# ENCLOSURE 7

## Outer Surface Weld Temperature of the NUHOMS® 24P and 32P DSCs

## Stored at CCNPP ISFSI Site – Non-Proprietary

**Calvert Cliffs Nuclear Power Plant, LLC**
**June 14, 2013**

NON - PROPRIETARY VERSION

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| AREVA<br>TRANSNUCLEAR INC. | **Form 3.2-1**<br>**Calculation Cover Sheet**<br>**TIP 3.2 (Revision 6)** | **Calculation No.:** 10955-0401<br>**Revision No.:** 1<br>**Page: 1 of 46** |
|---|---|---|

| | |
|---|---|
| **DCR NO (if applicable) : 10955-003** | **PROJECT NAME: CCNPP ISFSI Renewal** |
| **PROJECT NO: 10955** | **CLIENT: Transnuclear, Inc.** |

**CALCULATION TITLE:**

Outer Surface Weld Temperature of the NUHOMS® 24P and 32P DSCs Stored at CCNPP ISFSI Site

**SUMMARY DESCRIPTION:**

**1) Calculation Summary**

This calculation utilizes ANSYS FLUENT to analyze the thermal performance of the NUHOMS® 24P and 32P DSCs, and determines the heat load at which the confinement weld temperature on the outer surface of the NUHOMS® 24P and 32P DSCs is 80 °C. The DSCs subject to this evaluation are stored in site-specific HSMs designed for Calvert Cliffs Nuclear Power Plant (CCNPP) ISFSI site.

**2) Storage Media Description**

Secure network server initially, then redundant tape backup

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

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

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

| **Software Utilized (subject to test requirements of TIP 3.3):** | **Version:** |
|---|---|
| ANSYS FLUENT | 14.0 |

| | |
|---|---|
| **Calculation is complete:**<br>Originator Name and Signature: Hui Liu [signature] | Date: 6/5/2013 |
| **Calculation has been checked for consistency, completeness and correctness:**<br>Checker Name and Signature: Kamran Tavassoli [signature] | Date: 6/5/2013 |
| **Calculation is approved for use:**<br>[signature]<br>Project Engineer Name and Signature: Girish Patel | Date: 6/6/2013 |

## REVISION SUMMARY

| REV. | DESCRIPTION | AFFECTED PAGES | AFFECTED Computational I/O |
|---|---|---|---|
| 0 | Initial Issue | All | All |
| 1 | The V&V test plan and test report, E-33868 and E-33869 are approved. Conditional release note on the coversheet is removed. | 1-2 | None |
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## 1.0 PURPOSE

Prior research indicates that dry storage canisters may be susceptible to chloride-induced stress corrosion cracking (CISCC) initiation with surface temperatures between 30 and 80 °C [1]. This calculation provides an estimate of the temperatures on the outer surface of the NUHOMS® 24P and 32P DSCs for various heat loads between 2 and 19 kW, and determines the heat load at which the confinement weld temperature on the outer surface of the DSCs is 80 °C. For this evaluation, a half symmetric 3-dimensional Computational Fluid Dynamics (CFD) model in ANSYS FLUENT is used to simulate the air flow and heat transfer within the HSM loaded with DSCs.

Furthermore, this calculation provides an estimate of the cooling and storage time for DSCs to achieve the maximum temperatures as obtained from CFD simulations.

## 2.0 REFERENCES

[1] Calculation, "Calvert Cliffs Nuclear Power Plant (CCNPP) ISFSI: Canister Cask Stress Corrosion Cracking Review for License Renewal", Transnuclear Inc., Calculation No. 10955-EE-00, Rev. B.

[2] Updated Safety Analysis Report for Calvert Cliffs Nuclear Power Plant Independent Spent Fue Storage Installation, Transnuclear Inc., Rev. 17.

[3] Drawing, Horizontal Storage Modules Concrete Plans, Transnuclear Inc., Drawing No. 84080, Rev. 2.

[4] Drawings for 24P DSC:

- CCNPP Drawing 84003 BGEDRWG, NUHOMS-24 ISFSI DSC Shell Assembly, Rev. 0000.
- CCNPP Drawing 84004 BGEDRWG, NUHOMS-24P ISFSI DSC Shell Assembly, Rev. 0000.
- CCNPP Drawing 84006 BGEDRWG, NUHOMS-24P ISFSI DSC Main Assembly, Rev. 0000.
- CCNPP Drawing 84007 BGEDRWG, NUHOMS-24 ISFSI DSC Main Assembly, Rev. 0001.
- CCNPP Drawing 84005 BGEDRWG, NUHOMS-24P ISFSI DSC Shell Assembly, Rev. 0000.

[5] Drawings for 32P DSC:

- CCNPP Drawing 84218 BGEDRWG, NUHOMS-32P DSC Shell & Bottom Plug Assembly, Rev. 0000.
- CCNPP Drawing 84219 BGEDRWG, NUHOMS-32P DSC Shell & Siphon Pipe Assembly Details, Rev. 0000.
- CCNPP Drawing 84220 BGEDRWG, NUHOMS-32P DSC Siphon Pipe/Adapter & Lifting Block Details, Rev. 0000.
- CCNPP Drawing 84221 BGEDRWG, NUHOMS-32P DSC Top Shield Plug Details, Rev. 0000.
- CCNPP Drawing 84222 BGEDRWG, NUHOMS-32P Top Cover Plate & Siphon/Vent Port Covers, Rev. 0000.

[6] Calculation, "HSM Thermal Analysis, Normal Storage Conditions", Transnuclear Inc., Calculation No. 1095-18, Rev. 0.

[7] Calculation, "Thermal Evaluation of NUHOMS 32PHB Transfer Cask for Normal, Off Normal, and Accident Conditions", Transnuclear Inc., Calculation No. NUH32PHB-0402, Rev. 0.

[8] ASME Boiler and Pressure Vessel Code, 2010 Edition, II, Part D.

[9] CoC 1004, Final Safety Analysis Report for the Standardized NUHOMS Horizontal Modular Storage System for Irradiated Nuclear Fuel, Transnuclear Inc., NUH-003, Rev. 13.

[10] ANSYS Design Modeler, Version 14.0, ANSYS.

[11] ANSYS ICEM CFD Software, Version 14.0, ANSYS.

[12] ANSYS FLUENT Software User Manual, Version 14.0, ANSYS.

[13] S. Suffield, J. Cuta, J. Fort, B. Collins, H. Adkins and E. Siciliano, "Thermal Modeling of NUHOMS HSM-15 and HSM-1 Storage Modules at Calvert Cliffs Nuclear Power Station ISFSI", PNNL-21788, 2012.

[14] A. Zigh and J. Solis, ""Computational Fluid Dynamics Best Practice Guidelines in the Analysis of Storage Dry Cask"," in *WM2008 Conference*, Phoenix, AZ, 2008.

[15] ASHRAE Handbook, Fundamentals, SI Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1997.

[16] W. Rohsenow, J. Hartnett and Y. Cho, Handbook of Heat Transfer, 3rd Edition, 1998.

[17] Calculation, "Finite Element Models, Thermal Analysis", Transnuclear Inc., Calculation No. 1095-5.

[18] Safety Analysis Report for NUHOMS-MP197 Transport Packaging, Transnuclear Inc., Rev. 11.

## 3.0 ASSUMPTIONS AND CONSERVATISMS

Proprietary Information Withheld Pursuant to 10 CFR 2.390

# 4.0 DESIGN INPUTS

## 4.1 Design

The designs of HSM for CCNPP ISFSI site, NUHOMS® 24P and 32P DSCs are obtained from references [3], [4], and [5].

## 4.2 Material Properties

The materials used in the ANSYS FLUENT model for HSM loaded with DSC are listed in Table 4-1. The properties for each material are listed in Table 4-2 through Table 4-7.

For ease of modeling, the thermal evaluation in FLUENT is performed using SI units.

**Table 4-1: List of Materials in the ANSYS FLUENT Model for HSM Loaded with DSC**

| Component | Material |
|---|---|
| **24P and 32P DSC** | |
| DSC Shell | Stainless Steel SA240,Type 304 (see Table 4-2) |
| DSC Top End Plates | Effective properties (see Table 4-3) |
| DSC Bottom End Plates | Effective properties (see Table 4-4) |
| **HSM** | |
| Concrete Walls, Roof and Floor | Concrete (see Table 4-5) |
| Heat Shield | Stainless Steel SA240,Type 304 (see Table 4-2) |
| Rail | Carbon Steel A36 (see Table 4-6) |
| **HSM Air Region** | Air (see Table 4-7) |

**Table 4-2: Material Properties for DSC Shell and Heat Shield**

| Material Name | Temperature | | Thermal Conductivity (section 4.0 of [6]) | | Emissivity |
|---|---|---|---|---|---|
| | (°F) | (K) | (Btu/hr-ft-°F) | (W/m-K) | |
| Stainless Steel SA240, Type 304 | 100 | 311 | 8.7 | 15.047 | 0.587 |
| | 200 | 366 | 9.3 | 16.084 | |
| | 300 | 422 | 9.8 | 16.949 | |
| | 400 | 478 | 10.4 | 17.987 | |
| | 500 | 533 | 10.9 | 18.852 | |
| | 600 | 589 | 11.3 | 19.543 | |

**Table 4-3: Material Properties for DSC Top End Plates**

(Effective properties are calculated in Section 5.3.4 based on the methodology described in [7])

| Temperature (K) | Effective Thermal Conductivity in Radial Direction $k_{eff,radial}$ (W/m-K) | Effective Thermal Conductivity in Axial Direction $k_{eff,axial}$ (W/m-K) |
|---|---|---|
| 294 | 2.962 | 0.093 |
| 311 | 2.955 | 0.097 |
| 366 | 2.957 | 0.110 |
| 422 | 2.952 | 0.123 |
| 478 | 2.993 | 0.135 |
| 533 | 2.951 | 0.146 |
| 589 | 2.933 | 0.157 |
| 644 | 2.923 | 0.167 |
| 700 | 2.905 | 0.177 |
| 755 | 2.895 | 0.187 |
| 811 | 2.885 | 0.196 |

**Table 4-4: Material Properties for DSC Bottom End Plates**

(Effective properties are calculated in Section 5.3.4 based on the methodology described in [7])

| Temperature (K) | Effective Thermal Conductivity in Radial Direction $k_{eff,radial}$ (W/m-K) | Effective Thermal Conductivity in Axial Direction $k_{eff,axial}$ (W/m-K) |
|---|---|---|
| 294 | 2.696 | 0.094 |
| 311 | 2.687 | 0.098 |
| 366 | 2.677 | 0.112 |
| 422 | 2.662 | 0.125 |
| 478 | 2.689 | 0.137 |
| 533 | 2.637 | 0.148 |
| 589 | 2.612 | 0.159 |
| 644 | 2.592 | 0.170 |
| 700 | 2.566 | 0.180 |
| 755 | 2.546 | 0.190 |
| 811 | 2.526 | 0.200 |

## Table 4-5: Material Properties for HSM Concrete Walls, Roof, and Floor

| Material Name | Temperature | | Thermal Conductivity (section 4.0 of [6]) | | Emissivity |
|---|---|---|---|---|---|
| | (°F) | (K) | (Btu/hr-ft-°F) | (W/m-K) | |
| Concrete | 100 | 311 | 1.17 | 2.024 | 0.8 |
| | 200 | 366 | 1.14 | 1.972 | |
| | 500 | 533 | 1.04 | 1.799 | |
| | 1000 | 811 | 0.8 | 1.384 | |

## Table 4-6: Material Properties for Rail

| Material Name | Temperature | | Thermal Conductivity [8] | | Emissivity (section U.4.2 of [9]) |
|---|---|---|---|---|---|
| | (°F) | (K) | (Btu/hr-in-°F) | (W/m-K) | |
| Carbon Steel A36 | 70 | 294 | 2.908 | 60.353 | 0.55 |
| | 100 | 311 | 2.892 | 60.021 | |
| | 200 | 366 | 2.808 | 58.277 | |
| | 300 | 422 | 2.692 | 55.87 | |
| | 400 | 478 | 2.575 | 53.442 | |
| | 500 | 533 | 2.45 | 50.847 | |
| | 600 | 589 | 2.333 | 48.419 | |
| | 700 | 644 | 2.217 | 46.012 | |
| | 800 | 700 | 2.108 | 43.75 | |
| | 900 | 755 | 1.983 | 41.155 | |
| | 1000 | 811 | 1.867 | 38.748 | |

## Table 4-7: Material Properties for Air

| Material Name | Temperature (K) | Density (kg/m$^3$) [6] | Viscosity (Pa-s) [6] | Thermal Conductivity (W/m-K) [6] |
|---|---|---|---|---|
| Air | 255 | 1.386 | 1.625E-05 | 0.02268 |
| | 265 | 1.333 | 1.675E-05 | 0.02348 |
| | 280 | 1.261 | 1.750E-05 | 0.02467 |
| | 295 | 1.197 | 1.822E-05 | 0.02585 |
| | 310 | 1.139 | 1.893E-05 | 0.02701 |
| | 325 | 1.086 | 1.963E-05 | 0.02815 |
| | 340 | 1.038 | 2.030E-05 | 0.02928 |
| | 355 | 0.995 | 2.097E-05 | 0.03039 |
| | 370 | 0.954 | 2.160E-05 | 0.03150 |
| | 385 | 0.917 | 2.224E-05 | 0.03259 |
| | 400 | 0.882 | 2.286E-05 | 0.03365 |
| | 420 | 0.840 | 2.366E-05 | 0.03505 |
| | 440 | 0.802 | 2.445E-05 | 0.03643 |
| | 450 | 0.784 | 2.485E-05 | 0.03710 |

4.3 Design Load Cases

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For ease of modeling, the thermal evaluation in FLUENT is performed using SI units.

Ambient conditions are normal ambient conditions as specified for CCNPP ISFSI [2], 70 °F ambient temperature and solar heat flux of 82 Btu/hr-ft$^2$-°F.

**Table 4-8: Load Cases for Thermal Evaluation**

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# 5.0 METHODOLOGY

## 5.1 CAD Model

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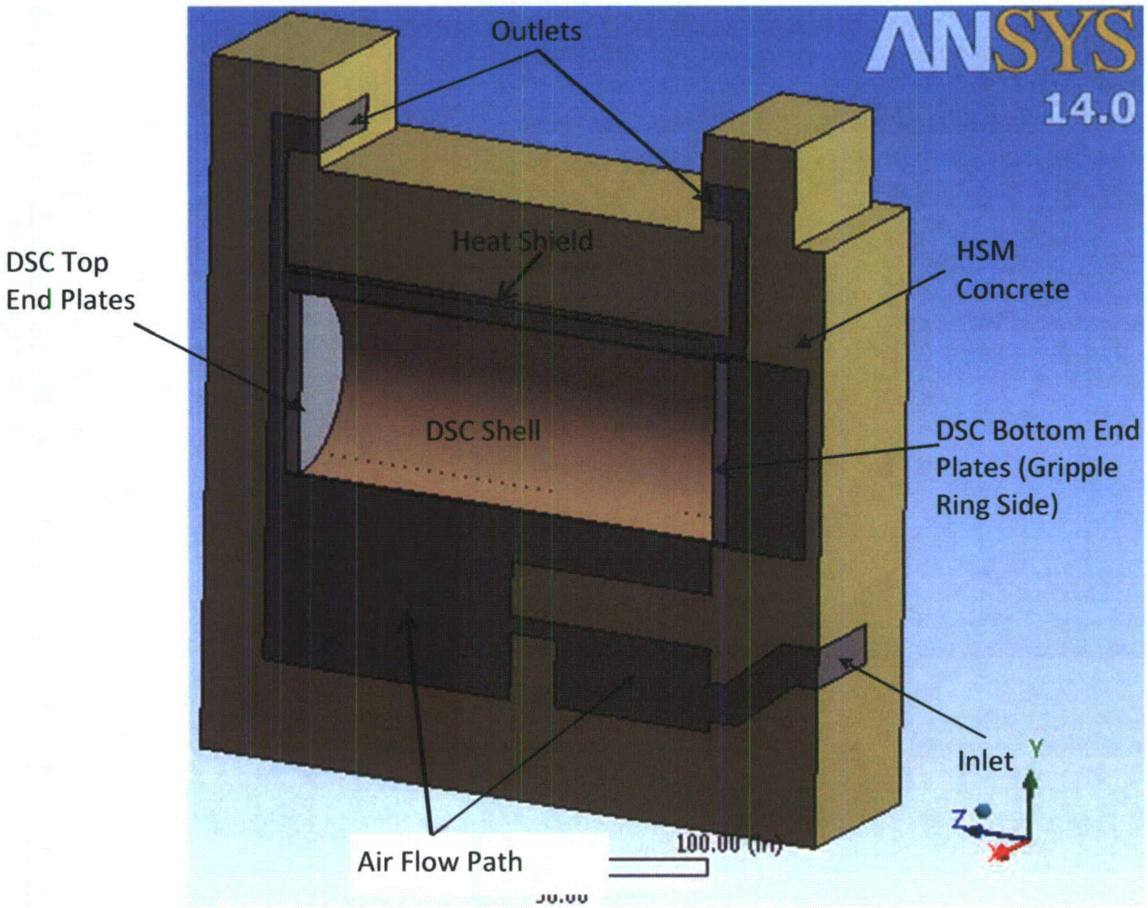


**Figure 5-1: CCNPP HSM with 24P/32P DSC Shell and End Plates**

5.2 Meshing

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Figure 5-2 shows an axial view of the mesh along the symmetrical mid-plane of the model.

Figure 5-3 shows a cross sectional view through a transverse slice near the DSC top end plates together with the detailed views around the DSC shell and rail.

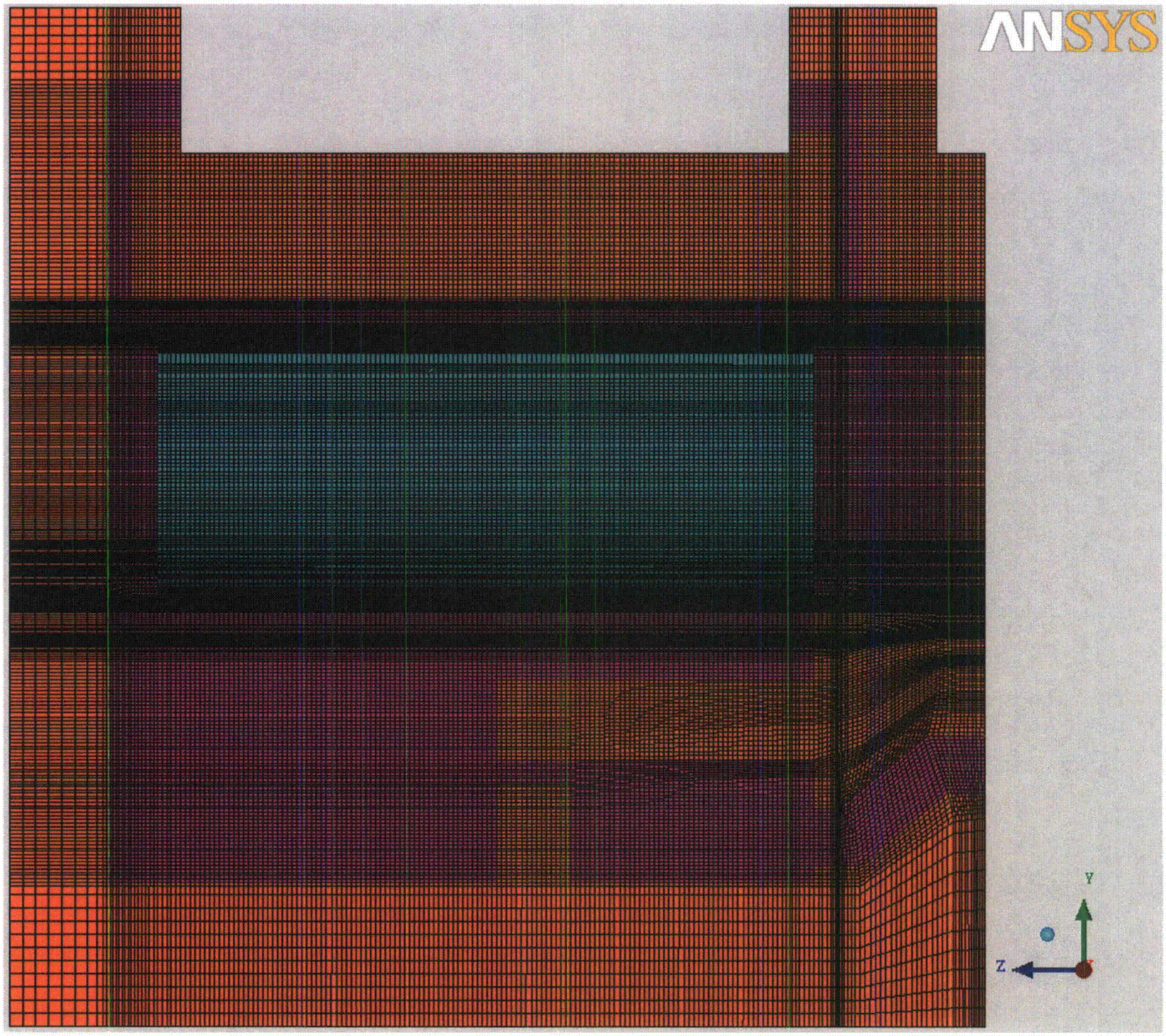


**Figure 5-2: Axial View of the Hexahedral Mesh on the Symmetrical Mid-plane for CCNPP HSM and DSC.**

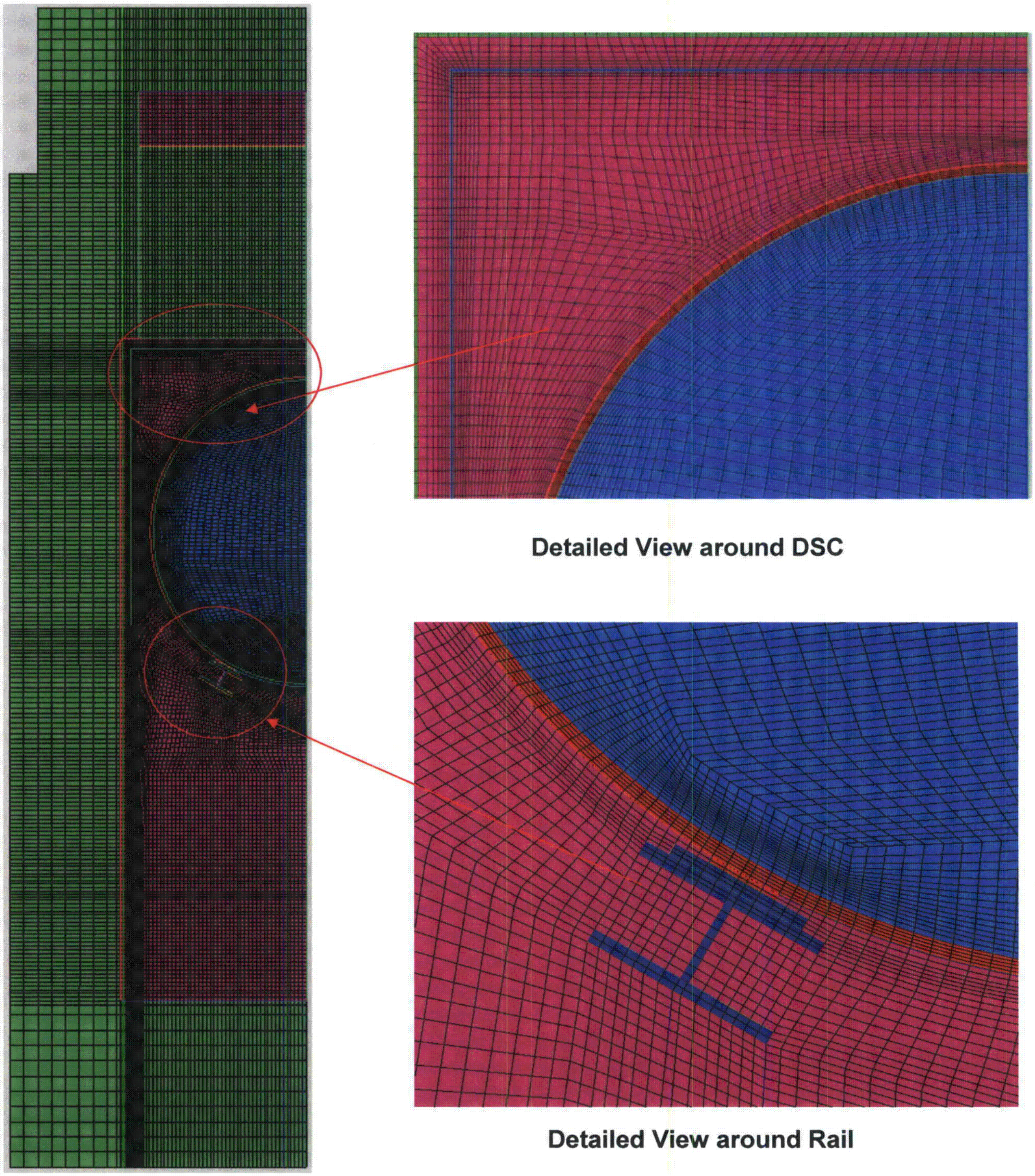


**Figure 5-3: Cross Sectional View of the Half-symmetrical Hexahedral Mesh for CCNPP HSM and DSC.**

## 5.3 CFD Modeling

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**Figure 5-4: A Typical Fluid-solid Interface in ANSYS FLUENT**

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Figure 5-5: Contact Resistance Prescribed on the Interface between Rail and DSC.

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**Table 5-1: Thickness of the Top End Assembly**

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**Table 5-2: Thickness of the Bottom End Assembly**

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## 6.0 RESULTS AND CONCLUSIONS

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**Table 6-1: Maximum DSC Shell Temperature and Minimum Weld Temperature versus Heat Load**

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**Figure 6-1: Minimum DSC Shell Weld Temperature versus Heat Load**

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**Figure 6-2: Load Case #1 (2 kW Heat Load), Temperature Contours of the Half DSC Shell**

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**Figure 6-3: Load Case #2 (6 kW Heat Load), Temperature Contours of the Half DSC Shell**

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**Figure 6-4: Load Case #3 (10.5 kW Heat Load), Temperature Contours of the Half DSC Shell**

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**Figure 6-5: Load Case #4 (15 kW Heat Load), Temperature Contours of the Half DSC Shell**

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**Figure 6-6: Load Case #5 (19 kW Heat Load), Temperature Contours of the Half DSC Shell**

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Table 6-2: Summary of Convergences of CFD Models

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## 7.0 LISTING OF COMPUTER FILES

**Table 7-1: List of Geometry and Mesh Files**

| File Name | Description | Date/Time |
|---|---|---|
| CCNPP-HSMb.wbpz | ANSYS Workbench Archive with Geometry | 02/26/2013 2:43PM |
| Good_complete.prj | ANSYS ICEM mesh project file | 03/21/2013 2:49 PM |
| fluent.msh | Unstructured mesh file in FLUENT format | 03/13/2013 9:18 AM |

**Table 7-2: List of Computational Files**

| Run | Description | Date/Time |
|---|---|---|
| CCNPP-HSM-C5-kW.[ext] [ext]=inp, cas.gz, data.gz, out | ANSYS Fluent files for Load Case # 1 | 03/29/2013 2:59PM |
| CCNPP-HSM-C1-kW.[ext] [ext]=inp, cas.gz, data.gz, out | ANSYS Fluent files for Load Case # 2 | 03/29/2013 2:23PM |
| CCNPP-HSM-C4-kW.[ext] [ext]=inp, cas.gz, data.gz, out | ANSYS Fluent files for Load Case # 3 | 03/31/2013 3:52PM |
| CCNPP-HSM-C3-kW.[ext] [ext]=inp, cas.gz, data.gz, out | ANSYS Fluent files for Load Case # 4 | 3/31/2013 4:52PM |
| CCNPP-HSM-C2-kW.[ext] [ext]=inp, cas.gz, data.gz, out | ANSYS Fluent files for Load Case # 5 | 3/31/2013 2:52PM |

**Table 7-3: List of Excel Spreadsheets**

| File Name | Description | Date/Time |
|---|---|---|
| CFD-Model2.xls | Excel spreadsheet that documents material properties, mesh information, CFD model results and convergences | 04/02/2013 10:50AM |
| Heat load during storage Rev0A.xls | Excel spreadsheet that calculates cooling and storage time for various heat loads | 04/15/2013 12:44PM |

**Table 7-4: List of User-Defined Functions in ANSYS FLUENT**

| File Name | Description | Date/Time |
|---|---|---|
| CCHSM-Roof-Insolance.c | User-defined function in FLUENT to calculate the total heat flux on HSM roof as the boundary condition | 3/27/2013 2:40PM |
| CCHSM-Front-Insolance.c | User-defined function in FLUENT to calculate the total heat flux on HSM front wall as the boundary condition | 3/27/2013 2:40PM |

## APPENDIX A: LIST OF USER-DEFINED FUNCTIONS IN ANSYS FLUENT

Table A-1 lists the thermal properties of air used to calculate the total heat transfer coefficient on the external boundaries of HSM roof and front wall. The correlations are discussed in Section 5.3.3.g.

**Table A-1: Air Thermal Properties**

| Temperature (K) | Thermal Conductivity (W/m-K) |
|---|---|
| 200 | 0.01822 |
| 250 | 0.02228 |
| 300 | 0.02607 |
| 400 | 0.03304 |
| 500 | 0.03948 |
| 600 | 0.04557 |
| 800 | 0.05698 |
| 1000 | 0.06721 |

The above data are calculated based on the following polynomial function from [16].

$k = \sum C_i\, T_i$ for conductivity in(W/m-K) and T in (K)

| For 250 < T < 1050 K | |
|---|---|
| C0 | -2.2765010E-03 |
| C1 | 1.2598485E-04 |
| C2 | -1.4815235E-07 |
| C3 | 1.7355064E-10 |
| C4 | -1.0666570E-13 |
| C5 | 2.4766304E-17 |

$c_p = \sum A_i\, T_i$ for specific heat in (kJ/kg-K) and T in (K)

| For 250 < T < 1050 K | |
|---|---|
| A0 | 1.03409E+0 |
| A1 | -2.848870E-4 |
| A2 | 7.816818E-7 |
| A3 | -4.970786E-10 |
| A4 | 1.077024E-13 |

$\mu = \sum B_i\, T_i$ for viscosity (N-s/m$^2$)×10$^6$ and T in (K)

| For 250 < T ≤ 600 K | |
|---|---|
| B0 | -9.8601E-1 |
| B1 | 9.080125E-2 |
| B2 | -1.17635575E-4 |
| B3 | 1.2349703E-7 |
| B4 | -5.7971299E-11 |

| For 600 < T < 1050 K | |
|---|---|
| B0 | 4.8856745 |
| B1 | 5.43232E-2 |
| B2 | -2.4261775E-5 |
| B3 | 7.9306E-9 |
| B4 | -1.10398E-12 |

$\rho = P / RT$ for density (kg/m$^3$) with P=101.3 kPa; $R$ = 0.287040 kJ/kg-K; $T$ = air temp in (K)

$\Pr = c_p\, \mu / k$ Prandtl number

**Proprietary Information on Pages 35 through 40 are Withheld Pursuant to 10 CFR 2.390**

## APPENDIX B: MINIMUM WELD TEMPERATURES AND MAXIMUM DSC SHELL TEMPERATURES AS A FUNCTION OF STORAGE TIME

The minimum weld temperatures and the maximum DSC shell temperatures as a function of heat load were provided in Section 6.0. This appendix provides an estimate of the behavior of these temperatures as a function of storage time.

The heat load of a fuel assembly stored in the DSC decreases during the storage time. The safety analysis report for MP197HB cask [18] provides an equation in Table A.1.4.1-6 to estimate the decay heat load of a PWR fuel assembly based on the fuel characteristics (burnup and initial enrichment) and cooling time. Although, this equation is developed based on a CE 16x16 fuel assembly, it provides adequate accuracy to estimate the residual heat load during storage time for the purposes of this calculation.

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**Table B-1: Heat Load per Fuel Assembly in 24P or 32P DSCs**

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The calculated cooling times for fuel assemblies in the 24P DSC and 32P DSC are presented in Table B-2 and Table B-3, respectively.

**Table B-2: Cooling Time for Fuel Assemblies in 24P DSC**

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**Table B-3: Cooling Time for Fuel Assemblies in 32P DSC**

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**Table B-4: Minimum Weld Temperature and Maximum DSC Shell Temperature versus Storage Time for 24P DSC**

**Proprietary Information Withheld Pursuant to 10 CFR 2.390**

**Table B-5: Minimum Weld Temperature and Maximum DSC Shell Temperature versus Storage Time for 32P DSC**

**Proprietary Information Withheld Pursuant to 10 CFR 2.390**

The values presented in Table B-4 and Table B-5 are plotted in Figure B-1 through Figure B-4.

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**Figure B-1: Minimum Weld Temperature versus Storage Time for 24P DSC**

**Proprietary Information Withheld Pursuant to 10 CFR 2.390**

**Figure B-2: Maximum DSC Shell Temperature versus Storage Time for 24P DSC**

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**Figure B-3: Minimum Weld Temperature versus Storage Time for 32P DSC**

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**Figure B-4: Maximum DSC Shell Temperature versus Storage Time for 32P DSC**