**ATTACHMENT (7)**

# TRANSNUCLEAR CALCULATION NO. 1095-6 –

# NON-PROPRIETARY VERSION

**Calvert Cliffs Nuclear Power Plant, LLC**
**March 9, 2011**

| TRANSNUCLEAR | Form 3.1-1 Calculation | Calc. No.: | 1095-6 | | |
|---|---|---|---|---|---|
| | | Rev. No.: | 1 | | |
| Project No.: 10950 | DCR No.: 10950-15, rev. 0 | Page: | 1 | of | 34 |

**Project Name:** NUHOMS-32P for CCNPP

**Calculation Title:** NUHOMS-32P, Transfer Thermal Analysis, 103°F Ambient

**Number of CDs attached:** 0 – The CD for Calc1095-6, rev. 0 is unchanged

**If original issue, 10CFR72.48 review required?**

☒ **No (explain)** ☐ **Yes, LR No.** ______

This calculation is performed in support of the licensee, CCNPP

1. **This calculation is complete and ready for independent review**

   Originator's Signature [signature] Date: 5/20/04

2. **This calculation has been checked for consistency, completeness, and arithmetic correctness. All comments have been incorporated or otherwise resolved satisfactorily. All "no" items in the Review Checklist have been resolved satisfactorily.**

   Checker Signature [signature] Date: 5/21/04

3. **Calculation preparation and check complies with procedure - package is complete**

   PE's Signature [signature] Date: 5/21/04

## 1.0 Purpose

To determine component temperatures of the NUHOMS-32P packaging during transport with an ambient temperature of 103 °F and an insolation of 127 Btu/hr-ft$^2$ using the same methodology as the Calvert Cliffs supporting calculations.

## 2.0 References

1) Kreith et. al., The CRC Handbook of Thermal Engineering, 2000.
2) "The Topical Report for the NUTECH Horizontal Modular Storage System for Irradiated Nuclear Fuel", Rev. 1A.
3) Rohsenow et. al., Handbook of Heat Transfer Fundamentals, 1985.
4) Calculation 1095-5, Rev. 0, Finite Element Models, Thermal Analysis
5) (NOT USED)
6) *Chemical Engineers' Handbook, Fifth Edition*, Perry P.H. and Chilton C.H., McGraw-Hill Book Co., New York, 1973.
7) Calvert Cliffs Independent Spent Fuel Storage Installation, Safety Analysis Report, Volume 1, Rev. 11
8) ANSYS Computer Code and User's Manuals, Volumes 1-4, Rev. 5.6. See Test Reports E-17740, E-17741, and E-18554 through E-18557 for validation of computer code.
9) ANSYS files: /Calc1095-6/ CCCask.db, CCCask.rth, RadMat.sub, CCCask.mac
CCBasket.db, CCBasket.rth, CCBasket.mac

## 3.0 Assumptions

This analysis is performed using the finite element models created within Reference 4. All assumptions, material properties, and modeling details are the same as those in Reference 4.

The material properties for air, used in the determination of the total heat transfer coefficients, are reprinted in Appendix A.

## 4.0 Discussion

The three-dimensional quarter-symmetry finite element models of the NUHOMS-32P packaging described in Reference 4 are used for the analysis. All assumptions and material properties from Reference 4 remain unchanged within this calculation. For conservatism, temperature distributions are determined under steady-state conditions.

Two finite element models are used within the analysis:

- A cask body model consisting of the cask body, lid, ram plate, and canister.
- A basket model consisting of the canister, basket, and fuel assemblies.

The cask body model is run with the fuel decay heat load applied as a heat flux to the canister inner cavity surfaces. An insolance of 127 Btu/hr-ft$^2$ is applied to surfaces of the packaging exposed to the ambient. The solar heat load is applied as a heat flux to the outer surface effect elements of the finite element model

The temperature distribution within the canister calculated within the cask body model is applied to the canister within the basket model. Noding of the canister within the two finite element models is identical. The fuel decay heat load is applied to the fuel elements of the basket model as an internal heat generation.

Boundary condition details and verification can be found in the Appendices.

The approach used within the analysis is the same as that used in the supporting calculations for the Calvert Cliffs ISFSI SAR.

## 4.1 Thermal Design Criteria

- A maximum fuel cladding temperature limit of 570 °C (1058 °F) is set for the fuel assemblies with an inert cover gas as concluded in Reference 2.
- A maximum temperature limit of 327 °C (620 °F) is set for the lead, corresponding to the melting point (Reference 6).
- A maximum limit of 280 °F on the bulk temperature of the resin is set in Reference 7.

## 5.0 Results

Temperature distributions obtained from the finite element models are found in Appendix C.

## 6.0 Conclusions

Maximum Component Temperatures in NUHOMS-32P packaging

| Component | Maximum Temperature | Thermal Limits |
|---|---|---|
| (---) | ($^{o}$F) | ($^{o}$F) |
| Outer Shell | 271 | --- |
| Radial Neutron Shield * | 277 | 280 |
| Top Neutron Shield * | 253 | 280 |
| Bottom Neutron Shield * | 263 | 280 |
| Lead | 370 | 620 |
| Cask Body | 355 | --- |
| Fuel Cladding | 742 | 1058 |
| Cask Lid | 318 | --- |
| Ram Plate | 252 | --- |
| Canister | 460 | --- |
| Fuel Compartments | 717 | --- |
| Peripheral Inserts | 573 | --- |
| Aluminum Basket Plates | 717 | --- |
| Stainless Steel Bars | 717 | --- |

*This is a mass-averaged (bulk) temperature of the neutron absorbing resin determined via the BulkTemp.mac macro (See Appendix D)

All components remain below thermal design criteria during normal conditions of transport.

# APPENDIX A

## Total Heat Transfer Coefficients

The exposed portions of the packaging dissipate heat to the ambient via natural convection and radiation.

Radiation Coefficient

The heat transfer coefficient, $H_r$, for heat dissipation by radiation, is given by the equation:

$$H_r = F_{12}\left[\frac{\sigma(T_1^4 - (E)(T_2^4))}{T_1 - T_2}\right] Btu/hr - ft^2 - {}^{o}F$$

where,

$F_{12}$ = the gray body exchange coefficient
= (surface emissivity) (view factor)
E = 1.0
$T_1$ = surface temperature, $^{o}$R
$T_2$ = ambient temperature, $^{o}$R

Emissivity and Absorptivity

The external surfaces of the packaging are stainless steel (emissivity = 0.587, Reference 2). A solar absorptivity of 0.587 is used within the analysis.

Horizontal Cylinders

Heat dissipation by natural convection from horizontal cylinders is described by the following equations (Reference 1):

$$Nu = h_c \frac{L}{k} = \left((Nu_l)^{15} + (Nu_t)^{15}\right)^{1/15}$$

$Nu_l$ = Laminar portion of the heat transfer coefficent.
$Nu_t$ = Turbulent portion of the heat transfer coefficent.

$$Nu_t = \overline{C_t} Ra^{1/3}$$

$$\overline{C_t} = 0.103 \text{ for } Pr \approx 0.71$$

$$Nu_l = \frac{2f}{\left(1 + \frac{2f}{Nu^T}\right)}$$

$$f = 0.8 \text{ for } Ra > 10^{-2}; \quad Ra = Gr*Pr$$

$$Nu^T = 0.772\left(\overline{C_l} Ra^{1/4}\right)$$

$$\overline{C_l} = \frac{0.671}{\left(1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right)^{4/9}}$$

$Nu^T$ accounts for the effect of the boundary layer thickness.
where,

| | |
| --- | --- |
| Nu | = Nusselt number |
| Gr | = Grashof number = $\rho^2 g\beta(T_s - T_a)L^3/\mu^2$ |
| Pr | = Prandtl number |
| Ra | = Rayleigh number = Gr*Pr |
| $\rho$ | = density |
| g | = acceleration due to gravity |
| $\beta$ | = temperature coefficient of volume expansion |
| $\mu$ | = absolute viscosity |
| L | = characteristic length |
| $h_c$ | = natural convection coefficient |
| k | = thermal conductivity |

The total heat transfer coefficients for radial surfaces of horizontal cylinders are calculated and input into ANSYS via the HTOT_HCY macro, included within this appendix.

## Vertical Flat Plates

Heat dissipation by natural convection from vertical flat plates is described by the following equations (Reference 1):

$$Nu = h_c \frac{L}{k} = \left((Nu_l)^6 + (Nu_t)^6\right)^{1/6} \quad \text{for } 1 < Ra < 10^{12}; \; Ra = Gr * Pr$$

$$Nu_t = \frac{C_t^V Ra^{1/3}}{\left(1 + 1.4x10^9\left(\frac{Pr}{Ra}\right)\right)}$$

$$C_t^V = \frac{0.13Pr^{0.22}}{\left(1 + 0.61Pr^{0.81}\right)^{0.42}}$$

$$Nu_l = \frac{2.0}{\ln\left(1 + \frac{2.0}{Nu^T}\right)}$$

$Nu_l$ = Laminar portion of the heat transfer coefficent.
$Nu_t$ = Turbulent portion of the heat transfer coefficent.

$$Nu^T = \overline{C_l} Ra^{1/4}$$

$$\overline{C_l} = \frac{0.671}{\left(1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right)^{4/9}}$$

$Nu^T$ accounts for the effect of the boundary layer thickness.
where,

- Nu = Nusselt number
- Gr = Grashof number = $\rho^2 g\beta(T_s - T_a)L^3/\mu^2$
- Pr = Prandtl number
- Ra = Rayleigh number = Gr*Pr
- $\rho$ = density
- g = acceleration due to gravity
- $\beta$ = temperature coefficient of volume expansion
- $\mu$ = absolute viscosity
- L = characteristic length
- $h_c$ = natural convection coefficient
- k = thermal conductivity

The total heat transfer coefficients for vertical flat surfaces are calculated and input into ANSYS via the HTOT_VPL macro, included within this appendix.

Total Heat Transfer Coefficients, Cask Radial Surfaces

Mat, 1
ε = 0.587
View Factor = 1.0
L = 89.00"

| $T_s$ (°F) | $T_{avg}$ (°F) | k (Btu/h-ft-°F) | Ra (---) | $H_c$ (Btu/h-in²-°F) | $H_r$ (Btu/h-in²-°F) | $H_{tot}$ (Btu/h-in²-°F) |
|---|---|---|---|---|---|---|
| 110 | 106.5 | 0.0158 | 3.38E+09 | 0.0023 | 0.0051 | 0.0074 |
| 115 | 109.0 | 0.0159 | 5.67E+09 | 0.0027 | 0.0051 | 0.0079 |
| 120 | 111.5 | 0.0160 | 7.88E+09 | 0.0031 | 0.0052 | 0.0083 |
| 125 | 114.0 | 0.0160 | 9.99E+09 | 0.0033 | 0.0053 | 0.0086 |
| 130 | 116.5 | 0.0161 | 1.20E+10 | 0.0036 | 0.0054 | 0.0089 |
| 135 | 119.0 | 0.0161 | 1.40E+10 | 0.0037 | 0.0054 | 0.0092 |
| 140 | 121.5 | 0.0162 | 1.58E+10 | 0.0039 | 0.0055 | 0.0094 |
| 145 | 124.0 | 0.0163 | 1.76E+10 | 0.0041 | 0.0056 | 0.0097 |
| 150 | 126.5 | 0.0163 | 1.93E+10 | 0.0042 | 0.0056 | 0.0099 |
| 155 | 129.0 | 0.0164 | 2.10E+10 | 0.0044 | 0.0057 | 0.0101 |
| 160 | 131.5 | 0.0164 | 2.25E+10 | 0.0045 | 0.0058 | 0.0103 |
| 165 | 134.0 | 0.0165 | 2.40E+10 | 0.0046 | 0.0059 | 0.0105 |
| 170 | 136.5 | 0.0166 | 2.55E+10 | 0.0047 | 0.0060 | 0.0106 |
| 175 | 139.0 | 0.0166 | 2.69E+10 | 0.0048 | 0.0060 | 0.0108 |
| 180 | 141.5 | 0.0167 | 2.82E+10 | 0.0049 | 0.0061 | 0.0110 |
| 185 | 144.0 | 0.0167 | 2.95E+10 | 0.0050 | 0.0062 | 0.0112 |
| 190 | 146.5 | 0.0168 | 3.07E+10 | 0.0051 | 0.0063 | 0.0113 |
| 195 | 149.0 | 0.0168 | 3.18E+10 | 0.0051 | 0.0063 | 0.0115 |
| 200 | 151.5 | 0.0169 | 3.29E+10 | 0.0052 | 0.0064 | 0.0117 |
| 205 | 154.0 | 0.0170 | 3.40E+10 | 0.0053 | 0.0065 | 0.0118 |
| 210 | 156.5 | 0.0170 | 3.50E+10 | 0.0054 | 0.0066 | 0.0120 |
| 215 | 159.0 | 0.0171 | 3.59E+10 | 0.0054 | 0.0067 | 0.0121 |
| 220 | 161.5 | 0.0171 | 3.69E+10 | 0.0055 | 0.0068 | 0.0123 |
| 225 | 164.0 | 0.0172 | 3.77E+10 | 0.0056 | 0.0069 | 0.0124 |
| 230 | 166.5 | 0.0173 | 3.86E+10 | 0.0056 | 0.0069 | 0.0126 |
| 235 | 169.0 | 0.0173 | 3.94E+10 | 0.0057 | 0.0070 | 0.0127 |
| 240 | 171.5 | 0.0174 | 4.01E+10 | 0.0057 | 0.0071 | 0.0129 |
| 245 | 174.0 | 0.0175 | 4.08E+10 | 0.0058 | 0.0072 | 0.0130 |
| 250 | 176.5 | 0.0175 | 4.15E+10 | 0.0059 | 0.0073 | 0.0132 |
| 255 | 179.0 | 0.0176 | 4.22E+10 | 0.0059 | 0.0074 | 0.0133 |

Total Heat Transfer Coefficients, Cask Radial Surfaces

Mat, 1
ε = 0.587
View Factor = 1.0
L = 89.00"

| $T_s$ (°F) | $T_{avg}$ (°F) | k (Btu/h-ft-°F) | Ra (---) | $H_c$ (Btu/h-ft²-°F) | $H_r$ (Btu/h-in²-°F) | $H_{tot}$ (Btu/h-in²-°F) |
|---|---|---|---|---|---|---|
| 260 | 181.5 | 0.0177 | 4.28E+10 | 0.0060 | 0.0075 | 0.0134 |
| 265 | 184.0 | 0.0177 | 4.34E+10 | 0.0060 | 0.0076 | 0.0136 |
| 270 | 186.5 | 0.0178 | 4.39E+10 | 0.0060 | 0.0077 | 0.0137 |
| 275 | 189.0 | 0.0178 | 4.44E+10 | 0.0061 | 0.0078 | 0.0139 |
| 280 | 191.5 | 0.0179 | 4.49E+10 | 0.0061 | 0.0079 | 0.0140 |
| 285 | 194.0 | 0.0179 | 4.54E+10 | 0.0062 | 0.0080 | 0.0141 |
| 290 | 196.5 | 0.0180 | 4.59E+10 | 0.0062 | 0.0081 | 0.0143 |
| 295 | 199.0 | 0.0180 | 4.63E+10 | 0.0062 | 0.0082 | 0.0144 |
| 300 | 201.5 | 0.0181 | 4.67E+10 | 0.0063 | 0.0083 | 0.0146 |
| 305 | 204.0 | 0.0182 | 4.71E+10 | 0.0063 | 0.0084 | 0.0147 |
| 310 | 206.5 | 0.0182 | 4.74E+10 | 0.0064 | 0.0085 | 0.0148 |
| 315 | 209.0 | 0.0183 | 4.77E+10 | 0.0064 | 0.0086 | 0.0150 |
| 320 | 211.5 | 0.0183 | 4.80E+10 | 0.0064 | 0.0087 | 0.0151 |
| 325 | 214.0 | 0.0184 | 4.83E+10 | 0.0065 | 0.0088 | 0.0152 |
| 330 | 216.5 | 0.0184 | 4.86E+10 | 0.0065 | 0.0089 | 0.0154 |
| 335 | 219.0 | 0.0185 | 4.88E+10 | 0.0065 | 0.0090 | 0.0155 |
| 340 | 221.5 | 0.0185 | 4.90E+10 | 0.0065 | 0.0091 | 0.0157 |
| 345 | 224.0 | 0.0186 | 4.92E+10 | 0.0066 | 0.0092 | 0.0158 |
| 350 | 226.5 | 0.0187 | 4.94E+10 | 0.0066 | 0.0093 | 0.0159 |
| 355 | 229.0 | 0.0187 | 4.96E+10 | 0.0066 | 0.0094 | 0.0161 |
| 360 | 231.5 | 0.0188 | 4.98E+10 | 0.0067 | 0.0096 | 0.0162 |
| 365 | 234.0 | 0.0188 | 4.99E+10 | 0.0067 | 0.0097 | 0.0164 |
| 370 | 236.5 | 0.0189 | 5.00E+10 | 0.0067 | 0.0098 | 0.0165 |
| 375 | 239.0 | 0.0189 | 5.01E+10 | 0.0067 | 0.0099 | 0.0166 |
| 380 | 241.5 | 0.0190 | 5.03E+10 | 0.0068 | 0.0100 | 0.0168 |
| 385 | 244.0 | 0.0190 | 5.03E+10 | 0.0068 | 0.0101 | 0.0169 |
| 390 | 246.5 | 0.0191 | 5.04E+10 | 0.0068 | 0.0103 | 0.0171 |
| 395 | 249.0 | 0.0192 | 5.05E+10 | 0.0068 | 0.0104 | 0.0172 |
| 400 | 251.5 | 0.0192 | 5.06E+10 | 0.0069 | 0.0105 | 0.0174 |
| 405 | 254.0 | 0.0193 | 5.06E+10 | 0.0069 | 0.0106 | 0.0175 |

Total Heat Transfer Coefficients, Cask Vertical Surfaces

Mat, 2
$\varepsilon$ = 0.587
View Factor = 1.0
L = 89.00"

| $T_s$ (°F) | $T_{avg}$ (°F) | k (Btu/h-ft-°F) | Ra (---) | $H_c$ (Btu/h-in$^2$-°F) | $H_r$ (Btu/h-in$^2$-°F) | $H_{tot}$ (Btu/h-in$^2$-°F) |
|---|---|---|---|---|---|---|
| 110 | 106.5 | 0.0158 | 3.38E+09 | 0.0020 | 0.0051 | 0.0071 |
| 115 | 109.0 | 0.0159 | 5.67E+09 | 0.0025 | 0.0051 | 0.0077 |
| 120 | 111.5 | 0.0160 | 7.88E+09 | 0.0029 | 0.0052 | 0.0081 |
| 125 | 114.0 | 0.0160 | 9.99E+09 | 0.0031 | 0.0053 | 0.0084 |
| 130 | 116.5 | 0.0161 | 1.20E+10 | 0.0034 | 0.0054 | 0.0087 |
| 135 | 119.0 | 0.0161 | 1.40E+10 | 0.0036 | 0.0054 | 0.0090 |
| 140 | 121.5 | 0.0162 | 1.58E+10 | 0.0038 | 0.0055 | 0.0093 |
| 145 | 124.0 | 0.0163 | 1.76E+10 | 0.0040 | 0.0056 | 0.0095 |
| 150 | 126.5 | 0.0163 | 1.93E+10 | 0.0041 | 0.0056 | 0.0098 |
| 155 | 129.0 | 0.0164 | 2.10E+10 | 0.0042 | 0.0057 | 0.0100 |
| 160 | 131.5 | 0.0164 | 2.25E+10 | 0.0044 | 0.0058 | 0.0102 |
| 165 | 134.0 | 0.0165 | 2.40E+10 | 0.0045 | 0.0059 | 0.0104 |
| 170 | 136.5 | 0.0166 | 2.55E+10 | 0.0046 | 0.0060 | 0.0105 |
| 175 | 139.0 | 0.0166 | 2.69E+10 | 0.0047 | 0.0060 | 0.0107 |
| 180 | 141.5 | 0.0167 | 2.82E+10 | 0.0048 | 0.0061 | 0.0109 |
| 185 | 144.0 | 0.0167 | 2.95E+10 | 0.0049 | 0.0062 | 0.0111 |
| 190 | 146.5 | 0.0168 | 3.07E+10 | 0.0050 | 0.0063 | 0.0112 |
| 195 | 149.0 | 0.0168 | 3.18E+10 | 0.0051 | 0.0063 | 0.0114 |
| 200 | 151.5 | 0.0169 | 3.29E+10 | 0.0051 | 0.0064 | 0.0116 |
| 205 | 154.0 | 0.0170 | 3.40E+10 | 0.0052 | 0.0065 | 0.0117 |
| 210 | 156.5 | 0.0170 | 3.50E+10 | 0.0053 | 0.0066 | 0.0119 |
| 215 | 159.0 | 0.0171 | 3.59E+10 | 0.0054 | 0.0067 | 0.0120 |
| 220 | 161.5 | 0.0171 | 3.69E+10 | 0.0054 | 0.0068 | 0.0122 |
| 225 | 164.0 | 0.0172 | 3.77E+10 | 0.0055 | 0.0069 | 0.0123 |
| 230 | 166.5 | 0.0173 | 3.86E+10 | 0.0056 | 0.0069 | 0.0125 |
| 235 | 169.0 | 0.0173 | 3.94E+10 | 0.0056 | 0.0070 | 0.0126 |
| 240 | 171.5 | 0.0174 | 4.01E+10 | 0.0057 | 0.0071 | 0.0128 |
| 245 | 174.0 | 0.0175 | 4.08E+10 | 0.0057 | 0.0072 | 0.0129 |
| 250 | 176.5 | 0.0175 | 4.15E+10 | 0.0058 | 0.0073 | 0.0131 |
| 255 | 179.0 | 0.0176 | 4.22E+10 | 0.0058 | 0.0074 | 0.0132 |

Total Heat Transfer Coefficients, Cask Vertical Surfaces

Mat, 2
ε = 0.587
View Factor = 1.0
L = 89.00"

| $T_s$ (°F) | $T_{avg}$ (°F) | k (Btu/h-ft-°F) | Ra (---) | $H_c$ (Btu/h-ft²-°F) | $H_r$ (Btu/h-in²-°F) | $H_{tot}$ (Btu/h-in²-°F) |
|---|---|---|---|---|---|---|
| 260 | 181.5 | 0.0177 | 4.28E+10 | 0.0059 | 0.0075 | 0.0134 |
| 265 | 184.0 | 0.0177 | 4.34E+10 | 0.0059 | 0.0076 | 0.0135 |
| 270 | 186.5 | 0.0178 | 4.39E+10 | 0.0060 | 0.0077 | 0.0136 |
| 275 | 189.0 | 0.0178 | 4.44E+10 | 0.0060 | 0.0078 | 0.0138 |
| 280 | 191.5 | 0.0179 | 4.49E+10 | 0.0061 | 0.0079 | 0.0139 |
| 285 | 194.0 | 0.0179 | 4.54E+10 | 0.0061 | 0.0080 | 0.0141 |
| 290 | 196.5 | 0.0180 | 4.59E+10 | 0.0061 | 0.0081 | 0.0142 |
| 295 | 199.0 | 0.0180 | 4.63E+10 | 0.0062 | 0.0082 | 0.0143 |
| 300 | 201.5 | 0.0181 | 4.67E+10 | 0.0062 | 0.0083 | 0.0145 |
| 305 | 204.0 | 0.0182 | 4.71E+10 | 0.0062 | 0.0084 | 0.0146 |
| 310 | 206.5 | 0.0182 | 4.74E+10 | 0.0063 | 0.0085 | 0.0148 |
| 315 | 209.0 | 0.0183 | 4.77E+10 | 0.0063 | 0.0086 | 0.0149 |
| 320 | 211.5 | 0.0183 | 4.80E+10 | 0.0063 | 0.0087 | 0.0150 |
| 325 | 214.0 | 0.0184 | 4.83E+10 | 0.0064 | 0.0088 | 0.0152 |
| 330 | 216.5 | 0.0184 | 4.86E+10 | 0.0064 | 0.0089 | 0.0153 |
| 335 | 219.0 | 0.0185 | 4.88E+10 | 0.0064 | 0.0090 | 0.0154 |
| 340 | 221.5 | 0.0185 | 4.90E+10 | 0.0065 | 0.0091 | 0.0156 |
| 345 | 224.0 | 0.0186 | 4.92E+10 | 0.0065 | 0.0092 | 0.0157 |
| 350 | 226.5 | 0.0187 | 4.94E+10 | 0.0065 | 0.0093 | 0.0159 |
| 355 | 229.0 | 0.0187 | 4.96E+10 | 0.0066 | 0.0094 | 0.0160 |
| 360 | 231.5 | 0.0188 | 4.98E+10 | 0.0066 | 0.0096 | 0.0161 |
| 365 | 234.0 | 0.0188 | 4.99E+10 | 0.0066 | 0.0097 | 0.0163 |
| 370 | 236.5 | 0.0189 | 5.00E+10 | 0.0066 | 0.0098 | 0.0164 |
| 375 | 239.0 | 0.0189 | 5.01E+10 | 0.0067 | 0.0099 | 0.0166 |
| 380 | 241.5 | 0.0190 | 5.03E+10 | 0.0067 | 0.0100 | 0.0167 |
| 385 | 244.0 | 0.0190 | 5.03E+10 | 0.0067 | 0.0101 | 0.0168 |
| 390 | 246.5 | 0.0191 | 5.04E+10 | 0.0067 | 0.0103 | 0.0170 |
| 395 | 249.0 | 0.0192 | 5.05E+10 | 0.0068 | 0.0104 | 0.0171 |
| 400 | 251.5 | 0.0192 | 5.06E+10 | 0.0068 | 0.0105 | 0.0173 |
| 405 | 254.0 | 0.0193 | 5.06E+10 | 0.0068 | 0.0106 | 0.0174 |

Air Properties

| Temperature[1] | ρ[1] | Conductivity[1] | Prandtl #[1] | Dyn. Visc.[1] |
|---|---|---|---|---|
| (K) | (kg/m³) | (W/m-K) | (-----) | (Pa-s) |
| 255 | 1.386 | 22.68E-3 | 0.721 | 16.25E-6 |
| 265 | 1.333 | 23.48E-3 | 0.717 | 16.75E-6 |
| 280 | 1.261 | 24.67E-3 | 0.713 | 17.50E-6 |
| 295 | 1.197 | 25.85E-3 | 0.709 | 18.22E-6 |
| 310 | 1.139 | 27.01E-3 | 0.705 | 18.93E-6 |
| 325 | 1.086 | 28.15E-3 | 0.702 | 19.63E-6 |
| 340 | 1.038 | 29.28E-3 | 0.699 | 20.30E-6 |
| 355 | 0.9945 | 30.39E-3 | 0.696 | 20.97E-6 |
| 370 | 0.9539 | 31.50E-3 | 0.693 | 21.60E-6 |
| 385 | 0.9169 | 32.59E-3 | 0.690 | 22.24E-6 |
| 400 | 0.8822 | 33.65E-3 | 0.689 | 22.86E-6 |
| 420 | 0.8402 | 35.05E-3 | 0.687 | 23.66E-6 |
| 440 | 0.8021 | 36.43E-3 | 0.684 | 24.45E-6 |

| Temperature | Conductivity | Conductivity | Prandtl # | Kin. Visc. |
|---|---|---|---|---|
| (°F) | (Btu/hr-ft-°F) | (Btu/hr-in-°F) | (-----) | (ft²-hr) |
| -1 | 0.0131 | 0.0011 | 0.721 | 0.4543 |
| 17 | 0.0136 | 0.0011 | 0.717 | 0.4869 |
| 44 | 0.0143 | 0.0012 | 0.713 | 0.5378 |
| 71 | 0.0149 | 0.0012 | 0.709 | 0.5898 |
| 98 | 0.0156 | 0.0013 | 0.705 | 0.6440 |
| 125 | 0.0163 | 0.0014 | 0.702 | 0.7004 |
| 152 | 0.0169 | 0.0014 | 0.699 | 0.7578 |
| 179 | 0.0176 | 0.0015 | 0.696 | 0.8171 |
| 206 | 0.0182 | 0.0015 | 0.693 | 0.8775 |
| 233 | 0.0188 | 0.0016 | 0.690 | 0.9399 |
| 260 | 0.0194 | 0.0016 | 0.689 | 1.0041 |
| 296 | 0.0203 | 0.0017 | 0.687 | 1.0912 |
| 332 | 0.0210 | 0.0018 | 0.684 | 1.1812 |

HTOT_HCY.MAC

**PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390**

**PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390**

# PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390

HTOT_VPL.MAC

**PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390**

# PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390

# PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390

# APPENDIX B

## Fuel Decay Heat Load

The heat load is 660 W/assembly. Multiplying by 32 assemblies and converting to Btu/hr yields a total heat load of 72,068 Btu/hr.

### Cask Body Model

The decay heat load is applied as heat fluxes to the elements that model the inner cavity of the canister.

The cask body model was run without insolation in order to verify the heat flux boundary condition application. The heat dissipated from the model via convection is compared to the anticipated result below.

| Decay Heat Load of Fuel | Heat Dissipated via Conv. (x4) | Percent Difference |
|---|---|---|
| (Btu/hr) | (Btu/hr) | (-----) |
| 72,068 | 72,056 | 0.0% |

### Basket Model

Only the active length of the fuel assemblies is included within the basket finite element model. The decay heat load of the fuel is modeled as an internal heat generation within these fuel elements. A peaking factor of 1.08 was applied to the total decay heat load.

Decay Heat Load of Fuel = (1.08)(72,068) = 77,833 Btu/hr

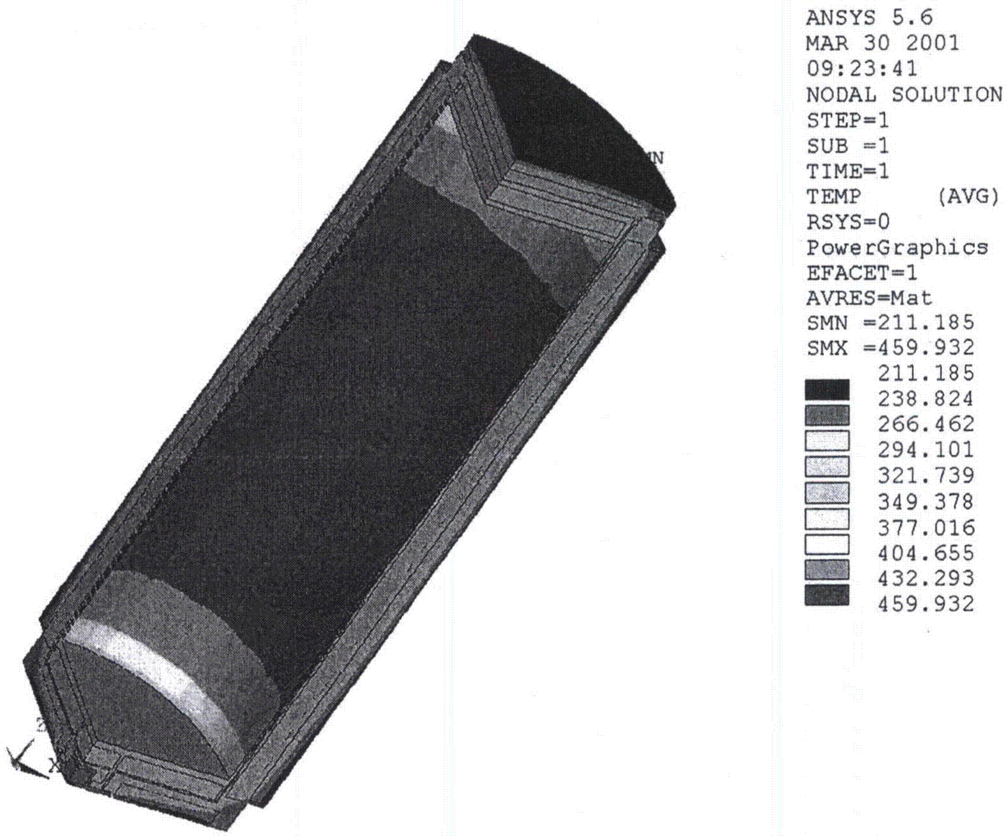
The basket model was run in order to verify the internal heat generation boundary condition application. The reaction solution of the basket model is compared to the anticipated result below.

| Decay Heat Load of Fuel | Reaction Solution. (x4) | Percent Difference |
|---|---|---|
| (Btu/hr) | (Btu/hr) | (-----) |
| 77,833 | 77,832 | 0.0% |

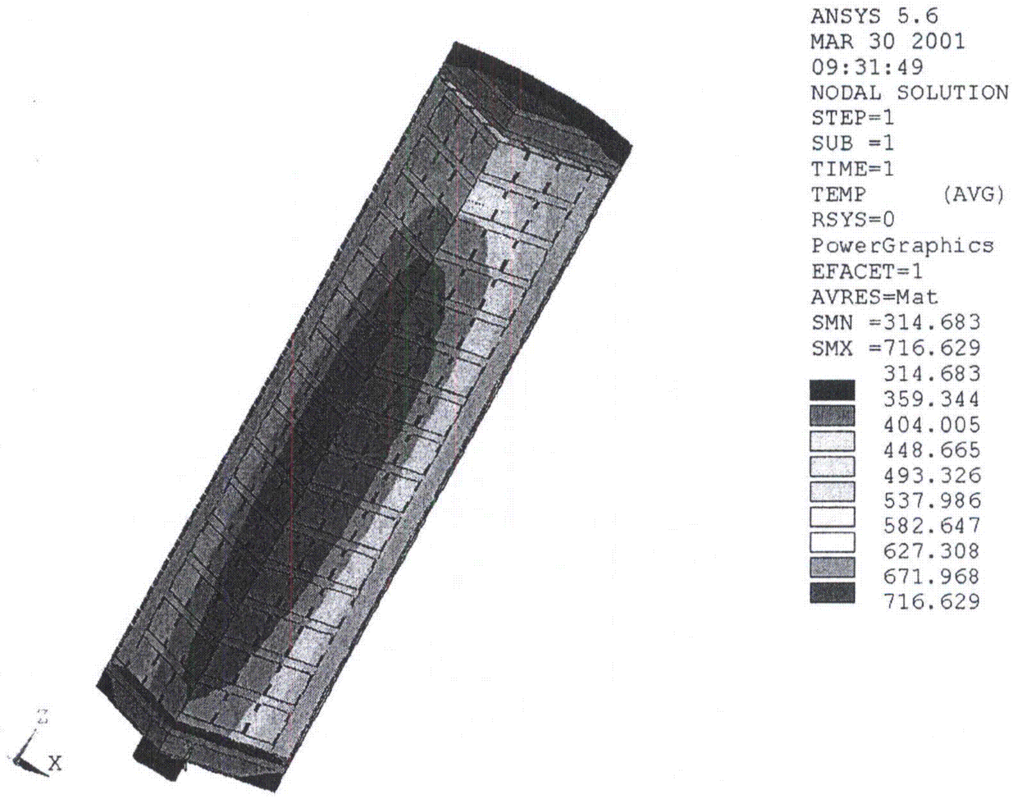
# APPENDIX C

## Temperature Distributions

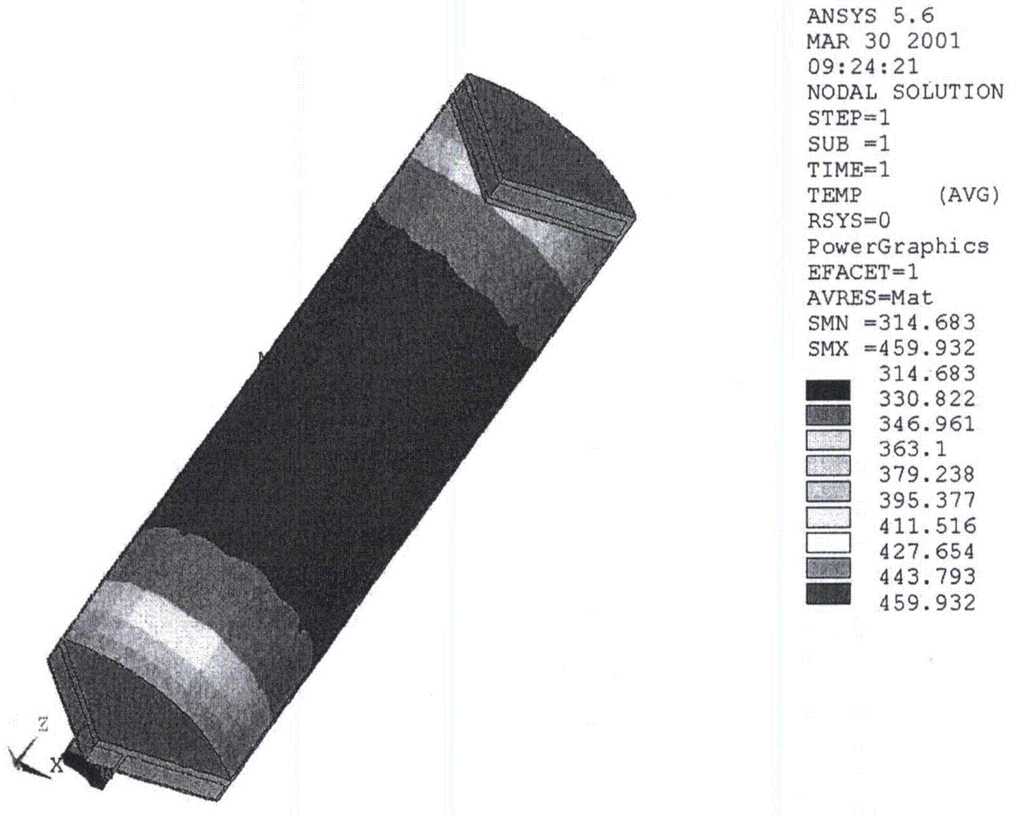
## Cask Body Model



## Basket Model

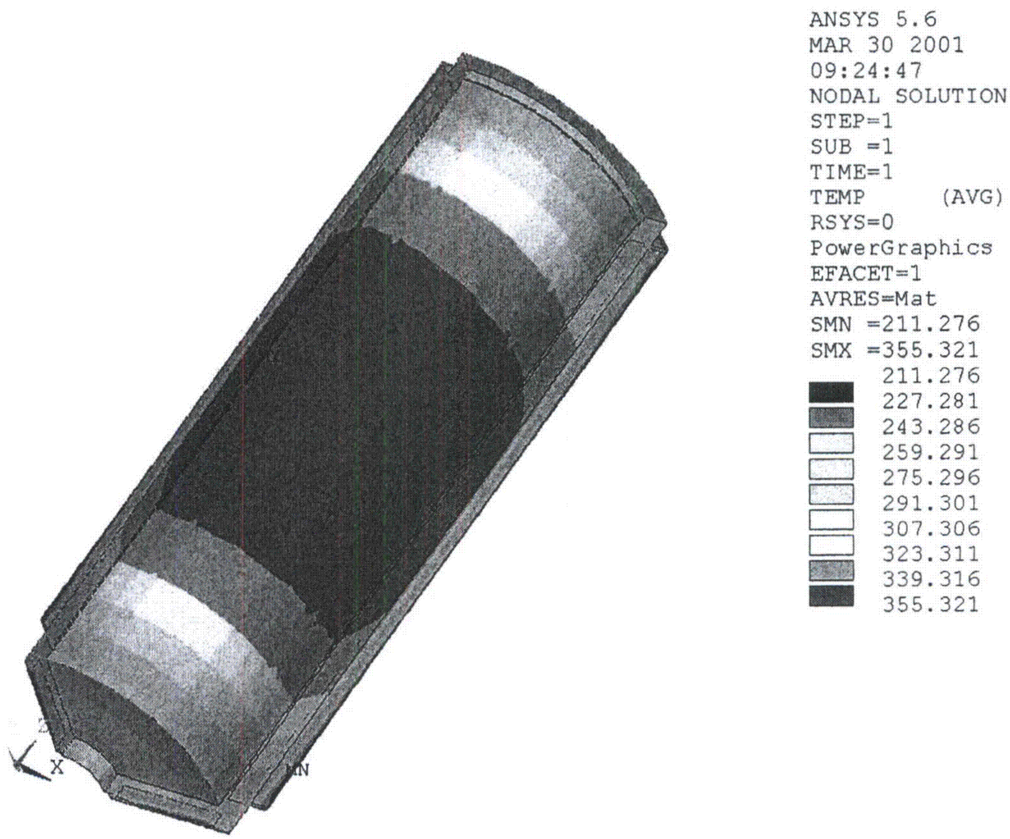


## Canister



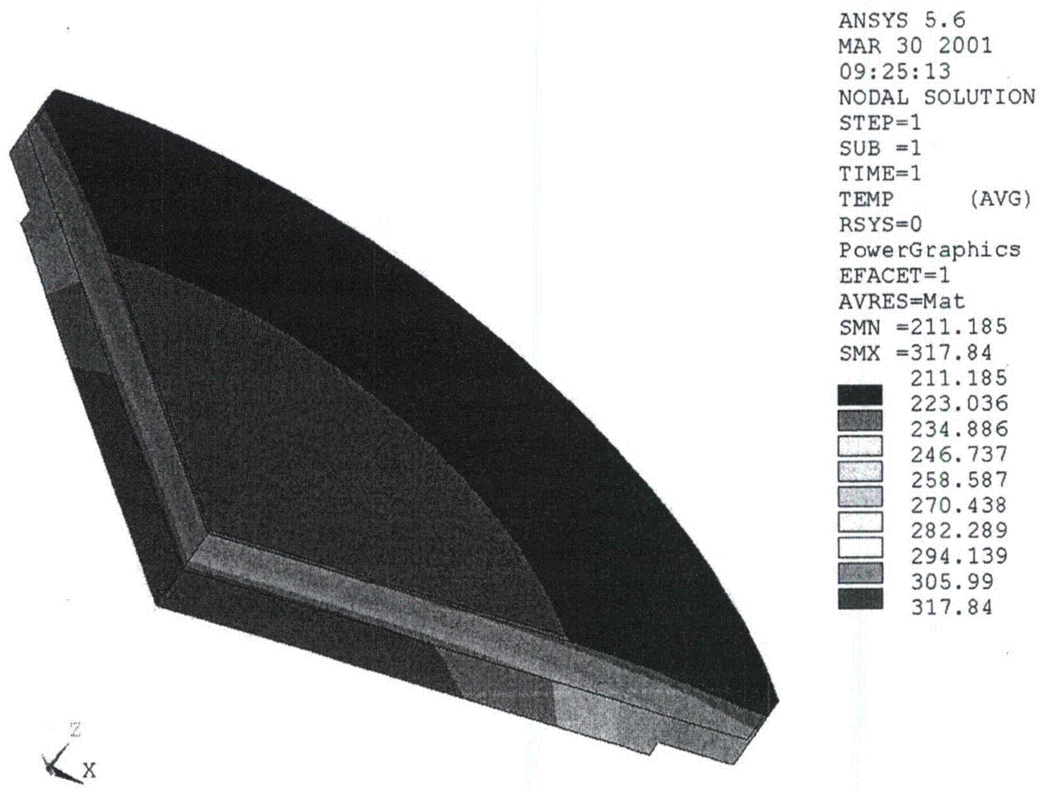
ANSYS 5.6
MAR 30 2001
09:24:21
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =314.683
SMX =459.932
314.683
330.822
346.961
363.1
379.238
395.377
411.516
427.654
443.793
459.932
Z
X

## Cask Body



ANSYS 5.6
MAR 30 2001
09:24:47
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =211.276
SMX =355.321
211.276
227.281
243.286
259.291
275.296
291.301
307.306
323.311
339.316
355.321
X

## Cask Lid


ANSYS 5.6
MAR 30 2001
09:25:13
NODAL SOLUTION
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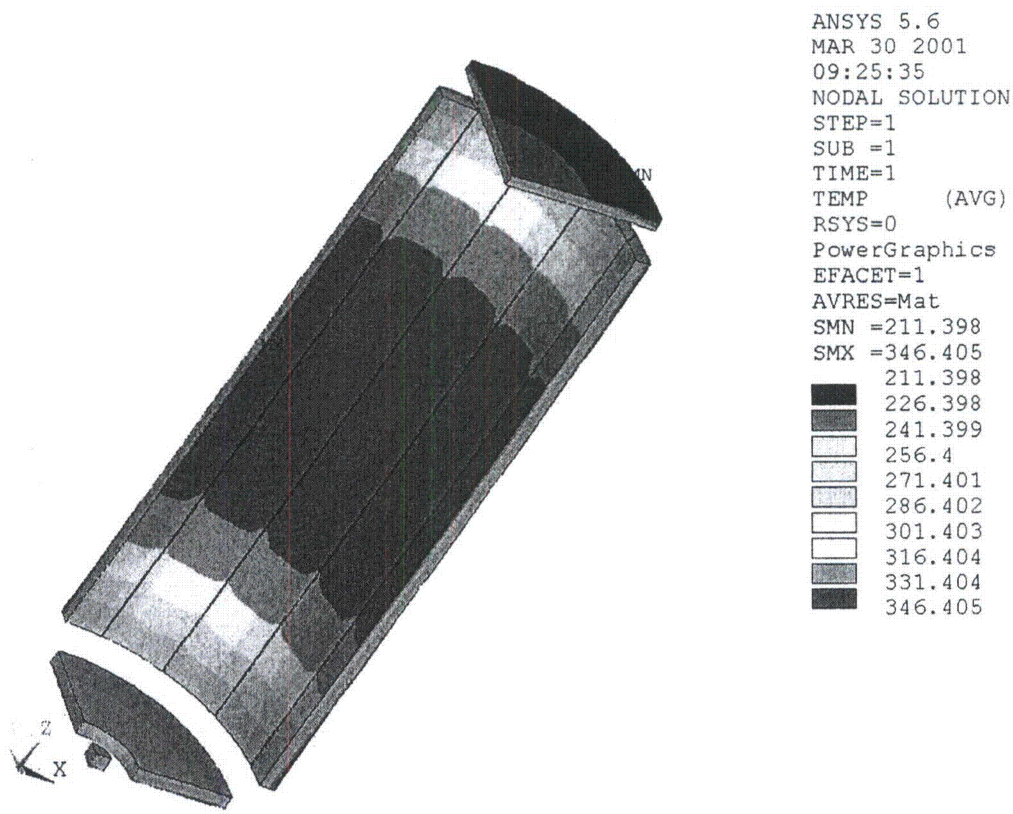
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =211.185
SMX =317.84
211.185
223.036
234.886
246.737
258.587
270.438
282.289
294.139
305.99
317.84
Z
X

**Resin**



ANSYS 5.6
MAR 30 2001
09:25:35
NODAL SOLUTION
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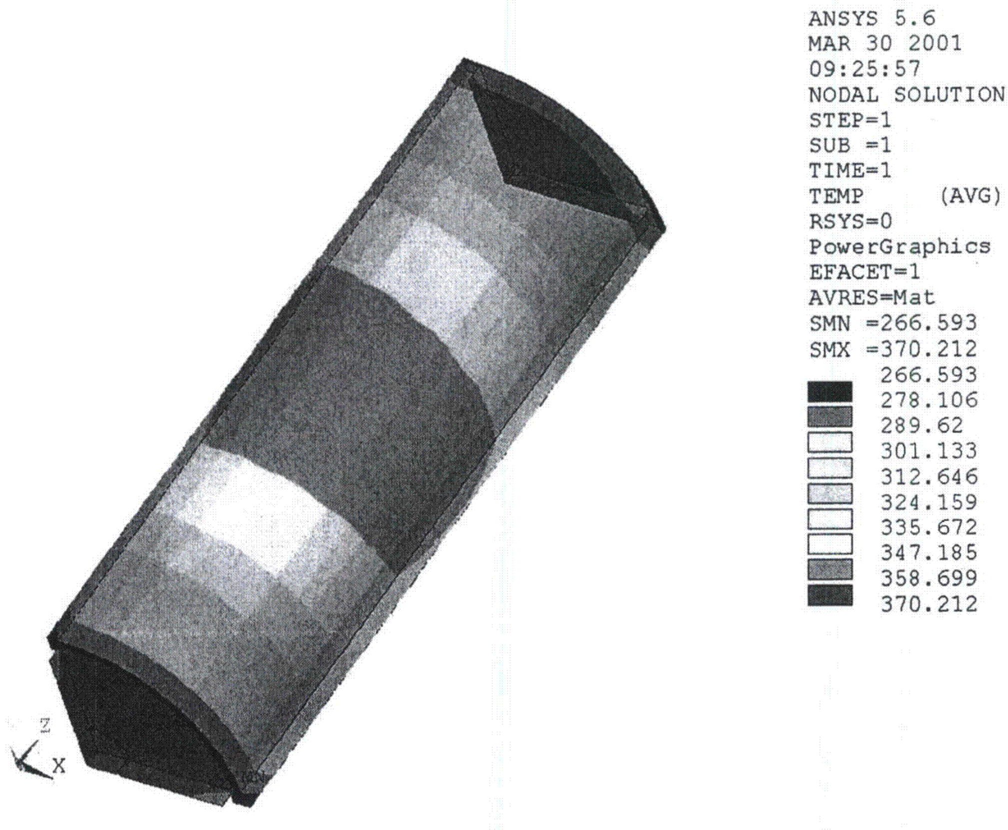
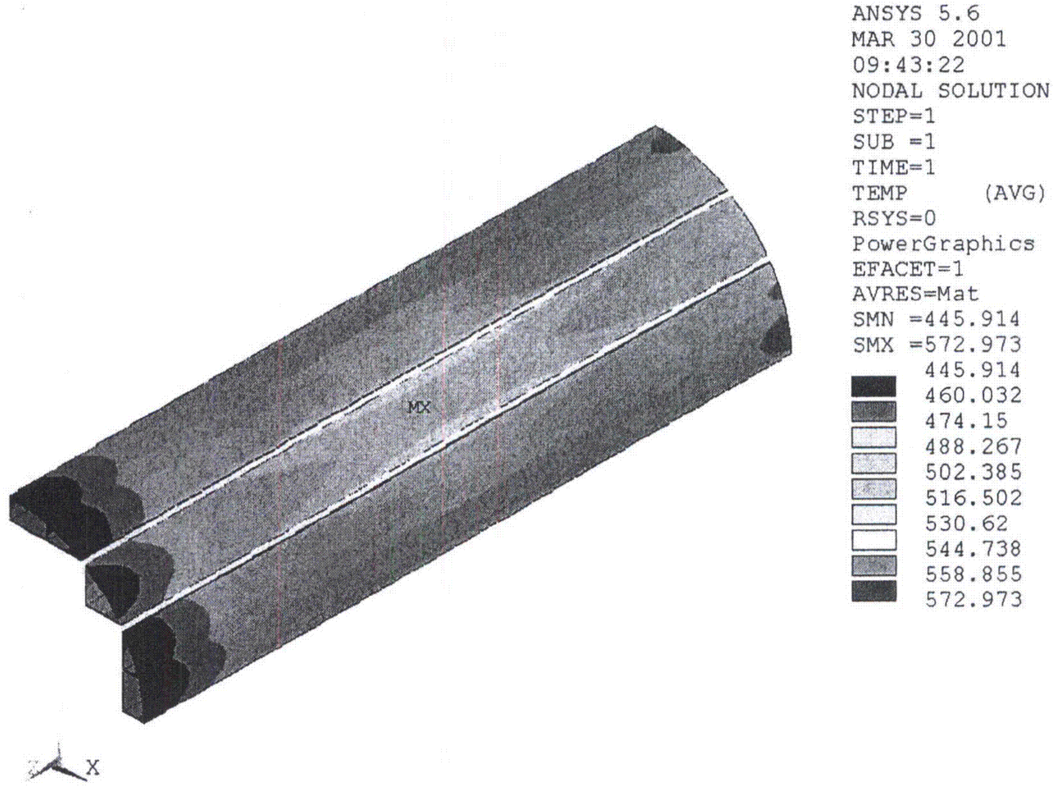
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =211.398
SMX =346.405
211.398
226.398
241.399
256.4
271.401
286.402
301.403
316.404
331.404
346.405
Z
X

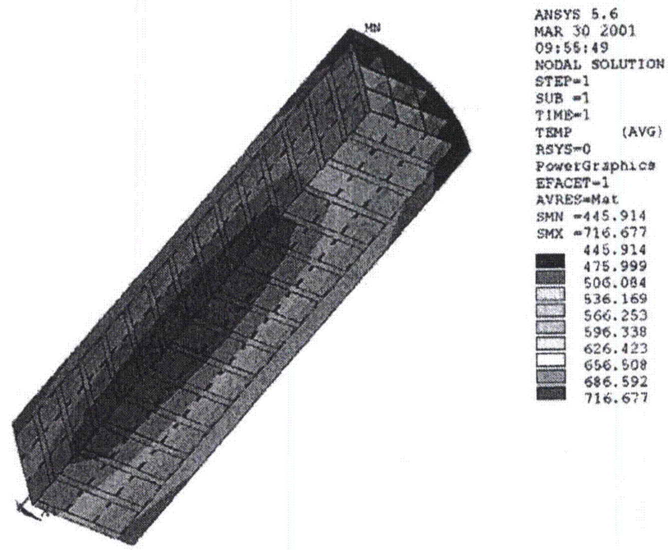
## Lead


ANSYS 5.6
MAR 30 2001
09:25:57
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =266.593
SMX =370.212
266.593
278.106
289.62
301.133
312.646
324.159
335.672
347.185
358.699
370.212
Z
X

## Peripheral Inserts



## Basket



ANSYS 5.6
MAR 30 2001
09:55:49
NODAL SOLUTION
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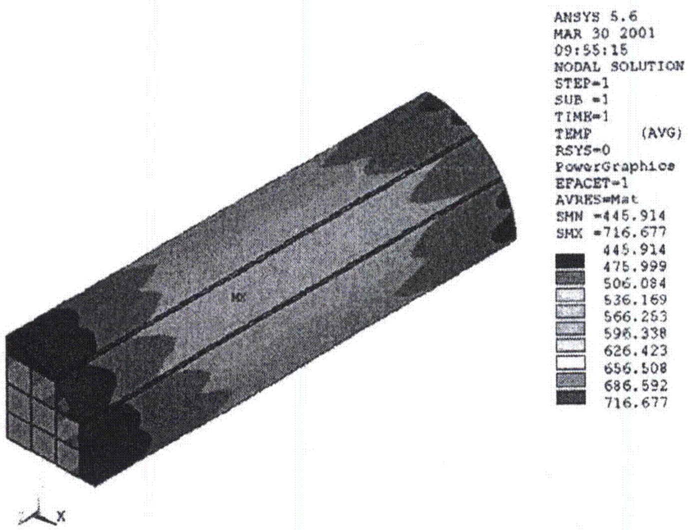
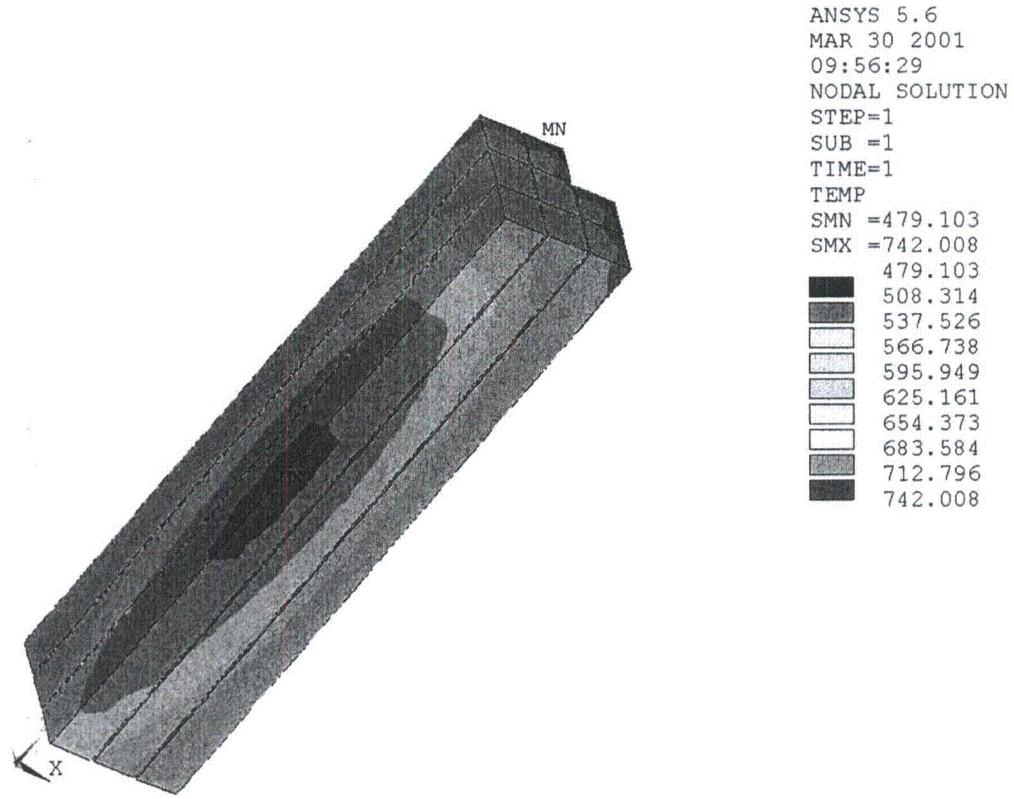
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =445.914
SMX =716.677
445.914
475.999
506.084
536.169
566.253
596.338
626.423
656.508
686.592
716.677
MN

ANSYS 5.6
MAR 30 2001
09:55:15
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =445.914
SMX =716.677
445.914
475.999
506.084
536.169
566.253
596.338
626.423
656.508
686.592
716.677
MX
X

## Fuel Assemblies



# APPENDIX D

## BulkTemp.mac Macro

**PROPRIETARY INFORMATION WITHHELD UNDER 10CFR 2.390**

# APPENDIX E

## Heat Transfer Coefficients

In this section a brief comparison is conducted to determine that the equations for the heat transfer coefficients used in this analysis are more conservative than the equations used in the Topical Report for the NUHOMS 24P system in Reference 2. The equations used in Calculation 1095-6 correspond to the last stand of heat transfer knowledge. These equations are stated in Appendix A.

Equations from Reference 2 are as follows:

Horizontal Cylinder:
$Hc = 0.22(\Delta t)^{1/3}$ (Btu/hr-ft$^2$-°F)

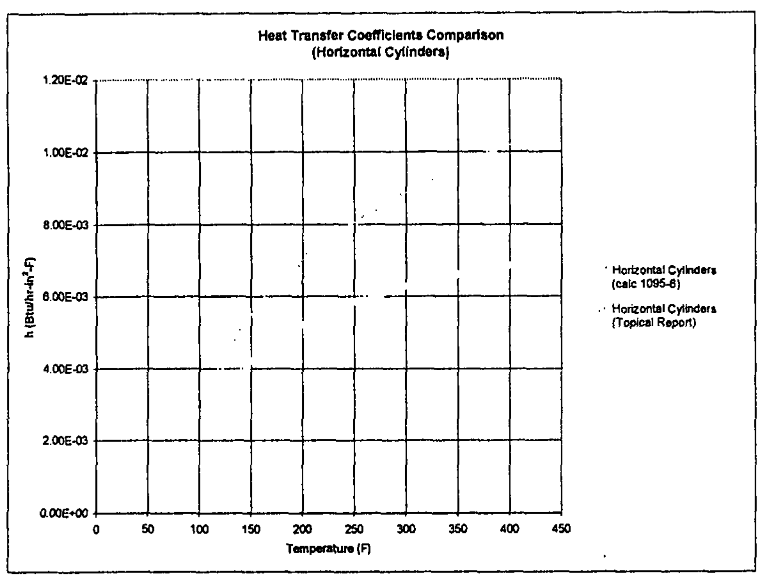
Vertical Plate:
$Hc = 0.19(\Delta t)^{1/3}$ (Btu/hr-ft$^2$-°F)

$\Delta t$ = Twall – Tamb
Tamb = 103 °F

The following tables show the tabulated values for each correlation. The values are graphed to visualize the comparison of each set of values. Each set is divided into equations of horizontal cylinder coefficients and vertical plate coefficients.

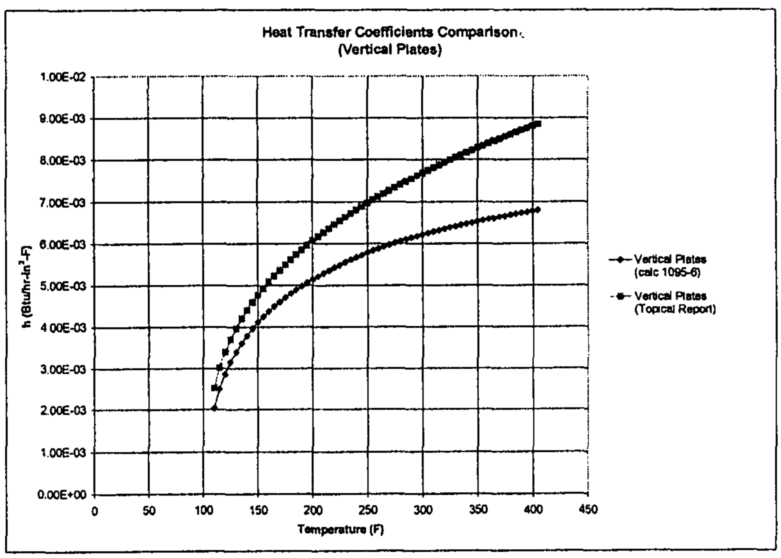
## Horizontal Cylinder

| Twall (F) | Hc (Ref. 1) (Btu/hr-in$^2$-F) | Hc (Ref. 2) (Btu/hr-in$^2$-F) | Twall (F) | Hc (Ref. 1) (Btu/hr-in$^2$-F) | Hc (Ref. 2) (Btu/hr-in$^2$-F) |
|---|---|---|---|---|---|
| 110 | 2.29E-03 | 2.92E-03 | 335 | 6.52E-03 | 9.39E-03 |
| 115 | 2.73E-03 | 3.50E-03 | 340 | 6.55E-03 | 9.45E-03 |
| 120 | 3.06E-03 | 3.93E-03 | 345 | 6.57E-03 | 9.52E-03 |
| 125 | 3.33E-03 | 4.28E-03 | 350 | 6.60E-03 | 9.59E-03 |
| 130 | 3.55E-03 | 4.58E-03 | 355 | 6.63E-03 | 9.65E-03 |
| 135 | 3.75E-03 | 4.85E-03 | 360 | 6.66E-03 | 9.71E-03 |
| 140 | 3.92E-03 | 5.09E-03 | 365 | 6.68E-03 | 9.78E-03 |
| 145 | 4.08E-03 | 5.31E-03 | 370 | 6.71E-03 | 9.84E-03 |
| 150 | 4.23E-03 | 5.51E-03 | 375 | 6.73E-03 | 9.90E-03 |
| 155 | 4.36E-03 | 5.70E-03 | 380 | 6.76E-03 | 9.96E-03 |
| 160 | 4.48E-03 | 5.88E-03 | 385 | 6.78E-03 | 1.00E-02 |
| 165 | 4.59E-03 | 6.05E-03 | 390 | 6.81E-03 | 1.01E-02 |
| 170 | 4.70E-03 | 6.21E-03 | 395 | 6.83E-03 | 1.01E-02 |
| 175 | 4.80E-03 | 6.36E-03 | 400 | 6.85E-03 | 1.02E-02 |
| 180 | 4.89E-03 | 6.50E-03 | 405 | 6.87E-03 | 1.03E-02 |
| 185 | 4.98E-03 | 6.64E-03 | | | |
| 190 | 5.06E-03 | 6.77E-03 | | | |
| 195 | 5.14E-03 | 6.90E-03 | | | |
| 200 | 5.22E-03 | 7.02E-03 | | | |
| 205 | 5.30E-03 | 7.14E-03 | | | |
| 210 | 5.37E-03 | 7.25E-03 | | | |
| 215 | 5.44E-03 | 7.36E-03 | | | |
| 220 | 5.50E-03 | 7.47E-03 | | | |
| 225 | 5.57E-03 | 7.58E-03 | | | |
| 230 | 5.63E-03 | 7.68E-03 | | | |
| 235 | 5.69E-03 | 7.78E-03 | | | |
| 240 | 5.75E-03 | 7.88E-03 | | | |
| 245 | 5.80E-03 | 7.97E-03 | | | |
| 250 | 5.86E-03 | 8.06E-03 | | | |
| 255 | 5.91E-03 | 8.15E-03 | | | |
| 260 | 5.96E-03 | 8.24E-03 | | | |
| 265 | 6.00E-03 | 8.33E-03 | | | |
| 270 | 6.05E-03 | 8.41E-03 | | | |
| 275 | 6.09E-03 | 8.50E-03 | | | |
| 280 | 6.13E-03 | 8.58E-03 | | | |
| 285 | 6.17E-03 | 8.66E-03 | | | |
| 290 | 6.21E-03 | 8.74E-03 | | | |
| 295 | 6.25E-03 | 8.81E-03 | | | |
| 300 | 6.29E-03 | 8.89E-03 | | | |
| 305 | 6.32E-03 | 8.96E-03 | | | |
| 310 | 6.36E-03 | 9.04E-03 | | | |
| 315 | 6.39E-03 | 9.11E-03 | | | |
| 320 | 6.42E-03 | 9.18E-03 | | | |
| 325 | 6.45E-03 | 9.25E-03 | | | |
| 330 | 6.49E-03 | 9.32E-03 | | | |



## Vertical Plates

| Twall (F) | Hc (Ref. 1) (Btu/hr-in$^2$-F) | Hc (Ref. 2) (Btu/hr-in$^2$-F) | Twall (F) | Hc (Ref. 1) (Btu/hr-in$^2$-F) | Hc (Ref. 2) (Btu/hr-in$^2$-F) |
|---|---|---|---|---|---|
| 110 | 2.03E-03 | 2.52E-03 | 330 | 6.41E-03 | 8.05E-03 |
| 115 | 2.50E-03 | 3.02E-03 | 335 | 6.44E-03 | 8.11E-03 |
| 120 | 2.86E-03 | 3.39E-03 | 340 | 6.47E-03 | 8.17E-03 |
| 125 | 3.15E-03 | 3.70E-03 | 345 | 6.50E-03 | 8.22E-03 |
| 130 | 3.39E-03 | 3.96E-03 | 350 | 6.53E-03 | 8.28E-03 |
| 135 | 3.60E-03 | 4.19E-03 | 355 | 6.55E-03 | 8.33E-03 |
| 140 | 3.79E-03 | 4.40E-03 | 360 | 6.58E-03 | 8.39E-03 |
| 145 | 3.96E-03 | 4.59E-03 | 365 | 6.61E-03 | 8.44E-03 |
| 150 | 4.11E-03 | 4.76E-03 | 370 | 6.63E-03 | 8.50E-03 |
| 155 | 4.25E-03 | 4.92E-03 | 375 | 6.66E-03 | 8.55E-03 |
| 160 | 4.37E-03 | 5.08E-03 | 380 | 6.68E-03 | 8.60E-03 |
| 165 | 4.49E-03 | 5.22E-03 | 385 | 6.70E-03 | 8.65E-03 |
| 170 | 4.60E-03 | 5.36E-03 | 390 | 6.73E-03 | 8.70E-03 |
| 175 | 4.70E-03 | 5.49E-03 | 395 | 6.75E-03 | 8.75E-03 |
| 180 | 4.80E-03 | 5.61E-03 | 400 | 6.77E-03 | 8.80E-03 |
| 185 | 4.89E-03 | 5.73E-03 | 405 | 6.79E-03 | 8.85E-03 |
| 190 | 4.98E-03 | 5.85E-03 | | | |
| 195 | 5.06E-03 | 5.96E-03 | | | |
| 200 | 5.14E-03 | 6.06E-03 | | | |
| 205 | 5.21E-03 | 6.16E-03 | | | |
| 210 | 5.29E-03 | 6.26E-03 | | | |
| 215 | 5.36E-03 | 6.36E-03 | | | |
| 220 | 5.42E-03 | 6.45E-03 | | | |
| 225 | 5.49E-03 | 6.54E-03 | | | |
| 230 | 5.55E-03 | 6.63E-03 | | | |
| 235 | 5.61E-03 | 6.72E-03 | | | |
| 240 | 5.67E-03 | 6.80E-03 | | | |
| 245 | 5.73E-03 | 6.88E-03 | | | |
| 250 | 5.78E-03 | 6.96E-03 | | | |
| 255 | 5.83E-03 | 7.04E-03 | | | |
| 260 | 5.88E-03 | 7.12E-03 | | | |
| 265 | 5.93E-03 | 7.19E-03 | | | |
| 270 | 5.97E-03 | 7.27E-03 | | | |
| 275 | 6.01E-03 | 7.34E-03 | | | |
| 280 | 6.06E-03 | 7.41E-03 | | | |
| 285 | 6.10E-03 | 7.48E-03 | | | |
| 290 | 6.14E-03 | 7.55E-03 | | | |
| 295 | 6.17E-03 | 7.61E-03 | | | |
| 300 | 6.21E-03 | 7.68E-03 | | | |
| 305 | 6.25E-03 | 7.74E-03 | | | |
| 310 | 6.28E-03 | 7.81E-03 | | | |
| 315 | 6.32E-03 | 7.87E-03 | | | |
| 320 | 6.35E-03 | 7.93E-03 | | | |
| 325 | 6.38E-03 | 7.99E-03 | | | |



According to the graphs the values from Reference 1 are considerably less than those from Reference 2. This concludes that there is less convection in the FE model of calculation 1095-6. Due to lower convection heat transfer, calculation 1095-6 results in higher component temperatures within the transfer cask and therefore it is conservative.