TN Calculation 1121-0400, Revision 1,

Calculation of OS197L Cask Shell Temperature with 11.0 and 18.4 kW Heat Loads

TRANSNUCLEAR AN AREVA COMPANY	**Calculation**	**Calculation No.:** 1121-0400 **Revision No.:** 1 **Page:** 1 of 32

CALCULATION TITLE: **Calculation of OS197L Cask Shell Temperature with 11.0 and 18.4 kW Heat Loads**

Project: OPPD Fort Calhoun Station, Spent Fuel Storage System

DCR: 1121-011

SUMMARY DESCRIPTION:

The NUHOMS® OS197L (75 ton) transfer cask is designed without a typical lead gamma shield and with a removable water filled neutron shield. To compensate for this reduced shielding capability, the transfer skid for the OS197L cask is designed with auxiliary shielding. While the auxiliary shielding prevents direct insolation heating of the cask surface, it also affects the convective and radiative heat transfer from the cask. This calculation documents the predicted cask shell temperature of the OS197L transfer cask within its auxiliary shielding enclosure using a computational fluid dynamics (CFD) analysis. The analysis, which supports an exemption request, is conducted for the bounding off-normal transfer condition with a peak ambient temperature of 117°F, regulatory insolation, and for decay heat loads of 11.0 and 18.4 kW. The results of the analysis are used as a boundary condition in the detailed analysis of the OS197L cask for transfer conditions.

If original issue, is licensing review per TIP 3.5 required?

Yes ☐ **No** ☒ **(explain below)** **Licensing Review No.:** ____________

This calculation is in support of an exemption request to be submitted to the NRC following review and approval by OPPD.

Software Utilized:	**Version:**	**Number of CDs:**
Fluent / Gambit	6.2 / 2.2	1

Calculation is complete:

Gregory Banken Gregory L Banken 6/4/06 (Date)

Calculation has been check for consistency, completeness and correctness:

Larry Nielsen LH Nielsen 6/5/06 (Date)

Calculation is approved for use:

James W. Axline (Project Engineer Signature) 6/5/06 (Date)

PROJECT NO:	**1121**	**REVISION:**	1
CALCULATION NO:	**1121-0400**	**PAGE:**	2 of 32

REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISCS
0	6/1/2006	Initial issue	All	1
1	6/5/06	Added analysis for 11.0 kW decay heat load and revised solution scheme for pressure to improve solution convergence	1 to 5, 13, 16 to 32	1

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1.0 INTRODUCTION

The NUHOMS® OS197L (75 ton) transfer cask is designed without a typical lead gamma shield and with a removable water filled neutron shield. To compensate for this reduced shielding capability, the transfer skid for the OS197L cask is designed with auxiliary shielding. While the auxiliary shielding prevents direct insolation heating of the cask surface, it also affects the convective and radiative heat transfer from the cask.

1.1 Objective

The objective of this calculation is to determine the temperature distribution around the shell of the OS197L transfer cask's neutron shield while the cask is in its auxiliary shielding enclosure on the transfer skid. The average shell temperature is to be determined using a computational fluid dynamics (CFD) methodology and for the bounding off-normal condition of 117°F with decay heat loads of 11.0 and 18.4 kW.

1.2 Purpose

The purpose of this calculation is to provide a safety basis prediction of the average temperature on the cask's water filled neutron shield while the cask is within its auxiliary shielding enclosure on the transfer skid. The predicted average temperature is to be used as the boundary condition for separate, detailed analysis of the OS197L cask under transfer conditions.

1.3 Scope

The scope of this calculation is limited to steady-state conditions at the off-normal condition of 117°F and for decay heat loads of 11.0 and 18.4 kW. The OS197L transfer cask is assumed to be mounted horizontally on the transfer skid and with its removable liquid neutron shields installed. The dimensions and thermo-physical properties of the cask and auxiliary shielding are as detailed herein.

2.0 DESIGN INPUT

The geometry of the CFD model is based on the following applicable design drawings:

1) NUHOMS® OS197-Light Onsite Transfer Cask, Cask Body Assembly, Drawing #NUH06L-1001 [1]
2) NUHOMS® OS197-Light Onsite Transfer Cask, Light Neutron Shield Assembly, Drawing #NUH06L-1002 [2]
3) NUHOMS® OS197-Light Onsite Transfer Cask, Standard Shielding Assembly, Drawing #NUH06L-1003 [3]
4) NUHOMS® OS197-Light Onsite Transfer Cask, Support Skid Assembly, Drawing #NUH06L-1006 [4]
5) NUHOMS® OS197-Light Onsite Transfer Cask, Support Skid Additional Shielding, Drawing #NUH06L-1007 [5].

The OS917L cask uses a 3.5-inch thick removable liquid neutron shield. The shield provides a total water thickness of 3-inches. Figure 2-2 illustrates the shield design. The outer diameter of the OS197L cask with the cask shield installed is 80.36-inches.

Figure 2-3 illustrates a solid view of the OS197L transfer cask mounted on the transfer skid, while Figure 2-4 presents a cross-section view through the cask-skid assembly.

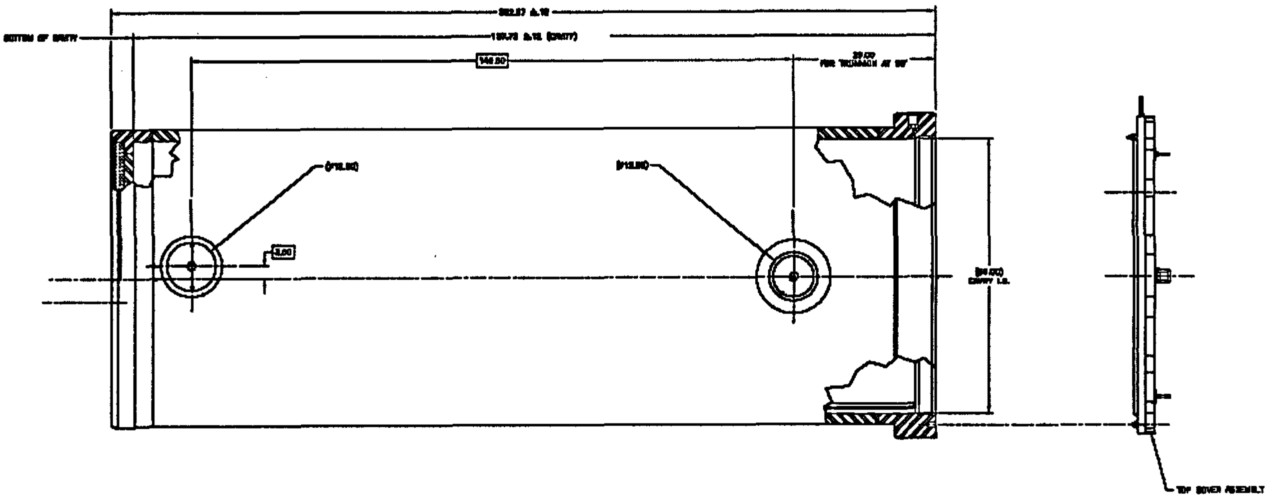


Figure 2-1 - NUHOMS® OS197-Light Cask Body Assembly

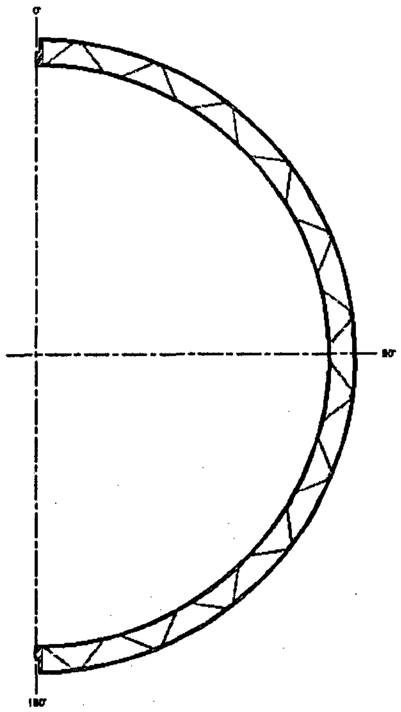
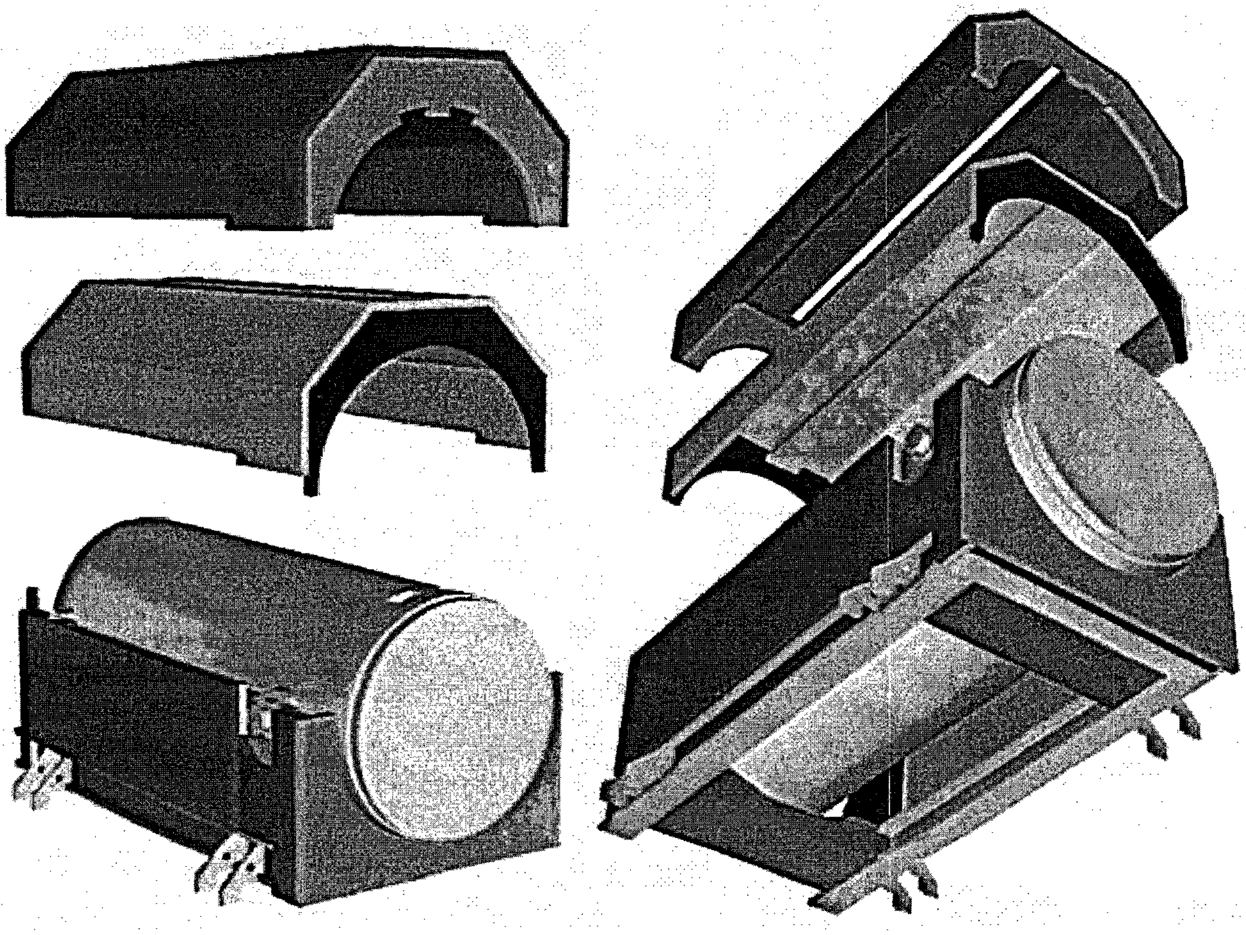


Figure 2-2 - OS197L Cask Shielding Assembly



Exploded Side View

Exploded Bottom View

Figure 2-3 - OS197L (75 ton) Transfer Cask within Transfer Skid with Additional Auxiliary Shielding

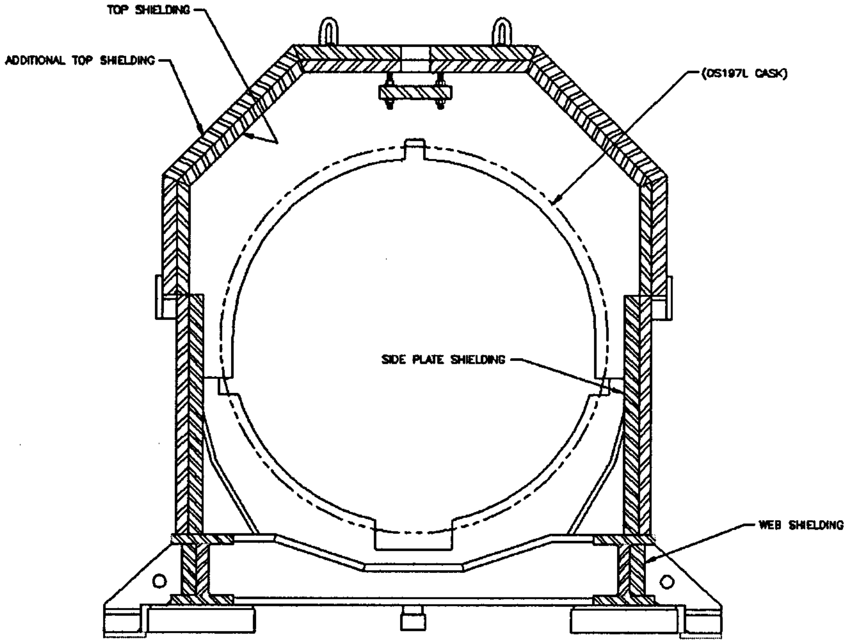


Figure 2-4 - Cross-Section View through OS197L Transfer Skid

3.0 MODELING ASSUMPTIONS

3.1 General Assumptions

The general assumptions used in the CFD modeling are:

1. Any heat removed through the cask end plugs is conservatively neglected.
2. The total decay heat is considered evenly distributed over the outer surface of the cask's liquid neutron shield shell. This assumption is consistent with previous OS197 analysis methodology and reflects the axial spreading of the decay heat load due to the high axial conductivity of the DSC basket and rails, and, second, the water filled neutron shield.
3. The CFD modeling need only address the geometry of the OS197L cask and its transport skid as it exists between the front and rear trunnion towers. While the combination of the tower structure and the cask trunnions will reduce the local flow area between the cask and the skid's auxiliary shielding, the potential reduction in the convective heat transfer from the cask will be limited to the lower half of the cask and to the width of the trunnions. Further, the approximately 113.5 inches between the front and rear trunnion towers spans 62% of the length of the liquid neutron shield, over which the majority of the heat rejection will occur. The OS197L transfer skid geometry results in a minimum clearance of approximately 3.8 inches between the cask and the transfer skid, even at the trunnion towers.
4. The outer surfaces of the shielding on the transfer skid are finished with a 'dark blue' color coating that yields a solar absorptivity of 0.90 or less and an emissivity of 0.85 or greater. Similarly, the inner surface of the shielding is to have a similar finish that yields an emissivity of 0.85 or greater.
5. The regulatory insolation [6] averaged over 12 hours is applied to the outer surfaces of the auxiliary shielding. While the thickness of the auxiliary shielding, combined with the thermal mass of the OS197 casks and payload, could justify the use of 24-averaged values, the 12-hour average values provide conservatism. The 12-hour average insolation on the roof of the transfer skid is assumed to be 245.8 Btu/hr-ft^2, 61.5 Btu/hr-ft^2 on the vertical surfaces, and 122.9 Btu/hr-ft^2 on the angled portion of the auxiliary shielding. These incident heating values are reduced by 10% to account for the assumed solar absorptivity of 0.90 for the coating used on the shields (see assumption 4).
6. The analysis is conducted for a steady-state ambient temperature of 107°F. A steady-state analysis at this temperature level has been shown by previous analyses to bound the transient thermal performance achieved using a diurnal cycle for ambient air with a peak of 117°F.

3.2 Material Properties

The use of steady-state analysis simplifies the required material properties in that the density and specific heat of the cask shell and the auxiliary shields are not needed for the calculation. Further, since conduction within the cask shell is conservatively ignored, the thermal conductivity of the Type 304 stainless steel is also not required for the analysis. The auxiliary shields on the transfer skid are assumed to be fabricated of carbon steel with a fixed (and conservatively low) thermal conductivity of 24.4 Btu/hr-ft-°F. The emissivity of the cask neutron shield shell is assumed to be 0.587 [7], while the emissivity of the auxiliary shields is assumed be 0.8 on both the inner and outer surfaces.

The piecewise linear, temperature dependent, thermal properties used for air [8] are presented in Table 3-1. The density of the air is computed using the ideal gas relationship.

Table 3-1 - Material Properties, Air

Temperature °F	Density lbm/ft^3	Specific Heat Btu/lbm-°F	Conductivity Btu/hr-ft-°F	Viscosity lbm/ft-sec
0	Ideal gas assumed	0.240	0.0131	1.098E-05
50		0.240	0.0143	1.191E-05
100		0.241	0.0155	1.280E-05
200		0.242	0.0178	1.446E-05
300		0.243	0.0199	1.601E-05
400		0.245	0.0220	1.746E-05
500		0.248	0.0240	1.883E-05
600		0.251	0.0259	2.012E-05

4.0 METHODOLOGY

The FLUENT™, Version 6.2, and GAMBIT™, Version 2.2, codes [9] are used for this analysis. The FLUENT™ code is a general-purpose computational fluid dynamics (CFD) code that is recognized internationally as one of the premier codes in its class. The general modeling capabilities of the code as they relate to this application include:

- Meshing flexibility using structured and unstructured mesh generation with hexahedra, non-hexahedra, and tetrahedral mesh types
- Capability to model low speed, buoyancy driven flow regimes
- Steady-state and transient flows
- Inviscid, laminar, and turbulent flows
- Heat transfer including forced, natural, and mixed convection, conjugate heat transfer, and radiation
- Custom materials property database
- Integrated problem set-up and post-processing

GAMBIT™ is an interactive, object-based software code that allows complex geometries to be modeled and meshed using a combination of shapes. Quadrilateral and triangular elements are used for 2D simulations, while hexahedra, tetrahedra, prisms, and pyramid shaped elements are available for 3D simulations. The GAMBIT ™ module does not perform any CFD related numerical calculations itself, but serves as a preprocessor to the Fluent™ code to generate a computational mesh. GAMBIT ™ has many automated features for building or joining hybrid meshes with attention to boundary layers, non-uniform sizing, and core regions of hexahedral cells.

The verification and validation of the FLUENT™ and GAMBIT™ codes for the computation of generic buoyancy driven convection heat transfer within an enclosure is documented in [10].

A three-dimensional model of the OS197L cask and transfer skid was created using GAMBIT™ from the design reference drawings listed in Section 2.0. The model (see Figure 4-1) represents a 12-inch long segment of the cask and transfer skid. For the purposes of this calculation the cask is represented simply by the outer shell of its liquid neutron shield. The heat transfer within the cask is evaluated by a separate, detailed model of the cask. Per [3], the length of the neutron shield is 187.85-inches long. Subtracting 4-inches for the top and bottom shield rings yields a net water jacket length of 183.85-inches. Based on this length, an outside radius for the neutron shield shell of 40.18-inches, and a decay heat loading of 18.4 kW, the uniform heat flux applied over the surface area of the shell is computed as:

$$\ddot{q} = \frac{18.4\text{kW} \cdot 3412.1415 \frac{\text{Btu}/\text{hr}}{\text{kW}}}{\left(2 \cdot \pi \cdot 40.18\,\text{in} \cdot 183.85\,\text{in}/144 \frac{\text{in}^2}{\text{ft}^2}\right)} = 194.784 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

Similarly, for a decay heat loading of 11.0 kW, the uniform heat flux applied over the surface area of the shell is computed as:

$$\ddot{q} = \frac{11.0\text{kW} \cdot 3412.1415 \frac{\text{Btu}/\text{hr}}{\text{kW}}}{\left(2 \cdot \pi \cdot 40.18\,\text{in} \cdot 183.85\,\text{in}/144 \frac{\text{in}^2}{\text{ft}^2}\right)} = 116.447 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2}$$

Symmetry conditions are assumed along the vertical centerline of the cask-transfer skid assembly and at each end of the modeled segment. The computational mesh extends 150-inches in the x-direction and 200-inches in the y-direction to capture the flow field surrounding the transfer skid. Figure 4-2 illustrates perspective and plane views of the computational mesh at the centerline of the model. A total of approximately 68,300 mesh elements are used. Boundary layer meshes are used around the cask shell and the shield surfaces to improve the prediction of the flow and heat transfer near and at these surfaces. The boundary layer mesh on the cask shell uses an initial mesh element height of 0.0275-inches, a growth factor of 1.38 on subsequent mesh elements, and extends out approximately 1.75 inches (10 mesh cells). Similar boundary layer meshes are used on the inner and outer surfaces of the shields, except that the number of cells is reduced to 5 and 6, respectively. Figure 4-3 presents enlarged views of the computation mesh illustrating the boundary layer mesh on the cask shell and the inner surface of the shields.

Radiation exchange is modeled using the discrete ordinate methodology.

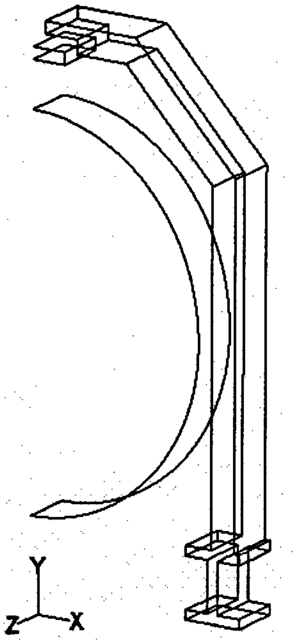


Figure 4-1 - Wire Frame Representation of OS197L Cask and Transfer Skid CFD Model

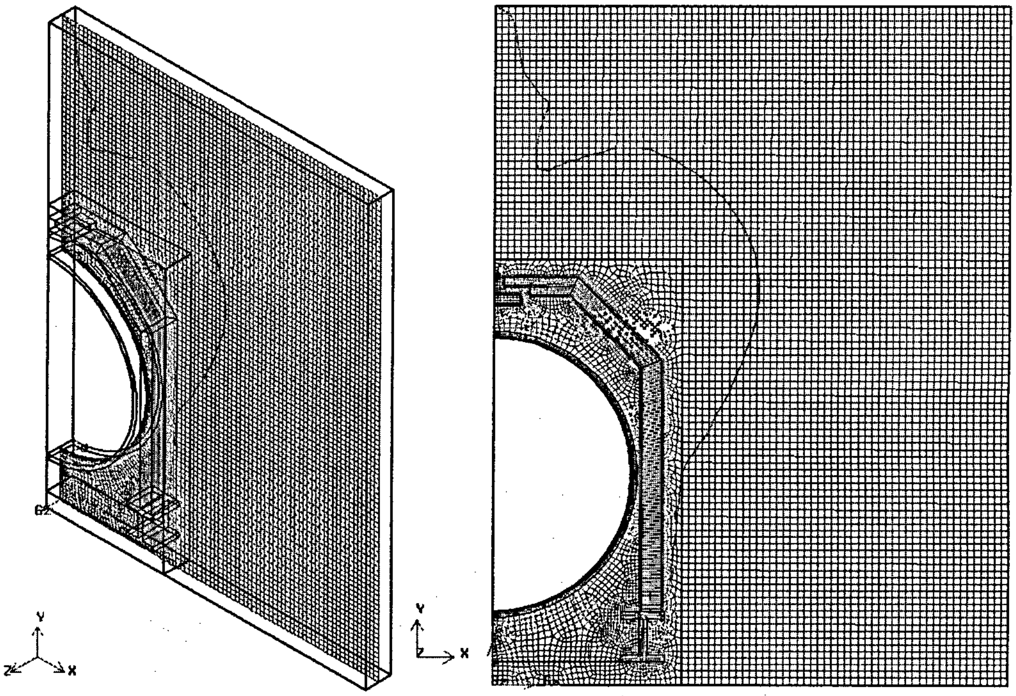
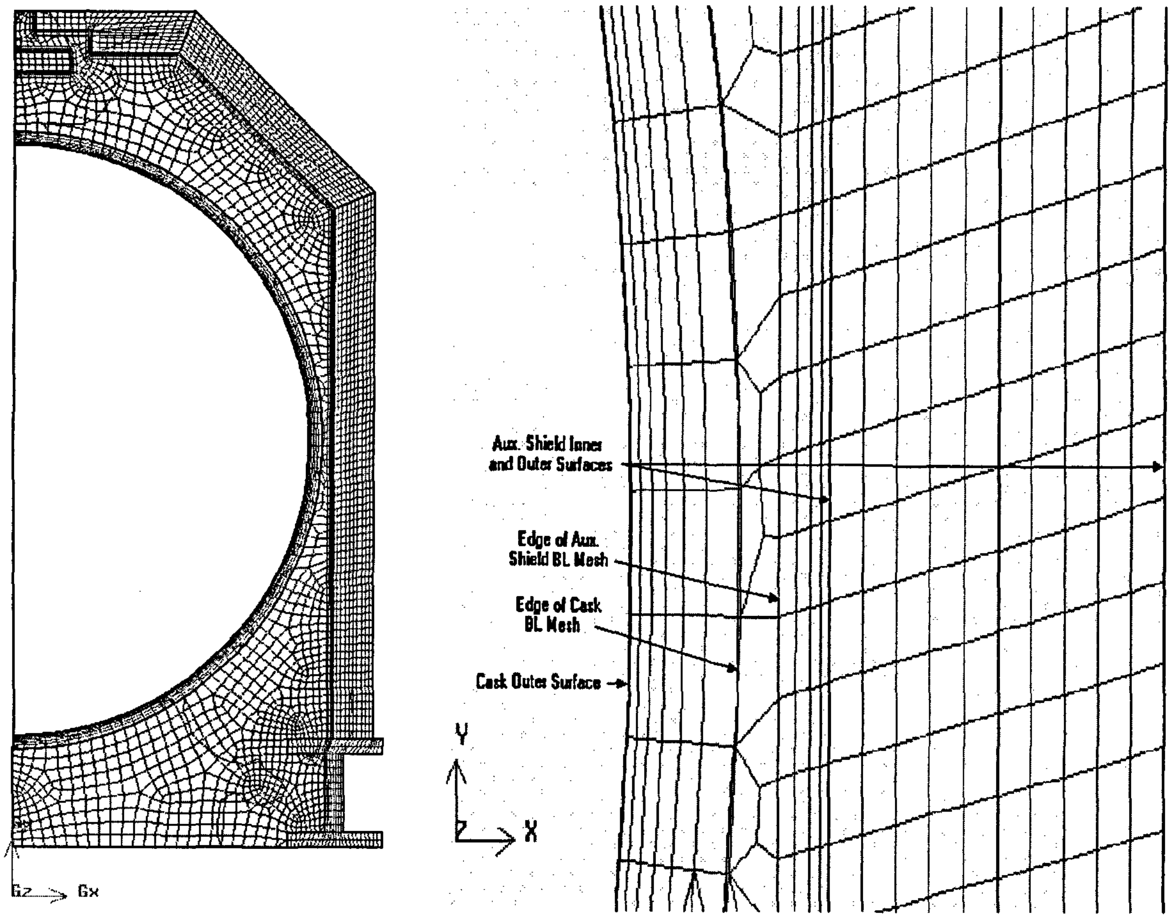


Figure 4-2 - Perspective and Plan Views of OS197L Cask/Transfer Skid Mesh



Interior Mesh

Enlarged View At Side of Cask

Figure 4-3 - Enlarged Views of OS197L Cask/Transfer Skid Mesh

5.0 CALCULATION RESULTS

5.1 OS197L (75-ton) Cask and Transfer Skid with 18.4 kW Decay Heat Load

The FLUENT™ model of the OS197L cask and transfer skid described in Section 4.0 was used to compute the flow and temperature distribution for the bounding off-normal hot condition of transfer with a decay heat loading of 18.4 kW. A second order discretization scheme for energy, momentum, and turbulence, a first order discretization on the discrete ordinate calculation, and the PRESTO solution scheme for pressure are used for the solution. The realizable turbulence model with enhanced wall functions is used to compute the turbulent heat transfer at the surface of the cask.

Figure 5-1 illustrates the predicted temperature distribution in the cask-transfer skid assembly, while Figure 5-2 and Figure 5-3 present the temperature distribution for the exterior surface of the cask's neutron shield and the transfer skid shield, respectively.

The peak temperature on the cask shell is predicted to occur back from the centerline of the cask, at the point where the flow separates from the cask and heads towards the exit. The fact that the cask shell temperature reaches a peak and then decreases slightly at the very top of the cask is attributed to the presence of flow recirculation in this region. Because of this recirculation, the surface flow does not stagnate at the top, center of the cask, as it would be for an isolated cask, and a lower surface temperature is achieved.

Figure 5-4 and Figure 5-5 illustrate the velocity profiles at the centerline of the model. As expected, the regions of elevated flow velocity occur adjacent to the cask surface, at the exit from the enclosure, and at the point where the cask-to-shield gap is a minimum. The minimum cask-shield gap for the modeled section of the OS197L cask and transfer skid combination is approximately 3.3-inches. Figure 5-6 illustrates an enlarged view of the velocity profile at the exit from the auxiliary shielding enclosure. The predicted region of flow stagnation and reversal under the hat section of the enclosure can be seen in the figure.

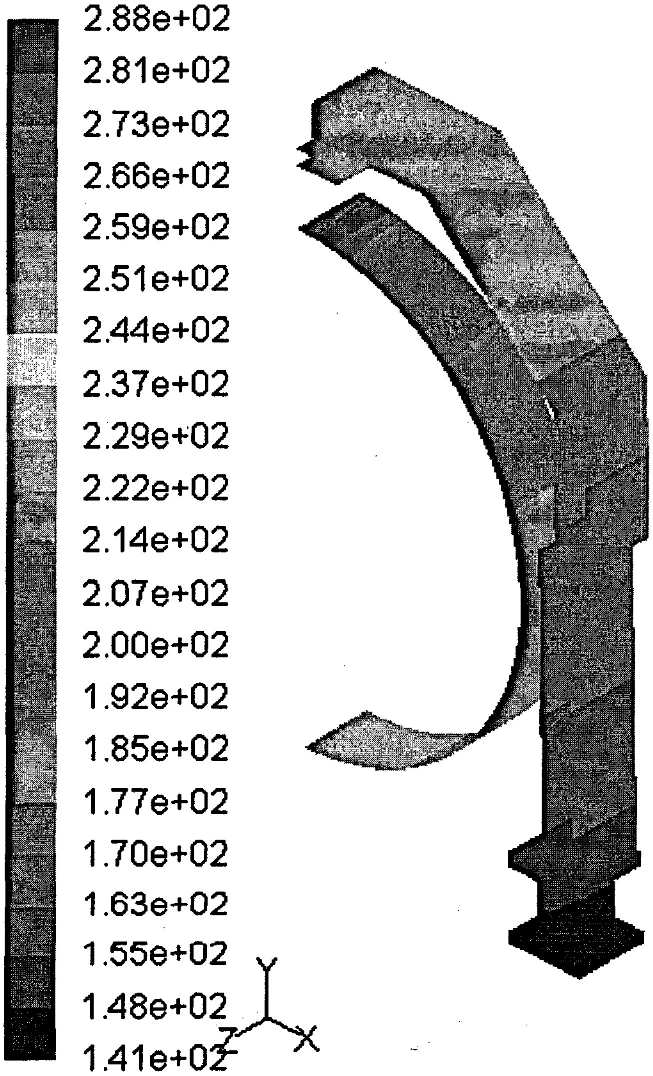
Based on this analysis, the temperature on the cask's neutron shield is predicted to vary from 247°F to a maximum temperature of 288°F. The area-weighted average temperature over the surface of the shell is predicted to be 258°F.

5.2 OS197L (75-ton) Cask and Transfer Skid with 11.0 kW Decay Heat Load

The analysis described above was repeated for a decay heat loading of 11.0 kW. Figure 5-7 illustrates the predicted temperature distribution in the cask-transfer skid assembly, while Figure 5-8 and Figure 5-9 present the temperature distribution for the exterior surface of the cask's neutron shield and the transfer skid shield, respectively. The results again indicate that the peak shell temperature occur back from the centerline of the cask.

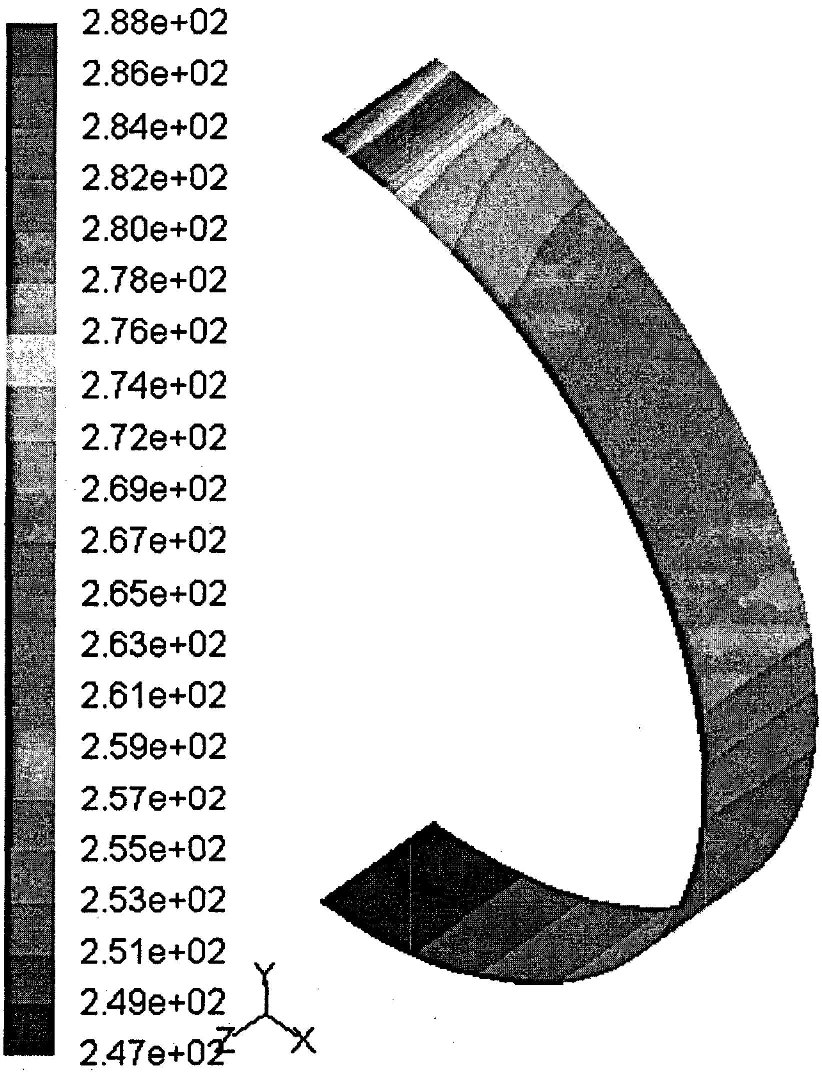
Figure 5-10 and Figure 5-11 illustrate perspective and plan views of the velocity profile at the centerline of the model. Except for the expected decrease in the peak velocity, the results are similar to those seen for the 18.4 kW decay loading. Figure 5-12 illustrates an enlarged view of the velocity profile at the exit from the auxiliary shielding enclosure.

Based on this analysis, the temperature on the cask's neutron shield is predicted to vary from 192°F to a maximum temperature of 241°F. The area-weighted average temperature over the surface of the shell is predicted to be 214°F.



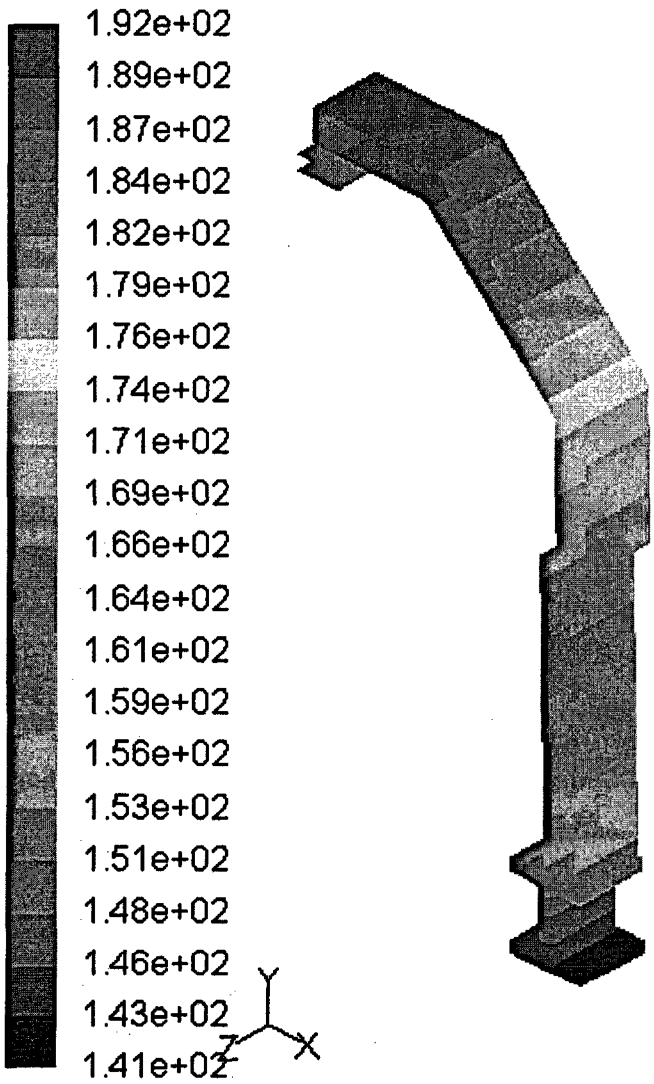
Note: Temperature is in units of °F

Figure 5-1 - Temperature Distribution for OS197L Cask-Transfer Skid Assembly with 18.4 kW Decay Heat



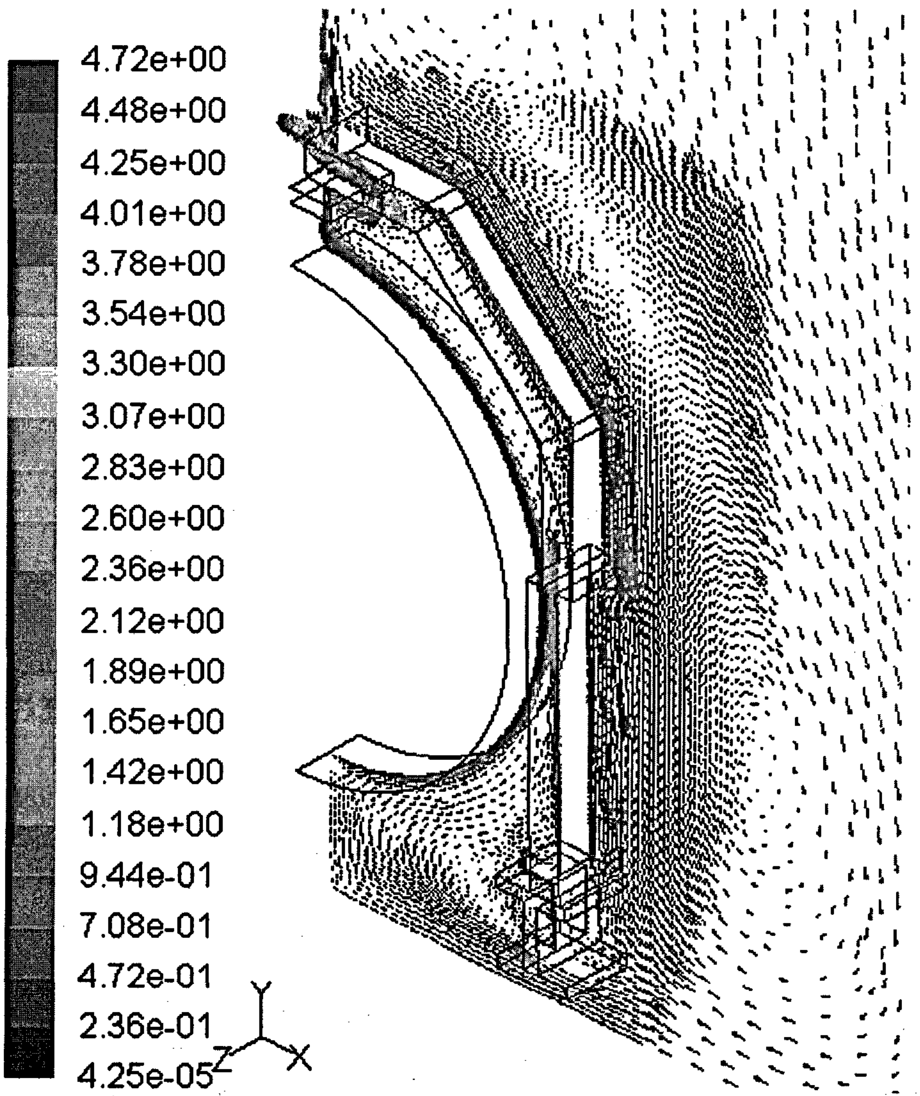
Note: Temperature is in units of °F

Figure 5-2 - Temperature Distribution Over OS197L Cask Exterior Shell with 18.4 kW Decay Heat Load



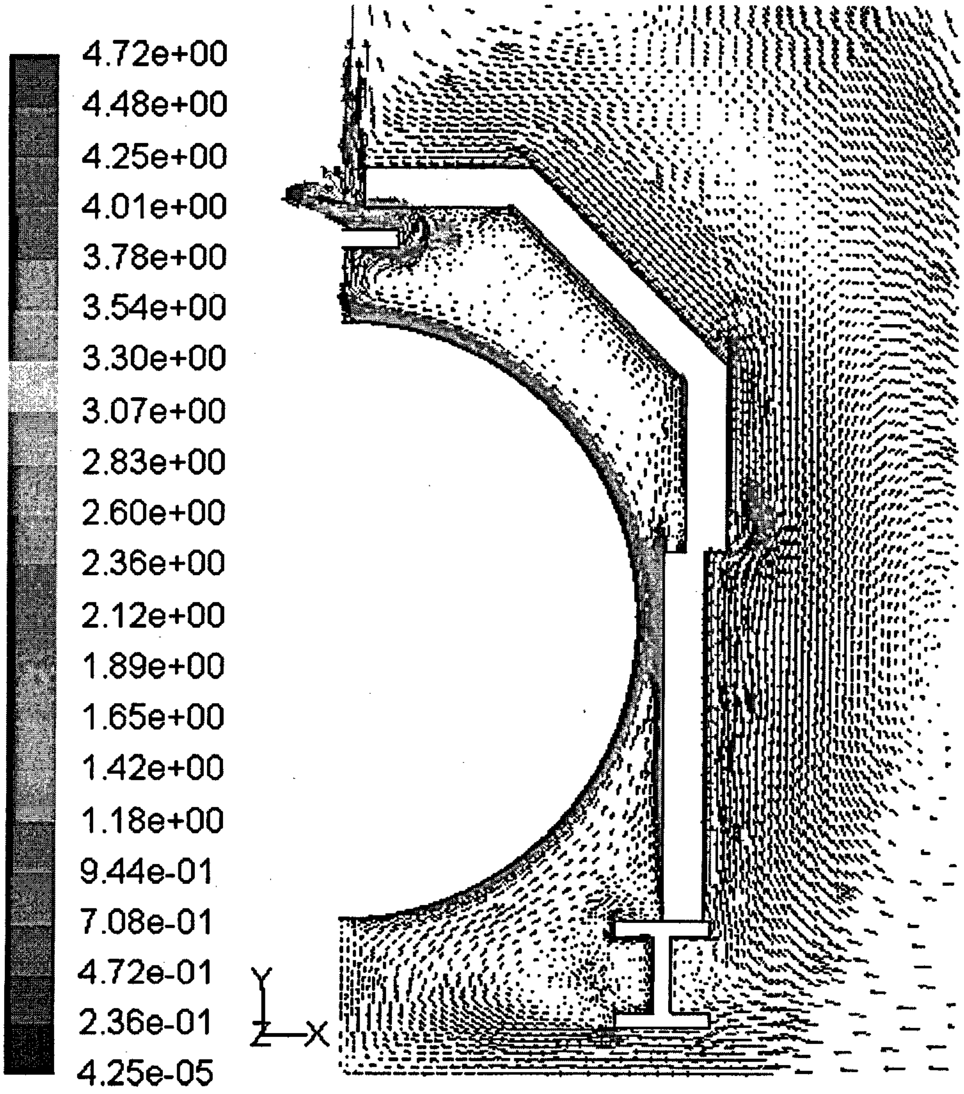
Note: Temperature is in units of °F

Figure 5-3 - Temperature Distribution for Transfer Skid Shields with 18.4 kW Decay Heat Load



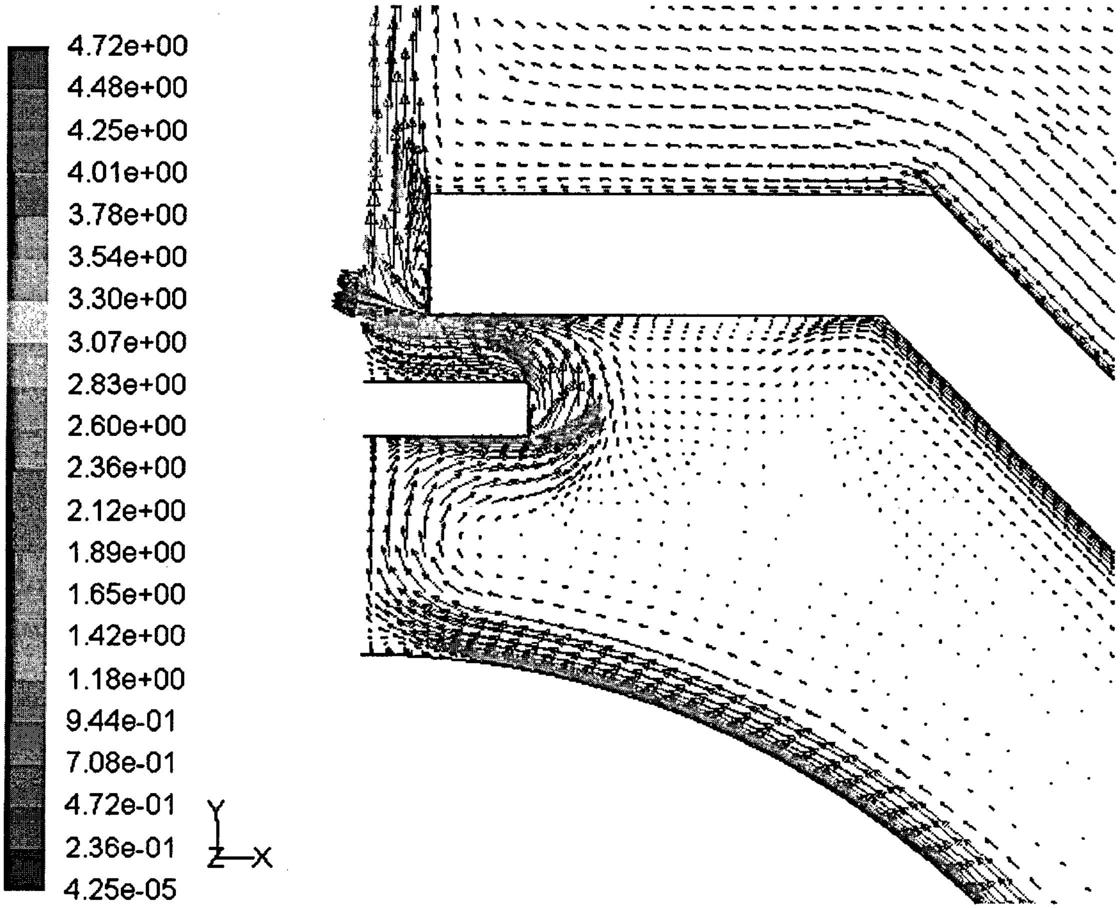
Note: Velocity is in units of ft/sec

Figure 5-4 - Velocity Distribution at Model Centerline with 18.4 kW Decay Heat Load



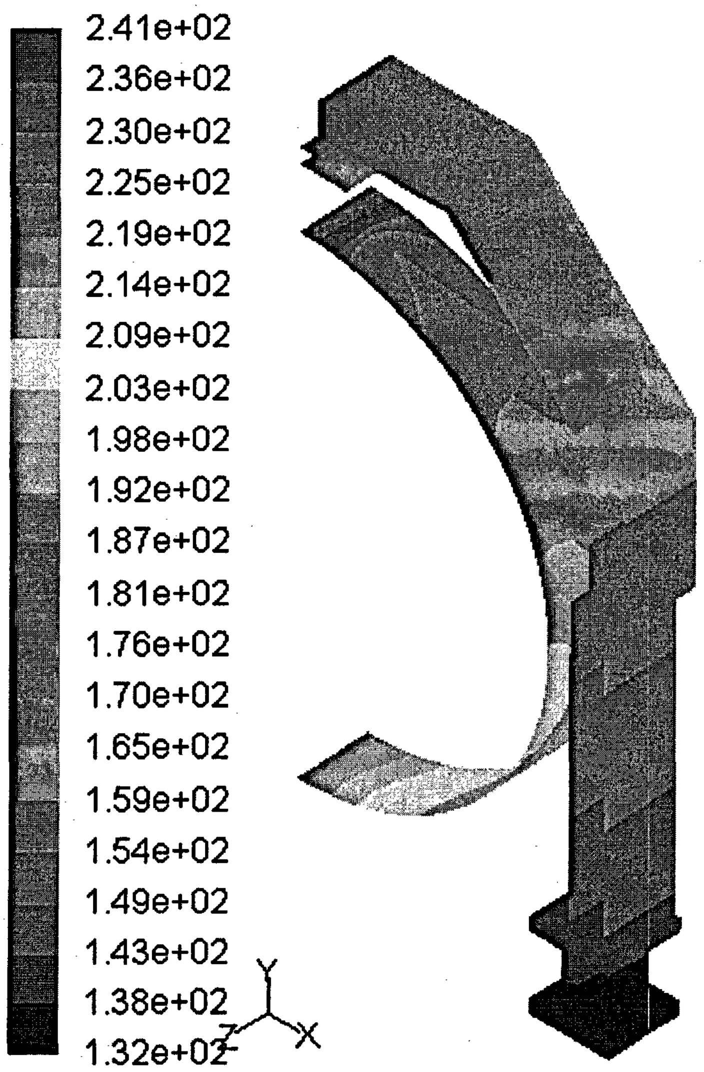
Note: Velocity is in units of ft/sec

Figure 5-5 - Velocity Distribution at Model Centerline with 18.4 kW Decay Heat Load, Plan View



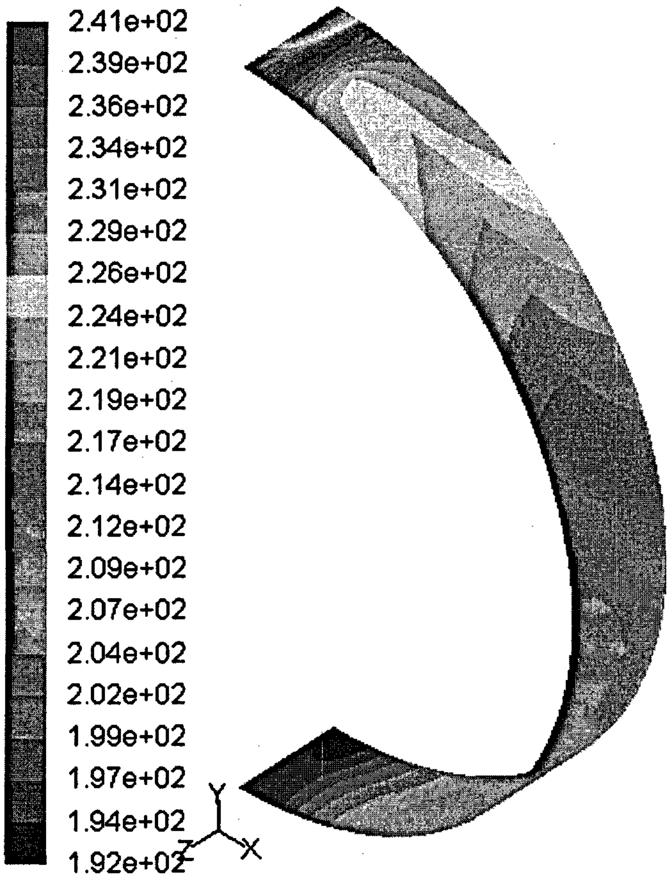
Note: Velocity is in units of ft/sec

Figure 5-6 - Velocity Distribution at EnclosureExit with 18.4 kW Decay Heat Load, Plan View



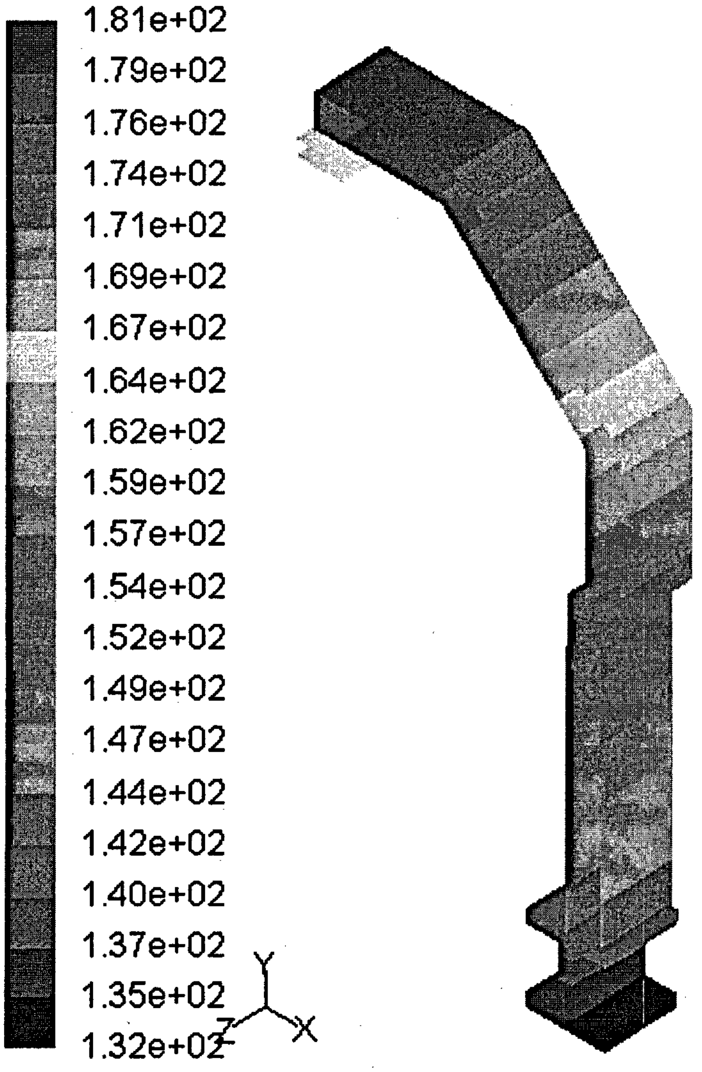
Note: Temperature is in units of °F

Figure 5-7 - Temperature Distribution for OS197L Cask-Transfer Skid Assembly with 11.0 kW Decay Heat Load



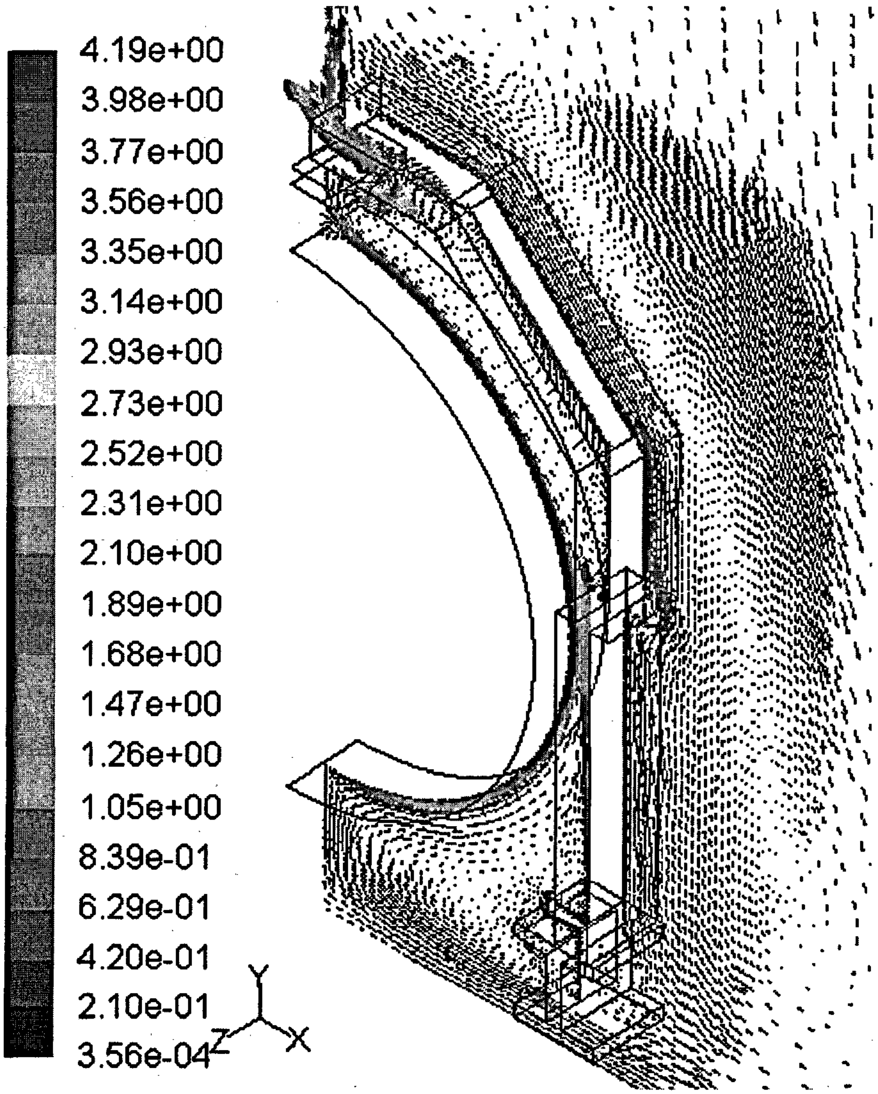
Note: Temperature is in units of °F

Figure 5-8 - Temperature Distribution Over OS197L Cask Exterior Shell with 11.0 kW Decay Heat Load



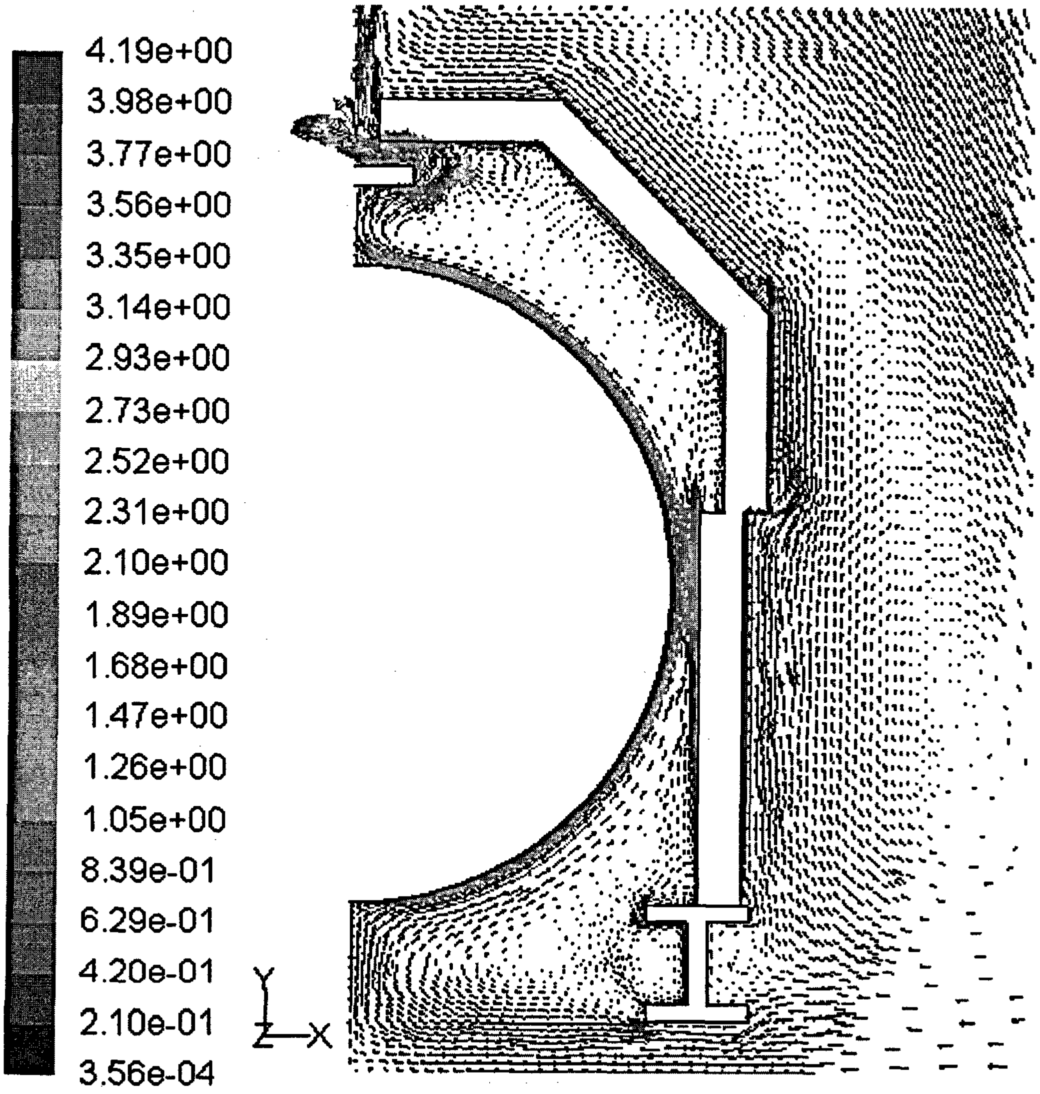
Note: Temperature is in units of °F

Figure 5-9 - Temperature Distribution for OS197L Transfer Skid Shields with 18.4 kW Decay Heat Load



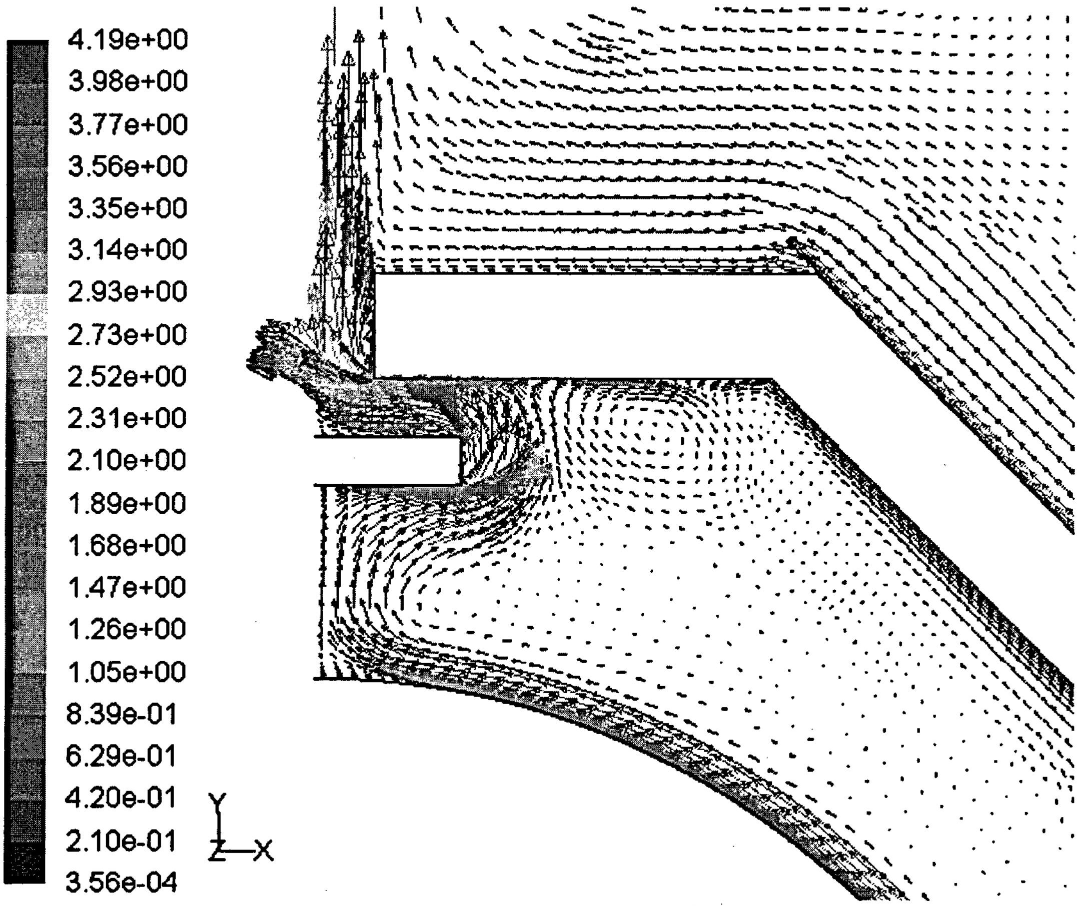
Note: Velocity is in units of ft/sec

Figure 5-10 - Velocity Distribution at Model Centerline with 11.0 kW Decay Heat Load



Note: Velocity is in units of ft/sec

Figure 5-11 - Velocity Distribution at Model Centerline with 11.0 kW Decay Heat Load



Note: Velocity is in units of ft/sec

Figure 5-12 - Velocity Distribution at Enclosure Exit with 11.0 kW Decay Heat Load, Plan View

6.0 CONCLUSIONS

The predicted cask shell temperature of the OS197L transfer cask within its auxiliary shielding enclosure has been computed using a computational fluid dynamics (CFD) analysis. The analysis was conducted for the bounding off-normal condition of 117°F, with regulatory insolation loading, and for decay heat loads of 11.0 and 18.4 kW. While the presence of the auxiliary shielding enclosure results in higher cask surface temperatures compared with the situation without the enclosures, the level of the temperature increase is relatively modest due to the fact that the enclosure shields the cask from direct insolation heating.

The temperature on the cask's neutron shield is predicted to vary from 247°F at the bottom to a maximum temperature of 288°F near the top of the cask for a decay heat loading of 18.4 kW. The area-weighted average temperature over the surface of the cask's exterior shell for the OS197L cask and transfer skid combination is predicted to be 258°F. The peak shell temperature reduces to 241°F and the minimum shell temperature to 192°F for a decay heat loading of 11.0 kW. The associated average shell temperature is 214°F.

7.0 REFERENCES

1. NUHOMS® OS197-Light Onsite Transfer Cask, Cask Body Assembly. Drawing Number NUH06L-1001, Rev. 1, Transnuclear, Inc.
2. NUHOMS® OS197-Light Onsite Transfer Cask, Light Neutron Shield Assembly. Drawing Number NUH06L-1002, Rev. 1, Transnuclear, Inc.
3. NUHOMS® OS197-Light Onsite Transfer Cask, Standard Shielding Assembly. Drawing Number NUH06L-1003, Rev. G, Transnuclear, Inc.
4. NUHOMS® OS197-Light Onsite Transfer Cask, Support Skid Assembly. Drawing #NUH06L-1006, Rev. 1, Transnuclear, Inc.
5. NUHOMS® OS197-Light Onsite Transfer Cask, Support Skid Additional Shielding. Drawing Number NUH06L-1007, Rev. 1, Transnuclear, Inc.
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8. Roshenow, W. M., J. P. Hartnett, and Y. I. Cho, *Handbook of Heat Transfer*, 3rd Edition, 1998.
9. FLUENT™, Version 6.2, and GAMBIT™, Version 2.2, Fluent, Inc, 10 Cavendish Ct., Lebanon, NH 03766, phone: (603) 643-2600, website: http://www.fluent.com.
10. V&V Test Report, *FLUENT™ Version 6.2 / GAMBIT™ Version 2.2*, Transnuclear, Inc, File Number QA040.231.0001, Rev. 0.

8.0 ELECTRONIC RUN LOG

The input and output files for this calculation are too large to be included in this document. Instead, these files are contained on an optical disk that accompanies this calculation. Table 8-1 lists the files associated with the results presented in this calculation.

Table 8-1 - FLUENT™ Run Log

Configuration	Operating Condition	File Name	Date
OS197L	Off-normal Hot Transfer, Steady-state Condition with 18.4 kW Decay Heat Loading	OS197L_FtCalhoun_18.4kW_R1.cas OS197L_FtCalhoun_18.4kW_R1.dat OS197L_Rev1.dbs	6/2/2006 " 1/27/2006
OS197L	Off-normal Hot Transfer, Steady-state Condition with 11.0 kW Decay Heat Loading	OS197L_FtCalhoun_11.0kW_R1.cas OS197L_FtCalhoun_11.0kW_R1.dat OS197L_Rev1.dbs	6/3/2006 " 1/27/2006