# DESIGN GUIDE FOR USE OF

# LAST-A-FOAM® FR-3700

FOR

# CRASH & FIRE PROTECTION

OF

# RADIOACTIVE MATERIAL

# SHIPPING CONTAINERS

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# PREFACE

Thank you for your interest in General Plastics Manufacturing Company and its LAST-A-FOAM® products! For over 60 years, General Plastics has been a leader in non-metallic and cellular-solid technologies. The following contains the collected knowledge of LAST-A-FOAM® FR-3700 and presents it for the designers of nuclear (or hazardous waste) material transportation packages, fire protection applications, or other application which involve conditions which require absorption of significant mechanical or thermal energy. This information is assembled into one document for convenience, though most applications will not require knowledge of all aspects of FR-3700 capabilities. We hope you find this information useful for your application.

The designer is invited to use these discussions when considering LAST-A-FOAM® FR-3700 in a crash and/or fire protection application. In addition to FR-3700, General Plastics has many other foam formulations. Each formulation has unique properties to suite a variety of applications.

General Plastics is happy to offer design assistance ranging from telephone advice to testing of scale models.

This data is presented in good faith and is believed to be accurate and well suited for comparative analysis. However, General Plastics Manufacturing Company cannot assume responsibility for the results obtained by others over whose methods we have no control. Therefore, this information is made available for guidance purposes. Because many factors can affect subsequent material processing, application and use, it is important that prospective users conduct any performance testing necessary to assure the suitability and safety of LAST-A-FOAM® products in any proposed application.

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# Introduction

This design guide presents a synopsis of the collected knowledge of LAST-A-FOAM® FR-3700 and its application to radioactive material shipping container design. Presented within are both specific data and generalized discussions to assist the designer in understanding the behavior of LAST-A-FOAM® FR-3700 when exposed to the design conditions typical to radioactive materials shipping containers.

## *Company Background*

General Plastics Manufacturing Company has been a manufacturer of plastic parts and aircraft assemblies for over 50 years, and a producer of rigid and flexible polyurethane foams and parts for over 30 years.

Our position as a world leader in the formulation and manufacture of cellular solid materials puts us in a unique spot to provide material test and evaluation services to technical organizations. Our extensive customer base, which includes military, nuclear, and aerospace firms, requires General Plastics to maintain a very capable quality and testing facility to support our customer's needs. Diversity is our strength. Ongoing research and development programs have kept General Plastics ahead in our markets. The company has experienced a steady, growing demand for its products in the aerospace, defense, nuclear, construction and marine industries. Lasting partnerships have been forged with industry giants including Boeing, Sandia, BWXT Pantex, and Lockheed to name a few, ensuring a consistent demand for services and a competent operation capable of producing premium materials for a variety of customers.

## *Quality*

General Plastics has the Quality Assurance program and test facilities necessary to provide all required test data and certifications for application in nuclear material shipping containers. General Plastics is qualified to NQA-1 as well as MIL-I-45208 and AS9100 (AS9100 is effectively ISO for aerospace). Additionally, General Plastics is DI-9000A qualified, and is a delegated-source inspection raw material supplier to the Boeing Commercial Airplane Company. We have held this delegated-source appointment since 1988.

## *LAST-A-FOAM® FR 3700 Product Description*

LAST-A-FOAM® FR-3700 is HCFC-free, rigid, closed-cell, flame retardant polyurethane foam available in densities ranging from 4 to 40 pounds per cubic foot. It exhibits a high strength-to-weight ratio due to its cellular structure and cross-linked resin. Also, because of its closed-cell structure, LAST-A-FOAM® FR-3700 has significant resistance to water absorption, and will not swell, crack, or split on exposure to water. LAST-A-FOAM® is stable, inert, and is resistant to most chemicals and solvents. It is easily worked with common tools, and performs well as a primary or replacement for many materials in a variety of applications.

LAST-A-FOAM® FR-3700 makes an ideal candidate material for many highly engineered applications. A prime example of a highly engineered application in which LAST-A-FOAM® FR-3700 has a history of successful use is radioactive materials (RAM) transportation packages. The regulations governing RAM packages often require the accident conditions energy absorption of 30 foot free drops and exposure to a 1,475°F, 30-minute fire. LAST-A-FOAM® FR-3700 is one of very few materials that can serve the dual purpose of assisting the RAM package design in mitigating *both* mechanical and thermal energy.

# Product Data

LAST-A-FOAM® FR-3700 is a HCFC-free, rigid, closed-cell, flame-retardant polyurethane foam available in densities ranging from 4 to 40 pounds per cubic foot. It exhibits a high strength-to-weight ratio due to its cellular structure and crosslinked resin. Also, because of its closed-cell structure, LAST-A-FOAM® FR-3700 has great resistance to water absorption, and will not swell, crack, or split on exposure to water. LAST-A-FOAM® is stable, inert, and is resistant to most chemicals and solvents. It is easily worked with common tools, and performs well as a primary or replacement material in a variety of applications.

## Basic Properties

**Table 1**: Basic Physical Properties

| Property | English/Metric | Test Method |
|---|---|---|
| Closed Cell Content | 96.7% | ASTM D-2856 Procedure B |
| Water Absorption | < 85% by weight | ASTM D-2842 |
| Glass Transition | 279°F / 137°C | MDSC |
| Hardness, Shore-D | 1.7812(D) + 0.37 | ASTM D-2240 |
| Tumbling Friability - loss $^{w}/_{o}$ | $41.314 \times 2.7183^{-0.1873(D)}$ | ASTM C-421 (20 min. @ 60 rpm) |

**Table 2**: Basic Chemical Properties

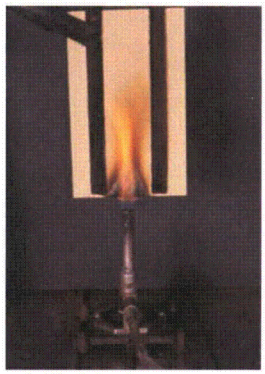
| Property | English/Metric | | Test Method |
|---|---|---|---|
| Chemical Composition | Carbon (C) | 50-70% | -- |
| | Oxygen (O) | 14-34% | |
| | Nitrogen (N) | 4-12% | |
| | Hydrogen (H) | 4-10% | |
| | Phosphorous (P) | 0-2% | |
| | Silicon (Si) | < 1% | |
| | Chloride (Cl) | < 1800 ppm | |
| | Other | < 1% | |
| Leachable Chlorides | < 1 ppm | | GP-TM9510 |

**Table 3**: Thermal Properties

| Property | | English | Metric | Test Method |
|---|---|---|---|---|
| Thermal Conductivity | | BTU/hr-ft$^2$-°F/inch | W/m-K | ASTM C177 @75°F (24°C) |
| | FR-3704 | 0.200 | 0.029 | |
| | FR-3706 | 0.205 | 0.030 | |
| | FR-3708 | 0.209 | 0.030 | |
| | FR-3710 | 0.213 | 0.031 | |
| | FR-3718 | 0.324 | 0.047 | |
| | FR-3720 | 0.349 | 0.050 | |
| | FR-3725 | 0.414 | 0.060 | |
| Specific Heat @25°C | | 0.353 BTU/lb-°F | 1.477 J/g°C | ASTM E-1269 |
| Heat of Combustion | | 11,706 BTU/lb | 27.17 MJ/Kg | ASTM D-240 |
| Coefficient of Linear Thermal Expansion From -50°F to 200°F | | $3.5 \times 10^{-5}$ in/in/°F to $5.0 \times 10^{-5}$ in/in/°F | $6.2 \times 10^{-5}$ K$^{-1}$ to $9.0 \times 10^{-5}$ K$^{-1}$ | ASTM C-518 |

## Fire Safety & Protection

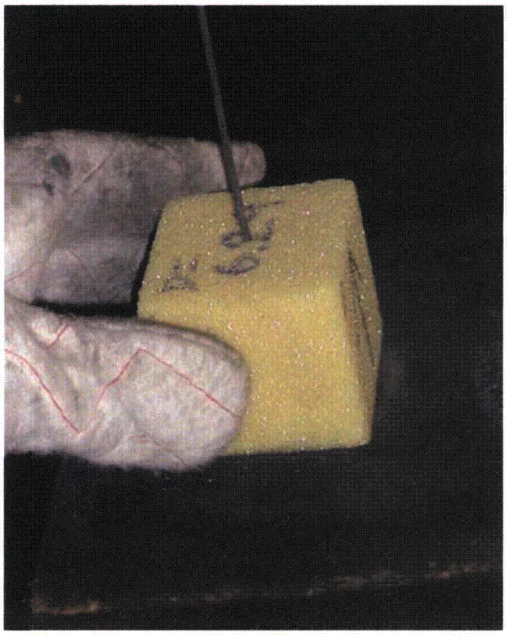
LAST-A-FOAM® FR-3700 rigid polyurethane foam is flame retardant. However, it is an organic material and *will* burn in the presence of sufficient heat and oxygen. It is important to understand that FR-3700 is a thermoset plastic and does not melt.



Applications using FR-3700 for fire protection take advantage of the fire retardant mechanisms engineered into the product. The primary fire retardant mechanism of FR-3700 is the production of an intumescent char when thermally attacked. Two tests demonstrate the capabilities of LAST-A-FOAM® FR-3700 in a fire. The basic fire retardant nature of FR-3700 is determined using Federal Aviation Regulation (FAR) 25.853 flame test {14CFR25.853(a) App. F(a)(1)(I)}. The second test is intumescence. Both tests are described below.

The pyrolysis gasses produced by decomposition reactions must be vented from the vessel to avoid an explosive pressure release and to allow the gasses to remove the heat from the container.. It is recommended that vents be provided in a ratio one square inch to 10-25 square feet of exposed hot face surface. Vents should be placed so that the breakdown products and gases are channeled away from sensitive areas of the payload such as seal sections.

When subjected to thermal attack, FR-3700 decomposes and forms an intumescent char. The intumescent char formed during pyrolysis allows the foam to 'heal' cracks from any proceeding event (such as a mechanical impact). The resulting intumescing char produced by FR-3700 can effectively seal openings and preclude the "chimney affect", or other heat transfer modes. Shown in the following figures, you can see how the examples which began as 2 inch cubes, demonstrates intumescence in the direction of heat application. The char also provides a secondary thermal barrier that decomposes (very slowly) at temperatures above 2,000°F.



Before

After

The Federal Aviation Regulation (FAR) 25.853(a) App. F(a)(1)(I) flame test is commonly used to asses the relative burning characteristics of foam plastic materials under controlled laboratory conditions. The results of these tests performed on LAST-A-FOAM® are shown in Table 4.

**Table 4**: Typical FAR 25.853 flame test results

| LAST-A-FOAM® Grade | FAR 25.835 12-second Ignition | | FAR 25.835 60-second Ignition | |
|---|---|---|---|---|
| | Extinguish Time, Seconds | Burn Distance, inches (mm) | Extinguish Time, Seconds | Burn Distance, inches (mm) |
| FR-3704 | 0.5 | 5.7 (144.8) | 0.7 | 5.6 (142.2) |
| FR-3706 | 3.0 | 5.2 (132.0) | 0.8 | 5.4 (137.2) |
| FR-3710 | 2.5 | 3.8 (96.5) | -0- | 4.6 (116.8) |
| FR-3718 | 6.1 | 2.7 (68.6) | -0- | 4.5 (114.3) |
| FR-3720 | 5.5 | 2.9 (73.7) | -0- | 4.7 (119.4) |

The results of these test are not to be considered or used as fire hazard classifications, and are not intended or implied to reflect hazards presented by this or any other material in actual fire conditions.

In the above tests, a 0.5 inch x 3.0 inch x 12 inch (12.7 mm x 76.2 mm x 305 mm) long foam sample is mounted in a vertical position. The lower end is exposed to a 1.5 inch (38.1 mm) Bunsen burner flame for the described time. The time to flame extinguishment after removal of the flame and burned length of the sample are recorded.

## Chemical Resistance

LAST-A-FOAM® products exhibit very good-to-excellent resistance to a wide range of chemicals and solvents. Common petroleum products such as oil or gasoline have a negligible affect on LAST-A-FOAM®. Exposure to liquid acids and bases, either in dilute or highly-concentrated forms, does not significantly deteriorate foam properties at normal room temperatures. Some chlorinated solvents will cause LAST-A-FOAM® to temporarily swell or soften on exposure, which can be useful in some production situations. If you need specific advice regarding chemical resistance, please contact us.

## Bonding, Filling, and Sealing LAST-A-FOAM

LAST-A-FOAM® can be bonded, filled sealed and painted with a wide variety of commercially available finishing products. Our customers report greatest success with automotive and wood finishing materials, but the range of usable products is not limited to those types.

General Plastics Manufacturing Company has prepare a "Guide to Bonding, Filling, and Sealing LAST-A-FOAM® Products", available on request, to help with making appropriate finishing material selections. You should follow manufacturer's safety instructions when using any bonding, filling, or finishing product with LAST-A-FOAM®, and observe their recommended precautions.

## Long Term Life Performance

General Plastics Manufacturing Company's LAST-A-FOAM® FR-3700 is often chosen for long term applications. Therefore it is imperative that the foam retain its physical properties over the normal life span of the application. A sample of twenty year old LAST-A-FOAM® FR-3720 was obtained and tested for compressive strength and char formation. Maintenance of compressive strength is a good indicator of the material's overall structural performance while the formation of closed cell char foam is the key factor in fire retardancy.

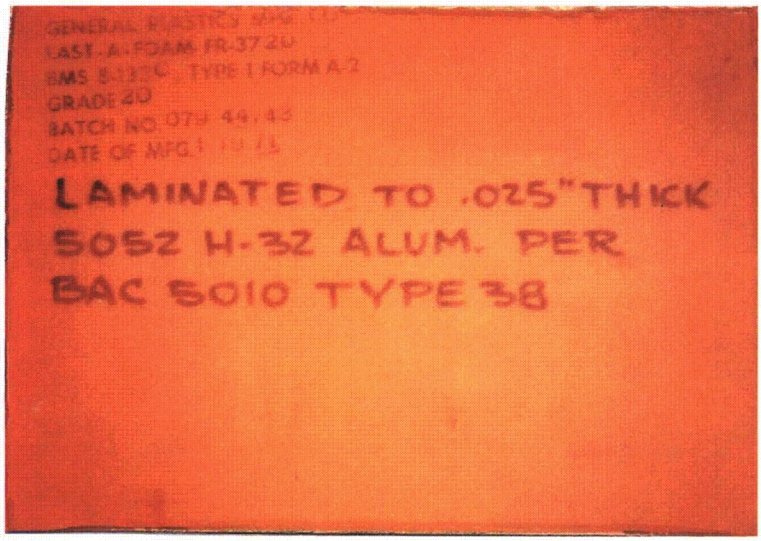



**Figure 1 -** The sample pictured at left was manufactured in January of 1971 and tested in November 1990. The sample consists of two sheets of one half inch FR-3720 laminated to an aluminum sheet. The foam was cut off the aluminum sheet prior to testing.

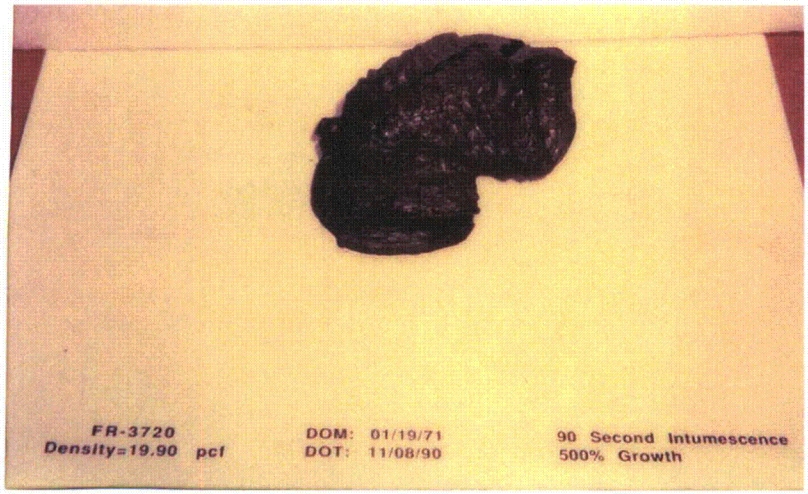



**Figure 2 -** The photo at right demonstrates that the intumescent char forming ability of FR-3720 is not affected by age.

The compressive strength was 1,393 psi with a modulus of 34,968 psi/in. This compares very favorably with General Plastics published nominal compressive strength values for LAST-A-FOAM® FR-3720 of 1,105 psi and 27,957 psi/in. The higher values found in the 20 year old sample may be partly due to the 0.5 in thick sample vs the standard one in. thick and partly due to long term cure effects. (see Figure 3).

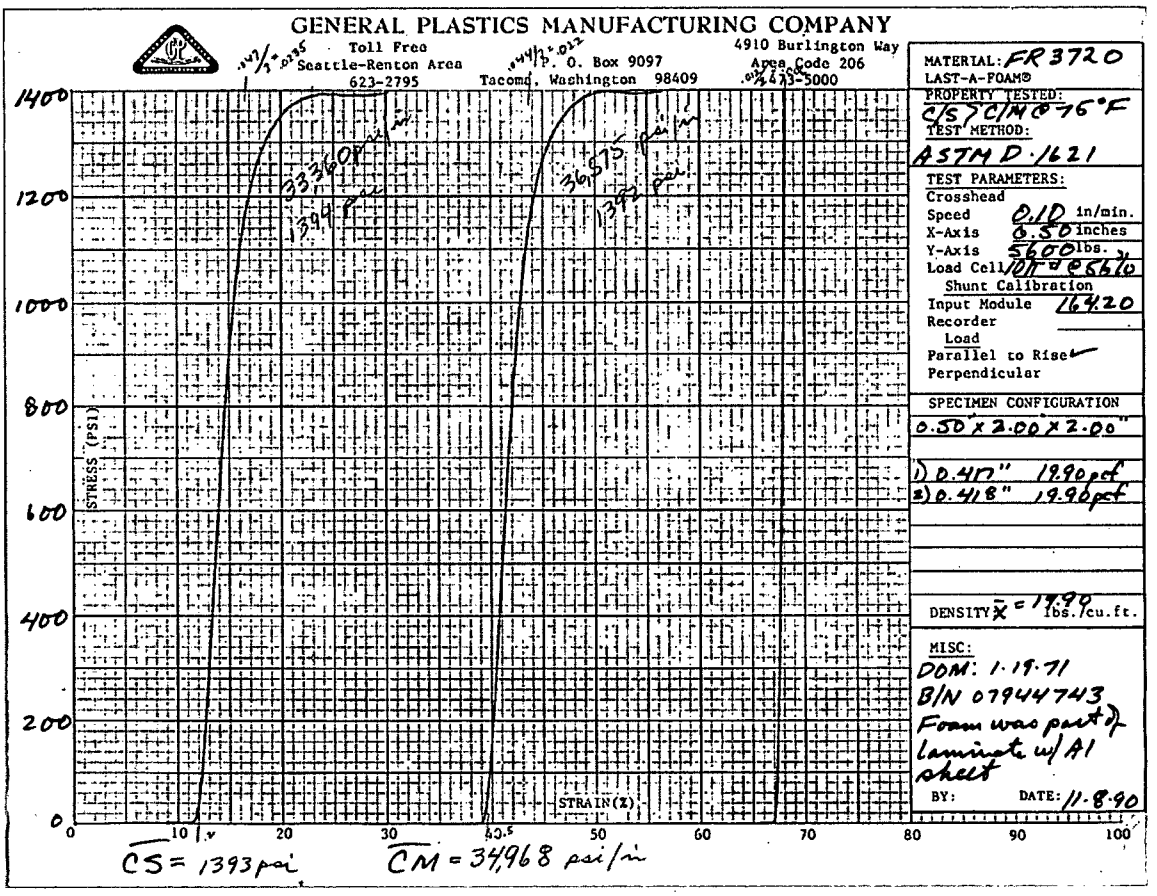



**Figure 3:** Long-Term Compressive Strength

## Effect of Radiation

Cubic specimens (2.5 inch) LAST-A-FOAM® FR-3710 were submitted to the University of Michigan Phoenix Memorial Laboratory. The Specimens were irradiated in a Cobalt-60 Irradiator to a maximum cumulative dose of $2 \times 10^8$ rads (gamma). This dosage is representative of approximately 40 years of life in a field of 500 rads per hour. Discoloration was observed to increase with dosage but was not correlated with any change of physical properties. The compressive strength of the specimens was unaffected by the radiation as evidenced by the data shown in Table 5 and Table 6. (Test date: 1994)

**Table 5:** Average of five specimens at each dosage (results for individual tests available upon request)

| Exposure | DENSITY lbs/ft$^3$ | Stress(psi) @ % Crush | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10% | 20% | 30% | 40% | 50% | 60% | 65% | 70% |
| Control | 10.78 | 352 | 359 | 382 | 426 | 508 | 686 | 851 | 1,121 |
| $2 \times 10^7$ rads | 10.68 | 341 | 348 | 373 | 417 | 499 | 678 | 848 | 1,137 |
| $4.2 \times 10^7$ rads | 10.58 | 328 | 336 | 360 | 405 | 488 | 666 | 835 | 1,122 |
| $7 \times 10^7$ rads | 10.64 | 333 | 341 | 366 | 408 | 491 | 666 | 831 | 1,106 |
| $2 \times 10^8$ rads | 10.76 | 347 | 356 | 380 | 422 | 507 | 682 | 844 | 1,112 |

## Water Immersion

Using the same cubic samples from the radiation testing, LAST-A-FOAM® FR-3710 was shown to remain resistant to significant water absorption. The samples were placed in water at temperature of 125°F (52°C) and a pressure of 17.7 psig (122 kPa). As shown by the results presented in Table 6, water absorption occurs slowly, even considering the affects of radiation exposure. Resistance to water absorption is consistent with the close cell content of LAST-A-FOAM® FR-3700 of greater than 95%.

**Table 6:** Water Absorption as a function of time and Radiation Exposure

| Time and Radiation Exposure | Density, lbs/ft$^3$ | Before Submersion | After Submersion | Weight Gain, grams | % Gain By Volume, * |
|---|---|---|---|---|---|
| **1 Day Immersion** | | | | | |
| Non Irradiated | 10.61 | 44.19 | 47.29 | 3.10 | 1.21 |
| 2.0 X $10^7$ rads | 10.72 | 44.72 | 48.47 | 3.75 | 1.46 |
| 4.2 X $10^7$ rads | 10.96 | 45.66 | 48.88 | 3.22 | 1.26 |
| 7.0 X $10^7$ rads | 10.64 | 44.66 | 48.67 | 4.01 | 1.57 |
| **10 Day Immersion** | | | | **Average-->** | **1.37** |
| Non Irradiated | 10.80 | 44.73 | 50.12 | 5.39 | 2.11 |
| 2.0 X $10^7$ rads | 10.61 | 44.51 | 51.93 | 7.42 | 2.90 |
| 4.2 X $10^7$ rads | 10.62 | 44.62 | 52.85 | 8.23 | 3.21 |
| 7.0 X $10^7$ rads | 10.65 | 44.29 | 53.78 | 9.49 | 3.71 |
| **100 Day Immersion** | | | | **Average-->** | **2.98** |
| Non Irradiated | 10.87 | 45.35 | 61.74 | 16.39 | 6.40 |
| 2.0 X $10^7$ rads | 10.59 | 44.3 | 66.30 | 22.00 | 8.59 |
| 4.2 X $10^7$ rads | 10.89 | 45.35 | 67.70 | 22.35 | 8.73 |
| 7.0 X $10^7$ rads | 10.62 | 44.44 | 69.26 | 24.82 | 9.69 |
| **156 Day Immersion** | | | | **Average-->** | **8.35** |
| Non Irradiated | 10.67 | 44.22 | 65.12 | 20.90 | 8.16 |
| 2.0 X $10^7$ rads | 10.52 | 43.89 | 69.70 | 25.81 | 10.08 |
| 4.2 X $10^7$ rads | 10.73 | 44.66 | 72.06 | 27.40 | 10.70 |
| 7.0 X $10^7$ rads | 10.73 | 44.58 | 74.59 | 30.01 | 11.72 |
| | | | | **Average-->** | **10.17** |

## Mechanical Properties

The data below are nominal values and appropriate tolerances should be considered when incorporating foam materials into static structural applications. Datasheet with values calculated may be found by following the link: LAST-A-FOAM® FR-3700 Datasheets.

**CAUTION:** When using metric units, you must convert the input variable, D (density), to English units (1 $lb_m/ft^3$ = 16.02 $kg/m^3$).

| Property | | Line of Best Fit Where 'D' is the foam density in $lb_m/ft^3$ (1 $lb_m/ft^3$ = 16.02 $kg/m^3$) | | Test Method |
|---|---|---|---|---|
| | | English (psi) | Metric (MPa) | |
| Compressive Strength | | | | |
| Parallel to Rise | | | | |
| | @75°F | $= 8.745\ (D)^{1.6154}$ | $=0.0603\ (D)^{1.6154}$ | ASTM D-1621 |
| | @250°F | $= 4.537\ (D)^{1.6050}$ | $=0.0313\ (D)^{1.6154}$ | |
| Perpendicular to Rise | | | | |
| | @75°F | $= 3.456\ (D)^{1.9178}$ | $=0.0238\ (D)^{1.6154}$ | ASTM D-1621 |
| | @250°F | $= 2.966\ (D)^{1.7146}$ | $=0.0205\ (D)^{1.6154}$ | |
| Compressive Modulus | | | | |
| Parallel to Rise | @75°F | $= 276.2\ (D)^{1.5413}$ | $=1.9043\ (D)^{1.6154}$ | ASTM D-1621 |
| | @250°F | $= 144.0\ (D)^{1.6396}$ | $=0.9928\ (D)^{1.6154}$ | |
| Perpendicular to Rise | @75°F | $= 74.66\ (D)^{1.9995}$ | $=0.5148\ (D)^{1.6154}$ | ASTM D-1621 |
| | @250°F | $= 93.03\ (D)^{1.7174}$ | $=0.6414\ (D)^{1.6154}$ | |
| Tensile Strength | | | | |
| Parallel to Rise | | $= 29.68\ (D)^{1.1496}$ | $=0.2046\ (D)^{1.6154}$ | ASTM D-1623 Type "A" Specimens |
| Perpendicular to Rise | | $= 14.74\ (D)^{1.3852}$ | $=0.1016\ (D)^{1.6154}$ | |
| Tensile Modulus | | | | |
| Parallel to Rise | | $= 922.4\ (D)^{1.1817}$ | $=6.3597\ (D)^{1.6154}$ | ASTM D-1623 Type "B" Specimens |
| Perpendicular to Rise | | $= 286.5\ (D)^{1.5324}$ | $=1.9753\ (D)^{1.6154}$ | |
| Shear Strength | | | | |
| Parallel to Rise | | $= 7.530\ (D)^{1.5433}$ | $=0.0519\ (D)^{1.6154}$ | ASTM C-273 Compression Shear |
| Perpendicular to Rise | | $= 11.60\ (D)^{1.3754}$ | $=0.0800(D)^{1.6154}$ | |
| Shear Modulus | | | | |
| Parallel to Rise | | $= 40.53\ (D)^{1.8555}$ | $=0.2794\ (D)^{1.6154}$ | ASTM C-273 Compression Shear |
| Perpendicular to Rise | | $= 133.0\ (D)^{1.4209}$ | $=0.9170\ (D)^{1.6154}$ | |
| Flexural Strength | | | | |
| Parallel to Rise | | $= 8.287\ (D)^{1.6660}$ | $=0.0571\ (D)^{1.6154}$ | ASTM D-790 Method 1-A |
| Perpendicular to Rise | | $= 21.17\ (D)^{1.3614}$ | $=0.1456\ (D)^{1.6154}$ | |
| Flexural Modulus | | | | |
| Parallel to Rise | | $= 151.2\ (D)^{1.8084}$ | $=1.0425\ (D)^{1.6154}$ | ASTM D-790 Method 1-A |
| Perpendicular to Rise | | $= 545.8\ (D)^{1.3628}$ | $=3.7631\ (D)^{1.6154}$ | |

## Static Crush Strength

The Static Crush Strength of the foam has been developed from experimental test results of various densities of LAST-A-FOAM® FR-3700 series rigid polyurethane foams at various compressive strains. This information is provided as an aid to designers of crushable, energy-absorbing, packaging systems in selecting the appropriate density of General Plastics' FR-3700 series foams. While impact data may be helpful in the selection of a foam density for a particular application, it is often more practicable to use the static crush strength values in Quality Assurance Testing.

If a crush strength other than that found in the table is desired for a particular application General Plastics would be pleased to engineer LAST-A-FOAM® FR-3700 to more nearly meet the desired properties. This is accomplished by developing intermediate nominal density foam. For example, a nominal 14.5 $lb_m/ft^3$ density would produce a crush strength (predicted) of about 1,000 psi at 50% strain parallel to rise.

The design data provided in Table 7 and Table 8 has been updated to provide the most suitable correlation of crush strength to density to the designers of Radioactive Materials Packages. All of the crush strength values are nominal and the affect of tolerance should be carefully considered. The **minimum** tolerance on the nominal crush strength is ±10% for densities above 8 $lb/ft^3$, and ±15% for densities equal to or below 8 $lb/ft^3$, however we recommend ±15% for densities above 8 $lb/ft^3$, and ±20% for densities equal to or below 8 $lb/ft^3$.

The data presented in this design guide is based on testing of samples taken from our production bun stock. The conditions surrounding in-situ installations are invariably different than the conditions used to manufacture the bun stock from which the samples were taken. Both the nominal values and recommended tolerances are likely to be somewhat affected by the design of the in-situ installation. Please do not hesitate to contact General Plastics Mfg. Co. for questions about our design data or for assistance in interpreting the information in the guide.

**Table 7:** Static Nominal Crush Strength, *Parallel* to Direction of Rise (see **Table 8** for *Perpendicular* to Rise)

| For 4 to 10 $lb_m/ft^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Temp** | **Correlation Factors** | **Crush Strength, psi, Parallel to Direction of Rise** | | | | | | | |
| | | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **65%** | **70%** |
| -20°F | $C_T$ | 1.29 | 1.36 | 1.32 | 1.29 | 1.26 | 1.28 | 1.29 | 1.37 |
| 75°F | $Y_{int}$ | **7.3058** | **6.7276** | **6.4961** | **6.9137** | **5.6711** | **5.3279** | **5.9871** | **6.2085** |
| | S | **1.6590** | **1.7021** | **1.7350** | **1.7255** | **1.8877** | **2.0431** | **2.0870** | **2.1868** |
| 100°F | $C_T$ | 0.87 | 0.88 | 0.89 | 0.89 | 0.90 | 0.91 | 0.91 | 0.96 |
| 140°F | $C_T$ | 0.73 | 0.75 | 0.76 | 0.77 | 0.78 | 0.78 | 0.79 | 0.84 |
| 180°F | $C_T$ | 0.65 | 0.66 | 0.67 | 0.68 | 0.69 | 0.68 | 0.68 | 0.71 |
| 220°F | $C_T$ | 0.61 | 0.60 | 0.60 | 0.61 | 0.61 | 0.59 | 0.59 | 0.61 |
| 260°F | $C_T$ | 0.45 | 0.44 | 0.46 | 0.47 | 0.48 | 0.49 | 0.49 | 0.52 |
| **For 11 to 40 $lb_m/ft^3$** | | | | | | | | | |
| **Temp** | **Correlation Factor** | **Crush Strength, psi, Parallel to Direction of Rise** | | | | | | | |
| | | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **65%** | **70%** |
| -20°F | $C_T$ | 1.35 | 1.33 | 1.32 | 1.31 | 1.31 | 1.30 | 1.28 | 1.26 |
| 75°F | $Y_{int}$ | **4.3422** | **3.8755** | **3.5241** | **3.0307** | **3.0402** | **3.4889** | **5.8935** | **5.6055** |
| | S | **1.8809** | **1.9321** | **1.9872** | **2.0755** | **2.1451** | **2.2143** | **2.1041** | **2.2368** |
| 100°F | $C_T$ | 0.86 | 0.87 | 0.88 | 0.88 | 0.89 | 0.90 | 0.90 | 0.97 |
| 140°F | $C_T$ | 0.72 | 0.74 | 0.75 | 0.75 | 0.75 | 0.76 | 0.76 | 0.81 |
| 180°F | $C_T$ | 0.62 | 0.63 | 0.65 | 0.65 | 0.65 | 0.65 | 0.64 | 0.68 |
| 220°F | $C_T$ | 0.56 | 0.56 | 0.57 | 0.57 | 0.56 | 0.54 | 0.54 | 0.57 |
| 260°F | $C_T$ | 0.40 | 0.40 | 0.41 | 0.42 | 0.41 | 0.43 | 0.43 | 0.47 |

The room temperature (75°F) foam crush strength is calculated at each %-Crush and is a function of density; $\sigma = Y_{int}(\rho)^S$, where $Y_{int}$ and S are defined above, $\rho$ is the nominal foam density in $lb/ft^3$, and $\sigma$ in the resulting crush stress in psi at the indicated strain. The foam crush strength at temperatures other than 75°F is calculated at each %-Crush and is a function of the strength at 75°F; $\sigma = \sigma_{75°F} C_T$. General Plastics Mfg. Co. is re-investigating the correlations factors at temperatures above and below 75°F. Please contact us for more specific and detailed data, as needed.

**Table 8:** Static Nominal Crush Strength, *Perpendicular* to Direction of Rise (see **Table 7** for *Parallel* to Rise)

| For 4 to 10 $lb_m/ft^3$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Temp** | **Correlation Factors (see below)** | **Crush Strength, psi, Perpendicular to Direction of Rise** | | | | | | | |
| | | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **65%** | **70%** |
| -20°F | $C_T$ | 1.32 | 1.35 | 1.34 | 1.32 | 1.32 | 1.33 | 1.34 | 1.36 |
| 75°F | $Y_{int}$ | **6.3841** | **6.5943** | **6.1154** | **5.7722** | **5.3041** | **5.3181** | **5.7864** | **5.7701** |
| | S | **1.7182** | **1.6946** | **1.7403** | **1.8023** | **1.9054** | **2.0392** | **2.1002** | **2.2255** |
| 100°F | $C_T$ | 0.85 | 0.87 | 0.88 | 0.89 | 0.90 | 0.91 | 0.91 | 0.92 |
| 140°F | $C_T$ | 0.75 | 0.77 | 0.78 | 0.79 | 0.79 | 0.79 | 0.79 | 0.80 |
| 180°F | $C_T$ | 0.63 | 0.66 | 0.68 | 0.69 | 0.69 | 0.70 | 0.69 | 0.70 |
| 220°F | $C_T$ | 0.59 | 0.59 | 0.60 | 0.61 | 0.60 | 0.60 | 0.59 | 0.60 |
| 260°F | $C_T$ | 0.45 | 0.45 | 0.47 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 |
| **For 11 to 40 $lb_m/ft^3$** | | | | | | | | | |
| **Temp** | **Correlation Factors (see below)** | **Crush Strength, psi, Perpendicular to Direction of Rise** | | | | | | | |
| | | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **65%** | **70%** |
| -20°F | $C_T$ | 1.34 | 1.33 | 1.32 | 1.33 | 1.30 | 1.28 | 1.24 | 1.17 |
| 75°F | $Y_{int}$ | **4.1342** | **3.5581** | **3.2664** | **2.8352** | **2.8988** | **3.3972** | **6.5439** | **5.6464** |
| | S | **1.8957** | **1.9593** | **2.0109** | **2.0955** | **2.1602** | **2.2242** | **2.0660** | **2.2321** |
| 100°F | $C_T$ | 0.84 | 0.85 | 0.86 | 0.88 | 0.87 | 0.88 | 0.88 | 0.90 |
| 140°F | $C_T$ | 0.72 | 0.73 | 0.74 | 0.76 | 0.75 | 0.76 | 0.76 | 0.79 |
| 180°F | $C_T$ | 0.62 | 0.63 | 0.64 | 0.65 | 0.65 | 0.65 | 0.65 | 0.67 |
| 220°F | $C_T$ | 0.53 | 0.53 | 0.54 | 0.55 | 0.54 | 0.54 | 0.54 | 0.56 |
| 260°F | $C_T$ | 0.39 | 0.39 | 0.40 | 0.41 | 0.41 | 0.40 | 0.40 | 0.42 |

The room temperature (75°F) foam crush strength is calculated at each %-Crush and is a function of density; $\sigma = Y_{int}(\rho)^S$, where $Y_{int}$ and S are defined above, $\rho$ is the nominal foam density in $lb/ft^3$, and $\sigma$ in the resulting crush stress in psi at the indicated strain. The foam crush strength at temperatures other than 75°F is calculated at each %-Crush and is a function of the strength at 75°F; $\sigma = \sigma_{75°F} C_T$. General Plastics Mfg. Co. is re-investigating the correlations factors at temperatures above and below 75°F. Please contact us for more specific and detailed data, as needed.

## Dynamic Crush Strength

The crush strength of LAST-A-FOAM®, like many materials, is modestly sensitive to strain rate. The static to dynamic adjustment shown in Table 9 is based on a significant testing program and included strain rates in the range of 30 $sec^{-1}$ to 100 $sec^{-1}$. It is expected that the adjustment will provide good predictions of dynamic impact strength of FR-3700 for most Packaging design conditions. This information is intended to be a guide for designers of impact mitigating devices. The constitutive material models may be useful in targeting a foam density or rage for a particular application. However, each design should be thoroughly analyzed or tested to understand the implications of the complete design.

**Table 9:** Static to Dynamic Crush Strength Adjustment

| Strain | 10% | 20% | 30% | 40% | 50% | 60% | 65% | 70% |
|---|---|---|---|---|---|---|---|---|
| $Y_{int}$ | 1.2971 | 1.4397 | 1.5181 | 1.3887 | 1.4419 | 1.4275 | 1.3871 | 1.4660 |
| S | 1.0330 | 1.0069 | 0.9941 | 1.0028 | 0.9912 | 0.9831 | 0.9910 | 0.9586 |

The dynamic crush strength is calculated at each %-strain and a function of the static crush strength at the same %-strain;

$$\sigma_{Dynamic} = y_{int}\left(\sigma_{Static}\right)^{S}.$$

CAUTION: Use only units of PSI for input $\sigma_{Static}$ value.

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# References

Collected papers and discussions about the behavior of LAST-A-FOAM® FR-3700. Many of these papers were written for, and presented at design symposiums such as Waste Management and PATRAM.


1. *Thermal Assault and Polyurethane Foam - Evaluating Protective Mechanisms.* – Presented at PATRAM 2004
2. *Thermal Assault and Polyurethane Foam - Evaluating Protective Mechanisms for Transport Containers.* – Presented at PATRAM 2004
3. *A Comparison of Requirements and Test Methodologies for a Variety of Impact Absorbing Materials*, Presented at Waste Management 2001
4. *Machine Design Magazine cut sheet ; Foam Protects Waste Containers from Fire and Shock*, 1991
5. *Rigid Polyurethane Foam for Impact and Thermal Protection*, – Presented at PATRAM 1995
6. *LAST-A-FOAM® FR-3700 In Fire Protection Applications*, General Plastics Mfg. Co. White Paper, 1991
7. *LAST-A-FOAM® FR-3700 Intumescent Char and Fire Resistance*, General Plastics Mfg. Co. White Paper, 1991
8. *Fire Resistance Performance*, General Plastics Mfg. Co. White Paper, 1990
9. *Thermal Decomposition of LAST-A-FOAM® FR-3700*, General Plastics Mfg. Co. White Paper, 1991
10. *LAST-A-FOAM® FR-3700 Dynamic Impact Applications*, General Plastics Mfg. Co. White Paper, 1998
11. *LAST-A-FOAM® FR-3700 Impact Configuration Effects*, General Plastics Mfg. Co. White Paper
12. *LAST-A-FOAM® FR-3700 Material Safety Data Sheet*


Examples (limited set) of licensed Radioactive Material Packages using **LAST-A-FOAM® FR-3700.**

| | |
|---|---|
| Package Model No.: **TRUPACT II**<br>US Certificate No.: **USA/9218/B(U)F-85**<br>Licensee: **U.S. Department of Energy** | Package Model No.: **RH-TRU 72-B**<br>US Certificate No.: **USA/9212/B(M)F-85**<br>Licensee: **U.S. Department of Energy** |
| Package Model No.: **125-B**<br>US Certificate No.: **USA/9200/B(M)F-85**<br>Licensee: **U.S. Department of Energy** | Package Model No.: **NUHOMS® MP187 Multi-Purpose Cask**<br>US Certificate No.: **USA/9255/B(U)F-85**<br>Licensee: **Transnuclear, Inc.** |
| Package Model No.: **F-423**<br>US Certificate No.: **USA/9299/B(U)-85**<br>Licensee: **MDS Nordion** | Package Model No.: **Traveller STD and Traveller XLR**<br>US Certificate No.: **USA/9279/AF-96**<br>Licensee: **Westinghouse Electric Company** |
| Package Model No.: **UX-30**<br>US Certificate No.: **USA/9196/B(U)-85**<br>Licensee: **Duratek** | Package Model No.: **New Powder Container (NPC)**<br>US Certificate No.: **USA/9294/AF-96**<br>Licensee: **Global Nuclear Fuel** |

# NOTES

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# Air Properties

## Air Properties

Properties from Incropera, Frank P., David P. DeWitt, *Fundamentals of Heat and Mass Transfer*, New York: John Wiley & Sons, Incorporated, 4th Ed., 1996.

Used modeling air gaps. Illustrations that follow show the Air gap locations (excerpt from Revision A of this report) and size of gap within the cask (dimensions included, Model AOS-165 provided as an example).

$$Gr = \frac{gS^3}{T\mu^2}\Delta T$$

This part is calculated for different temperatures.

Results shows for large range of $\Delta T$,

$Gr < 2000 \quad \therefore N_u = 1$

$\therefore h_c = k/s \quad k_c = h_c S$

Radiation assuming T1 ~ T2 (temperature across gap)

$h_r = J * F * 4T^3$

$F = 0.351$ (refer to Paragraph 3.3.1.2, "Enclosed Air Space Property Sets," within this report)

$K_R = h_r S$

Excerpt, *Fundamentals of Heat and Mass Transfer*, Table a.4, "Thermophysical Properties of Gases at Atmospheric Pressure," Page 839



**TABLE A.4** Thermophysical Properties of Gases at Atmospheric Pressure[a]

| $T$ (K) | $\rho$ (kg/m³) | $c_p$ (kJ/kg · K) | $\mu \cdot 10^7$ (N · s/m²) | $\nu \cdot 10^6$ (m²/s) | $k \cdot 10^3$ (W/m · K) | $\alpha \cdot 10^6$ (m²/s) | $Pr$ |
|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | |
| 100 | 3.5562 | 1.032 | 71.1 | 2.00 | 9.34 | 2.54 | 0.786 |
| 150 | 2.3364 | 1.012 | 103.4 | 4.426 | 13.8 | 5.84 | 0.758 |
| 200 | 1.7458 | 1.007 | 132.5 | 7.590 | 18.1 | 10.3 | 0.737 |
| 250 | 1.3947 | 1.006 | 159.6 | 11.44 | 22.3 | 15.9 | 0.720 |
| 300 | 1.1614 | 1.007 | 184.6 | 15.89 | 26.3 | 22.5 | 0.707 |
| 350 | 0.9950 | 1.009 | 208.2 | 20.92 | 30.0 | 29.9 | 0.700 |
| 400 | 0.8711 | 1.014 | 230.1 | 26.41 | 33.8 | 38.3 | 0.690 |
| 450 | 0.7740 | 1.021 | 250.7 | 32.39 | 37.3 | 47.2 | 0.686 |
| 500 | 0.6964 | 1.030 | 270.1 | 38.79 | 40.7 | 56.7 | 0.684 |
| 550 | 0.6329 | 1.040 | 288.4 | 45.57 | 43.9 | 66.7 | 0.683 |
| 600 | 0.5804 | 1.051 | 305.8 | 52.69 | 46.9 | 76.9 | 0.685 |
| 650 | 0.5356 | 1.063 | 322.5 | 60.21 | 49.7 | 87.3 | 0.690 |
| 700 | 0.4975 | 1.075 | 338.8 | 68.10 | 52.4 | 98.0 | 0.695 |
| 750 | 0.4643 | 1.087 | 354.6 | 76.37 | 54.9 | 109 | 0.702 |
| 800 | 0.4354 | 1.099 | 369.8 | 84.93 | 57.3 | 120 | 0.709 |
| 850 | 0.4097 | 1.110 | 384.3 | 93.80 | 59.6 | 131 | 0.716 |
| 900 | 0.3868 | 1.121 | 398.1 | 102.9 | 62.0 | 143 | 0.720 |
| 950 | 0.3666 | 1.131 | 411.3 | 112.2 | 64.3 | 155 | 0.723 |
| 1000 | 0.3482 | 1.141 | 424.4 | 121.9 | 66.7 | 168 | 0.726 |
| 1100 | 0.3166 | 1.159 | 449.0 | 141.8 | 71.5 | 195 | 0.728 |
| 1200 | 0.2902 | 1.175 | 473.0 | 162.9 | 76.3 | 224 | 0.728 |
| 1300 | 0.2679 | 1.189 | 496.0 | 185.1 | 82 | 238 | 0.719 |
| 1400 | 0.2488 | 1.207 | 530 | 213 | 91 | 303 | 0.703 |
| 1500 | 0.2322 | 1.230 | 557 | 240 | 100 | 350 | 0.685 |
| 1600 | 0.2177 | 1.248 | 584 | 268 | 106 | 390 | 0.688 |
| 1700 | 0.2049 | 1.267 | 611 | 298 | 113 | 435 | 0.685 |
| 1800 | 0.1935 | 1.286 | 637 | 329 | 120 | 482 | 0.683 |
| 1900 | 0.1833 | 1.307 | 663 | 362 | 128 | 534 | 0.677 |
| 2000 | 0.1741 | 1.337 | 689 | 396 | 137 | 589 | 0.672 |
| 2100 | 0.1658 | 1.372 | 715 | 431 | 147 | 646 | 0.667 |
| 2200 | 0.1582 | 1.417 | 740 | 468 | 160 | 714 | 0.655 |
| 2300 | 0.1513 | 1.478 | 766 | 506 | 175 | 783 | 0.647 |
| 2400 | 0.1448 | 1.558 | 792 | 547 | 196 | 869 | 0.630 |
| 2500 | 0.1389 | 1.665 | 818 | 589 | 222 | 960 | 0.613 |
| 3000 | 0.1135 | 2.726 | 955 | 841 | 486 | 1570 | 0.536 |
| **Ammonia ($NH_3$)** | | | | | | | |
| 300 | 0.6894 | 2.158 | 101.5 | 14.7 | 24.7 | 16.6 | 0.887 |
| 320 | 0.6448 | 2.170 | 109 | 16.9 | 27.2 | 19.4 | 0.870 |
| 340 | 0.6059 | 2.192 | 116.5 | 19.2 | 29.3 | 22.1 | 0.872 |
| 360 | 0.5716 | 2.221 | 124 | 21.7 | 31.6 | 24.9 | 0.872 |
| 380 | 0.5410 | 2.254 | 131 | 24.2 | 34.0 | 27.9 | 0.869 |

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 outer surface and the regulatory environments. Another convective surface is located on the side of the cask's outer 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 3-2 illustrates all components and interfaces of the thermal model.

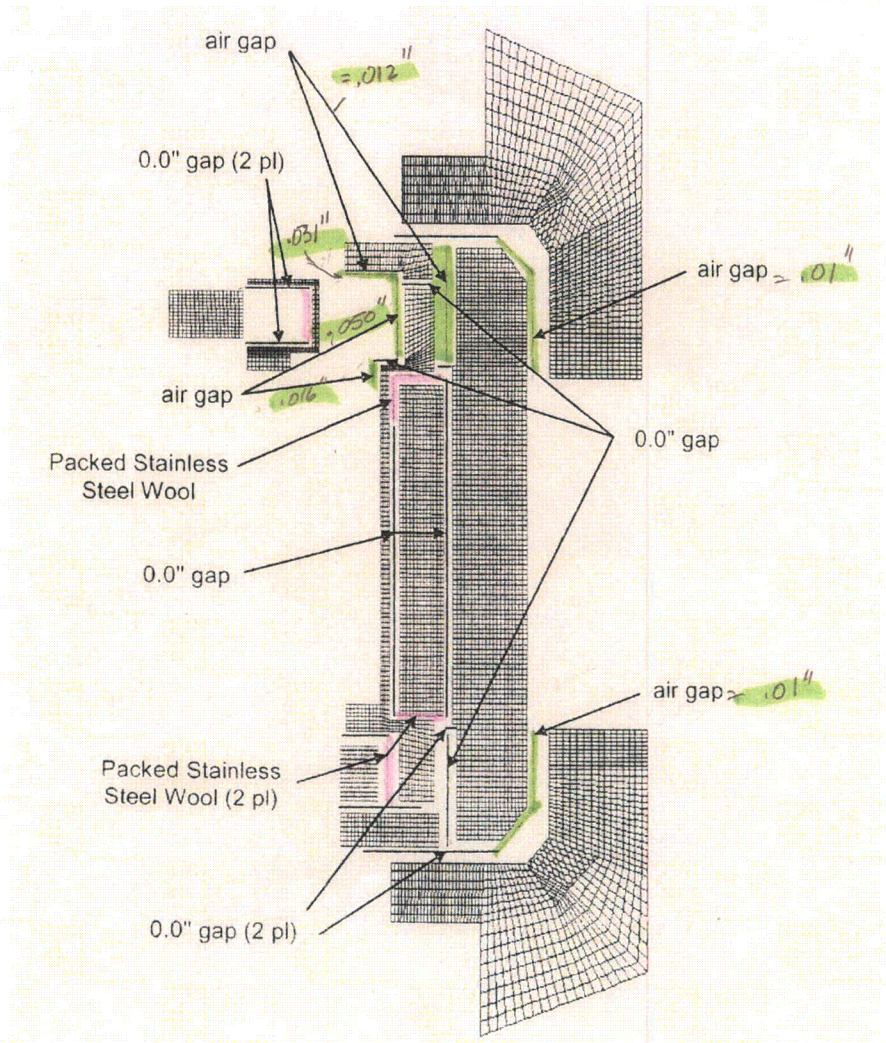
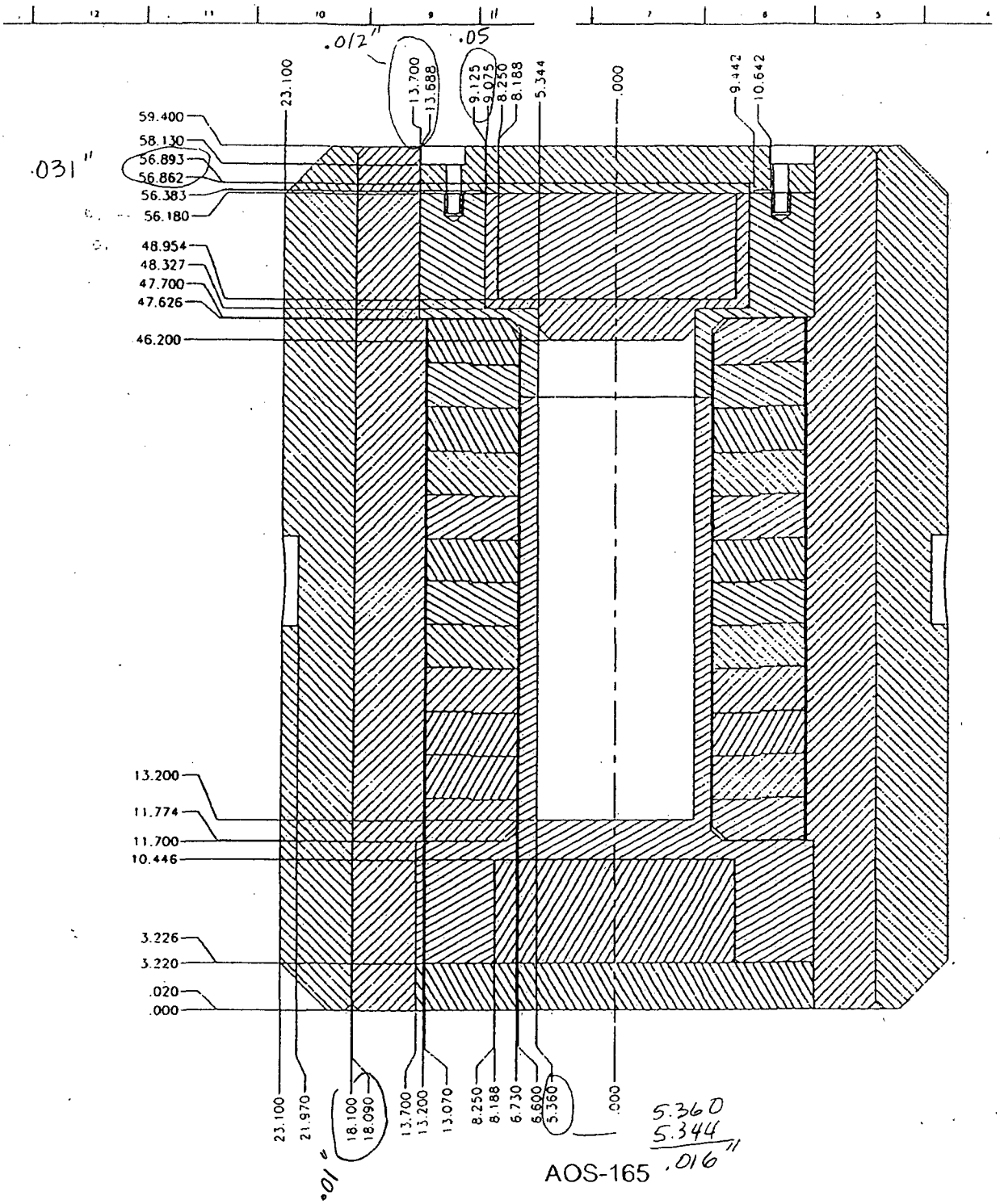



**Figure 3-2. Expanded View of Thermal Model Defining Component Interfaces**

## Size of Gap within Cask – Model AOS-165




AOS-165

# Port Seal

**Compound Data Sheet**
**Parker O-Ring Division United States**

# MATERIAL REPORT

REPORT NUMBER: KK2206
DATE: 06/19/96

**TITLE:** Evaluation of Parker Compound S1224-70 to ASTM D2000 7GE705 A19 B37 EA14 EO16 E036 F19 G11

**PURPOSE:** To determine if S1224-70 meets the callout.

**CONCLUSION:** Compound S1224-70 meets the ASTM D2000 callout.

Recommended temperature limits: -65$^0$F to 450$^0$F

Recommended For
Dry heat
Some petroleum oils
Moderate water resistance
Fire resistant hydraulic fluids (HFD-R and HFD-S)
Ozone, aging, and weather resistance
Low temperature

Not Recommended For
Ketones
Acids
Silicone oils
Auto and aircraft brake fluid

Parker O-Ring Division
2360 Palumbo Drive
Lexington, Kentucky 40509
(859) 269-2351

# Compound Data Sheet
**Parker O-Ring Division United States**

## REPORT DATA

| Report Number: | KK2206 |
|---|---|

| | ASTM D2000 **7GE705 A19 B37 EA14 EO16 E036 F19 G11** Pass / Fail Limits | **S1224-70** Slab Results |
|---|---|---|
| Basic Physical Properties | | |
| Hardness | 70 +/- 5 | 69 |
| Tensile Strength, psi min | 725 | 1204 |
| Elongation, % min | 150 | 265 |
| ASTM D573 Heat Aging, 70 HRS @ 225$^0$C | | |
| Hardness Change, pts max | +10 | +6 |
| Tensile Change, % max | -25 | -14 |
| Elongation Change, % max | -30 | -26 |
| Compression Set ASTM D395, 22 HRS @ 347$^0$F, plies | | |
| % of Original Deflection, max | 30 | 23 |
| Fluid Immersion, ASTM #1 Oil, 70 HRS @ 150$^0$C | | |
| Hardness Change, pts | 0 to -15 | -9 |
| Tensile Change, % max | -20 | +10 |
| Elongation Change, % max | -20 | +3 |
| Volume Change, % | 0 to +15 | +4 |
| Fluid Immersion, ASTM #3 Oil, 70 HRS @ 302$^0$F | | |
| Hardness Change, pts max | -40 | -19 |
| Volume Change, % max | +60 | +35 |
| Fluid Immersion ASTM D471 Water 70 HRS. @ 212$^0$F | | |
| Hardness Change, pts. max. | +/-5 | 0 |
| Volume Change, % max. | +/-5 | 0 |
| Tear Resistance, ASTM D624, Die B | | |
| kN/M, min | 9 | 14 |
| Low Temperature BrittlenessTest ASTM D2137, Method A | | |
| 3 min. @ -55$^0$C | Pass | Pass |

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# Lid Seal

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Our sales and engineering staff are focused on individual markets, not territories, to maintain expertise in a specific field. If you have questions or would like to discuss a specific application, please contact us at our world headquarters in Columbia, South Carolina (USA).

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**Design for Assembly**

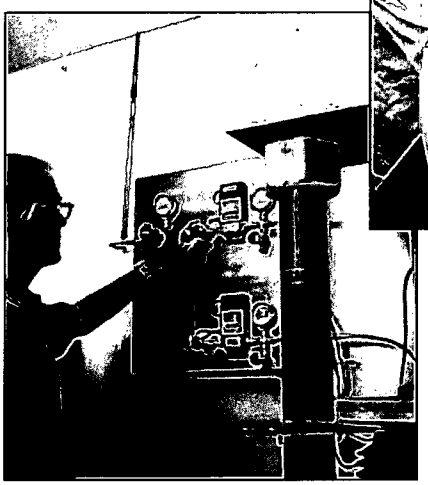
- 3D models of parts and assemblies produced in SolidWorks

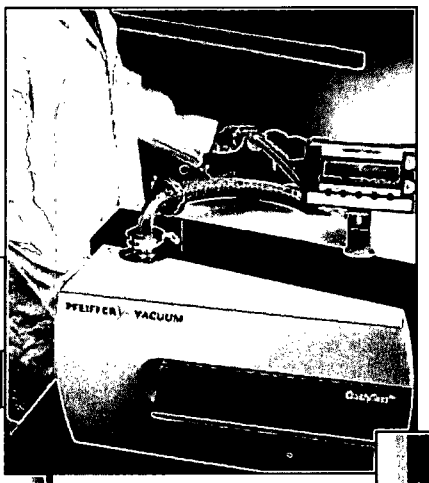
**ANSYS Computational Analysis**

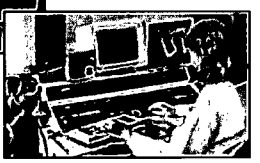
- Nonlinear mechanical behavior of metallic, elastomer and composite materials
- Contact stress evaluation
- Creep relaxation in joint assemblies
- Multi-axial fatigue
- Pressure and thermal effects

**Physical Testing**

- Compression load characterization
- Helium leakage
- Nitrogen leakage up to 4000 psi
- Thermal cycling from -70 to 200°C
- Seal characterization at temperatures up to 1200°C
- Cyclic durability







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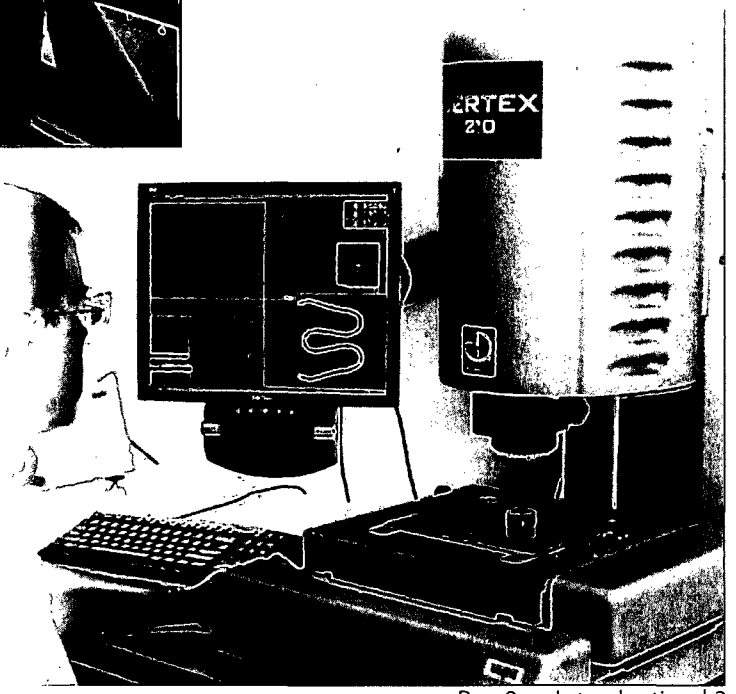
We perform Liquid Penetrant Inspection and Radiographic Examination to Section V of the ASME Boiler & Pressure Vessel Code.



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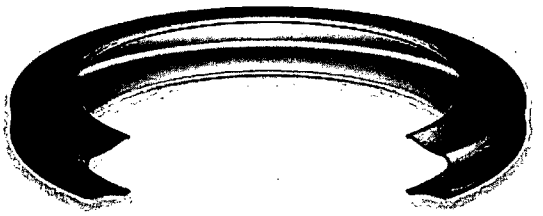

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1. Communication from ATI Firth Sterling to Alpha-Omega Services, Inc., and GE Energy.

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### 2.10.8 AOS Internet ftp Site

This appendix contains information related the LIBRA FEA Computer Program, the Post-Processors used in manipulating LIBRA output files. Almost the entire thermal and stress analyses in the SAR are based upon application of the Structural Mechanical Analysis, Inc. (SMA), LIBRA finite element program. The LIBRA program has been used by GE-Hitachi Nuclear Energy Americas, LLC ("GEH") for many years, and was used in the licensing of the GE Model 2000 Type B transport package. SMA has proprietorship of the LIBRA program; as a result, SMA was able to develop sophisticated post-processing tools integrated with the LIBRA program that facilitated the AOS analyses, to show compliance with the applicable regulatory requirements.

All files, including the LIBRA program, are located on an Internet ftp site, ftp.rjpsite.com.

Files and folders (of files) stored on this site can be downloaded to a personal computer, by executing the following protocol:

**ftp site address:** ftp.rjpsite.com

**user name:** rjpftp

**password:** *provided upon written request to AOS*

***Note:*** *The following instructions were written using Internet Explorer v6.0 on a computer running Windows XP, and a mouse with right- and left-clicking capability. Your method of access may be different.*

To copy data files or folders from the AOS ftp site, to your computer:

1. Access the ftp site.

   This can be done by entering **ftp.rjpsite.com** in the address field of Windows Explorer or any web browser.

2. When prompted, enter the user name and password, then click the button that allows you to proceed. (In Windows XP, the button is labeled **Log On**.)

3. Click **data**. The list expands to indicate the files and folders under the **data** folder.

   From here, file access works much like it does in your computer's folder system. You can click folders to open and see what files are stored in them.

4. To copy a file or folder to your computer, right-click the file or folder, then click **Copy To Folder...**.

5. When prompted, select the location in which to store the file or folder on your computer, then click **OK** to start the copy process.

***Note:*** *The download may take awhile, depending upon your Internet connection speed.*

6. To exit the ftp site, simply close the Explorer or browser window.

Figure 2-48 illustrates the rjpsite.com file structure.

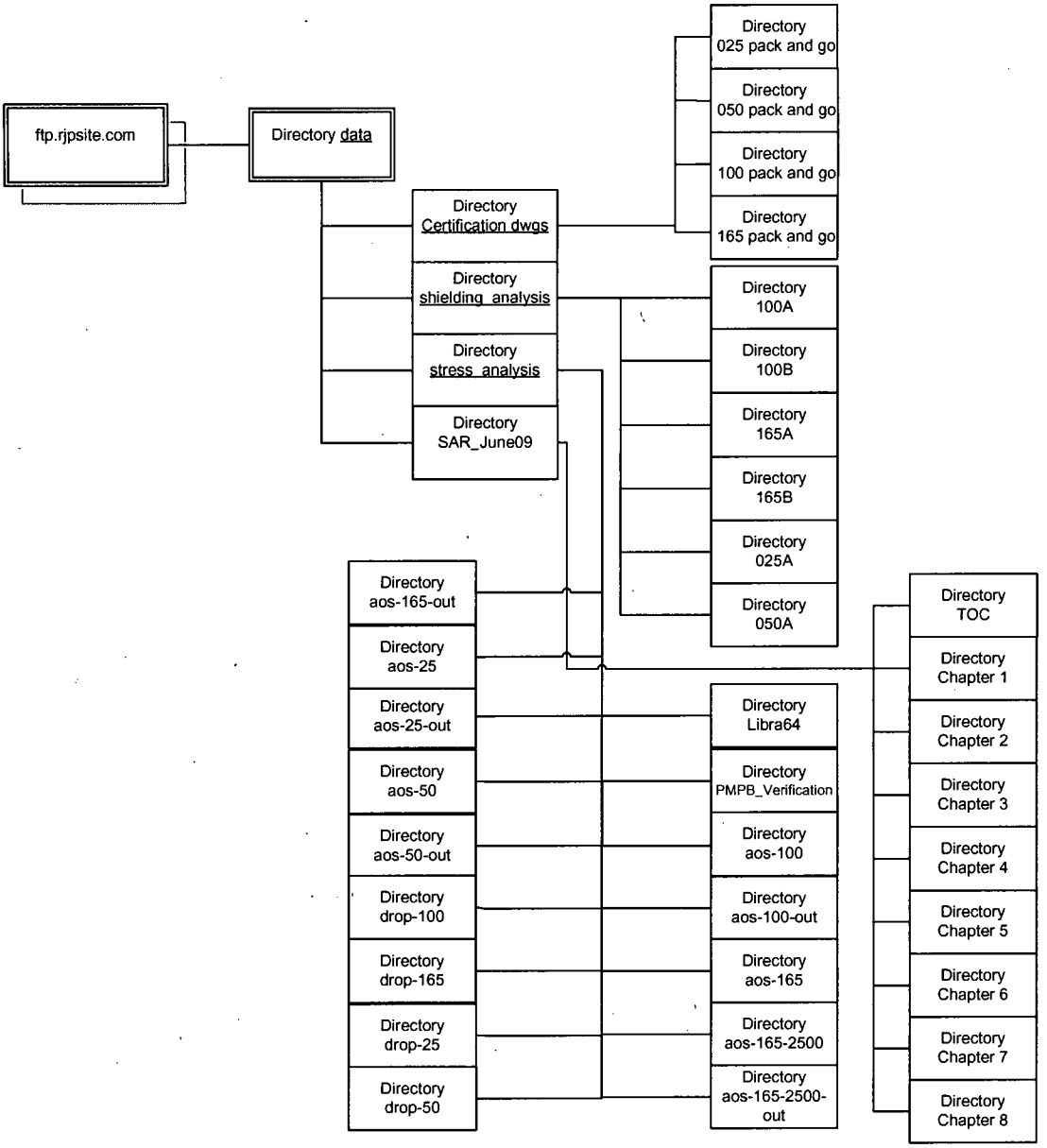


**Figure 2-48. rjpsite.com File Structure**

## 2.11 REFERENCES


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[2.3] U.S. NRC, *Regulatory Guide 7.6*, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Rev. 1, 1978.

[2.4] U.S. NRC, *Regulatory Guide 7.8*, "Load Combinations for the Structural Analysis of Shipping Casks," Table 10, Rev. 1, 1989.

[2.5] Holman, W. R. and R. T. Langland, *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick*, Lawrence Livermore Laboratory; Livermore, California; August, 1981; NUREG/CR-1815.

[2.6] ASME, *Boiler and Pressure Vessel Code*, Section II, Part D, 2001.

[2.7] Flügge, Wilhelm, Ed., *Handbook of Engineering Mechanics*, McGraw-Hill Higher Education, New York, 1962, pp. 44-40, Case 4.

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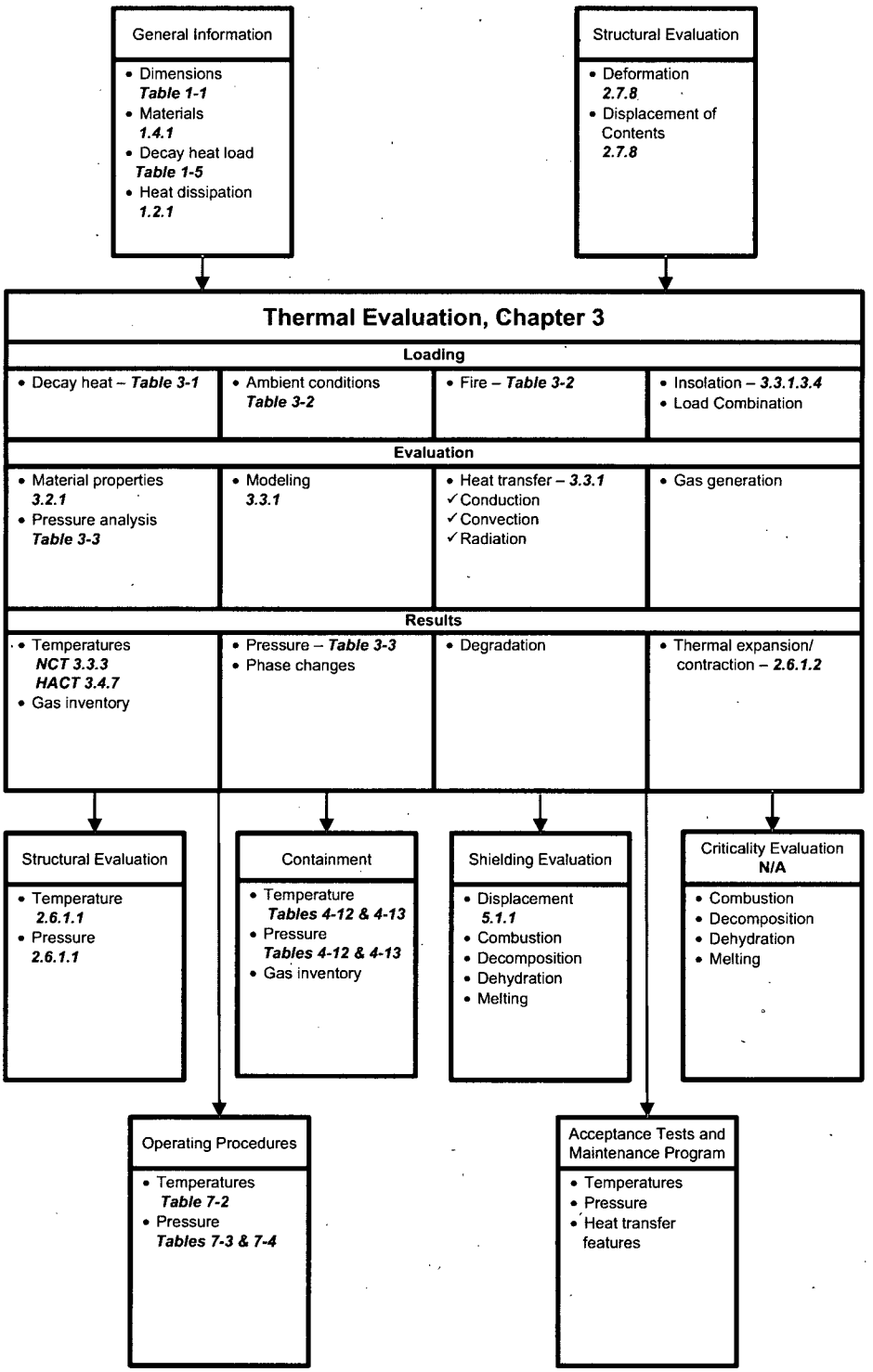
# 3 THERMAL EVALUATION



***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.

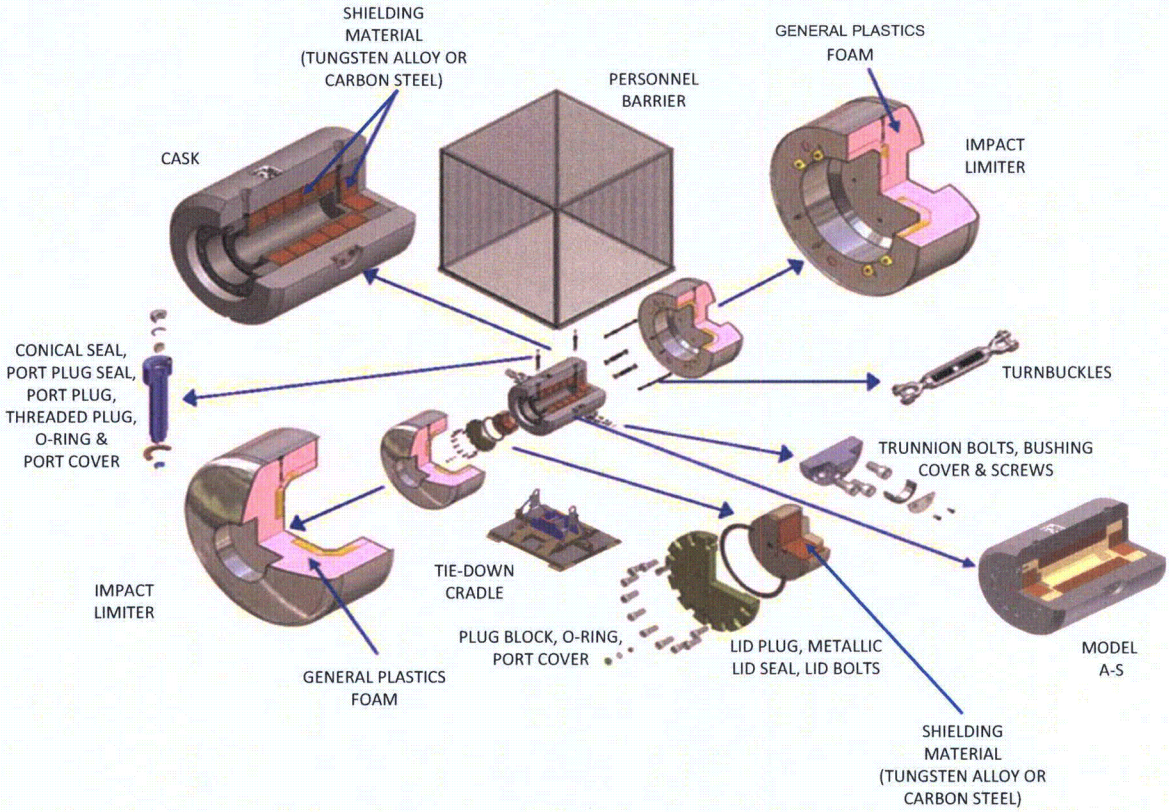



**Figure 3-1. Transport Package, Isometric View – Models AOS-100A and AOS-100A-S**

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 the maximum temperatures determined by each analyses within a regulatory environment, as well as each component's thermal criteria, for each AOS Transport Packaging System model.

**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[1], TBq / Ci | | Fissile Materials, U-235 eq/Bup/ Cool | Decay Heat, Watts | Packaging[2] | 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 |

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

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

**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 Cavity Pressure Due to Normal Conditions of Transport – All Models**

| Model | Volume | | Temperature (T)[1] | | Pressure (P)[2] | | | Design Pressure[3] | |
|---|---|---|---|---|---|---|---|---|---|
| | l | in$^3$ | °C | °F | kPa | psia | | kPa | psia |
| AOS-025 | 0.17 | 10 | 60 | 141 | 143 | 16 | < | 207 | 30 |
| AOS-050 | 1.36 | 83 | 92 | 198 | 134 | 18 | < | 414 | 60 |
| AOS-100A<br>AOS-100A-S | 11.21 | 684 | 90 | 195 | 137 | 22 | < | 1,931 | 280 |
| AOS-100B | 11.21 | 684 | 90 | 195 | 137 | 22 | < | 1,931 | 280 |
| AOS-165A | 49 | 2,978 | 344 | 652 | 224 | 30 | < | 1,517 | 220 |
| AOS-165B | 49 | 2,978 | 172 | 341 | 224 | 30 | < | 1,517 | 220 |

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

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

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

**Initial Condition**

$P_1$ = 30 psia

$T_1$ = 78°F

**Final Condition**

$P_2$ = ?

$T_2$ = 256°F

$$P_2 = \frac{(256 + 460)}{(78 + 460)} * 14.7 = 21 \text{ psia}$$

*3. **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 | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-025A | Cask Cavity | 99 | 210 | 60 | 141 | 149 | 300 | -15 | 5 | -40 | -40 | -4 | 24 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 98 | 209 | 60 | 140 | 149 | 299 | -16 | 3 | -40 | -40 | -5 | 23 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 98 | 208 | 59 | 139 | 149 | 300 | -16 | 3 | -40 | -40 | -5 | 22 | -29 | -20 | 427°C (800°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) |
| | Overpack Inside Surface | 98 | 208 | 59 | 139 | 214 | 417 | -16 | 2 | -40 | -40 | -6 | 22 | -29 | -20 | 400°C (752°F) |
| | Overpack Accessible Outside Surface[3] | 87 | 188 | 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 |

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

| Model | Component | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 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 | 427°C (800°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 |
| | Overpack Inside Surface | 124 | 255 | 88 | 190 | 289 | 553 | 14 | 57 | -40 | -40 | 24 | 76 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[3] | 96 | 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 |

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

| Model | Component | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 4 | | 5 | | 6 | | 7 | | |
| | | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | °C | °F | |
| AOS-100A, AOS-100A-S | Cask Cavity | 126 | 258 | 90 | 195 | 185 | 365 | 12 | 54 | -40 | -40 | 25 | 78 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 121 | 250 | 86 | 186 | 204 | 400 | 8 | 46 | -40 | -40 | 21 | 69 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 118 | 245 | 82 | 180 | 185 | 365 | 4 | 39 | -40 | -40 | 17 | 63 | -29 | -20 | 427°C (800°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 |
| | Overpack Inside Surface | 119 | 246 | 83 | 182 | 618 | 1,145 | 5 | 40 | -40 | -40 | 118 | 64 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[3] | 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 |

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

| Model | Component | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 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 | 198 | 388 | 12 | 54 | -40 | -40 | 25 | 78 | -29 | -20 | 400°C (752°F) |
| | Shielding Material | 122 | 251 | 86 | 187 | 207 | 404 | 8 | 46 | -40 | -40 | 21 | 70 | -29 | -20 | 400°C (752°F) |
| | Cask Seal Area | 118 | 245 | 82 | 180 | 172 | 342 | 4 | 39 | -40 | -40 | 17 | 63 | -29 | -20 | 427°C (800°F) Metallic Seal |
| | Cask Test Port | 116 | 241 | 81 | 177 | 173 | 343 | 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 | 172 | 341 | 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 |
| | Overpack Inside Surface | 119 | 246 | 83 | 182 | 618 | 1,145 | 5 | 40 | -40 | -40 | 18 | 64 | -29 | -20 | 400°C (752°F) Conditions 1 and 2 |
| | Overpack Accessible Outside Surface[3] | 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 |

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

| Model | Component | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 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[3] | 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 |

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

| Model | Component | Thermal Temperatures, by Condition | | | | | | | | | | | | | | Regulatory/Component Criteria[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3[2] | | 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[3] | 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 |

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

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

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

## 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.

### 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."*

### 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)

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

### 3.2.1.3 Carbon Steel

Table 3-6 lists the thermophysical properties of carbon steel (~ 0.5% carbon), as they apply to the transport packages **[3.13]**. Figure 3-2 illustrates carbon steel's conductivity versus temperature, for the Model AOS-100B.

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

| Property | @ 20°C | Temperature (°F) | Conductivity | | |
|---|---|---|---|---|---|
| | | | Btu/hr-ft-F | Btu/hr-in-F | K (W/m-C) |
| Density | 7,833 kg/m$^3$ | -32 | 31.779 | 2.648 | 550 |
| | 489.0 lb/ft$^3$ | 212 | 30.046 | 2.504 | 520 |
| | 0.283 lb/in$^3$ | 392 | 27.734 | 2.311 | 480 |
| Specific Heat (Cp) | 0.465 KJ/kg°C | 572 | 26.001 | 2.167 | 450 |
| | 0.222 Btu/lb | 752 | 24.268 | 2.022 | 420 |
| Thermal Differential | 1.474E-5 m$^2$/s | 1,112 | 20.223 | 1.685 | 350 |

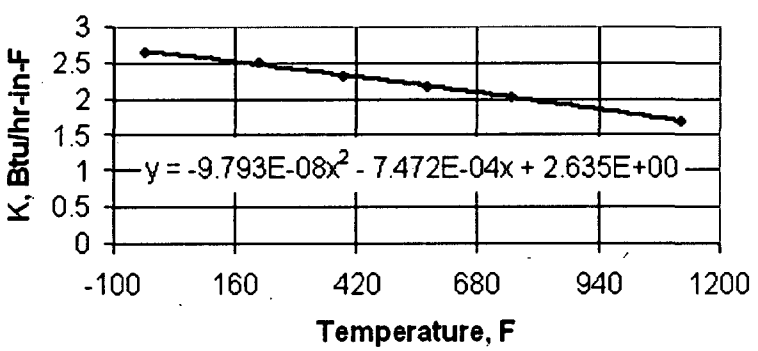



**Figure 3-2. Carbon Steel Conductivity (~ 0.5% Carbon) versus Temperature – Model AOS-100B**

### 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.

**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 |

### 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

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

### 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.

## 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

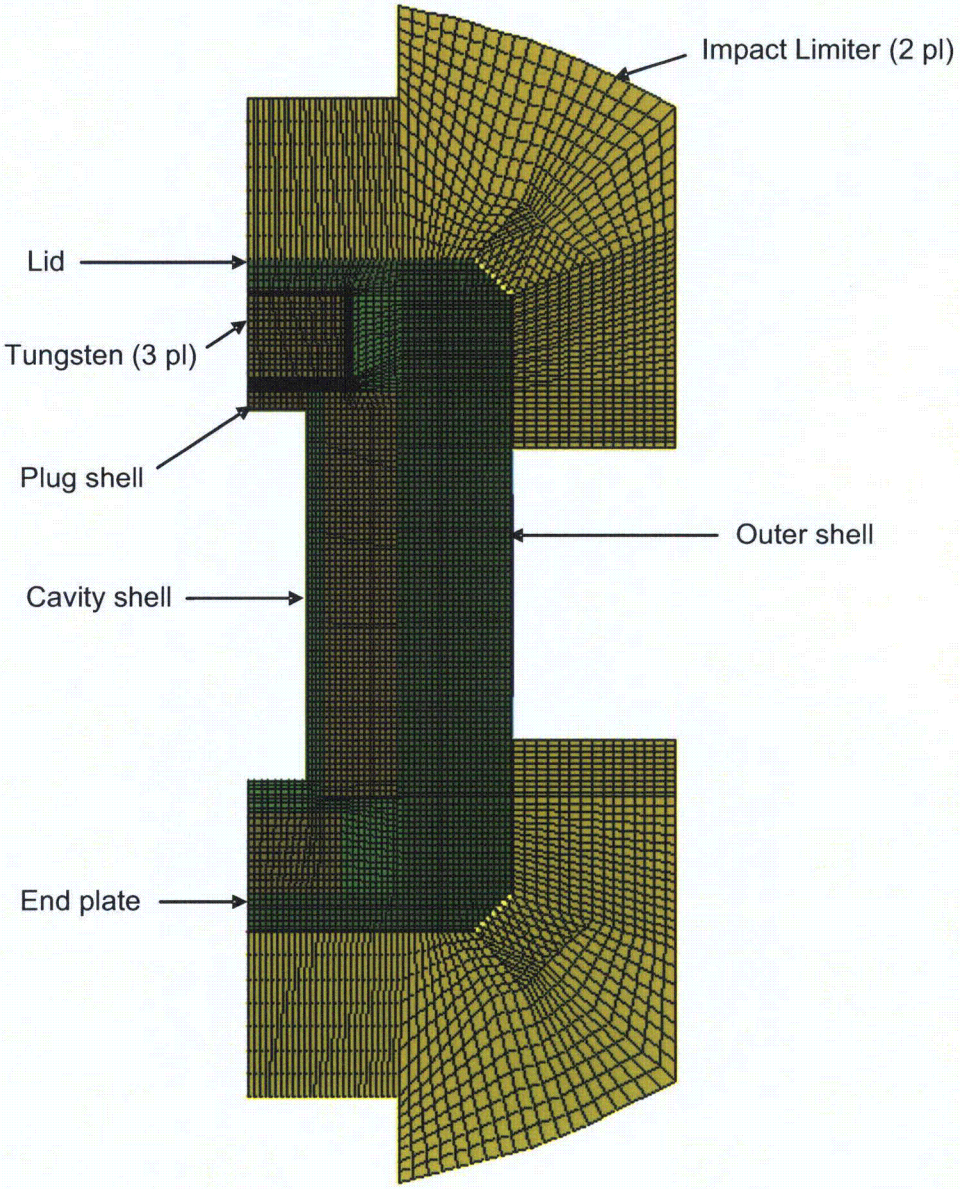



**Figure 3-3. Thermal Finite Element Model – Normal Conditions of Transport**

### 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.)

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.

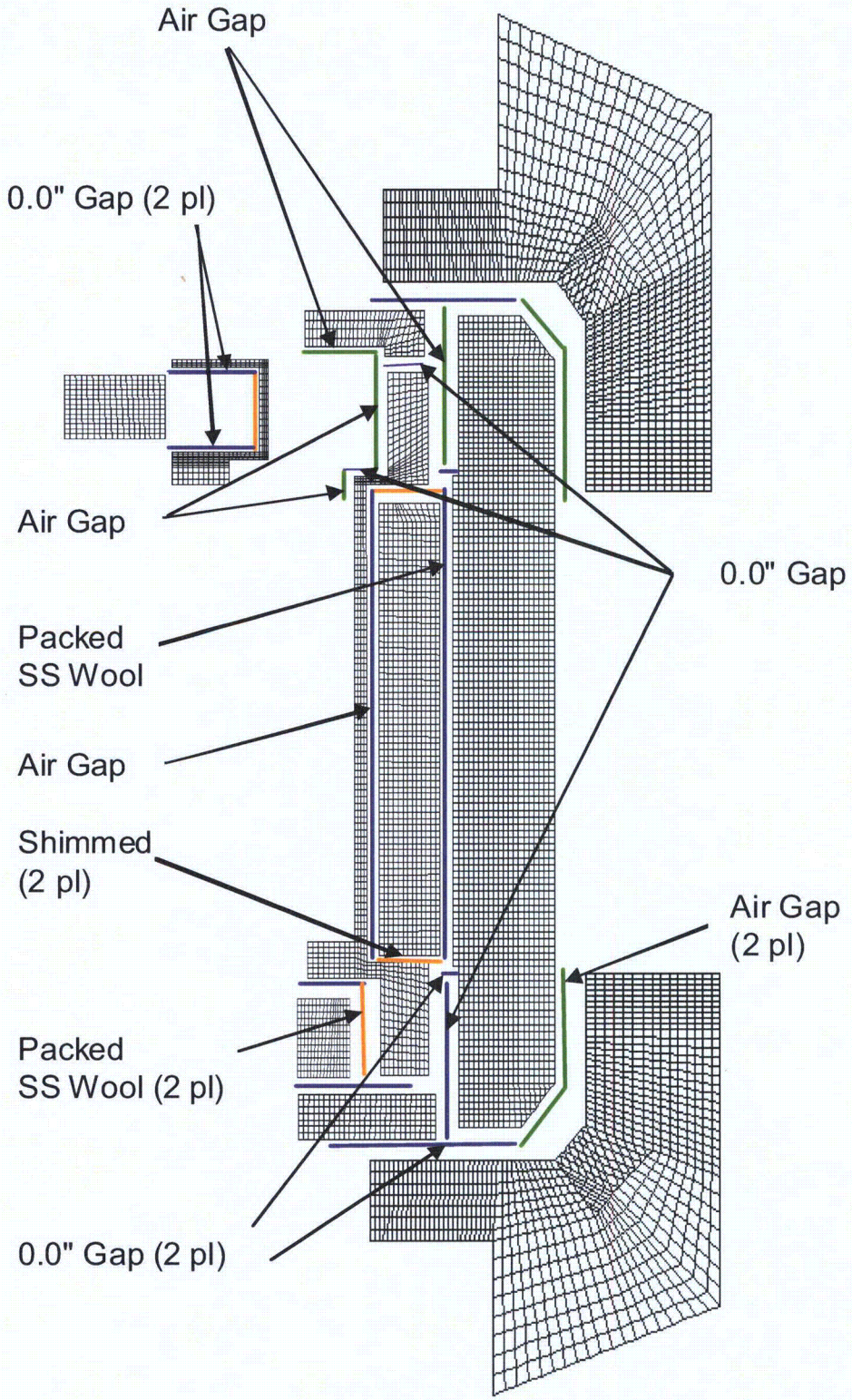



**Figure 3-4. Expanded View of Thermal Model Defining Component Interfaces**

### 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:

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

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

### 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

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.

**Table 3-11. Correlation Applicable to Vertical Air Gap Geometries – Model AOS-165[1]**

| 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 |

1. *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.

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

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.

**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)[1] |
| 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 | $1.458E-3 + 1.346E-6T + 6.437E-10T^2$ |
| | 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 | $1.684E-3 + 7.550E-7T + 7.256E-9T^2$ |

*1. Temperature unit is °F.*

### 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.)

**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 |

**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 |

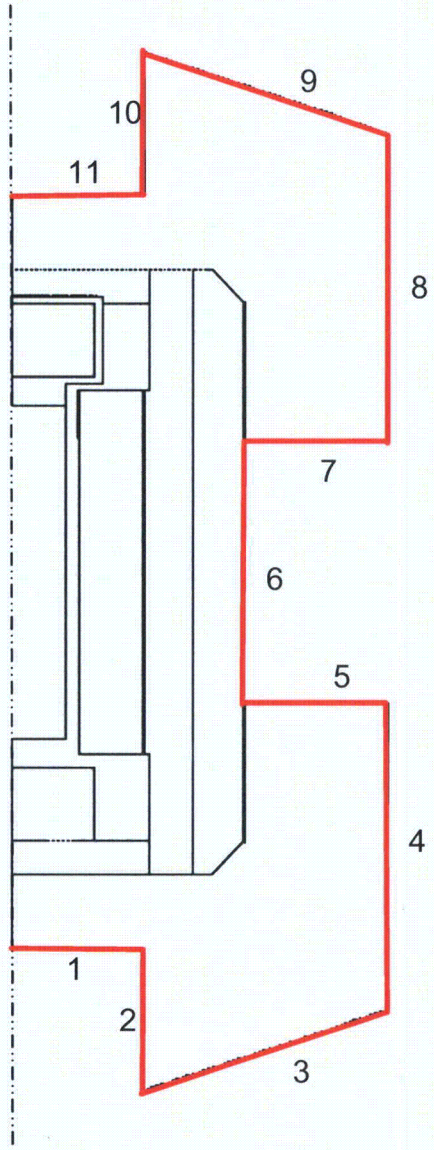



**Figure 3-5. Cask Assembly External Surface Identification**

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.

**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 |

**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 | 9.808E-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 | 9.808E-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 | 1.116E-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 |

**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 |

**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 |

**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 |

**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 |

#### 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:

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

### 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 |

### 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 minimum 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 |

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 |

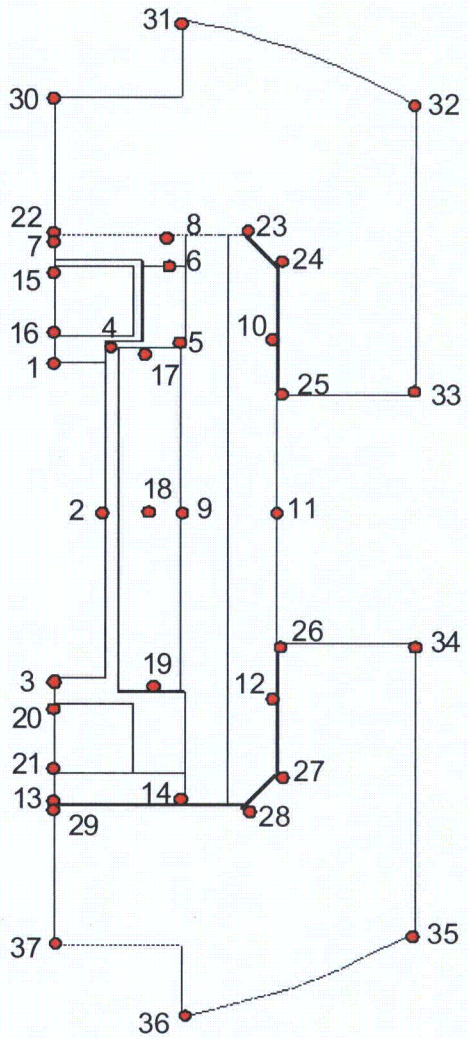



**Figure 3-6. Selected Nodal Locations for Normal Conditions of Transport – Models AOS-100**

**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 |

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 |

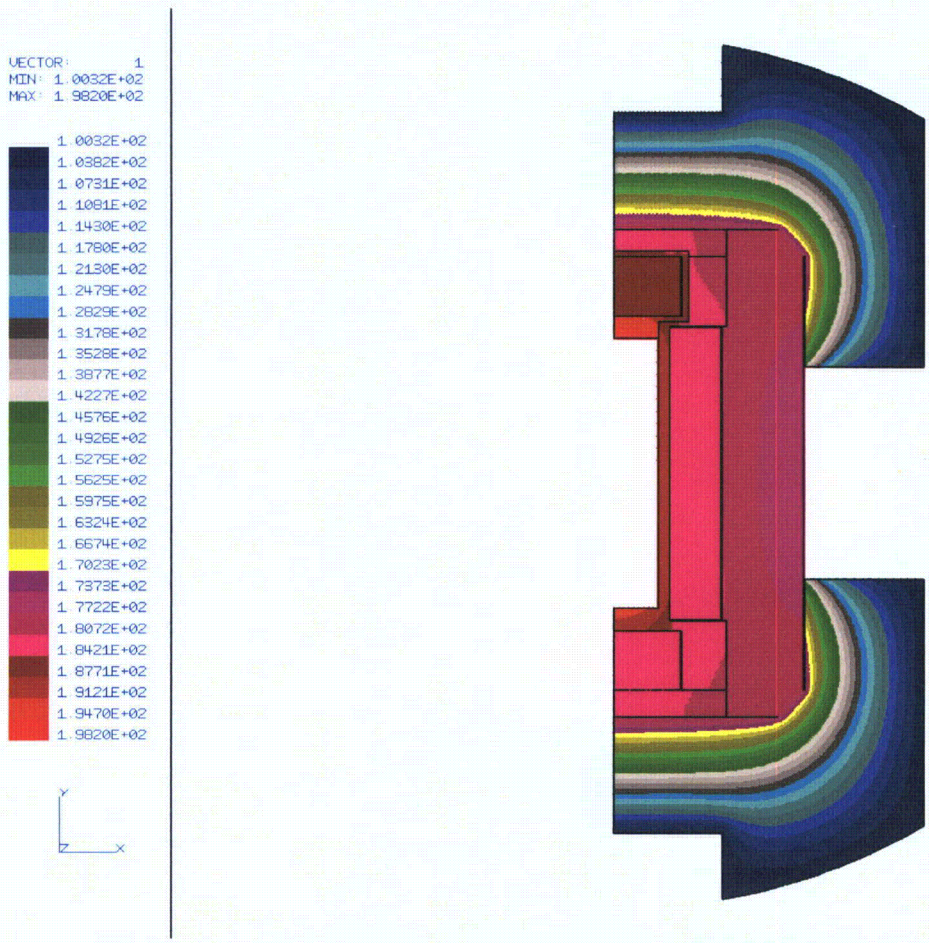



**Figure 3-7. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

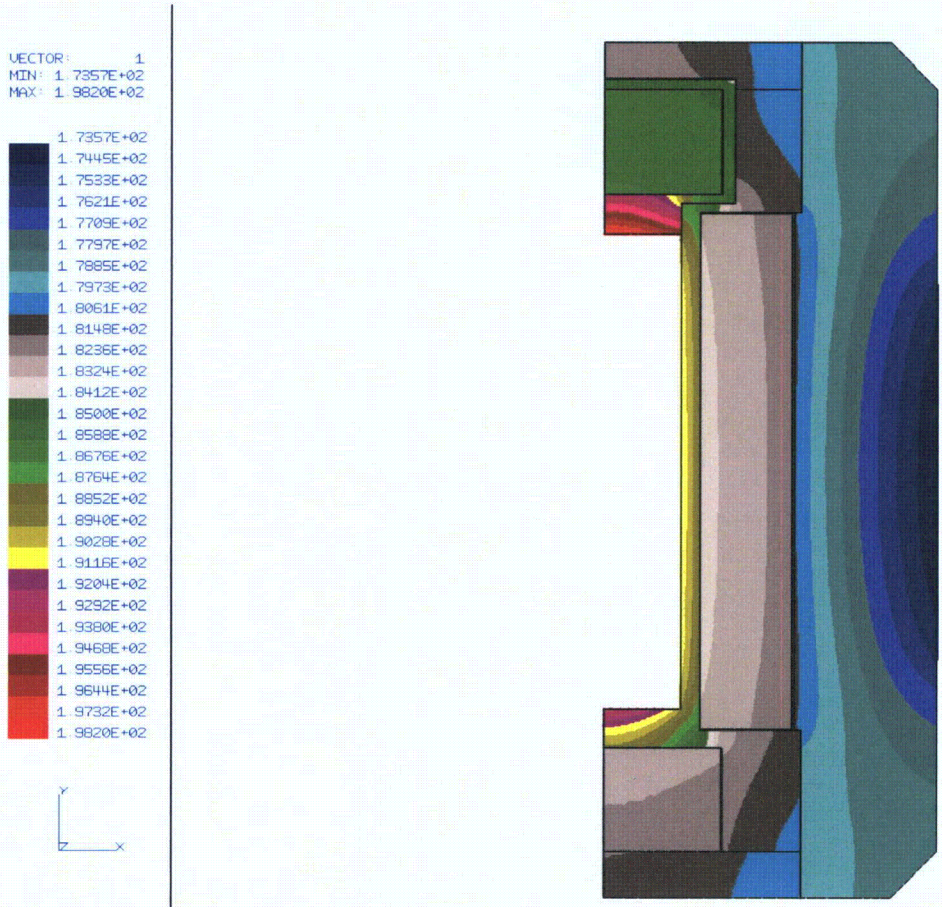



**Figure 3-8. Load Case 101 – 100°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

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

| 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 |

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 |

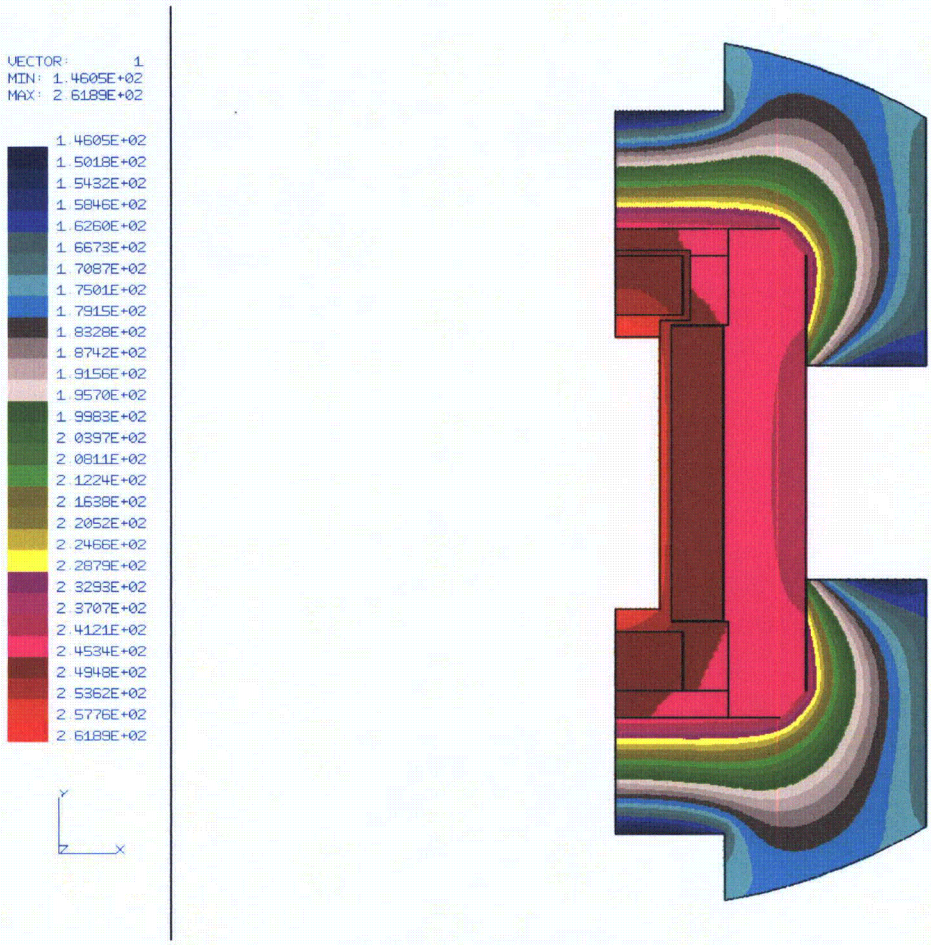



**Figure 3-9. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

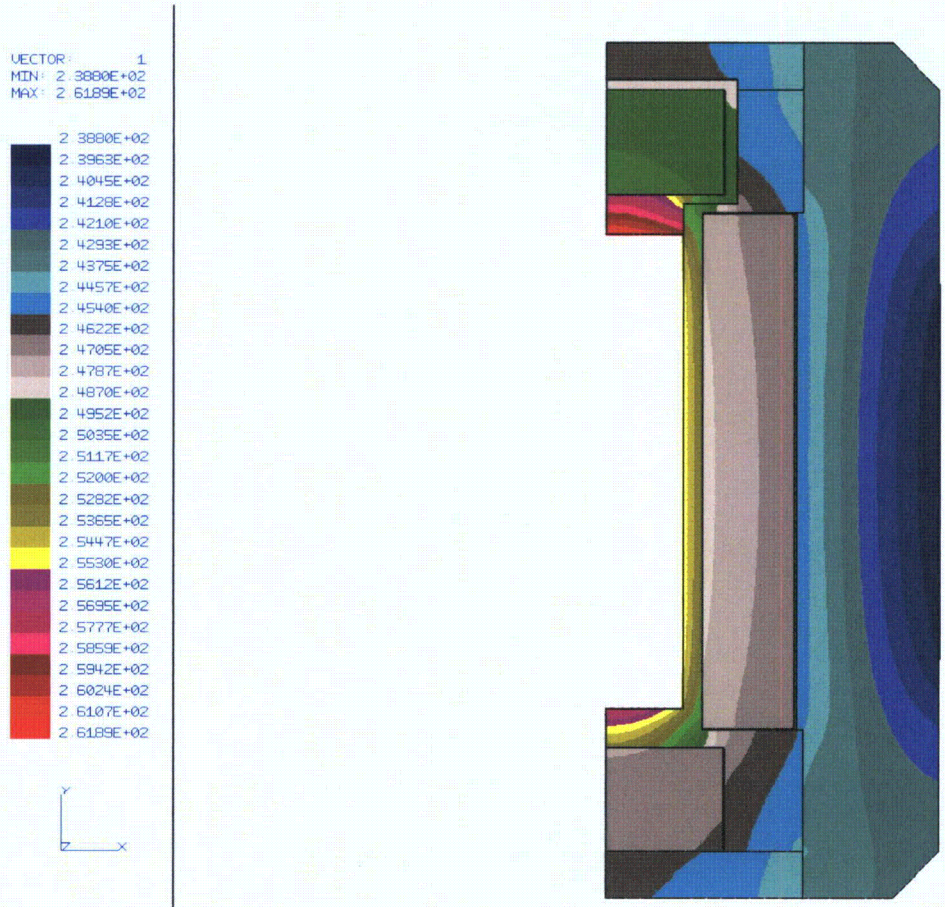



**Figure 3-10. Load Case 102 – 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-100**

**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 |

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 |

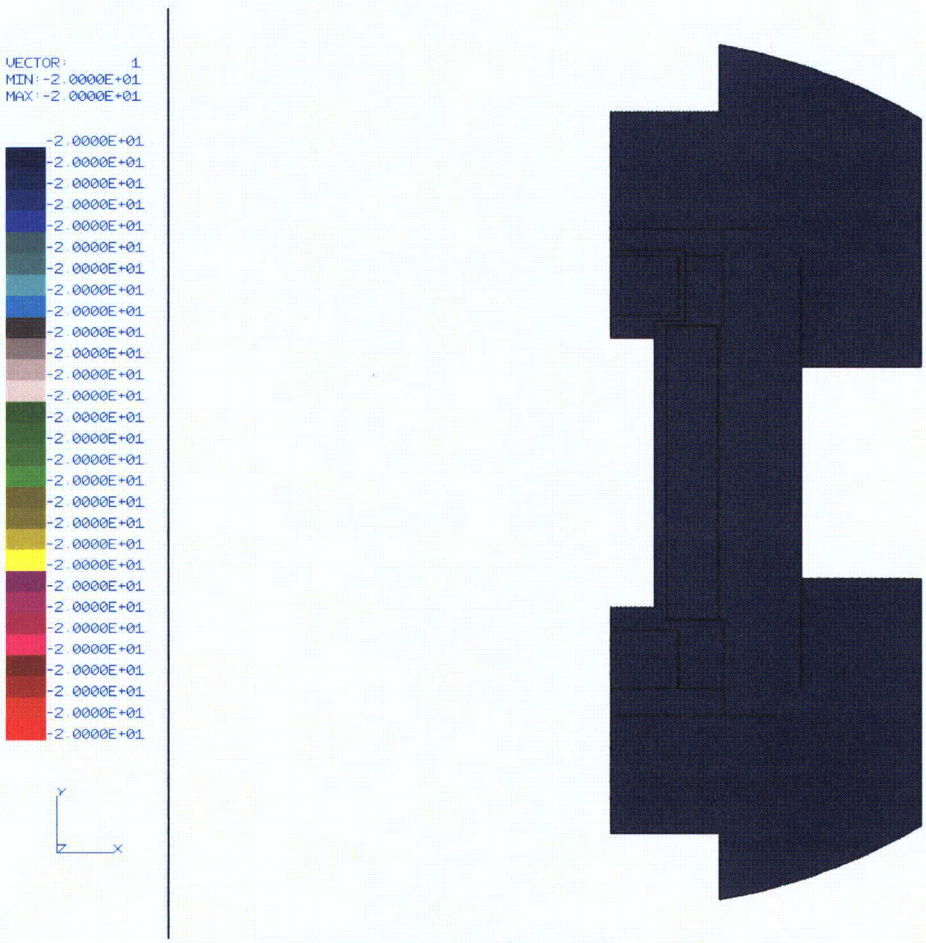



**Figure 3-11. Load Case 103 – -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

**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 |

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 |

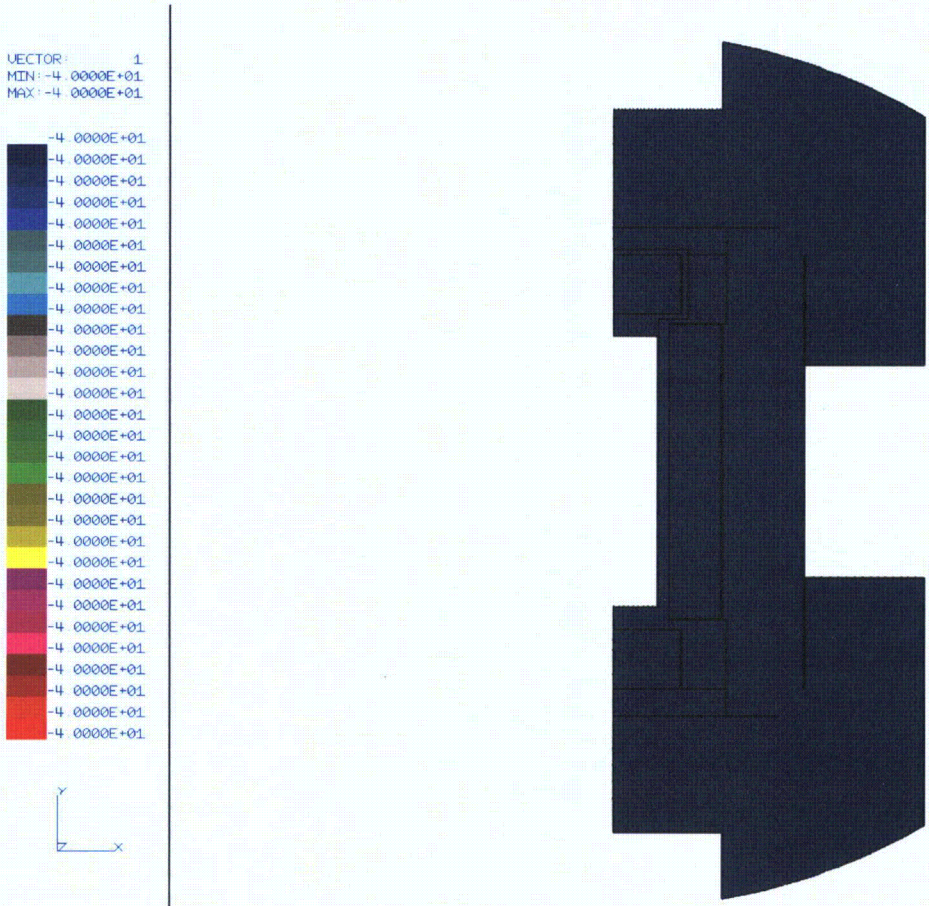



**Figure 3-12. Load Case 104 – -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

**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 |

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 |

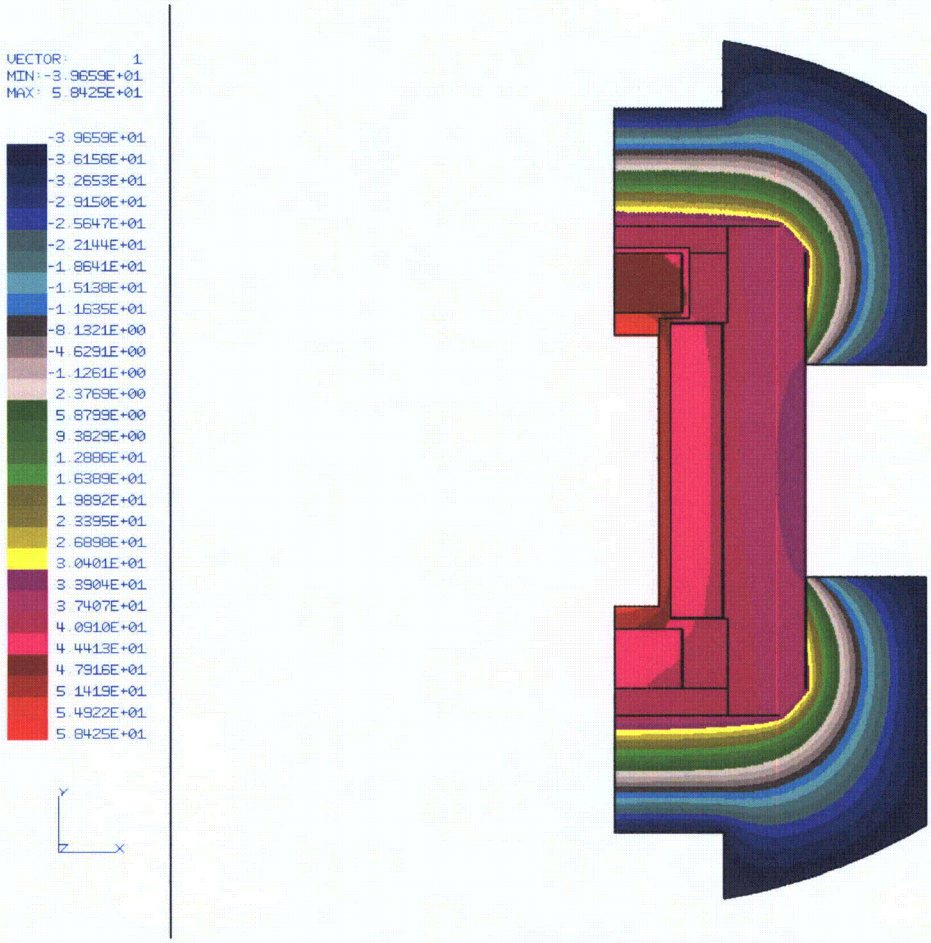



**Figure 3-13. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

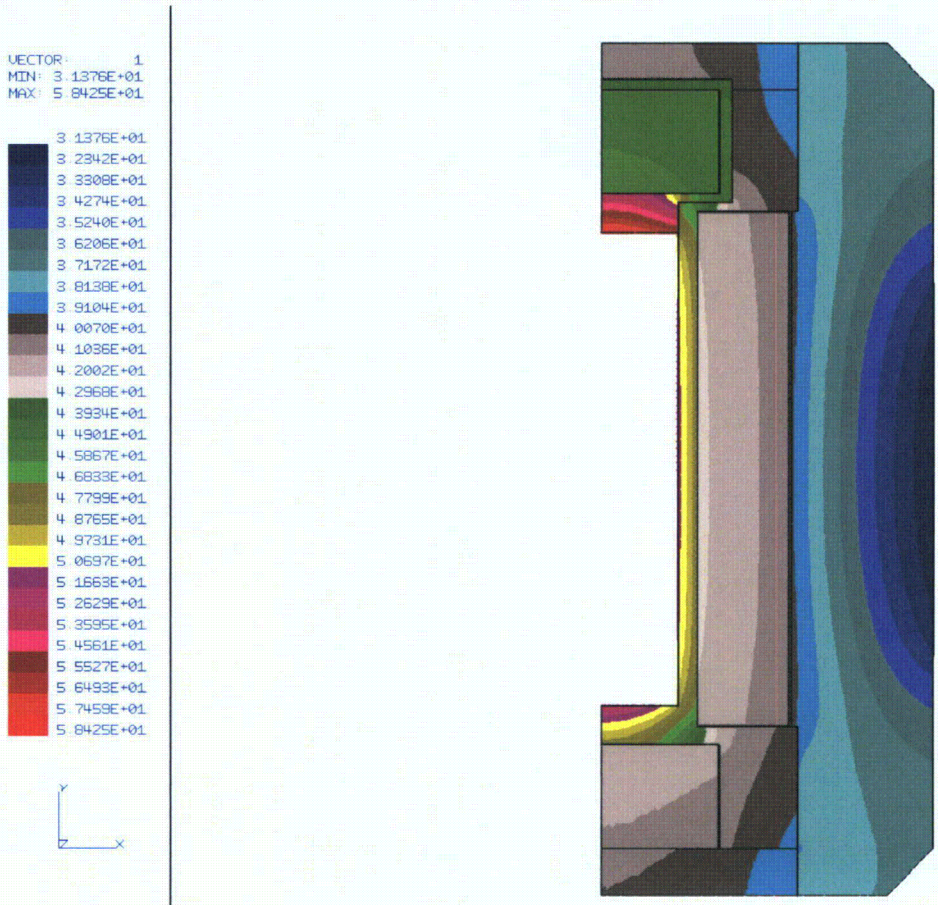



**Figure 3-14. Load Case 105 – -40°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 |

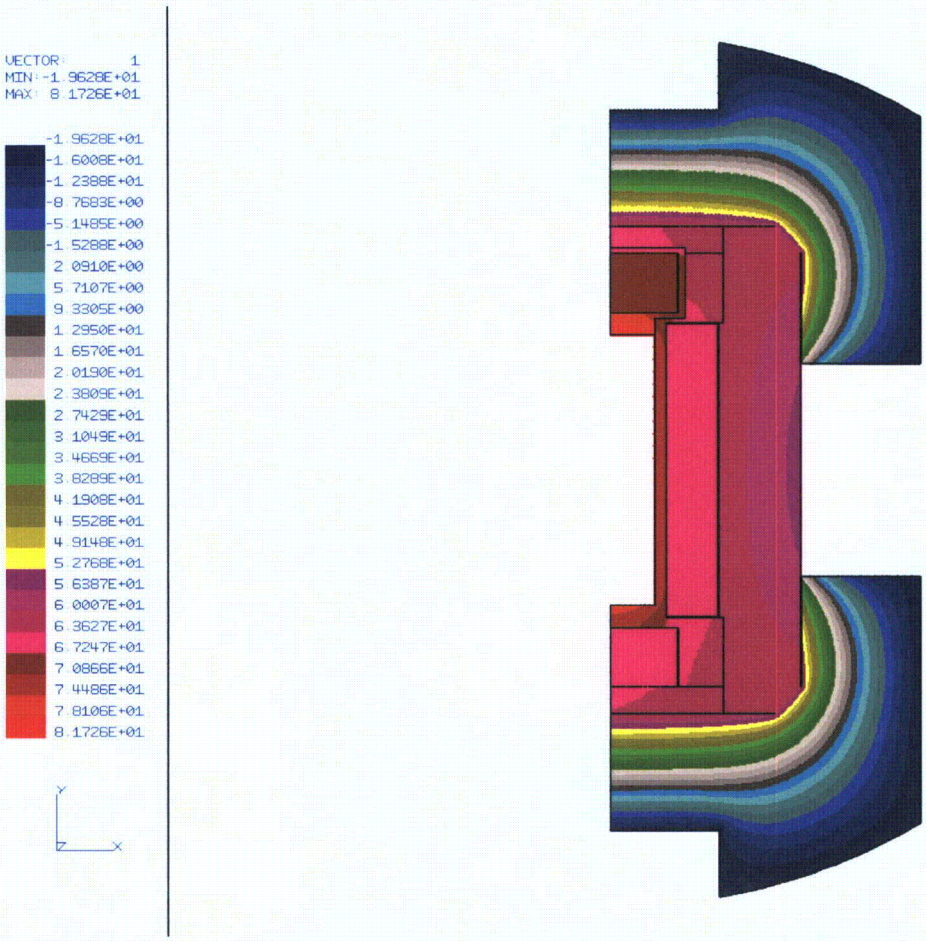



**Figure 3-15. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

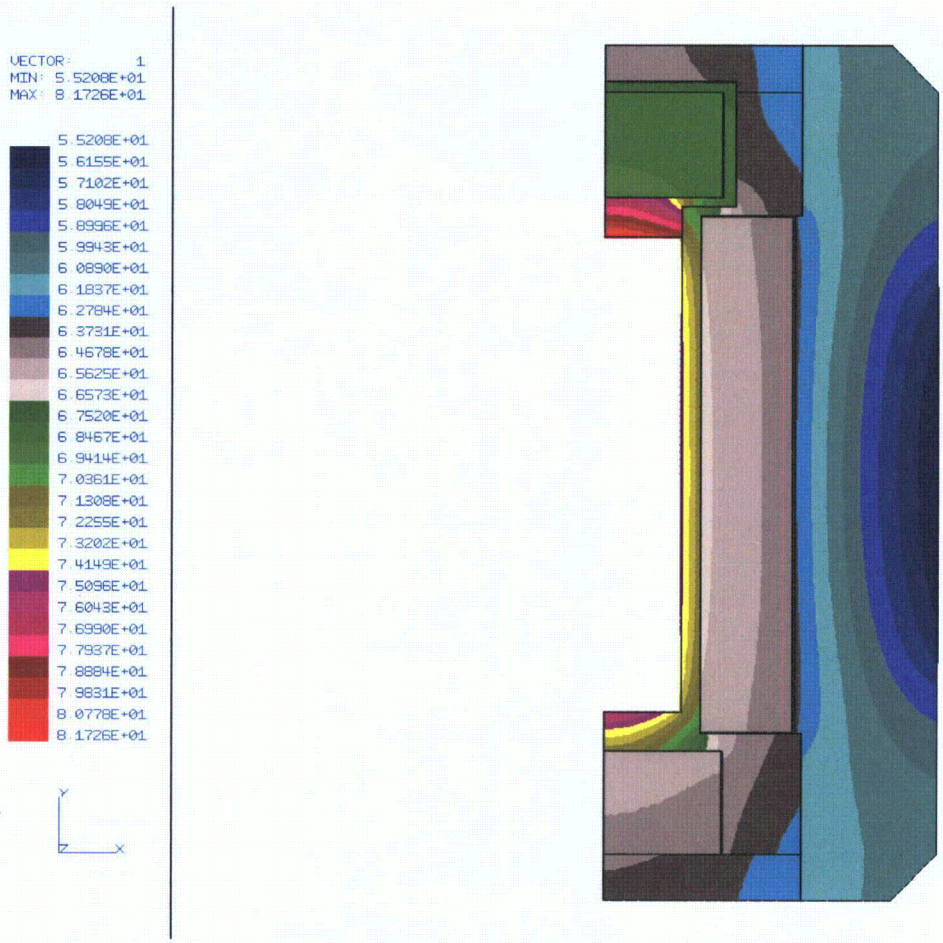



**Figure 3-16. Load Case 106 – -20°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

### 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 minimum 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 |
|---|---|---|
| 101 | 100°F Ambient, Carbon Steel Shielding, Maximum Decay Heat | Table 3-27 |
| 102 | 100°F Ambient, Carbon Steel Shielding, Maximum Decay Heat, Maximum Insolation | Table 3-28 |
| 103 | -20°F Ambient, Carbon Steel Shielding, Zero Decay Heat, Zero Insolation | Table 3-29 |
| 104 | -40°F Ambient, Carbon Steel Shielding, Zero Decay Heat, Zero Insolation | Table 3-30 |
| 105 | -40°F Ambient, Carbon Steel Shielding, Maximum Decay Heat | Table 3-31 |
| 106 | -20°F Ambient, Carbon Steel Shielding, Maximum Decay Heat | Table 3-32 |

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

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 92.61 | 198.70 |
| 2 | 4532 | 88.83 | 191.90 |
| 3 | 4227 | 90.33 | 194.60 |
| 4 | 4752 | 86.89 | 188.40 |
| 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 | 86.06 | 186.90 |
| 17 | 7371 | 83.72 | 182.70 |
| 18 | 6942 | 83.94 | 183.10 |
| 19 | 6267 | 83.72 | 182.70 |
| 20 | 6121 | 84.22 | 183.60 |
| 21 | 6001 | 83.50 | 182.30 |
| 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 |

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 620 | 8.2722E+01 | 1.8090E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 8.3167E+01 | 1.8170E+02 |
| Lid | 3233 | 3424 | 3233 | 8.3444E+01 | 1.8220E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 9.0333E+01 | 1.9460E+02 |
| Plug | 5001 | 5404 | 5001 | 9.2611E+01 | 1.9870E+02 |
| Carbon Steel | 6001 | 7656 | 7377 | 8.6056E+01 | 1.8690E+02 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 8.3167E+01 | 1.8170E+02 |

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

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 128.00 | 262.40 |
| 2 | 4532 | 124.44 | 256.00 |
| 3 | 4227 | 125.89 | 258.60 |
| 4 | 4752 | 122.50 | 252.50 |
| 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 | 121.61 | 250.90 |
| 17 | 7371 | 119.50 | 247.10 |
| 18 | 6942 | 119.83 | 247.70 |
| 19 | 6267 | 119.50 | 247.10 |
| 20 | 6121 | 119.89 | 247.80 |
| 21 | 6001 | 119.17 | 246.50 |
| 22 | 9501 | 118.83 | 245.90 |
| 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 |

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 624 | 1.1850E+02 | 2.4530E+02 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.1883E+02 | 2.4590E+02 |
| Lid | 3233 | 3424 | 3233 | 1.1906E+02 | 2.4630E+02 |
| Shell Cavity | 4001 | 4998 | 4227 | 1.2589E+02 | 2.5860E+02 |
| Plug | 5001 | 5404 | 5001 | 1.2800E+02 | 2.6240E+02 |
| Carbon Steel | 6001 | 7656 | 7377 | 1.2161E+02 | 2.5090E+02 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 1.1883E+02 | 2.4590E+02 |

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

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 |
| Carbon Steel | 6001 | 7656 | 6001 | -2.8889E+01 | -2.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -2.8889E+01 | -2.0000E+01 |

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

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 |
| Carbon Steel | 6001 | 7656 | 6001 | -4.0000E+01 | -4.0000E+01 |
| LAST-A-FOAM | 8001 | 10791 | 8001 | -4.0000E+01 | -4.0000E+01 |

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

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 14.92 | 58.85 |
| 2 | 4532 | 10.95 | 51.71 |
| 3 | 4227 | 12.37 | 54.27 |
| 4 | 4752 | 8.70 | 47.66 |
| 5 | 4838 | 4.17 | 39.50 |
| 6 | 4995 | 3.92 | 39.06 |
| 7 | 3309 | 4.78 | 40.61 |
| 8 | 3419 | 3.91 | 39.03 |
| 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 | 4.49 | 40.08 |
| 14 | 3148 | 3.47 | 38.24 |
| 15 | 7533 | 7.07 | 44.72 |
| 16 | 7377 | 7.92 | 46.26 |
| 17 | 7371 | 5.19 | 41.35 |
| 18 | 6942 | 5.36 | 41.64 |
| 19 | 6267 | 5.17 | 41.30 |
| 20 | 6121 | 5.77 | 42.38 |
| 21 | 6001 | 5.03 | 41.05 |
| 22 | 9501 | 4.72 | 40.49 |
| 23 | 9950 | 2.44 | 36.39 |
| 24 | 10014 | 1.04 | 33.87 |
| 25 | 10781 | -18.40 | -1.13 |
| 26 | 9091 | -18.50 | -1.30 |
| 27 | 8463 | 0.87 | 33.56 |
| 28 | 8462 | 2.55 | 36.59 |
| 29 | 8197 | 4.43 | 39.97 |
| 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 |

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 | 4.7000E+00 | 4.0460E+01 |
| Lid | 3233 | 3424 | 3233 | 4.9778E+00 | 4.0960E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 1.2372E+01 | 5.4270E+01 |
| Plug | 5001 | 5404 | 5001 | 1.4917E+01 | 5.8850E+01 |
| Carbon Steel | 6001 | 7656 | 7377 | 7.9222E+00 | 4.6260E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 4.7167E+00 | 4.0490E+01 |

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

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 27.87 | 82.16 |
| 2 | 4532 | 23.94 | 75.10 |
| 3 | 4227 | 25.38 | 77.68 |
| 4 | 4752 | 21.74 | 71.13 |
| 5 | 4838 | 17.27 | 63.08 |
| 6 | 4995 | 17.01 | 62.62 |
| 7 | 3309 | 17.86 | 64.15 |
| 8 | 3419 | 16.99 | 62.59 |
| 9 | 678 | 17.16 | 62.89 |
| 10 | 2537 | 15.13 | 59.24 |
| 11 | 1888 | 12.89 | 55.20 |
| 12 | 583 | 15.28 | 59.51 |
| 13 | 3001 | 17.57 | 63.63 |
| 14 | 3148 | 16.56 | 61.81 |
| 15 | 7533 | 20.09 | 68.17 |
| 16 | 7377 | 20.95 | 69.71 |
| 17 | 7371 | 18.31 | 64.96 |
| 18 | 6942 | 18.49 | 65.28 |
| 19 | 6267 | 18.28 | 64.91 |
| 20 | 6121 | 18.85 | 65.93 |
| 21 | 6001 | 18.11 | 64.60 |
| 22 | 9501 | 17.79 | 64.03 |
| 23 | 9950 | 15.53 | 59.96 |
| 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 | 15.64 | 60.15 |
| 29 | 8197 | 17.51 | 63.51 |
| 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 |

Maximum Component Temperatures

| Component | Node_1 | Node_2 | Node | Max_Temp(C) | Max_Temp(F) |
|---|---|---|---|---|---|
| Outside Shell | 101 | 2894 | 606 | 1.7283E+01 | 6.3110E+01 |
| Bottom Plate | 3001 | 3232 | 3120 | 1.7783E+01 | 6.4010E+01 |
| Lid | 3233 | 3424 | 3233 | 1.8056E+01 | 6.4500E+01 |
| Shell Cavity | 4001 | 4998 | 4227 | 2.5378E+01 | 7.7680E+01 |
| Plug | 5001 | 5404 | 5001 | 2.7867E+01 | 8.2160E+01 |
| Carbon Steel | 6001 | 7656 | 7377 | 2.0950E+01 | 6.9710E+01 |
| LAST-A-FOAM | 8001 | 10791 | 9501 | 1.7794E+01 | 6.4030E+01 |

## 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 ms **[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 3-17 (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

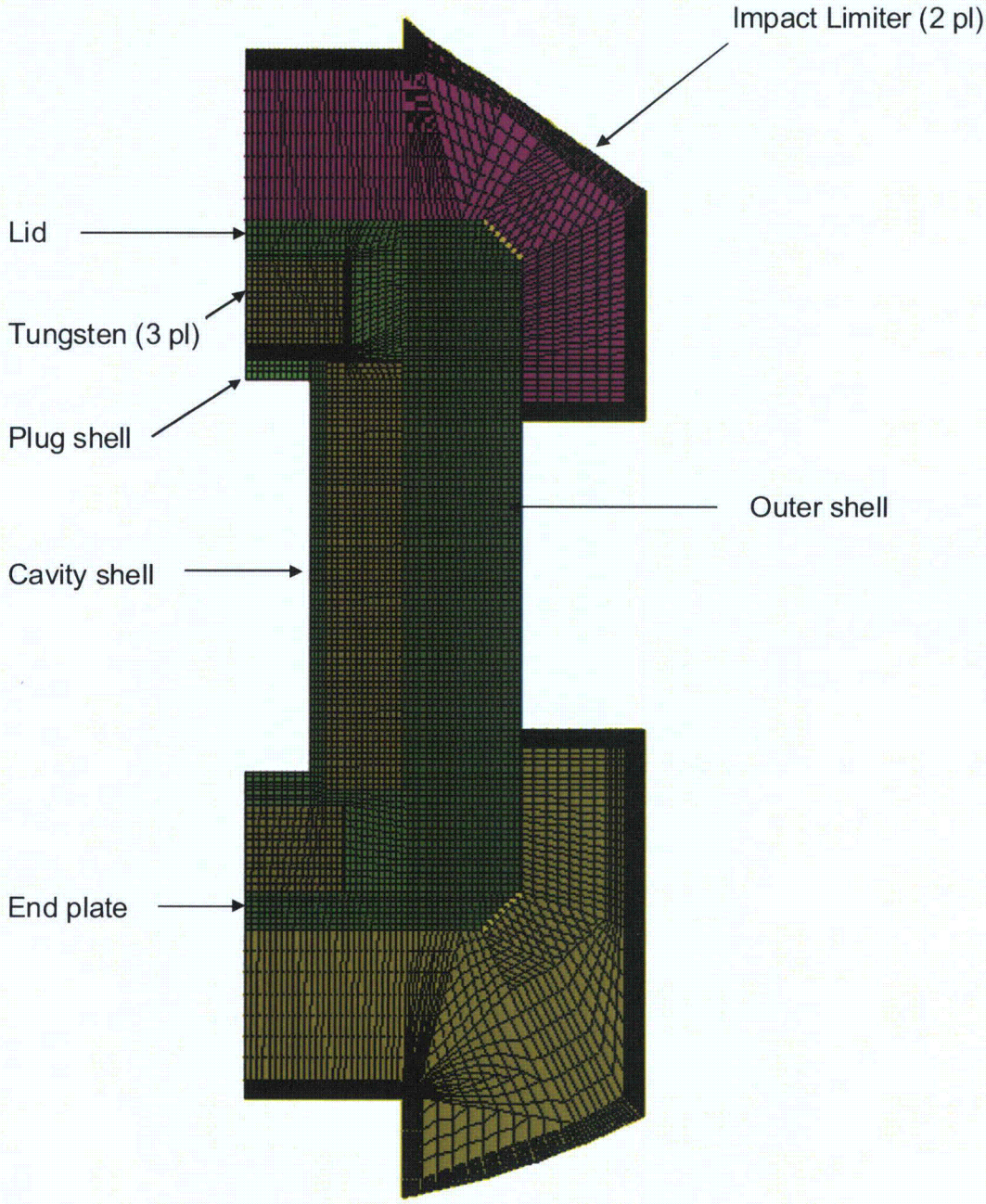



**Figure 3-17. Thermal Finite Element Model – Fire Conditions of Transport**

### 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 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

Stress associated with thermal conditions are provided in Chapter 2, "Structural Evaluation."

### 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.*

### 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 minimum 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 3-18 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 3-19 | Figure 3-20 | Figure 3-21 |
| 112 | Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-36 | – | Figure 3-22 | Figure 3-23 |
| 113 | Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-37 | – | Figure 3-24 | Figure 3-25 |
| 114 | Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-38 | – | Figure 3-26 | Figure 3-27 |
| 115 | Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-39 | – | Figure 3-28 | Figure 3-29 |
| 116 | Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation | Table 3-40 | – | Figure 3-30 | Figure 3-31 |

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 |

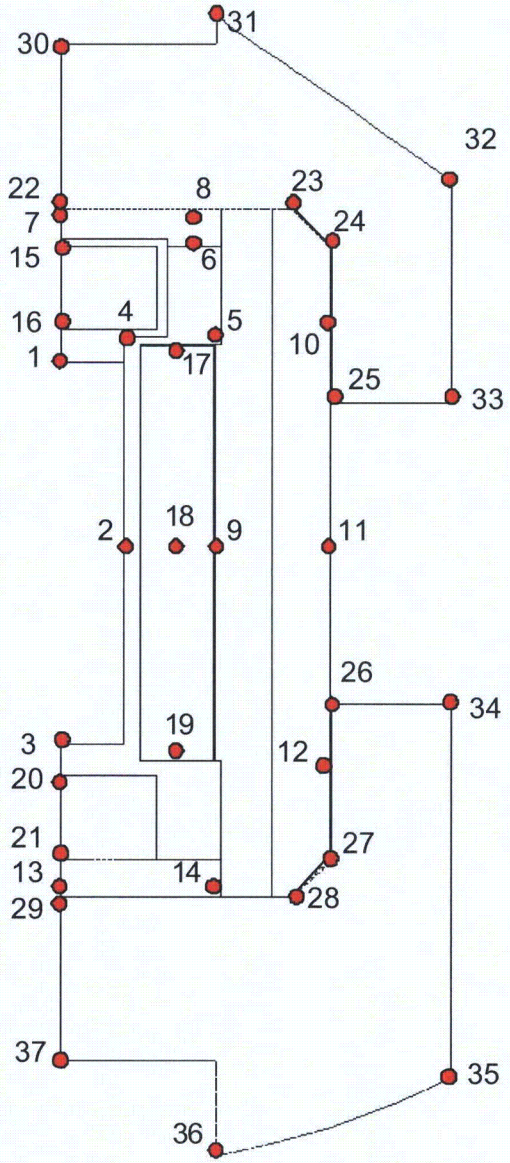



**Figure 3-18. Selected Nodal Locations for Fire Conditions of Transport – Model AOS-100**

**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 |

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 |

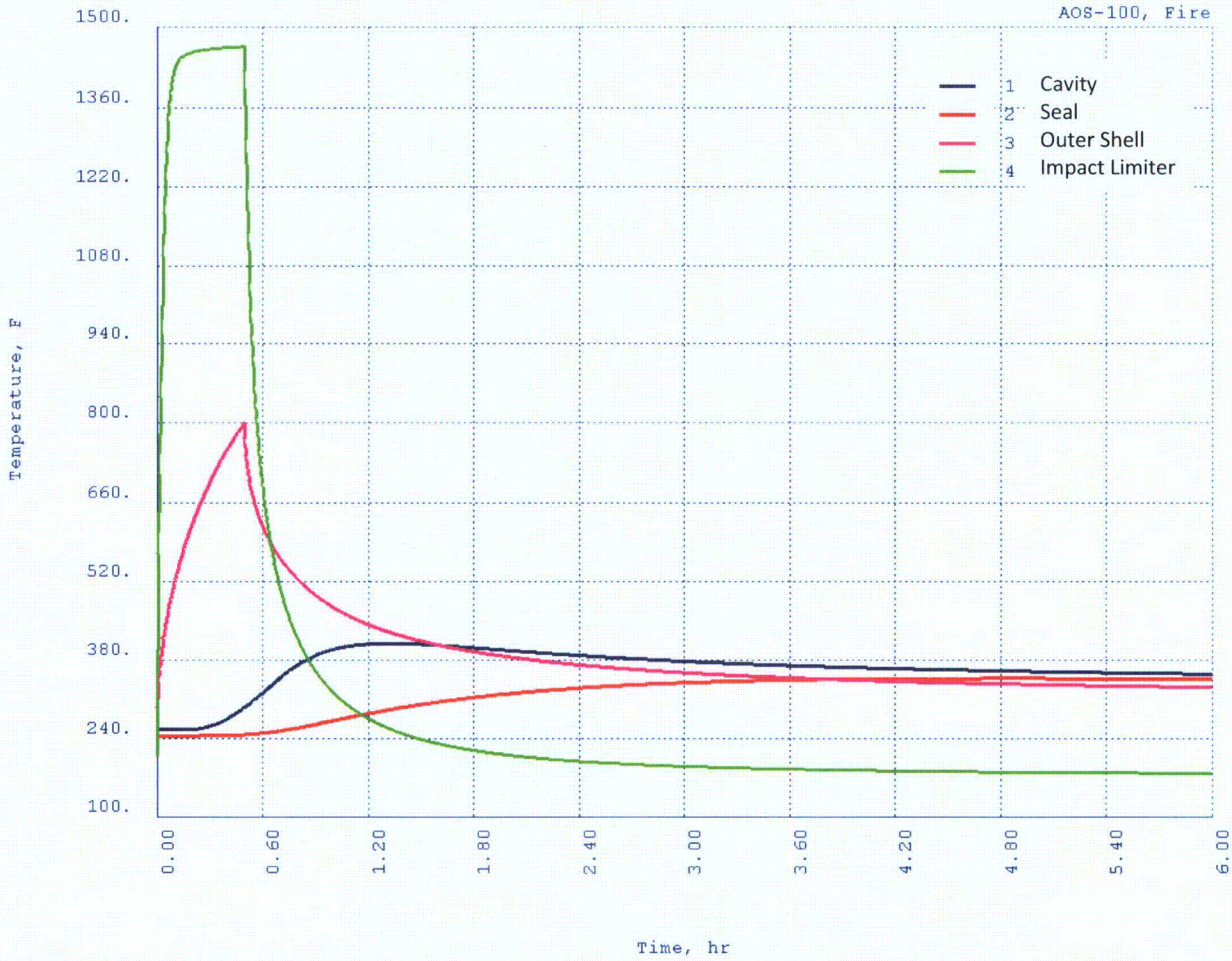



**Figure 3-19. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Temperature versus Time – Models AOS-100A and AOS-100A-S**

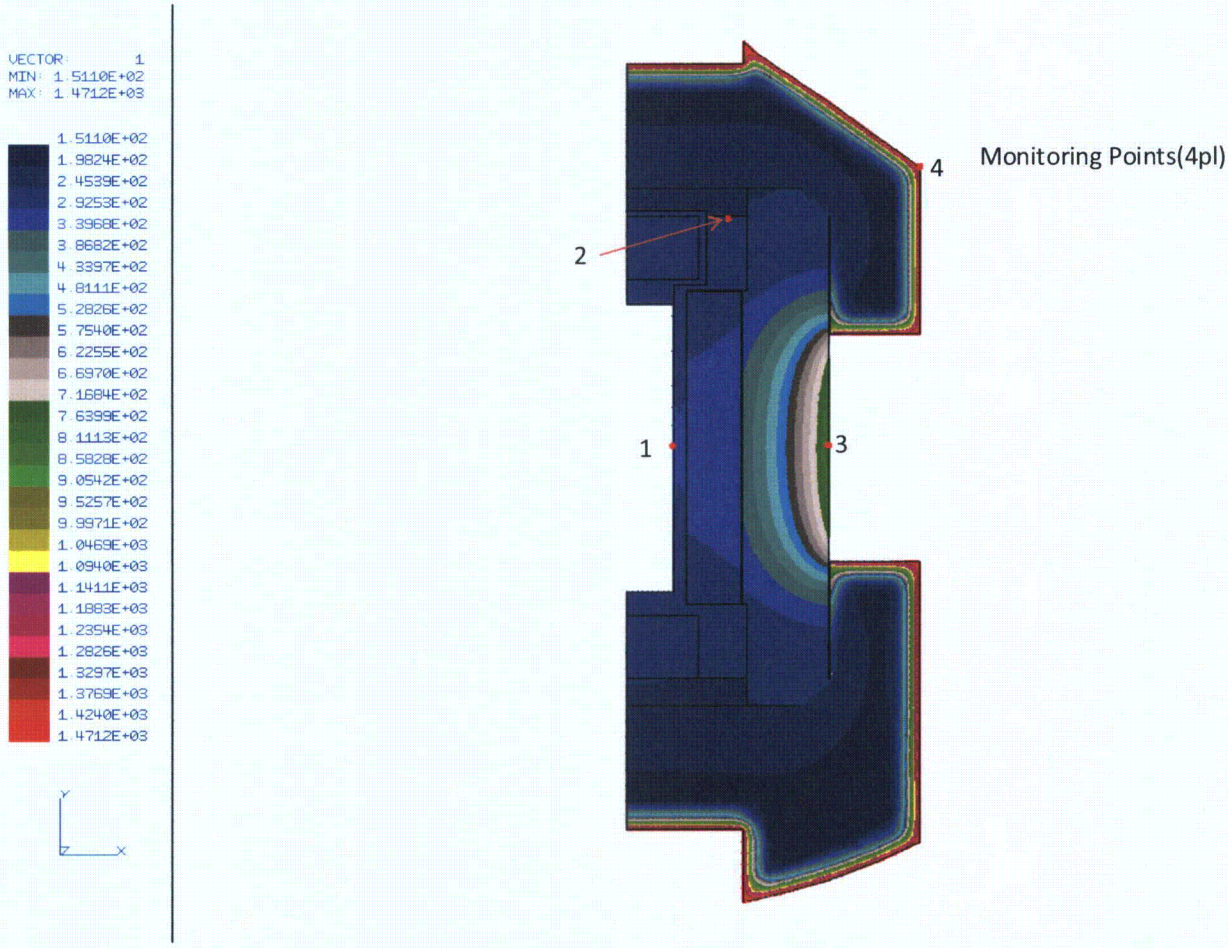



**Figure 3-20. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S**

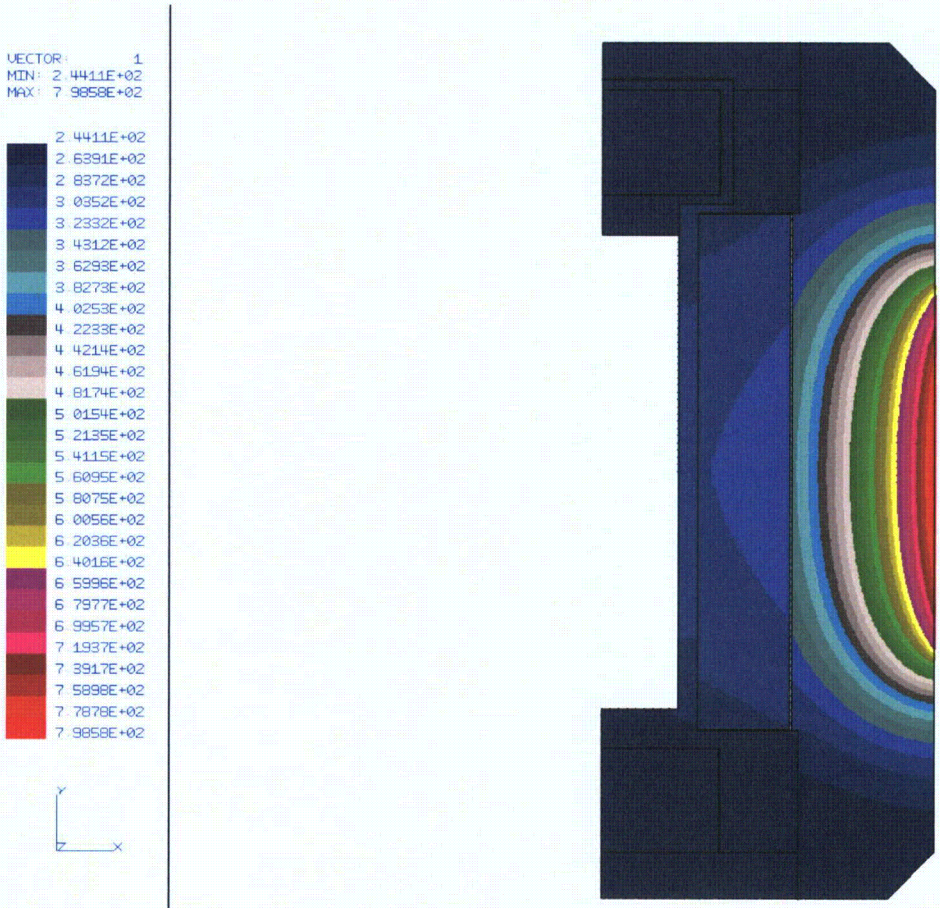



**Figure 3-21. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 | 3232 | 1.3050E+02 | 2.6690E+02 |
| Lid | 3233 | 3424 | 3360 | 1.2978E+02 | 2.6560E+02 |
| Shell Cavity | 4001 | 4998 | 4527 | 2.0278E+02 | 3.9700E+02 |
| Plug | 5001 | 5404 | 5012 | 1.4861E+02 | 2.9950E+02 |
| Tungsten Alloy | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

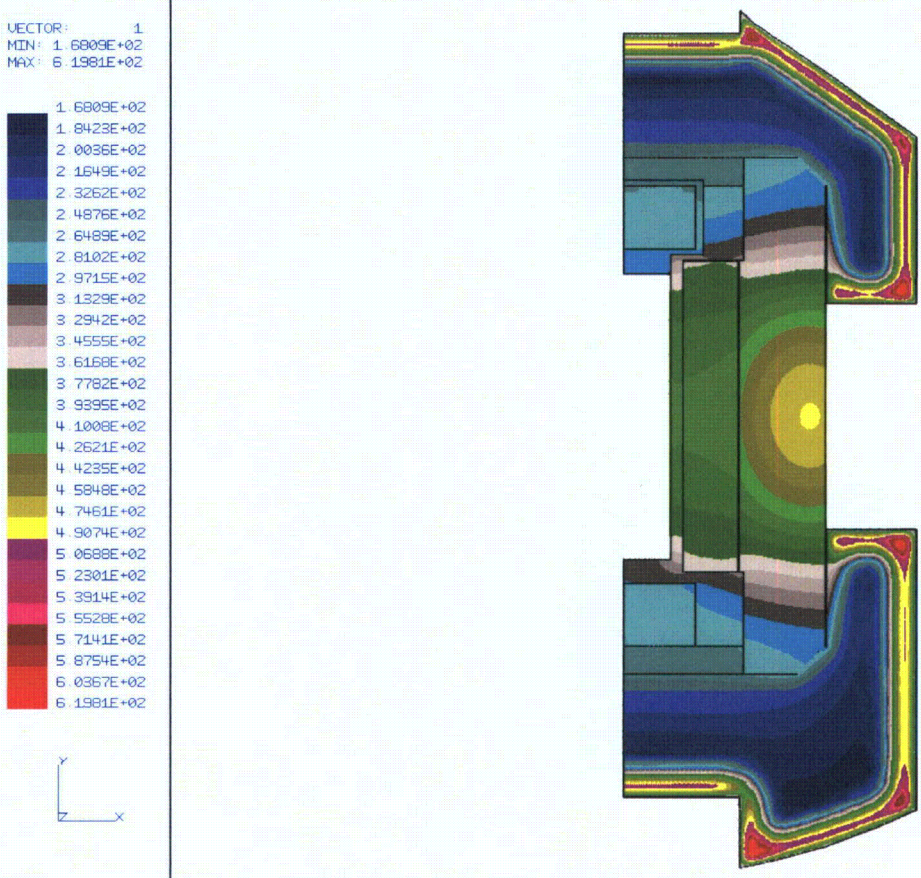



**Figure 3-22. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

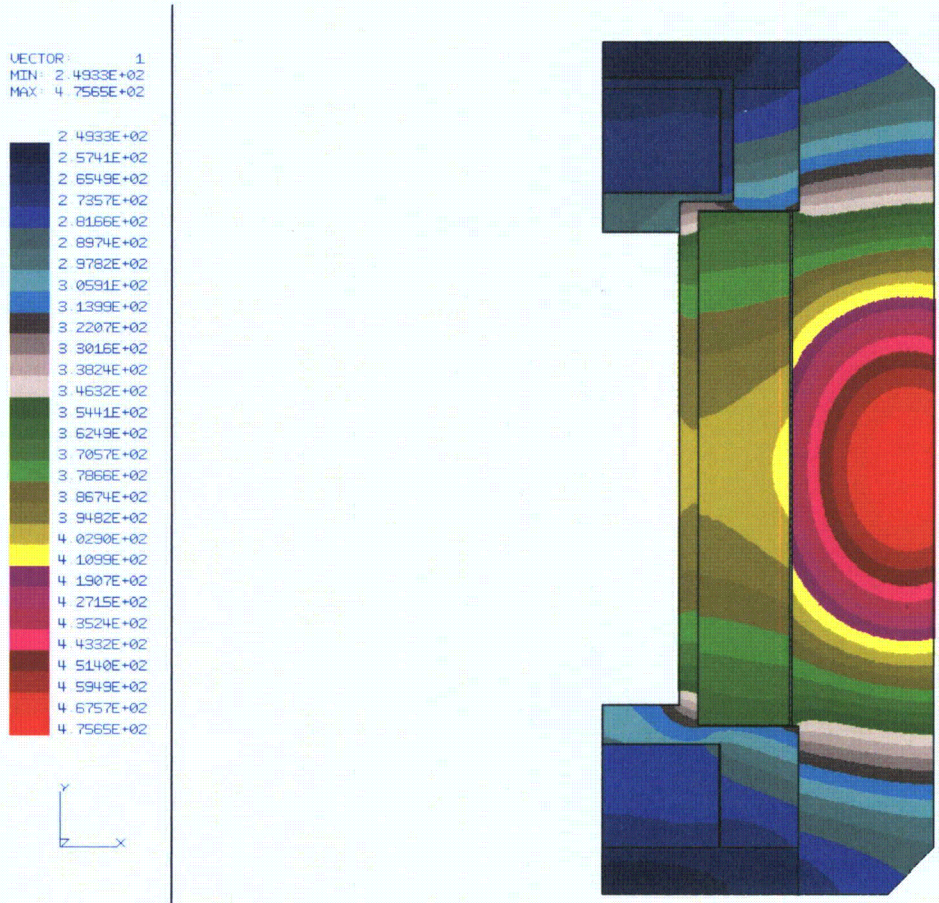



**Figure 3-23. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 | 3232 | 1.3050E+02 | 2.6690E+02 |
| Lid | 3233 | 3424 | 3360 | 1.2978E+02 | 2.6560E+02 |
| Shell Cavity | 4001 | 4998 | 4527 | 2.0278E+02 | 3.9700E+02 |
| Plug | 5001 | 5404 | 5012 | 1.4861E+02 | 2.9950E+02 |
| Tungsten Alloy | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

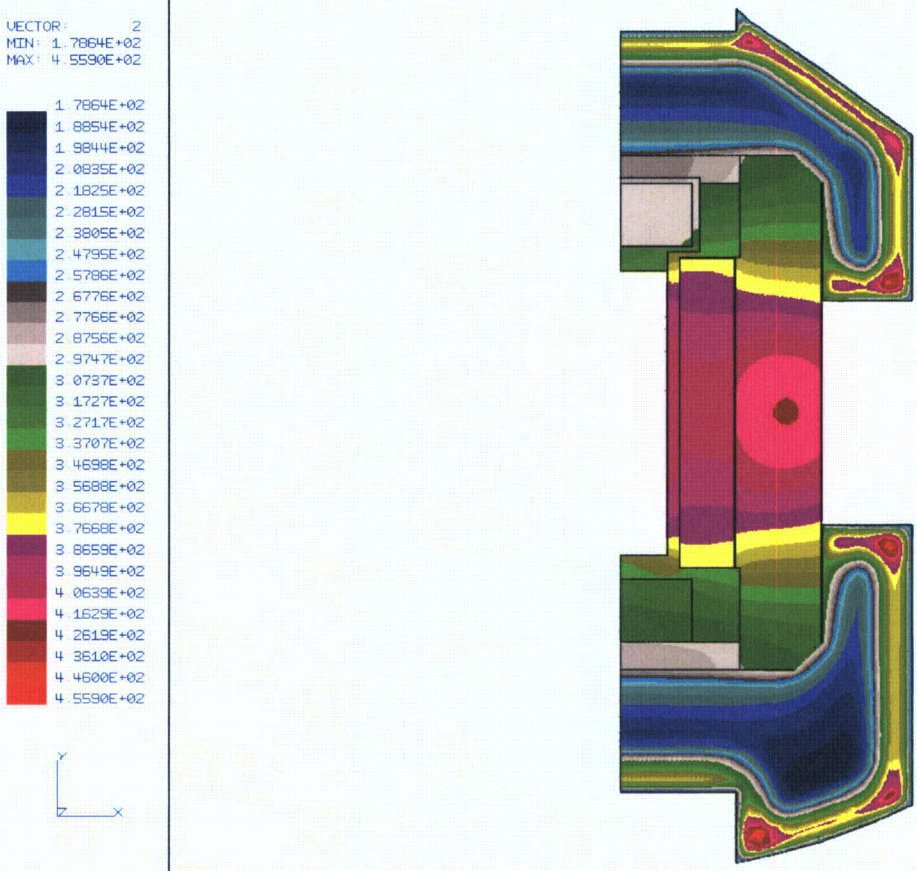



**Figure 3-24. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

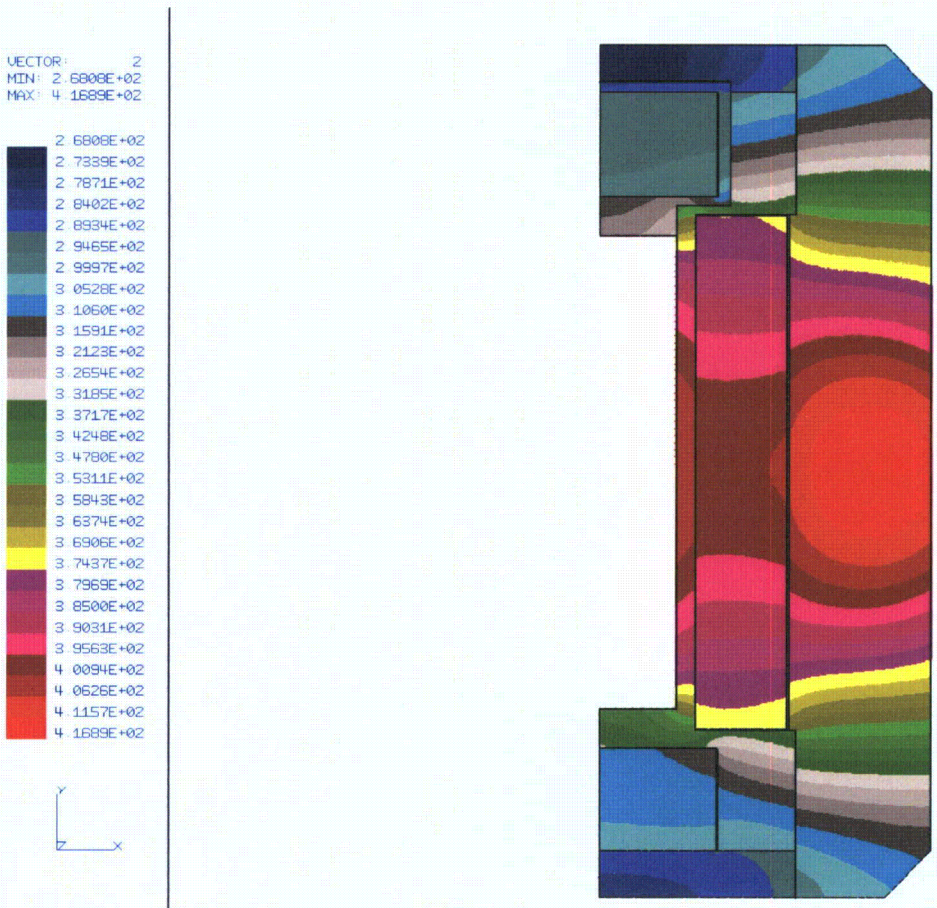



**Figure 3-25. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 | 3232 | 1.3050E+02 | 2.6690E+02 |
| Lid | 3233 | 3424 | 3360 | 1.2978E+02 | 2.6560E+02 |
| Shell Cavity | 4001 | 4998 | 4527 | 2.0278E+02 | 3.9700E+02 |
| Plug | 5001 | 5404 | 5012 | 1.4861E+02 | 2.9950E+02 |
| Tungsten Alloy | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

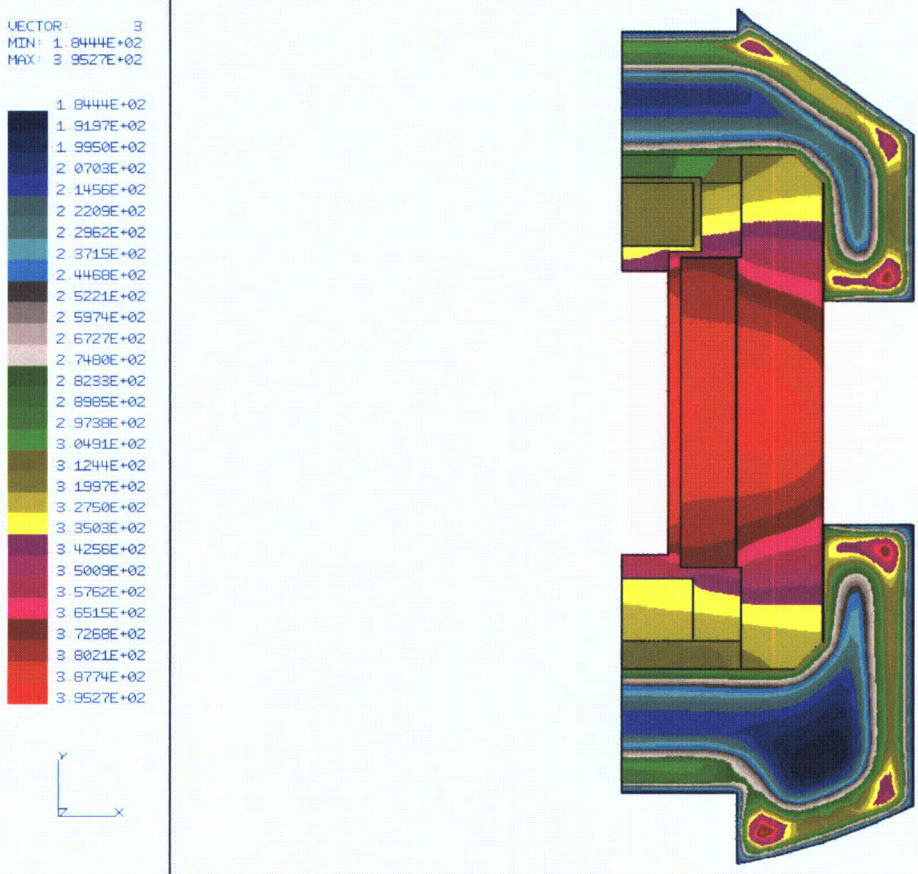



**Figure 3-26. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

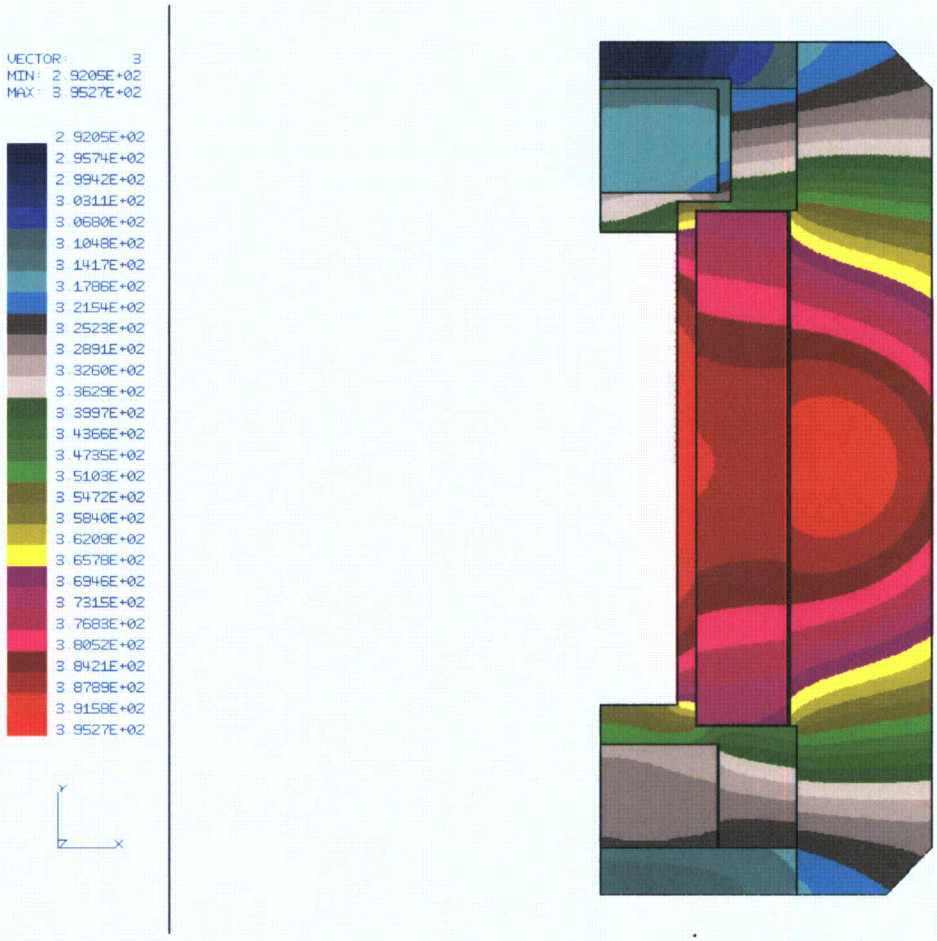



**Figure 3-27. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 | 3232 | 1.3050E+02 | 2.6690E+02 |
| Lid | 3233 | 3424 | 3360 | 1.2978E+02 | 2.6560E+02 |
| Shell Cavity | 4001 | 4998 | 4527 | 2.0278E+02 | 3.9700E+02 |
| Plug | 5001 | 5404 | 5012 | 1.4861E+02 | 2.9950E+02 |
| Tungsten Alloy | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

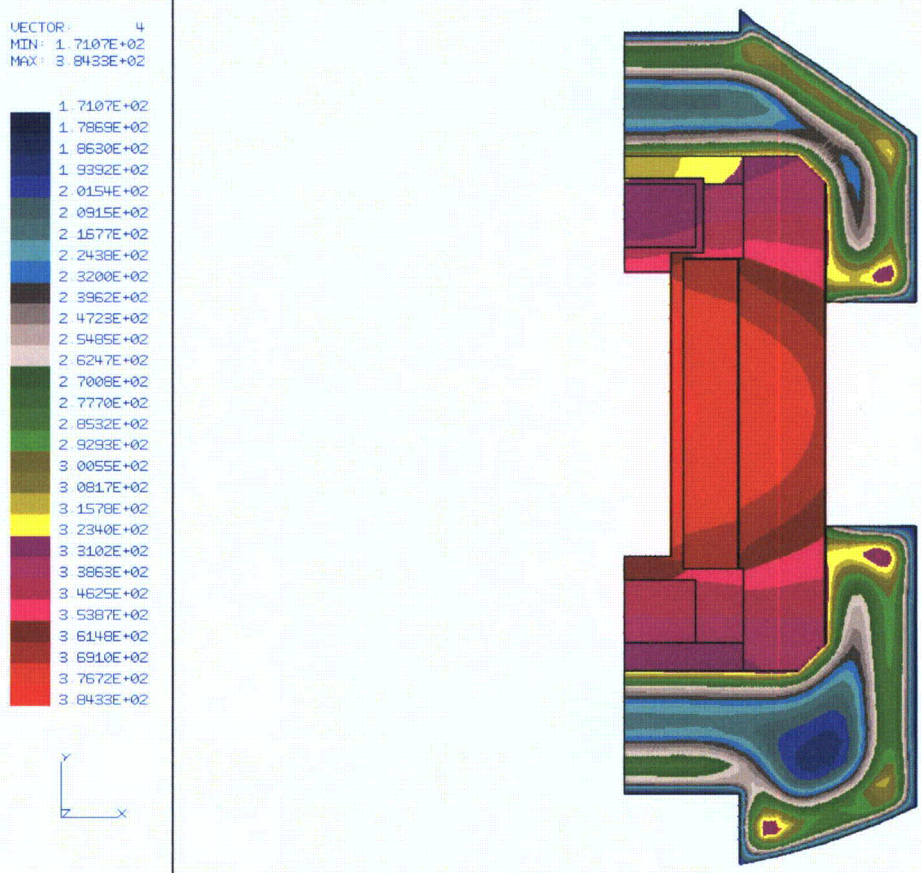



**Figure 3-28. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

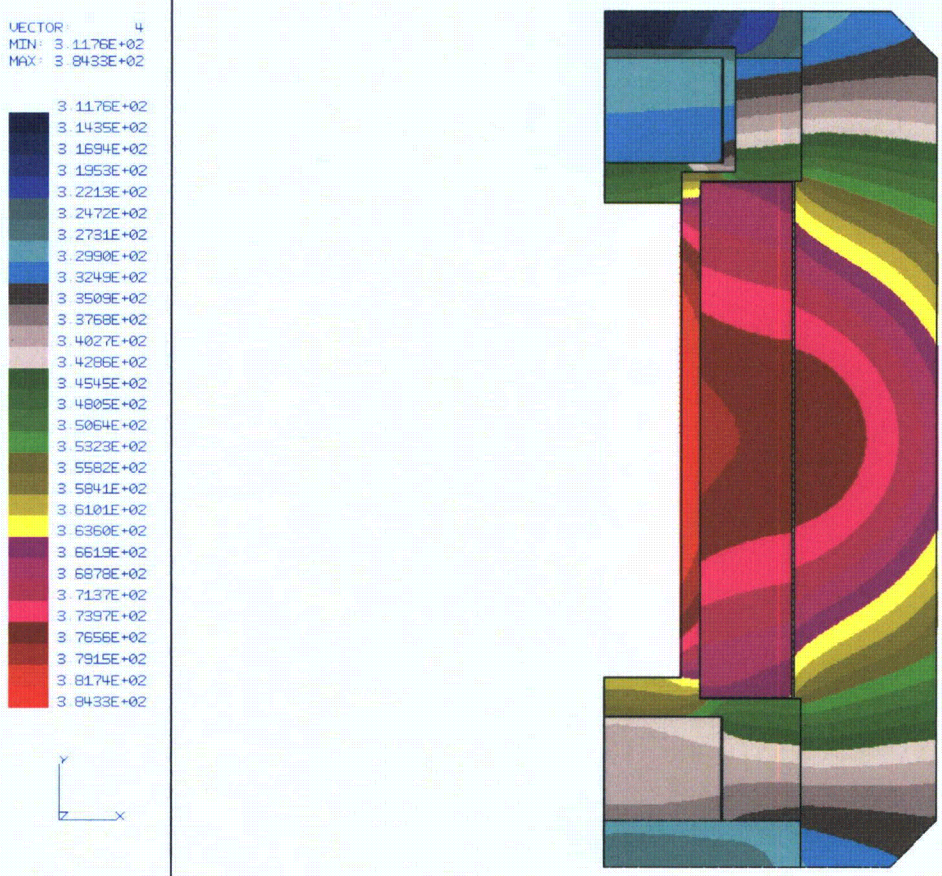



**Figure 3-29. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

**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 |

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 | 3232 | 1.3050E+02 | 2.6690E+02 |
| Lid | 3233 | 3424 | 3360 | 1.2978E+02 | 2.6560E+02 |
| Shell Cavity | 4001 | 4998 | 4527 | 2.0278E+02 | 3.9700E+02 |
| Plug | 5001 | 5404 | 5012 | 1.4861E+02 | 2.9950E+02 |
| Tungsten Alloy | 6001 | 7656 | 6949 | 2.0761E+02 | 4.0570E+02 |
| LAST-A-FOAM | 8001 | 18126 | 17671 | 3.2656E+02 | 6.1980E+02 |

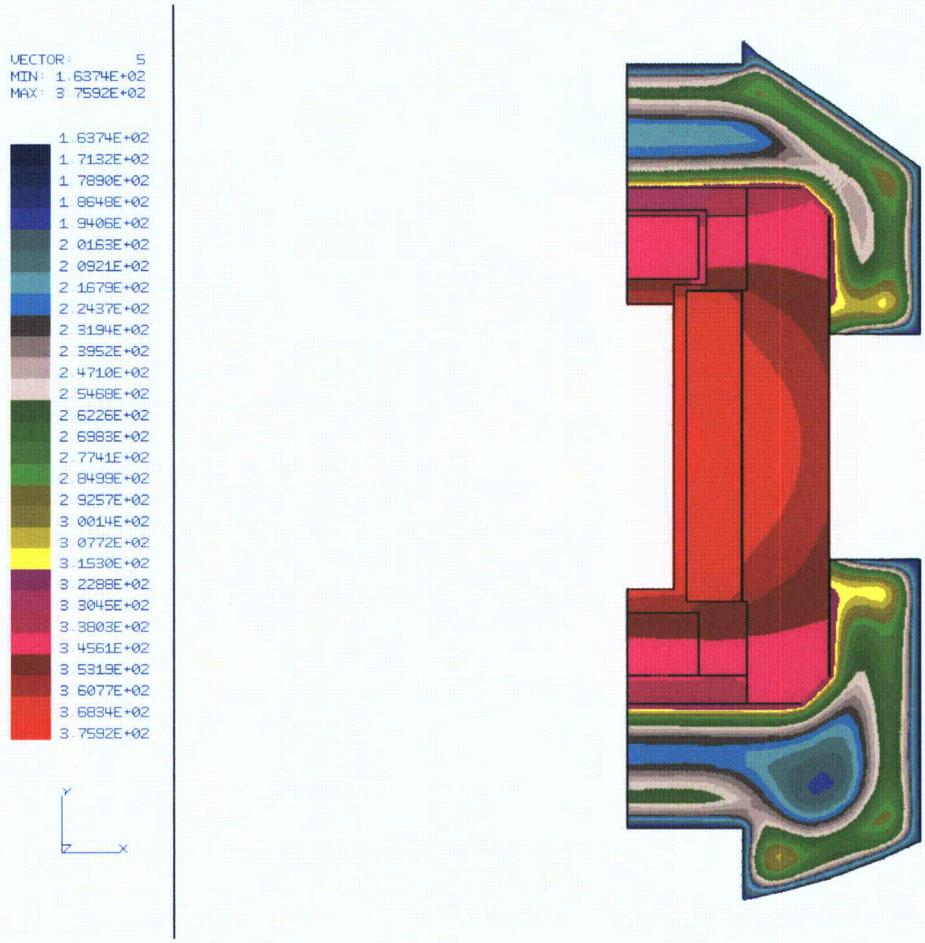



**Figure 3-30. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S**

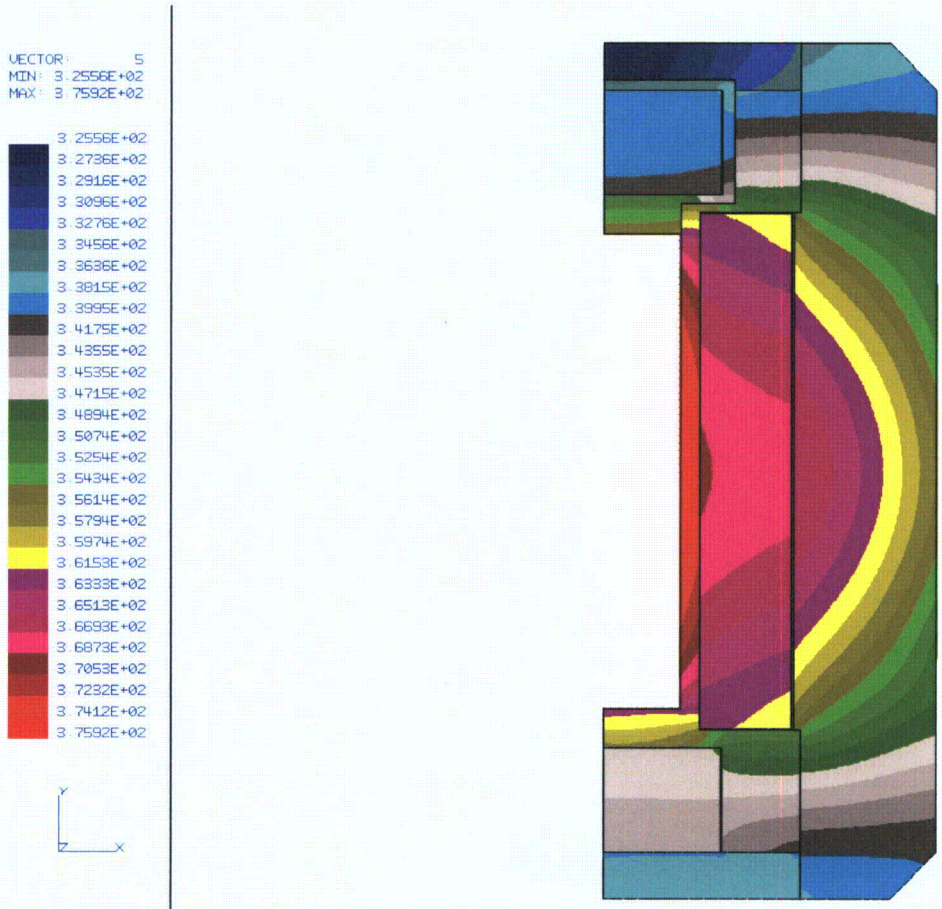



**Figure 3-31. Load Case 116 – Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S**

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

Table 3-33 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 102 and 111 through 115. Each table provides a list of temperatures at each monitoring node. Also listed are the minimum 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 3-18 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.*

*Results data is not included for Load Case 116.*

*The comparison results between the tungsten alloy and carbon steel shielding, in the data that follows, are similar at 1,475°F; therefore, solutions at -20°F and -40°F are not provided.*

*The model used is not the same as what is to be updated. The overpack does not reflect a deformed corner, and the mesh does not reflect the refined mesh required, that eliminates the initial temperature drop during the beginning of the cool-down solution.*

**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 |
|---|---|---|---|---|---|
| 102 | 100°F Ambient, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-42 | – | Figure 3-32 | Figure 3-33 |
| 111 | Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding | Table 3-43 | Figure 3-34 | Figure 3-35 | Figure 3-36 |
| 112 | Fire at 60 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-44 | – | Figure 3-37 | Figure 3-38 |
| 113 | Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-44 | – | Figure 3-39 | Figure 3-40 |
| 114 | Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-44 | – | Figure 3-41 | Figure 3-42 |
| 115 | Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding | Table 3-44 | – | Figure 3-43 | Figure 3-44 |
| 116 | Fire at 180 Minutes, 100°F, 400W Decay Heat, Maximum Insolation | – | – | – | – |

**Table 3-42. Load Case 102 – 100°F Ambient, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding – Model AOS-100B**

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 124.94 | 256.90 |
| 2 | 4532 | 124.56 | 256.20 |
| 3 | 4227 | 124.22 | 255.60 |
| 4 | 4752 | 120.22 | 248.40 |
| 5 | 4838 | 117.06 | 242.70 |
| 6 | 3309 | 117.44 | 243.40 |
| 7 | 3419 | 116.56 | 241.80 |
| 8 | 4995 | 116.67 | 242.00 |
| 9 | 678 | 116.89 | 242.40 |
| 10 | 2537 | 114.56 | 238.20 |
| 11 | 1888 | 113.61 | 236.50 |
| 12 | 583 | 114.72 | 238.50 |
| 13 | 3001 | 117.39 | 243.30 |
| 14 | 3148 | 116.33 | 241.40 |
| 15 | 7533 | 118.72 | 245.70 |
| 16 | 7377 | 119.72 | 247.50 |
| 17 | 7371 | 118.39 | 245.10 |
| 18 | 6942 | 119.00 | 246.20 |
| 19 | 6267 | 118.33 | 245.00 |
| 20 | 6121 | 118.83 | 245.90 |
| 21 | 6001 | 117.89 | 244.20 |
| 22 | 9501 | 117.39 | 243.30 |
| 23 | 9950 | 115.11 | 239.20 |
| 24 | 10014 | 114.00 | 237.20 |
| 25 | 10781 | 96.83 | 206.30 |
| 26 | 9091 | 96.72 | 206.10 |
| 27 | 8463 | 113.83 | 236.90 |
| 28 | 8462 | 115.17 | 239.30 |
| 29 | 8197 | 117.33 | 243.20 |
| 30 | 9711 | 64.78 | 148.60 |
| 31 | 9821 | 82.89 | 181.20 |
| 32 | 10158 | 79.94 | 175.90 |
| 33 | 10605 | 70.50 | 158.90 |
| 34 | 9102 | 70.50 | 158.90 |
| 35 | 8578 | 79.94 | 175.90 |
| 36 | 8225 | 82.67 | 180.80 |
| 37 | 8001 | 64.78 | 148.60 |

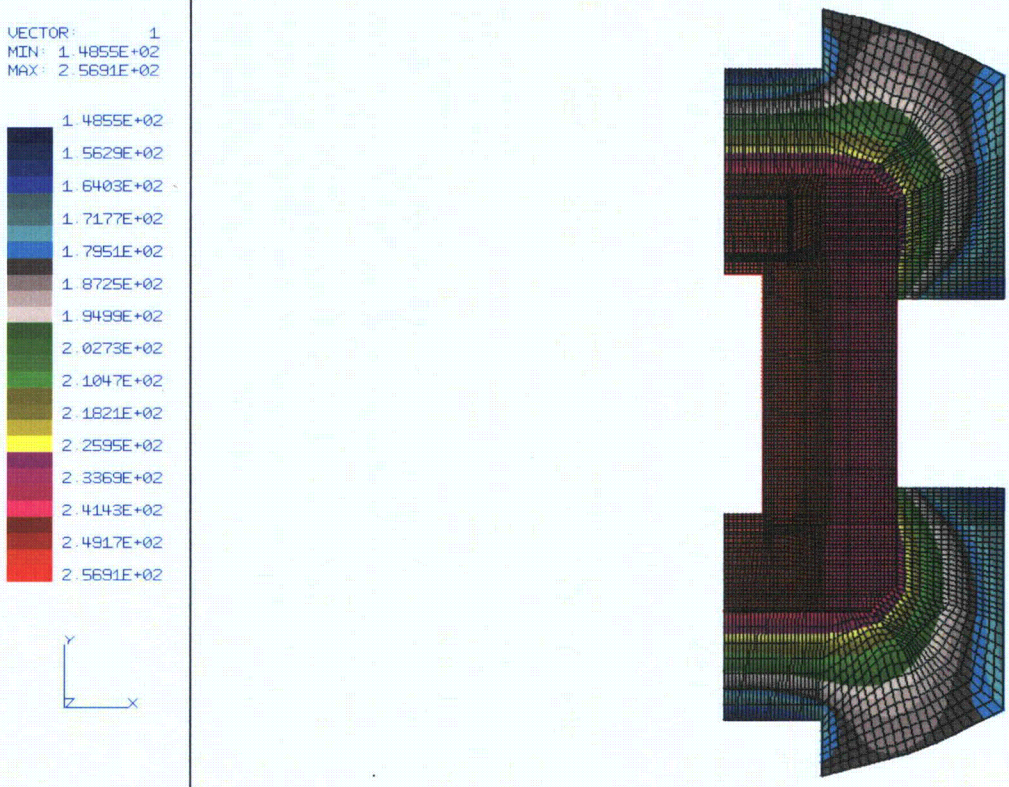



**Figure 3-32. Load Case 102 – 100°F Ambient, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

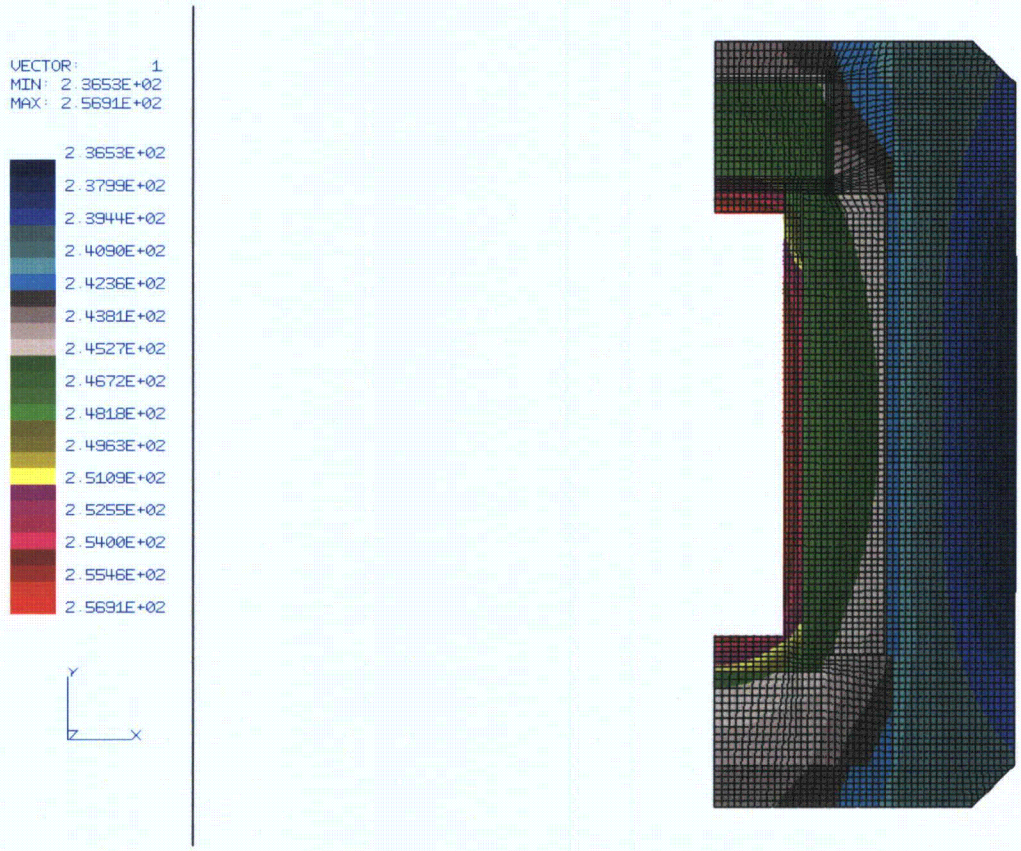



**Figure 3-33. Load Case 102 – 100°F Ambient, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

**Table 3-43. 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 | 125.39 | 257.70 |
| 2 | 4532 | 135.28 | 275.50 |
| 3 | 4227 | 125.22 | 257.40 |
| 4 | 4752 | 123.83 | 254.90 |
| 5 | 4838 | 129.50 | 265.10 |
| 6 | 3309 | 117.00 | 242.60 |
| 7 | 3419 | 116.50 | 241.70 |
| 8 | 4995 | 117.56 | 243.60 |
| 9 | 678 | 181.22 | 358.20 |
| 10 | 2537 | 161.44 | 322.60 |
| 11 | 1888 | 406.83 | 764.30 |
| 12 | 583 | 158.00 | 316.40 |
| 13 | 3001 | 117.22 | 243.00 |
| 14 | 3148 | 116.83 | 242.30 |
| 15 | 7533 | 118.72 | 245.70 |
| 16 | 7377 | 120.00 | 248.00 |
| 17 | 7371 | 126.94 | 260.50 |
| 18 | 6942 | 139.72 | 283.50 |
| 19 | 6267 | 126.72 | 260.10 |
| 20 | 6121 | 119.56 | 247.20 |
| 21 | 6001 | 118.22 | 244.80 |
| 22 | 9501 | 116.94 | 242.50 |
| 23 | 9864 | 117.11 | 242.80 |
| 24 | 9932 | 124.28 | 255.70 |
| 25 | 10674 | 543.89 | 1011.00 |
| 26 | 9091 | 544.44 | 1012.00 |
| 27 | 8463 | 125.50 | 257.90 |
| 28 | 8462 | 117.61 | 243.70 |
| 29 | 8197 | 117.17 | 242.90 |
| 30 | 9741 | 792.78 | 1459.00 |
| 31 | 9770 | 792.22 | 1458.00 |
| 32 | 10051 | 797.22 | 1467.00 |
| 33 | 10498 | 797.22 | 1467.00 |
| 34 | 9102 | 797.22 | 1467.00 |
| 35 | 8578 | 796.67 | 1466.00 |
| 36 | 8225 | 797.78 | 1468.00 |
| 37 | 8001 | 795.00 | 1463.00 |

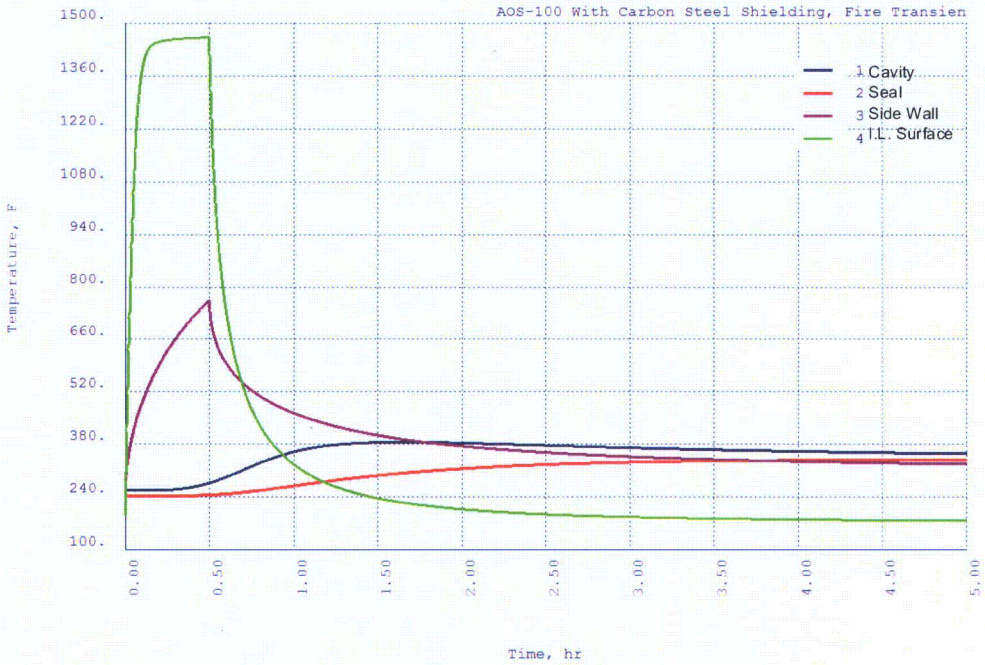



**Figure 3-34. Carbon Steel Shielding, 5-Hour Thermal Transient, Fire at 30 Minutes, 1,475°F Ambient, 4.5-Hour Cool Down at 100°F Ambient with Solar Heat, 400W Maximum Decay Heat Present throughout Transient – Model AOS-100B**

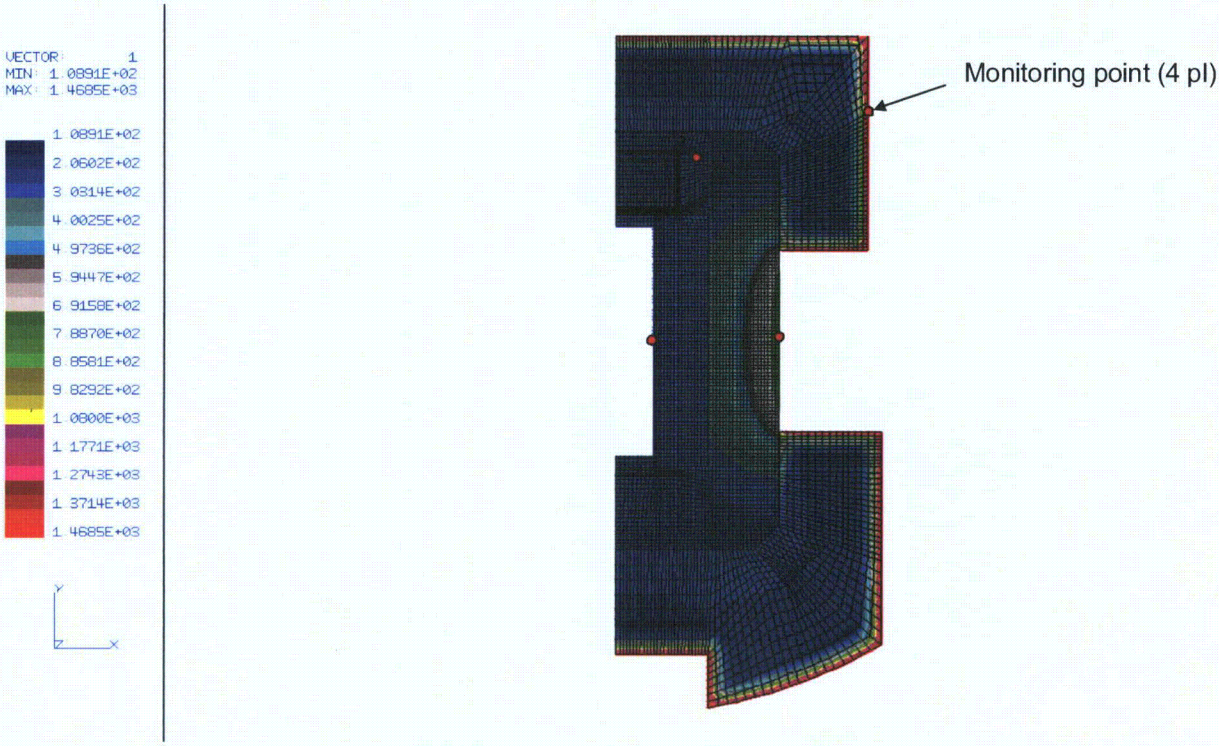



**Figure 3-35. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding, Entire Model – Model AOS-100B**

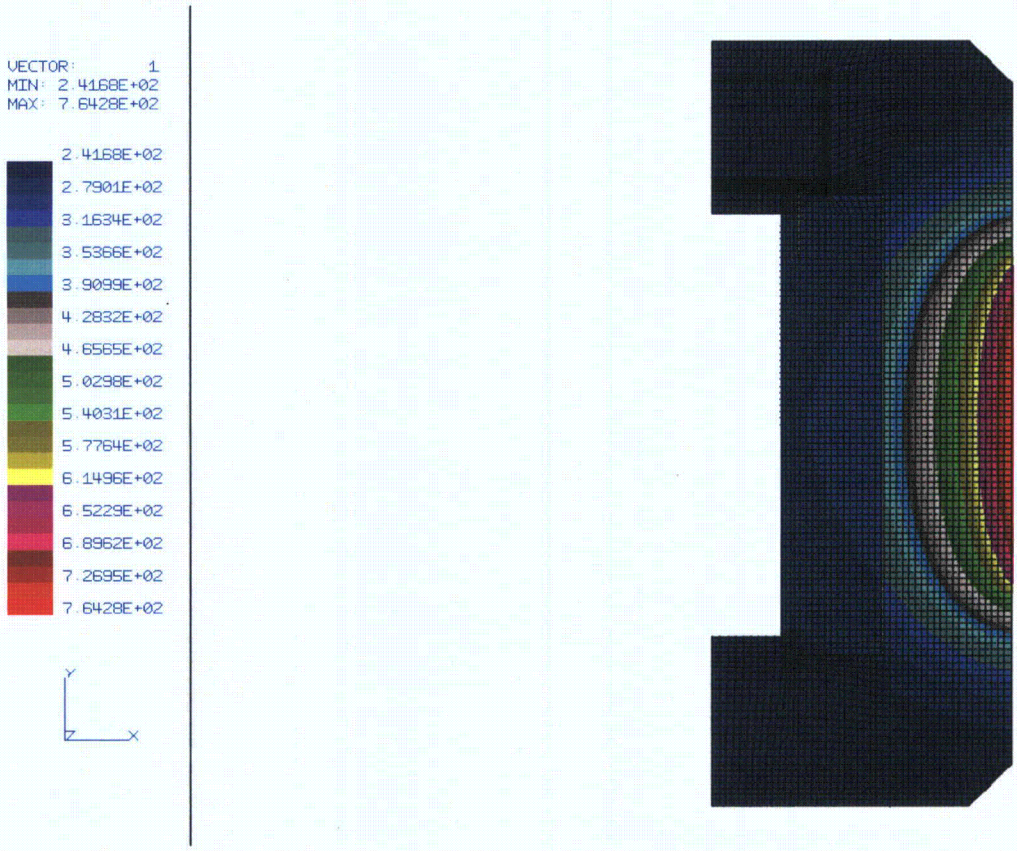



**Figure 3-36. Load Case 111 – Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat plus Solar, Carbon Steel Shielding, Cask Model – Model AOS-100B**

**Table 3-44. Load Case 112 – 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**

Temperatures @ 1.000 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 137.67 | 279.80 |
| 2 | 4532 | 180.89 | 357.60 |
| 3 | 4227 | 142.50 | 288.50 |
| 4 | 4752 | 146.28 | 295.30 |
| 5 | 4838 | 157.67 | 315.80 |
| 6 | 3309 | 119.89 | 247.80 |
| 7 | 3419 | 124.78 | 256.60 |
| 8 | 4995 | 130.94 | 267.70 |
| 9 | 678 | 212.89 | 415.20 |
| 10 | 2537 | 171.00 | 339.80 |
| 11 | 1888 | 238.89 | 462.00 |
| 12 | 583 | 169.72 | 337.50 |
| 13 | 3001 | 122.50 | 252.50 |
| 14 | 3148 | 127.61 | 261.70 |
| 15 | 7533 | 126.67 | 260.00 |
| 16 | 7377 | 130.00 | 266.00 |
| 17 | 7371 | 157.94 | 316.30 |
| 18 | 6942 | 184.61 | 364.30 |
| 19 | 6267 | 156.56 | 313.80 |
| 20 | 6121 | 133.33 | 272.00 |
| 21 | 6001 | 128.89 | 264.00 |
| 22 | 9501 | 119.67 | 247.40 |
| 23 | 9864 | 133.17 | 271.70 |
| 24 | 9932 | 141.39 | 286.50 |
| 25 | 10674 | 188.94 | 372.10 |
| 26 | 9091 | 189.72 | 373.50 |
| 27 | 8463 | 143.11 | 289.60 |
| 28 | 8462 | 133.94 | 273.10 |
| 29 | 8197 | 122.11 | 251.80 |
| 30 | 9741 | 178.72 | 353.70 |
| 31 | 9770 | 178.56 | 353.40 |
| 32 | 10051 | 171.28 | 340.30 |
| 33 | 10498 | 167.67 | 333.80 |
| 34 | 9102 | 167.56 | 333.60 |
| 35 | 8578 | 167.28 | 333.10 |
| 36 | 8225 | 182.94 | 361.30 |
| 37 | 8001 | 171.39 | 340.50 |

Temperatures @ 1.500 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 154.61 | 310.30 |
| 2 | 4532 | 195.17 | 383.30 |
| 3 | 4227 | 161.61 | 322.90 |
| 4 | 4752 | 161.94 | 323.50 |
| 5 | 4838 | 167.67 | 333.80 |
| 6 | 3309 | 131.28 | 268.30 |
| 7 | 3419 | 139.11 | 282.40 |
| 8 | 4995 | 146.11 | 295.00 |
| 9 | 678 | 201.22 | 394.20 |
| 10 | 2537 | 168.89 | 336.00 |
| 11 | 1888 | 205.78 | 402.40 |
| 12 | 583 | 168.28 | 334.90 |
| 13 | 3001 | 137.17 | 278.90 |
| 14 | 3148 | 142.56 | 288.60 |
| 15 | 7533 | 141.72 | 287.10 |
| 16 | 7377 | 145.83 | 294.50 |
| 17 | 7371 | 171.11 | 340.00 |
| 18 | 6942 | 192.06 | 377.70 |
| 19 | 6267 | 169.89 | 337.80 |
| 20 | 6121 | 150.94 | 303.70 |
| 21 | 6001 | 145.56 | 294.00 |
| 22 | 9501 | 130.83 | 267.50 |
| 23 | 9864 | 146.28 | 295.30 |
| 24 | 9932 | 149.22 | 300.60 |
| 25 | 10674 | 155.22 | 311.40 |
| 26 | 9091 | 155.44 | 311.80 |
| 27 | 8463 | 149.89 | 301.80 |
| 28 | 8462 | 146.94 | 296.50 |
| 29 | 8197 | 136.50 | 277.70 |
| 30 | 9741 | 117.00 | 242.60 |
| 31 | 9770 | 116.94 | 242.50 |
| 32 | 10051 | 114.89 | 238.80 |
| 33 | 10498 | 113.11 | 235.60 |
| 34 | 9102 | 112.50 | 234.50 |
| 35 | 8578 | 116.06 | 240.90 |
| 36 | 8225 | 126.39 | 259.50 |
| 37 | 8001 | 111.67 | 233.00 |

Temperatures @ 2.000 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 165.83 | 330.50 |
| 2 | 4532 | 194.22 | 381.60 |
| 3 | 4227 | 171.50 | 340.70 |
| 4 | 4752 | 169.33 | 336.80 |
| 5 | 4838 | 170.89 | 339.60 |
| 6 | 3309 | 144.61 | 292.30 |
| 7 | 3419 | 150.56 | 303.00 |
| 8 | 4995 | 156.06 | 312.90 |
| 9 | 678 | 191.56 | 376.80 |
| 10 | 2537 | 168.28 | 334.90 |
| 11 | 1888 | 189.44 | 373.00 |
| 12 | 583 | 167.94 | 334.30 |
| 13 | 3001 | 150.89 | 303.60 |
| 14 | 3148 | 153.56 | 308.40 |
| 15 | 7533 | 154.17 | 309.50 |
| 16 | 7377 | 157.72 | 315.90 |
| 17 | 7371 | 174.72 | 346.50 |
| 18 | 6942 | 189.11 | 372.40 |
| 19 | 6267 | 174.11 | 345.40 |
| 20 | 6121 | 161.89 | 323.40 |
| 21 | 6001 | 157.50 | 315.50 |
| 22 | 9501 | 144.17 | 291.50 |
| 23 | 9864 | 154.28 | 309.70 |
| 24 | 9932 | 154.94 | 310.90 |
| 25 | 10674 | 144.72 | 292.50 |
| 26 | 9091 | 144.61 | 292.30 |
| 27 | 8463 | 155.17 | 311.30 |
| 28 | 8462 | 154.94 | 310.90 |
| 29 | 8197 | 150.28 | 302.50 |
| 30 | 9741 | 94.61 | 202.30 |
| 31 | 9770 | 94.61 | 202.30 |
| 32 | 10051 | 95.17 | 203.30 |
| 33 | 10498 | 95.06 | 203.10 |
| 34 | 9102 | 94.11 | 201.40 |
| 35 | 8578 | 100.17 | 212.30 |
| 36 | 8225 | 107.28 | 225.10 |
| 37 | 8001 | 91.50 | 196.70 |

Temperatures @ 2.500 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 172.22 | 342.00 |
| 2 | 4532 | 190.44 | 374.80 |
| 3 | 4227 | 176.06 | 348.90 |
| 4 | 4752 | 172.67 | 342.80 |
| 5 | 4838 | 171.83 | 341.30 |
| 6 | 3309 | 154.72 | 310.50 |
| 7 | 3419 | 158.22 | 316.80 |
| 8 | 4995 | 162.06 | 323.70 |
| 9 | 678 | 184.50 | 364.10 |
| 10 | 2537 | 168.06 | 334.50 |
| 11 | 1888 | 179.89 | 355.80 |
| 12 | 583 | 168.00 | 334.40 |
| 13 | 3001 | 159.94 | 319.90 |
| 14 | 3148 | 160.56 | 321.00 |
| 15 | 7533 | 162.22 | 324.00 |
| 16 | 7377 | 165.00 | 329.00 |
| 17 | 7371 | 175.22 | 347.40 |
| 18 | 6942 | 184.78 | 364.60 |
| 19 | 6267 | 175.11 | 347.20 |
| 20 | 6121 | 167.83 | 334.10 |
| 21 | 6001 | 164.61 | 328.30 |
| 22 | 9501 | 154.33 | 309.80 |
| 23 | 9864 | 159.33 | 318.80 |
| 24 | 9932 | 158.78 | 317.80 |
| 25 | 10674 | 140.22 | 284.40 |
| 26 | 9091 | 139.94 | 283.90 |
| 27 | 8463 | 159.00 | 318.20 |
| 28 | 8462 | 160.06 | 320.10 |
| 29 | 8197 | 159.50 | 319.10 |
| 30 | 9741 | 83.78 | 182.80 |
| 31 | 9770 | 83.78 | 182.80 |
| 32 | 10051 | 85.94 | 186.70 |
| 33 | 10498 | 87.11 | 188.80 |
| 34 | 9102 | 85.94 | 186.70 |
| 35 | 8578 | 93.11 | 199.60 |
| 36 | 8225 | 98.56 | 209.40 |
| 37 | 8001 | 82.22 | 180.00 |

Temperatures @ 3.000 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 175.61 | 348.10 |
| 2 | 4532 | 186.83 | 368.30 |
| 3 | 4227 | 178.00 | 352.40 |
| 4 | 4752 | 174.06 | 345.30 |
| 5 | 4838 | 171.89 | 341.40 |
| 6 | 3309 | 161.33 | 322.40 |
| 7 | 3419 | 163.00 | 325.40 |
| 8 | 4995 | 165.61 | 330.10 |
| 9 | 678 | 179.44 | 355.00 |
| 10 | 2537 | 167.78 | 334.00 |
| 11 | 1888 | 173.83 | 344.90 |
| 12 | 583 | 168.00 | 334.40 |
| 13 | 3001 | 165.28 | 329.50 |
| 14 | 3148 | 164.78 | 328.60 |
| 15 | 7533 | 166.89 | 332.40 |
| 16 | 7377 | 169.11 | 336.40 |
| 17 | 7371 | 174.78 | 346.60 |
| 18 | 6942 | 181.00 | 357.80 |
| 19 | 6267 | 174.89 | 346.80 |
| 20 | 6121 | 170.83 | 339.50 |
| 21 | 6001 | 168.44 | 335.20 |
| 22 | 9501 | 160.94 | 321.70 |
| 23 | 9864 | 162.44 | 324.40 |
| 24 | 9932 | 161.28 | 322.30 |
| 25 | 10674 | 137.78 | 280.00 |
| 26 | 9091 | 137.50 | 279.50 |
| 27 | 8463 | 161.50 | 322.70 |
| 28 | 8462 | 163.33 | 326.00 |
| 29 | 8197 | 164.94 | 328.90 |
| 30 | 9741 | 77.67 | 171.80 |
| 31 | 9770 | 77.67 | 171.80 |
| 32 | 10051 | 80.89 | 177.60 |
| 33 | 10498 | 82.89 | 181.20 |
| 34 | 9102 | 81.61 | 178.90 |
| 35 | 8578 | 89.39 | 192.90 |
| 36 | 8225 | 93.89 | 201.00 |
| 37 | 8001 | 77.22 | 171.00 |

Temperatures @ 3.500 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 177.22 | 351.00 |
| 2 | 4532 | 183.89 | 363.00 |
| 3 | 4227 | 178.61 | 353.50 |
| 4 | 4752 | 174.39 | 345.90 |
| 5 | 4838 | 171.50 | 340.70 |
| 6 | 3309 | 165.28 | 329.50 |
| 7 | 3419 | 165.78 | 330.40 |
| 8 | 4995 | 167.56 | 333.60 |
| 9 | 678 | 175.83 | 348.50 |
| 10 | 2537 | 167.39 | 333.30 |
| 11 | 1888 | 169.67 | 337.40 |
| 12 | 583 | 167.78 | 334.00 |
| 13 | 3001 | 168.17 | 334.70 |
| 14 | 3148 | 167.11 | 332.80 |
| 15 | 7533 | 169.50 | 337.10 |
| 16 | 7377 | 171.28 | 340.30 |
| 17 | 7371 | 174.00 | 345.20 |
| 18 | 6942 | 178.06 | 352.50 |
| 19 | 6267 | 174.22 | 345.60 |
| 20 | 6121 | 172.22 | 342.00 |
| 21 | 6001 | 170.33 | 338.60 |
| 22 | 9501 | 164.94 | 328.90 |
| 23 | 9864 | 164.28 | 327.70 |
| 24 | 9932 | 162.78 | 325.00 |
| 25 | 10674 | 136.22 | 277.20 |
| 26 | 9091 | 136.00 | 276.80 |
| 27 | 8463 | 163.11 | 325.60 |
| 28 | 8462 | 165.22 | 329.40 |
| 29 | 8197 | 167.89 | 334.20 |
| 30 | 9741 | 73.83 | 164.90 |
| 31 | 9770 | 73.83 | 164.90 |
| 32 | 10051 | 77.83 | 172.10 |
| 33 | 10498 | 80.44 | 176.80 |
| 34 | 9102 | 79.06 | 174.30 |
| 35 | 8578 | 87.11 | 188.80 |
| 36 | 8225 | 91.06 | 195.90 |
| 37 | 8001 | 74.22 | 165.60 |

Temperatures @ 4.000 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 177.89 | 352.20 |
| 2 | 4532 | 181.56 | 358.80 |
| 3 | 4227 | 178.56 | 353.40 |
| 4 | 4752 | 174.22 | 345.60 |
| 5 | 4838 | 170.94 | 339.70 |
| 6 | 3309 | 167.44 | 333.40 |
| 7 | 3419 | 167.33 | 333.20 |
| 8 | 4995 | 168.50 | 335.30 |
| 9 | 678 | 173.11 | 343.60 |
| 10 | 2537 | 166.89 | 332.40 |
| 11 | 1888 | 166.72 | 332.10 |
| 12 | 583 | 167.44 | 333.40 |
| 13 | 3001 | 169.61 | 337.30 |
| 14 | 3148 | 168.33 | 335.00 |
| 15 | 7533 | 170.78 | 339.40 |
| 16 | 7377 | 172.28 | 342.10 |
| 17 | 7371 | 173.11 | 343.60 |
| 18 | 6942 | 175.72 | 348.30 |
| 19 | 6267 | 173.39 | 344.10 |
| 20 | 6121 | 172.67 | 342.80 |
| 21 | 6001 | 171.17 | 340.10 |
| 22 | 9501 | 167.22 | 333.00 |
| 23 | 9864 | 165.28 | 329.50 |
| 24 | 9932 | 163.61 | 326.50 |
| 25 | 10674 | 135.11 | 275.20 |
| 26 | 9091 | 134.94 | 274.90 |
| 27 | 8463 | 163.94 | 327.10 |
| 28 | 8462 | 166.22 | 331.20 |
| 29 | 8197 | 169.39 | 336.90 |
| 30 | 9741 | 71.28 | 160.30 |
| 31 | 9770 | 71.28 | 160.30 |
| 32 | 10051 | 75.83 | 168.50 |
| 33 | 10498 | 78.89 | 174.00 |
| 34 | 9102 | 77.39 | 171.30 |
| 35 | 8578 | 85.61 | 186.10 |
| 36 | 8225 | 89.22 | 192.60 |
| 37 | 8001 | 72.22 | 162.00 |

Temperatures @ 4.500 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 177.89 | 352.20 |
| 2 | 4532 | 179.67 | 355.40 |
| 3 | 4227 | 178.17 | 352.70 |
| 4 | 4752 | 173.78 | 344.80 |
| 5 | 4838 | 170.22 | 338.40 |
| 6 | 3309 | 168.56 | 335.40 |
| 7 | 3419 | 168.00 | 334.40 |
| 8 | 4995 | 168.78 | 335.80 |
| 9 | 678 | 171.00 | 339.80 |
| 10 | 2537 | 166.28 | 331.30 |
| 11 | 1888 | 164.56 | 328.20 |
| 12 | 583 | 166.89 | 332.40 |
| 13 | 3001 | 170.22 | 338.40 |
| 14 | 3148 | 168.78 | 335.80 |
| 15 | 7533 | 171.22 | 340.20 |
| 16 | 7377 | 172.50 | 342.50 |
| 17 | 7371 | 172.17 | 341.90 |
| 18 | 6942 | 173.83 | 344.90 |
| 19 | 6267 | 172.56 | 342.60 |
| 20 | 6121 | 172.56 | 342.60 |
| 21 | 6001 | 171.33 | 340.40 |
| 22 | 9501 | 168.33 | 335.00 |
| 23 | 9864 | 165.67 | 330.20 |
| 24 | 9932 | 163.89 | 327.00 |
| 25 | 10674 | 134.22 | 273.60 |
| 26 | 9091 | 134.06 | 273.30 |
| 27 | 8463 | 164.28 | 327.70 |
| 28 | 8462 | 166.61 | 331.90 |
| 29 | 8197 | 170.00 | 338.00 |
| 30 | 9741 | 69.50 | 157.10 |
| 31 | 9770 | 69.50 | 157.10 |
| 32 | 10051 | 74.44 | 166.00 |
| 33 | 10498 | 77.78 | 172.00 |
| 34 | 9102 | 76.28 | 169.30 |
| 35 | 8578 | 84.56 | 184.20 |
| 36 | 8225 | 88.00 | 190.40 |
| 37 | 8001 | 70.83 | 159.50 |

Temperatures @ 5.000 hr

| Location | Node | Temp(C) | Temp(F) |
|---|---|---|---|
| 1 | 5001 | 177.61 | 351.70 |
| 2 | 4532 | 178.17 | 352.70 |
| 3 | 4227 | 177.56 | 351.60 |
| 4 | 4752 | 173.17 | 343.70 |
| 5 | 4838 | 169.50 | 337.10 |
| 6 | 3309 | 169.00 | 336.20 |
| 7 | 3419 | 168.17 | 334.70 |
| 8 | 4995 | 168.72 | 335.70 |
| 9 | 678 | 169.33 | 336.80 |
| 10 | 2537 | 165.67 | 330.20 |
| 11 | 1888 | 162.83 | 325.10 |
| 12 | 583 | 166.28 | 331.30 |
| 13 | 3001 | 170.22 | 338.40 |
| 14 | 3148 | 168.78 | 335.80 |
| 15 | 7533 | 171.17 | 340.10 |
| 16 | 7377 | 172.39 | 342.30 |
| 17 | 7371 | 171.28 | 340.30 |
| 18 | 6942 | 172.33 | 342.20 |
| 19 | 6267 | 171.61 | 340.90 |
| 20 | 6121 | 172.17 | 341.90 |
| 21 | 6001 | 171.06 | 339.90 |
| 22 | 9501 | 168.78 | 335.80 |
| 23 | 9864 | 165.67 | 330.20 |
| 24 | 9932 | 163.89 | 327.00 |
| 25 | 10674 | 133.44 | 272.20 |
| 26 | 9091 | 133.28 | 271.90 |
| 27 | 8463 | 164.28 | 327.70 |
| 28 | 8462 | 166.61 | 331.90 |
| 29 | 8197 | 170.06 | 338.10 |
| 30 | 9741 | 68.17 | 154.70 |
| 31 | 9770 | 68.17 | 154.70 |
| 32 | 10051 | 73.44 | 164.20 |
| 33 | 10498 | 77.00 | 170.60 |
| 34 | 9102 | 75.50 | 167.90 |
| 35 | 8578 | 83.83 | 182.90 |
| 36 | 8225 | 87.06 | 188.70 |
| 37 | 8001 | 69.83 | 157.70 |

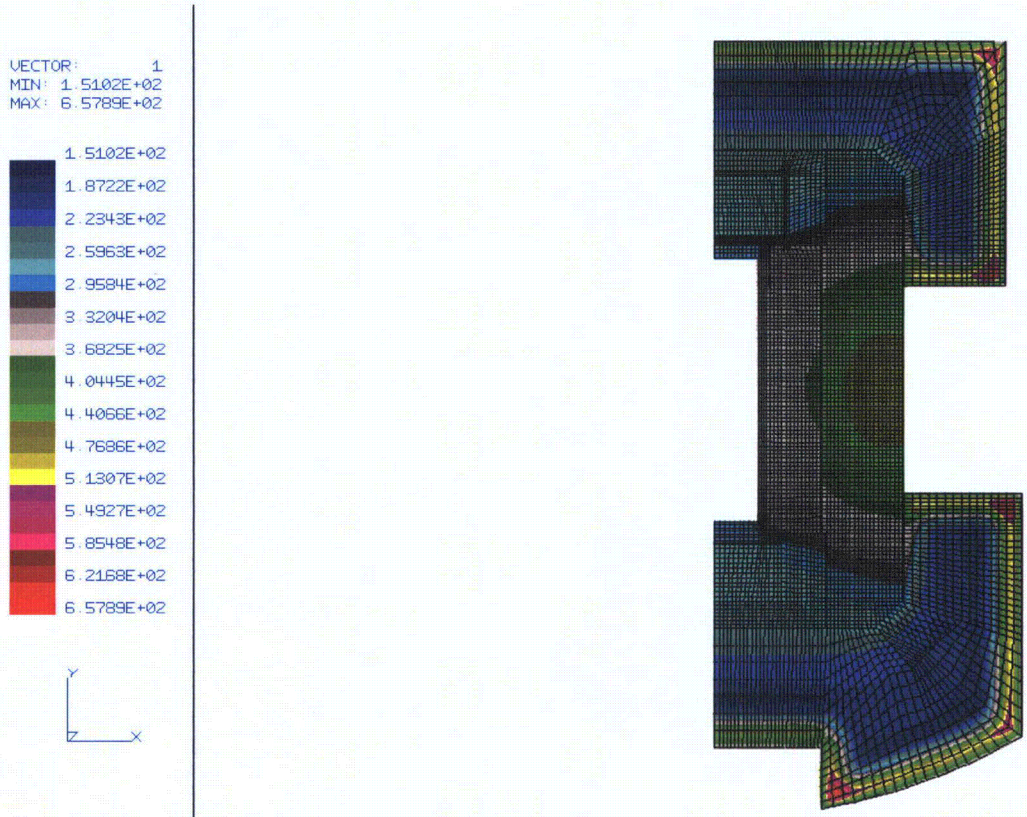



**Figure 3-37. Load Case 112 – Fire at 60 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

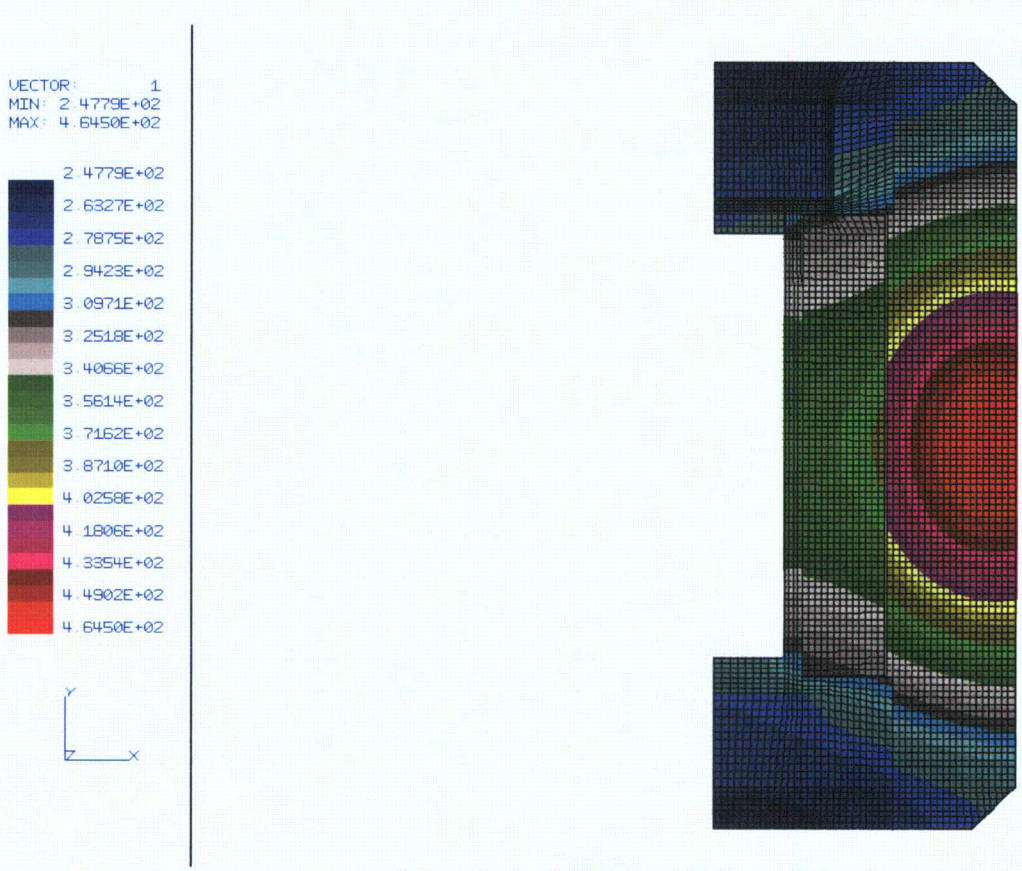



**Figure 3-38. Load Case 112 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

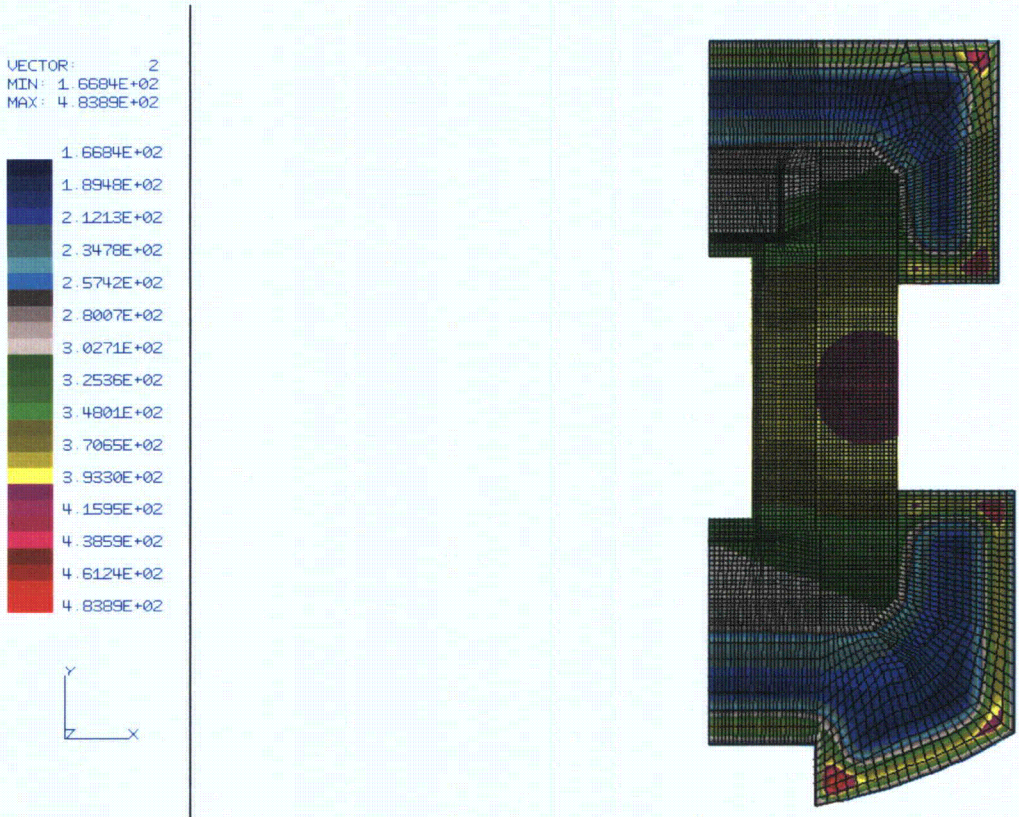



**Figure 3-39. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

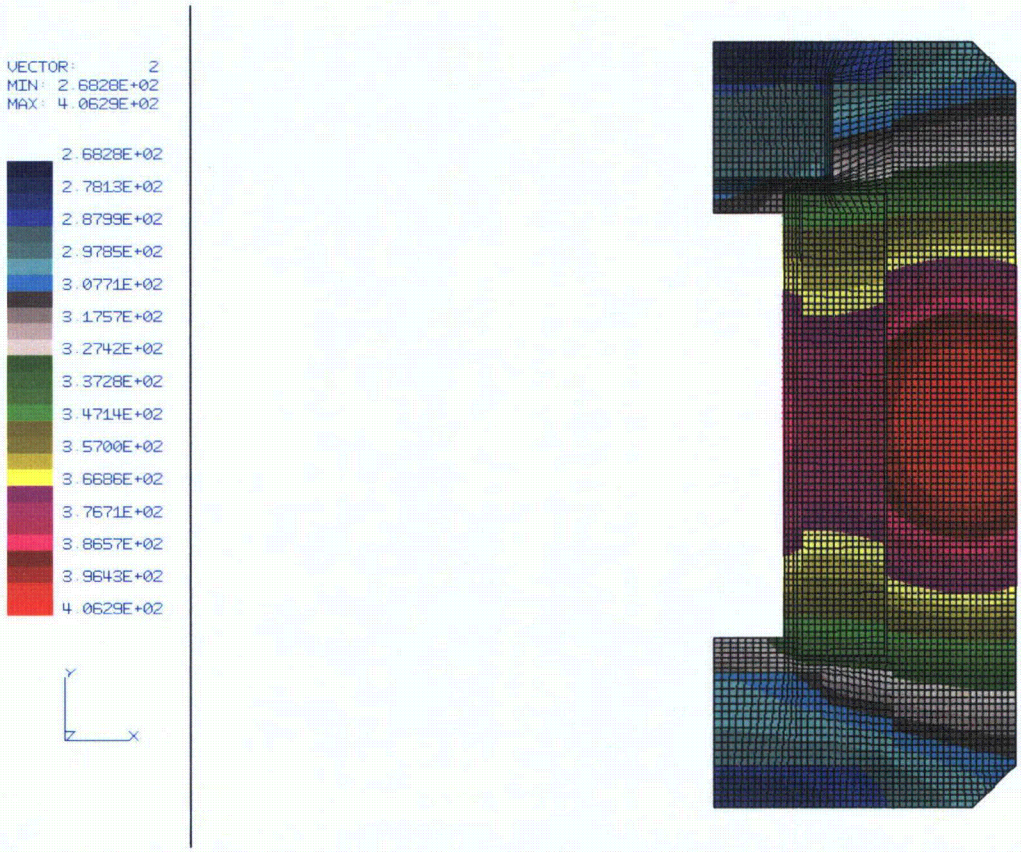



**Figure 3-40. Load Case 113 – Fire at 90 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

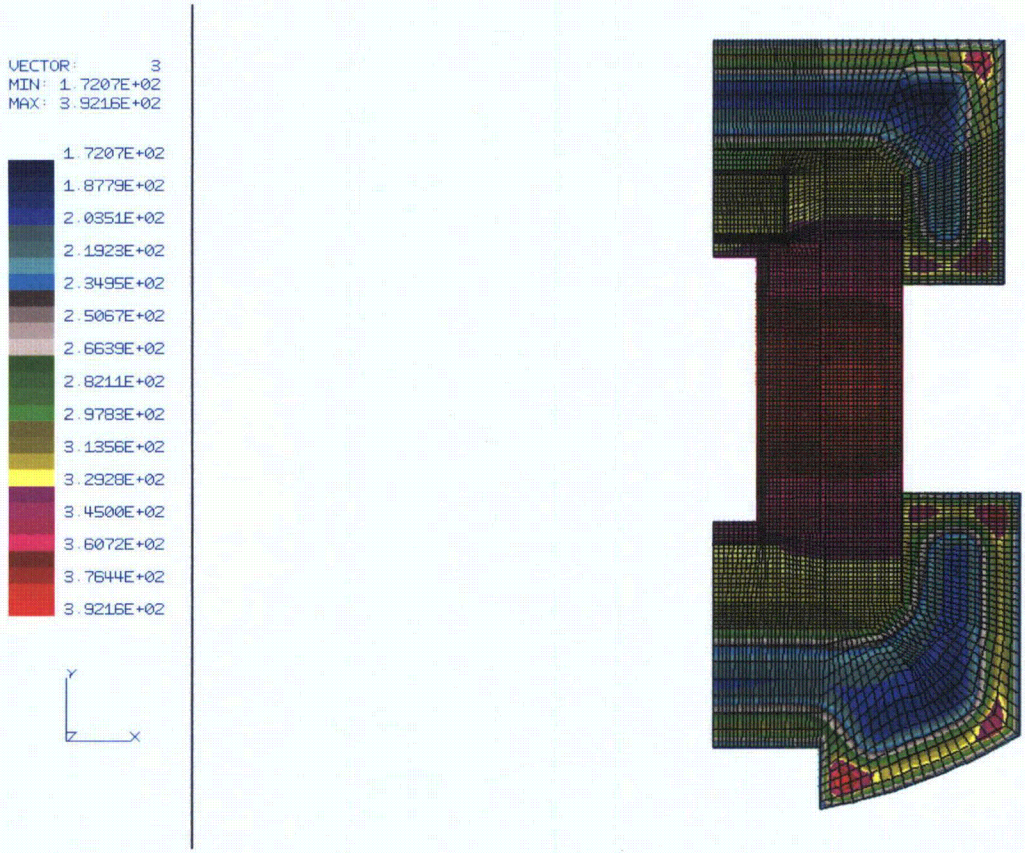



**Figure 3-41. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

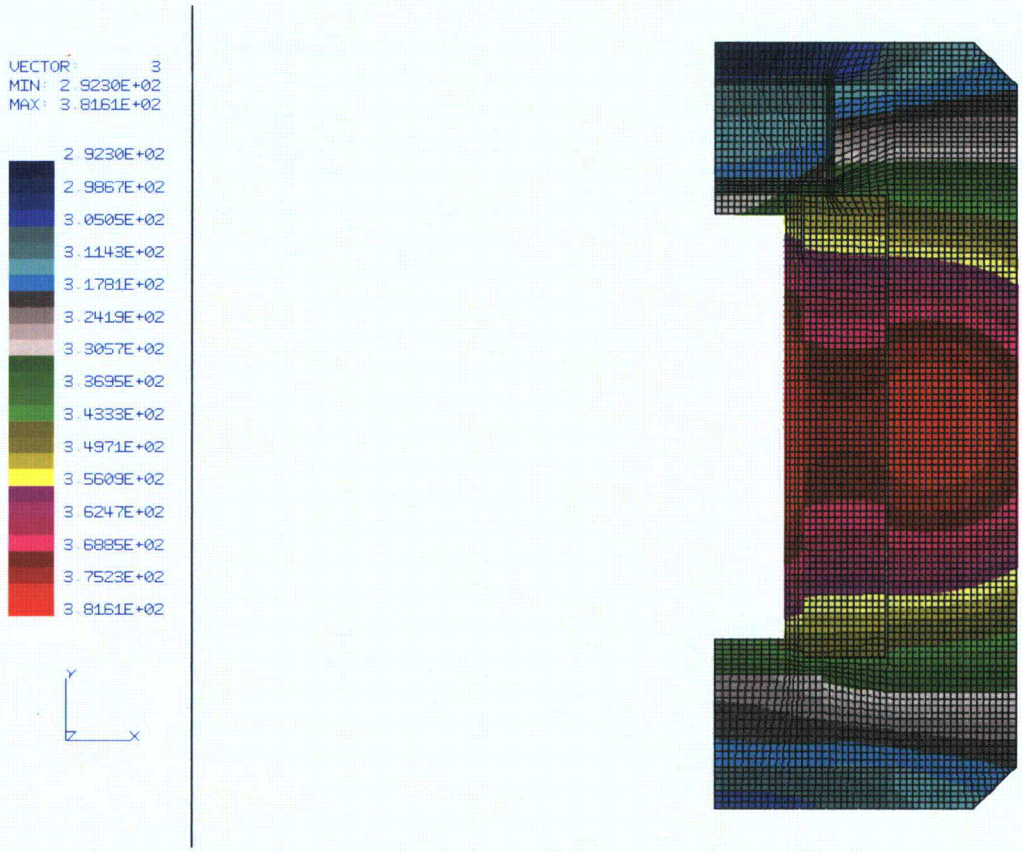



**Figure 3-42. Load Case 114 – Fire at 120 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Cask Model – Model AOS-100B**

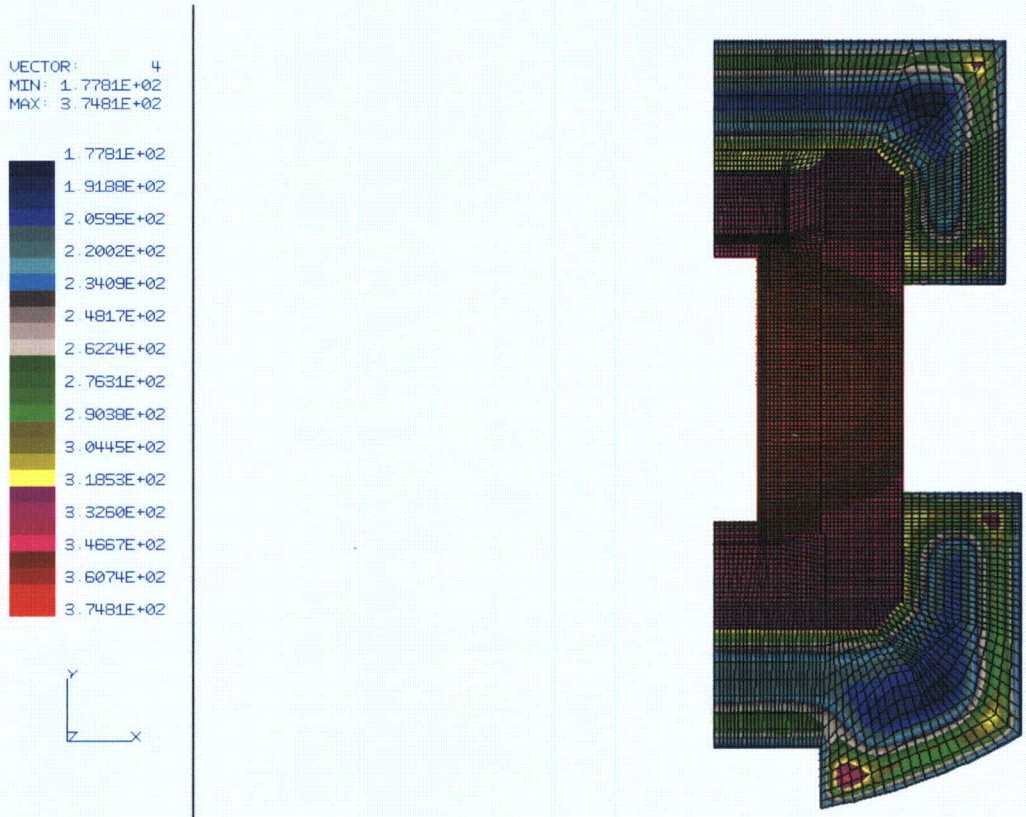



**Figure 3-43. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Model – Model AOS-100B**

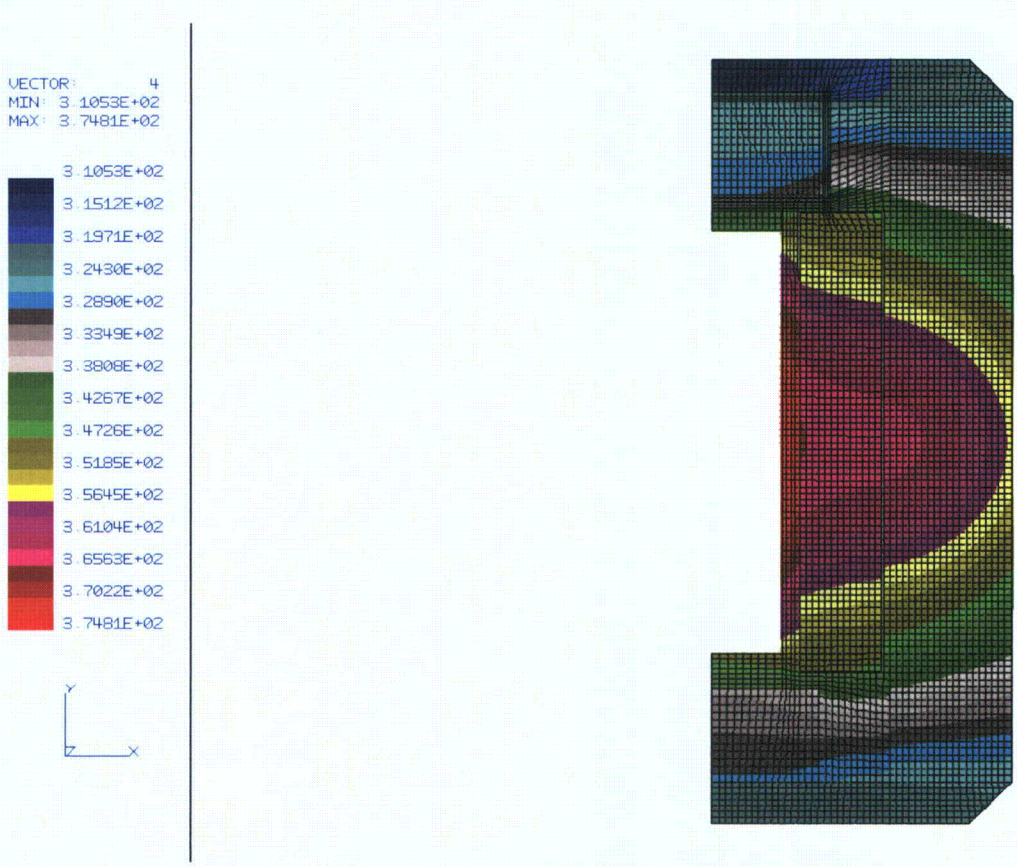



**Figure 3-44. Load Case 115 – Fire at 150 Minutes, 100°F, Maximum Decay Heat plus Solar, Maximum Insolation, Carbon Steel Shielding, Entire Cask – Model AOS-100B**

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