PACIFIC NUCLEAR FUEL SERVICES

# CALCULATION PACKAGE

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**CALCULATION TITLE:**

Cask Axial and Radial Thermal Analysis for Standardized NUHOMS®-24P Design With 5-year Old Fuel (1 kW per Fuel Assembly)

**PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:**

Determination of the temperature distribution for the NUHOMS®-24P Cask/DSC under several different steady-state design conditions, loaded with 40,000 MWd/MTU, 5-year old fuel.

A 1-dimensional cylindrical model is used to determine the temperature distribution in the Cask/DSC radial and axial directions.

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## 1.0 INTRODUCTION

The objective of the calculation is to determine the standardized NUHOMS®-24P Cask and DSC composite layer temperature distributions in the Cask/DSC axial and radial directions. The value for the decay heat term used in the calculations is based upon 40,000 MWd/MTU, 5-year old PWR fuel (per reference 9).

The calculations include cases for each of the following ambient temperatures: -40° F, 0° F, 70° F, 100° F, and 125° F. Cases are considered to account for the top and bottom effects of the Cask/DSC horizontal orientation (ie., solar load differential and the differing height of the air gap in the annular region between the DSC exterior and the interior Cask cavity). Special cases are considered to determine the maximum DSC shell temperature. Finally, the accident cases are considered in which the Cask neutron shield is considered to be void of material.

Note: The radial cases assume that the Cask outer shell is fabricated from carbon steel in lieu of 304 stainless steel; therefore, the calculations result in inner shell temperatures which are 1 to 2 degrees lower than would result if 304 stainless steel were considered. Although slightly nonconservative, this is considered an insignificant difference.

## 2.0 METHODOLOGY

The methodology used in this calculation is identical to that used in Reference 6. The model and formulas used in the calculation are identical to those used in Reference 4 and are listed in Sections 2.1 and 2.4 of the calculation package.

### 2.1 Description of Radial Model

The cask outside surface tempearture is calculated first, and then the temperature distributions across each layer are determined, working inward. Iterations are made for each calculation using temperature dependent material properties. This is repeated until the cask temperature distribution has converged.

All of the temperature drops, including the cask outer surface temperature, are calculated using the thermal resistance concept,

$$Q = \frac{T_i - T_o}{\Sigma R_n} \qquad (1)$$

where Q is the total cask cavity heat load (Btu/hr), $T_i$ is the inside temperature, $T_o$ is the outside temperature, and $R_n$ is the total thermal resistance for heat transfer mode n. Heat transfer modes used are conduction, convection, and radiation. A detailed description of the equations used is given below.

## 2.2 Cask Radial Outer Surface Temperature

The cask outer surface temperature is calculated assuming that heat is transferred from the cask outer surface to the air by convection and radiation. The contribution due to radiation is included in the convection term by superposing their effects as shown below.

$$Q = h_c A(T_o - T_\infty) + \epsilon \sigma A(T_o^4 - T_\infty^4) \qquad (2)$$

where Q is the total cask cavity heat load (Btu/hr), $\epsilon$ is the cask outside surface emissivity, $\sigma$ is the Stefan-Boltzmann constant, $h_c$ is the convective heat transfer coefficient, and A is the cask surface area for heat transfer. For a horizontal cylinder, $h_c$ is equal to [4],

$$h_c = 0.18(T_o - T_\infty)^{1/3} \qquad (3)$$

For a vertical cylinder $h_c$ is assumed to be that of a vertical plate, and is equal to the value given by Equation 3 after replacing the coefficient 0.18 with 0.19 [4]. The total heat load on the cask outer surface, Q, is the sum of the total cask decay heat and the solar heat flux,

$$Q = Q_{fuel} + 2\pi r_o l q_{solar} \qquad (4)$$

where $r_o$ is the cask outside radius, l is the cask inner cavity length, $Q_{fuel}$ is the total cask cavity heat load, and $q_{solar}$ is the solar heat flux.

By defining a radiation coefficient $h_r$ as,

$$h_r = \epsilon\sigma(T_o+T_\infty)(T_o^2+T_\infty^2) \quad (5)$$

Equation 2 can be rearranged into the form,

$$T_o = \frac{Q}{A(h_c+h_r)} + T_\infty \quad (6)$$

This relation gives the outside cask temperature in terms of the total cask heat load, ambient temperature, cask area, and the sum of the heat transfer coefficients. Because the heat transfer coefficients are in turn dependent on the cask surface temperature, iterations are necessary to determine the cask surface temperature.

## 2.3 Radial Internal Temperature Drops

The only mode of heat transfer assumed to occur in the internal cask layers is conduction. The thermal resistance for conduction across concentric cylinders is equal to,

$$R_c = \frac{\ln\left[\frac{r_o}{r_i}\right]}{2\pi kl} \quad (7)$$

where $r_o$ is the outside radius, $r_i$ is the inside radius, and k is the thermal conductivity of the layer material. Substituting into Equation 1 and rearranging gives,

$$T_i = \frac{Q\cdot\ln\left[\frac{r_o}{r_i}\right]}{2\pi kl} + T_o \quad (8)$$

where Q in this case is equal to the total decay heat generation rate of the fuel assemblies.

### 2.3.1 Radial Internal Thermal Radiation

Layers through which there is thermal radiation heat transfer are modelled as having two thermal resistances in parallel, radiation and conduction. The total thermal resistance for two resistances in parallel is given by,

$$R_{total} = \frac{1}{\frac{1}{R_c} + \frac{1}{R_r}} \qquad (9)$$

The resistance due to conduction, $R_c$ is identical to that in Equation 7, and the resistance due to radiation is given by,

$$R_r = \frac{1}{2\pi h_r r_i l} \qquad (10)$$

where the radiation coefficient $h_r$ for two concentric cylinders is given by,

$$h_r = \frac{\sigma (T_i + T_o)(T_i^2 + T_o^2)}{\frac{1}{\epsilon_i} + \frac{r_i}{r_o}\left(\frac{1}{\epsilon_o} - 1\right)} \qquad (11)$$

where $\epsilon_i$ and $\epsilon_o$ are the emissivities of the inside and outside surfaces respectively. Substituting Equations 7, 9, and 10 into Equation 1 and rearranging gives the temperature on the inside surface,

$$T_i = \frac{Q}{2\pi h_r r_i l + \frac{2\pi k l}{\ln\left(\frac{r_o}{r_i}\right)}} + T_o \qquad (12)$$

The radiation coefficient $h_r$ is calculated by assuming temperatures for Equation 11 and iterating till convergence is achieved.

2.3.2 Radial Internal Convection

Internal convection in an annular region is modeled by substituting the thermal conductivity with an effective thermal conductivity which includes the effects of convection. Effective conductivities are provided in the material library for air and water (airconv and h20conv). Credit for convection in an annular region is taken if the Grashof number for that annular region falls within the turbulent regime, ie.:

$$Gr_\delta = \frac{g\beta(T_i - T_o)(r_o - r_i)^3}{\nu^2} \qquad (13)$$

where ß is the thermal coefficient of volume expansion, g is the gravitational constant, and nu is the kinematic viscosity. The fluid flow in the annulus must be in the turbulent regime in order for the convection corrected conductivities to be used. Turbulent flow occurs when the product of the Grashof and the Prandtl numbers ($Gr_\delta Pr$) is greater than $10^7$ [2].

2.4 Description of Axial Thermal Model

The methodology used for the axial case is identical to the technique employed in the cask radial thermal analysis (refer to Section 2.1). The difference between the radial and axial cases is in the equations used to calculate the heat loads and the thermal resistances. These differences are discussed below.

2.4.1 Axial Heat Fluxes

For the axial case, all layers are assumed to be flat plates, so heat fluxes are not dependent on the axial location. Therefore, a unit area heat flux, q (Btu/hr·ft$^2$), is used in the axial analysis. The heat flux in the cask ends due to the fuel decay heat is chosen to be equal to the decay heat divided by the entire cask internal cavity area [5]:

$$q_{fuel} = \frac{Q_{fuel}}{2\pi r_i^2 + 2\pi r_i l} \qquad (14)$$

The solar heat flux on the cask outside ends is set equal to 20% of the input solar heat flux for a horizontal cask [11], to 100% of the input solar heat flux for the top end of a vertical cask, and to zero for the bottom end of a vertical cask.

### 2.4.2 Cask Axial Outer Surface Temperature

For the bottom end of a vertical cask, the surface temperature is set equal to the ambient temperature (representing the floor). The unit area heat flux is equal to $Q/A_{cask}$, and the equation for determining the cask surface temperature for the other orientations is:

$$T_o = \frac{q}{h_r+h_c} + T_\infty \tag{15}$$

The convective heat transfer coefficient, $h_c$, for a vertical flat plate is given by [5]:

$$h_c = 0.19(T_o-T_\infty)^{\frac{1}{3}} \tag{16}$$

The radiation heat transfer coefficient, $h_r$, for a vertical flat plate is given by [5]:

$$h_r=\epsilon\cdot\sigma\cdot(T_o+T_\infty)\cdot(T_o^2+T_\infty^2) \tag{17}$$

### 2.4.3 Axial Conduction

For conduction across an internal layer, the inside layer temperature is given by,

$$T_i = \frac{q}{k}(L_o-L_i) + T_o \tag{18}$$

Where $L_o - L_i$ is the thickness of the layer.

### 2.4.4 Axial Internal Radiation

The radiation coefficient for radiation between two parallel flat plates is given by,

$$h_r = \frac{\sigma (T_i + T_o)(T_i^2 + T_o^2)}{\frac{1}{\epsilon_i} + \frac{1}{\epsilon_o} - 1} \tag{19}$$

The inside temperature is given by

$$T_i = \frac{q}{h_r + \frac{k}{L_o - L_i}} + T_o \tag{20}$$

or, rearranging the terms yields equation (8) below:

$$q = (T_i - T_o) x [h_r + \frac{k}{L_o - L_i}] \tag{21}$$

### 2.5 Cask/DSC Radial Geometry

The thermal calculations herein are based upon the Cask and DSC shell lengths and radii specified in Section 3.0.

An interior Cask cavity length of 187.75" is assumed to form the basis for the Cask shell temperature determinations (assuming the cask cover plate is not in place). With the cask cover plate the cask cavity is 196.75". If 196.75" were used as the cask cavity length in the calculations, the cask shell temperatures would increase by approximately one degree Fahrenheit. This would be a negligible increase in cask shell temperatures.

When the maximum DSC outer shell temperature is calculated, to ensure conservative results, the DSC interior cavity length of 167" is assumed to be exposed to the radial decay heat.

2.6 Cask/DSC Axial Geometry

The thermal calculations herein are based upon the Cask and DSC shell lengths and radii specified in Section 3.0.

An interior Cask cavity length of 187.75" is assumed to form the basis for the Cask axial shell temperature determinations (assuming the cask cover plate is not in place). With the cask cover plate installed, the cask cavity is 196.75". If 196.75" were used as the cask cavity length in the calculations, the cask axial shell temperatures would increase by approximately one degree Fahrenheit. This would be a negligible increase in cask shell temperatures.

When the maximum DSC outer shell temperature is calculated, to ensure conservative results, the DSC interior cavity length of 167" is used to calculate the heat flux through the DSC surfaces.

A 0.50" air gap was conservatively assumed for the maximum DSC exterior temperature horizonal orientation calculations. The actual (70° F) longitudinal clearance between the DSC and cask is 0.75" under cold conditions; however, to determine a conservative heating effect on the DSC, it is assumed that a 0.50" air gap exists at both the top and bottom ends. The use of a 0.5" air gap at the top and bottom ends of the DSC is conservative; the thermal expansion of the DSC (due to fuel assembly decay heat) will reduce the gap below 0.50".

## 2.7 Material Properties

The thermal conductivities of the materials in the Cask and DSC are listed below:

**304 Stainless Steel** (Reference 5)

| **T** (°F) | **k** (Btu/hr-ft$^2$-°F) |
|---|---|
| 32 | 8.1 |
| 212 | 8.7 |
| 392 | 8.7 |
| 572 | 9.4 |
| 752 | 10 |
| 1112 | 11 |
| 1472 | 13 |

**Carbon Steel** (Reference 5)

| **T** (°F) | **k** (Btu/hr-ft$^2$-°F) |
|---|---|
| 32 | 25 |
| 212 | 25 |
| 392 | 24 |
| 572 | 23 |
| 752 | 21 |
| 1112 | 19 |
| 1472 | 17 |
| 1832 | 16 |

**Lead** (Reference 5)

| **T** (°F) | **k** (Btu/hr-ft$^2$-°F) |
|---|---|
| 32 | 20.3 |
| 212 | 19.3 |
| 392 | 18.2 |
| 572 | 17.2 |
| 630 | 12.1 |
| 717 | 9.7 |
| 800 | 9 |
| 980 | 8.7 |
| 1276 | 8.6 |

**Air** (Reference 5)

| T (°F) | k (@ 14.7 psia) (Btu/hr-ft$^2$-°F) |
|---|---|
| 80.6 | 0.0151 |
| 170 | 0.0172 |
| 261 | 0.0191 |
| 351 | 0.021 |
| 441 | 0.0228 |
| 531 | 0.0246 |
| 621 | 0.0263 |
| 711 | 0.028 |

**Airconv** (Reference 5)
**(Air with natural convection)**

| T (°F) | k (@ 14.7 psia) (Btu/hr-ft$^2$-°F) |
|---|---|
| 150 | 0.1 |

**NS-3 with Stiffeners**

| T (°F) | k @ 250° F (Btu/hr-ft$^2$-°F) |
|---|---|
| 150 | 1.13 (refer to Section 3.4 for calculation) |

## 3.0 CALCULATIONS

### 3.1 Radial Thermal Cases

This section includes the results of the calculations (which utilizes the methodology described in Section 2). The results include the input data and the Cask/DSC temperature distribution output data for the different cases. The following radial thermal cases were considered:

| Case[1] | Orientation/Top or Bottom Model | Ambient | Solar Yes/No | Solar Load (btuh/ft^2) [1] | Remarks |
|---|---|---|---|---|---|
| 1A | Horizontal/Top | -40 | No | 0 | 0.375" Air Gap |
| 1B | Horizontal/Bottom | -40 | No | 0 | No Air Gap |
| 1C | Horizontal | -40 | No | 0 | 0.75" Air Gap w/ Cask Cav Length of 167" |
| 2A | Horizontal/Top | 0 | No | 0 | 0.375" Air Gap |
| 2B | Horizontal/Bottom | 0 | No | 0 | No Air Gap |
| 2C | Horizontal | 0 | No | 0 | 0.75" Air Gap w/ Cask Cav Length of 167" |
| 3A | Horizontal/Top | 70' | Yes | 62 | 0.375" Air Gap |
| 3B | Horizontal/Bottom | 70 | No | 0 | No Air Gap |
| 3C | Horizontal | 70 | Yes | 62 | 0.75" Air Gap w/ Cask Cav Length of 167" |
| 3D | Vertical | 70 | No | 0 | 0.375" Air Gap |
| 4A | Horizontal/Top | 100 | Yes | 62 | 0.375" Air Gap |
| 4B | Horizontal/Bottom | 100 | No | 0 | No Air Gap |
| 4C | Horizontal | 100 | Yes | 62 | 0.75" Air Gap w/ Cask Cav Length of 167" |
| 4D | Vertical | 100 | No | 0 | |
| 5A | Horizontal/Top | 125 | Yes | 123 | 0.375" Air Gap |
| 5B | Horizontal/Bottom | 125 | No | 0 | No Air Gap |

[1] Cases 1C, 2C, 3C, 4C and 5C are used for determining the maximum DSC surface temperature - only.

| | | | | | |
|---|---|---|---|---|---|
| 5C | Horizontal | 125 | Yes | 123 | 0.75" Air Gap w/ Cask Cav Length of 167" |
| 5D | Horizontal/Accident | 125 | Yes | 123 | 0.375" Air Gap w/ no neutron shield |
| 5E | Horizontal/Accident | 125 | Yes | 123 | 0.75" Air Gap w/ no neu sh & 167" cav |

## 3.2 Axial Thermal Cases

This section includes the results of the calculations (which utilizes the methodology described in Section 2). The results include the input data and the Cask/DSC temperature distribution output data for the different cases. The following axial thermal cases were considered:

| Case [2] | Orientation/Top or Bottom Model | Ambient Temp (F) | Solar Yes/No | Solar Load (btuh/ft^2) | Remarks |
|---|---|---|---|---|---|
| 1A | Horizontal/Top | -40 | No | 0 | 0.5" Air Gap & 167" Cask Cavity |
| 1B | Horizontal/Top | -40 | No | 0 | No Air Gap |
| 2A | Horizontal/Top | 0 | No | 0 | 0.5" Air Gap & 167" Cask Cavity |
| 2B | Horizontal/Top | 0 | No | 0 | No Air Gap |
| 3A | Horizontal/Top | 70 | Yes | 62 | 0.5" Air Gap & 167" Cask Cavity |
| 3B | Horizontal/Top | 70 | Yes | 62 | No Air Gap |
| 4A | Horizontal/Top | 100 | Yes | 62 | 0.5" Air Gap & 167" Cask Cavity |
| 4B | Horizontal/Top | 100 | Yes | 62 | No Air Gap |
| 4C | Vertical | 100 | No | 0 | |
| 5A | Horizontal/Top | 125 | Yes | 123 | 0.5" Air Gap & 167" Cask Cavity |
| 5B | Horizontal/Top | 125 | Yes | 123 | No Air Gap |
| 6A | Horizontal/Bottom | -40 | No | 0 | 0.5" Air Gap & 167" Cask Cavity |

[2] Cases 1A, 2A, 3A, 4A, 5A, 6A, 7A, 8A, 9A & 10A were included for determining the DSC axial temperature distributions - only.

| | | | | | |
|---|---|---|---|---|---|
| 6B | Horizontal/Bottom | -40 | No | 0 | No Air Gap |
| 7A | Horizontal/Bottom | 0 | No | 0 | 0.5" Air Gap & 167" Cask Cavity |
| 7B | Horizontal/Bottom | 0 | No | 0 | No Air Gap |
| 8A | Horizontal/Bottom | 70 | Yes | 62 | 0.5" Air Gap & 167" Cask Cavity |
| 8B | Horizontal/Bottom | 70 | Yes | 62 | No Air Gap |
| 9A | Horizontal/Bottom | 100 | Yes | 62 | 0.5" Air Gap & 167" Cask Cavity |
| 9B | Horizontal/Bottom | 100 | Yes | 62 | No Air Gap |
| 9C | Vertical | 100 | No | 0 | |
| 10A | Horizontal/Bottom | 125 | Yes | 123 | 0.5" Air Gap & 167" Cask Cavity |
| 10B | Horizontal/Bottom | 125 | Yes | 123 | No Air Gap |

### 3.3 Fuel Decay Heat Calculation

The unit fuel decay heat is based upon PWR fuel with a 30,000 MWd/MTU burnup, 5-year old fuel. The decay heat rate for this fuel is given as:

1.0 kW per fuel assembly (reference 9)

The temperature distributions calculated herein are valid for all PWR fuel types and various cooling times as long as the decay heat per fuel assembly is less than or equal to 1.0 kW. The heat flux used herein is based upon the above decay heat rate per fuel assembly, the number of assemblies per DSC, and the ratio of the radial surface area to total surface area of the DSC.

The radial heat is calculated as follows:

$$Q=\frac{(1kW)\times(24f/a)\times\Pi\times D\times L}{\Pi\times D\times L+\Pi\times\frac{D^2}{2}}$$

Which reduces to:

$$Q=\frac{(1kW)\times(24f/a)\times\Pi\times L}{\Pi\times L+\Pi\times\frac{D}{2}}$$

The heat flux used for the axial case is calculated based upon the total decay heat divided by the interior surface area of the cask.

Where:
- Q = Decay heat (kW)
- L = Cask cavity length
- D = Cask interior radius

$$Q=\frac{(1.0kW)\times(24f/a)\times144}{2\times\Pi\times r\times L+2\times\Pi\times r^2}$$

Note: Per the sample problem presented in Section 3.5.2, the axial heat flux used is 0.08 kW/ft^2 or 274.8 Btu/hr/ft^2.

3.4 Calculation of NS-3-Stiff Thermal Conductivity

The calculation of the thermal conductivity of the neutron shield is calculated using a weighted average of Bisco NS-3 and stainless steel (ie., taking into account the twenty four 304 stainless steel support angle strips).

The mass of steel in the neutron shield is calculated by (refer to Ref 6):

Vol of steel = 0.125" x 4.25" x 177.85"
Vol of steel = 94.48 $in^3$ per strip
Mass of steel (total) = 94.48 $in^3$ * 24 strips * 492 $lbs/ft^3$ * 1/1728
Mass of steel (total) = 645.7 lbm

The mass of NS-3 is calculated by:

Vol of NS-3 = $\{(\pi/4) * (85^2 - 79^2)(176.85) - (94.48)(24)]/1728$
Vol of NS-3 = 77.8 $ft^3$
Mass of NS-3 = 77.8 $ft^3$ * 110 $lbs/ft^3$ (Reference 6)
Mass of NS-3 = 8556 lbm

The average value of the thermal conductivity, $k_{NS3\text{-}stif}$, is determined by:

$$k_{NS3\text{-}stif} = (8556 \text{ lbm})(k_{ns3}) + (645.7 \text{ lbm})(k_{304ss})/(8556 + 645.7)$$

Where: $k_{ns3}$ = 0.4883 $Btu/hr/ft^2°F$ @ 150° F (reference 6)
$k_{304ss}$ = 9.0 $Btu/hr/ft^2°F$ @ 150°F (see thermal conductivities on page 11 & note below)
$k_{304ss}$ = 9.6 $Btu/hr/ft^2°F$ @ 250°F (see page 11 & note below)

Substituting yields (see note below):

$k_{NS3\text{-}stif}$ = (8556 lbm)(0.4883) + (645.7 lbm)(9.6)/(8556 + 645.7)

$k_{NS3\text{-}stif}$ = 1.127 say 1.13 $Btu/hr/ft^2°F$

Note: Accident cases 5D & 5E described in Section 3.1, 3.2 are the most conservative cases considered and therefore govern the design temperature at which the thermal conductivity of NS3-stif is evaluated. These cases will yield temperatures in the neutron shield in excess of 250° F, therefore, the thermal conductivity of 1.13 is used. All other cases use the same constant value for $k_{NS3\text{-}stif}$; with a minimal non-conservative effect in the calculated shell temperatures for the -40° F, 0° F and

70° F cases directly related to the temperature dependent thermal conductivity of the 304 stainless steel stiffeners.

## 3.5 Sample Problems

### 3.5.1 Radial Case Sample Problem

The following is a sample problem which demonstrates the use of the Section 2 methodology for the radial case (Radial Case 5E):

```
Outside Temperature:

Q   =   (1*24.000)*3414*(167.00/(167.00+33.00))   +
(2*3.1416*(42.63/12)*(167.00/12)*123.0)
Q = 106624 Btu/hr
A = (2*3.1416*42.63*167.00/144) = 310.6 ft²
hc = 0.18*(282.7-125.0)^(1/3) = 0.9726 Btu/hr·ft²·°F
hr = (0.587*1.73E-09*(282.7+125.0+919.34)*
     ((282.7+459.67)^2+(125.0+459.67)^2))
hr = 1.2034 Btu/hr·ft²·°F

Tout = (106624/(310.6*(0.9726+1.2034))+125.0) = 282.7 °F
Agrees with initial estimate of 282.7 °F

Inside Temperatures
Q = (1*24.000)*3414*(167.00/(167.00+33.00)) = 68416.6 Btu/hr
Layer: N. Shield Panel
Tavg = (283.0+282.7)/2 = 282.9 °F
k of ss304 at 282.9 °F is given by: [5]
k = (282.9-250.0)*(9.8000-9.6000)/(300.0-250.0)+9.6000
  =  9.7315 Btu/hr·ft·°F
No thermal radiation in layer
The conduction term is given by:
(2*3.1416*9.7315*(167.00/12))/LN(42.63/42.50)=289741.117 Btu/hr·°F

Ti = (68417)/(2*3.1416*(42.50/12)*(167.00/12)*0.000+289741.1)+282.7=283.0 °F
Agrees with initial estimate of 283.0 °F

Layer: Neutron Shield
Tavg = (405.0+283.0)/2 = 344.0 °F
k of airconv at 344.0 °F is given by: [5]
k = 0.1000 Btu/hr·ft·°F
hr = (1.73E-09*(405.0+283.0+919.34)*((405.0+459.67)^2+(283.0+459.67)^2))/
     (1/0.587+(39.50/42.50)*(1/0.587-1))=1.533 Btu/hr·ft²·°F
The conduction term is given by:
(2*3.1416*0.1000*(167.00/12))/LN(42.50/39.50)=119.449 Btu/hr·°F

Ti = (68417)/(2*3.1416*(39.50/12)*(167.00/12)*1.533+119.4)+283.0=405.0 °F
Agrees with initial estimate of 405.0 °F

Layer: Outer Shell
Tavg = (406.3+405.0)/2 = 405.7 °F
k of csteel at 405.7 °F is given by: [5]
k = (405.7-392.0)*(23.0000-24.0000)/(572.0-392.0)+24.0000
  = 23.9241 Btu/hr·ft·°F
No thermal radiation in layer
The conduction term is given by:
(2*3.1416*23.9241*(167.00/12))/LN(39.50/38.00)=54035.111 Btu/hr·°F
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```
Ti = (68417)/(2*3.1416*(38.00/12)*(167.00/12)*0.000+54035.1)+405.0=406.3 °F
Agrees with initial estimate of 406.3 °F

Layer: Gamma Shield
Tavg = (410.5+406.3)/2 = 408.4 °F
k of lead at 408.4 °F is given by: [5]
k = (408.4-392.0)*(17.2000-18.2000)/(572.0-392.0)+18.2000
  = 18.1089 Btu/hr·ft·°F
No thermal radiation in layer
The conduction term is given by:
(2*3.1416*18.1089*(167.00/12))/LN(38.00/34.50)=16387.410 Btu/hr·°F

Ti = (68417)/(2*3.1416*(34.50/12)*(167.00/12)*0.000+16387.4)+406.3=410.5 °F
Agrees with initial estimate of 410.5 °F

Layer: Inner Shell
Tavg = (411.6+410.5)/2 = 411.0 °F
k of ss304 at 411.0 °F is given by: [5]
k = (411.0-400.0)*(10.6000-10.4000)/(450.0-400.0)+10.4000
  = 10.4441 Btu/hr·ft·°F
No thermal radiation in layer
The conduction term is given by:
(2*3.1416*10.4441*(167.00/12))/LN(34.50/34.00)=62556.011 Btu/hr·°F

Ti = (68417)/(2*3.1416*(34.00/12)*(167.00/12)*0.000+62556.0)+410.5=411.6 °F
Agrees with initial estimate of 411.6 °F

Layer: Air Gap
Tavg = (517.7+411.6)/2 = 464.6 °F
k of air at 464.6 °F is given by: [5]
k = (464.6-392.0)*(0.0248-0.0214)/(572.0-392.0)+0.0214
  = 0.0228 Btu/hr·ft·°F
hr = (1.73E-09*(517.7+411.6+919.34)*((517.7+459.67)^2+(411.6+459.67)^2))/
     (1/0.587+(33.25/34.00)*(1/0.587-1))=2.292 Btu/hr·ft²·°F
The conduction term is given by:
(2*3.1416*0.0228*(167.00/12))/LN(34.00/33.25)=89.269 Btu/hr·°F

Ti = (68417)/(2*3.1416*(33.25/12)*(167.00/12)*2.292+89.3)+411.6=517.7 °F
Agrees with initial estimate of 517.7 °F

Layer: DSC
Tavg = (518.2+517.7)/2 = 518.0 °F
k of ss304 at 518.0 °F is given by: [5]
k = (518.0-500.0)*(11.1000-10.9000)/(550.0-500.0)+10.9000
  = 10.9719 Btu/hr·ft·°F
No thermal radiation in layer
The conduction term is given by:
(2*3.1416*10.9719*(167.00/12))/LN(33.25/33.00)=127118.707 Btu/hr·°F

Ti = (68417)/(2*3.1416*(33.00/12)*(167.00/12)*0.000+127118.7)+517.7=518.2 °F
Agrees with initial estimate of 518.2 °F

All layers agree with initial guesses.
Calculations are completed.
```

### 3.5.2 Axial Case Sample Problem

The following is a sample problem which demonstrates the use of the Section 2 methodology for the axial case:

Case 10A: 125 F Ambient, Top End, W/ Solar, W/ Air Gap, 167" Cask Cavity.

```
Orientation:
Emissivity of Cask Outer Surface = 0.587
Ambient Temperature = 125 inches
Solar Heat Load = 123 Btu/hr/ft^2
Cask Internal Radius = 34 inches
Cask Cavity Length = 167 inches

Heat Flux Calculations:
Decay Heat of Fuel Assembly = 1.00 kW
Decay Heat (per DSC w/ 24 f/a's), Q = 24.0 kW
Decay Heat (per DSC w/ 24 f/a's), Q = 81946 Btu/hr
Vertical Surface Solar Heat Flux = 0.2 * 123 = 25 Btu/hr
Unit Decay Heat, q = 81946/(2*Pi*34 + 2*Pi*34*167)*144 = 274.8 Btu/hr/ft^2
Total Exterior Vert Surf Heat Flux = 24.6 + 274.8 = 299.4 Btu/hr/ft^2

Layer:  Exterior Plate
Assume Delta T = 140.5 F
Tamb = 125.000 F
Tamb = 585.000 R
To = 265.523 F
To = 725.193 R
hc = 0.19 * (140.523)^1/3 = 0.988
hr = 0.587*(585.0 + 725.2)*(585.0^2 + 725.2^2)*(0.1714E-8)
   = 1.135 Btu/hr/ft^2/F
q = 140.523 * (0.988 + 1.135) = 298 Btu/hr/ft^2

Layer:  Bottom Plate
To = 265.523 F
Average Plate Temperature = 266.839 F
k @ 266.839 F = 8.700 Btu/hr/ft/F
Plate thickness = 1.00 inches
Ti = 275/8.70 * (1.00/12) + 265.52 = 268.155 F
Delta T = 268.155 - 265.523 = 2.632 F

Layer:  Neutron Shield
To = 268.155 F
Average Plate Temperature = 320.928 F
k @ 320.928 F = 0.488 Btu/hr/ft/F
Plate thickness = 2.25 inches
Ti = 275/0.488 * (2.25/12) + 268.15 = 373.701 F
Delta T = 373.701 - 268.155 = 105.546 F

Bottom Struc Plate Temperature Calculations:
To = 373.701 F
Average Plate Temperature = 376.004 F
k @ 376.004 F = 8.700 Btu/hr/ft/F
Plate thickness = 1.75 inches
```

```
Ti = 275/8.70 * (1.75/12) + 373.70 = 378.307 F
Delta T = 378.307 - 373.701 = 4.607 F

Layer:  Air Gap
To = 378.307 F
To = 837.977 R
Assumed Ti = 485.921 F
Assumed Ti = 945.591 R
Resulting Assumed Delta T = 107.614 R
Air Gap Thickness = 0.50 inches
Eo = 0.587
Ei = 0.587
1/Eo = 1.704
1/Ei = 1.704
(1/Ei + 1/Eo) - 1 = 2.407
hr = (0.17E-8)*(837.977 + 945.591)*(837.977^2 + 945.591^2)/2.407
   = 2.011 Btu/hr/ft^2/F
k = 0.023 Btu/hr/ft/F
k/0.50/12 = 0.543
Delta T (incl conduction) = 275/(2.011 + 0.023) = 107.614 F
Ti (calc'd - including conduction) = 107.614 + 378.307 = 485.921 F

Layer:  DSC Top Plate
To = 485.921 F
Average Plate Temperature = 488.129 F
k @ 488.129 F = 9.074 Btu/hr/ft/F
Plate thickness = 1.75 inches
Ti = 275/9.074 * (1.75/12) + 485.92 = 490.337 F

Layer:  DSC Plug
To = 490.337 F
Average Plate Temperature = 499.129 F
k @ 499.129 F = 9.117 Btu/hr/ft/F
Plate thickness = 7.00 inches
Ti = 275/9.117 * (7.00/12) + 490.337 = 507.921 F
```

All temperatures agree with initial guesses.
The axial layer sample problem is complete.

### 3.6 Results for Cask/DSC Radial Cases

Case 1A: -40° F, No solar, Horizontal w/ 0.375" air gap (Cask top model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | -40 | °F |
| Solar Heat Load | 0 | Btu/hr·ft$^2$ |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.92E+00* | *321.3* | *320.0* |
| *Air Gap* | *air* | *0.375* | *yes* | *1.83E-02* | *320.0* | 161.0 |
| Inner Shell | ss304 | 0.500 | no | 9.06E+00 | 161.0 | 159.8 |
| Gamma Shield | lead | 3.500 | no | 1.96E+01 | 159.8 | 156.3 |
| Outer Shell | csteel | 1.500 | no | 2.50E+01 | 156.3 | 155.2 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 155.2 | 100.5 |
| N. Shield Panel | ss304 | 0.125 | no | 8.70E+00 | 100.5 | 100.3 |

Note: Numbers and text in italic type are included for information only.

Case 1B: -40° F, No solar, Horizontal w/ no air gap
(Cask bottom model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | -40 | °F |
| Solar Heat Load | 0 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.08E+00* | *163.9* | *162.4* |
| *Air Gap* | *air* | *0.000* | *no* | *1.66E-02* | *162.4* | 162.4 |
| Inner Shell | ss304 | 0.500 | no | 9.07E+00 | 162.4 | 161.3 |
| Gamma Shield | lead | 3.500 | no | 1.96E+01 | 161.3 | 157.7 |
| Outer Shell | csteel | 1.500 | no | 2.50E+01 | 157.7 | 156.6 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 156.6 | 101.4 |
| N. Shield Panel | ss304 | 0.125 | no | 8.71E+00 | 101.4 | 101.2 |

Note: Numbers and text in italic type are included for information only.

Case 1C: -40° F, No solar, Horizontal w/ 0.75" air gap
(Model to determine maximum DSC shell temperature only)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | -40 °F |
| Solar Heat Load | 0 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 167 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.02E+01 | 370.5 | 370.0 |
| Air Gap | air | 0.750 | yes | 1.90E-02 | 370.0 | *177.6* |
| *Inner Shell* | *ss304* | *0.500* | *no* | *9.16E+00* | *177.6* | *176.4* |
| *Gamma Shield* | *lead* | *3.500* | *no* | *1.95E+01* | *176.4* | *172.5* |
| *Outer Shell* | *csteel* | *1.500* | *no* | *2.50E+01* | *172.5* | *171.3* |
| *Neutron Shield* | *ns3stif* | *3.000* | *no* | *9.49E-01* | *171.3* | *110.9* |
| *N. Shield Panel* | *ss304* | *0.125* | *no* | *8.76E+00* | *110.9* | *110.7* |

Note: Numbers and text in italic type are included for information only.

Case 2A: 0° F, No solar, Horizontal w/ 0.375" air gap
(Cask top model)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | 0 °F |
| Solar Heat Load | 0 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 187.75 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *1.00E+01* | *340.9* | *339.6* |
| *Air Gap* | *air* | *0.375* | *yes* | *1.88E-02* | *339.6* | 192.4 |
| Inner Shell | ss304 | 0.500 | no | 9.25E+00 | 192.4 | 191.3 |
| Gamma Shield | lead | 3.500 | no | 1.94E+01 | 191.3 | 187.8 |
| Outer Shell | csteel | 1.500 | no | 2.50E+01 | 187.8 | 186.7 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 186.7 | 132.0 |
| N. Shield Panel | ss304 | 0.125 | no | 8.89E+00 | 132.0 | 131.7 |

Note: Numbers and text in italic type are included for information only.

Case 2B: 0° F, No solar, Horizontal w/ no air gap
(Cask bottom model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 0 | °F |
| Solar Heat Load | 0 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.27E+00* | *195.3* | *193.8* |
| *Air Gap* | *air* | *0.000* | *no* | *1.73E-02* | *193.8* | 193.8 |
| Inner Shell | ss304 | 0.500 | no | 9.26E+00 | 193.8 | 192.7 |
| Gamma Shield | lead | 3.500 | no | 1.94E+01 | 192.7 | 189.1 |
| Outer Shell | csteel | 1.500 | no | 2.50E+01 | 189.1 | 188.0 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 188.0 | 132.8 |
| N. Shield Panel | ss304 | 0.125 | no | 8.90E+00 | 132.8 | 132.6 |

Note: Numbers and text in italic type are included for information only.

Case 2C: 0° F, No solar, Horizontal w/ 0.75" air gap & 167" Cask Cavity Length
(Model to determine maximum DSC shell temp only)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | 0 °F |
| Solar Heat Load | 0 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 167 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.03E+01 | 387.0 | 386.4 |
| Air Gap | air | 0.750 | yes | 1.95E-02 | 386.4 | *208.6* |
| *Inner Shell* | *ss304* | *0.500* | *no* | *9.35E+00* | *208.6* | *207.3* |
| *Gamma Shield* | *lead* | *3.500* | *no* | *1.93E+01* | *207.3* | *203.4* |
| *Outer Shell* | *csteel* | *1.500* | *no* | *2.50E+01* | *203.4* | *202.2* |
| *Neutron Shield* | *ns3stif* | *3.000* | *no* | *9.49E-01* | *202.2* | *141.9* |
| *N. Shield Panel* | *ss304* | *0.125* | *no* | *8.95E+00* | *141.9* | *141.6* |

Note: Numbers and text in italic type are included for information only.

Case 3A: 70° F, Solar Load, Horizontal w/ 0.375" air gap
(Cask top model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 70 | °F |
| Solar Heat Load | 62 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *1.04E+01* | *395.2* | *393.9* |
| *Air Gap* | *air* | *0.375* | *yes* | *2.02E-02* | *393.9* | 273.3 |
| Inner Shell | ss304 | 0.500 | no | 9.69E+00 | 273.3 | 272.2 |
| Gamma Shield | lead | 3.500 | no | 1.89E+01 | 272.2 | 268.6 |
| Outer Shell | csteel | 1.500 | no | 2.47E+01 | 268.6 | 267.5 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 267.5 | 212.8 |
| N. Shield Panel | ss304 | 0.125 | no | 9.38E+00 | 212.8 | 212.6 |

Note: Numbers and text in italic type are included for information only.

Case 3B: 70° F, No Solar Load, Horizontal w/ no air gap
(Cask bottom model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 70 | °F |
| Solar Heat Load | 0 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.60E+00* | *249.9* | *248.5* |
| *Air Gap* | *air* | *0.000* | *no* | *1.85E-02* | *248.5* | 248.5 |
| Inner Shell | ss304 | 0.500 | no | 9.59E+00 | 248.5 | 247.5 |
| Gamma Shield | lead | 3.500 | no | 1.91E+01 | 247.5 | 243.8 |
| Outer Shell | csteel | 1.500 | no | 2.48E+01 | 243.8 | 242.7 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 242.7 | 187.5 |
| N. Shield Panel | ss304 | 0.125 | no | 9.22E+00 | 187.5 | 187.3 |

Note: Numbers and text in italic type are included for information only.

Case 3C: 70° F, Solar Load, Horizontal w/ 0.75" air gap & 167" Cask Cavity Length
(Model to determine maximum DSC shell temp only)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | 70 °F |
| Solar Heat Load | 62 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 167 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.05E+01 | 433.6 | 433.1 |
| Air Gap | air | 0.750 | yes | 2.08E-02 | 433.1 | *287.8* |
| *Inner Shell* | *ss304* | *0.500* | *no* | *9.75E+00* | *287.8* | *286.6* |
| *Gamma Shield* | *lead* | *3.500* | *no* | *1.89E+01* | *286.6* | *282.6* |
| *Outer Shell* | *csteel* | *1.500* | *no* | *2.46E+01* | *282.6* | *281.4* |
| *Neutron Shield* | *ns3stif* | *3.000* | *no* | *9.49E-01* | *281.4* | *221.0* |
| *N. Shield Panel* | *ss304* | *0.125* | *no* | *9.43E+00* | *221.0* | *220.8* |

Note: Numbers and text in italic type are included for information only.

Case 3D: 70° F, No Solar Load, Vertical w/ 0.375" air gap

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 70 | °F |
| Solar Heat Load | 0 | $Btu/hr \cdot ft^2$ |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Vertical | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.625 | no | 1.02E+01 | 375.4 | 374.1 |
| Air Gap | air | 0.375 | yes | 1.97E-02 | 374.1 | 244.7 |
| Inner Shell | ss304 | 0.500 | no | 9.57E+00 | 244.7 | 243.7 |
| Gamma Shield | lead | 3.500 | no | 1.91E+01 | 243.7 | 240.1 |
| Outer Shell | csteel | 1.500 | no | 2.48E+01 | 240.1 | 239.0 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 239.0 | 184.3 |
| N. Shield Panel | ss304 | 0.125 | no | 9.21E+00 | 184.3 | 184.1 |

Case 4A: 100° F, Solar Load, Horizontal w/ 0.375" air gap (Cask top model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 100 | °F |
| Solar Heat Load | 62 | $Btu/hr \cdot ft^2$ |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *1.04E+01* | *411.1* | *409.9* |
| *Air Gap* | *air* | *0.375* | *yes* | *2.06E-02* | *409.9* | 295.7 |
| Inner Shell | ss304 | 0.500 | no | 9.78E+00 | 295.7 | 294.7 |
| Gamma Shield | lead | 3.500 | no | 1.88E+01 | 294.7 | 291.0 |
| Outer Shell | csteel | 1.500 | no | 2.46E+01 | 291.0 | 289.9 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 289.9 | 235.2 |
| N. Shield Panel | ss304 | 0.125 | no | 9.51E+00 | 235.2 | 235.0 |

Note: Numbers and text in italic type are included for information only.

Case 4B: 100° F, No Solar Load, Horizontal w/ no air gap

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 100 | °F |
| Solar Heat Load | 0 | $Btu/hr{\cdot}ft^2$ |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.69E+00* | *273.4* | *272.1* |
| *Air Gap* | *air* | *0.000* | *no* | *1.89E-02* | *272.1* | 272.1 |
| Inner Shell | ss304 | 0.500 | no | 9.69E+00 | 272.1 | 271.0 |
| Gamma Shield | lead | 3.500 | no | 1.90E+01 | 271.0 | 267.3 |
| Outer Shell | csteel | 1.500 | no | 2.47E+01 | 267.3 | 266.2 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 266.2 | 211.0 |
| N. Shield Panel | ss304 | 0.125 | no | 9.37E+00 | 211.0 | 210.8 |

Note: Numbers and text in italic type are included for information only.

Case 4C: 100° F, Solar Load, Horizontal w/ 0.75" air gap and 167" Cask Cavity Length
(Model to determine DSC maximum shell temp only)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | 100 °F |
| Solar Heat Load | 62 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 167 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.06E+01 | 447.7 | 447.2 |
| Air Gap | air | 0.750 | yes | 2.11E-02 | 447.2 | *309.9* |
| *Inner Shell* | *ss304* | *0.500* | *no* | *9.86E+00* | *309.9* | *308.8* |
| *Gamma Shield* | *lead* | *3.500* | *no* | *1.87E+01* | *308.8* | *304.7* |
| *Outer Shell* | *csteel* | *1.500* | *no* | *2.45E+01* | *304.7* | *303.5* |
| *Neutron Shield* | *ns3stif* | *3.000* | *no* | *9.49E-01* | *303.5* | *243.1* |
| *N. Shield Panel* | *ss304* | *0.125* | *no* | *9.56E+00* | *243.1* | *242.9* |

Note: Numbers and text in italic type are included for information only.

Case 4D: 100° F, No Solar Load, Vertical w/ 0.375" air gap and 167" Cask Cavity Length

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 100 | °F |
| Solar Heat Load | 0 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 167 | in |
| Orientation | Vertical | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.625 | no | 1.04E+01 | 412.6 | 411.2 |
| Air Gap | air | 0.375 | yes | 2.05E-02 | 411.2 | 283.3 |
| Inner Shell | ss304 | 0.500 | no | 9.73E+00 | 283.3 | 282.1 |
| Gamma Shield | lead | 3.500 | no | 1.89E+01 | 282.1 | 278.1 |
| Outer Shell | csteel | 1.500 | no | 2.46E+01 | 278.1 | 276.9 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 276.9 | 216.6 |
| N. Shield Panel | ss304 | 0.125 | no | 9.40E+00 | 216.6 | 216.3 |

Case 5A: 125° F, Max Solar Load, Horizontal w/ 0.375" air gap (Cask top model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 125 | °F |
| Solar Heat Load | 123 | $Btu/hr \cdot ft^2$ |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k ($Btu/hr \cdot ft \cdot °F$) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *1.06E+01* | *441.0* | *439.7* |
| *Air Gap* | *air* | *0.375* | *yes* | *2.13E-02* | *439.7* | 336.4 |
| Inner Shell | ss304 | 0.500 | no | 1.00E+01 | 336.4 | 335.4 |
| Gamma Shield | lead | 3.500 | no | 1.86E+01 | 335.4 | 331.7 |
| Outer Shell | csteel | 1.500 | no | 2.43E+01 | 331.7 | 330.6 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 330.6 | 275.9 |
| N. Shield Panel | ss304 | 0.125 | no | 9.70E+00 | 275.9 | 275.7 |

Note: Numbers and text in italic type are included for information only.

Case 5B: 125° F, No Solar Load, Horizontal w/ no air gap (Cask bottom model)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 125 | °F |
| Solar Heat Load | 0 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 187.75 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| *DSC* | *ss304* | *0.625* | *no* | *9.77E+00* | *293.1* | *291.7* |
| *Air Gap* | *air* | *0.000* | *no* | *1.93E-02* | *291.7* | 291.7 |
| Inner Shell | ss304 | 0.500 | no | 9.76E+00 | 291.7 | 290.7 |
| Gamma Shield | lead | 3.500 | no | 1.88E+01 | 290.7 | 287.0 |
| Outer Shell | csteel | 1.500 | no | 2.46E+01 | 287.0 | 285.9 |
| Neutron Shield | ns3stif | 3.000 | no | 9.49E-01 | 285.9 | 230.7 |
| N. Shield Panel | ss304 | 0.125 | no | 9.48E+00 | 230.7 | 230.4 |

Note: Numbers and text in italic type are included for information only.

Case 5C: 125° F, Solar Load, Horizontal w/ 0.75" air gap and 167" Cask Cavity Length
(Model to determine maximum DSC shell temp only)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 125 | °F |
| Solar Heat Load | 123 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 167 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.07E+01 | 474.4 | 473.8 |
| Air Gap | air | 0.750 | yes | 2.18E-02 | 473.8 | *349.8* |
| *Inner Shell* | *ss304* | *0.500* | *no* | *1.01E+01* | *349.8* | *348.7* |
| *Gamma Shield* | *lead* | *3.500* | *no* | *1.85E+01* | *348.7* | *344.6* |
| *Outer Shell* | *csteel* | *1.500* | *no* | *2.43E+01* | *344.6* | *343.3* |
| *Neutron Shield* | *ns3stif* | *3.000* | *no* | *9.49E-01* | *343.3* | *283.0* |
| *N. Shield Panel* | *ss304* | *0.125* | *no* | *9.73E+00* | *283.0* | *282.7* |

Note: Numbers and text in italic type are included for information only.

Case 5D: 125° F, Max Solar Load, Horizontal w/ 0.375" air gap and with no neutron shield
(Accident case)

| | |
|---|---|
| Number of Assemblies | 24 |
| Decay Heat per Assembly | 1 kW |
| Ambient Temperature | 125 °F |
| Solar Heat Load | 123 Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 |
| Cask Inner Radius | 33 in |
| Cask Cavity Length | 187.75 in |
| Orientation | Horizontal |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.625 | no | 1.08E+01 | 486.7 | 485.5 |
| Air Gap | air | 0.375 | yes | 2.23E-02 | 485.5 | 396.1 |
| Inner Shell | ss304 | 0.500 | no | 1.04E+01 | 396.1 | 395.1 |
| Gamma Shield | lead | 3.500 | no | 1.82E+01 | 395.1 | 391.3 |
| Outer Shell | csteel | 1.500 | no | 2.40E+01 | 391.3 | 390.2 |
| Neutron Shield | airconv | 3.000 | yes | 1.00E-01 | 390.2 | 275.9 |
| N. Shield Panel | ss304 | 0.125 | no | 9.70E+00 | 275.9 | 275.7 |

Case 5E: 125° F, Max Solar Load, Horizontal w/ 0.75" air gap and with no neutron shield
(Accident case)

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1 | kW |
| Ambient Temperature | 125 | °F |
| Solar Heat Load | 123 | Btu/hr·ft² |
| Emissivity of Outer Surfac | 0.587 | |
| Cask Inner Radius | 33 | in |
| Cask Cavity Length | 167 | in |
| Orientation | Horizontal | |

| Cask Layer | Material | Thickness (IN) | Radiation | k (Btu/hr·ft·°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|---|
| DSC | ss304 | 0.250 | no | 1.10E+01 | 518.2 | 517.7 |
| Air Gap | air | 0.750 | yes | 2.28E-02 | 517.7 | 411.6 |
| Inner Shell | ss304 | 0.500 | no | 1.04E+01 | 411.6 | 410.5 |
| Gamma Shield | lead | 3.500 | no | 1.81E+01 | 410.5 | 406.3 |
| Outer Shell | csteel | 1.500 | no | 2.39E+01 | 406.3 | 405.0 |
| Neutron Shield | airconv | 3.000 | yes | 1.00E-01 | 405.0 | 283.0 |
| N. Shield Panel | ss304 | 0.125 | no | 9.73E+00 | 283.0 | 282.7 |

## 3.7 Results for Cask/DSC Axial Cases

Case 1A: -40 F Ambient, Top End, No Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine the DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.175003 |
| Ambient Temperature | -40 | °F | hr | 1.175003 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 187.750 | in | | |
| Convection Coefficient | 1.033 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.516 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 8.750 | 8.700 | 383.804 | 362.927 |
| DSC Top Plate | ss304 | 1.250 | 8.700 | 362.927 | 359.944 |
| Air Gap | air | 0.500 | 0.020 | 359.944 | *208.534* |
| *Cask Struc Plate* | *csteel* | *3.000* | *25.000* | *208.534* | *206.043* |
| *Neutron Shield* | *NS3* | *2.000* | *0.488* | *206.043* | *121.003* |
| *Cask Top Plate* | *csteel* | *0.250* | *25.000* | *121.003* | *120.796* |

Note: Numbers and text in italic type are calculated for information only.

Case 1B: -40 F Ambient, Top End, No Solar, No Air Gap, Cask layers only

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1.00 | kW hr |
| Ambient Temperature | -40 | °F |
| Solar Heat Load | 0 | Btu/hr-ft^2 |
| Emissivity of Outer Surface | 0.587 | |
| Cask Inner Radius | 34.000 | in |
| Cask Cavity Length | 187.750 | in |
| Convection Coefficient | 1.033 | Btu/hr-ft^2-°F) |
| Radiation Coefficient | 0.516 | Btu/hr-ft^2-°F) |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 3.000 | 25.000 | 208.534 | 206.043 |
| Neutron Shield | ns3 | 2.000 | 0.488 | 206.043 | 121.003 |
| Outer Plate | csteel | 0.250 | 25.000 | 121.003 | 120.796 |

Case 2A: 0 F Ambient, Top End, No Solar, W/ Air Gap, 167" Cask Cavity
(Model to determine the DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal Radiation | |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.295601 |
| Ambient Temperature | 0 | °F | hr | 1.295601 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 187.750 | in | | |
| Convection Coefficient | 1.013 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.630 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 8.750 | 8.703 | 403.271 | 382.402 |
| DSC Top Plate | ss304 | 1.250 | 8.700 | 382.402 | 379.419 |
| Air Gap | air | 0.500 | 0.020 | 379.419 | *239.360* |
| *Cask Struc Plate* | *csteel* | *3.000* | *24.855* | *239.360* | *236.855* |
| *Neutron Shield* | *NS3* | *2.000* | *0.488* | *236.855* | *151.815* |
| *Cask Top Plate* | *csteel* | *0.250* | *25.000* | *151.815* | *151.608* |

Note: Numbers and text in italic type are included for information only.

Case 2B: 0 F Ambient, Top End, No Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 0 | °F | |
| Solar Heat Load | 0 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 1.013 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.630 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 3.000 | 24.855 | 239.360 | 236.855 |
| Neutron Shield | ns3 | 2.000 | 0.488 | 236.855 | 151.815 |
| Outer Plate | csteel | 0.250 | 25.000 | 151.815 | 151.608 |

Case 3A: 70 F Ambient, Top End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.678937 |
| Ambient Temperature | 70 | °F | hr | 1.678937 |
| Solar Heat Load | 62 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 1.010 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.903 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 8.750 | 8.951 | 467.704 | 445.316 |
| DSC Top Plate | ss304 | 1.250 | 8.901 | 445.316 | 442.100 |
| Air Gap | air | 0.500 | 0.022 | 442.100 | *316.994* |
| *Cask Struc Plate* | *csteel* | *3.000* | *24.425* | *316.994* | *314.181* |
| *Neutron Shield* | *NS3* | *2.000* | *0.488* | *314.181* | *220.363* |
| *Cask Top Plate* | *csteel* | *0.250* | *24.954* | *220.363* | *220.134* |

Note: Numbers and text in italic type are included for information only.

Case 3B: 70 F Ambient, Top End, W/ Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 70 | °F | |
| Solar Heat Load | 62 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 0.987 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.879 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 3.000 | 24.530 | 297.902 | 295.364 |
| Neutron Shield | ns3 | 2.000 | 0.488 | 295.364 | 210.324 |
| Outer Plate | csteel | 0.250 | 25.000 | 210.324 | 210.117 |

Case 4A: 100 F Ambient, Top End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial shell temps only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.794342 |
| Ambient Temperature | 100 | °F | hr | 1.794342 |
| Solar Heat Load | 62 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 0.992 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 1.023 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 8.750 | 9.011 | 483.206 | 460.969 |
| DSC Top Plate | ss304 | 1.250 | 8.962 | 460.969 | 457.775 |
| Air Gap | air | 0.500 | 0.022 | 457.775 | *339.382* |
| *Cask Struc Plate* | *csteel* | *3.000* | *24.300* | *339.382* | *336.554* |
| *Neutron Shield* | *NS3* | *2.000* | *0.488* | *336.554* | *242.736* |
| *Cask Top Plate* | *csteel* | *0.250* | *24.830* | *242.736* | *242.505* |

Note: Numbers and text in italic type are included for information only.

Case 4B: 100 F Ambient, Top End, W/ Solar, No Air Gap, Cask layers only.

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | | |
| Decay Heat per Assembly | 1.00 | kW | hr | ERR |
| Ambient Temperature | 100 | °F | | |
| Solar Heat Load | 62 | Btu/hr-ft^2 | | |
| Emissivity of Outer Surface | 0.587 | | | |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 187.750 | in | | |
| Convection Coefficient | 0.970 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.998 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 3.000 | 24.403 | 320.682 | 318.130 |
| Neutron Shield | ns3 | 2.000 | 0.488 | 318.130 | 233.091 |
| Outer Plate | csteel | 0.250 | 24.883 | 233.091 | 232.882 |

Case 4C: 100 F Ambient, Top End, No Solar, w/ 0.5" Air Gap.

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.814545 |
| Ambient Temperature | 100 | °F | hr | 1.814545 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 1.116 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.992 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 9.018 | 482.711 | 464.935 |
| DSC Top Plate | ss304 | 1.750 | 8.975 | 464.935 | 460.470 |
| Air Gap | air | 0.500 | 0.022 | 460.470 | 343.176 |
| Bottom Struc Plate | ss304 | 1.750 | 8.700 | 343.176 | 338.569 |
| Neutron Shield | NS3 | 2.250 | 0.488 | 338.569 | 233.023 |
| Bottom Plate | ss304 | 1.000 | 8.700 | 233.023 | 230.391 |

Case 5A: 125 F Ambient, Top End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial shell temps only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.919935 |
| Ambient Temperature | 125 | °F | hr | 1.919935 |
| Solar Heat Load | 123 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 0.988 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 1.143 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 8.750 | 9.075 | 499.549 | 477.469 |
| DSC Top Plate | ss304 | 1.250 | 9.026 | 477.469 | 474.297 |
| Air Gap | air | 0.500 | 0.022 | 474.297 | *362.415* |
| *Cask Struc Plate* | *csteel* | *3.000* | *24.172* | *362.415* | *359.573* |
| *Neutron Shield* | *NS3* | *2.000* | *0.488* | *359.573* | *265.754* |
| *Cask Top Plate* | *csteel* | *0.250* | *24.702* | *265.754* | *265.523* |

Note: Numbers and text in italic type are included for information only.

Case 5B: 125 F Ambient, Top End, W/ Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 125 | °F | |
| Solar Heat Load | 123 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 0.966 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 1.118 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 3.000 | 24.273 | 344.178 | 341.613 |
| Neutron Shield | ns3 | 2.000 | 0.488 | 341.613 | 256.573 |
| Outer Plate | csteel | 0.250 | 24.753 | 256.573 | 256.364 |

# Pacific Nuclear Fuel Services, Inc.
San Jose, California

PROJECT NUHOMS 10CFR72 CERTIFICATION FILE NO. NUH004.0407
CLIENT PNFSI

Case 6A: -40 F Ambient, Bottom End, No Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.351262 |
| Ambient Temperature | -40 | °F | hr | 1.351262 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 1.058 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.536 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 8.764 | 417.603 | 399.312 |
| DSC Top Plate | ss304 | 1.750 | 8.719 | 399.312 | 394.716 |
| Air Gap | air | 0.500 | 0.020 | 394.716 | *245.326* |
| *Bottom Struc Plate* | *ss304* | *1.750* | *8.700* | *245.326* | *240.719* |
| *Neutron Shield* | *NS3* | *2.250* | *0.488* | *240.719* | *135.173* |
| *Bottom Plate* | *ss304* | *1.000* | *8.439* | *135.173* | *132.460* |

Note: Numbers and text in italic type are included for information only.

| REVISION | 0 | | | | PAGE 54 OF 65 |
|---|---|---|---|---|---|
| PREPARED BY/DATE | KC 3/19/91 | | | | |
| CHECKED BY/DATE | RJM 8/29/91 | | | | |

Case 6B: -40 F Ambient, Bottom End, No Solar, No Air Gap, Cask Layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | -40 | °F | |
| Solar Heat Load | 0 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 1.033 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.516 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 1.750 | 24.967 | 218.750 | 217.295 |
| Neutron Shield | ns3 | 2.250 | 0.488 | 217.295 | 121.626 |
| Outer Plate | csteel | 1.000 | 25.000 | 121.626 | 120.796 |

Case 7A: 0 F Ambient, Bottom End, No Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.481999 |
| Ambient Temperature | 0 | °F | hr | 1.481999 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 1.037 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.651 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 8.839 | 436.853 | 418.717 |
| DSC Top Plate | ss304 | 1.750 | 8.795 | 418.717 | 414.160 |
| Air Gap | air | 0.500 | 0.021 | 414.160 | *275.568* |
| *Bottom Struc Plate* | *ss304* | *1.750* | *8.700* | *275.568* | *270.961* |
| *Neutron Shield* | *NS3* | *2.250* | *0.488* | *270.961* | *165.416* |
| *Bottom Plate* | *ss304* | *1.000* | *8.540* | *165.416* | *162.734* |

Note: Numbers and text in italic type are included for information only.

Case 7B: 0 F Ambient, Bottom End, No Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 0 | °F | |
| Solar Heat Load | 0 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 1.013 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.630 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 1.750 | 24.795 | 249.572 | 248.107 |
| Neutron Shield | ns3 | 2.250 | 0.488 | 248.107 | 152.438 |
| Outer Plate | csteel | 1.000 | 25.000 | 152.438 | 151.608 |

Case 8A: 70 F Ambient, Bottom End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.760358 |
| Ambient Temperature | 70 | °F | hr | 1.760358 |
| Solar Heat Load | 62 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 1.010 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.903 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 8.990 | 475.521 | 457.690 |
| DSC Top Plate | ss304 | 1.750 | 8.947 | 457.690 | 453.210 |
| Air Gap | air | 0.500 | 0.022 | 453.210 | *332.918* |
| *Bottom Struc Plate* | *ss304* | *1.750* | *8.700* | *332.918* | *328.312* |
| *Neutron Shield* | *NS3* | *2.250* | *0.488* | *328.312* | *222.766* |
| *Bottom Plate* | *ss304* | *1.000* | *8.700* | *222.766* | *220.134* |

Note: Numbers and text in italic type are included for information only.

Case 8B: 70 F Ambient, Bottom End, W/ Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 70 | °F | |
| Solar Heat Load | 62 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 0.987 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.879 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 1.750 | 24.470 | 308.101 | 306.616 |
| Neutron Shield | ns3 | 2.250 | 0.488 | 306.616 | 210.947 |
| Outer Plate | csteel | 1.000 | 25.000 | 210.947 | 210.117 |

Case 9A: 100 F Ambient, Bottom End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.880328 |
| Ambient Temperature | 100 | °F | hr | 1.880328 |
| Solar Heat Load | 62 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 0.992 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 1.023 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 9.052 | 491.304 | 473.594 |
| DSC Top Plate | ss304 | 1.750 | 9.009 | 473.594 | 469.145 |
| Air Gap | air | 0.500 | 0.022 | 469.145 | *355.290* |
| *Bottom Struc Plate* | *ss304* | *1.750* | *8.700* | *355.290* | *350.683* |
| *Neutron Shield* | *NS3* | *2.250* | *0.488* | *350.683* | *245.138* |
| *Bottom Plate* | *ss304* | *1.000* | *8.700* | *245.138* | *242.505* |

Note: Numbers and text in italic type are included for information only.

Case 9B: 100 F Ambient, Bottom End, W/ Solar, No Air Gap, Cask layers only.

| | | | |
|---|---|---|---|
| Number of Assemblies | 24 | | |
| Decay Heat per Assembly | 1.00 | kW | hr |
| Ambient Temperature | 100 | °F | |
| Solar Heat Load | 62 | Btu/hr-ft^2 | |
| Emissivity of Outer Surface | 0.587 | | |
| Cask Inner Radius | 34.000 | in | |
| Cask Cavity Length | 187.750 | in | |
| Convection Coefficient | 0.970 | Btu/hr-ft^2-°F) | |
| Radiation Coefficient | 0.998 | Btu/hr-ft^2-°F) | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 1.750 | 24.344 | 330.878 | 329.386 |
| Neutron Shield | ns3 | 2.250 | 0.488 | 329.386 | 233.717 |
| Outer Plate | csteel | 1.000 | 24.882 | 233.717 | 232.882 |

Case 9B: 100 F Ambient, Bottom End, No Solar, w/ 0.5" Air Gap.

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 1.222544 |
| Ambient Temperature | 100 | °F | hr | 1.222544 |
| Solar Heat Load | 0 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 0.000 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 0.705 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 8.700 | 397.821 | 379.395 |
| DSC Top Plate | ss304 | 1.750 | 8.700 | 379.395 | 374.788 |
| Air Gap | air | 0.500 | 0.020 | 374.788 | 212.904 |
| Bottom Struc Plate | ss304 | 1.750 | 8.695 | 212.904 | 208.295 |
| Neutron Shield | NS3 | 2.250 | 0.488 | 208.295 | 102.749 |
| Bottom Plate | ss304 | 1.000 | 8.331 | 102.749 | 100.000 |

Case 10A: 125 F Ambient, Bottom End, W/ Solar, W/ Air Gap, 167" Cask Cavity.
(Model to determine DSC axial temp distribution only)

| | | | | |
|---|---|---|---|---|
| Number of Assemblies | 24 | | Internal | Radiation |
| Decay Heat per Assembly | 1.00 | kW | hr | 2.010767 |
| Ambient Temperature | 125 | °F | hr | 2.010767 |
| Solar Heat Load | 123 | Btu/hr-ft^2 | ei | 0.587 |
| Emissivity of Outer Surface | 0.587 | | eo | 0.587 |
| Cask Inner Radius | 34.000 | in | | |
| Cask Cavity Length | 167.000 | in | | |
| Convection Coefficient | 0.988 | Btu/hr-ft^2-°F) | | |
| Radiation Coefficient | 1.143 | Btu/hr-ft^2-°F) | | |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| DSC Plug | ss304 | 7.000 | 9.117 | 507.921 | 490.337 |
| DSC Top Plate | ss304 | 1.750 | 9.074 | 490.337 | 485.921 |
| Air Gap | air | 0.500 | 0.023 | 485.921 | *378.307* |
| *Bottom Struc Plate* | *ss304* | *1.750* | *8.700* | *378.307* | *373.701* |
| *Neutron Shield* | *NS3* | *2.250* | *0.488* | *373.701* | *268.155* |
| *Bottom Plate* | *ss304* | *1.000* | *8.700* | *268.155* | *265.523* |

Note: Numbers and text in italic type are included for information only.

Case 10B: 125 F Ambient, Bottom End, W/ Solar, No Air Gap, Cask layers only.

| | | |
|---|---|---|
| Number of Assemblies | 24 | |
| Decay Heat per Assembly | 1.00 | kW hr |
| Ambient Temperature | 125 | °F |
| Solar Heat Load | 123 | Btu/hr-ft^2 |
| Emissivity of Outer Surface | 0.587 | |
| Cask Inner Radius | 34.000 | in |
| Cask Cavity Length | 187.750 | in |
| Convection Coefficient | 0.966 | Btu/hr-ft^2-°F) |
| Radiation Coefficient | 1.118 | Btu/hr-ft^2-°F) |

| Cask Layer | Material | Thickness (in) | k (Btu/hr-ft-°F) | Ti (°F) | To (°F) |
|---|---|---|---|---|---|
| Top Cover Plate | csteel | 1.750 | 24.213 | 354.372 | 352.872 |
| Neutron Shield | ns3 | 2.250 | 0.488 | 352.872 | 257.202 |
| Outer Plate | csteel | 1.000 | 24.751 | 257.202 | 256.364 |

## 4.0 REFERENCES

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