CNS Type B Casks

Evaluation of Effectiveness of the Secondary Lid

Thermal Shields for the 8-120B and 10-160B Casks

Project Number: 12CV01.1001-01

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Print Name	Chad Hendrix
Sign / Date	

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0	5/15/12	Original Issue	Mirza Baig	Chad Hendrix	J.D. Sohl
1	6/20/12	Revised to Include Vent Seal Time-History	Mirza Baig	Chad Hendrix	Mirza Baig
2	6/25/12	Revised to Include Appendix 4	J.D. Sparks	Chad Hendrix	Brent Jones
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HISTORY SHEET

Rev	Reason for revision	Originator
0	Initial Issue	Mirza Baig
1	Revised to include vent seal time-history	Mirza Baig
2	Revised to Include Appendix 4. Restructured the calculation main body and added several references to Appendix 4. Added an Appendix 4 summary of results section.	JD Sparks
3	Included Assumptions in Appendix 4. Removed the references to 450°F as the acceptable temperature for the seals.	Mirza Baig

Calculation Summary and Control Sheet

Quality Level / Category: ☒QL-1 ☐QL-2 ☐QL-3 ☐QL-4	
Calculation results rely on a COMPUTER PROGRAM: ☒ Yes ☐ No If "Yes," complete Verification and Validation Information section	**Verification and Validation Information** Program Used: ANSYS Revision: 13.0 Desktop Computer tag #: 28254-D V&V report (number and rev): SW-072 Rev.1 & SW-073 Rev.1
Results generated using a SOFTWARE TOOL are reported and checked by hand for applications that are not validated and verified: ☐ Yes ☒ No ("No" to be checked only if a software tool is not used)	**Note: All calculations, including those generated using a software tool, shall be hand checked unless a computer program was used to perform the calculation AND proper documentation exists confirming that the computer program has been verified and validated in accordance with ES-QA-PR-019, Computer Software Management, and that modeling conditions are within the scope of the verification and validation of the program.**
Calculation contains Unverified Assumptions: ☐ Yes ☒ No	**Note: If calculation contains unverified assumptions identify them in the box below.**

Identify and Number Unverified Assumptions:
None

Identify Design Inputs (may reference appropriate calculation section):
See Section 3.0.

Results and Conclusions:
It has been shown in this document that, with the use of the thermal-shield on the secondary lids of the 8-120B and the 10-160B casks, during the HAC fire test the seal temperatures will remain well below the maximum working temperature limits specified in the respective safety analyses reports. The maximum calculated seal temperature for the 8-120B casks is 288°F and that for the 10-160B casks is 328°F.

Appendix 4 evaluated the damaged thermal shield temperatures. The maximum temperature range for the 8-120B cask secondary seals is 271°F to 331°F. The 10-160B cask temperature ranges for the secondary lid seals is 300°F to 375°F and for the vent port seals is 288°F to 357°F.

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1. INTRODUCTION

The Energy*Solutions* document titled "HAC Fire Analyses of the 8-120B and 10-160B Casks with Ruptured Impact Limiter Ends" (Reference 1) indicated that during the hypothetical fire test, the secondary lid seal temperatures of these casks will rise above the specified material temperature limit if the sheet metal of the impact limiter which covers the hollow portion of the impact limiters were to be damaged during the puncture drop test. In order to protect the seals during the fire test, attachable thermal-shields (References 2 and 3) have been designed that can be used with these casks. This document evaluates their effectiveness in protecting the seals during the fire test.

The thermal-shields consist of two stainless-steel plates that are separated by thin air gap. Pipe stubs are welded to these plates that act as the stand-offs which provide additional air pocket above the secondary lids. The thermal-shield assemblies are attached to the lid-lifting lugs with the help of hitch-pins.

Thermal analyses have been performed using ANSYS Version 13.0 finite element code (Reference 4). For the analyses, detailed 3-dimensional finite element models of the secondary lids and the thermal-shields have been utilized. This means that it is assumed that the secondary lid portion can be isolated from the complete package model for the analysis purpose. To validate this assumption, the finite element model of the secondary lid (without the thermal-shield) was analyzed for the fire transient analysis. From the results of this analysis the seal temperature time-history was compared with those obtained from the complete model analysis of the package performed in Reference 1. The comparison showed that the 3-dimensional model of the secondary lid alone resulted in a conservative prediction of the seal temperature, which validated the assumption.

The detailed models of the thermal-shield were added to the finite element models of the secondary lid. These combined models were analyzed for the initiation, duration and the cool-down of hypothetical fire as specified in 10 CFR 71.73(b)(4) (Reference 5). The analyses were performed for both the 8-120B and the 10-160B cask secondary lids.

Based on the results of the analyses, presented in Section 6 of this report, it is concluded that with the use of the thermal-shields the secondary lid seal temperatures can be substantially reduced. The maximum temperature calculated for the 8-120B cask secondary lid seals are 288°F and that for the 10-160B cask secondary lid seals is 328°F (see Tables 1 and 2). The maximum temperature calculated in this document may be used for establishing the hot temperature limit of the seal material.

Appendix 4 evaluated the 8-120B and 10-160B casks for the impact on the thermal profile after the thermal shield is damaged in the puncture tests as described in calculation CALC-CSK-12CV01-ST-0001. The maximum temperature range for the 8-120B cask secondary

seals is 271°F to 331°F. The 10-160B cask temperature ranges for the secondary lid seals is 300°F to 375°F and for the vent port seals is 288°F to 357°F.

2. ASSUMPTIONS

The major assumptions used in the finite element analyses are listed below.

- The heat transfer between the primary and secondary lid by conduction through the bolts have been neglected. This assumption is conservative for the evaluation of the secondary lid seal's temperature because it eliminates the heat flow through this path. This in turn increases the heat flow towards the secondary lid seals.
- The heat transfer by radiation between the secondary and primary lid surfaces facing each other has been neglected. As described above, this is conservative due to eliminating the heat flow away from the secondary lid seals.
- The secondary lid comprises of two circular plates that are welded only along the circumference. The un-welded interface between the two plates has been examined in two extreme conditions – (1) when they are totally connected, and (2) when they are totally disconnected. The larger of the two temperatures is reported as the seal's temperature during the fire event.
- The stand-off pipes on the thermal-shields are welded to the circular plate by fillet welds on one end and rest on the secondary lid on the other. It is assumed that there are no thermal resistances at both the ends of these pipes. This is conservative because the full-contact at these locations transfers more heat to the lids during the fire than with the partial contact.
- The thermal emissivity of polished stainless steel is 0.15 (per Reference 6) or 0.074 (per Reference 12). In order to be conservative, a large value of 0.3 has been used in the analyses.
- The air pocket between the thermal-shield and the lid includes seven pipe stand-offs. They will help prevent formation of convective current. However, with conservative estimates, it has been shown that the heat transfer due to natural convection will be much smaller than the heat transfer due to radiation. The conservative use of emissivity of 0.3 adequately envelopes any heat transfer due to natural convection. See Section 4.6 for comparison of heat transfer coefficients due to convection and radiation.
- The exposed portions of the lid-lifting lugs are included in the model. They have been subjected to the same boundary conditions as the outside surface of the thermal-shield. The holes of the lugs have been neglected for conservatism.

3. INPUT

The input data for the analyses performed in this document have been obtained from the following sources.

8-120B Cask

Thermal-Shield Geometry .... Reference 2
Secondary Lid Geometry .... Reference 7
Cask Internal Heat Loading = 200 W .... Reference 8
Loading Initial and Boundary Conditions............................. Reference 5
Material Properties................................. As noted in Tables 3 through 5

10-160B Cask

Thermal-Shield Geometry .... Reference 3
Secondary Lid Geometry .... Reference 9
Cask Internal Heat Loading = 200 W .... Reference 10
Loading Initial and Boundary Conditions............................. Reference 5
Material Properties................................. As noted in Tables 3 through 5

4. CALCULATION METHODOLOGY

The methodologies used in the finite element modeling are based on the theoretical background provided below.

4.1. Natural Convection Modeling

The convective heat transfer per unit area between the cask and the atmosphere, q, is governed by the equation:

$$q = hA\left(T_s - T_a\right)$$

Where,

h = Heat transfer coefficient (Btu/sec-in^2-°F)

A = Area (in^2)

T_s = cask surface temperature (°F)

T_a = ambient temperature (°F)

The heat transfer coefficient for the natural convection is given by the following relationship (see for example Ref. 6, page 135).

$$h = C\left(T_s - T_a\right)^{1/3}$$

Where, for horizontal cask,

$C = 0.18$ (Btu/hr-ft^2-°F$^{4/3}$)

$= 3.4722\times10^{-7}$ (Btu/sec-in^2-°F$^{4/3}$)

4.2. Forced Convection Modeling

The heat transfer coefficient for the forced convection during the fire is based on the explanatory material for the IAEA regulations in Safety Series No.37 (Ref. 11), the pool fire gas velocity is taken to be 10 m/sec (393.6 in/sec). The forced convection heat transfer coefficient for large casks, according to Ref. 11, is:

$$h = 10 \frac{W}{m^2 \, °C}$$

For conversion, using,

1 W = 9.4804×10^{-4} Btu/sec

1 m = 39.37 inch

1°C = 1.8°F

Therefore,

$$h = \frac{10 \times 9.4804 \times 10^{-4}}{39.37^2 \times 1.8} = 3.398 \times 10^{-6} \frac{\text{Btu}}{\text{sec} - \text{in}^2 - °\text{F}}$$

The heat transfer coefficients for forced convection are also obtained from additional sources and compared with the IAEA recommended value. It is shown that the value calculated above is larger than the values calculated from other sources. Therefore, the IAEA recommended value will result in a conservative prediction of the cask temperatures during the HAC fire test.

A comprehensive heat transfer coefficient formula for a horizontal cylinder, which is applicable over a large range of Reynolds number values, is listed in Reference 12. This formula is referred to as Churchill-Bernstein formula, which relates Reynolds and Prandtl number with Nusselt number as follows:

$$Nu_d = 0.3 + \frac{0.62\, Re^{1/2}\, Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{3/4}} \left[1 + \left(\frac{Re}{282{,}000}\right)^{5/8}\right]^{4/5} \quad \text{........... Equation (1)}$$

Where,

Re = Reynolds Number $= \dfrac{\rho_f u_\infty d}{\mu_f}$

ρ_f = Air density at film temperature (1475ºF use 1500ºF)

= 1.1707×10^{-5} lb/in^3 (see Table in Section 4.0)

u_∞ = Air velocity = 32.8 ft/sec = 394 in/sec

d = diameter of the cylinder = 73.2 in

μ_f = Air viscosity at film temperature

= 91.75×10^{-8} lb_f-sec/ft^2 (Reference 13 Mark's Handbook)

= 246.2×10^{-8} lb/(in-sec)

Therefore,

$$Re = \frac{\left(1.1707\times10^{-5}\,\dfrac{lb}{in^3}\right)\times\left(394\,\dfrac{in}{\sec}\right)\times(73.2in)}{246.2\times10^{-8}\,\dfrac{lb}{in\cdot\sec}} = 137{,}140$$

Also,

Pr = Prandtl Number

$$= \frac{\mu_f C_{pf}}{k_f}$$

Cpf = Specific heat of the air at constant pressure at film temperature

= 0.2766 Btu/lb-ºF (see Table in Section 4.0)

kf = Conductivity of air at film temperature

= 9.706×10-7 Btu/sec-in-ºF

Therefore,

$$Pr = \frac{\left(246.2\times10^{-8}\,\dfrac{lb}{in\cdot\sec}\right)\times\left(0.2766\,\dfrac{Btu}{lb\cdot\deg F}\right)}{9.706\times10^{-7}\,\dfrac{Btu}{\sec\cdot in\cdot\deg F}} = 0.7$$

Substitution of these values in Equation 1 results in:

$$Nu_d = 0.3 + \frac{0.62 \times (137{,}140)^{1/2} \times (0.7)^{1/3}}{\left[1 + \left(\frac{0.4}{0.7}\right)^{2/3}\right]^{3/4}} \left[1 + \left(\frac{137{,}140}{282{,}000}\right)^{5/8}\right]^{4/5} = 0.3 + \left(\frac{203.86}{1.481} \times [1 + 0.6373]^{4/5}\right)$$

$$= 0.3 + [(137.65) \times (1.4836)] = 204.5 \approx 205$$

Where,

$$Nu_d = \text{Nusselt Number} = \frac{hd}{k_f}$$

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{205 \times (9.706 \times 10^{-7})}{73.2} = 2.718 \times 10^{-6} \frac{\text{Btu}}{\text{sec} \cdot \text{in}^2 \cdot \text{degF}}$$ ......Equation 2

For vertical cylinders Reference 11 gives the following equation relating the Reynolds number, Prandtl number and Nusselt number as follows.

$$Nu = (0.664) \times (\text{Re}_L)^{0.5} \times (\text{Pr})^{1/3}$$ ......Equation 3

The limits of applicability of this equation are:

$\text{Re}_L < 5 \times 10^5$ and Pr >0.1

Where the Reynolds number Re_L is based on the cylinder length,

$L = 87.0$ in

$$\mathrm{Re}_L = \frac{\left(1.1707\times10^{-5}\right)\times\left(394\right)\times\left(87.0\right)}{246.2\times10^{-8}} = 162{,}995 \approx 1.63\times10^{5}$$

Substitution of values in Equation 3 gives,

$$Nu = \left(0.664\right)\times\left(\mathrm{Re}_L\right)^{0.5}\times\left(\mathrm{Pr}\right)^{1/3} = \left(0.664\right)\times\left(1.63\times10^{5}\right)^{0.5}\times\left(0.7\right)^{1/3} = 238.03$$

The forced convection heat transfer coefficient is, therefore;

$$h = \frac{\left(238.03\right)\times\left(9.706\times10^{-7}\right)}{87} = 2.656\times10^{-6}\ \frac{\mathrm{Btu}}{\mathrm{sec}\cdot\mathrm{in}^{2}\cdot\mathrm{degF}}$$

The forced convection heat transfer coefficients for both horizontal and vertical cylinders calculated above are both smaller than IAEA recommended value for the 8-120B cask geometry. Therefore, in order to predict the cask temperature conservatively during the HAC fire test, the IAEA recommended value has been used in all the analyses.

4.3. Radiation Modeling

The heat transfer by radiation between two nodes of a finite element model is governed by the following equation (see for example Reference 12).

$$q = \sigma\ \varepsilon\ F\ A\left(T_I^4 - T_J^4\right)$$

where:

q = heat flow rate (Btu/sec)

σ = Stefan-Boltzmann Constant

= 1.7136×10^{-9} (Btu/hr-ft^2-R^4)

= 3.3056×10^{-15} (Btu/sec-in^2-R^4)

ε = effective emissivity (a function of emissivities of the two surfaces)

F = geometric form factor

A = area (in^2)

T = temperature (°R)

I = first node number

J = second node number

Three radiation heat transfer systems are modeled: (1) radiation heat transfer between the thermal-shield outside surface and the environment, (2) radiation between the two plates of the thermal-shield, and (3) radiation between the inside surface of the thermal-shield and the outside surface of the secondary lid.

The regulations (Article 71.73 of Reference 5) require that an average environment emissivity coefficient of 0.9 must be used for HAC fire test. It also requires that for purpose of calculation, the surface absorptivity coefficient must be either that which the package may be expected to possess if exposed to fire specified or 0.8, whichever is greater. It is conservatively assumed in the analyses that the package has an absorptivity of 1.0. Therefore, an emissivity coefficient of 0.9 has been conservatively specified for all the elements that radiate heat to the environment. Form factor value of 1.0 is used and the area of the surface is automatically calculated by the computer program. During the cool-down period, the surface emissivity is conservatively reduced to the effective emissivity of 0.7347 (see Reference 14 for details).

The heat transfer due to radiation between the thermal-shield plates and the secondary lid is based on their material emissivity and a form factor calculated by the computer program.

4.4. Solar Insolation Modeling

The total insolation is required to be 800 gcal/cm^2 for a 12-hour period for flat surfaces according to the Code of Federal Regulations 10CFR71.71 (Reference 5). The total insolation of 800 gcal/cm^2 is divided by 12 hours of assumed sunlight to yield an average insolation rate. This insolation is further divided by 2 to account for the 24 hours day which results in an insolation rate of 2.582×10^{-4} Btu/sec-in^2. The insolation heat load is applied to the outside surface of the thermal-shield.

4.5. Internal Heat Loading

<u>8-120B Cask</u>

The 200-Watt internal heat load content of the 8-120B is modeled as a constant heat flux over the exposed sidewall inner surface of the cask.

Internal heat load, $q = 200\text{ W} = 200\times9.4804\times10^{-4} = 0.1896$ Btu/sec

The cask inside diameter is 61.8" and the cavity height is 75". Thus, the heat flux on the inside surface of the cask is:

$$q_s = 0.1896/ (\pi\times61.8\times75 + 2\times\pi/4\times61.8^2)$$

$$= 9.2216\times10^{-6}\text{ Btu/(sec-in}^2)$$

10-160B Cask

The 200-Watt internal heat load content of the 10-160B is modeled as a constant heat flux over the exposed sidewall inner surface of the cask.

Internal heat load, q = 200 W = $200 \times 9.4804 \times 10^{-4}$ = 0.1896 Btu/sec

The cask inside diameter is 67.75” and the cavity height is 76.75”. Thus, the heat flux on the inside surface of the cask is:

$$q_s = 0.1896 / (\pi \times 67.75 \times 76.75 + 2 \times \pi/4 \times 67.75^2)$$

$$= 8.052 \times 10^{-6} \text{ Btu/(sec-in}^2)$$

4.5.1. Comparison of Heat Transfer Coefficients due to Radiation and Natural Convection

In order to evaluate the effect of natural convection in the air pocket between the lid and the thermal-shield, a conservatively estimated natural heat transfer coefficient has been compared with that of the heat transfer due to radiation. It has been shown that the heat transfer due to natural convection is much smaller than that due to radiation. The conservative use of higher emissivity for the shield surface envelopes the heat transfer due to natural convection.

The air mass is idealized as an enclosed air mass in a closed horizontal chamber that is heated from the bottom. For this case the heat transfer coefficient is obtained from Reference 15.

The largest temperature difference between the inner plate of the thermal-shield and the secondary lid outside surface occurs at the end of the fire. At this time the two components have the following average temperature:

Thermal-shield inner plate = 1,100°F = 866.3°K

Secondary Lid = 300°F = 421.9°K

Average air temperature between these components is (866.3+421.9)/2 = 644.1°K ≅ 650°K.

From Reference 15, the air properties at this temperature are obtained as follows:

Density, $\rho = 0.543$ kg/m^3

Heat capacity, $C_p = 1.0635$ kJ/kg-°K

Viscosity, $\mu = 3.177 \times 10^{-5}$ kg/m-s

$\upsilon = 58.51 \times 10^{-6}$ m^2/s

Conductance, $k = 0.04953$ W/m-°K

Prandtl Number, $P_r = 0.682$

Raleigh Number,

$$R_a = \frac{g\beta(T_h - T_c)\delta^3}{\nu^2} P_r$$

$g = 9.81$ m/s^2

$\beta = 1/T_\infty = 1/650$°K

$\delta = 2.3125$ in $= 0.059$ m

$$R_a = \frac{9.8 \times 1 \times (866.3 - 421.9) \times 0.059^3}{650 \times (58.51 \times 10^{-6})^2} \times 0.682$$

$R_a = 274{,}137$

Nusselt Number,

$$N_u = 1 + 1.44 \times \left[1 - \frac{1{,}708}{R_a}\right]^* + \left[\left(\frac{R_a}{5{,}830}\right)^{1/3} - 1\right]^*$$

$$= 1 + 1.44 \times \left[1 - \frac{1{,}708}{274{,}137}\right]^* + \left[\left(\frac{274{,}137}{5{,}830}\right)^{1/3} - 1\right]^*$$

$= 1 + 1.44 \times 0.994 + 2.605 = 5.036$

$$N_u = \frac{h\delta}{k}$$

$$h = \frac{N_u k}{\delta}$$

$h_{convection} = 5.036 \times 0.04953/0.059 = 4.23$ W/m^2-°C

Heat transfer by radiation is governed by the equation,

$$\dot{q} = \sigma\epsilon AF\left(T_I{}^4 - T_J{}^4\right)$$

From which the equivalent heat transfer coefficient can be obtained as,

$h_{radiation} = \sigma\varepsilon(T_I^4 - T_J^4)/(T_I - T_J)$

$= 5.6697 \times 10^{-8} \times 0.3 \times (866.3^4 - 421.9^4)/(866.3 - 421.9)$

$= 20.34$ W/ m^2-°C

(It should be noted that the use of 0.3 as the effective emissivity between the two surfaces that have emissivity of 0.3 and 0.9 is conservative)

If the effect of natural convection were included, the total heat transfer coefficient,

$$h = 20.34 + 4.23 = 24.57 \text{ W/ m}^2\text{-°C}$$

$$= 24.57/20.34\ h_{radiation} = 1.21\ h_{radiation}$$

Since for the heat transfer due to radiation the emissivity of the transfer-shield has been conservatively increase from 0.074 (for polished stainless steel) to 0.3 (see Section 2.0 Assumptions), the effect of natural convection in the air pocket between the secondary lid and the thermal-shield is conservatively included.

5. CALCULATIONS

The thermal analyses of the lids under hypothetical fire accident test conditions have been performed using finite element modeling techniques. The ANSYS finite element analysis code (Reference 4) has been employed to perform the analyses.

The finite element model is made of 3-dimensional thermal solid elements (ANSYS SOLID70) that represent the major components of the lid and the thermal- shields. The interstitial air masses between the structural components are also modeled by these elements.

The heat transfer by radiation, natural convection and the forced convection between the thermal-shield and the ambient is modeled by 3-d thermal surface elements (SURF 152). The solar insolation is also modeled by these elements. The internal heat load is modeled by specifying the surface flux on appropriate element surfaces.

Contact-target pairs have been used for connecting various parts of the model that have different grid geometry. They are also used to connect the stand-off pipes between various surfaces. As explained under the assumptions, for conservatism these pipes are conservatively assumed to be totally connected to their interface surfaces. The heat transfer due to radiation between the two plates of the thermal-shield and between the thermal-shield and the lid surface is also modeled by the contact-target pairs. For modeling the contact-target pairs 3-dimensional, 8 node thermal contact element (CONTA174) and 3-d target segment (TARGE170) have been utilized.

Figure 1 shows finite element model of the 8-120B Cask secondary Lid (without the thermal-shield). Figure 2 shows the contact target elements used in this model and Figure 3 shows the surface effect elements used in this model.

The finite element model is analyzed in the following manner:

1. The initial temperature condition is obtained by running the finite element model with the following boundary conditions:
   - Internal heat load – 200 W

- Solar insolation - yes
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

2. The fire transient is run with the body temperature resulting from the above initial conditions. The fire transient is run for 30 minutes (1,800 sec) with the following boundary conditions:
    - Internal heat load – 200 W
    - Solar insolation - no
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by forced convection – yes
    - Ambient air temperature - 1475°F
3. The end of fire analysis of the model is performed with the body temperature resulting from the above fire transient to 1801 sec with the following boundary conditions:
    - Internal heat load – 200 W
    - Solar insolation - no
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by natural convection – yes
    - Ambient air temperature - 100°F
4. The cool-down analysis of the model is performed with the body temperature resulting from the above fire transient to 14,000 sec with the following boundary conditions:
    - Internal heat load – 200 W
    - Solar insolation - yes
    - Heat Transfer to the ambient by radiation – yes
    - Heat transfer to the ambient by natural convection – yes
    - Ambient air temperature - 100°F

Figure 4 shows the boundary conditions used during the fire transient analysis.

The secondary lid seal temperature time-history obtained from the analysis of this model is shown in Figure 5. For comparison, the results obtained from the 2-dimensional analyses of Reference 1 are also shown in this figure. It is established from this analysis that the 3-dimensional model created here adequately represents the response of the lid when it is used in the package.

Figure 6 shows the complete finite element model of the 8-120B cask secondary lid with the thermal-shield. Figures 7 and 8 show the grid geometry of various components of the thermal-shield. Figure 9 shows the time-history plot of the secondary lid seal temperature. Figure 10 shows the temperature contour plot of lid (with thermal-shield) at the time when the seal temperature attains the peak value.

Figure 11 shows finite element model of the 10-160B Cask secondary Lid (without the thermal-shield). Figure 12 shows the contact target elements used in this model and Figure 13 shows the surface effect elements used in this model. Figure 14 shows the secondary lid (without thermal-shield) seal temperature time-history. Figure15 shows the temperature contour plot of lid (with thermal-shield) at the time when the seal temperature attains the peak value.

Figure 16 shows the complete finite element model of the 10-160B cask secondary lid with the thermal-shield. Figures 17 and 18 show the grid geometry of various components of the thermal-shield. Figure 19 shows the time-history plot of the secondary lid seal temperature. Figure 20 shows the temperature contour plot of lid (with thermal-shield) at the time when the seal temperature attains the peak value.

6. RESULTS AND CONCLUSIONS

6.1. Main Calculation Results

In the analyses presented in this document, it has been first established that an isolated finite element model of the secondary lid of the 8-120B Cask can be used to conservatively represent the lid thermal response to the hypothetical fire of the entire package. Following this, the finite element models of the 8-120B and 10-160B Cask secondary lids with the thermal-shield was analyzed for the hypothetical fire transient. The maximum seal temperature was obtained from the time-history of the temperature at the seal locations.

Maximum Seal Temperature, 8-120B Cask = 288°F (Figure 9 and Appendix 2)

Maximum Seal Temperature, 10-160B Cask = 328°F (Figure 19 and Appendix 2)

These temperatures are well below the maximum working temperature limits specified in the respective safety analyses reports.

The 8-120B cask does not have any other seals on the pressure boundary that will be affected due to the scenario analyzed in this document. 10-160B cask includes an optional vent seal that is located on the secondary lid. Figure 21 provides the time-history plot of the temperatures of two nodes located in the vicinity of this seal. The printout of the results from the FEM analysis is included in Appendix 2. The maximum temperature this seal attains during the fire test is 308°F.

6.2. Appendix 4 Summary of Results

This calculation evaluates the 8-120B and 10-160B casks for the impact on the thermal profile after the thermal shield is damaged in the puncture tests as described in calculation CALC-CSK-12CV01-ST-0001.

The maximum temperature range for the 8-120B cask secondary seals is 271°F to 331°F. The 10-160B cask temperature ranges for the secondary lid seals is 300°F to 375°F and for the vent port seals is 288°F to 357°F.

7. ELECTRONIC FILES

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Volume Serial Number is 6CE2-030A

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 Directory of E:\TH-0002 Rev.3\10-160B Cask\With Damaged TS\Emissivity = 0.3

07/18/2012  02:07 PM    <DIR>          .
07/18/2012  02:27 PM    <DIR>          ..
06/22/2012  03:57 PM            27,464 10damaged_SBE03.txt
06/22/2012  04:16 PM            13,942 10SBE03000.png
06/22/2012  04:16 PM            12,231 10SBE03001.png
06/22/2012  04:16 PM               332 scndry_seal_maxs_and_mins.out
06/22/2012  04:16 PM               223 vent_port_maxs_and_mins.out
               5 File(s)         54,192 bytes
```

```
 Directory of E:\TH-0002 Rev.3\10-160B Cask\With Damaged TS\Emissivity = 0.9

07/18/2012  02:07 PM    <DIR>          .
07/18/2012  02:27 PM    <DIR>          ..
06/22/2012  04:05 PM            27,464 10damaged_SBE09.txt
06/22/2012  04:18 PM            13,703 10SBE09000.png
06/22/2012  04:18 PM            12,072 10SBE09001.png
06/22/2012  04:18 PM               332 scndry_seal_maxs_and_mins.out
06/22/2012  04:18 PM               223 vent_port_maxs_and_mins.out
               5 File(s)         53,794 bytes

 Directory of E:\TH-0002 Rev.3\10-160B Cask\With Undamaged TS

07/18/2012  02:03 PM    <DIR>          .
07/18/2012  02:04 PM    <DIR>          ..
05/10/2012  09:22 AM        83,689,472 file.db
05/10/2012  08:50 AM           143,199 file000.png
05/10/2012  08:52 AM           121,777 file001.png
05/10/2012  08:53 AM           146,301 file002.png
05/10/2012  09:17 AM           125,170 file003.png
05/10/2012  09:18 AM            23,841 file004.png
05/26/2012  03:20 PM            22,418 file005.png
05/10/2012  09:21 AM         1,389,445 model.out
05/10/2012  09:13 AM            15,175 PRVAR.lis
05/26/2012  03:19 PM               284 VentTH.in
05/26/2012  03:17 PM             2,600 VentTH.out
              11 File(s)     85,679,682 bytes

 Directory of E:\TH-0002 Rev.3\10-160B Cask\Without TS

07/18/2012  02:02 PM    <DIR>          .
07/18/2012  02:04 PM    <DIR>          ..
04/30/2012  05:52 PM        30,670,848 file.db
03/19/2012  10:39 AM            23,662 file000.png
04/30/2012  02:43 PM           104,021 file001.png
04/30/2012  02:44 PM            95,268 file002.png
04/30/2012  02:54 PM           121,745 file003.png
04/30/2012  05:36 PM            73,229 file004.png
04/30/2012  05:37 PM           144,843 file005.png
05/14/2012  10:46 AM         1,388,795 model.out
03/19/2012  10:39 AM            18,619 Seal Temp.lis
               9 File(s)     32,641,030 bytes

 Directory of E:\TH-0002 Rev.3\8-120B Cask

07/18/2012  02:05 PM    <DIR>          .
07/18/2012  01:58 PM    <DIR>          ..
07/18/2012  02:25 PM    <DIR>          With Damaged TS
07/18/2012  02:05 PM    <DIR>          With Undamaged TS
07/18/2012  02:04 PM    <DIR>          Without TS
               0 File(s)              0 bytes

 Directory of E:\TH-0002 Rev.3\8-120B Cask\With Damaged TS

07/18/2012  02:25 PM    <DIR>          .
07/18/2012  02:05 PM    <DIR>          ..
07/18/2012  02:06 PM    <DIR>          Emissivity = 0.3
07/18/2012  02:06 PM    <DIR>          Emissivity = 0.9
               0 File(s)              0 bytes
```

```
 Directory of E:\TH-0002 Rev.3\8-120B Cask\With Damaged TS\Emissivity = 0.3

07/18/2012  02:06 PM    <DIR>          .
07/18/2012  02:25 PM    <DIR>          ..
06/21/2012  10:38 PM            23,150 1damaged_SBE03.txt
06/22/2012  04:12 PM            22,016 SBE03000.png
06/22/2012  04:12 PM               389 Seal_max_temp&time_e=0.3.out
               3 File(s)         45,555 bytes

 Directory of E:\TH-0002 Rev.3\8-120B Cask\With Damaged TS\Emissivity = 0.9

07/18/2012  02:06 PM    <DIR>          .
07/18/2012  02:25 PM    <DIR>          ..
06/21/2012  10:41 PM            23,150 1damaged_SBE09.txt
06/22/2012  04:14 PM            21,902 SBE09000.png
06/22/2012  04:14 PM               389 Seal_max_temp&time_e=0.9.out
               3 File(s)         45,441 bytes

 Directory of E:\TH-0002 Rev.3\8-120B Cask\With Undamaged TS

07/18/2012  02:05 PM    <DIR>          .
07/18/2012  02:05 PM    <DIR>          ..
05/10/2012  10:21 AM        69,468,160 file.db
05/09/2012  05:17 PM           107,688 file000.png
05/09/2012  05:19 PM           145,256 file001.png
05/09/2012  05:20 PM           113,538 file002.png
05/10/2012  08:08 AM            20,493 file003.png
05/10/2012  08:35 AM           144,475 file004.png
05/10/2012  10:21 AM         5,786,571 model.out
05/10/2012  08:25 AM            11,731 PRVAR.lis
               8 File(s)     75,797,912 bytes

 Directory of E:\TH-0002 Rev.3\8-120B Cask\Without TS

07/18/2012  02:04 PM    <DIR>          .
07/18/2012  02:05 PM    <DIR>          ..
03/19/2012  09:43 AM        22,216,704 file.db
03/19/2012  09:43 AM            23,233 file000.png
04/26/2012  11:15 AM           113,822 file001.png
04/26/2012  11:22 AM            98,585 file002.png
04/26/2012  11:26 AM            82,971 file003.png
04/26/2012  04:17 PM         3,176,967 model.out
03/19/2012  09:42 AM            11,731 Seal Temp.lis
               7 File(s)     25,724,013 bytes

     Total Files Listed:
              51 File(s)    220,041,619 bytes
              39 Dir(s)               0 bytes free
```

8. REFERENCES

1. Energy*Solutions* Document CALC-CSK-12CV01-TH-0001, Rev.0, HAC Fire Analyses of the 8-120B and 10-160B Casks with Ruptured Impact Limiter Ends.
2. Energy*Solutions* Drawing DWG-CSK-12CV01-EG-0001-01, Rev.0, 8-120B Cask Secondary Lid Thermal-Shield.

3. Energy*Solutions* Drawing DWG-CSK-12CV01-EG-0002-01, Rev.0, 10-160B Cask Secondary Lid Thermal-Shield.
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5. Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material, 2011.
6. Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.
7. Energy*Solutions* Drawing No. C-110-E-0007, Rev. 14, 8-120B Shipping Cask.
8. Safety Analysis Report for Model 8-120B Type B Shipping Packaging, Revision 7, January 2010.
9. Energy*Solutions* Drawing No. C-110-D-29003-010, Rev. 14, Cask Assembly, General Notes/Parts List, 10-160B.
10. Consolidated Safety Analysis Report for Model 10-160B Type B Radwaste Shipping Cask, Revision 3, January 2011.
11. IAEA Safety Series No.37, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material - 1985 Edition, International Atomic Energy Agency, Vienna, 1990.
12. Heat Transfer, J.P. Holman, McGraw Hill Book Company, New York, Fifth Edition, 1981.
13. Mark's Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw Hill Book Company, New York.
14. Energy*Solutions* Document TH-028, Revision 2, Fire Transient Analyses of the 8-120B Cask Using Finite Element Models.
15. Heat Transfer, A Basic Approach, M. Necati Özişik, McGraw Hill Publication.
16. ASME Boiler & Pressure Vessel Code, 2010, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2

Table 1

Summary of Results – 8-120B Cask Secondary Lid Thermal-Shield

Configuration	Maximum Temperature
Without Thermal-Shield	599°F
With Thermal-Shield	288°F

Table 2

Summary of Results – 10-160B Cask Secondary Lid Thermal-Shield

Configuration	Maximum Temperature
Without Thermal-Shield	765°F
With Thermal-Shield	328°F

Table 3

Temperature-Independent Metal Thermal Properties

Material	Property	Value	Reference
Carbon Steel	Density	0.2818 lb/in^3	Reference 16
	Emissivity	0.9 (Painted Surface)	Reference 12
Stainless Steel	Density	0.2824 lb/in^3	Reference 16
	Emissivity	0.074	Reference 12

Table 4

Temperature-Dependent Metal Thermal Properties

Temp.	Stainless Steel (Ref. 16)		Carbon Steel (Ref. 16)	
(°F)	Sp. Heat Btu/lb-°F	Conductivity $\times 10^{-3}$ Btu/sec-in-°F	Sp. Heat Btu/lb-°F	Conductivity $\times 10^{-3}$ Btu/sec-in-°F
70	0.117	0.199	0.104	0.813
100	0.117	0.201	0.106	0.803
150	0.120	0.208	0.109	0.789
200	0.122	0.215	0.113	0.778
250	0.125	0.222	0.115	0.762
300	0.126	0.227	0.118	0.748
350	0.128	0.234	0.122	0.731
400	0.129	0.241	0.124	0.715
450	0.130	0.245	0.126	0.701
500	0.131	0.252	0.128	0.677
550	0.132	0.257	0.131	0.667
600	0.133	0.262	0.133	0.648
650	0.134	0.269	0.135	0.632
700	0.135	0.273	0.139	0.616
750	0.136	0.278	0.142	0.600
800	0.136	0.282	0.146	0.583
900	0.138	0.294	0.154	0.551
1,000	0.139	0.306	0.163	0.519
1,100	0.141	0.315	0.172	0.484
1,200	0.141	0.324	0.184	0.451

Table 5

Temperature-Dependent Air Thermal Properties

Temp. (°F)	Air (Ref. 12)		
	Density $\times 10^{-5}$ lb/in³	Sp. Heat Btu/lb-°F	Conductivity $\times 10^{-7}$ Btu/sec-in-°F
70	4.351	0.2402	3.449
100	4.112	0.2404	3.621
150	3.752	0.2408	3.903
200	3.468	0.2414	4.177
250	3.236	0.2421	4.446
300	3.031	0.2429	4.704
350	2.831	0.2438	4.957
400	2.673	0.2450	5.204
450	2.522	0.2461	5.448
500	2.396	0.2474	5.688
550	2.278	0.2490	5.921
600	2.168	0.2511	6.143
650	2.071	0.2527	6.363
700	1.980	0.2538	6.581
750	1.898	0.2552	6.790
800	1.818	0.2568	6.996
900	1.690	0.2596	7.409
1,000	1.571	0.2628	7.804
1,100	1.472	0.2659	8.175
1,200	1.385	0.2689	8.545
1,300	1.304	0.2717	8.897
1,400	1.235	0.2742	9.285
1,500	1.171	0.2766	9.707

Figures

(21 pages)

Appendix 1

FEM Data Print-Out

(51 Pages)

Appendix 2

ANSYS Result Print-Out

(23 Pages)

Appendix 3

Media Disk (CD)

(1 Disk)

Appendix 4

Analysis of the Damaged Thermal-Shield

(32 Pages)