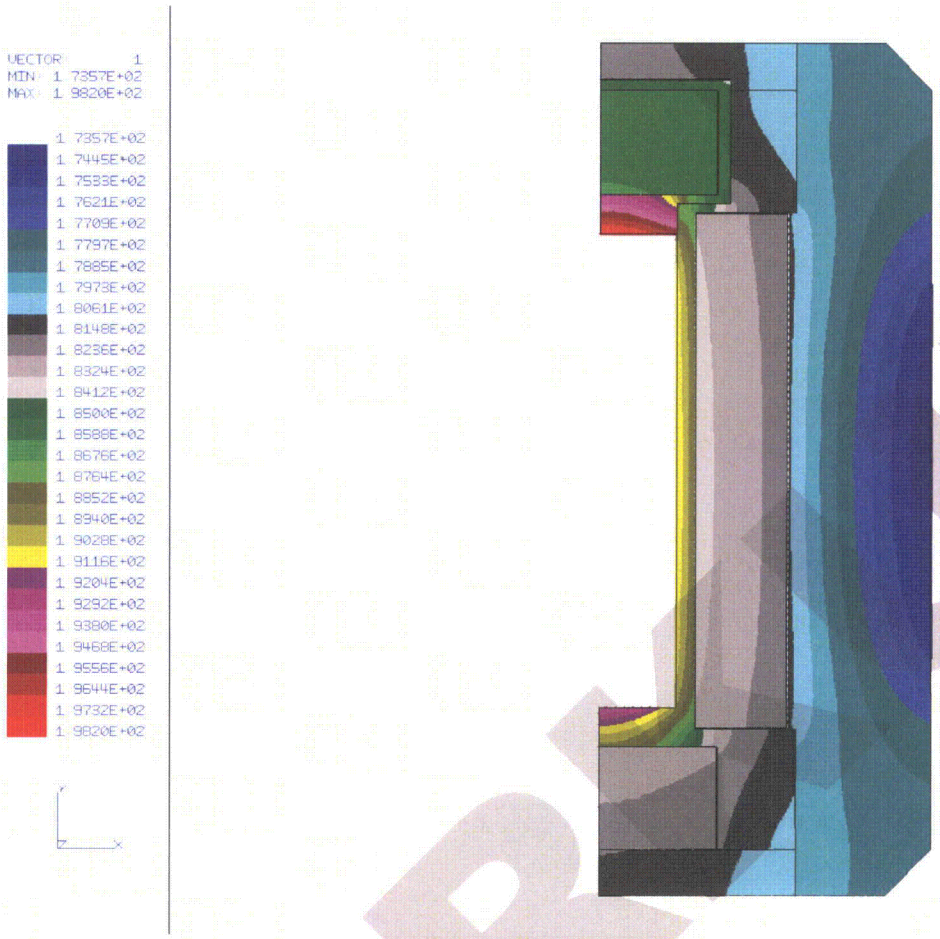


**Figure 3-8. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

MARKUP

**Table 3-21. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 127.72 | 261.90 |
| 2 | 4532 | 123.94 | 255.10 |
| 3 | 4227 | 125.61 | 258.10 |
| 4 | 4752 | 122.22 | 252.00 |
| 5 | 4838 | 118.39 | 245.10 |
| 6 | 4995 | 118.11 | 244.60 |
| 7 | 3309 | 118.83 | 245.90 |
| 8 | 3419 | 118.06 | 244.50 |
| 9 | 678 | 118.50 | 245.30 |
| 10 | 2537 | 116.33 | 241.40 |
| 11 | 1888 | 114.89 | 238.80 |
| 12 | 583 | 116.44 | 241.60 |
| 13 | 3001 | 118.61 | 245.50 |
| 14 | 3148 | 117.67 | 243.80 |
| 15 | 7533 | 120.67 | 249.20 |
| 16 | 7377 | 121.22 | 250.20 |
| 17 | 7371 | 119.39 | 246.90 |
| 18 | 6942 | 119.61 | 247.30 |
| 19 | 6267 | 119.39 | 246.90 |
| 20 | 6121 | 119.61 | 247.30 |
| 21 | 6001 | 119.11 | 246.40 |
| 22 | 9501 | 118.78 | 245.80 |
| 23 | 9950 | 116.78 | 242.20 |
| 24 | 10014 | 115.67 | 240.20 |
| 25 | 10781 | 91.06 | 195.90 |
| 26 | 9091 | 91.00 | 195.80 |
| 27 | 8463 | 115.44 | 239.80 |
| 28 | 8462 | 116.89 | 242.40 |
| 29 | 8197 | 118.50 | 245.30 |
| 30 | 9711 | 63.39 | 146.10 |
| 31 | 9821 | 79.00 | 174.20 |
| 32 | 10158 | 76.94 | 170.50 |
| 33 | 10605 | 68.72 | 155.70 |
| 34 | 9102 | 68.72 | 155.70 |
| 35 | 8578 | 76.94 | 170.50 |
| 36 | 8225 | 79.00 | 174.20 |
| 37 | 8001 | 63.33 | 146.00 |

MARKUP

Maximum Component Temperatures

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

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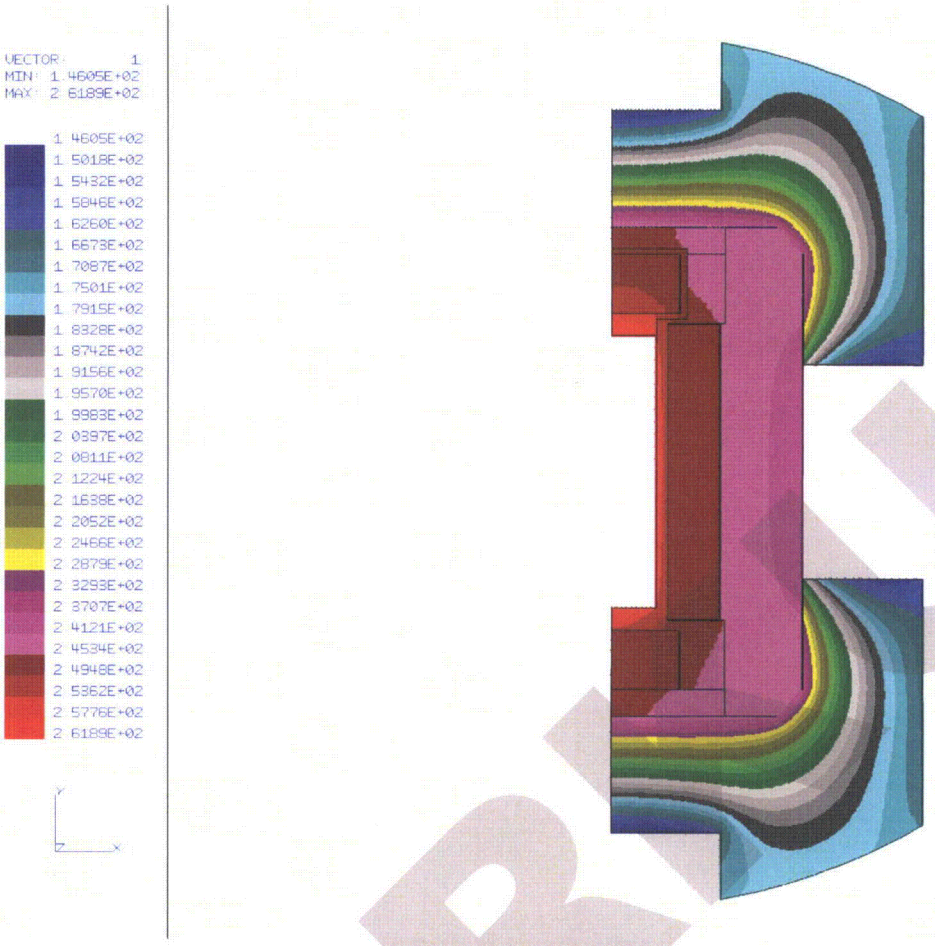


**Figure 3-9. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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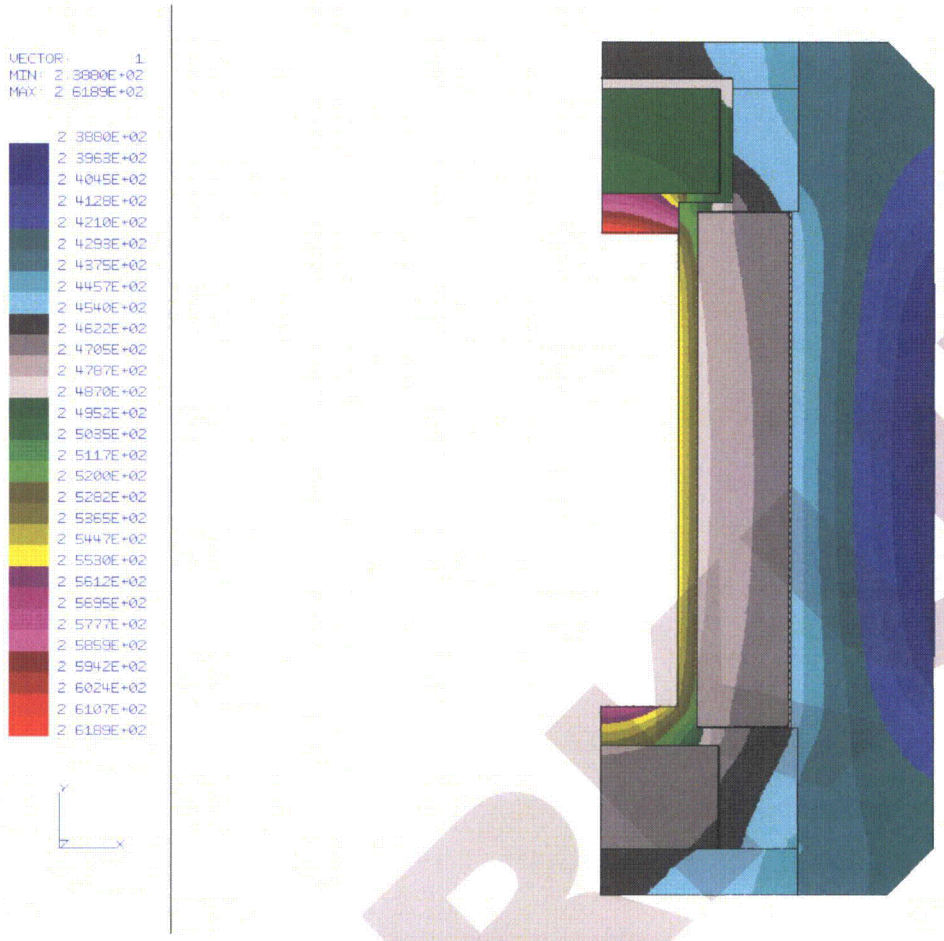


**Figure 3-10. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

MARKUP

**Table 3-22. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation – Models AOS-100A and AOS-100A-S**

| 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 | 4995 | -28.89 | -20.00 |
| 7 | 3309 | -28.89 | -20.00 |
| 8 | 3419 | -28.89 | -20.00 |
| 9 | 678 | -28.89 | -20.00 |
| 10 | 2537 | -28.89 | -20.00 |
| 11 | 1888 | -28.89 | -20.00 |
| 12 | 583 | -28.89 | -20.00 |
| 13 | 3001 | -28.89 | -20.00 |
| 14 | 3148 | -28.89 | -20.00 |
| 15 | 7533 | -28.89 | -20.00 |
| 16 | 7377 | -28.89 | -20.00 |
| 17 | 7371 | -28.89 | -20.00 |
| 18 | 6942 | -28.89 | -20.00 |
| 19 | 6267 | -28.89 | -20.00 |
| 20 | 6121 | -28.89 | -20.00 |
| 21 | 6001 | -28.89 | -20.00 |
| 22 | 9501 | -28.89 | -20.00 |
| 23 | 9950 | -28.89 | -20.00 |
| 24 | 10014 | -28.89 | -20.00 |
| 25 | 10781 | -28.89 | -20.00 |
| 26 | 9091 | -28.89 | -20.00 |
| 27 | 8463 | -28.89 | -20.00 |
| 28 | 8462 | -28.89 | -20.00 |
| 29 | 8197 | -28.89 | -20.00 |
| 30 | 9711 | -28.89 | -20.00 |
| 31 | 9821 | -28.89 | -20.00 |
| 32 | 10158 | -28.89 | -20.00 |
| 33 | 10605 | -28.89 | -20.00 |
| 34 | 9102 | -28.89 | -20.00 |
| 35 | 8578 | -28.89 | -20.00 |
| 36 | 8225 | -28.89 | -20.00 |
| 37 | 8001 | -28.89 | -20.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 101 | -2.8889E+01 | -2.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -2.8889E+01 | -2.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -2.8889E+01 | -2.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -2.8889E+01 | -2.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -2.8889E+01 | -2.0000E+01 |
| Tungsten Alloy | 6001 | 7656 | 6001 | -2.8889E+01 | -2.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -2.8889E+01 | -2.0000E+01 |

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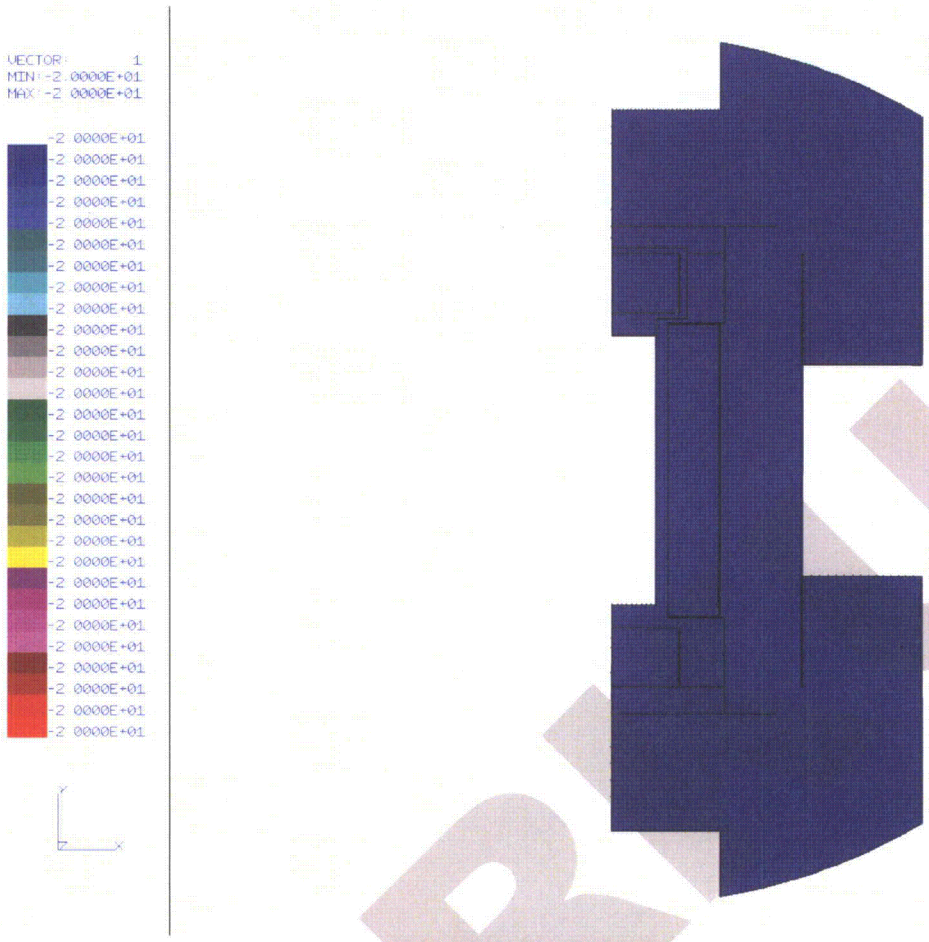


**Figure 3-11. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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**Table 3-23. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation – Models AOS-100A and AOS-100A-S**

| 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 | 4995 | -40.00 | -40.00 |
| 7 | 3309 | -40.00 | -40.00 |
| 8 | 3419 | -40.00 | -40.00 |
| 9 | 678 | -40.00 | -40.00 |
| 10 | 2537 | -40.00 | -40.00 |
| 11 | 1888 | -40.00 | -40.00 |
| 12 | 583 | -40.00 | -40.00 |
| 13 | 3001 | -40.00 | -40.00 |
| 14 | 3148 | -40.00 | -40.00 |
| 15 | 7533 | -40.00 | -40.00 |
| 16 | 7377 | -40.00 | -40.00 |
| 17 | 7371 | -40.00 | -40.00 |
| 18 | 6942 | -40.00 | -40.00 |
| 19 | 6267 | -40.00 | -40.00 |
| 20 | 6121 | -40.00 | -40.00 |
| 21 | 6001 | -40.00 | -40.00 |
| 22 | 9501 | -40.00 | -40.00 |
| 23 | 9950 | -40.00 | -40.00 |
| 24 | 10014 | -40.00 | -40.00 |
| 25 | 10781 | -40.00 | -40.00 |
| 26 | 9091 | -40.00 | -40.00 |
| 27 | 8463 | -40.00 | -40.00 |
| 28 | 8462 | -40.00 | -40.00 |
| 29 | 8197 | -40.00 | -40.00 |
| 30 | 9711 | -40.00 | -40.00 |
| 31 | 9821 | -40.00 | -40.00 |
| 32 | 10158 | -40.00 | -40.00 |
| 33 | 10605 | -40.00 | -40.00 |
| 34 | 9102 | -40.00 | -40.00 |
| 35 | 8578 | -40.00 | -40.00 |
| 36 | 8225 | -40.00 | -40.00 |
| 37 | 8001 | -40.00 | -40.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 101 | -4.0000E+01 | -4.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -4.0000E+01 | -4.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -4.0000E+01 | -4.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -4.0000E+01 | -4.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -4.0000E+01 | -4.0000E+01 |
| Tungsten Alloy | 6001 | 7656 | 6001 | -4.0000E+01 | -4.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -4.0000E+01 | -4.0000E+01 |

MARKUP

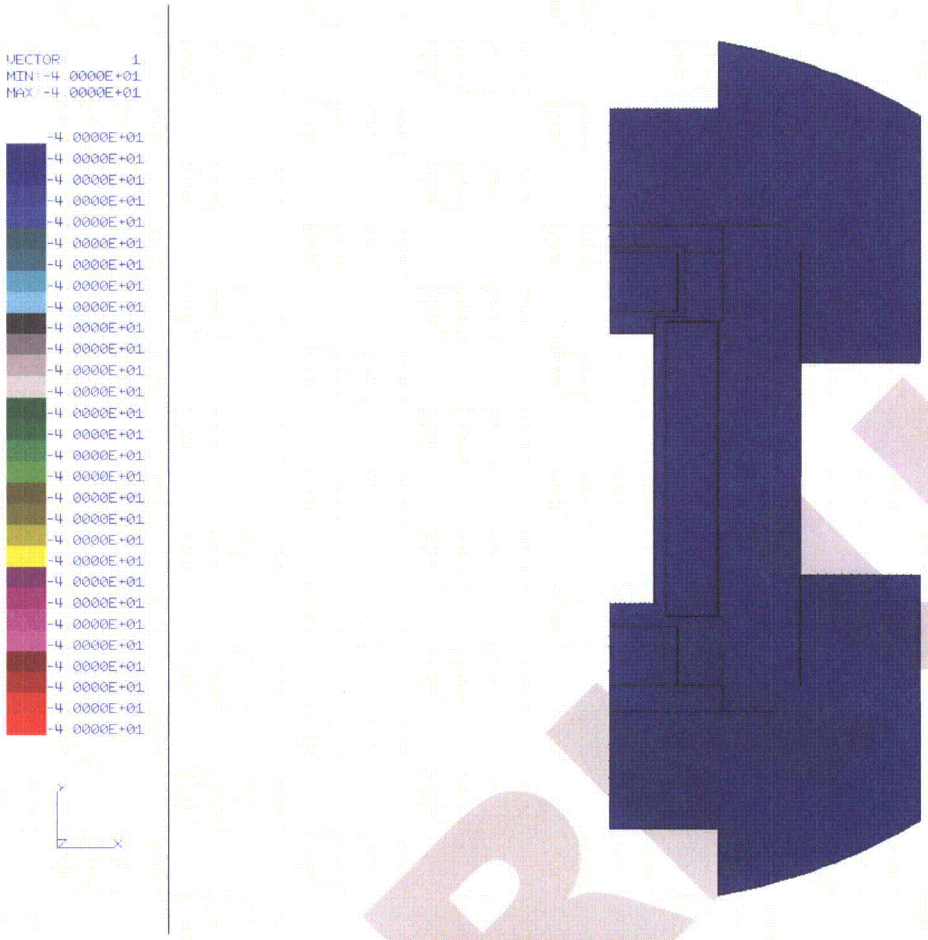


**Figure 3-12. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

MARKUP

**Table 3-24. Load Case 105 – -40°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 14.68 | 58.42 |
| 2 | 4532 | 10.58 | 51.04 |
| 3 | 4227 | 12.16 | 53.88 |
| 4 | 4752 | 8.47 | 47.25 |
| 5 | 4838 | 4.14 | 39.46 |
| 6 | 4995 | 3.89 | 39.00 |
| 7 | 3309 | 4.74 | 40.53 |
| 8 | 3419 | 3.88 | 38.98 |
| 9 | 678 | 4.03 | 39.25 |
| 10 | 2537 | 2.02 | 35.63 |
| 11 | 1888 | -0.34 | 31.38 |
| 12 | 583 | 2.17 | 35.91 |
| 13 | 3001 | 4.46 | 40.02 |
| 14 | 3148 | 3.45 | 38.21 |
| 15 | 7533 | 6.97 | 44.55 |
| 16 | 7377 | 7.58 | 45.65 |
| 17 | 7371 | 5.08 | 41.14 |
| 18 | 6942 | 5.19 | 41.34 |
| 19 | 6267 | 5.06 | 41.10 |
| 20 | 6121 | 5.49 | 41.89 |
| 21 | 6001 | 4.97 | 40.95 |
| 22 | 9501 | 4.68 | 40.42 |
| 23 | 9950 | 2.43 | 36.37 |
| 24 | 10014 | 1.03 | 33.85 |
| 25 | 10781 | -18.41 | -1.13 |
| 26 | 9091 | -18.50 | -1.30 |
| 27 | 8463 | 0.86 | 33.54 |
| 28 | 8462 | 2.54 | 36.57 |
| 29 | 8197 | 4.40 | 39.92 |
| 30 | 9711 | -38.86 | -37.95 |
| 31 | 9821 | -39.70 | -39.46 |
| 32 | 10158 | -39.81 | -39.66 |
| 33 | 10605 | -39.14 | -38.46 |
| 34 | 9102 | -39.15 | -38.47 |
| 35 | 8578 | -39.81 | -39.66 |
| 36 | 8225 | -39.70 | -39.46 |
| 37 | 8001 | -38.86 | -37.95 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 4.1889E+00 | 3.9540E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | 4.6611E+00 | 4.0390E+01 |
| Lid | 3233 | 3424 | 3233 | 4.9333E+00 | 4.0880E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 1.2156E+01 | 5.3880E+01 |
| Plug | 5001 | 5404 | 5001 | 1.4678E+01 | 5.8420E+01 |
| Tungsten Alloy | 6001 | 7656 | 7377 | 7.5833E+00 | 4.5650E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 4.6778E+00 | 4.0420E+01 |

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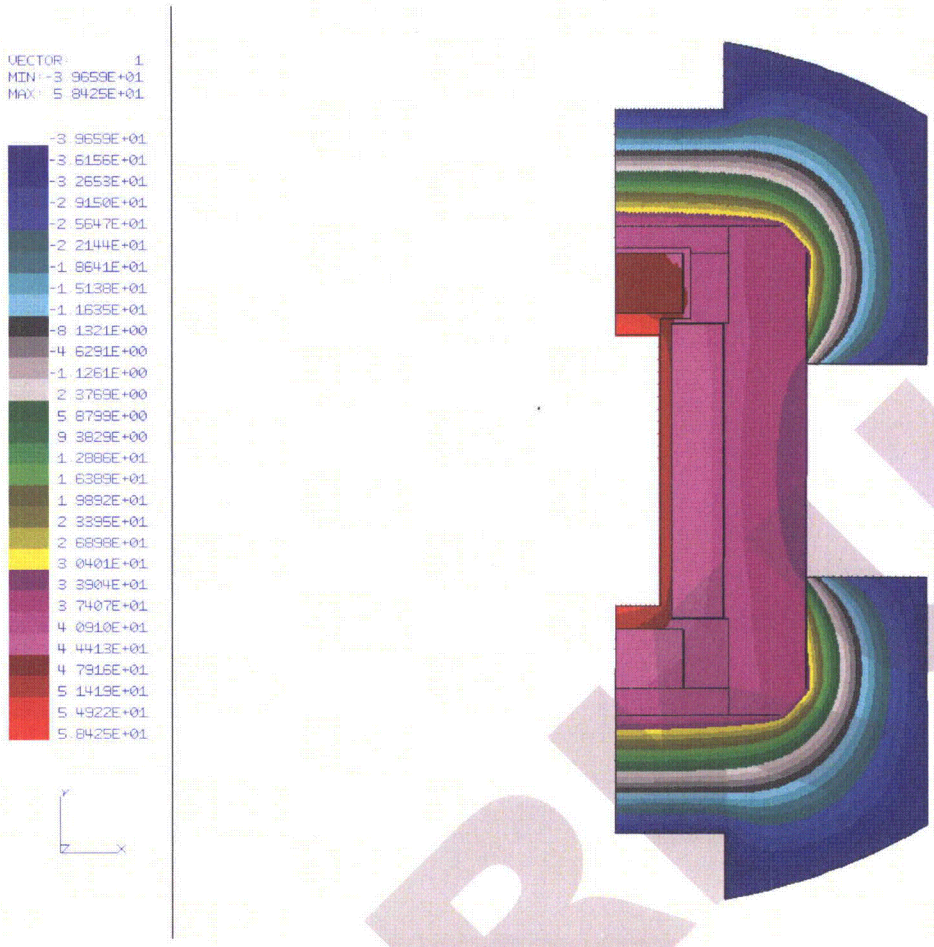


**Figure 3-13. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

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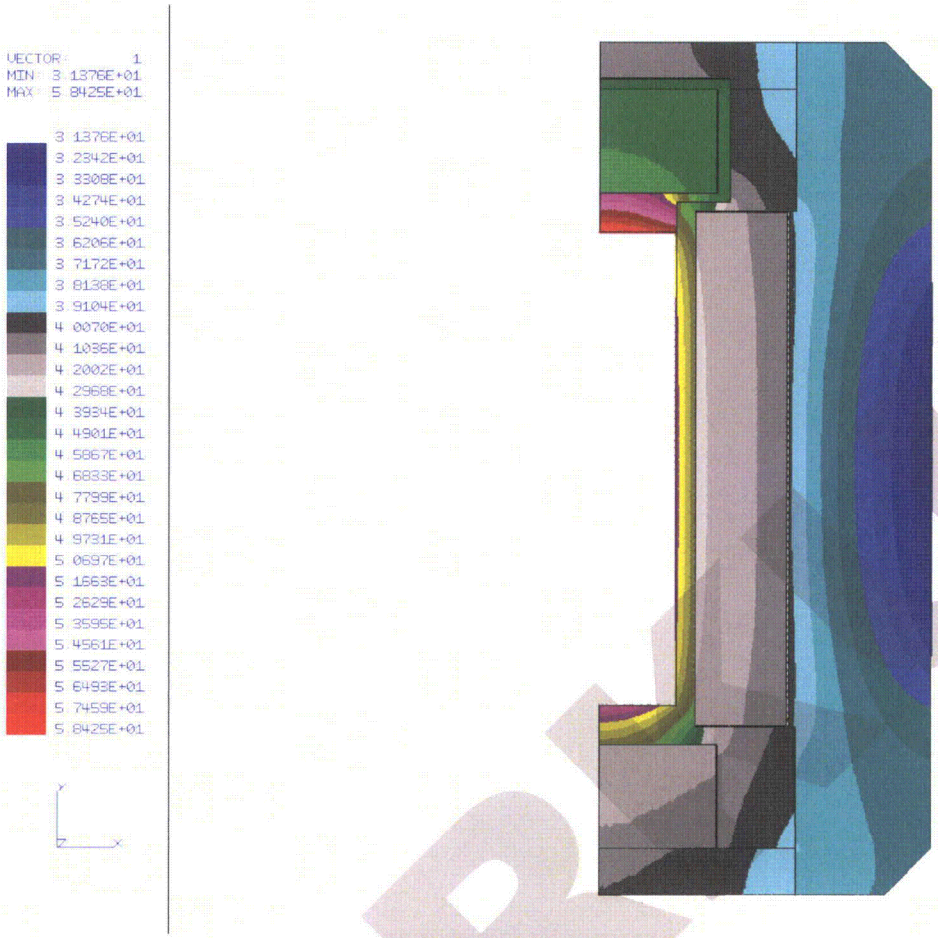


**Figure 3-14. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

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**Table 3-25. Load Case 106 – -20°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 27.63 | 81.73 |
| 2 | 4532 | 23.56 | 74.40 |
| 3 | 4227 | 25.16 | 77.29 |
| 4 | 4752 | 21.51 | 70.72 |
| 5 | 4838 | 17.24 | 63.04 |
| 6 | 4995 | 16.98 | 62.57 |
| 7 | 3309 | 17.82 | 64.08 |
| 8 | 3419 | 16.97 | 62.54 |
| 9 | 678 | 17.16 | 62.89 |
| 10 | 2537 | 15.13 | 59.24 |
| 11 | 1888 | 12.89 | 55.21 |
| 12 | 583 | 15.28 | 59.51 |
| 13 | 3001 | 17.54 | 63.58 |
| 14 | 3148 | 16.54 | 61.78 |
| 15 | 7533 | 20.00 | 68.00 |
| 16 | 7377 | 20.61 | 69.09 |
| 17 | 7371 | 18.19 | 64.75 |
| 18 | 6942 | 18.32 | 64.97 |
| 19 | 6267 | 18.17 | 64.71 |
| 20 | 6121 | 18.58 | 65.44 |
| 21 | 6001 | 18.06 | 64.50 |
| 22 | 9501 | 17.76 | 63.96 |
| 23 | 9950 | 15.52 | 59.94 |
| 24 | 10014 | 14.11 | 57.39 |
| 25 | 10781 | -5.99 | 21.21 |
| 26 | 9091 | -6.10 | 21.02 |
| 27 | 8463 | 13.93 | 57.07 |
| 28 | 8462 | 15.63 | 60.13 |
| 29 | 8197 | 17.48 | 63.47 |
| 30 | 9711 | -27.63 | -17.74 |
| 31 | 9821 | -28.55 | -19.39 |
| 32 | 10158 | -28.68 | -19.63 |
| 33 | 10605 | -27.94 | -18.29 |
| 34 | 9102 | -27.94 | -18.30 |
| 35 | 8578 | -28.68 | -19.63 |
| 36 | 8225 | -28.55 | -19.39 |
| 37 | 8001 | -27.64 | -17.75 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 1.7300E+01 | 6.3140E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7744E+01 | 6.3940E+01 |
| Lid | 3233 | 3424 | 3233 | 1.8011E+01 | 6.4420E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 2.5161E+01 | 7.7290E+01 |
| Plug | 5001 | 5404 | 5001 | 2.7628E+01 | 8.1730E+01 |
| Tungsten Alloy | 6001 | 7656 | 7377 | 2.0606E+01 | 6.9090E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 1.7756E+01 | 6.3960E+01 |

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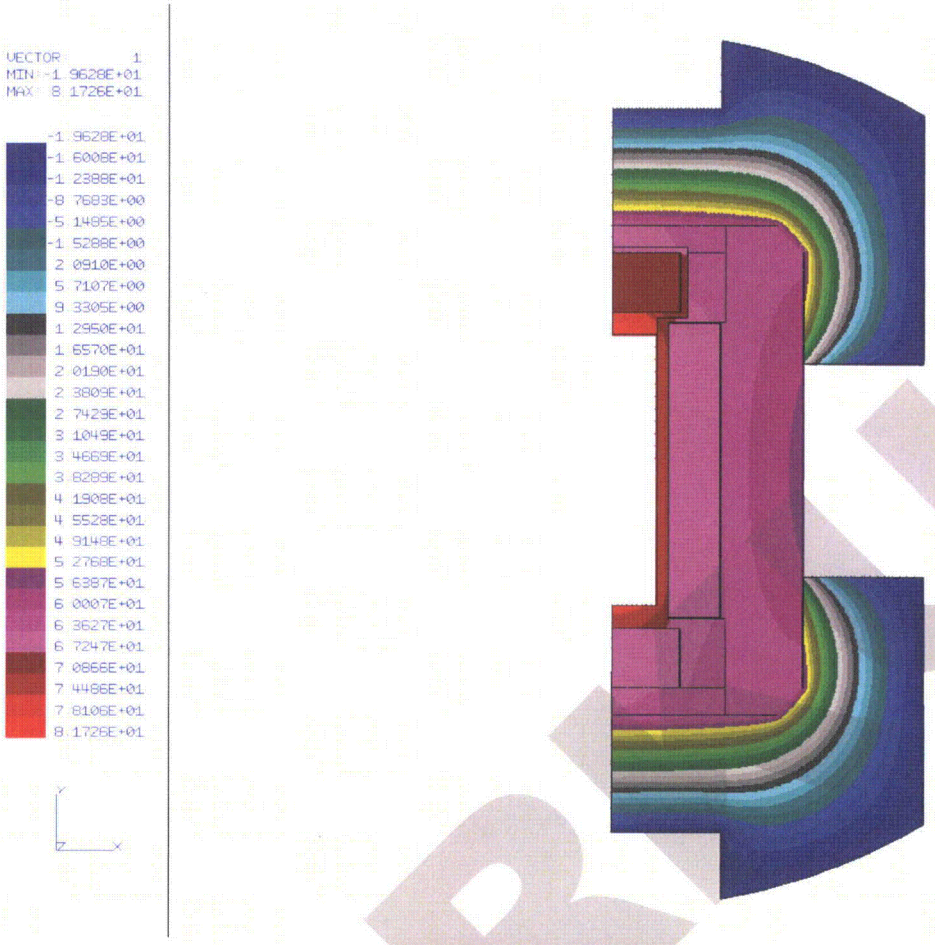


**Figure 3-15. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

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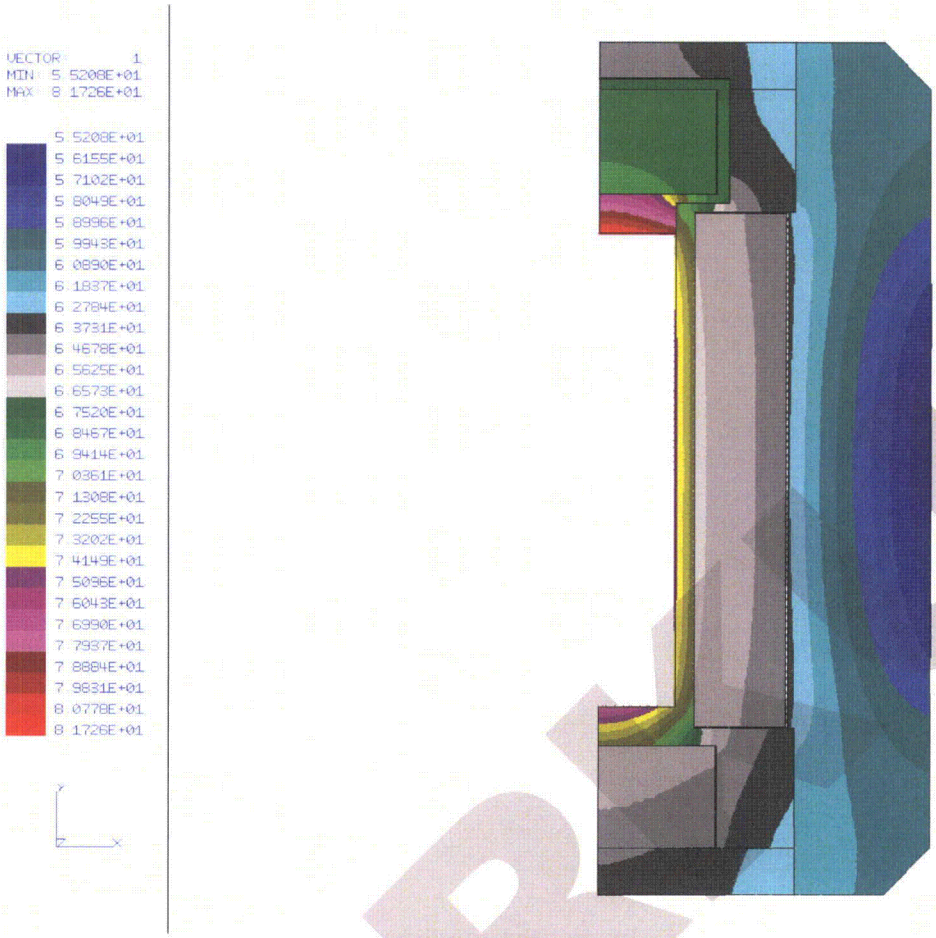


**Figure 3-16. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

MARKUP

### 3.3.3 Normal Conditions of Transport Results – Model AOS-100B

Table 3-26 lists the tables and figures in this subsection that present the Model AOS-100B 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. Also listed are the maximum temperatures within each transport package component.

Table 3-19 lists the temperature monitoring points (nodes) for the Model AOS-100B transport package, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-6 illustrates the location of each node on the transport package, under Normal conditions.

***Note:*** *Results for the Model AOS-100A and AOS-100A-S transport packages are provided in Subsection 3.3.2.*
*Results for the Model AOS-025, AOS-050, and AOS-165 transport packages are provided in Appendix 3.5.*

**Table 3-26. Normal Conditions of Transport Results – Model AOS-100B**

| Load Case | Description | Results Table | Entire Model | Cask Model |
|---|---|---|---|---|
| 101 | 100°F Ambient, Maximum Decay Heat, Carbon Steel Shielding | Table 3-27 | Figure 3-17 | Figure 3-18 |
| 102 | 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Carbon Steel Shielding | Table 3-28 | Figure 3-19 | Figure 3-20 |
| 103 | -20°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding | Table 3-29 | Figure 3-21 | Figure 3-22 |
| 104 | -40°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding | Table 3-30 | Figure 3-23 | Figure 3-24 |
| 105 | -40°F Ambient, Maximum Decay Heat, Carbon Steel Shielding | Table 3-31 | Figure 3-25 | Figure 3-26 |
| 106 | -20°F Ambient, Maximum Decay Heat, Carbon Steel Shielding | Table 3-32 | Figure 3-27 | Figure 3-28 |

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**Table 3-27. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 92.50 | 198.50 |
| 2 | 4532 | 88.67 | 191.60 |
| 3 | 4227 | 90.28 | 194.50 |
| 4 | 4752 | 86.78 | 188.20 |
| 5 | 4838 | 82.67 | 180.80 |
| 6 | 4995 | 82.44 | 180.40 |
| 7 | 3309 | 83.22 | 181.80 |
| 8 | 3419 | 82.44 | 180.40 |
| 9 | 678 | 82.61 | 180.70 |
| 10 | 2537 | 80.67 | 177.20 |
| 11 | 1888 | 78.67 | 173.60 |
| 12 | 583 | 80.83 | 177.50 |
| 13 | 3001 | 82.94 | 181.30 |
| 14 | 3148 | 82.00 | 179.60 |
| 15 | 7533 | 85.17 | 185.30 |
| 16 | 7377 | 85.94 | 186.70 |
| 17 | 7371 | 83.67 | 182.60 |
| 18 | 6942 | 83.89 | 183.00 |
| 19 | 6267 | 83.67 | 182.60 |
| 20 | 6121 | 84.11 | 183.40 |
| 21 | 6001 | 83.44 | 182.20 |
| 22 | 9501 | 83.17 | 181.70 |
| 23 | 9950 | 81.11 | 178.00 |
| 24 | 10014 | 79.94 | 175.90 |
| 25 | 10781 | 61.00 | 141.80 |
| 26 | 9091 | 60.89 | 141.60 |
| 27 | 8463 | 79.78 | 175.60 |
| 28 | 8462 | 81.17 | 178.10 |
| 29 | 8197 | 82.89 | 181.20 |
| 30 | 9711 | 38.78 | 101.80 |
| 31 | 9821 | 38.00 | 100.40 |
| 32 | 10158 | 37.94 | 100.30 |
| 33 | 10605 | 38.78 | 101.80 |
| 34 | 9102 | 38.78 | 101.80 |
| 35 | 8578 | 37.94 | 100.30 |
| 36 | 8225 | 38.00 | 100.40 |
| 37 | 8001 | 38.78 | 101.80 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outer Shell | 101 | 2894 | 606 | 8.2722E+01 | 1.8090E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 8.3111E+01 | 1.8160E+02 |
| Lid | 3233 | 3424 | 3233 | 8.3389E+01 | 1.8210E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 9.0278E+01 | 1.9450E+02 |
| Plug | 5001 | 5404 | 5001 | 9.2500E+01 | 1.9850E+02 |
| Tungsten | 6001 | 7656 | 7377 | 8.5944E+01 | 1.8670E+02 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 8.3167E+01 | 1.8170E+02 |

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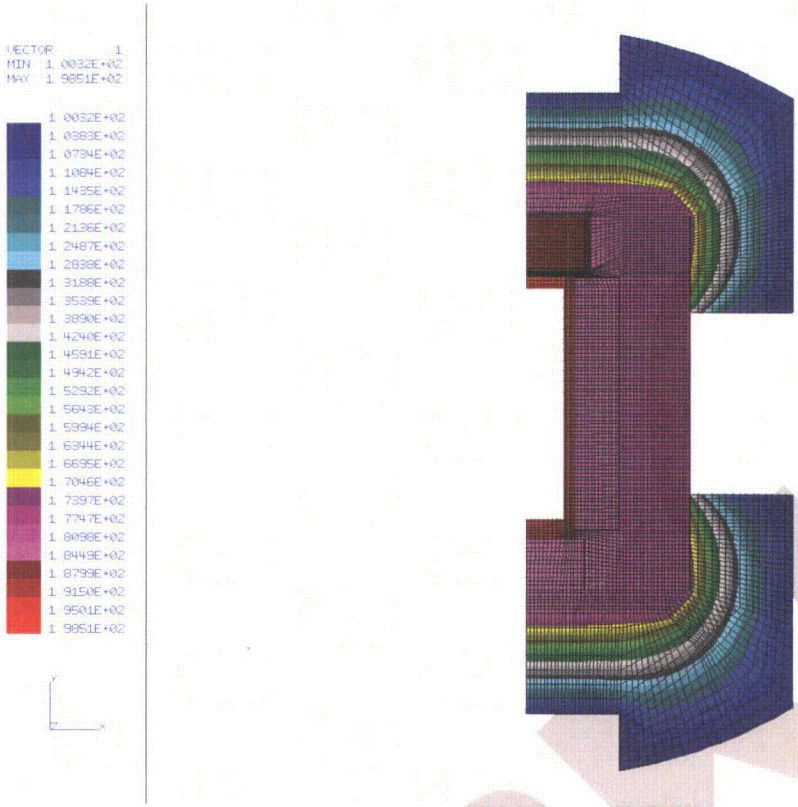


**Figure 3-17. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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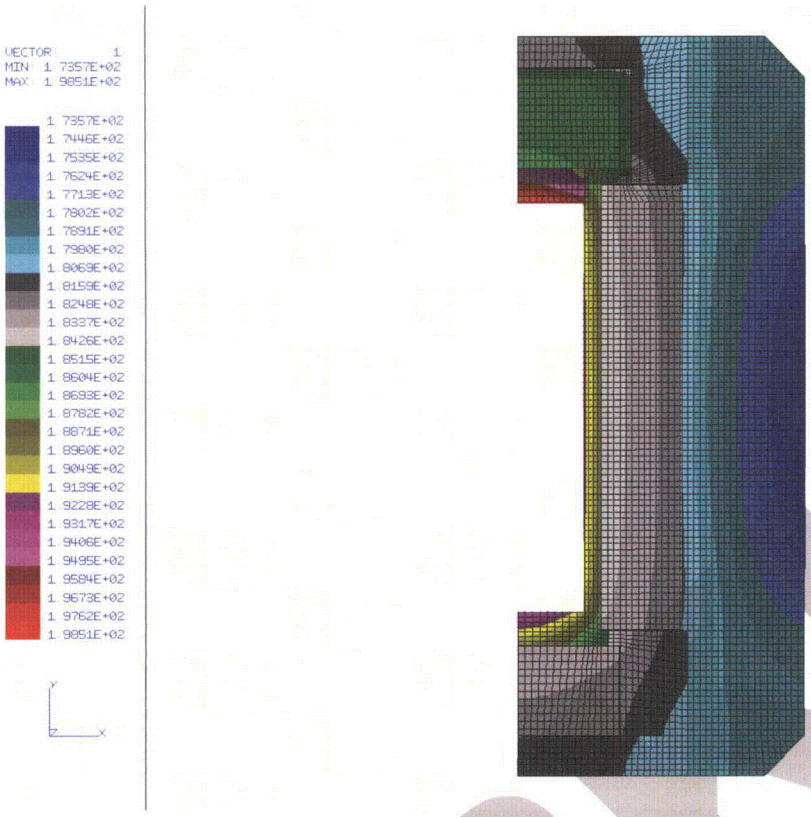


**Figure 3-18. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-28. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 127.89 | 262.20 |
| 2 | 4532 | 124.28 | 255.70 |
| 3 | 4227 | 125.83 | 258.50 |
| 4 | 4752 | 122.39 | 252.30 |
| 5 | 4838 | 118.39 | 245.10 |
| 6 | 4995 | 118.11 | 244.60 |
| 7 | 3309 | 118.89 | 246.00 |
| 8 | 3419 | 118.11 | 244.60 |
| 9 | 678 | 118.50 | 245.30 |
| 10 | 2537 | 116.33 | 241.40 |
| 11 | 1888 | 114.89 | 238.80 |
| 12 | 583 | 116.44 | 241.60 |
| 13 | 3001 | 118.61 | 245.50 |
| 14 | 3148 | 117.72 | 243.90 |
| 15 | 7533 | 120.72 | 249.30 |
| 16 | 7377 | 121.50 | 250.70 |
| 17 | 7371 | 119.44 | 247.00 |
| 18 | 6942 | 119.72 | 247.50 |
| 19 | 6267 | 119.44 | 247.00 |
| 20 | 6121 | 119.83 | 247.70 |
| 21 | 6001 | 119.17 | 246.50 |
| 22 | 9501 | 118.78 | 245.80 |
| 23 | 9950 | 116.83 | 242.30 |
| 24 | 10014 | 115.67 | 240.20 |
| 25 | 10781 | 91.06 | 195.90 |
| 26 | 9091 | 91.00 | 195.80 |
| 27 | 8463 | 115.44 | 239.80 |
| 28 | 8462 | 116.89 | 242.40 |
| 29 | 8197 | 118.56 | 245.40 |
| 30 | 9711 | 63.39 | 146.10 |
| 31 | 9821 | 79.00 | 174.20 |
| 32 | 10158 | 76.94 | 170.50 |
| 33 | 10605 | 68.72 | 155.70 |
| 34 | 9102 | 68.72 | 155.70 |
| 35 | 8578 | 76.94 | 170.50 |
| 36 | 8225 | 79.00 | 174.20 |
| 37 | 8001 | 63.33 | 146.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outer Shell | 101 | 2894 | 622 | 1.1850E+02 | 2.4530E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.1878E+02 | 2.4580E+02 |
| Lid | 3233 | 3424 | 3233 | 1.1906E+02 | 2.4630E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 1.2583E+02 | 2.5850E+02 |
| Plug | 5001 | 5404 | 5001 | 1.2789E+02 | 2.6220E+02 |
| Tungsten | 6001 | 7656 | 7377 | 1.2150E+02 | 2.5070E+02 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 1.1878E+02 | 2.4580E+02 |

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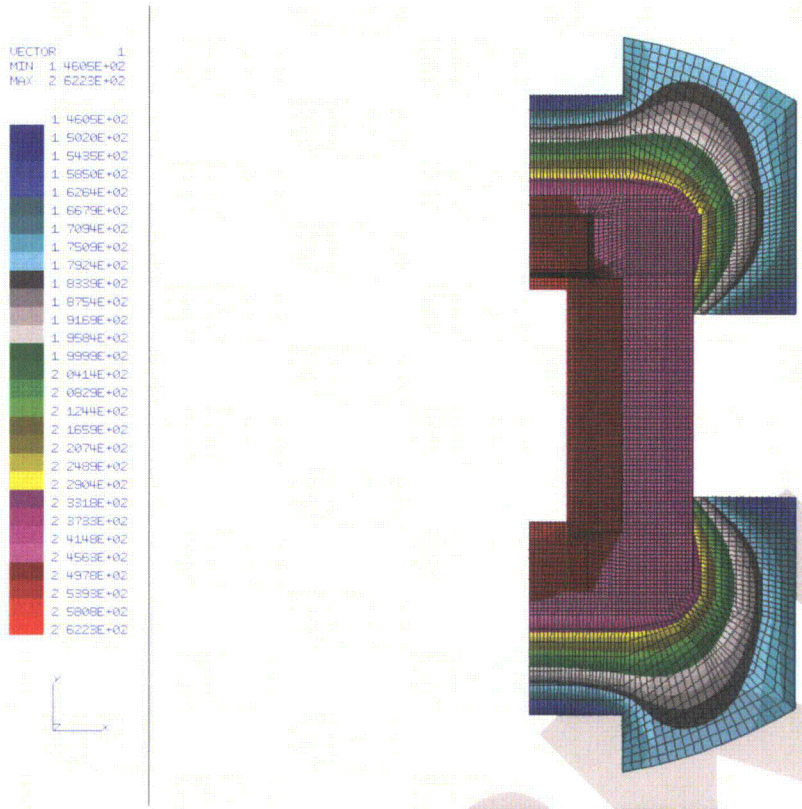


**Figure 3-19. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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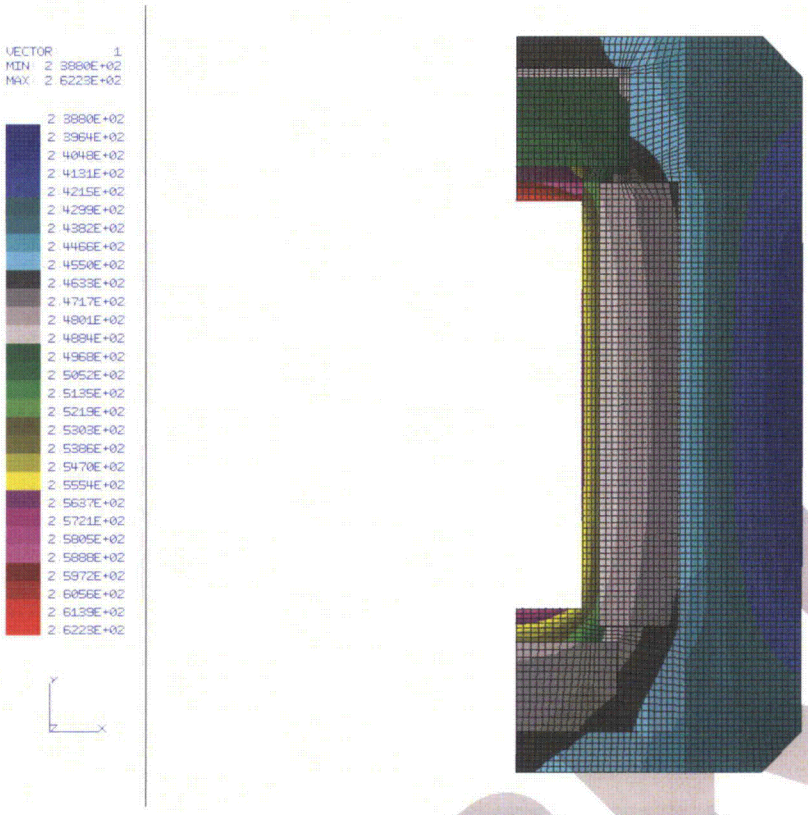


**Figure 3-20. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-29. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding – Model AOS-100B**

| 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 | 4995 | -28.89 | -20.00 |
| 7 | 3309 | -28.89 | -20.00 |
| 8 | 3419 | -28.89 | -20.00 |
| 9 | 678 | -28.89 | -20.00 |
| 10 | 2537 | -28.89 | -20.00 |
| 11 | 1888 | -28.89 | -20.00 |
| 12 | 583 | -28.89 | -20.00 |
| 13 | 3001 | -28.89 | -20.00 |
| 14 | 3148 | -28.89 | -20.00 |
| 15 | 7533 | -28.89 | -20.00 |
| 16 | 7377 | -28.89 | -20.00 |
| 17 | 7371 | -28.89 | -20.00 |
| 18 | 6942 | -28.89 | -20.00 |
| 19 | 6267 | -28.89 | -20.00 |
| 20 | 6121 | -28.89 | -20.00 |
| 21 | 6001 | -28.89 | -20.00 |
| 22 | 9501 | -28.89 | -20.00 |
| 23 | 9950 | -28.89 | -20.00 |
| 24 | 10014 | -28.89 | -20.00 |
| 25 | 10781 | -28.89 | -20.00 |
| 26 | 9091 | -28.89 | -20.00 |
| 27 | 8463 | -28.89 | -20.00 |
| 28 | 8462 | -28.89 | -20.00 |
| 29 | 8197 | -28.89 | -20.00 |
| 30 | 9711 | -28.89 | -20.00 |
| 31 | 9821 | -28.89 | -20.00 |
| 32 | 10158 | -28.89 | -20.00 |
| 33 | 10605 | -28.89 | -20.00 |
| 34 | 9102 | -28.89 | -20.00 |
| 35 | 8578 | -28.89 | -20.00 |
| 36 | 8225 | -28.89 | -20.00 |
| 37 | 8001 | -28.89 | -20.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outer Shell | 101 | 2894 | 101 | -2.8889E+01 | -2.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -2.8889E+01 | -2.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -2.8889E+01 | -2.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -2.8889E+01 | -2.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -2.8889E+01 | -2.0000E+01 |
| Tungsten | 6001 | 7656 | 6001 | -2.8889E+01 | -2.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -2.8889E+01 | -2.0000E+01 |

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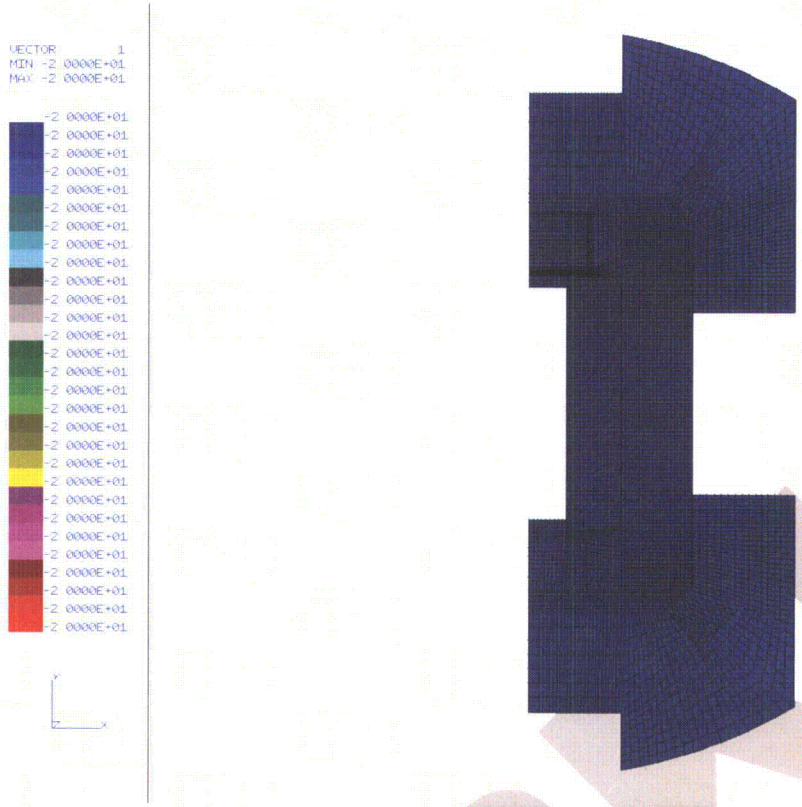


**Figure 3-21. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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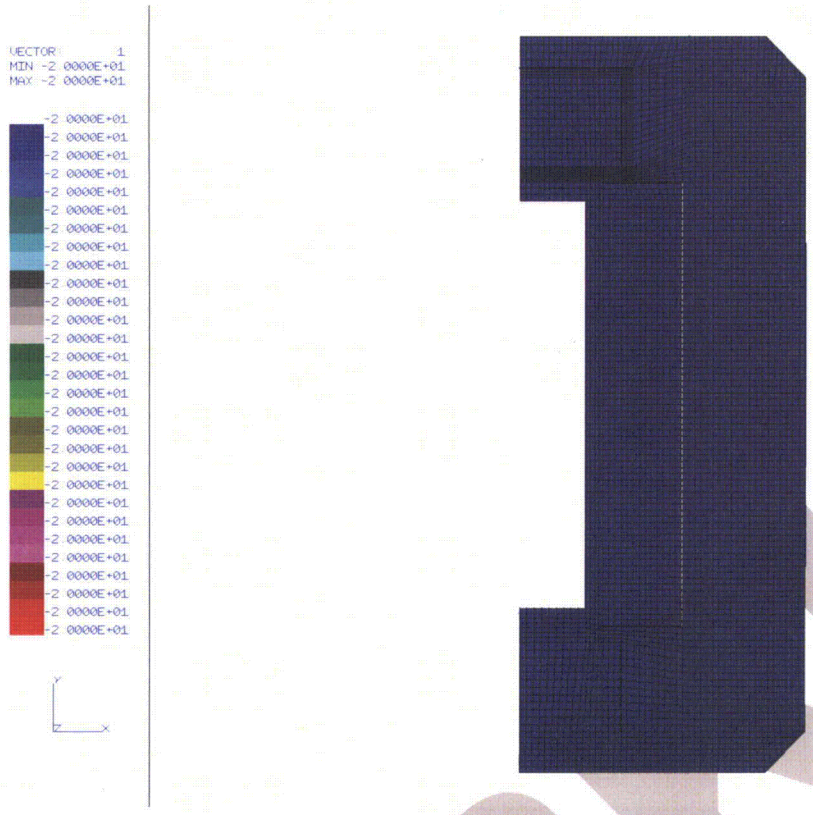


**Figure 3-22. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-30. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding – Model AOS-100B**

| 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 | 4995 | -40.00 | -40.00 |
| 7 | 3309 | -40.00 | -40.00 |
| 8 | 3419 | -40.00 | -40.00 |
| 9 | 678 | -40.00 | -40.00 |
| 10 | 2537 | -40.00 | -40.00 |
| 11 | 1888 | -40.00 | -40.00 |
| 12 | 583 | -40.00 | -40.00 |
| 13 | 3001 | -40.00 | -40.00 |
| 14 | 3148 | -40.00 | -40.00 |
| 15 | 7533 | -40.00 | -40.00 |
| 16 | 7377 | -40.00 | -40.00 |
| 17 | 7371 | -40.00 | -40.00 |
| 18 | 6942 | -40.00 | -40.00 |
| 19 | 6267 | -40.00 | -40.00 |
| 20 | 6121 | -40.00 | -40.00 |
| 21 | 6001 | -40.00 | -40.00 |
| 22 | 9501 | -40.00 | -40.00 |
| 23 | 9950 | -40.00 | -40.00 |
| 24 | 10014 | -40.00 | -40.00 |
| 25 | 10781 | -40.00 | -40.00 |
| 26 | 9091 | -40.00 | -40.00 |
| 27 | 8463 | -40.00 | -40.00 |
| 28 | 8462 | -40.00 | -40.00 |
| 29 | 8197 | -40.00 | -40.00 |
| 30 | 9711 | -40.00 | -40.00 |
| 31 | 9821 | -40.00 | -40.00 |
| 32 | 10158 | -40.00 | -40.00 |
| 33 | 10605 | -40.00 | -40.00 |
| 34 | 9102 | -40.00 | -40.00 |
| 35 | 8578 | -40.00 | -40.00 |
| 36 | 8225 | -40.00 | -40.00 |
| 37 | 8001 | -40.00 | -40.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 101 | -4.0000E+01 | -4.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -4.0000E+01 | -4.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -4.0000E+01 | -4.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -4.0000E+01 | -4.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -4.0000E+01 | -4.0000E+01 |
| Tungsten | 6001 | 7656 | 6001 | -4.0000E+01 | -4.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -4.0000E+01 | -4.0000E+01 |

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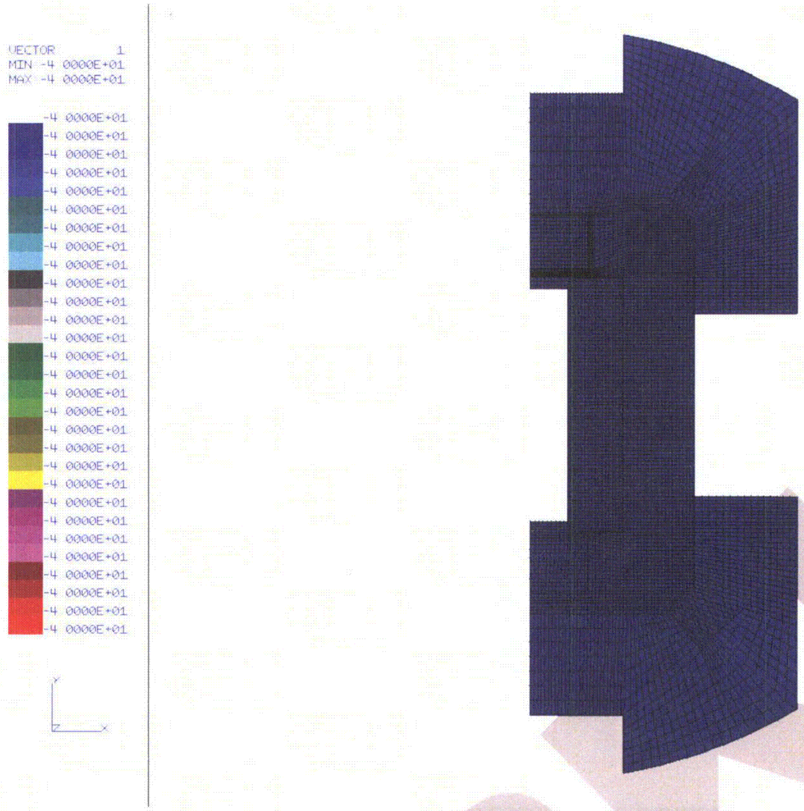


Figure 3-23. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B

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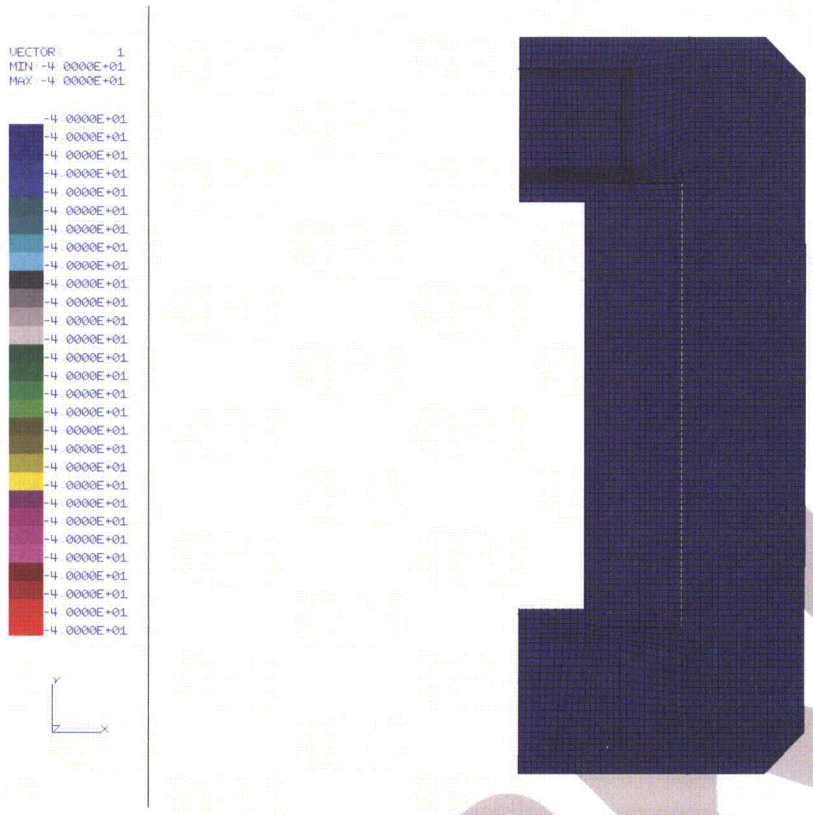


**Figure 3-24. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-31. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 14.82 | 58.68 |
| 2 | 4532 | 10.80 | 51.44 |
| 3 | 4227 | 12.28 | 54.11 |
| 4 | 4752 | 8.61 | 47.49 |
| 5 | 4838 | 4.16 | 39.48 |
| 6 | 4995 | 3.91 | 39.03 |
| 7 | 3309 | 4.77 | 40.58 |
| 8 | 3419 | 3.89 | 39.01 |
| 9 | 678 | 4.02 | 39.24 |
| 10 | 2537 | 2.02 | 35.64 |
| 11 | 1888 | -0.35 | 31.37 |
| 12 | 583 | 2.18 | 35.92 |
| 13 | 3001 | 4.48 | 40.06 |
| 14 | 3148 | 3.46 | 38.23 |
| 15 | 7533 | 7.03 | 44.65 |
| 16 | 7377 | 7.78 | 46.01 |
| 17 | 7371 | 5.15 | 41.27 |
| 18 | 6942 | 5.29 | 41.52 |
| 19 | 6267 | 5.12 | 41.22 |
| 20 | 6121 | 5.66 | 42.18 |
| 21 | 6001 | 5.01 | 41.01 |
| 22 | 9501 | 4.70 | 40.46 |
| 23 | 9950 | 2.43 | 36.38 |
| 24 | 10014 | 1.03 | 33.86 |
| 25 | 10781 | -18.40 | -1.13 |
| 26 | 9091 | -18.50 | -1.30 |
| 27 | 8463 | 0.86 | 33.55 |
| 28 | 8462 | 2.54 | 36.58 |
| 29 | 8197 | 4.42 | 39.95 |
| 30 | 9711 | -38.86 | -37.95 |
| 31 | 9821 | -39.70 | -39.46 |
| 32 | 10158 | -39.81 | -39.66 |
| 33 | 10605 | -39.14 | -38.46 |
| 34 | 9102 | -39.15 | -38.47 |
| 35 | 8578 | -39.81 | -39.66 |
| 36 | 8225 | -39.70 | -39.46 |
| 37 | 8001 | -38.86 | -37.95 |

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Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 4.1778E+00 | 3.9520E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | 4.6833E+00 | 4.0430E+01 |
| Lid | 3233 | 3424 | 3233 | 4.9611E+00 | 4.0930E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 1.2283E+01 | 5.4110E+01 |
| Plug | 5001 | 5404 | 5001 | 1.4822E+01 | 5.8680E+01 |
| Tungsten | 6001 | 7656 | 7377 | 7.7833E+00 | 4.6010E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 4.7000E+00 | 4.0460E+01 |

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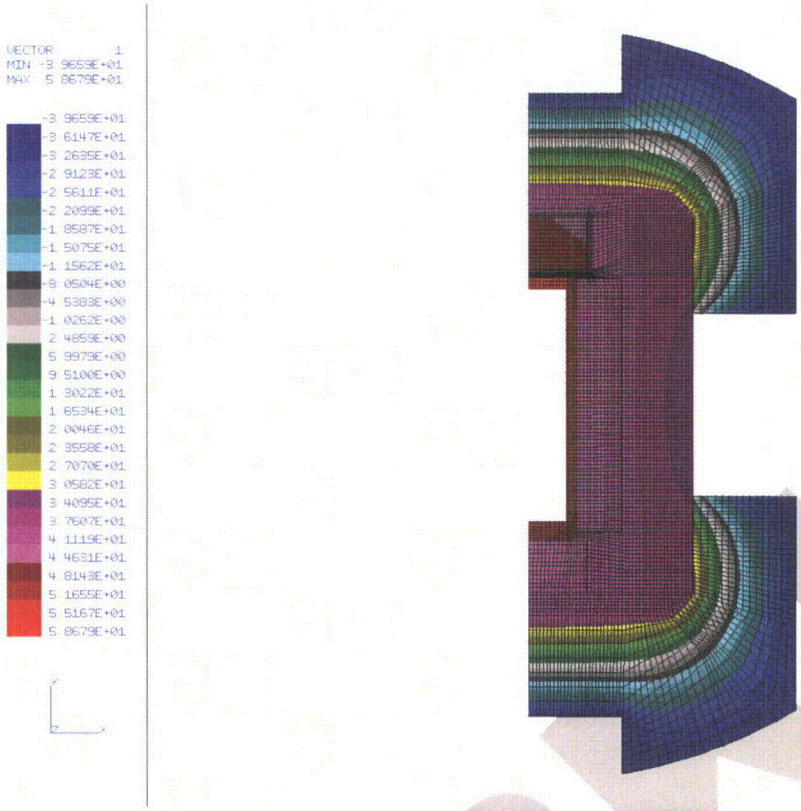


**Figure 3-25. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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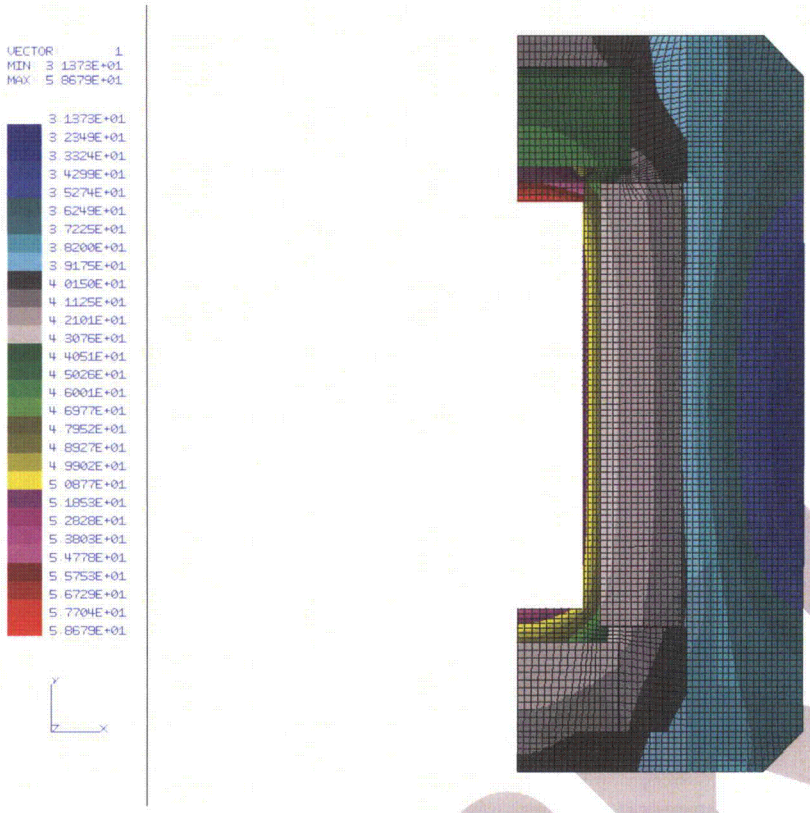


**Figure 3-26. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-32. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 27.77 | 81.99 |
| 2 | 4532 | 23.79 | 74.82 |
| 3 | 4227 | 25.29 | 77.52 |
| 4 | 4752 | 21.65 | 70.97 |
| 5 | 4838 | 17.26 | 63.06 |
| 6 | 4995 | 17.00 | 62.60 |
| 7 | 3309 | 17.84 | 64.12 |
| 8 | 3419 | 16.98 | 62.57 |
| 9 | 678 | 17.16 | 62.89 |
| 10 | 2537 | 15.13 | 59.24 |
| 11 | 1888 | 12.89 | 55.21 |
| 12 | 583 | 15.28 | 59.51 |
| 13 | 3001 | 17.56 | 63.61 |
| 14 | 3148 | 16.56 | 61.80 |
| 15 | 7533 | 20.06 | 68.10 |
| 16 | 7377 | 20.82 | 69.47 |
| 17 | 7371 | 18.27 | 64.88 |
| 18 | 6942 | 18.42 | 65.16 |
| 19 | 6267 | 18.24 | 64.83 |
| 20 | 6121 | 18.74 | 65.74 |
| 21 | 6001 | 18.09 | 64.56 |
| 22 | 9501 | 17.78 | 64.00 |
| 23 | 9950 | 15.53 | 59.95 |
| 24 | 10014 | 14.12 | 57.41 |
| 25 | 10781 | -5.99 | 21.21 |
| 26 | 9091 | -6.09 | 21.03 |
| 27 | 8463 | 13.93 | 57.08 |
| 28 | 8462 | 15.63 | 60.14 |
| 29 | 8197 | 17.49 | 63.49 |
| 30 | 9711 | -27.63 | -17.74 |
| 31 | 9821 | -28.55 | -19.39 |
| 32 | 10158 | -28.68 | -19.63 |
| 33 | 10605 | -27.94 | -18.29 |
| 34 | 9102 | -27.94 | -18.30 |
| 35 | 8578 | -28.68 | -19.63 |
| 36 | 8225 | -28.55 | -19.39 |
| 37 | 8001 | -27.64 | -17.75 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 1.7289E+01 | 6.3120E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7767E+01 | 6.3980E+01 |
| Lid | 3233 | 3424 | 3233 | 1.8039E+01 | 6.4470E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 2.5289E+01 | 7.7520E+01 |
| Plug | 5001 | 5404 | 5001 | 2.7772E+01 | 8.1990E+01 |
| Tungsten | 6001 | 7656 | 7377 | 2.0817E+01 | 6.9470E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 1.7778E+01 | 6.4000E+01 |

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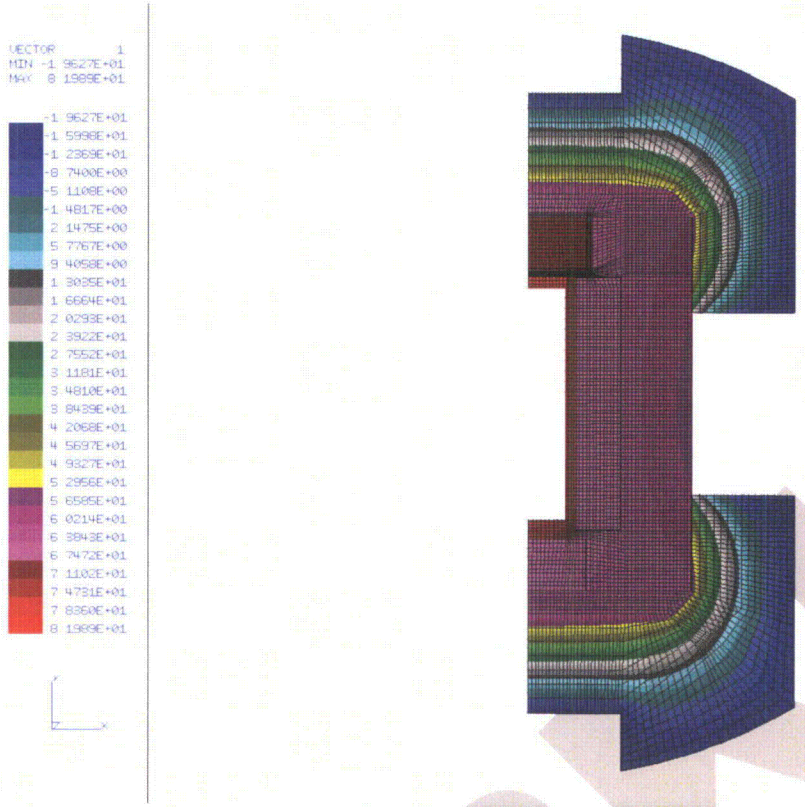


**Figure 3-27. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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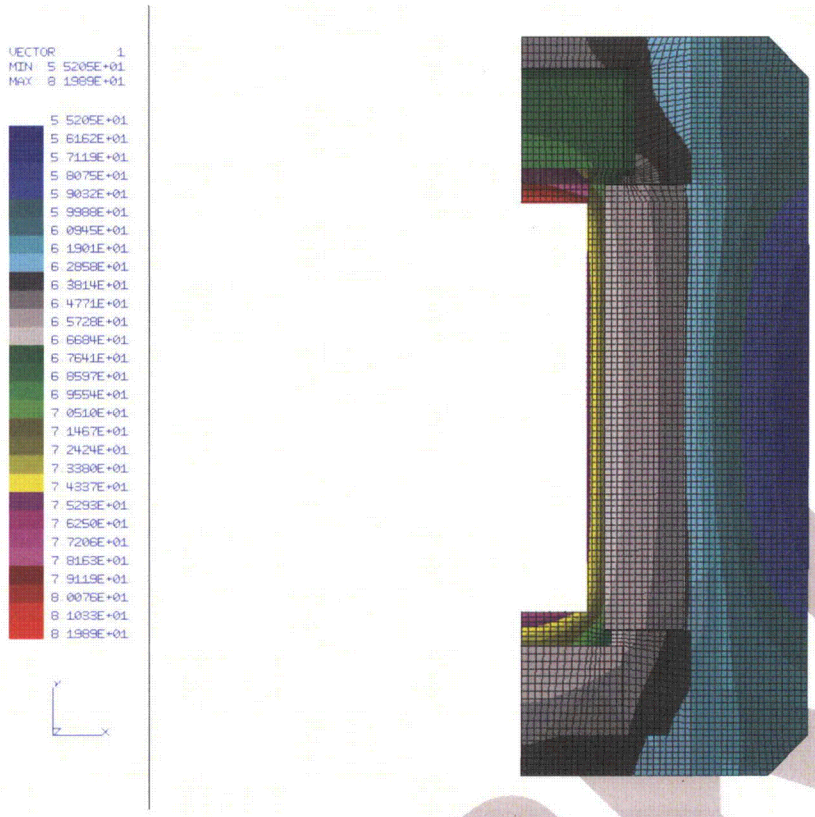


**Figure 3-28. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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## 3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

After two 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 package must be exposed to a fire transient. The thermal test consists of exposure of the entire package, for not less than 30 minutes, to a radiation environment of 800°C (1,475°F) with an emissivity coefficient of at least 0.9. The surface absorptivity of the package is taken as 0.8, and the convective heat coefficient is in the range of 5 to 10 w/m$^2$-°C **[3.11]**. The transient is then continued, until maximum temperature values within the cask are obtained.

The package's thermal performance during the fire transient is evaluated, using the finite element program LIBRA. In this evaluation, the properties are updated every time step, by the material function within the LIBRA Code. This function contains expressions relating element properties to temperature. Thermal properties, as well as density and heat capacitance, are periodically updated. The LIBRA program allows the user to select the time-marching scheme. In this analysis, the backward difference scheme is selected.

Figure 3-29 (a revised model of Figure 3-3, "Thermal Finite Element Model – Normal Conditions of Transport," which represents Normal conditions of transport) illustrates the LIBRA Finite Element model used for the Model AOS-100 transport package, for Fire conditions of transport, which includes the cask and impact limiter structures. Thermal models used for the fire event include reduced impact limiters that account for deformations from head-on, side, and corner 9-m (30-ft.) drops applied simultaneously. In contrast, the Model AOS-165 transport package's geometry has a 14.22 cm (5.6 in.) reduction due to head-on drop, and a 28.96 cm (11.4 in.) reduction due to the corner drops applied to the upper impact limiter. A 10.41 cm (4.1 in.) reduction due to the side drop is applied to both the upper and lower impact limiters. General Plastics LAST-A-FOAM properties are adjusted to the reduced volume. The cask is not altered for this event. For the other geometries, the reduced impact limiter effects are linearly scaled by their cask size. The encapsulated tungsten alloy shielding material is included in the cask model. Because an axisymmetric (2D) solution is used, only a cross-section of the package must be modeled. The model includes both conductive two-node axial and four-quadrilateral elements. Also, the boundary two-node element type is used. Air is represented to account not only for temperature variation, but also for different heat transfer modes. The mode of heat transfer across an air space varies, depending upon whether the air space is:

- Enclosed or open
- Vertically or horizontally oriented

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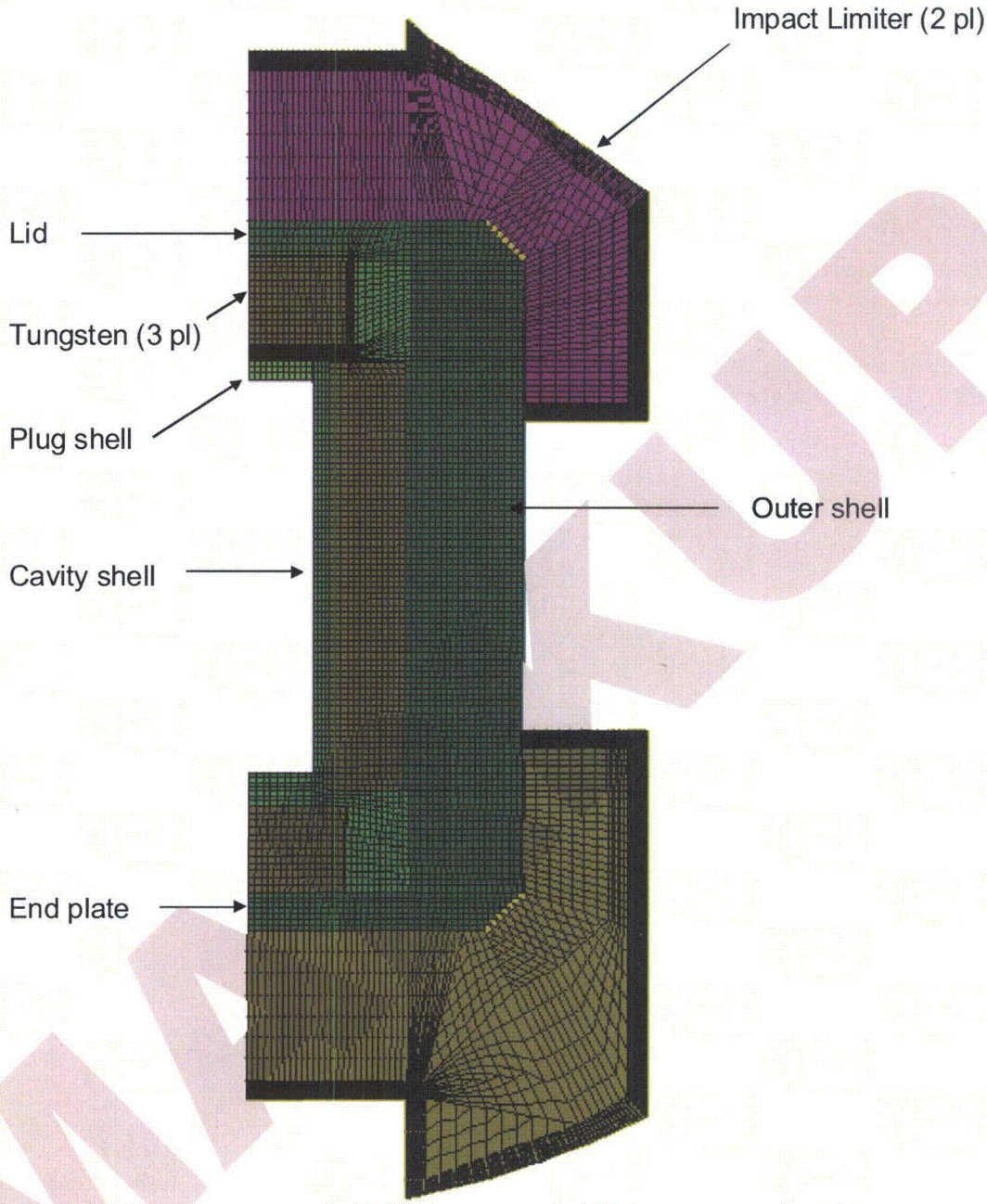


**Figure 3-29. Thermal Finite Element Model – Fire Conditions of Transport**

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### 3.4.1 Initial Conditions

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 began from 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. This ambient temperature is maintained for 0.5 hours. At this time, the ambient condition is reversed to the initial condition. The analysis continues until five (5) hours elapse.

### 3.4.3 Maximum Pressures and Temperatures

The maximum pressures are reported in Table 3-3, "Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models." The maximum temperatures are reported in Table 3-4, "Transport Package Temperature Summary – All Models." Temperature tables and contours plots of the Fire condition follows.

### 3.4.4 Maximum Thermal Stresses

Thermal stresses resulting from temperature gradients and differential thermal expansion for the Model AOS-100 transport package are provided in Chapter 2, Table 2-26 through Table 2-31 for Normal conditions of transport, and Table 2-66 through Table 2-71 for Hypothetical Accident conditions of transport.

Thermal stresses for the other models are provided in the Chapter 2 appendices, by model.

### 3.4.5 Hypothetical Accident Conditions for Fissile Material Packages for Air Transport

***Note:*** *Not applicable. Fuel is not an authorized content for the AOS Transport Packaging System.*

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## 3.4.6 Hypothetical Accident Conditions of Transport Results – Models AOS-100A and AOS-100A-S

Table 3-33 lists the tables and figures in this subsection that present the Model AOS-100A and AOS-100A-S transport package results under Hypothetical Accident conditions of transport, for Load Cases 111 through 116. Each table provides a list of temperatures at each monitoring node. Also listed are the maximum temperatures within each transport package component.

Table 3-34 lists the temperature monitoring points (nodes) for the Model AOS-100 (A, B, and A-S) transport package, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-30 illustrates the location of each node on the transport package, under Fire conditions.

***Note:*** *Results for the Model AOS-100B transport package are provided in Subsection 3.4.7. Results for the Model AOS-025, AOS-050, and AOS-165 transport packages are provided in Appendix 3.5.*

**Table 3-33. Hypothetical Accident Conditions of Transport Results – Models AOS-100A and AOS-100A-S**

| Load Case | Description | Results Table | Temperature versus Time | Entire Model | Cask Model |
|---|---|---|---|---|---|
| 111 | Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat | Table 3-35 | Figure 3-31 | Figure 3-32 | Figure 3-33 |
| 112 | Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-36 | – | Figure 3-34 | Figure 3-35 |
| 113 | Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-37 | – | Figure 3-36 | Figure 3-37 |
| 114 | Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-38 | – | Figure 3-38 | Figure 3-39 |
| 115 | Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-39 | – | Figure 3-40 | Figure 3-41 |
| 116 | Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-40 | – | Figure 3-42 | Figure 3-43 |

MINIMUM

**Table 3-34. Temperature Monitoring Points, All Conditions of Transport – Model AOS-100**

| Nodal Location | LIBRA Model Nodal Number | |
|---|---|---|
| | Normal Conditions | Fire Conditions |
| 1 | 5001 | 5001 |
| 2 | 4532 | 4532 |
| 3 | 4227 | 4227 |
| 4 | 4752 | 4752 |
| 5 | 4838 | 4838 |
| 6 | 4995 | 4995 |
| 7 | 3309 | 3309 |
| 8 | 3419 | 3419 |
| 9 | 678 | 678 |
| 10 | 2537 | 2537 |
| 11 | 1888 | 1888 |
| 12 | 583 | 583 |
| 13 | 3001 | 3001 |
| 14 | 3148 | 3148 |
| 15 | 7533 | 7533 |
| 16 | 7377 | 7377 |
| 17 | 7371 | 7371 |
| 18 | 6942 | 6942 |
| 19 | 6267 | 6267 |
| 20 | 6121 | 6121 |
| 21 | 6001 | 6001 |
| 22 | 9501 | 15481 |
| 23 | 9950 | 16630 |
| 24 | 10014 | 16694 |
| 25 | 10781 | 18111 |
| 26 | 9091 | 1153 |
| 27 | 8463 | 9785 |
| 28 | 8462 | 9571 |
| 29 | 8197 | 8197 |
| 30 | 9711 | 15451 |
| 31 | 9821 | 15961 |
| 32 | 10158 | 17022 |
| 33 | 10605 | 17743 |
| 34 | 9102 | 11051 |
| 35 | 8578 | 9900 |
| 36 | 8225 | 8673 |
| 37 | 8001 | 8225 |

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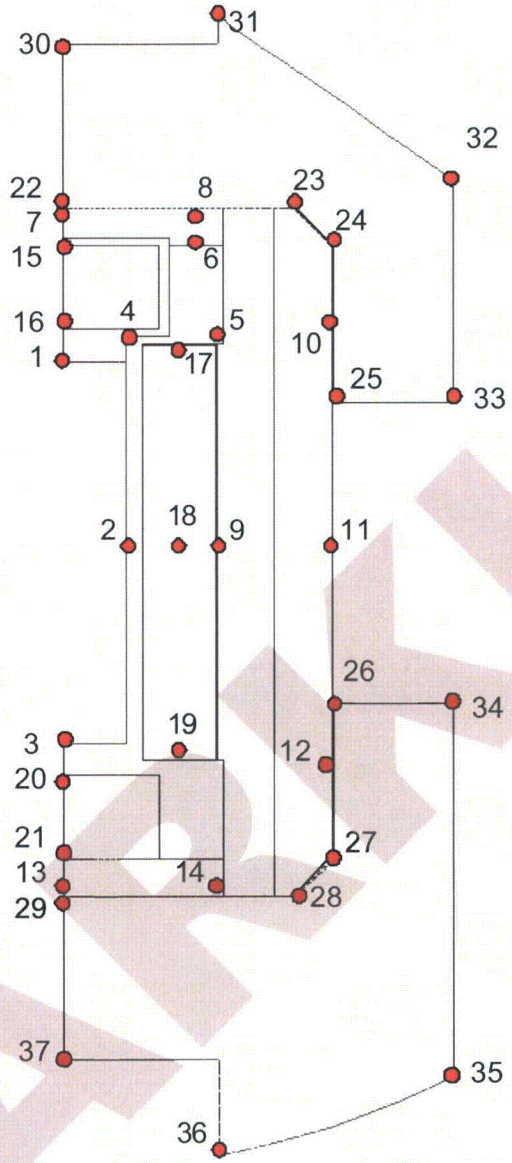


**Figure 3-30. Selected Nodal Locations for Fire Conditions of Transport – Model AOS-100**

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**Table 3-35. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 128.22 | 262.80 |
| 2 | 4532 | 145.72 | 294.30 |
| 3 | 4227 | 127.50 | 261.50 |
| 4 | 4752 | 128.78 | 263.80 |
| 5 | 4838 | 129.28 | 264.70 |
| 6 | 4995 | 118.89 | 246.00 |
| 7 | 3309 | 118.28 | 244.90 |
| 8 | 3419 | 117.83 | 244.10 |
| 9 | 678 | 179.22 | 354.60 |
| 10 | 2537 | 161.50 | 322.70 |
| 11 | 1888 | 425.89 | 798.60 |
| 12 | 583 | 158.67 | 317.60 |
| 13 | 3001 | 118.28 | 244.90 |
| 14 | 3148 | 118.22 | 244.80 |
| 15 | 7533 | 120.61 | 249.10 |
| 16 | 7377 | 121.39 | 250.50 |
| 17 | 7371 | 138.89 | 282.00 |
| 18 | 6942 | 152.94 | 307.30 |
| 19 | 6267 | 138.39 | 281.10 |
| 20 | 6121 | 120.56 | 249.00 |
| 21 | 6001 | 119.67 | 247.40 |
| 22 | 15481 | 118.22 | 244.80 |
| 23 | 16630 | 118.17 | 244.70 |
| 24 | 16694 | 122.17 | 251.90 |
| 25 | 18111 | 618.33 | 1145.00 |
| 26 | 11531 | 617.78 | 1144.00 |
| 27 | 9785 | 124.06 | 255.30 |
| 28 | 9571 | 118.78 | 245.80 |
| 29 | 8197 | 118.17 | 244.70 |
| 30 | 15451 | 793.89 | 1461.00 |
| 31 | 15961 | 799.44 | 1471.00 |
| 32 | 17022 | 796.11 | 1465.00 |
| 33 | 17743 | 797.78 | 1468.00 |
| 34 | 11051 | 798.89 | 1470.00 |
| 35 | 9900 | 797.78 | 1468.00 |
| 36 | 8673 | 798.89 | 1470.00 |
| 37 | 8225 | 795.56 | 1464.00 |

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Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1888 | 4.2589E+02 | 7.9860E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.1872E+02 | 2.4570E+02 |
| Lid | 3233 | 3424 | 3233 | 1.1850E+02 | 2.4530E+02 |
| Shell Cavity | 4001 | 4998 | 4531 | 1.4611E+02 | 2.9500E+02 |
| Plug | 5001 | 5404 | 5012 | 1.2856E+02 | 2.6340E+02 |
| Tungsten Alloy | 6001 | 7656 | 6938 | 1.6006E+02 | 3.2010E+02 |
| LAST-A-FOAM | 8001 | 18126 | 15913 | 7.9944E+02 | 1.4710E+03 |

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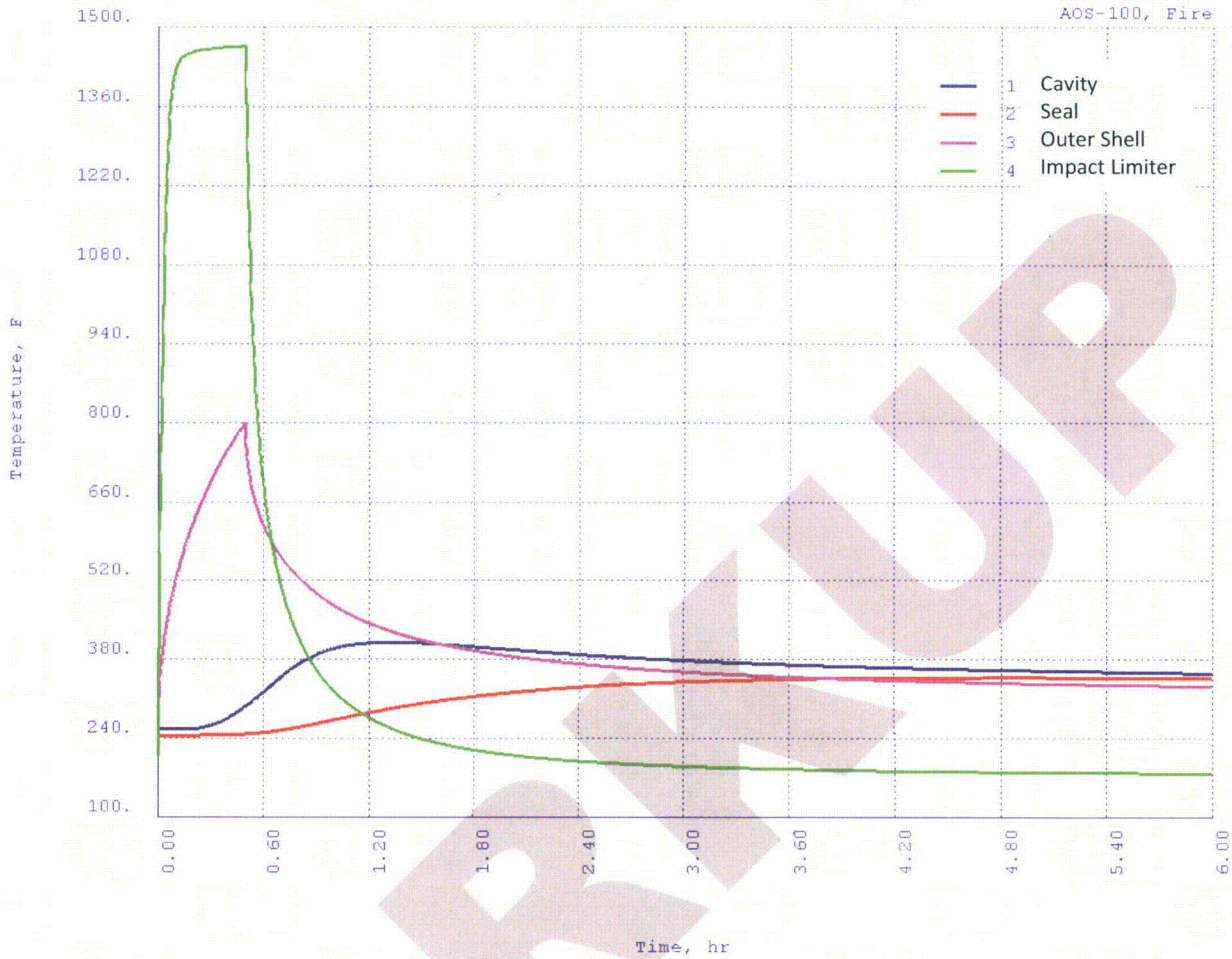


**Figure 3-31. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Temperature versus Time – Models AOS-100A and AOS-100A-S**

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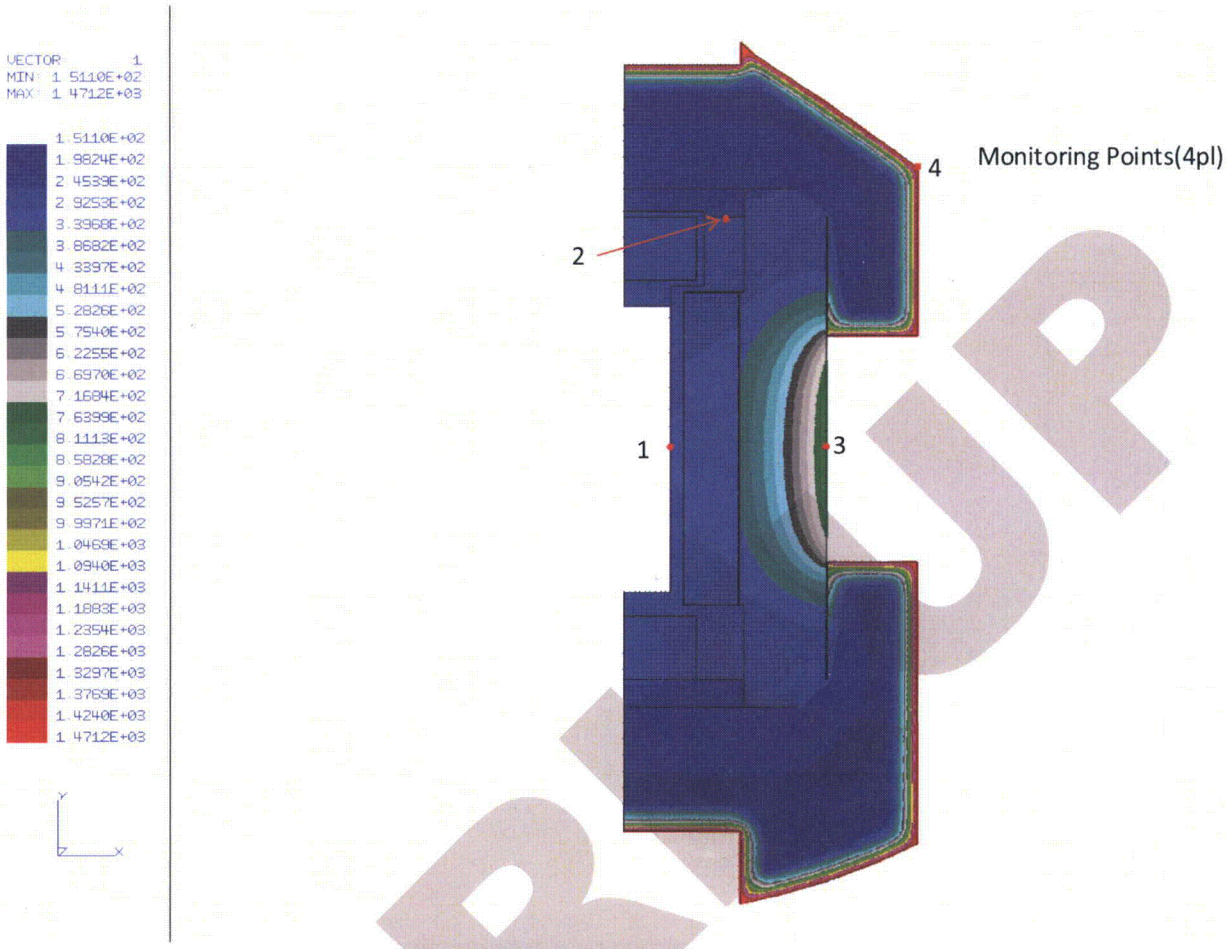


**Figure 3-32. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

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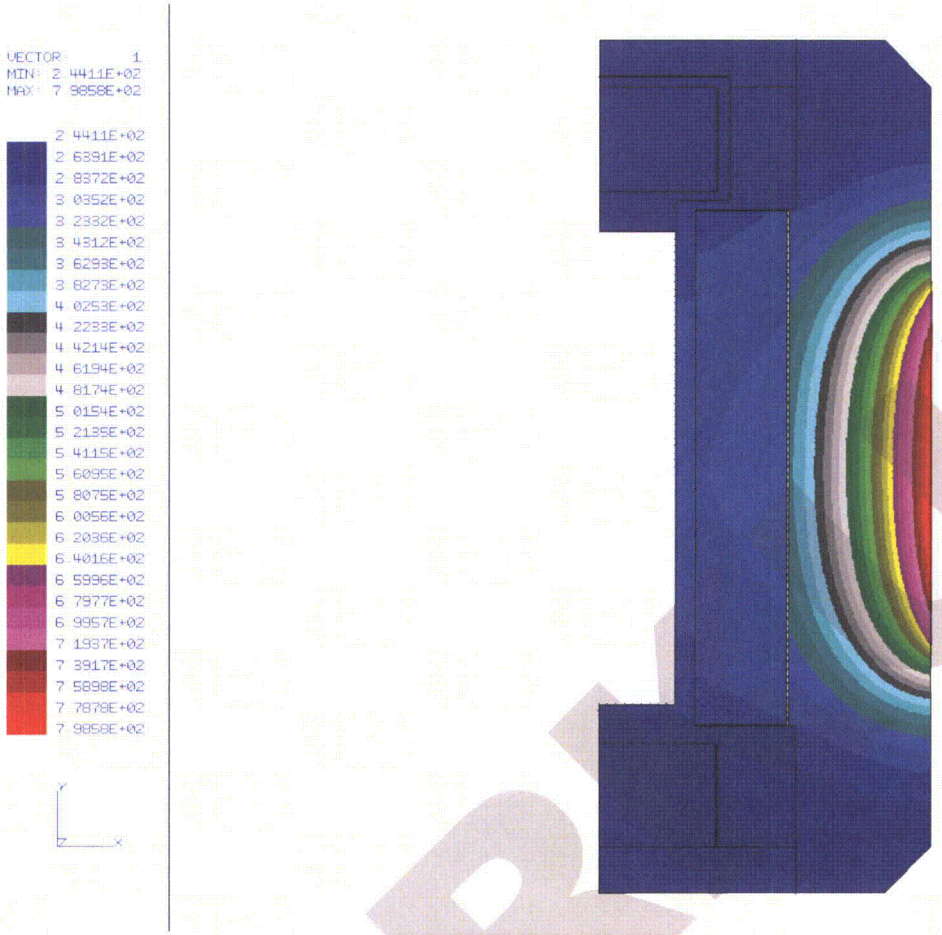


**Figure 3-33. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

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**Table 3-36. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 142.50 | 288.50 |
| 2 | 4532 | 202.78 | 397.00 |
| 3 | 4227 | 151.22 | 304.20 |
| 4 | 4752 | 159.17 | 318.50 |
| 5 | 4838 | 159.11 | 318.40 |
| 6 | 4995 | 132.94 | 271.30 |
| 7 | 3309 | 120.72 | 249.30 |
| 8 | 3419 | 125.39 | 257.70 |
| 9 | 678 | 217.39 | 423.30 |
| 10 | 2537 | 172.94 | 343.30 |
| 11 | 1888 | 245.06 | 473.10 |
| 12 | 583 | 171.61 | 340.90 |
| 13 | 3001 | 123.83 | 254.90 |
| 14 | 3148 | 129.89 | 265.80 |
| 15 | 7533 | 129.22 | 264.60 |
| 16 | 7377 | 131.28 | 268.30 |
| 17 | 7371 | 182.83 | 361.10 |
| 18 | 6942 | 203.94 | 399.10 |
| 19 | 6267 | 181.06 | 357.90 |
| 20 | 6121 | 136.44 | 277.60 |
| 21 | 6001 | 133.17 | 271.70 |
| 22 | 15481 | 120.50 | 248.90 |
| 23 | 16630 | 133.72 | 272.70 |
| 24 | 16694 | 138.33 | 281.00 |
| 25 | 18111 | 179.33 | 354.80 |
| 26 | 11531 | 175.61 | 348.10 |
| 27 | 9785 | 140.00 | 284.00 |
| 28 | 9571 | 134.78 | 274.60 |
| 29 | 8197 | 123.22 | 253.80 |
| 30 | 15451 | 157.83 | 316.10 |
| 31 | 15961 | 161.83 | 323.30 |
| 32 | 17022 | 160.94 | 321.70 |
| 33 | 17743 | 156.39 | 313.50 |
| 34 | 11051 | 148.33 | 299.00 |
| 35 | 9900 | 153.00 | 307.40 |
| 36 | 8673 | 160.50 | 320.90 |
| 37 | 8225 | 150.28 | 302.50 |

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Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4650E+02 | 4.7570E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7606E+02 | 3.4890E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7456E+02 | 3.4620E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0794E+02 | 4.0630E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8389E+02 | 3.6300E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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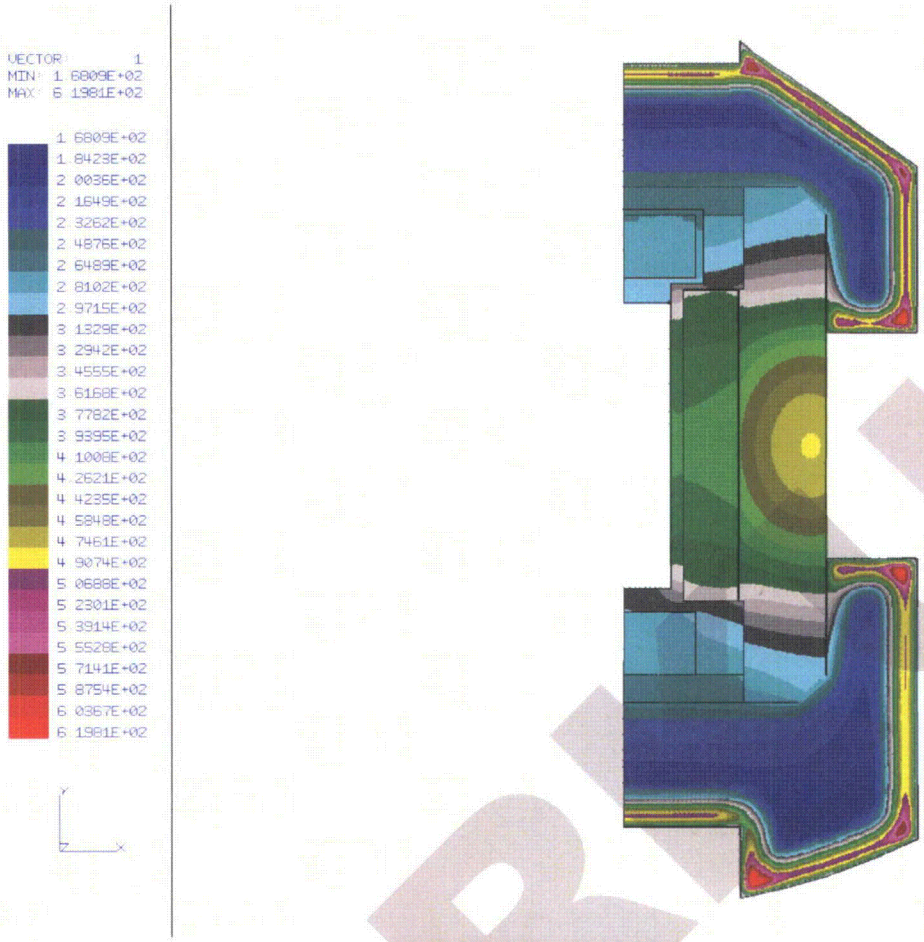


**Figure 3-34. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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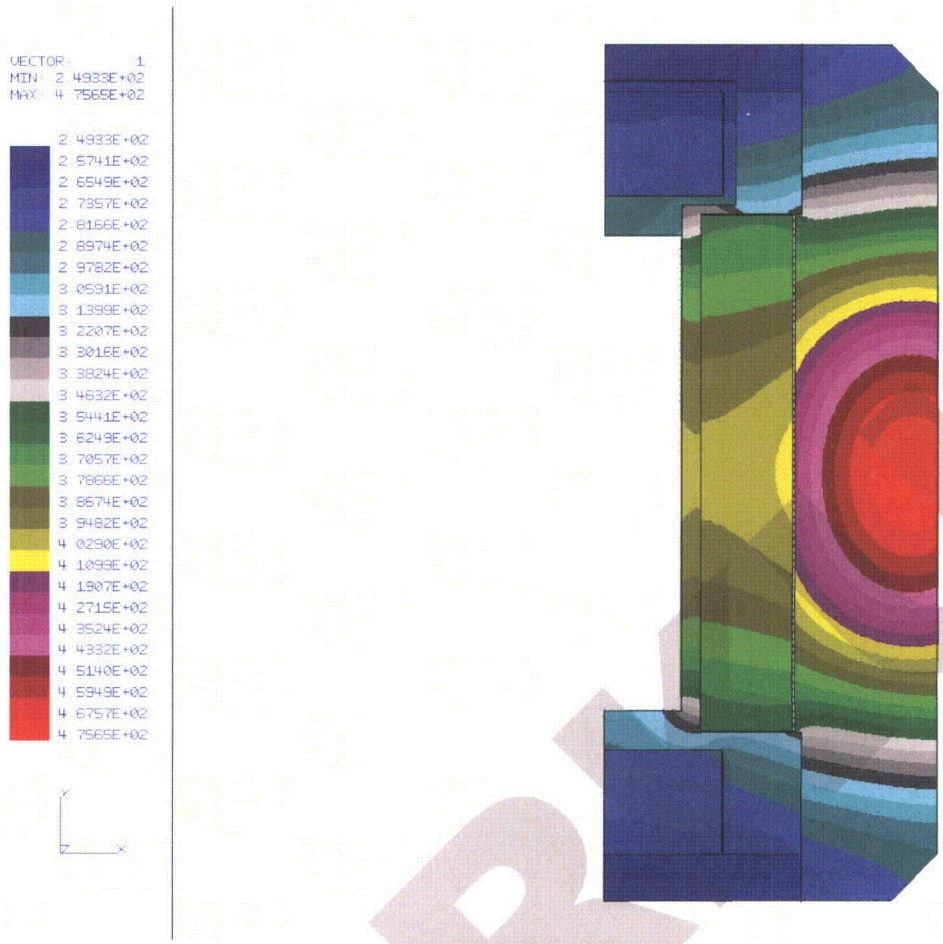


**Figure 3-35. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

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**Table 3-37. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 159.56 | 319.20 |
| 2 | 4532 | 207.94 | 406.30 |
| 3 | 4227 | 170.89 | 339.60 |
| 4 | 4752 | 173.00 | 343.40 |
| 5 | 4838 | 170.89 | 339.60 |
| 6 | 4995 | 149.00 | 300.20 |
| 7 | 3309 | 131.17 | 268.10 |
| 8 | 3419 | 139.61 | 283.30 |
| 9 | 678 | 208.28 | 406.90 |
| 10 | 2537 | 173.50 | 344.30 |
| 11 | 1888 | 211.22 | 412.20 |
| 12 | 583 | 172.67 | 342.80 |
| 13 | 3001 | 138.83 | 281.90 |
| 14 | 3148 | 145.56 | 294.00 |
| 15 | 7533 | 144.17 | 291.50 |
| 16 | 7377 | 146.61 | 295.90 |
| 17 | 7371 | 190.28 | 374.50 |
| 18 | 6942 | 204.44 | 400.00 |
| 19 | 6267 | 188.78 | 371.80 |
| 20 | 6121 | 154.50 | 310.10 |
| 21 | 6001 | 150.78 | 303.40 |
| 22 | 15481 | 130.67 | 267.20 |
| 23 | 16630 | 148.50 | 299.30 |
| 24 | 16694 | 149.61 | 301.30 |
| 25 | 18111 | 147.67 | 297.80 |
| 26 | 11531 | 145.00 | 293.00 |
| 27 | 9785 | 150.44 | 302.80 |
| 28 | 9571 | 149.33 | 300.80 |
| 29 | 8197 | 137.89 | 280.20 |
| 30 | 15451 | 107.61 | 225.70 |
| 31 | 15961 | 112.33 | 234.20 |
| 32 | 17022 | 114.17 | 237.50 |
| 33 | 17743 | 108.61 | 227.50 |
| 34 | 11051 | 102.67 | 216.80 |
| 35 | 9900 | 108.22 | 226.80 |
| 36 | 8673 | 113.17 | 235.70 |
| 37 | 8225 | 101.44 | 214.60 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4650E+02 | 4.7570E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7606E+02 | 3.4890E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7456E+02 | 3.4620E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0794E+02 | 4.0630E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8389E+02 | 3.6300E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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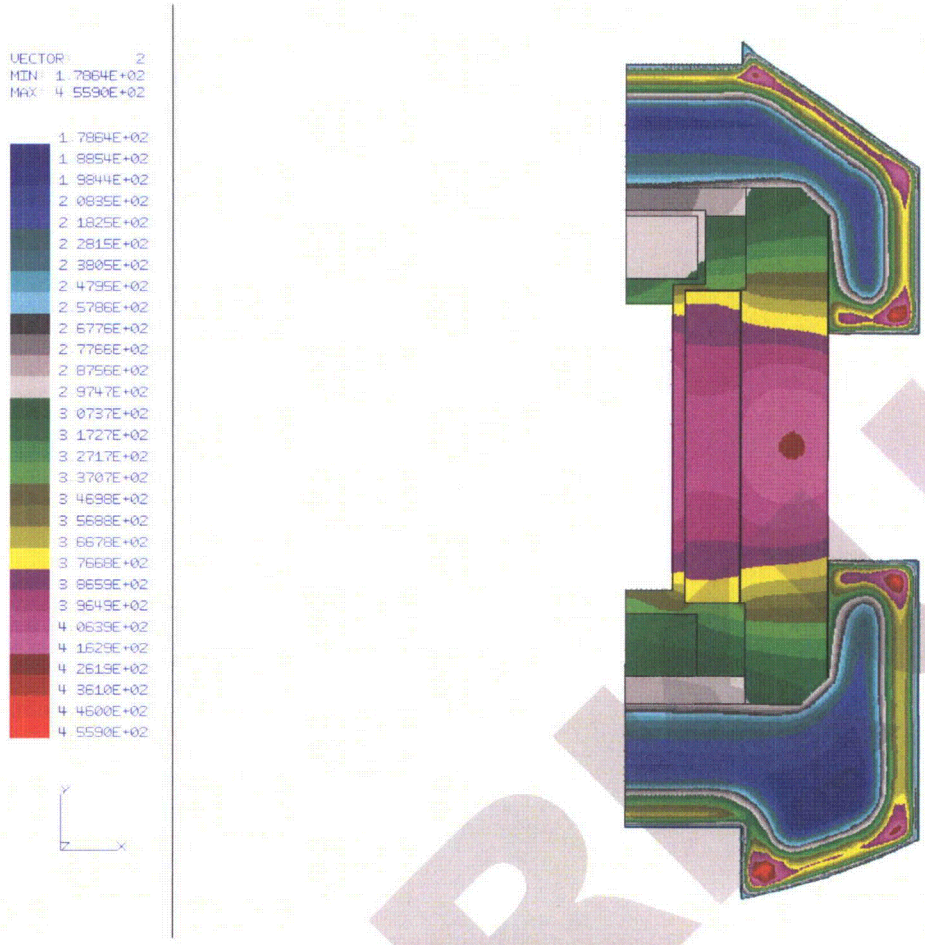


**Figure 3-36. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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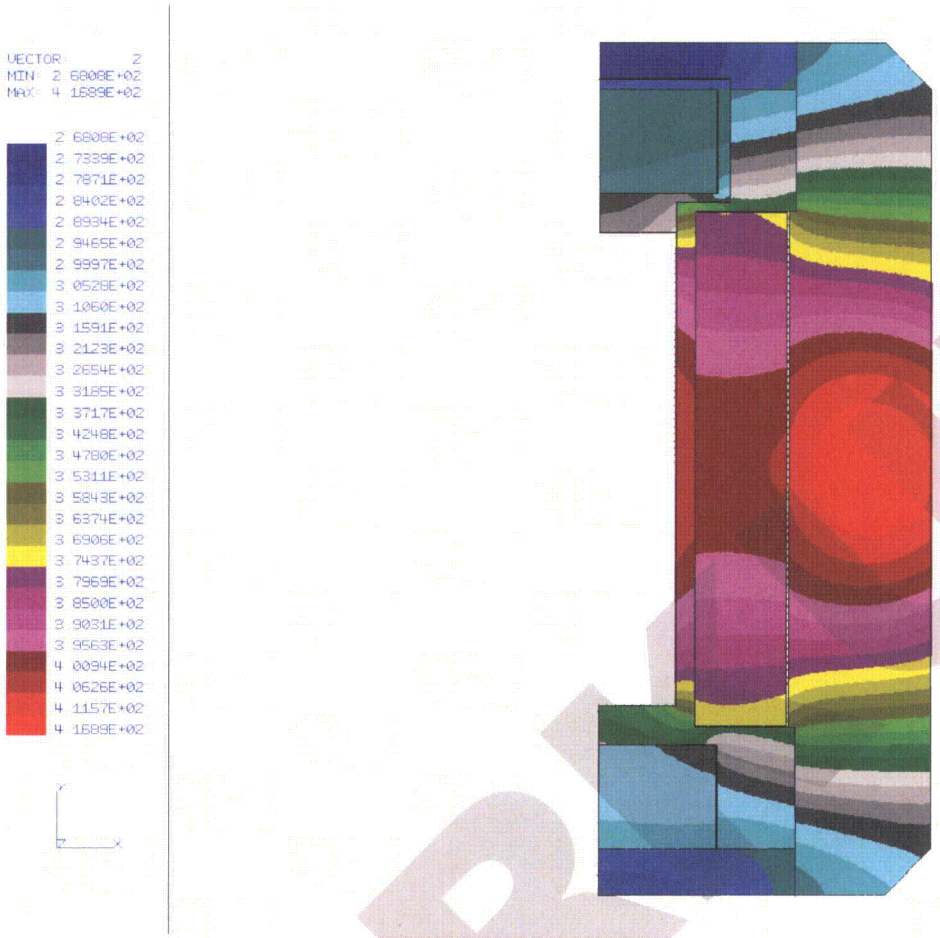


**Figure 3-37. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

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**Table 3-38. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 170.06 | 338.10 |
| 2 | 4532 | 201.83 | 395.30 |
| 3 | 4227 | 179.06 | 354.30 |
| 4 | 4752 | 177.67 | 351.80 |
| 5 | 4838 | 174.89 | 346.80 |
| 6 | 4995 | 159.56 | 319.20 |
| 7 | 3309 | 144.50 | 292.10 |
| 8 | 3419 | 151.89 | 305.40 |
| 9 | 678 | 198.61 | 389.50 |
| 10 | 2537 | 174.33 | 345.80 |
| 11 | 1888 | 195.44 | 383.80 |
| 12 | 583 | 173.78 | 344.80 |
| 13 | 3001 | 153.17 | 307.70 |
| 14 | 3148 | 157.33 | 315.20 |
| 15 | 7533 | 156.44 | 313.60 |
| 16 | 7377 | 158.50 | 317.30 |
| 17 | 7371 | 188.39 | 371.10 |
| 18 | 6942 | 197.56 | 387.60 |
| 19 | 6267 | 187.56 | 369.60 |
| 20 | 6121 | 165.39 | 329.70 |
| 21 | 6001 | 162.50 | 324.50 |
| 22 | 15481 | 143.89 | 291.00 |
| 23 | 16630 | 158.06 | 316.50 |
| 24 | 16694 | 157.39 | 315.30 |
| 25 | 18111 | 137.61 | 279.70 |
| 26 | 11531 | 135.78 | 276.40 |
| 27 | 9785 | 158.06 | 316.50 |
| 28 | 9571 | 158.89 | 318.00 |
| 29 | 8197 | 152.28 | 306.10 |
| 30 | 15451 | 89.44 | 193.00 |
| 31 | 15961 | 96.06 | 204.90 |
| 32 | 17022 | 98.44 | 209.20 |
| 33 | 17743 | 92.72 | 198.90 |
| 34 | 11051 | 88.61 | 191.50 |
| 35 | 9900 | 94.06 | 201.30 |
| 36 | 8673 | 97.61 | 207.70 |
| 37 | 8225 | 84.83 | 184.70 |

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Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4650E+02 | 4.7570E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7606E+02 | 3.4890E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7456E+02 | 3.4620E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0794E+02 | 4.0630E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8389E+02 | 3.6300E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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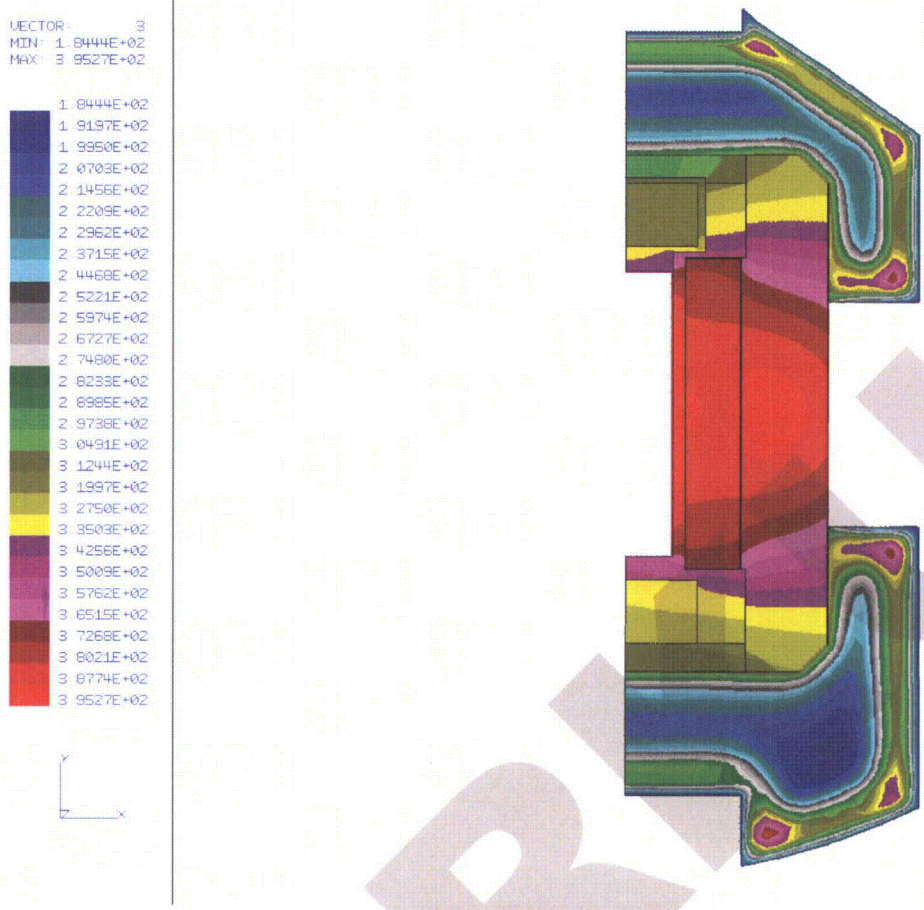


**Figure 3-38. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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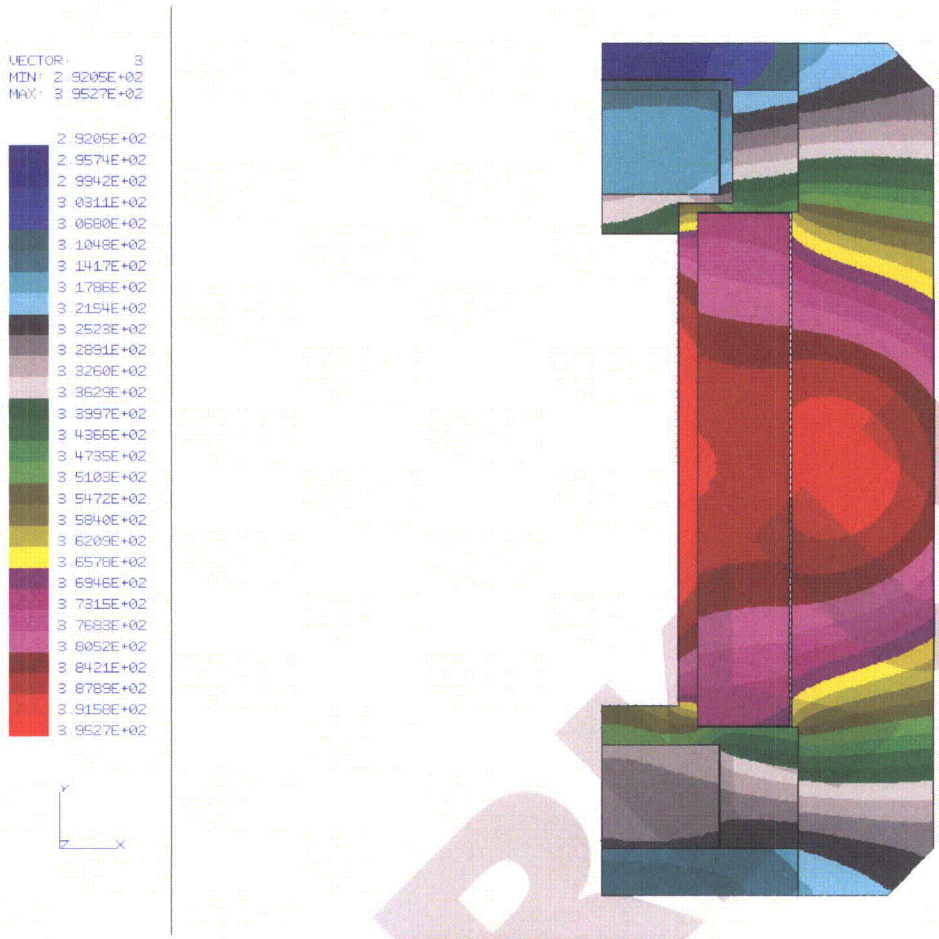


**Figure 3-39. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

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**Table 3-39. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 176.39 | 349.50 |
| 2 | 4532 | 195.72 | 384.30 |
| 3 | 4227 | 182.50 | 360.50 |
| 4 | 4752 | 179.44 | 355.00 |
| 5 | 4838 | 176.33 | 349.40 |
| 6 | 4995 | 166.06 | 330.90 |
| 7 | 3309 | 155.44 | 311.80 |
| 8 | 3419 | 160.67 | 321.20 |
| 9 | 678 | 191.28 | 376.30 |
| 10 | 2537 | 174.61 | 346.30 |
| 11 | 1888 | 186.17 | 367.10 |
| 12 | 583 | 174.50 | 346.10 |
| 13 | 3001 | 163.00 | 325.40 |
| 14 | 3148 | 165.00 | 329.00 |
| 15 | 7533 | 164.83 | 328.70 |
| 16 | 7377 | 166.44 | 331.60 |
| 17 | 7371 | 185.44 | 365.80 |
| 18 | 6942 | 191.39 | 376.50 |
| 19 | 6267 | 185.17 | 365.30 |
| 20 | 6121 | 171.50 | 340.70 |
| 21 | 6001 | 169.44 | 337.00 |
| 22 | 15481 | 154.89 | 310.80 |
| 23 | 16630 | 164.11 | 327.40 |
| 24 | 16694 | 162.50 | 324.50 |
| 25 | 18111 | 133.00 | 271.40 |
| 26 | 11531 | 131.72 | 269.10 |
| 27 | 9785 | 163.28 | 325.90 |
| 28 | 9571 | 165.06 | 329.10 |
| 29 | 8197 | 162.28 | 324.10 |
| 30 | 15451 | 80.67 | 177.20 |
| 31 | 15961 | 88.78 | 191.80 |
| 32 | 17022 | 91.11 | 196.00 |
| 33 | 17743 | 85.61 | 186.10 |
| 34 | 11051 | 82.67 | 180.80 |
| 35 | 9900 | 87.83 | 190.10 |
| 36 | 8673 | 90.67 | 195.20 |
| 37 | 8225 | 77.28 | 171.10 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4650E+02 | 4.7570E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7606E+02 | 3.4890E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7456E+02 | 3.4620E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0794E+02 | 4.0630E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8389E+02 | 3.6300E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

MARKUP

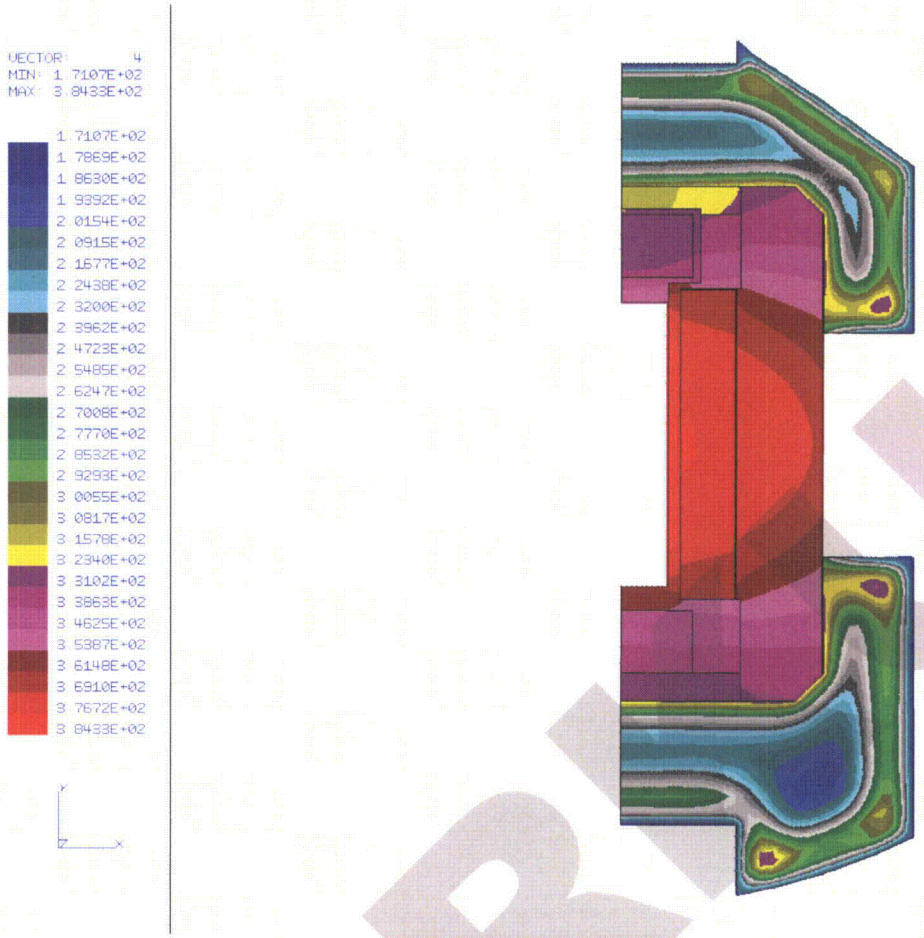


**Figure 3-40. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

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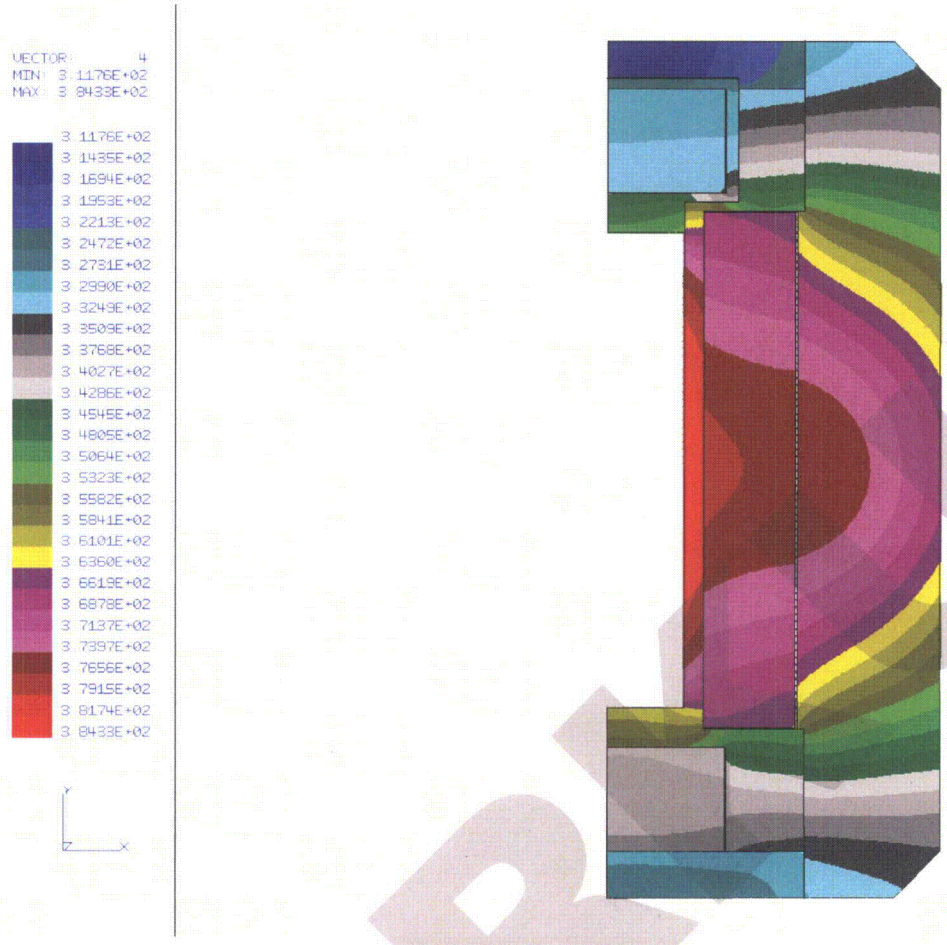


**Figure 3-41. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

MARKUP

**Table 3-40. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 180.17 | 356.30 |
| 2 | 4532 | 191.06 | 375.90 |
| 3 | 4227 | 183.89 | 363.00 |
| 4 | 4752 | 180.17 | 356.30 |
| 5 | 4838 | 176.72 | 350.10 |
| 6 | 4995 | 170.06 | 338.10 |
| 7 | 3309 | 163.11 | 325.60 |
| 8 | 3419 | 166.39 | 331.50 |
| 9 | 678 | 186.06 | 366.90 |
| 10 | 2537 | 174.44 | 346.00 |
| 11 | 1888 | 180.00 | 356.00 |
| 12 | 583 | 174.67 | 346.40 |
| 13 | 3001 | 169.06 | 336.30 |
| 14 | 3148 | 169.72 | 337.50 |
| 15 | 7533 | 170.17 | 338.30 |
| 16 | 7377 | 171.44 | 340.60 |
| 17 | 7371 | 182.94 | 361.30 |
| 18 | 6942 | 186.72 | 368.10 |
| 19 | 6267 | 182.94 | 361.30 |
| 20 | 6121 | 174.89 | 346.80 |
| 21 | 6001 | 173.39 | 344.10 |
| 22 | 15481 | 162.61 | 324.70 |
| 23 | 16630 | 167.89 | 334.20 |
| 24 | 16694 | 165.78 | 330.40 |
| 25 | 18111 | 130.33 | 266.60 |
| 26 | 11531 | 129.50 | 265.10 |
| 27 | 9785 | 166.72 | 332.10 |
| 28 | 9571 | 168.94 | 336.10 |
| 29 | 8197 | 168.50 | 335.30 |
| 30 | 15451 | 75.78 | 168.40 |
| 31 | 15961 | 84.94 | 184.90 |
| 32 | 17022 | 87.17 | 188.90 |
| 33 | 17743 | 81.78 | 179.20 |
| 34 | 11051 | 79.61 | 175.30 |
| 35 | 9900 | 84.56 | 184.20 |
| 36 | 8673 | 87.06 | 188.70 |
| 37 | 8225 | 73.17 | 163.70 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4650E+02 | 4.7570E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7606E+02 | 3.4890E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7456E+02 | 3.4620E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0794E+02 | 4.0630E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8389E+02 | 3.6300E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

MARKUP

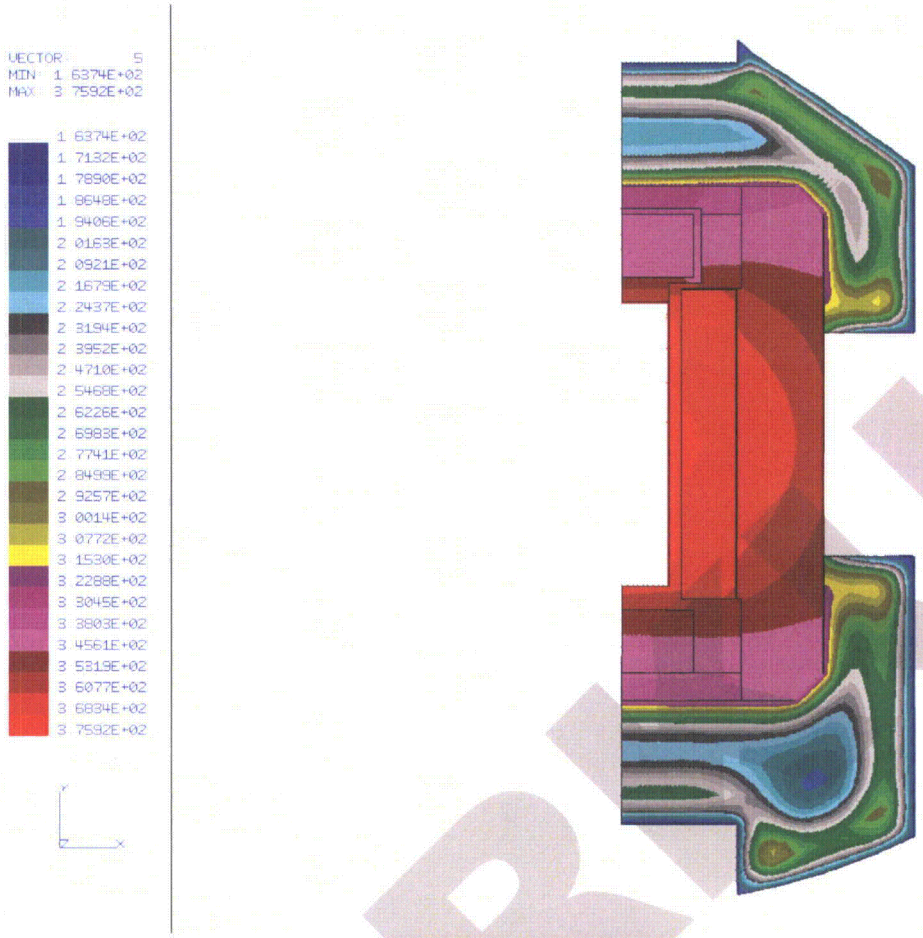


**Figure 3-42. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

MARKUP

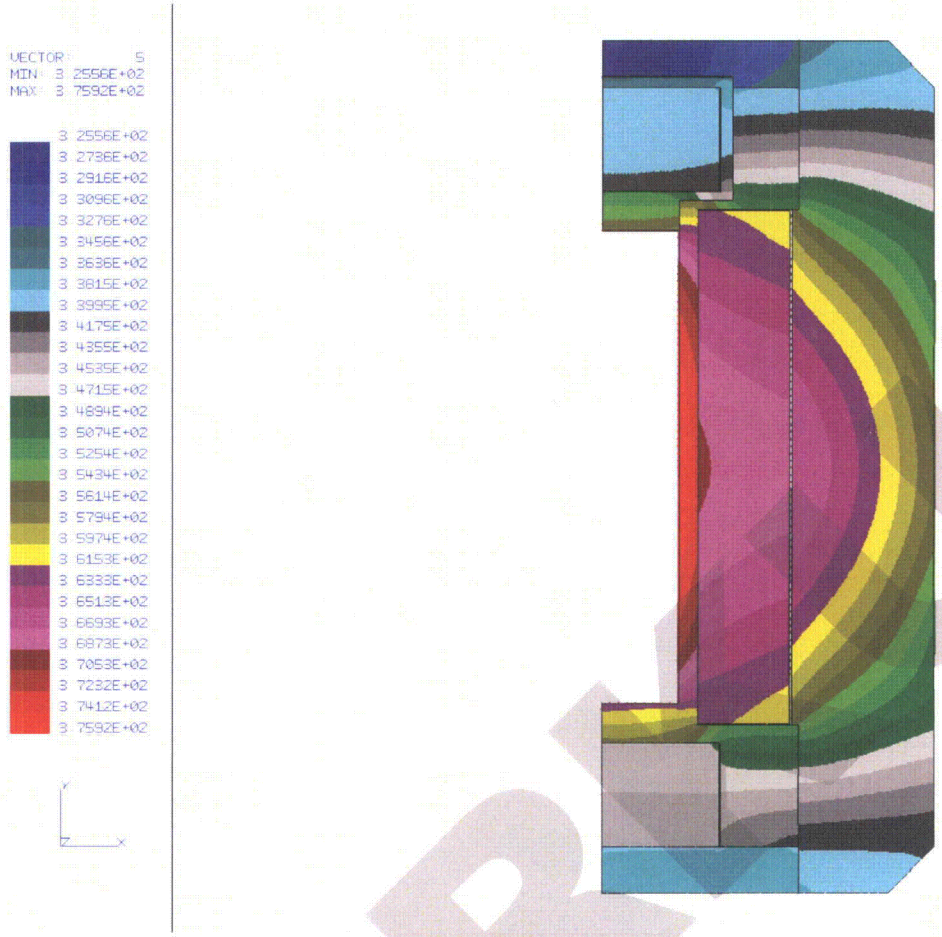


**Figure 3-43. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

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## 3.4.7 Hypothetical Accident Conditions of Transport Results – Models AOS-100B

Table 3-41 lists the tables and figures in this subsection that present the Model AOS-100B transport package with carbon shielding results under Hypothetical Accident conditions of transport, for Load Cases 111 through 116. Each table provides a list of temperatures at each monitoring node. Also listed are the maximum temperatures within each transport package component.

Table 3-34 lists the temperature monitoring points (nodes) for the Model AOS-100 (A, B, and A-S) transport package, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-30 illustrates the location of each node on the transport package, under Fire conditions.

***Notes:*** *Results for the Model AOS-100A and AOS-100A-S transport packages are provided in Subsection 3.4.6.*
*Results for the Model AOS-025, AOS-050, and AOS-165 transport packages are provided in Appendix 3.5.*

**Table 3-41. Hypothetical Accident Conditions of Transport Results – Model AOS-100B, with Carbon Shielding**

| Load Case | Description | Results Table | Temperature versus Time | Entire Model | Cask Model |
|---|---|---|---|---|---|
| 111 | Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding | Table 3-42 | Figure 3-44 | Figure 3-45 | Figure 3-46 |
| 112 | Fire at 60 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-43 | – | Figure 3-47 | Figure 3-48 |
| 113 | Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-44 | – | Figure 3-49 | Figure 3-50 |
| 114 | Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-45 | – | Figure 3-51 | Figure 3-52 |
| 115 | Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-46 | – | Figure 3-53 | Figure 3-54 |
| 116 | Fire at 180 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-47 | – | Figure 3-55 | Figure 3-56 |

PRELIMINARY

**Table 3-42. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding – Model AOS-100B**

Temperatures @ 0.500 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 128.06 | 262.50 |
| 2 | 4532 | 141.39 | 286.50 |
| 3 | 4227 | 126.94 | 260.50 |
| 4 | 4752 | 126.89 | 260.40 |
| 5 | 4838 | 128.17 | 262.70 |
| 6 | 4995 | 118.83 | 245.90 |
| 7 | 3309 | 118.28 | 244.90 |
| 8 | 3419 | 117.83 | 244.10 |
| 9 | 678 | 178.11 | 352.60 |
| 10 | 2537 | 161.50 | 322.70 |
| 11 | 1888 | 425.83 | 798.50 |
| 12 | 583 | 158.67 | 317.60 |
| 13 | 3001 | 118.22 | 244.80 |
| 14 | 3148 | 118.22 | 244.80 |
| 15 | 7533 | 120.44 | 248.80 |
| 16 | 7377 | 121.39 | 250.50 |
| 17 | 7371 | 134.00 | 273.20 |
| 18 | 6942 | 148.28 | 298.90 |
| 19 | 6267 | 133.61 | 272.50 |
| 20 | 6121 | 120.22 | 248.40 |
| 21 | 6001 | 119.22 | 246.60 |
| 22 | 15481 | 118.22 | 244.80 |
| 23 | 16630 | 118.17 | 244.70 |
| 24 | 16694 | 122.17 | 251.90 |
| 25 | 18111 | 618.33 | 1145.00 |
| 26 | 11531 | 617.78 | 1144.00 |
| 27 | 9785 | 124.06 | 255.30 |
| 28 | 9571 | 118.78 | 245.80 |
| 29 | 8197 | 118.11 | 244.60 |
| 30 | 15451 | 793.89 | 1461.00 |
| 31 | 15961 | 799.44 | 1471.00 |
| 32 | 17022 | 796.11 | 1465.00 |
| 33 | 17743 | 797.78 | 1468.00 |
| 34 | 11051 | 798.89 | 1470.00 |
| 35 | 9900 | 797.78 | 1468.00 |
| 36 | 8673 | 798.89 | 1470.00 |
| 37 | 8225 | 795.56 | 1464.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1888 | 4.2583E+02 | 7.9850E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.1856E+02 | 2.4540E+02 |
| Lid | 3233 | 3424 | 3233 | 1.1850E+02 | 2.4530E+02 |
| Shell Cavity | 4001 | 4998 | 4536 | 1.4156E+02 | 2.8680E+02 |
| Plug | 5001 | 5404 | 5001 | 1.2806E+02 | 2.6250E+02 |
| Tungsten | 6001 | 7656 | 6938 | 1.5839E+02 | 3.1710E+02 |
| LAST-A-FOAM | 8001 | 18126 | 15913 | 7.9944E+02 | 1.4710E+03 |

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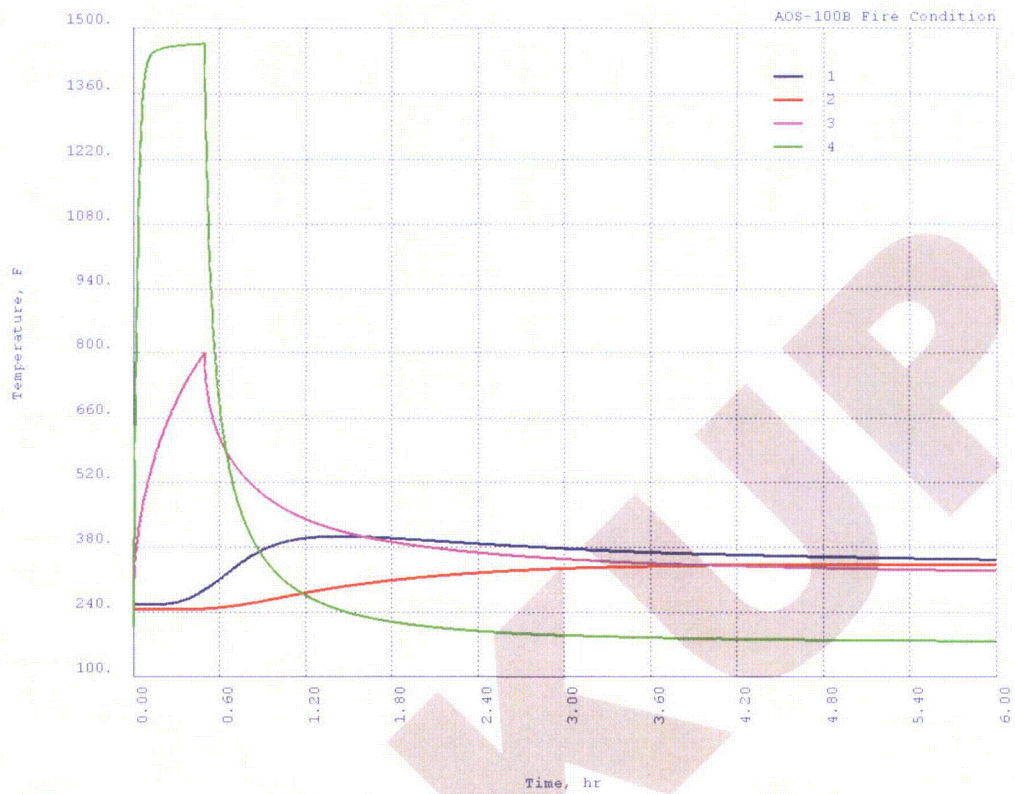


**Figure 3-44. Carbon Steel Shielding, 5-Hour Thermal Transient, Fire at 30 Minutes, 1,475°F Ambient, 4.5-Hour Cool Down at 100°F Ambient with Solar Heat, 400W Maximum Decay Heat Present throughout Transient – Model AOS-100B**

Figure 3-44 illustrates the Temperature Time history for four (4) monitoring points:

1. Cask Cavity wall at center.
2. Seal Area.
3. Outside Shell at Outside Center.
4. Upper Impact Limiter at Upper Corner.

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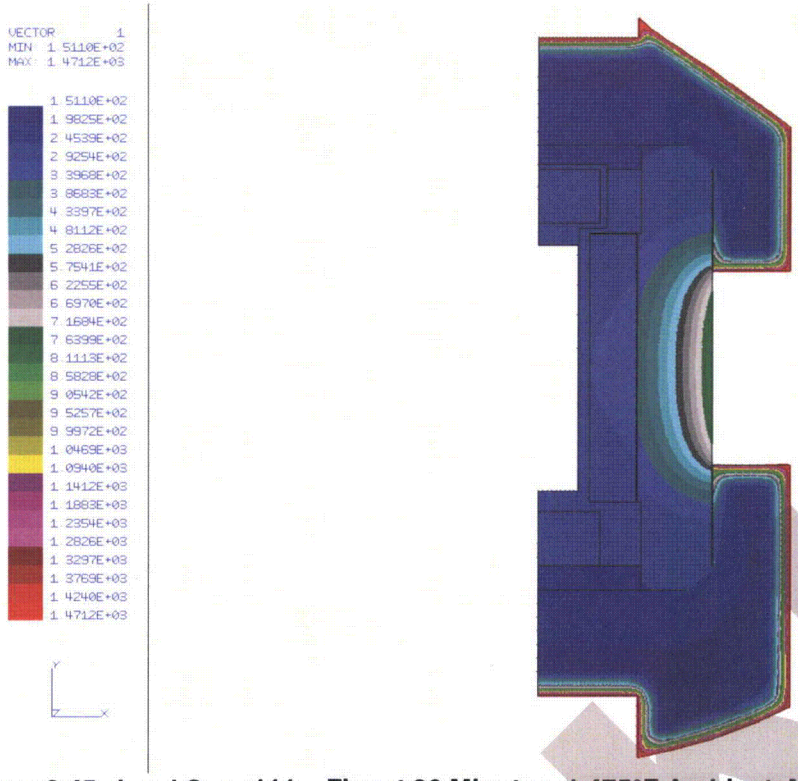


**Figure 3-45. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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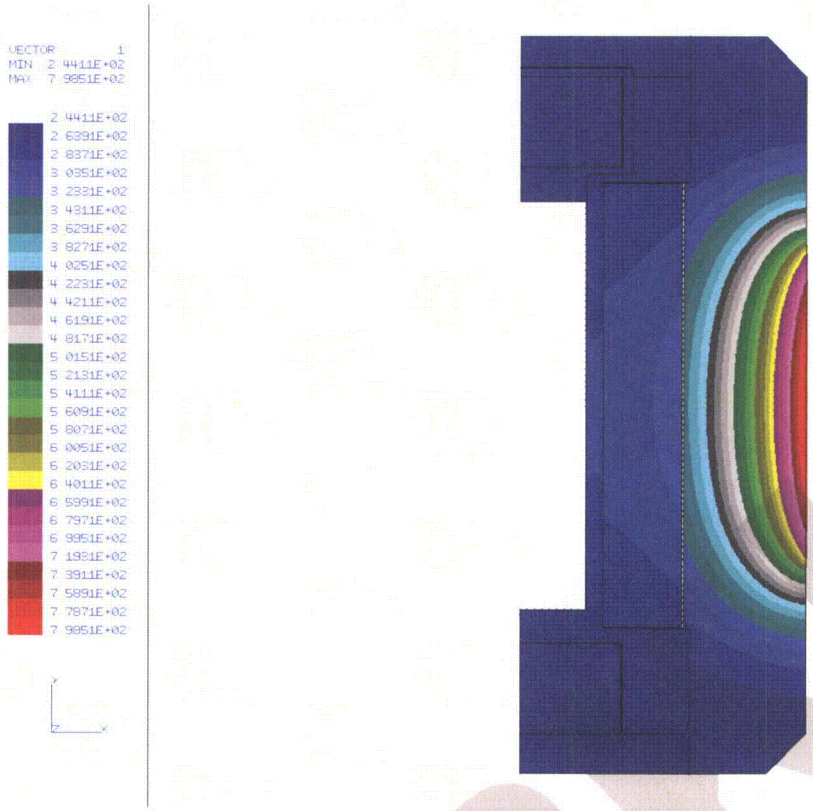


**Figure 3-46. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-43. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 139.22 | 282.60 |
| 2 | 4532 | 195.83 | 384.50 |
| 3 | 4227 | 146.11 | 295.00 |
| 4 | 4752 | 152.72 | 306.90 |
| 5 | 4838 | 154.94 | 310.90 |
| 6 | 4995 | 131.72 | 269.10 |
| 7 | 3309 | 120.28 | 248.50 |
| 8 | 3419 | 124.89 | 256.80 |
| 9 | 678 | 214.56 | 418.20 |
| 10 | 2537 | 172.06 | 341.70 |
| 11 | 1888 | 244.11 | 471.40 |
| 12 | 583 | 170.78 | 339.40 |
| 13 | 3001 | 122.39 | 252.30 |
| 14 | 3148 | 129.33 | 264.80 |
| 15 | 7533 | 126.17 | 259.10 |
| 16 | 7377 | 128.50 | 263.30 |
| 17 | 7371 | 173.11 | 343.60 |
| 18 | 6942 | 198.56 | 389.40 |
| 19 | 6267 | 171.39 | 340.50 |
| 20 | 6121 | 132.67 | 270.80 |
| 21 | 6001 | 129.06 | 264.30 |
| 22 | 15481 | 120.06 | 248.10 |
| 23 | 16630 | 133.44 | 272.20 |
| 24 | 16694 | 138.11 | 280.60 |
| 25 | 18111 | 179.06 | 354.30 |
| 26 | 11531 | 175.28 | 347.50 |
| 27 | 9785 | 139.83 | 283.70 |
| 28 | 9571 | 134.50 | 274.10 |
| 29 | 8197 | 121.94 | 251.50 |
| 30 | 15451 | 157.83 | 316.10 |
| 31 | 15961 | 161.83 | 323.30 |
| 32 | 17022 | 160.94 | 321.70 |
| 33 | 17743 | 156.33 | 313.40 |
| 34 | 11051 | 148.33 | 299.00 |
| 35 | 9900 | 153.00 | 307.40 |
| 36 | 8673 | 160.50 | 320.90 |
| 37 | 8225 | 150.28 | 302.50 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4544E+02 | 4.7380E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7356E+02 | 3.4440E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7217E+02 | 3.4190E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0533E+02 | 4.0160E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8156E+02 | 3.5880E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0433E+02 | 3.9980E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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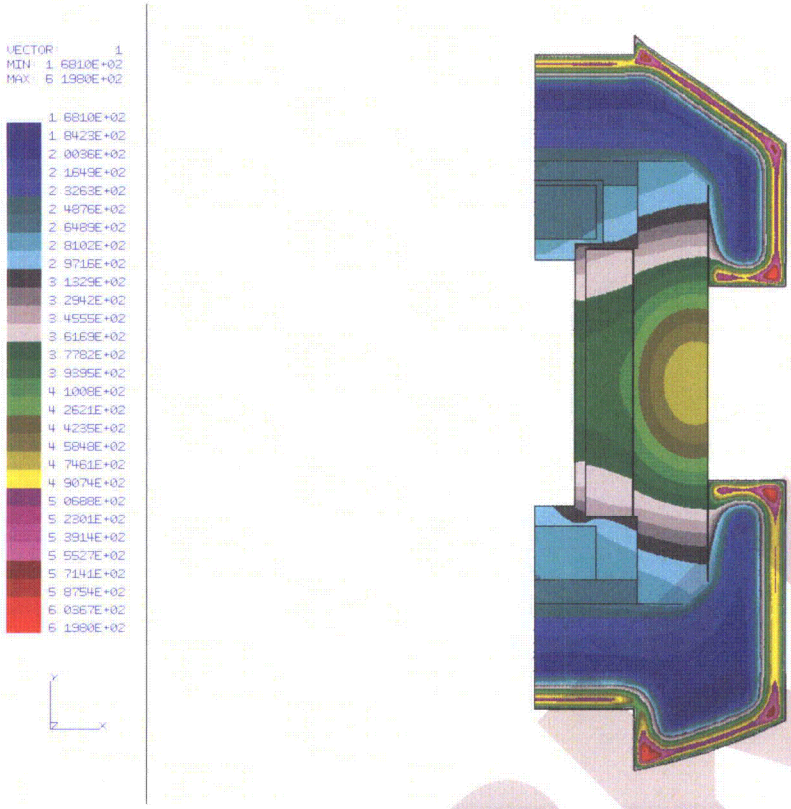


**Figure 3-47. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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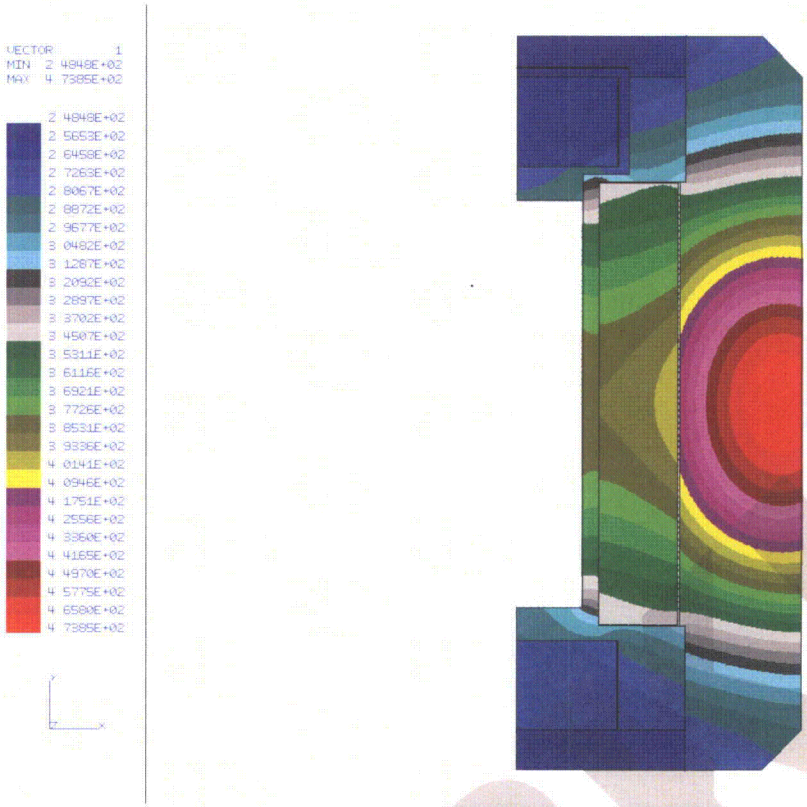


**Figure 3-48. Load Case 112 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

MARKUP

**Table 3-44. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 154.39 | 309.90 |
| 2 | 4532 | 205.33 | 401.60 |
| 3 | 4227 | 165.11 | 329.20 |
| 4 | 4752 | 167.28 | 333.10 |
| 5 | 4838 | 166.78 | 332.20 |
| 6 | 4995 | 146.61 | 295.90 |
| 7 | 3309 | 129.28 | 264.70 |
| 8 | 3419 | 137.94 | 280.30 |
| 9 | 678 | 206.33 | 403.40 |
| 10 | 2537 | 171.56 | 340.80 |
| 11 | 1888 | 209.28 | 408.70 |
| 12 | 583 | 170.78 | 339.40 |
| 13 | 3001 | 135.28 | 275.50 |
| 14 | 3148 | 143.67 | 290.60 |
| 15 | 7533 | 138.44 | 281.20 |
| 16 | 7377 | 141.50 | 286.70 |
| 17 | 7371 | 183.78 | 362.80 |
| 18 | 6942 | 202.39 | 396.30 |
| 19 | 6267 | 182.11 | 359.80 |
| 20 | 6121 | 149.39 | 300.90 |
| 21 | 6001 | 144.89 | 292.80 |
| 22 | 15481 | 128.89 | 264.00 |
| 23 | 16630 | 147.44 | 297.40 |
| 24 | 16694 | 148.67 | 299.60 |
| 25 | 18111 | 146.72 | 296.10 |
| 26 | 11531 | 144.06 | 291.30 |
| 27 | 9785 | 149.44 | 301.00 |
| 28 | 9571 | 148.11 | 298.60 |
| 29 | 8197 | 134.50 | 274.10 |
| 30 | 15451 | 107.61 | 225.70 |
| 31 | 15961 | 112.33 | 234.20 |
| 32 | 17022 | 114.17 | 237.50 |
| 33 | 17743 | 108.56 | 227.40 |
| 34 | 11051 | 102.61 | 216.70 |
| 35 | 9900 | 108.22 | 226.80 |
| 36 | 8673 | 113.17 | 235.70 |
| 37 | 8225 | 101.44 | 214.60 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4544E+02 | 4.7380E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7356E+02 | 3.4440E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7217E+02 | 3.4190E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0533E+02 | 4.0160E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8156E+02 | 3.5880E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0433E+02 | 3.9980E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

MARKUP

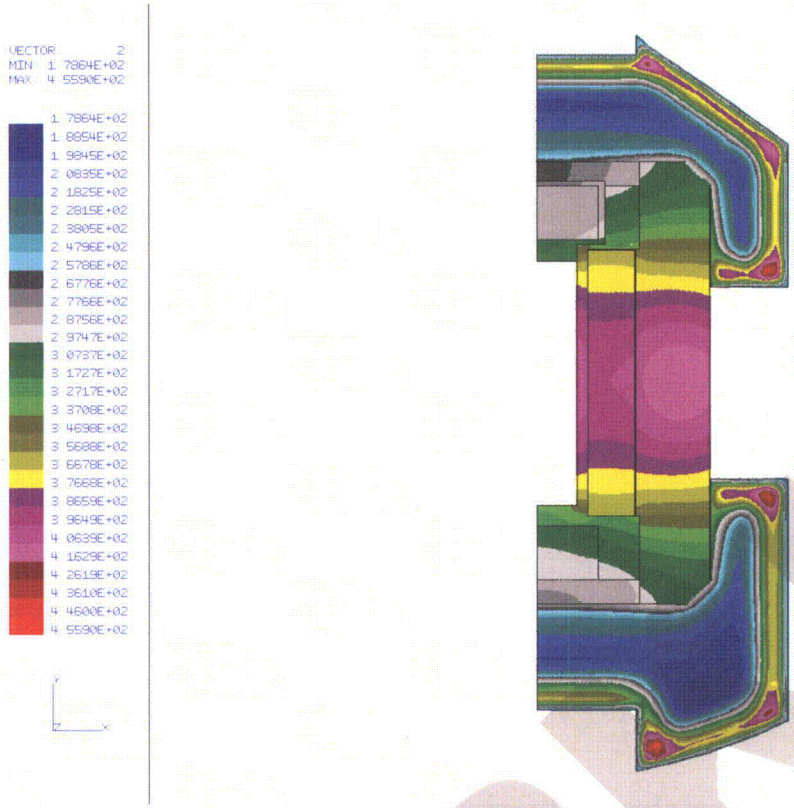


**Figure 3-49. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

MARKUP

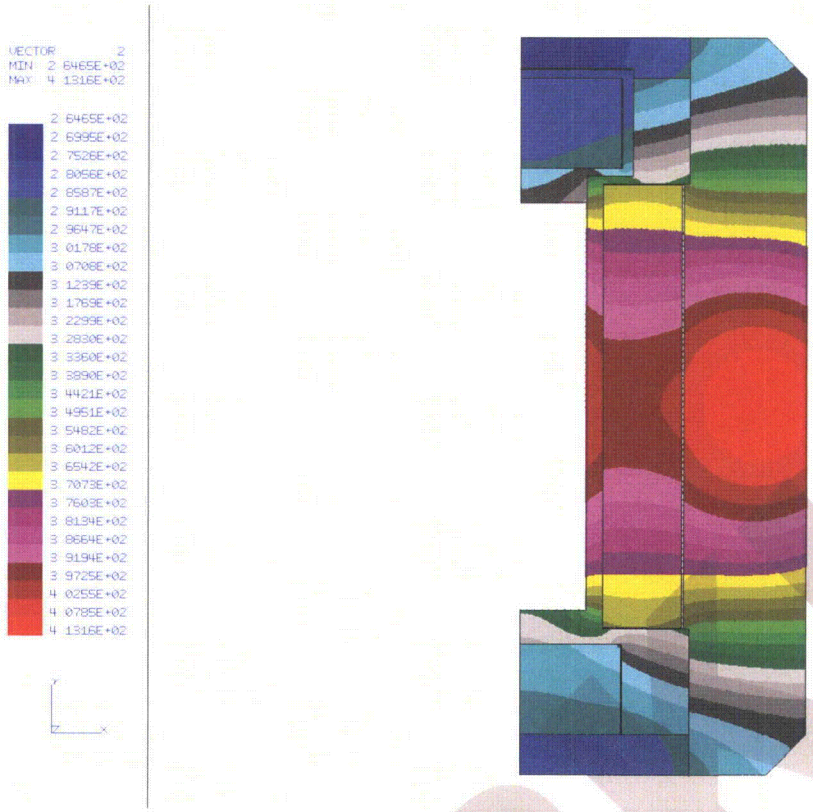


**Figure 3-50. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

MARKUP

**Table 3-45. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 164.83 | 328.70 |
| 2 | 4532 | 201.00 | 393.80 |
| 3 | 4227 | 174.39 | 345.90 |
| 4 | 4752 | 173.06 | 343.50 |
| 5 | 4838 | 171.39 | 340.50 |
| 6 | 4995 | 156.61 | 313.90 |
| 7 | 3309 | 141.28 | 286.30 |
| 8 | 3419 | 149.33 | 300.80 |
| 9 | 678 | 197.33 | 387.20 |
| 10 | 2537 | 171.94 | 341.50 |
| 11 | 1888 | 193.44 | 380.20 |
| 12 | 583 | 171.33 | 340.40 |
| 13 | 3001 | 148.78 | 299.80 |
| 14 | 3148 | 154.44 | 310.00 |
| 15 | 7533 | 150.11 | 302.20 |
| 16 | 7377 | 152.89 | 307.20 |
| 17 | 7371 | 184.17 | 363.50 |
| 18 | 6942 | 196.78 | 386.20 |
| 19 | 6267 | 183.11 | 361.60 |
| 20 | 6121 | 160.72 | 321.30 |
| 21 | 6001 | 156.89 | 314.40 |
| 22 | 15481 | 140.83 | 285.50 |
| 23 | 16630 | 156.22 | 313.20 |
| 24 | 16694 | 155.72 | 312.30 |
| 25 | 18111 | 136.39 | 277.50 |
| 26 | 11531 | 134.44 | 274.00 |
| 27 | 9785 | 156.17 | 313.10 |
| 28 | 9571 | 156.72 | 314.10 |
| 29 | 8197 | 148.00 | 298.40 |
| 30 | 15451 | 89.44 | 193.00 |
| 31 | 15961 | 96.06 | 204.90 |
| 32 | 17022 | 98.44 | 209.20 |
| 33 | 17743 | 92.67 | 198.80 |
| 34 | 11051 | 88.56 | 191.40 |
| 35 | 9900 | 94.06 | 201.30 |
| 36 | 8673 | 97.61 | 207.70 |
| 37 | 8225 | 84.83 | 184.70 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4544E+02 | 4.7380E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7356E+02 | 3.4440E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7217E+02 | 3.4190E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0533E+02 | 4.0160E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8156E+02 | 3.5880E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0433E+02 | 3.9980E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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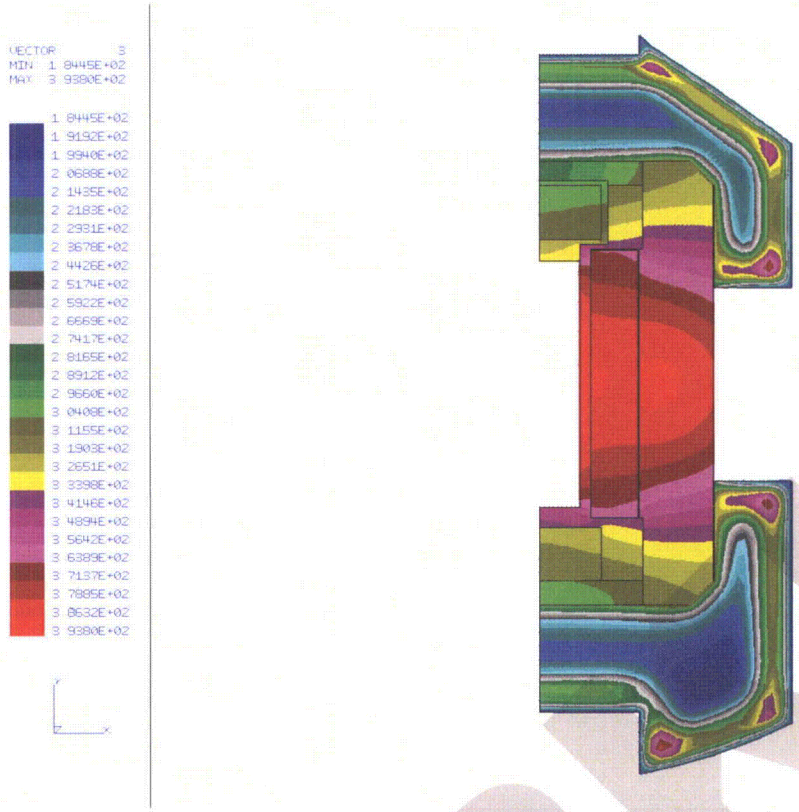


**Figure 3-51. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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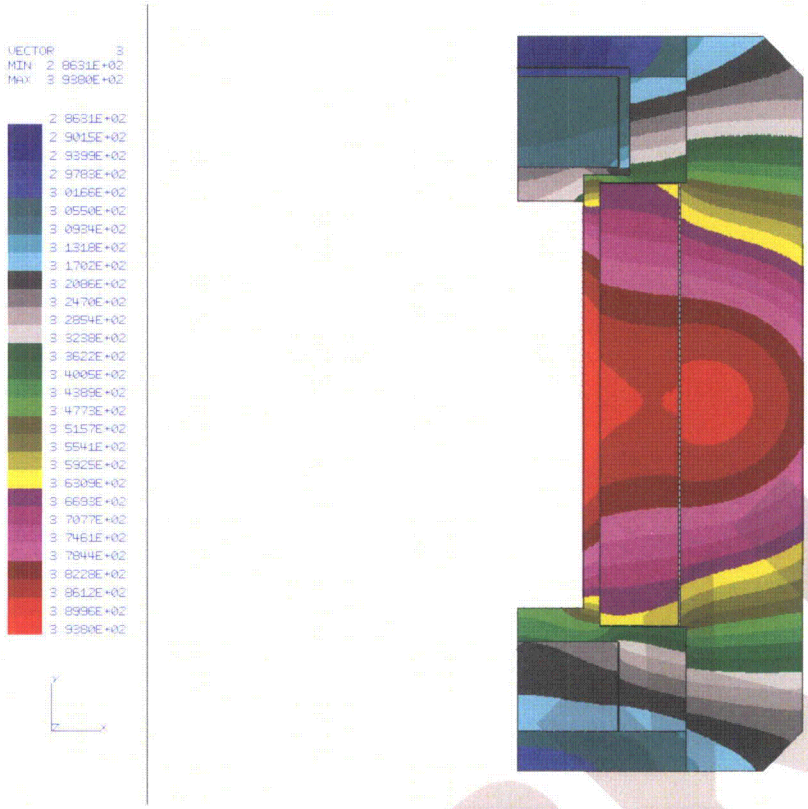


**Figure 3-52. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

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**Table 3-46. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 171.61 | 340.90 |
| 2 | 4532 | 195.33 | 383.60 |
| 3 | 4227 | 178.72 | 353.70 |
| 4 | 4752 | 175.72 | 348.30 |
| 5 | 4838 | 173.22 | 343.80 |
| 6 | 4995 | 163.00 | 325.40 |
| 7 | 3309 | 151.61 | 304.90 |
| 8 | 3419 | 157.56 | 315.60 |
| 9 | 678 | 190.22 | 374.40 |
| 10 | 2537 | 172.22 | 342.00 |
| 11 | 1888 | 184.33 | 363.80 |
| 12 | 583 | 171.89 | 341.40 |
| 13 | 3001 | 158.61 | 317.50 |
| 14 | 3148 | 161.78 | 323.20 |
| 15 | 7533 | 158.94 | 318.10 |
| 16 | 7377 | 161.22 | 322.20 |
| 17 | 7371 | 182.39 | 360.30 |
| 18 | 6942 | 190.83 | 375.50 |
| 19 | 6267 | 181.89 | 359.40 |
| 20 | 6121 | 167.50 | 333.50 |
| 21 | 6001 | 164.61 | 328.30 |
| 22 | 15481 | 151.17 | 304.10 |
| 23 | 16630 | 161.78 | 323.20 |
| 24 | 16694 | 160.33 | 320.60 |
| 25 | 18111 | 131.67 | 269.00 |
| 26 | 11531 | 130.33 | 266.60 |
| 27 | 9785 | 160.89 | 321.60 |
| 28 | 9571 | 162.39 | 324.30 |
| 29 | 8197 | 158.00 | 316.40 |
| 30 | 15451 | 80.67 | 177.20 |
| 31 | 15961 | 88.78 | 191.80 |
| 32 | 17022 | 91.11 | 196.00 |
| 33 | 17743 | 85.56 | 186.00 |
| 34 | 11051 | 82.61 | 180.70 |
| 35 | 9900 | 87.83 | 190.10 |
| 36 | 8673 | 90.67 | 195.20 |
| 37 | 8225 | 77.28 | 171.10 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4544E+02 | 4.7380E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7356E+02 | 3.4440E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7217E+02 | 3.4190E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0533E+02 | 4.0160E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8156E+02 | 3.5880E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0433E+02 | 3.9980E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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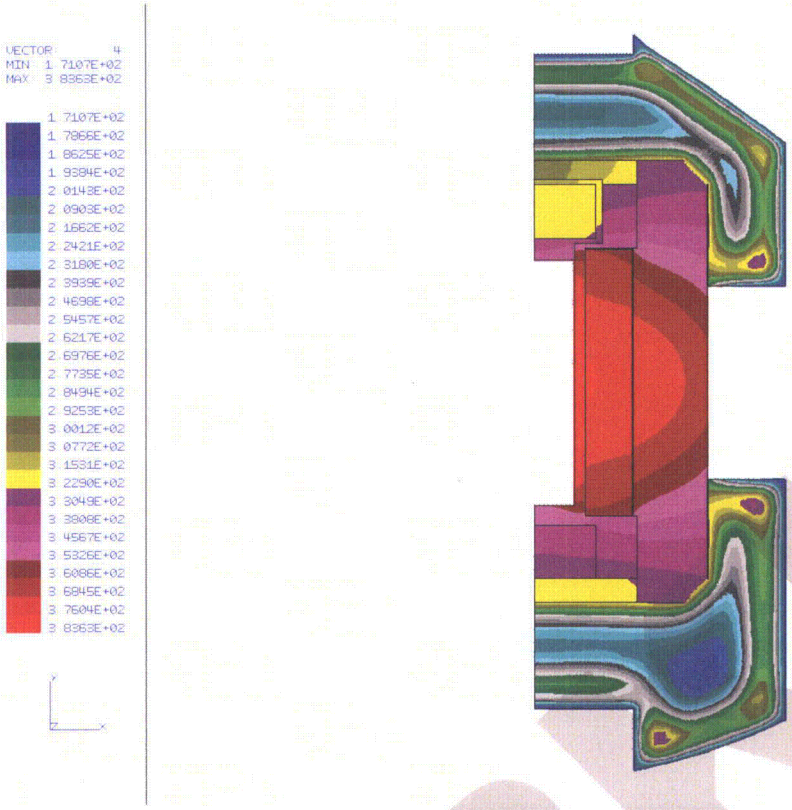


**Figure 3-53. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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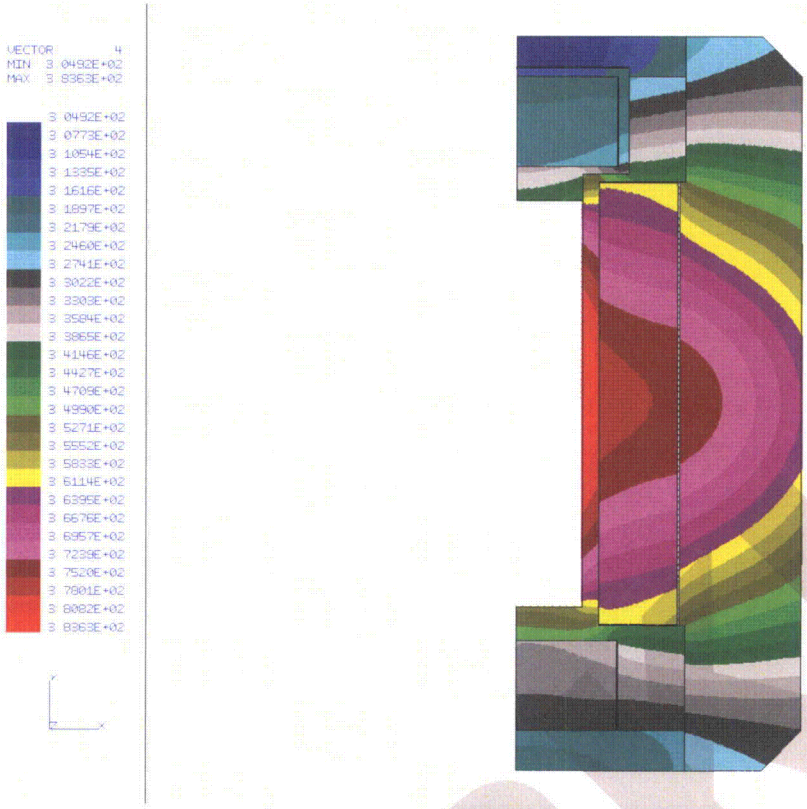


**Figure 3-54. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Cask – Model AOS-100B**

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**Table 3-47. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 175.94 | 348.70 |
| 2 | 4532 | 190.61 | 375.10 |
| 3 | 4227 | 180.78 | 357.40 |
| 4 | 4752 | 176.94 | 350.50 |
| 5 | 4838 | 173.94 | 345.10 |
| 6 | 4995 | 167.00 | 332.60 |
| 7 | 3309 | 159.22 | 318.60 |
| 8 | 3419 | 163.17 | 325.70 |
| 9 | 678 | 184.94 | 364.90 |
| 10 | 2537 | 172.11 | 341.80 |
| 11 | 1888 | 178.39 | 353.10 |
| 12 | 583 | 172.11 | 341.80 |
| 13 | 3001 | 165.06 | 329.10 |
| 14 | 3148 | 166.50 | 331.70 |
| 15 | 7533 | 165.06 | 329.10 |
| 16 | 7377 | 166.89 | 332.40 |
| 17 | 7371 | 180.44 | 356.80 |
| 18 | 6942 | 186.06 | 366.90 |
| 19 | 6267 | 180.33 | 356.60 |
| 20 | 6121 | 171.39 | 340.50 |
| 21 | 6001 | 169.28 | 336.70 |
| 22 | 15481 | 158.78 | 317.80 |
| 23 | 16630 | 165.33 | 329.60 |
| 24 | 16694 | 163.44 | 326.20 |
| 25 | 18111 | 129.06 | 264.30 |
| 26 | 11531 | 128.11 | 262.60 |
| 27 | 9785 | 164.11 | 327.40 |
| 28 | 9571 | 166.06 | 330.90 |
| 29 | 8197 | 164.50 | 328.10 |
| 30 | 15451 | 75.78 | 168.40 |
| 31 | 15961 | 84.94 | 184.90 |
| 32 | 17022 | 87.17 | 188.90 |
| 33 | 17743 | 81.72 | 179.10 |
| 34 | 11051 | 79.56 | 175.20 |
| 35 | 9900 | 84.56 | 184.20 |
| 36 | 8673 | 87.06 | 188.70 |
| 37 | 8225 | 73.17 | 163.70 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 1885 | 2.4544E+02 | 4.7380E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7356E+02 | 3.4440E+02 |
| Lid | 3233 | 3424 | 3233 | 1.7217E+02 | 3.4190E+02 |
| Shell Cavity | 4001 | 4998 | 4532 | 2.0533E+02 | 4.0160E+02 |
| Plug | 5001 | 5404 | 5001 | 1.8156E+02 | 3.5880E+02 |
| Tungsten | 6001 | 7656 | 6949 | 2.0433E+02 | 3.9980E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

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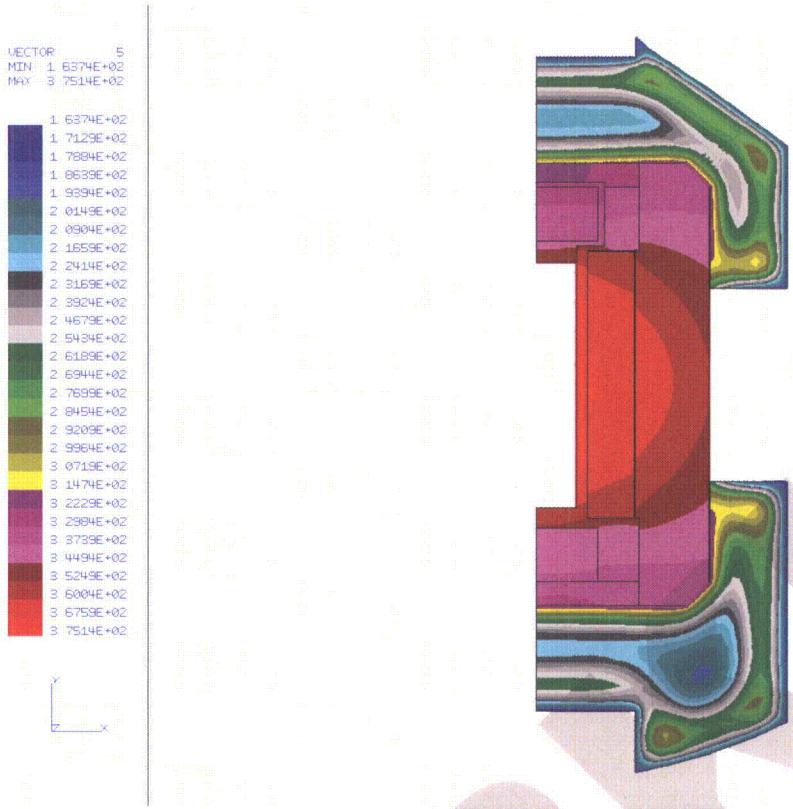


**Figure 3-55. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

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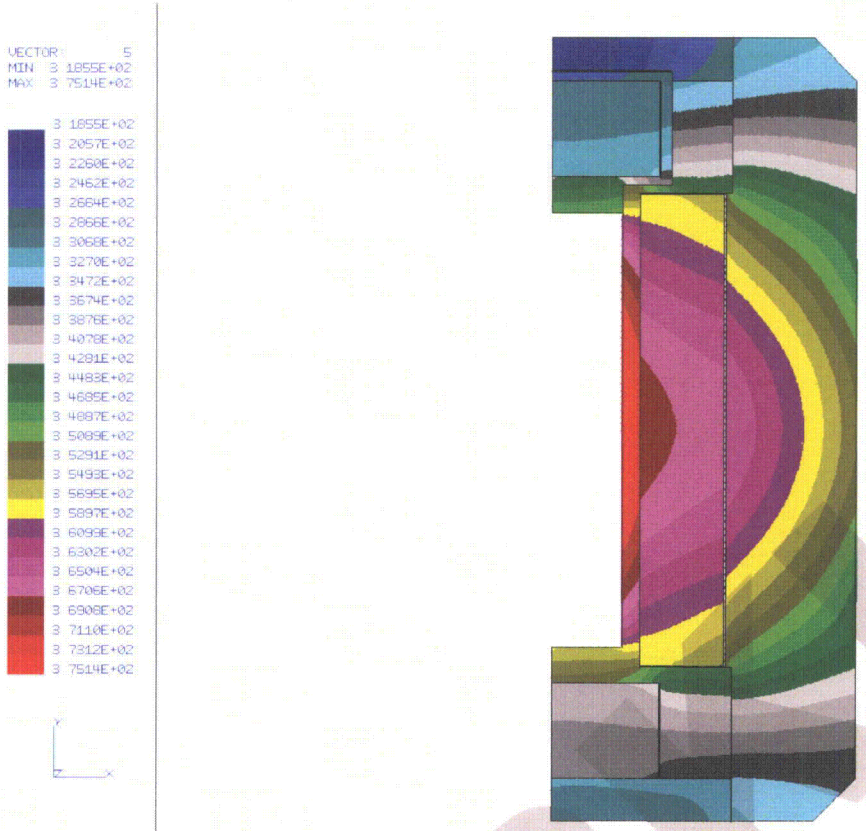


**Figure 3-56. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Cask – Model AOS-100B**

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## 3.5 APPENDIX

This appendix presents the following information:

- Normal Conditions of Transport Results
- Hypothetical Accident Conditions of Transport Results
- LIBRA Finite Element Program Heat Transfer Module
- Tungsten Alloy versus Carbon Steel Materials Comparison
- Material Properties Correlation between the Equations Provided in the Test and the LIBRA Input File
- Description of LIBRA Files and Post-Processors: AOS Safety Analysis Report
- Properties of Materials References
- Data CDs
- Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity
- Justification for Use of LAST-A-FOAM 3700 Thermal Properties

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### 3.5.1 Normal Conditions of Transport Results

This appendix presents the following:

- Normal Conditions of Transport Results – Model AOS-025
- Normal Conditions of Transport Results – Model AOS-050
- Normal Conditions of Transport Results – Model AOS-165

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### 3.5.1.1 Normal Conditions of Transport Results – Model AOS-025

Table 3-48 lists the tables and figures in this appendix that present the Model AOS-025 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. Also listed are the maximum temperatures within each transport package component.

Table 3-49 lists the temperature monitoring points (nodes) for the Model AOS-025 transport package, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-57 illustrates the location of each node on the transport package, under Normal conditions.

**Table 3-48. Normal Conditions of Transport Results – Model AOS-025**

| Load Case | Description | Results Table | Entire Model | Cask Model |
|---|---|---|---|---|
| 101 | 100°F Ambient, Maximum Decay Heat | Table 3-50 | Figure 3-58 | Figure 3-59 |
| 102 | 100°F Ambient, Maximum Decay Heat, Maximum Insolation | Table 3-51 | Figure 3-60 | Figure 3-61 |
| 103 | -20°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-52 | Figure 3-62 | – |
| 104 | -40°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-53 | Figure 3-63 | – |
| 105 | -40°F Ambient, Maximum Decay Heat | Table 3-54 | Figure 3-64 | Figure 3-65 |
| 106 | -20°F Ambient, Maximum Decay Heat | Table 3-55 | Figure 3-66 | Figure 3-67 |

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Table 3-49. Temperature Monitoring Points, All Conditions of Transport – Model AOS-025

| Nodal Location | LIBRA Model Nodal Number | |
|---|---|---|
| | Normal Conditions | Fire Conditions |
| 1 | 5001 | 5001 |
| 2 | 4532 | 4532 |
| 3 | 4227 | 4227 |
| 4 | 4752 | 4752 |
| 5 | 4838 | 4838 |
| 6 | 4995 | 4995 |
| 7 | 3309 | 3309 |
| 8 | 3419 | 3419 |
| 9 | 678 | 678 |
| 10 | 2537 | 2537 |
| 11 | 1888 | 1888 |
| 12 | 583 | 583 |
| 13 | 3001 | 3001 |
| 14 | 3148 | 3148 |
| 15 | 7533 | 7533 |
| 16 | 7377 | 7377 |
| 17 | 7371 | 7371 |
| 18 | 6942 | 6942 |
| 19 | 6267 | 6267 |
| 20 | 6121 | 6121 |
| 21 | 6001 | 6001 |
| 22 | 9501 | 11481 |
| 23 | 9950 | 12630 |
| 24 | 10014 | 12694 |
| 25 | 10781 | 13804 |
| 26 | 9091 | 10926 |
| 27 | 8463 | 9791 |
| 28 | 8462 | 9577 |
| 29 | 8197 | 8197 |
| 30 | 9711 | 11451 |
| 31 | 9821 | 11961 |
| 32 | 10158 | 13022 |
| 33 | 10605 | 13551 |
| 34 | 9102 | 10673 |
| 35 | 8578 | 9906 |
| 36 | 8225 | 8673 |
| 37 | 8001 | 8225 |

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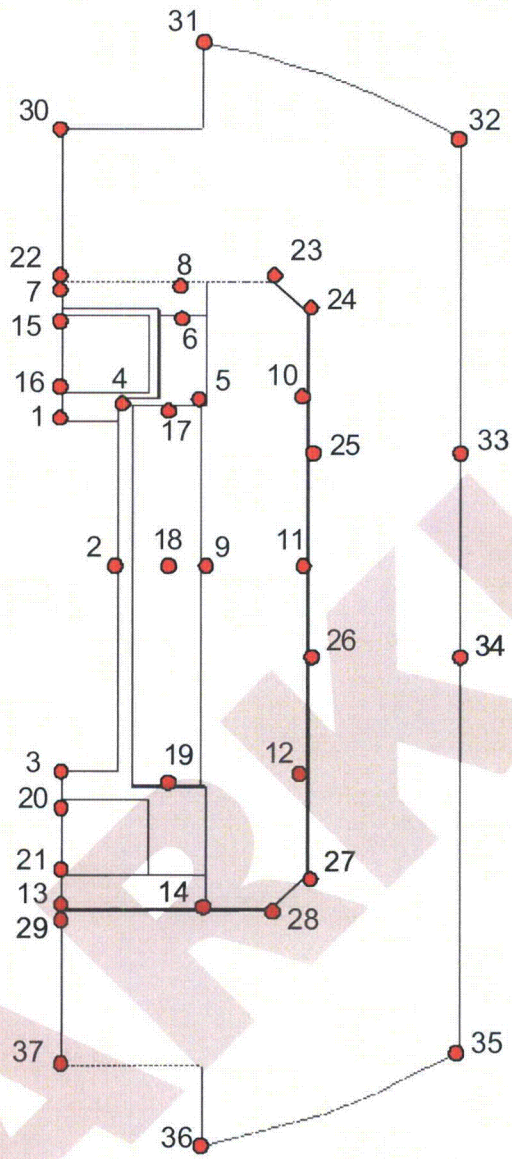


**Figure 3-57. Selected Nodal Locations for Normal Conditions of Transport – Model AOS-025**

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**Table 3-50. Load Case 101 – 100°F Ambient, Maximum Decay Heat – Model AOS-025**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 60.83 | 141.50 |
| 2 | 4532 | 60.11 | 140.20 |
| 3 | 4227 | 60.33 | 140.60 |
| 4 | 4752 | 60.00 | 140.00 |
| 5 | 4838 | 59.56 | 139.20 |
| 6 | 4995 | 59.44 | 139.00 |
| 7 | 3309 | 59.44 | 139.00 |
| 8 | 3419 | 59.39 | 138.90 |
| 9 | 678 | 59.56 | 139.20 |
| 10 | 2537 | 59.39 | 138.90 |
| 11 | 1888 | 59.17 | 138.50 |
| 12 | 583 | 59.11 | 138.40 |
| 13 | 3001 | 59.17 | 138.50 |
| 14 | 3148 | 59.17 | 138.50 |
| 15 | 7533 | 59.72 | 139.50 |
| 16 | 7377 | 59.78 | 139.60 |
| 17 | 7371 | 59.67 | 139.40 |
| 18 | 6942 | 59.67 | 139.40 |
| 19 | 6267 | 59.56 | 139.20 |
| 20 | 6121 | 59.44 | 139.00 |
| 21 | 6001 | 59.39 | 138.90 |
| 22 | 9501 | 59.33 | 138.80 |
| 23 | 9950 | 59.00 | 138.20 |
| 24 | 10014 | 58.83 | 137.90 |
| 25 | 10781 | 58.50 | 137.30 |
| 26 | 9091 | 57.00 | 134.60 |
| 27 | 8463 | 58.44 | 137.20 |
| 28 | 8462 | 58.72 | 137.70 |
| 29 | 8197 | 59.11 | 138.40 |
| 30 | 9711 | 38.83 | 101.90 |
| 31 | 9821 | 38.39 | 101.10 |
| 32 | 10158 | 38.61 | 101.50 |
| 33 | 10605 | 40.94 | 105.70 |
| 34 | 9102 | 43.11 | 109.60 |
| 35 | 8578 | 38.94 | 102.10 |
| 36 | 8225 | 38.67 | 101.60 |
| 37 | 8001 | 39.11 | 102.40 |

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Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 706 | 5.9611E+01 | 1.3930E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 5.9278E+01 | 1.3870E+02 |
| Lid | 3233 | 3424 | 3233 | 5.9444E+01 | 1.3900E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 6.0333E+01 | 1.4060E+02 |
| Plug | 5001 | 5404 | 5001 | 6.0833E+01 | 1.4150E+02 |
| Tungsten Alloy | 6001 | 7656 | 7377 | 5.9778E+01 | 1.3960E+02 |
| LAST-A-FOAM | 8001 | 11692 | 9501 | 5.9333E+01 | 1.3880E+02 |

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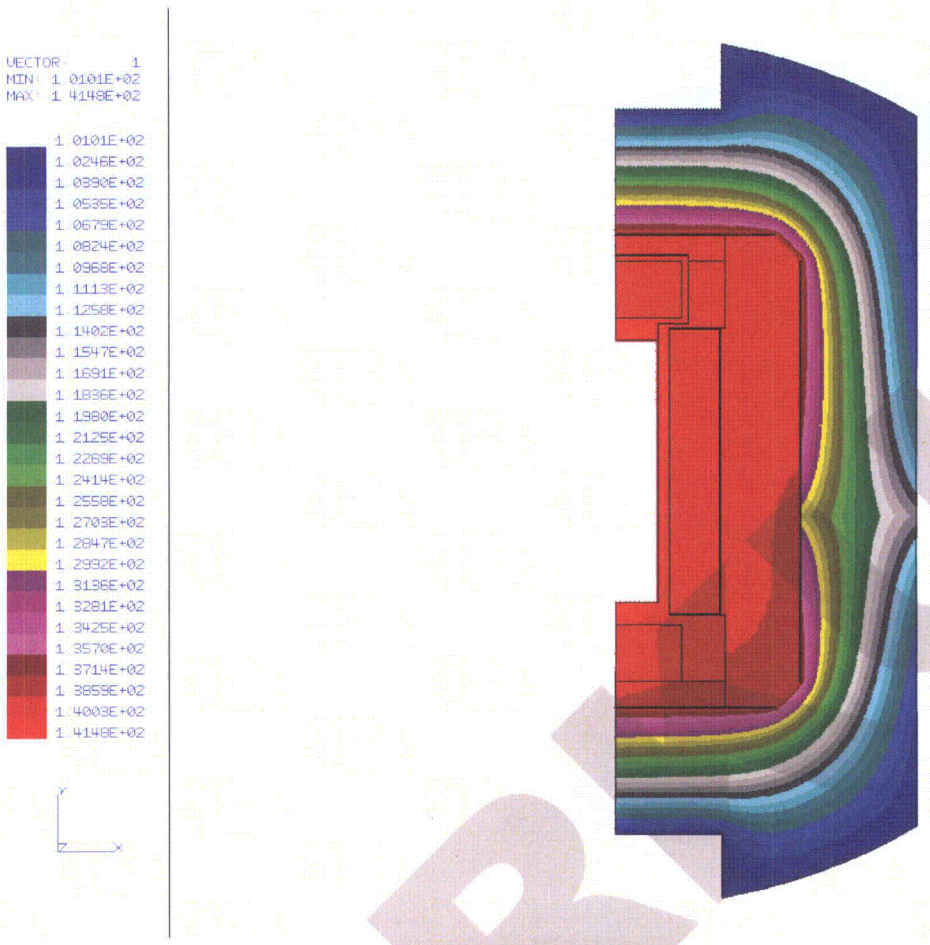


**Figure 3-58. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025**

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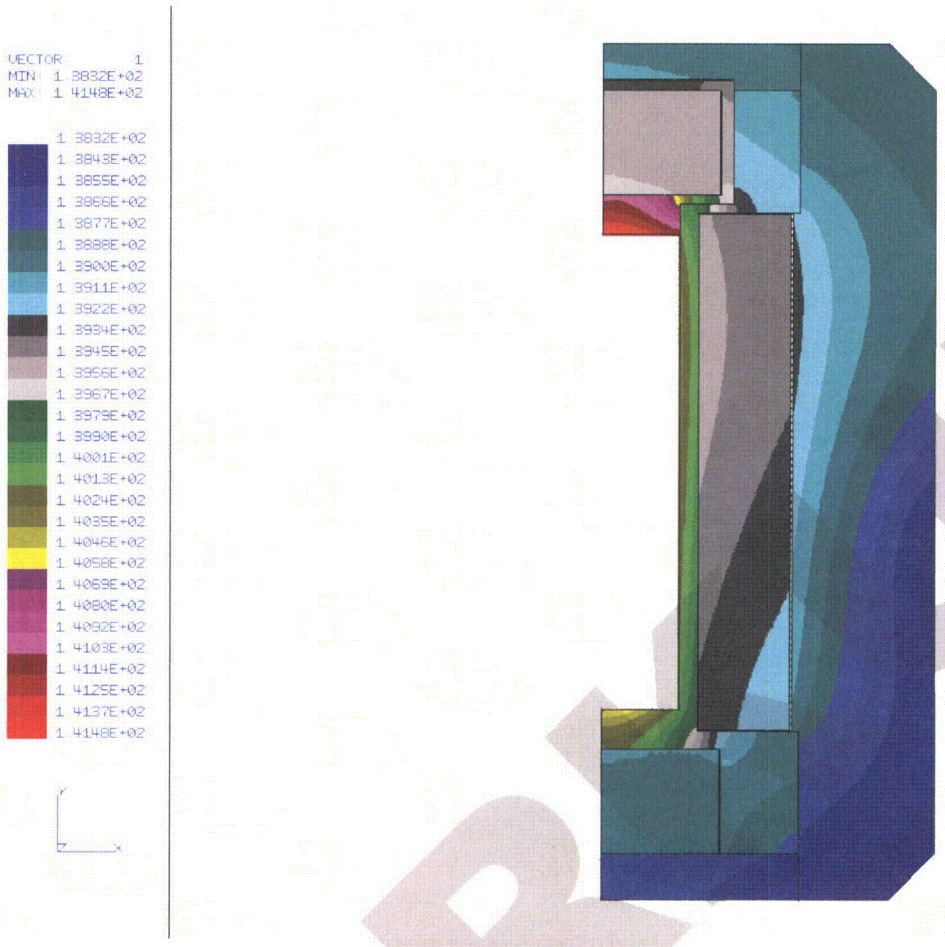


**Figure 3-59. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025**

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**Table 3-51. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-025**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 99.28 | 210.70 |
| 2 | 4532 | 98.56 | 209.40 |
| 3 | 4227 | 98.72 | 209.70 |
| 4 | 4752 | 98.50 | 209.30 |
| 5 | 4838 | 98.06 | 208.50 |
| 6 | 4995 | 98.00 | 208.40 |
| 7 | 3309 | 98.00 | 208.40 |
| 8 | 3419 | 98.00 | 208.40 |
| 9 | 678 | 98.00 | 208.40 |
| 10 | 2537 | 97.94 | 208.30 |
| 11 | 1888 | 97.67 | 207.80 |
| 12 | 583 | 97.50 | 207.50 |
| 13 | 3001 | 97.39 | 207.30 |
| 14 | 3148 | 97.44 | 207.40 |
| 15 | 7533 | 98.28 | 208.90 |
| 16 | 7377 | 98.33 | 209.00 |
| 17 | 7371 | 98.17 | 208.70 |
| 18 | 6942 | 98.11 | 208.60 |
| 19 | 6267 | 98.00 | 208.40 |
| 20 | 6121 | 97.83 | 208.10 |
| 21 | 6001 | 97.72 | 207.90 |
| 22 | 9501 | 97.94 | 208.30 |
| 23 | 9950 | 97.72 | 207.90 |
| 24 | 10014 | 97.56 | 207.60 |
| 25 | 10781 | 97.22 | 207.00 |
| 26 | 9091 | 95.67 | 204.20 |
| 27 | 8463 | 96.67 | 206.00 |
| 28 | 8462 | 96.94 | 206.50 |
| 29 | 8197 | 97.22 | 207.00 |
| 30 | 9711 | 87.17 | 188.90 |
| 31 | 9821 | 85.78 | 186.40 |
| 32 | 10158 | 85.67 | 186.20 |
| 33 | 10605 | 82.22 | 180.00 |
| 34 | 9102 | 82.33 | 180.20 |
| 35 | 8578 | 62.72 | 144.90 |
| 36 | 8225 | 45.56 | 114.00 |
| 37 | 8001 | 44.61 | 112.30 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 720 | 9.8111E+01 | 2.0860E+02 |
| Bottom Plate | 3001 | 3232 | 3103 | 9.7500E+01 | 2.0750E+02 |
| Lid | 3233 | 3424 | 3233 | 9.8056E+01 | 2.0850E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 9.8722E+01 | 2.0970E+02 |
| Plug | 5001 | 5404 | 5001 | 9.9278E+01 | 2.1070E+02 |
| Tungsten Alloy | 6001 | 7656 | 7377 | 9.8333E+01 | 2.0900E+02 |
| LAST-A-FOAM | 8001 | 11692 | 9501 | 9.7944E+01 | 2.0830E+02 |

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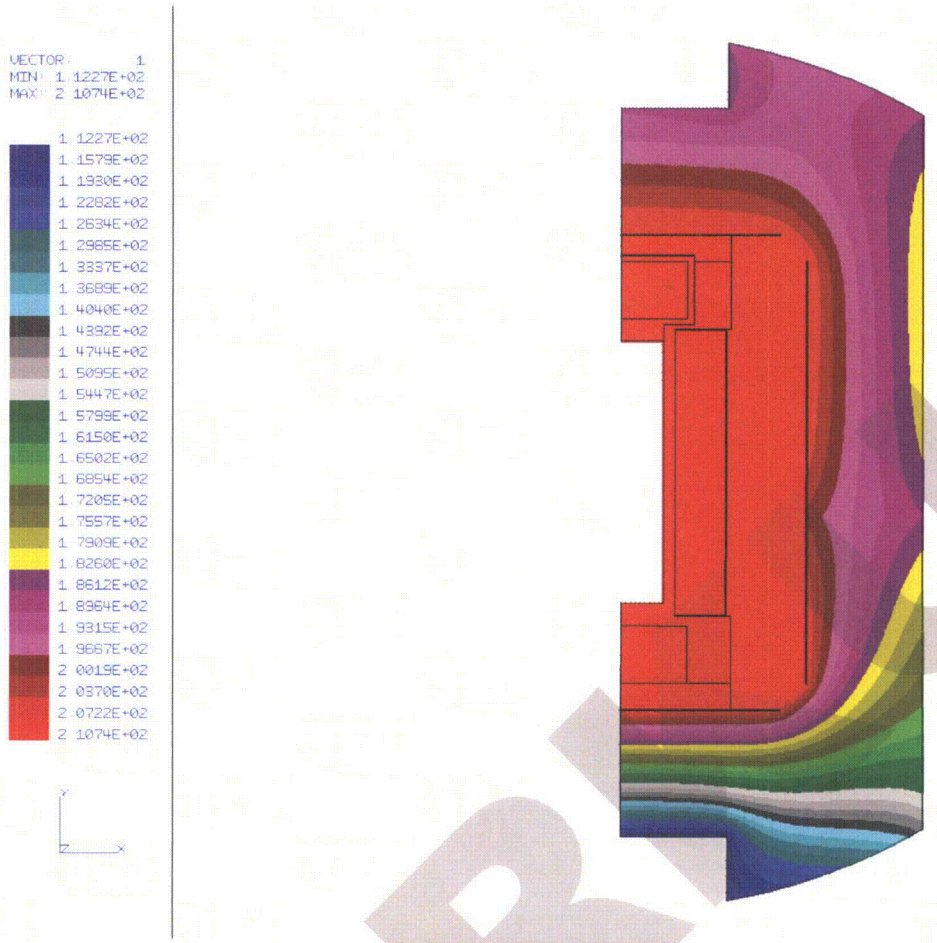


**Figure 3-60. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025**

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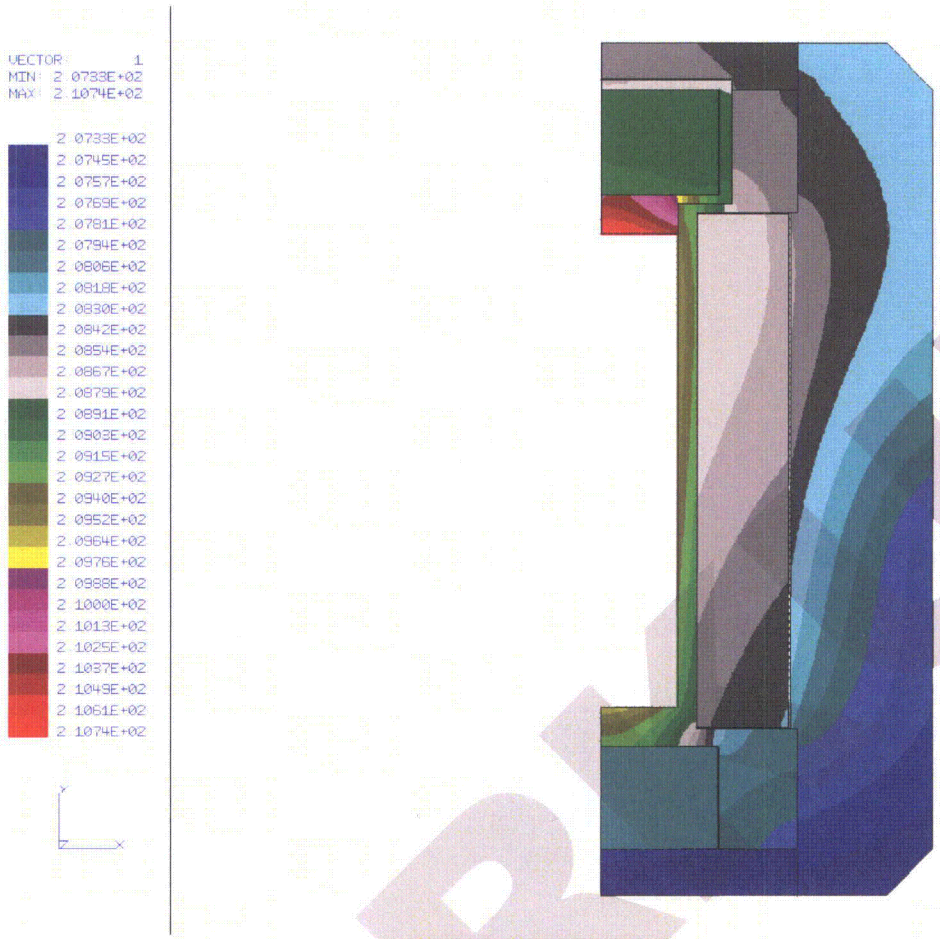


**Figure 3-61. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025**

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**Table 3-52. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025**

| 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 | 4995 | -28.89 | -20.00 |
| 7 | 3309 | -28.89 | -20.00 |
| 8 | 3419 | -28.89 | -20.00 |
| 9 | 678 | -28.89 | -20.00 |
| 10 | 2537 | -28.89 | -20.00 |
| 11 | 1888 | -28.89 | -20.00 |
| 12 | 583 | -28.89 | -20.00 |
| 13 | 3001 | -28.89 | -20.00 |
| 14 | 3148 | -28.89 | -20.00 |
| 15 | 7533 | -28.89 | -20.00 |
| 16 | 7377 | -28.89 | -20.00 |
| 17 | 7371 | -28.89 | -20.00 |
| 18 | 6942 | -28.89 | -20.00 |
| 19 | 6267 | -28.89 | -20.00 |
| 20 | 6121 | -28.89 | -20.00 |
| 21 | 6001 | -28.89 | -20.00 |
| 22 | 9501 | -28.89 | -20.00 |
| 23 | 9950 | -28.89 | -20.00 |
| 24 | 10014 | -28.89 | -20.00 |
| 25 | 10781 | -28.89 | -20.00 |
| 26 | 9091 | -28.89 | -20.00 |
| 27 | 8463 | -28.89 | -20.00 |
| 28 | 8462 | -28.89 | -20.00 |
| 29 | 8197 | -28.89 | -20.00 |
| 30 | 9711 | -28.89 | -20.00 |
| 31 | 9821 | -28.89 | -20.00 |
| 32 | 10158 | -28.89 | -20.00 |
| 33 | 10605 | -28.89 | -20.00 |
| 34 | 9102 | -28.89 | -20.00 |
| 35 | 8578 | -28.89 | -20.00 |
| 36 | 8225 | -28.89 | -20.00 |
| 37 | 8001 | -28.89 | -20.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 101 | -2.8889E+01 | -2.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -2.8889E+01 | -2.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -2.8889E+01 | -2.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -2.8889E+01 | -2.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -2.8889E+01 | -2.0000E+01 |
| Tungsten | 6001 | 7656 | 6001 | -2.8889E+01 | -2.0000E+01 |
| LAST-A-FOAM | 8001 | 11692 | 8001 | -2.8889E+01 | -2.0000E+01 |

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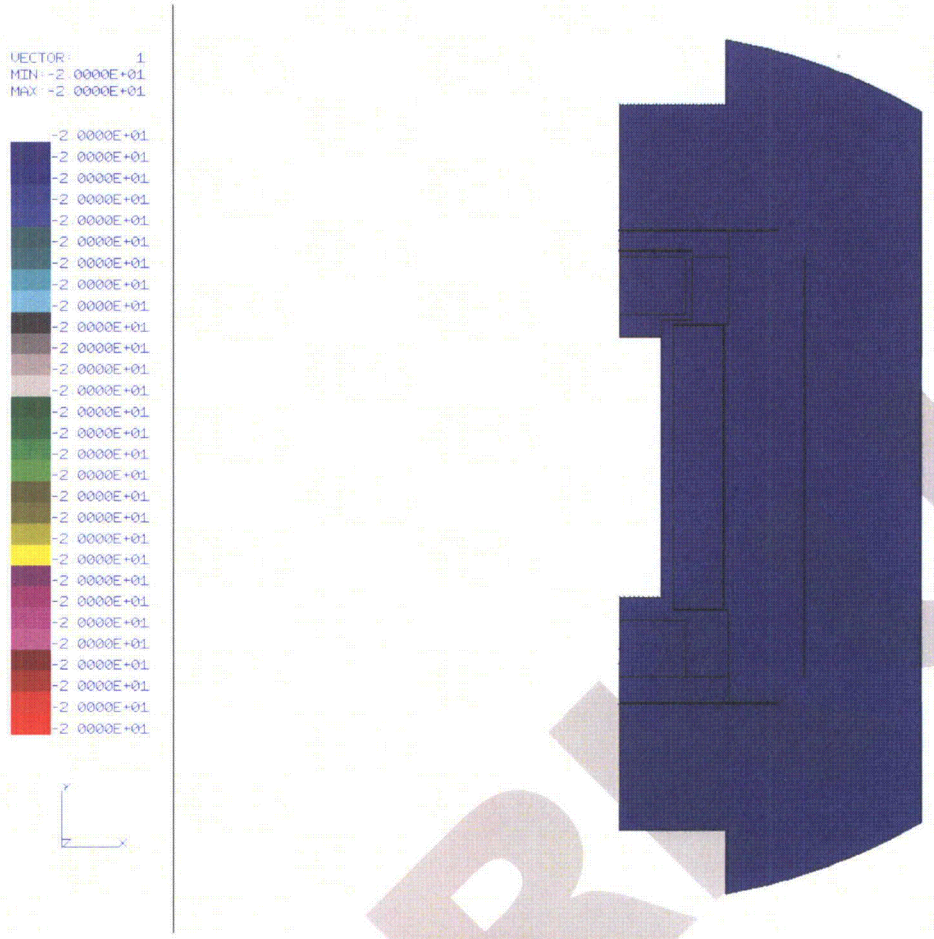


**Figure 3-62. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025**

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**Table 3-53. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025**

| 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 | 4995 | -40.00 | -40.00 |
| 7 | 3309 | -40.00 | -40.00 |
| 8 | 3419 | -40.00 | -40.00 |
| 9 | 678 | -40.00 | -40.00 |
| 10 | 2537 | -40.00 | -40.00 |
| 11 | 1888 | -40.00 | -40.00 |
| 12 | 583 | -40.00 | -40.00 |
| 13 | 3001 | -40.00 | -40.00 |
| 14 | 3148 | -40.00 | -40.00 |
| 15 | 7533 | -40.00 | -40.00 |
| 16 | 7377 | -40.00 | -40.00 |
| 17 | 7371 | -40.00 | -40.00 |
| 18 | 6942 | -40.00 | -40.00 |
| 19 | 6267 | -40.00 | -40.00 |
| 20 | 6121 | -40.00 | -40.00 |
| 21 | 6001 | -40.00 | -40.00 |
| 22 | 9501 | -40.00 | -40.00 |
| 23 | 9950 | -40.00 | -40.00 |
| 24 | 10014 | -40.00 | -40.00 |
| 25 | 10781 | -40.00 | -40.00 |
| 26 | 9091 | -40.00 | -40.00 |
| 27 | 8463 | -40.00 | -40.00 |
| 28 | 8462 | -40.00 | -40.00 |
| 29 | 8197 | -40.00 | -40.00 |
| 30 | 9711 | -40.00 | -40.00 |
| 31 | 9821 | -40.00 | -40.00 |
| 32 | 10158 | -40.00 | -40.00 |
| 33 | 10605 | -40.00 | -40.00 |
| 34 | 9102 | -40.00 | -40.00 |
| 35 | 8578 | -40.00 | -40.00 |
| 36 | 8225 | -40.00 | -40.00 |
| 37 | 8001 | -40.00 | -40.00 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 101 | -4.0000E+01 | -4.0000E+01 |
| Bottom Plate | 3001 | 3232 | 3001 | -4.0000E+01 | -4.0000E+01 |
| Lid | 3233 | 3424 | 3233 | -4.0000E+01 | -4.0000E+01 |
| Shell Cavity | 4001 | 4998 | 4001 | -4.0000E+01 | -4.0000E+01 |
| Plug | 5001 | 5404 | 5001 | -4.0000E+01 | -4.0000E+01 |
| Tungsten Alloy | 6001 | 7656 | 6001 | -4.0000E+01 | -4.0000E+01 |
| LAST-A-FOAM | 8001 | 11692 | 8001 | -4.0000E+01 | -4.0000E+01 |

MARKUP

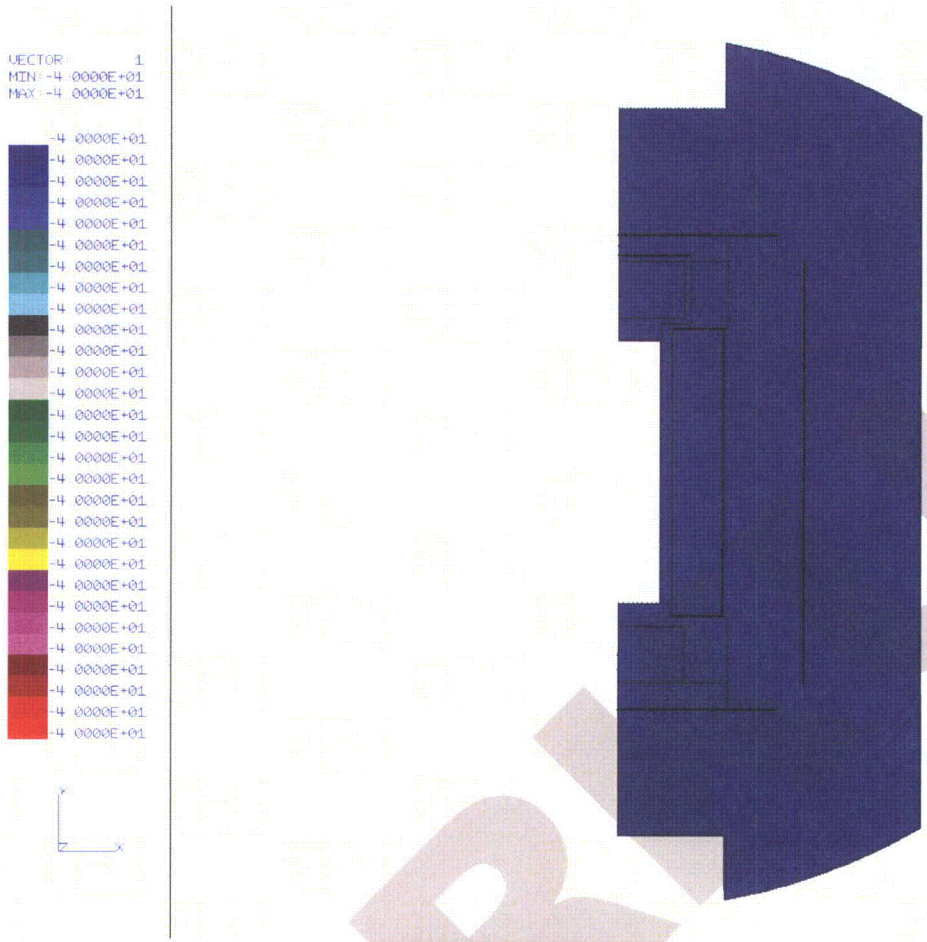


**Figure 3-63. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025**

MARKUP

**Table 3-54. Load Case 105 – -40°F Ambient, Maximum Decay Heat – Model AOS-025**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | -14.82 | 5.33 |
| 2 | 4532 | -15.55 | 4.01 |
| 3 | 4227 | -15.34 | 4.39 |
| 4 | 4752 | -15.70 | 3.74 |
| 5 | 4838 | -16.25 | 2.75 |
| 6 | 4995 | -16.33 | 2.60 |
| 7 | 3309 | -16.39 | 2.50 |
| 8 | 3419 | -16.42 | 2.44 |
| 9 | 678 | -16.22 | 2.81 |
| 10 | 2537 | -16.43 | 2.42 |
| 11 | 1888 | -16.59 | 2.14 |
| 12 | 583 | -16.66 | 2.00 |
| 13 | 3001 | -16.62 | 2.09 |
| 14 | 3148 | -16.67 | 2.00 |
| 15 | 7533 | -16.01 | 3.19 |
| 16 | 7377 | -15.94 | 3.30 |
| 17 | 7371 | -16.10 | 3.02 |
| 18 | 6942 | -16.11 | 3.00 |
| 19 | 6267 | -16.20 | 2.84 |
| 20 | 6121 | -16.31 | 2.64 |
| 21 | 6001 | -16.37 | 2.54 |
| 22 | 9501 | -16.48 | 2.33 |
| 23 | 9950 | -16.86 | 1.65 |
| 24 | 10014 | -17.12 | 1.18 |
| 25 | 10781 | -17.53 | 0.45 |
| 26 | 9091 | -19.23 | -2.62 |
| 27 | 8463 | -17.55 | 0.41 |
| 28 | 8462 | -17.14 | 1.14 |
| 29 | 8197 | -16.71 | 1.92 |
| 30 | 9711 | -38.79 | -37.83 |
| 31 | 9821 | -39.28 | -38.71 |
| 32 | 10158 | -39.00 | -38.20 |
| 33 | 10605 | -36.18 | -33.13 |
| 34 | 9102 | -33.87 | -28.97 |
| 35 | 8578 | -38.49 | -37.28 |
| 36 | 8225 | -38.88 | -37.99 |
| 37 | 8001 | -38.33 | -36.99 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 718 | -1.6176E+01 | 2.8840E+00 |
| Bottom Plate | 3001 | 3232 | 3120 | -1.6531E+01 | 2.2450E+00 |
| Lid | 3233 | 3424 | 3233 | -1.6324E+01 | 2.6160E+00 |
| Shell Cavity | 4001 | 4998 | 4227 | -1.5341E+01 | 4.3860E+00 |
| Plug | 5001 | 5404 | 5001 | -1.4819E+01 | 5.3260E+00 |
| Tungsten Alloy | 6001 | 7656 | 7377 | -1.5943E+01 | 3.3020E+00 |
| LAST-A-FOAM | 8001 | 11692 | 9501 | -1.6481E+01 | 2.3340E+00 |

MARKUP

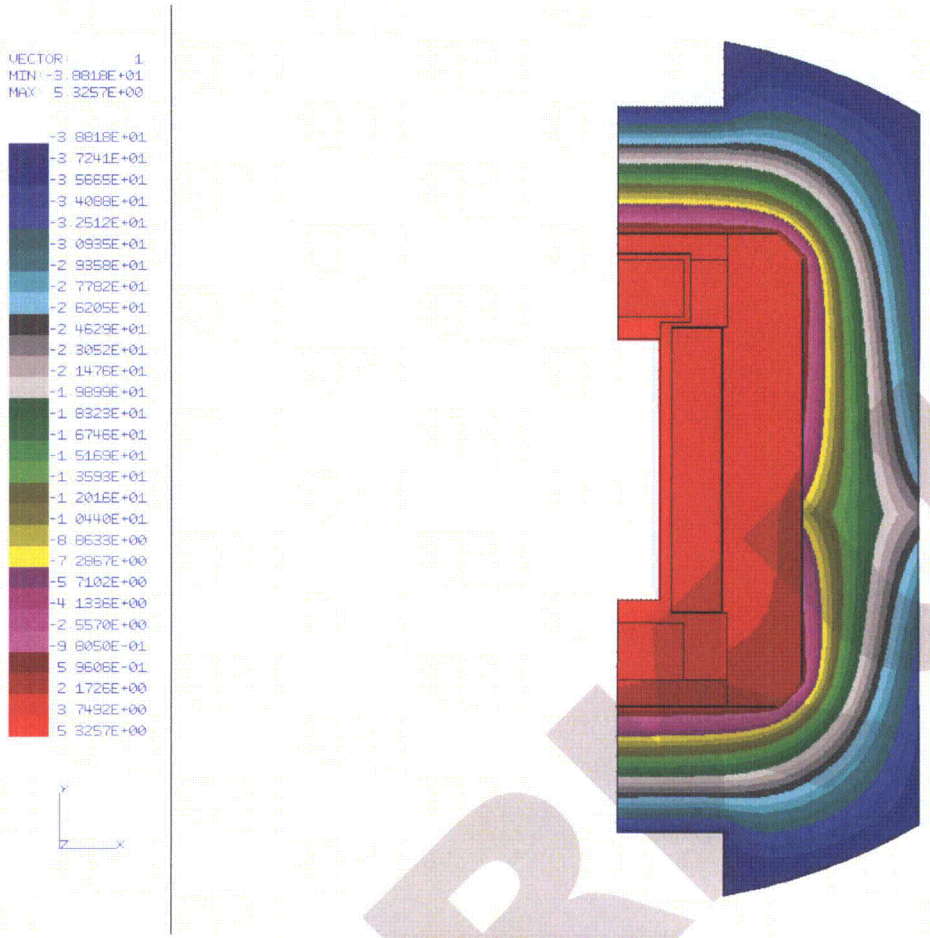


**Figure 3-64. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025**

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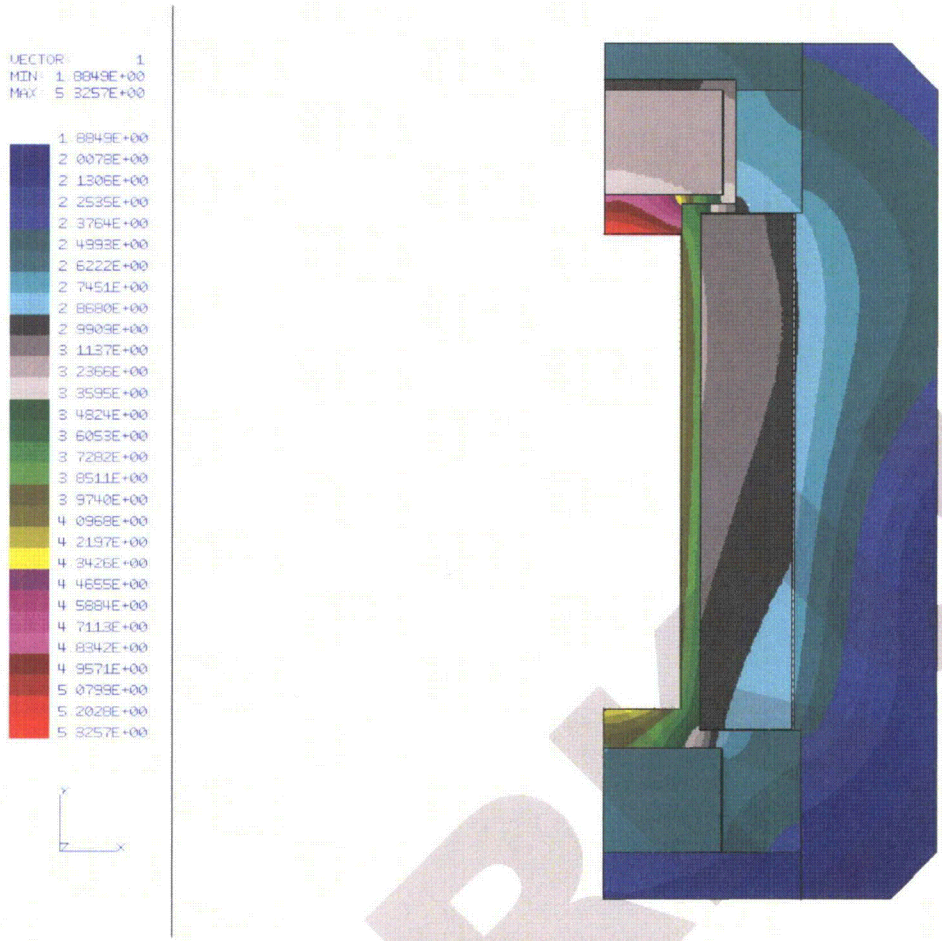


**Figure 3-65. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025**

MARKUP

**Table 3-55. Load Case 106 – -20°F Ambient, Maximum Decay Heat – Model AOS-025**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | -3.99 | 24.82 |
| 2 | 4532 | -4.71 | 23.52 |
| 3 | 4227 | -4.51 | 23.89 |
| 4 | 4752 | -4.86 | 23.26 |
| 5 | 4838 | -5.40 | 22.28 |
| 6 | 4995 | -5.48 | 22.14 |
| 7 | 3309 | -5.53 | 22.04 |
| 8 | 3419 | -5.57 | 21.98 |
| 9 | 678 | -5.37 | 22.34 |
| 10 | 2537 | -5.58 | 21.96 |
| 11 | 1888 | -5.74 | 21.67 |
| 12 | 583 | -5.81 | 21.55 |
| 13 | 3001 | -5.76 | 21.63 |
| 14 | 3148 | -5.81 | 21.54 |
| 15 | 7533 | -5.16 | 22.71 |
| 16 | 7377 | -5.10 | 22.82 |
| 17 | 7371 | -5.25 | 22.55 |
| 18 | 6942 | -5.26 | 22.53 |
| 19 | 6267 | -5.35 | 22.37 |
| 20 | 6121 | -5.46 | 22.17 |
| 21 | 6001 | -5.52 | 22.07 |
| 22 | 9501 | -5.62 | 21.88 |
| 23 | 9950 | -5.99 | 21.21 |
| 24 | 10014 | -6.24 | 20.76 |
| 25 | 10781 | -6.63 | 20.07 |
| 26 | 9091 | -8.30 | 17.06 |
| 27 | 8463 | -6.66 | 20.01 |
| 28 | 8462 | -6.27 | 20.71 |
| 29 | 8197 | -5.86 | 21.46 |
| 30 | 9711 | -27.69 | -17.84 |
| 31 | 9821 | -28.17 | -18.71 |
| 32 | 10158 | -27.89 | -18.21 |
| 33 | 10605 | -25.12 | -13.21 |
| 34 | 9102 | -22.82 | -9.08 |
| 35 | 8578 | -27.40 | -17.32 |
| 36 | 8225 | -27.79 | -18.03 |
| 37 | 8001 | -27.25 | -17.05 |

MARKUP

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 720 | -5.3222E+00 | 2.2420E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | -5.6778E+00 | 2.1780E+01 |
| Lid | 3233 | 3424 | 3233 | -5.4722E+00 | 2.2150E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | -4.5056E+00 | 2.3890E+01 |
| Plug | 5001 | 5404 | 5001 | -3.9889E+00 | 2.4820E+01 |
| Tungsten Alloy | 6001 | 7656 | 7377 | -5.1000E+00 | 2.2820E+01 |
| LAST-A-FOAM | 8001 | 11692 | 9501 | -5.6222E+00 | 2.1880E+01 |

MARKUP

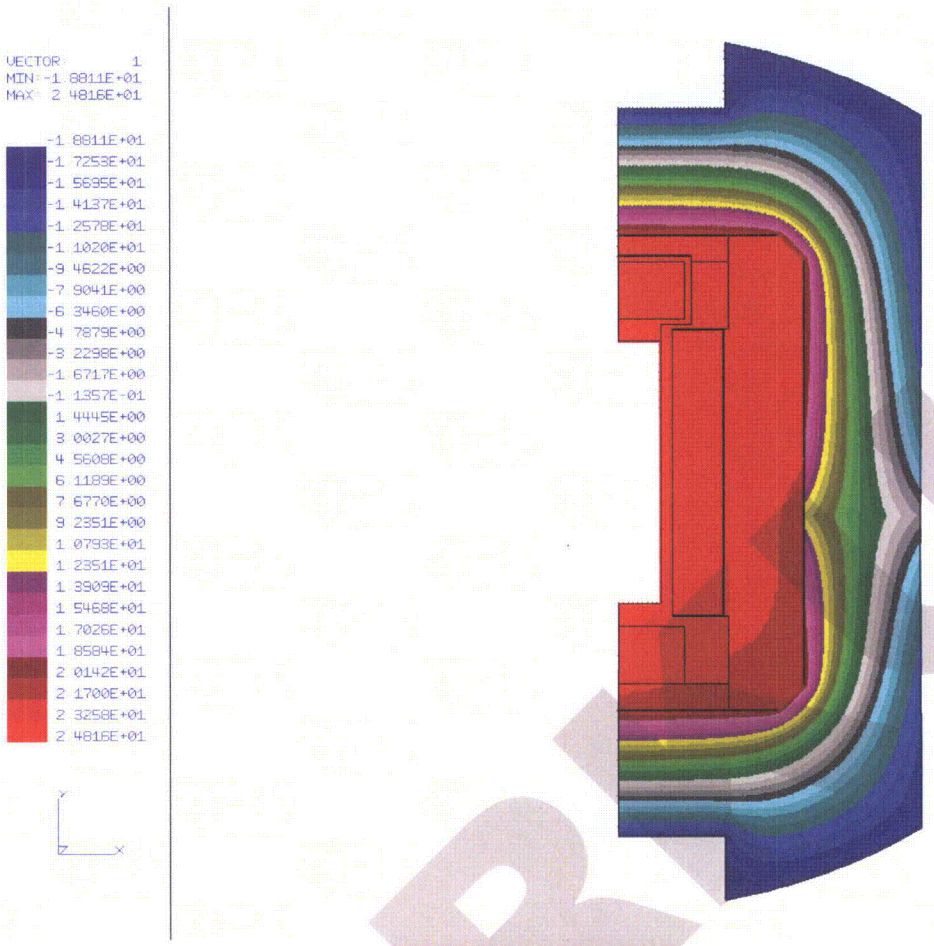


**Figure 3-66. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025**

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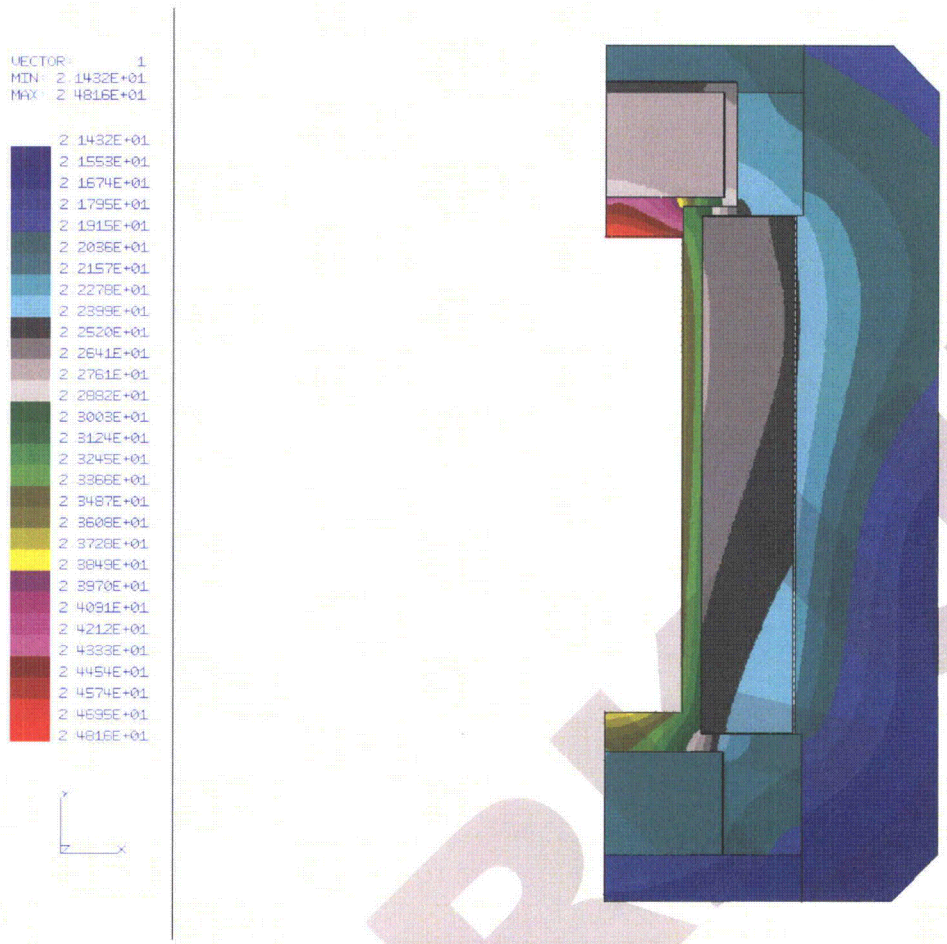


**Figure 3-67. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025**

MARKUP

### 3.5.1.2 Normal Conditions of Transport Results – Model AOS-050

Table 3-56 lists the tables and figures in this appendix that present the Model AOS-050 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. Also listed are the maximum temperatures within each transport package component.

Table 3-57 lists the temperature monitoring points (nodes) for the Model AOS-050 transport package, under Normal and Hypothetical Accident (Fire) conditions of transport. Figure 3-68 illustrates the location of each node on the transport package, under Normal conditions.

**Table 3-56. Normal Conditions of Transport Results – Model AOS-050**

| Load Case | Description | Results Table | Entire Model | Cask Model |
|---|---|---|---|---|
| 101 | 100°F Ambient, Maximum Decay Heat | Table 3-58 | Figure 3-69 | Figure 3-70 |
| 102 | 100°F Ambient, Maximum Decay Heat, Maximum Insolation | Table 3-59 | Figure 3-71 | Figure 3-72 |
| 103 | -20°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-60 | Figure 3-73 | – |
| 104 | -40°F Ambient, Zero Decay Heat, Zero Insolation | Table 3-61 | Figure 3-74 | – |
| 105 | -40°F Ambient, Maximum Decay Heat | Table 3-62 | Figure 3-75 | Figure 3-76 |
| 106 | -20°F Ambient, Maximum Decay Heat | Table 3-63 | Figure 3-77 | Figure 3-78 |

MARKUP

Table 3-57. Temperature Monitoring Points, All Conditions of Transport – Model AOS-050

| Nodal Location | LIBRA Model Nodal Number | |
|---|---|---|
| | Normal Conditions | Fire Conditions |
| 1 | 5001 | 5001 |
| 2 | 4532 | 4532 |
| 3 | 4227 | 4227 |
| 4 | 4752 | 4752 |
| 5 | 4838 | 4838 |
| 6 | 4995 | 4995 |
| 7 | 3309 | 3309 |
| 8 | 3419 | 3419 |
| 9 | 678 | 678 |
| 10 | 2537 | 2537 |
| 11 | 1888 | 1888 |
| 12 | 583 | 583 |
| 13 | 3001 | 3001 |
| 14 | 3148 | 3148 |
| 15 | 7533 | 7533 |
| 16 | 7377 | 7377 |
| 17 | 7371 | 7371 |
| 18 | 6942 | 6942 |
| 19 | 6267 | 6267 |
| 20 | 6121 | 6121 |
| 21 | 6001 | 6001 |
| 22 | 9501 | 15481 |
| 23 | 9950 | 16630 |
| 24 | 10014 | 16694 |
| 25 | 10781 | 17804 |
| 26 | 9091 | 11128 |
| 27 | 8463 | 9785 |
| 28 | 8462 | 9571 |
| 29 | 8197 | 8197 |
| 30 | 9711 | 15451 |
| 31 | 9821 | 15961 |
| 32 | 10158 | 17022 |
| 33 | 10605 | 17551 |
| 34 | 9102 | 10798 |
| 35 | 8578 | 9900 |
| 36 | 8225 | 8673 |
| 37 | 8001 | 8225 |

PRELIMINARY

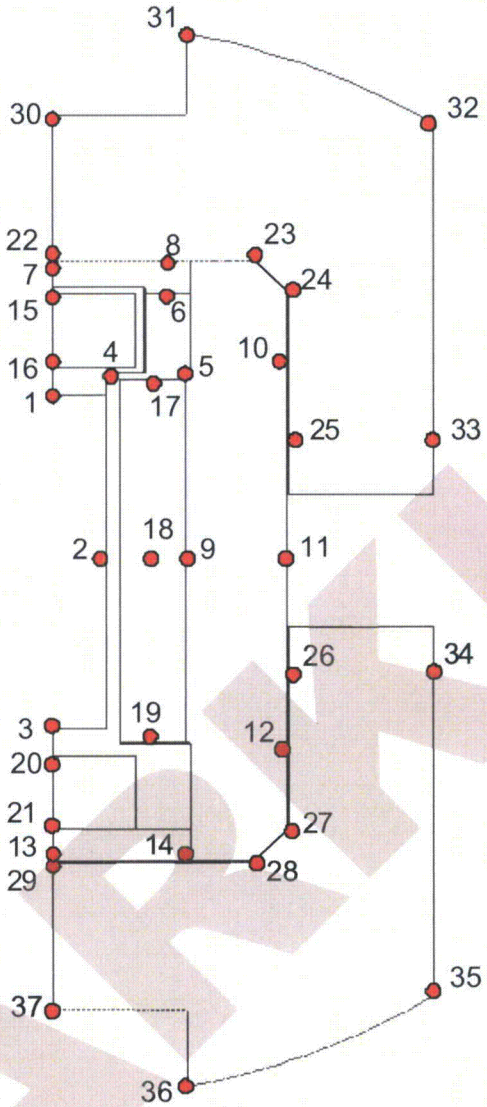


**Figure 3-68. Selected Nodal Locations for Normal Conditions of Transport – Model AOS-050**

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