DOC.20090323.0031

BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

3. System	4. Document Identifier
Naval Spent Nuclear Fuel Waste Package	51A-00C-DN00-00200-000-00A

5. Title
Naval Canister Temperatures in the Canister Transfer Machine

6. Group
Thermal Structural Analysis

7. Document Status Designation
☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled ☐ Superseded

8. Notes/Comments

Condition Report 13450 was initiated to track the error found in Naples 1999 (Reference 2.2.25) that is discussed in Section 6.2.3 of the calculation.

Because of a shortage of personnel who are qualified to check waste package design analyses, the EGS for this document was approved to check this calculation (Interoffice Memorandum No. 0204094572).

Attachments	Total Number of Pages
See Section 5	

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	61	61	Daniel Wang 3/17/09	Del Mecham 3/17/09	Del Mecham 3/17/09	Michael Anderson 3/25/09

ENCLOSURE 3

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

CONTENTS

FIGURES

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TABLES

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ACRONYMS

BSC	Bechtel SAIC Company, LLC
CD	Compact Disc
conv	convection
CRCF	Canister Receipt and Closure Facility
CRWMS M & O	Civilian Radioactive Waste Management System Management and Operating Contractor
CTM	Canister Transfer Machine
DOE	U.S. Department of Energy
h_{eff}	(Effective) Heat Transfer Coefficient
HP	Hewlett-Packard
IHF	Initial Handling Facility
NAC	Nuclear Assurance Corporation
NRC	U.S. Nuclear Regulatory Commission
NS-4-FR	Neutron Shielding-4, Fire Resistant
PC	Personal Computer
rad	radiation
SNF	Spent Nuclear Fuel
SS	Stainless Steel
TAD	Transportation, Aging, and Disposal
TEV	Transport and Emplacement Vehicle
UMS	Universal MPC (multi-purpose canister) System
WP	Waste Package

1. PURPOSE

The objective of this calculation is to evaluate the peak temperatures experienced by the naval spent fuel canisters in the canister transfer machine shielded transfer bell. A steady-state axisymmetric finite element model is used to evaluate temperatures under normal and off-normal conditions. This calculation evaluates both short and long canister configurations and incorporates heat generation rates with up to 5.0 kW/m axial peaking.

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Informal Study of Thermal Shunts for Neutron Shielding (Reference 2.2.15) and *Safety Analysis Report for the NAC-UMS Universal Transport Cask* (Reference 2.2.24) are used only to show that assumed values are within a realistic range. There are no direct inputs from these references, therefore they are considered acceptable for use in this calculation.

2.3 DESIGN CONSTRAINTS

None

2.4 DESIGN OUTPUTS

This calculation is performed to support information in the License Application.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 Dimensions and Materials of the Shield Bell

The materials of the canister transfer machine shielded transfer bell (hereafter, referred to as the shield bell) are assumed to be the same as those indicated in Reference 2.2.16 and are assumed to be the same as the final definitive design. The length of the shield bell is assumed to be the same as that listed in Reference 2.2.14. The shield bell is assumed to have a clearance of 6 inches between itself and the largest diameter canister, and to have dimensions as indicated in Reference 2.2.17, Attachment VI. Because few details are given, it is further assumed that an NS-4-FR (borated polyethylene) insulating layer surrounds the stainless steel layer but also has a thin 316 stainless steel outer layer which gives it its emissivity. Rationale: The design is preliminary, and will require verification at the completion of the final definitive design. This assumption is used in Sections 6.1 and 6.2 and Attachment I.

3.1.2 Dimensions and Materials of the Shield Bell Guide Sleeve

The shield bell guide sleeve (also referred to as the telescoping tube) is assumed to have a thickness of 1 inch, be composed of 316 stainless steel, and be integrally connected to the rest of the shield bell when retracted. Furthermore, any gaps between the sleeve sections are neglected. Rationale: The design is preliminary, and no detailed design information is currently available. This assumption is used in Sections 6.1 and 6.2 and Attachment I.

3.1.3 Effective Thermal Conductivity of NS-4-FR

An effective thermal conductivity of 6.5 W/m-K is assumed for NS-4-FR used in the shield bell. Rationale: Though the thermal conductivity of NS-4-FR without any thermal shunting is 0.646 W/m-K (Reference 2.2.26, Table 3.2-1), studies (such as Reference 2.2.15) have shown that if thermal shunts in the form of a honeycomb of some conductive material (such as aluminum or copper) permeate the NS-4-FR, the effective thermal conductivity of the neutron shielding can be increased to values at and beyond the utilized value of 6.5 W/m-K (up to 11.50 W/m-K, as indicated in Table 6 of Reference 2.2.15 for a honeycomb of copper, the most conductive shunting material evaluated therein). The value (6.5 W/m-K) is reasonable when compared to the effective thermal conductivity (7.89 W/m-K) of the neutron shield structure in the NAC-UMS shipping cask (Reference 2.2.24, Sections 1.2.1.2.1, 3.3.2, 3.4.1.1.1, and Table 3.2-1). The effectiveness of the engineered material as a neutron shield has not been evaluated. Furthermore, the shielding design of the shield bell is preliminary, and will require verification at the completion of the final definitive design. This assumption is used in Sections 6.2.2, 7.2.3, 7.3.3, and 7.4.3.

3.1.4 Design Room Temperature

The design room temperature for Room 2005 – Canister Transfer Area of the IHF is assumed to be 79 °F (26.1 °C). Rationale: This is the design room temperature indicated in Reference 2.2.7, Appendix A, p. 68. Although Reference 2.2.7 is a QA: N/A

calculation, this is the best information currently available and will require verification at the completion of the final definitive design. This assumption is used in Section 6.3.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Representation of Naval SNF Canister within Shield Bell

Only the shield bell portion of the canister transfer machine is modeled. Any canister support structures and/or grapples are ignored. Thus, the naval SNF canister is assumed to be "floating" inside the shield bell, such that there is no contact between the shield bell and the naval SNF canister. Rationale: This is a simplifying assumption necessary to keep the computational model to a reasonable size. Canister support structures and/or grapples within the shield bell will provide additional heat conduction paths from the canister surface; therefore, not modeling them is conservative. This assumption is used in Section 6.1.

3.2.2 Location of Naval Canister Within Shield Bell

The naval canister is positioned concentrically within the shield bell with its top end 1 m from the top end of the shield bell. Rationale: During normal operations, canisters transferred by the CTM are expected to move along most of the axial length of the shield bell. This position is chosen for simplicity. This assumption is used in Section 6.1.

3.2.3 Any Equipment in IHF Is Neglected

Any equipment present in the IHF other than the naval canister and the CTM shield bell is neglected. Rationale: This is a simplifying assumption necessary to keep the computational model to a reasonable size. Any equipment in the rooms will provide greater surface area for convection and radiation heat transfer to the environment. Therefore, modeling only the waste forms in the rooms is conservative. This assumption is used in Section 6.1.

3.2.4 Treatment of Ends of Naval Canister for Radiation

The naval canister is assumed to radiate only to the inner surface of the shield bell. That is, radiation out the axial ends of the shield bell to the environment or equipment is ignored. Rationale: Ignoring radiative heat transfer to the ambient results in reduced heat rejection to the environment, which is conservative. This assumption is used in Section 6.3.

3.2.5 Emissivity of Surroundings

A value of 1.0 is assumed for the emissivity of the surroundings for radiation to/from the shield bell outer surface. Rationale: This conservatively maximizes the calculated radiative energy incident on the shield bell outer surface, and maximizes temperatures. This assumption is used in Section 6.3.

3.2.6 Bounding Ambient Temperature

A temperature of 212 °F (100 °C) is assumed to be bounding for all ambient/wall temperatures experienced by the shield bell. Rationale: The maximum wall temperature reached in the vicinity of an 11.8 kW waste package in Reference 2.2.11, Table 81 and 82 is 225.4 °F (107.4 °C). The building layouts indicates that the building/room walls on the second floor of the IHF are significantly further from any heat source (i.e., the shield bell) than in the case of the CRCF lower transfer rooms (see References 2.2.13 and 2.2.8) and therefore can be expected to be significantly cooler. Therefore, a temperature of 212 °F (100 °C) is assumed to conservatively bound the ambient/wall temperatures that the shield bell outer surface would radiate/convect to in the IHF. This assumption is used in Sections 6.3 and 7.4.1.

3.2.7 Natural Convective Heat Transfer

Wherever convection is applicable, heat transfer coefficents for natural convection are utilized. Rationale: Heat transfer coefficients based on natural convection are typically lower than heat transfer coefficients based on forced convection; therefore, using heat transfer coefficients based on natural convection will provide conservative results for forced convection. This assumption is used in Section 6.3.

3.2.8 Conduction Through Air Ignored

Any thermal conduction through the air between the naval canister and the shield bell is ignored. Rationale: This assumption is made for modeling simplicity. Conductive heat transfer effects should be insignificant compared to the other heat transfer modes in action, and ignoring them is conservative. This assumption is used in Section 6.3.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). The naval SNF canisters are classified as Safety Category items (important to safety and important to waste isolation) in the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.12, Section 12.1.2). Therefore the approved version is designated as QA: QA.

4.2 USE OF SOFTWARE

The finite element computer code used for this calculation is ANSYS V8.0 (Reference 2.2.1), which is identified by the Software Tracking number 10364-8.0-00. Usage of ANSYS V8.0 in this calculation constitutes Level 1 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). ANSYS V8.0 is qualified, baselined, and listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1). Calculations using the ANSYS V8.0 software were executed on Hewlett-Packard (HP) 9000 Series workstations running operating system HP-UX 11.00.

The ANSYS V8.0 evaluations performed in this calculation are fully within the range of the validation performed for ANSYS V8.0 (Reference 2.2.20). Therefore, ANSYS V8.0 is appropriate for the thermal analysis as performed in this calculation. Access to, and use of, the code for this calculation was granted by Software Configuration Management in accordance with the appropriate procedures. The details of the ANSYS analyses are described in Section 6 and Attachments I and II; the results are presented in Section 7 and Attachments I and II of this calculation. All inputs and outputs are located in Attachment V.

Microsoft Excel 2003, which is a component of Microsoft Office 2003 Professional, is used for performing simple calculations and plotting results in Sections 6.3 and 7 and Attachments I, II, and III. The results are confirmed by hand calculation and visual inspection. Microsoft Excel 2003 was executed on a PC running the Microsoft Windows XP SP-2 operating system. Usage of Microsoft Office in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). Microsoft Office 2003 Professional is listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1). The Excel files are located in Attachment V.

Mathcad version 13.0 is used for unit conversion in Section 6.2.2. The results are confirmed by hand calculations. Mathcad was executed on a PC running the Microsoft Windows XP SP-2 operating system. Usage of Mathcad in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). Mathcad is listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1). The Mathcad files are located in Attachment V.

4.3 METHOD

The solution method employed is steady-state axisymmetric finite element analysis using the commercially available code ANSYS V8.0 (Reference 2.2.1) to determine the temperatures in the naval canister and CTM shield bell for both normal and off-normal conditions.

5. LIST OF ATTACHMENTS

Table 1. List of Attachments

Attachment	Description	Number of Pages
I	Sensitivity Studies	4
II	Scoping Cases	1
III	Naval Canister Heat Generation Profiles	6
IV	File Listing for Attachment V	7
V	One (1) Compact Disc (CD)	N/A

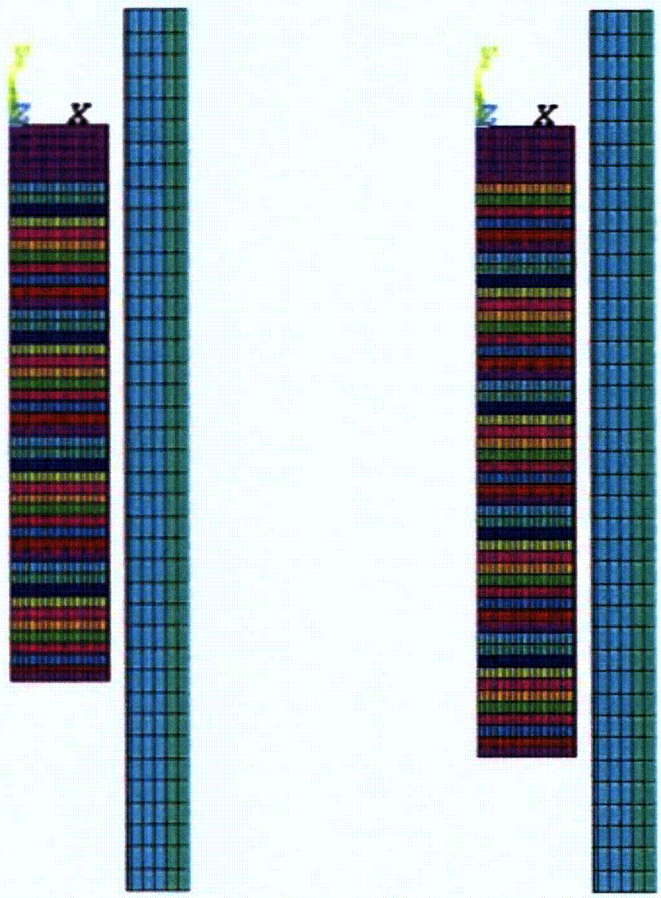
6. BODY OF CALCULATION

6.1 MODEL GEOMETRY

An axisymmetric model of the naval spent fuel canister in the CTM shield bell is utilized.

Only the shielding layers of the CTM are modeled; that is, any grapples or other physical contact between the canister and CTM are ignored (Assumption 3.2.3). The naval canister is modeled as "floating" concentrically within the shield bell (Assumption 3.2.1), with its top end located 1 m from the top of the shield bell shielding (Assumption 3.2.2).

The meshes of the naval canisters within the CTM are shown in Figure 1. The mesh of the naval short canister is depicted in (a), and the mesh of the naval long canister is depicted in (b).



(a) short (b) long

Figure 1. Axisymmetric ANSYS Meshes of the Naval Canisters in the Shield Bell

Key dimensions of the naval canisters are listed in Table 2.

Key dimensions of the CTM shield bell are listed in Table 3. Where available, applicable shield bell dimensions and thicknesses are taken from References 2.2.14 and 2.2.16; diametrical dimensions are assumed as indicated in Reference 2.2.17, Attachment VI (Assumption 3.1.1). Based on available information, the shield bell guide sleeve is assumed to consist of thin telescoping sheets of stainless steel, that can be considered integrally connected to the rest of the shield bell when retracted (Assumption 3.1.2).

Table 2. Naval SNF Canister Dimensions

Item	Dimension (in)	Reference
Naval SNF Canister Outer Diameter (Long and Short)	66.5	Reference 2.2.25, Enclosure 3, p. 2
Naval SNF Canister Wall Thickness (Long and Short)	1.0	Reference 2.2.6
Naval SNF Canister Top Lid Thickness (Long and Short)	15	Reference 2.2.5
Naval SNF Canister Bottom Lid Thickness (Long and Short)	3.5	Reference 2.2.5
Naval Long SNF Canister Active Fuel Length	192.13 (4.88 m)	Reference 2.2.22, Attachment 2, Table 1
Naval Short SNF Canister Active Fuel Length	166.93 (4.24 m)	Reference 2.2.22, Attachment 2, Table 1

Note: Reference 2.2.5 and Reference 2.2.6 are drawings from the supplier of the Naval SNF Canisters and, therefore, are considered appropriate for use in this calculation.

Table 3. CTM Shield Bell Dimensions

Component	Dimension	Reference
Shield Bell Length	25 ft	Reference 2.2.14
Shield Bell Outer Diameter	120.5 in	Reference 2.2.17, Attachment VI, Assumption 3.1.1
Shield Bell Inner Diameter	80.5 in	Reference 2.2.17, Attachment VI, Assumption 3.1.1
Shield Bell SS Layer Thickness	12 in	Reference 2.2.16, Table 64
Shield Bell Poly Layer Thickness	8 in	Reference 2.2.16, Table 64
Guide Sleeve Thickness	1 in	Assumption 3.1.2

6.2 MATERIAL PROPERTIES

Table 4 lists the materials used in the ANSYS representations of the naval canister and shield bell.

Table 4. Materials Used in the ANSYS Representation of Shield Bell

Component	Material	Reference
Transfer Shield Bell Outer Layer	NS-4-FR	Assumption 3.1.1; Ref 2.2.16, Section 7.2.2
Transfer Shield Bell Inner Layer	316 Stainless Steel	Assumption 3.1.1; Ref 2.2.16, Section 7.2.2
Telescoping Tube (Guide Sleeve)	316 Stainless Steel	Assumption 3.1.2
Naval SNF Canister	316 L Stainless Steel	Reference 2.2.6
Naval SNF	Homogeneous Material	Reference 2.2.25, Enclosure 1

Note: Reference 2.2.6 is a drawing from the supplier of the Naval SNF Canisters and, therefore, is considered appropriate for use in this calculation.

6.2.1 Stainless Steel 316/316L (316 SS/ 316L SS)

Table 5 lists the density and emissivity of 316 SS and 316L SS. The density is taken from Reference 2.2.3, Table X1.1. The emissivity is taken from Reference 2.2.4, Table 4.3.2 (median value).

Table 6 lists values of thermal conductivity, thermal diffusivity, and specific heat of 316 SS and 316L SS. Values for thermal conductivity and thermal diffusivity are taken from Reference 2.2.2, Section II, Part D, Table TCD, p. 663 (material group K). The derivation of specific heat is defined in Equation 1. The specific heat of 316 SS and 316L SS is calculated using Equation 1, using the density in Table 5.

$$Specific\ Heat\,(J/kg\cdot K) = \frac{Thermal\ Conductivity\,(W/m\cdot K)}{Density\,(kg/m^3)\times Thermal\ Diffusivity\,(m^2/s)} \qquad \text{(Equation 1)}$$

Table 5. Density and Emissivity of 316 SS and 316L SS

Density (kg/m^3)	Emissivity
7980	0.62

Table 6. Thermal Conductivity, Thermal Diffusivity, and Specific Heat of 316 SS and 316L SS

Temperature		Thermal Conductivity		Thermal Diffusivity		Specific Heat (J/kg·K)
(°F)	(°C)	(Btu/hr-ft-F)	(W/m-K)	(ft^2/hr)	(m^2/s)	
70	21.11	8.2	14.18	0.139	3.587E-06	495.4
100	37.78	8.3	14.35	0.140	3.613E-06	497.9
150	65.56	8.6	14.87	0.142	3.665E-06	508.6
200	93.33	8.8	15.22	0.145	3.742E-06	509.7
250	121.11	9.1	15.74	0.147	3.794E-06	519.9
300	148.89	9.3	16.08	0.150	3.871E-06	520.7
350	176.67	9.5	16.43	0.152	3.923E-06	524.9
400	204.44	9.8	16.95	0.155	4.000E-06	531.0
450	232.22	10.0	17.30	0.157	4.052E-06	534.9
500	260.00	10.2	17.64	0.160	4.129E-06	535.4
550	287.78	10.5	18.16	0.162	4.181E-06	544.3
600	315.56	10.7	18.51	0.165	4.258E-06	544.6
650	343.33	10.9	18.85	0.167	4.310E-06	548.2
700	371.11	11.2	19.37	0.170	4.387E-06	553.3
750	398.89	11.4	19.72	0.172	4.439E-06	556.6
800	426.67	11.6	20.06	0.175	4.516E-06	556.7
850	454.44	11.9	20.58	0.177	4.568E-06	564.6
900	482.22	12.1	20.93	0.179	4.619E-06	567.7
950	510.00	12.3	21.27	0.182	4.697E-06	567.6
1000	537.78	12.5	21.62	0.184	4.748E-06	570.5
1050	565.56	12.8	22.14	0.187	4.826E-06	574.9
1100	593.33	13.0	22.48	0.189	4.877E-06	577.7
1150	621.11	13.2	22.83	0.191	4.929E-06	580.4

6.2.2 NS-4-FR

Table 7 lists the density and specific heat of NS-4-FR, taken from Table 3.2-1 of Reference 2.2.26 (see Attachment V, file: *\Supplemental_Files\NS-4-FR_thermal_properties.xmcd* for unit conversion). Reference 2.2.26 is a Safety Analysis Report submitted to NRC for a particular cask design, and, therefore, is a reliable source suitable for use in this calculation.

Since the NS-4-FR is essentially a thermally insulating material, heat flow from the waste forms to the environment, through the shielding material, is limited. If thermal shunts in the form of a honeycomb of some conductive material (such as aluminum or copper) permeated the NS-4-FR, the effective thermal conductivity of the neutron shielding layer of the shield bell can be increased, thus allowing greater heat rejection to the environment. To reflect the anticipated addition of thermal shunts to the shielding material, a thermal conductivity of 6.5 W/m-K is assumed for materials specified as NS-4-FR (Assumption 3.1.3).

Table 7. Density, Thermal Conductivity, and Specific Heat of NS-4-FR

Density (kg/m^3)	Thermal Conductivity* (W/m-K)	Specific Heat (J/kg·K)
1630	6.5	1600

*See Assumption 3.1.3

6.2.3 Naval Canister

Table 8 lists the density and surface emissivity of the naval SNF canisters. The density of the naval SNF canisters is taken from Reference 2.2.25, Enclosure 1, p. 3 (maximum value). The emissivity is taken from Reference 2.2.25, Enclosure 1, p. 4. Table 9 and Table 10 list the effective thermal conductivity of the naval long and short SNF canisters, respectively, taken from Reference 2.2.25, Enclosure 1, p. 11. Table 11 lists the lumped specific heat of the naval SNF canisters, taken from Reference 2.2.25, Enclosure 1, p. 12. (Note that the units of the lumped specific heat shown on p. 12 of Reference 2.2.25 are in error. They should be kcal/kg·°C).

Table 8. Density and Surface Emissivity of Naval SNF Canisters

Density (kg/m^3)	Emissivity
4485	0.6

Table 9. Thermal Conductivity of Naval Long SNF Canister

Temperature (°C)	Thermal Conductivity (W/m·K)	Temperature (°C)	Thermal Conductivity (W/m·K)
77.78	2.45	189.14	3.39
89.61	2.62	193.11	3.38
109.98	2.71	195.20	3.37
129.11	2.90	203.17	3.44
135.20	2.87	204.59	3.46
142.72	2.00	204.97	3.49
155.84	3.12	207.36	3.49
159.20	3.06	219.36	3.58
167.42	3.18	228.56	3.66
167.84	3.26	236.22	3.72
178.75	3.23	239.03	3.74
181.64	3.27	242.72	3.76
184.95	3.28	244.75	3.78
188.03	3.35	279.34	4.00

Table 10. Thermal Conductivity of Naval Short SNF Canister

Temperature (°C)	Thermal Conductivity (W/m·K)	Temperature (°C)	Thermal Conductivity (W/m·K)
77.78	2.74	189.14	3.81
89.61	2.94	193.11	3.79
109.98	3.04	195.20	3.78
129.11	3.26	203.17	3.86
135.20	3.21	204.59	3.88
142.72	3.36	204.97	3.91
155.84	3.51	207.36	3.92
159.20	3.43	219.36	4.02
167.42	3.56	228.56	4.10
167.84	3.65	236.22	4.17
178.75	3.62	239.03	4.19
181.64	3.66	242.72	4.22
184.95	3.67	244.75	4.23
188.03	3.76	279.34	4.51

Table 11. Specific Heat of Naval SNF Canisters

Temperature (°C)	Specific Heat (J/kg·K)
0	397.48
38	418.40
93	435.14
148	451.87
204	472.79
260	481.16
316	493.71
371	502.08
400	506.26

6.3 BOUNDARY CONDITIONS

Convection (and radiation to the ambient/room walls) is modeled using an effective heat transfer coefficient. The derivation of the effective heat transfer coefficients is discussed in the following sub-sections.

For all radiation and convection heat transfer with the environment (room air or walls), the environment is modeled at one of three temperatures: 79 °F (26.1 °C), 116 °F (46.7 °C), or 212 °F (100 °C).

The 79 °F (26.1 °C) temperature represents the design room temperature for Room 2005 – Canister Transfer Area (Reference 2.2.7, Appendix A, p. 68) (see Assumption 3.1.4). Effective heat transfer coefficients at 79 °F are given in Table 12.

The 116 °F (46.7 °C) temperature represents the maximum ambient outdoor temperature (Reference 2.2.9, Section 6.1.6). Effective heat transfer coefficients at 116 °F are given in Table 13.

The 212 °F (100 °C) temperature is chosen as an assumed bounding temperature (see Assumption 3.2.6). Effective heat transfer coefficients at 212 °F are given in Table 14.

Calculations of all effective heat transfer coefficients can be seen in Attachment V, file: *\Supplemental_Files\NavyCTM_h_calc.xls* , tab: "0.62emis (default)".

Table 12. Effective Heat Transfer Coefficients for 79 °F (26.1 °C) Ambient Temperature

Surface Temperature (°C)	Effective Heat Transfer Coefficient, *h* (W/m²·K)		
	Radiation only	Convection only	Combined Rad + Conv
26.2	3.8	0.6	4.4
30	3.8	2.1	5.9
40	4.0	3.2	7.2
46.7	4.2	3.6	7.8
75	4.8	4.8	9.6
100	5.4	5.5	10.9
125	6.1	6.1	12.1
150	6.8	6.5	13.4
175	7.6	7.0	14.6
200	8.5	7.3	15.8
250	10.5	8.0	18.5
300	12.8	8.5	21.3
350	15.5	9.0	24.5
400	18.5	9.5	28.0

Table 13. Effective Heat Transfer Coefficients for 116 °F (46.7 °C) Ambient Temperature

Surface Temperature (°C)	Effective Heat Transfer Coefficient, *h* (W/m^2·K)		
	Radiation only	Convection only	Combined Rad + Conv
46.8	4.6	0.6	5.2
50	4.7	2.0	6.6
60	4.9	3.1	8.0
75	5.2	4.0	9.2
100	5.9	4.9	10.8
125	6.6	5.6	12.2
150	7.3	6.2	13.5
175	8.2	6.6	14.8
200	9.1	7.0	16.1
225	10.1	7.4	17.5
250	11.1	7.7	18.8
300	13.5	8.3	21.8
350	16.2	8.8	25.1
400	19.4	9.3	28.6

Table 14. Effective Heat Transfer Coefficients for 212 °F (100 °C) Ambient Temperature

Surface Temperature (°C)	Effective Heat Transfer Coefficient, *h* (W/m^2·K)		
	Radiation only	Convection only	Combined Rad + Conv
46.7	5.9	4.9	10.8
90	7.0	2.8	9.8
95	7.2	2.2	9.4
100	7.3	0.0	7.3
105	7.4	2.2	9.7
110	7.6	2.8	10.4
125	8.1	3.8	11.9
150	8.9	4.8	13.7
175	9.8	5.5	15.3
200	10.8	6.1	16.9
225	11.9	6.6	18.4
250	13.0	7.0	20.0
275	14.2	7.3	21.6
300	15.5	7.7	23.2
350	18.5	8.3	26.7
400	21.8	8.8	30.6

A combined radiation and convection boundary condition is applied on the outer surface of the shield bell (to the ambient environment) using an effective heat transfer coefficient. See Section 6.4.1.2 of Reference 2.2.10 for detailed explanation of how effective heat transfer coefficients are calculated. The combined radiation and convection are to an ambient environment temperature of one the three model temperatures discussed above.

Between the shield bell guide sleeve and the naval canister (in applicable cases), convective heat transfer is applied at one of the three model air temperatures discussed above. This is in addition to the radiation between the shield bell and the naval canister modeled in all cases. Any radiation to the ambient from these two surfaces (out the ends of the shield bell) is ignored (Assumption 3.2.4). Any conductive heat transfer through the air is also ignored (Assumption 3.2.8).

Radiation Effective Heat Transfer Coefficient

The radiation boundary condition involves a peripherally uniform ambient temperature of the surroundings. Consequently, the heat transfer may be considered similar to the general case of heat exchange between parallel plane surfaces. The heat flow between the outer surface of the shield bell, T_1, and the ambient, T_2, is:

$$q_r = \sigma \varepsilon_{eff} A \left(T_1^4 - T_2^4\right) \qquad \text{(Equation 2)}$$

In this equation, σ is the Stefan-Boltzmann constant, equal to 5.67 x 10^{-8} W/(m^2·K^4) (p. 610, Reference 2.2.23). The emissivity of the stainless steel is used for the outer surface of the shield bell, ε_{eff}. An emissivity of 1.0 is assumed for the ambient (Assumption 3.2.5).

Equation 2 can be rearranged as follows:

$$q_r = \left[\sigma \varepsilon_{eff} \left(T_1^2 + T_2^2\right)\left(T_1 + T_2\right)\right] A\left(T_1 - T_2\right) = h_r A\left(T_1 - T_2\right) \qquad \text{(Equation 3)}$$

where h_r is the effective coefficient for radiation heat transfer. Therefore,

$$h_r = [\sigma \varepsilon_{eff} (T_1^2 + T_2^2)(T_1 + T_2)] \qquad \text{(Equation 4)}$$

Convection Effective Heat Transfer Coefficient

For air at room temperature and atmospheric pressure, the average value of the convection heat transfer coefficient, h_c, for flow around horizontal cylinders is correlated by the following equation (Reference 2.2.4, p. 4-88) (Assumption 3.2.7) (heat transfer coefficients based on natural convection are typically lower than heat transfer coefficients based on forced convection; therefore, using heat transfer coefficients based on natural convection will provide conservative results for forced convection):

$$h_c = 0.19\,(\Delta T)^{1/3} \qquad \text{(Equation 5)}$$

which has units of Btu/hr·ft^2· F, with ΔT in degrees Fahrenheit, for $D^3\Delta T > 100$ ft^3· F. The heat transfer coefficients used are calculated using Equation 5 and temperatures in degrees Fahrenheit, and the results are converted into SI units using the conversion factor for Btu/hr·ft^2·°F to W/m^2·K (located inside the back cover of Reference 2.2.23):

$$1\,\frac{\mathrm{W}}{\mathrm{m}^2\cdot\mathrm{K}} = 0.17612\,\frac{\mathrm{Btu}}{\mathrm{hr}\cdot\mathrm{ft}^2\cdot{}^\circ\mathrm{F}} \qquad \text{(Equation 6)}$$

Combined Radiation & Convection Effective Heat Transfer Coefficient

The radiation heat transfer on the shield bell outer surface may be combined with convection heat transfer and characterized as an effective heat transfer coefficient, h_{eff}.

$$h_{eff} = h_r + h_c \qquad \text{(Equation 7)}$$

The combined flow of heat via radiation and convection to the surroundings is then:

$$q = q_r + q_c \qquad \text{(Equation 8)}$$

or

$$q = (h_r + h_c)\,A\,(T_1 - T_2) = h_{eff}\,A\,(T_1 - T_2) \qquad \text{(Equation 9)}$$

where q_r and q_c are the heat transfer rates for radiation and convection, respectively.

6.4 HEAT LOADS

In the ANSYS representations, the naval long SNF canister is axially divided into 51 sections, and the naval short SNF canister is axially divided into 45 sections. For both canisters, the top and bottom sections represent the top lid and bottom lid of the naval SNF canister, and as such, generate no heat. The remaining sections represent the naval SNF. There are eight heat generation profiles for the naval short SNF canister and eight heat generation profiles for the naval long SNF canister. All naval SNF canister heat generation profiles used in this calculation are listed in Table 29 through Table 32 in Attachment III.

An example plot of the heat generation data is shown in Figure 2 for Case Long2-3_5. Plots of the other heat generation cases can be seen in files: *\Supplemental_Files\ naval_long_canister_heat_gen.xls* and *\Supplemental_Files\ naval_short_canister_heat_gen.xls* of Attachment V.

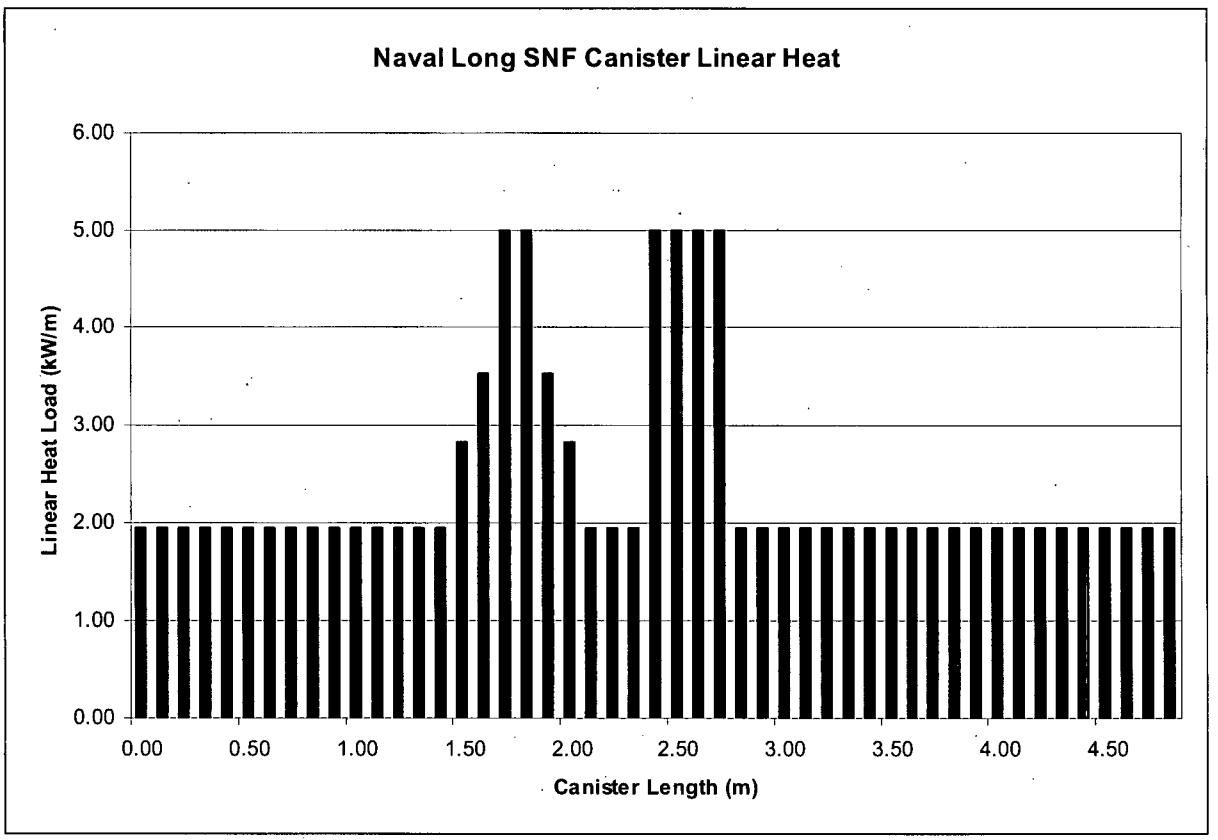


Figure 2. Naval Long SNF Canister Linear Heat Profile (Long2-3_5)
Source: Attachment V, file: *\Supplemental_Files\naval_long_canister_heat_gen.xls*, tab: "Case 2.3_5"

6.5 CALCULATION CASES

The primary ANSYS cases considered in this calculation are summarized in Table 15. The first grouping represents cases evaluated under normal operating conditions. The second grouping represents cases evaluated under mild off-normal conditions. The third grouping represents cases evaluated under extreme off-normal (bounding) conditions. For each case number listed in the table, one case is evaluated for each of the naval short and long canisters.

"Tube Conv" describes convective effects on the outer surface of the naval canister and the inner surface of the shield bell.

Table 15. Case Summary Table

Case Number	Outer Boundary Condition	Ambient Temp (°C)	Tube Conv Present?	Tube Conv Temp (°C)	File Location in Attachment V
2-1_3_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
2-2_1_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
2-2_3_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
2-3_5_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
3-1_3_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
3-2_1_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
3-2_3_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
3-3_5_RC_2_2	Rad + Conv	26.1	Yes	26.1	\ANSYS\RC_2_2\
2-1_3_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
2-2_1_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
2-2_3_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
2-3_5_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
3-1_3_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
3-2_1_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
3-2_3_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
3-3_5_RC_4_10	Rad + Conv	46.7	Yes	100	\ANSYS\RC_4_10\
2-1_3_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
2-2_1_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
2-2_3_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
2-3_5_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
3-1_3_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
3-2_1_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
3-2_3_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\
3-3_5_RC_10_N	Rad + Conv	100	No	N/A	\ANSYS\RC_10_N\

Additional sensitivity cases are evaluated in Attachment I - "Sensitivity Studies" to evaluate the impacts of various scenario modifications. Additional scoping cases are evaluated in Attachment II - "Scoping Cases" investigating various combinations of boundary condition temperatures.

7. RESULTS AND CONCLUSIONS

The outputs of this calculation are reasonable compared to the inputs, and the results are suitable for the intended use. While uncertainties have not been quantified, this calculation provides a range of thermal results that can be considered bounding for design guidance at this time. Various heat loads have been used together with nominal conservative assumptions. Future work may quantify the inherent safety margin.

To determine the peak temperatures experienced by waste canisters inside the Canister Transfer Machine shielded transfer bell, a steady-state axisymmetric ANSYS analysis was performed. A cross-sectional (axisymmetric) slice of a canister inside a CTM shield bell in the canister transfer room was utilized. See Section 6 for further scenario details.

7.1 THERMAL LIMITS

The following thermal limits apply to this calculation:

The maximum continuous operating temperature of NS-4-FR (neutron shielding material) is 300 °F or 148.9 °C (Reference 2.2.19, p. II-5). Attachment II of Reference 2.2.19 provides vendor data from a supplier of NS-4-FR, and, therefore, is suitable for use in this calculation.

The naval SNF canister surface temperature shall not exceed 400 °F (204.4 °C) from the time of detensioning the transportation cask closure until completion of emplacement of the naval waste package in the emplacement drift (Reference 2.2.21, Section 10.3.2.2, item 1).

7.2 NORMAL SCENARIO RESULTS

7.2.1 Brief Summary

A normal operating conditions scenario was modeled in which the the outer surface of the shield bell radiates and convects to an ambient temperature of 79 °F (26.1 °C), the design room temperature. Natural convection between the shield bell and the naval canister is modeled with an air temperature of 79 °F (26.1 °C).

7.2.2 Results

Peak temperature results for the naval long and short canisters under normal conditions are given in Table 16 and Table 17 respectively.

A graph of the temperatures along the length of the naval long canister surface under normal conditions (all cases) is presented in Figure 3. A similar graph for the naval short canister surface is presented in Figure 4.

Example temperature contour plots of the naval long canister in the shield bell under normal conditions (Cases Long_2-1_3_RC_2_2 and Long_3-1_3_RC_2_2) are presented in Figure 5 and Figure 6.

Table 16. Peak Temperatures of Naval Long Canister in Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Long2-1_3	26.1	26.1	168.5	92.9	42.3	42.0	39.8
Long2-2_1	26.1	26.1	73.0	49.9	31.4	31.3	30.6
Long2-2_3	26.1	26.1	150.7	84.5	39.5	39.3	37.4
Long2-3_5	26.1	26.1	192.6	103.6	44.0	43.7	41.0
Long3-1_3	26.1	26.1	166.1	91.7	42.0	41.8	39.6
Long3-2_1	26.1	26.1	73.6	50.2	31.5	31.4	30.7
Long3-2_3	26.1	26.1	151.9	85.0	39.7	39.5	37.7
Long3-3_5	26.1	26.1	189.8	102.3	43.5	43.2	40.7

Table 17. Peak Temperatures of Naval Short Canister in Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Short2-1_3	26.1	26.1	161.0	94.3	42.5	42.3	39.9
Short2-2_1	26.1	26.1	69.9	49.6	31.2	31.2	30.5
Short2-2_3	26.1	26.1	140.1	83.8	39.1	38.9	37.1
Short2-3_5	26.1	26.1	185.8	106.0	44.7	44.4	41.6
Short3-1_3	26.1	26.1	160.9	94.2	42.6	42.4	40.0
Short3-2_1	26.1	26.1	70.8	50.0	31.4	31.3	30.6
Short3-2_3	26.1	26.1	141.8	84.7	39.5	39.3	37.4
Short3-3_5	26.1	26.1	183.8	105.1	44.4	44.2	41.5

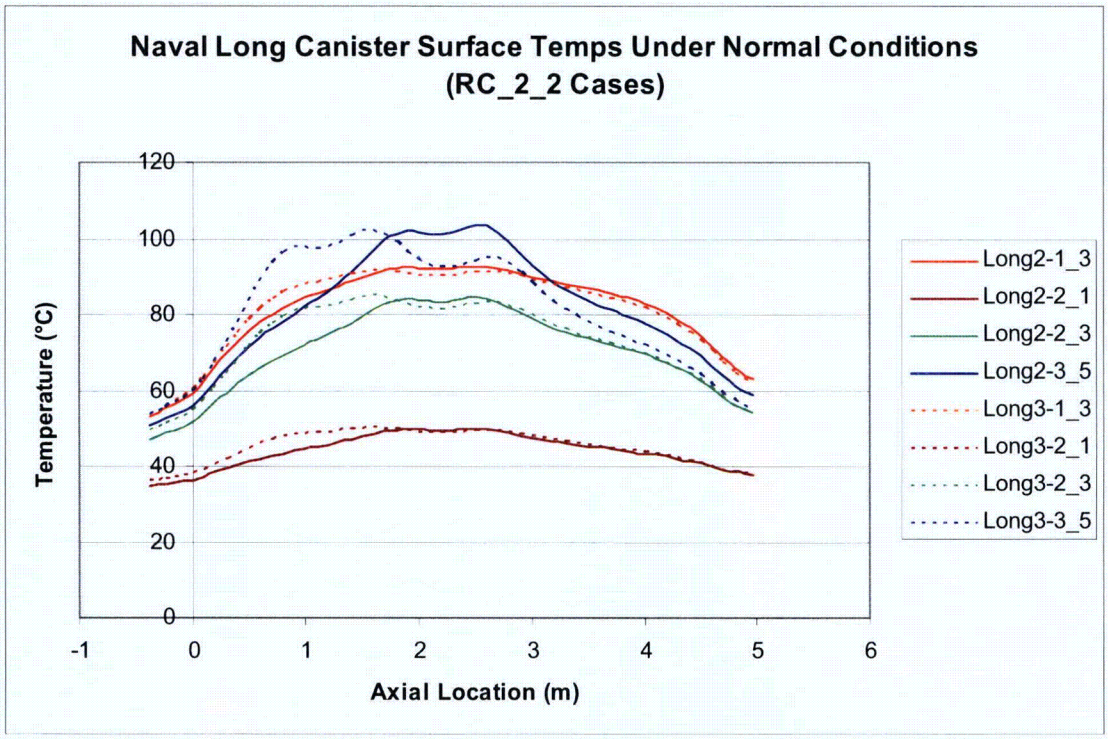


Figure 3. Naval Long SNF Canister Surface Temperature Profiles (°C) – Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Long RC_2_2"

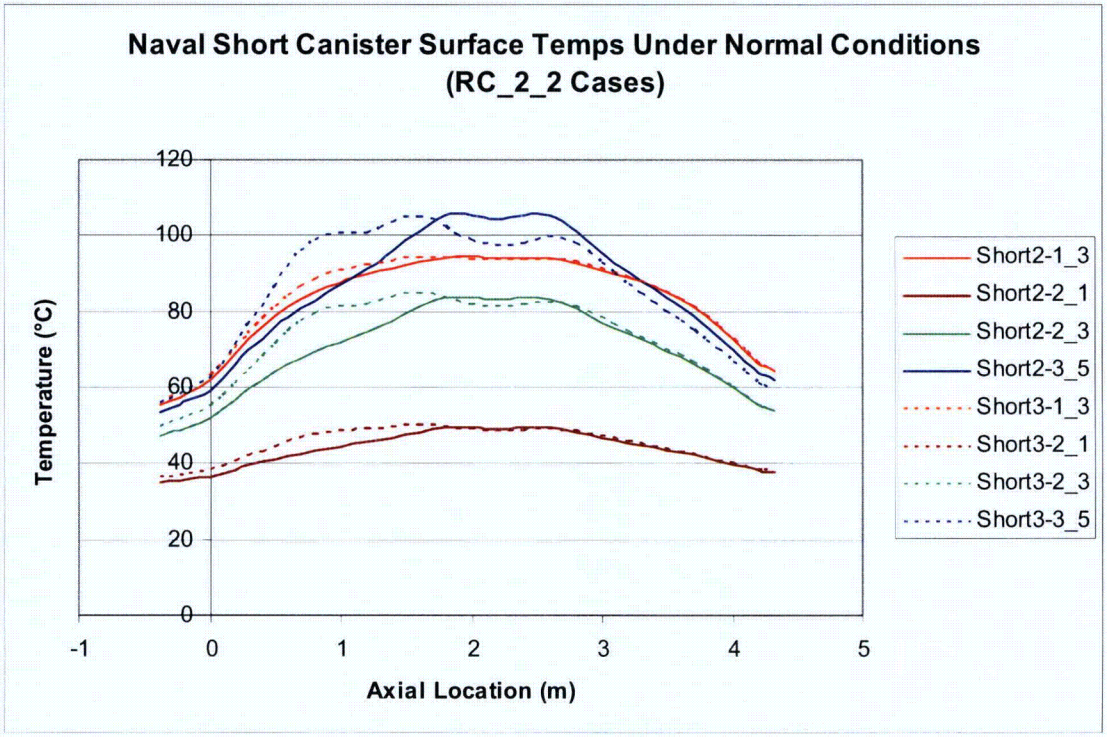


Figure 4. Naval Short SNF Canister Surface Temperature Profiles (°C) – Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Short RC_2_2"

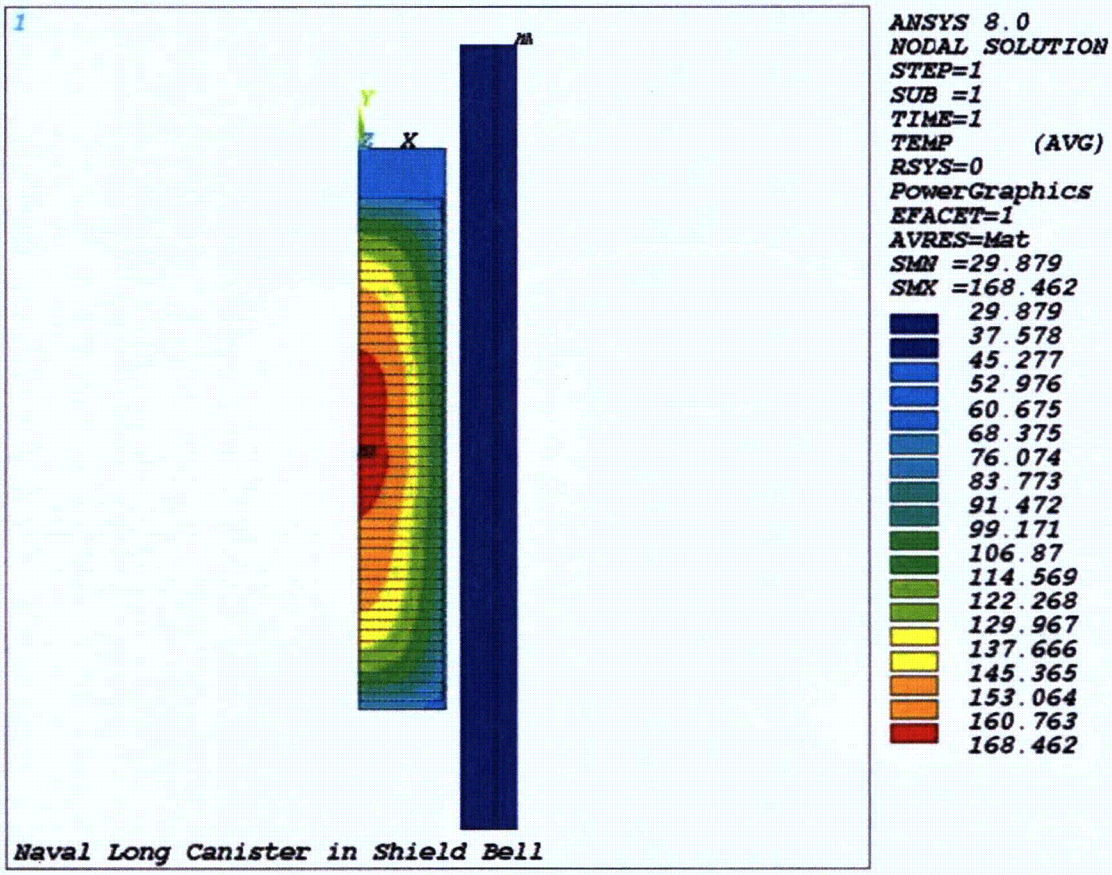


Figure 5. Temperature (°C) Contour of a Naval Long Canister in the Shield Bell – Normal Scenario (Case Long_2-1_3_RC_2_2 – steady state, 2 peaks)

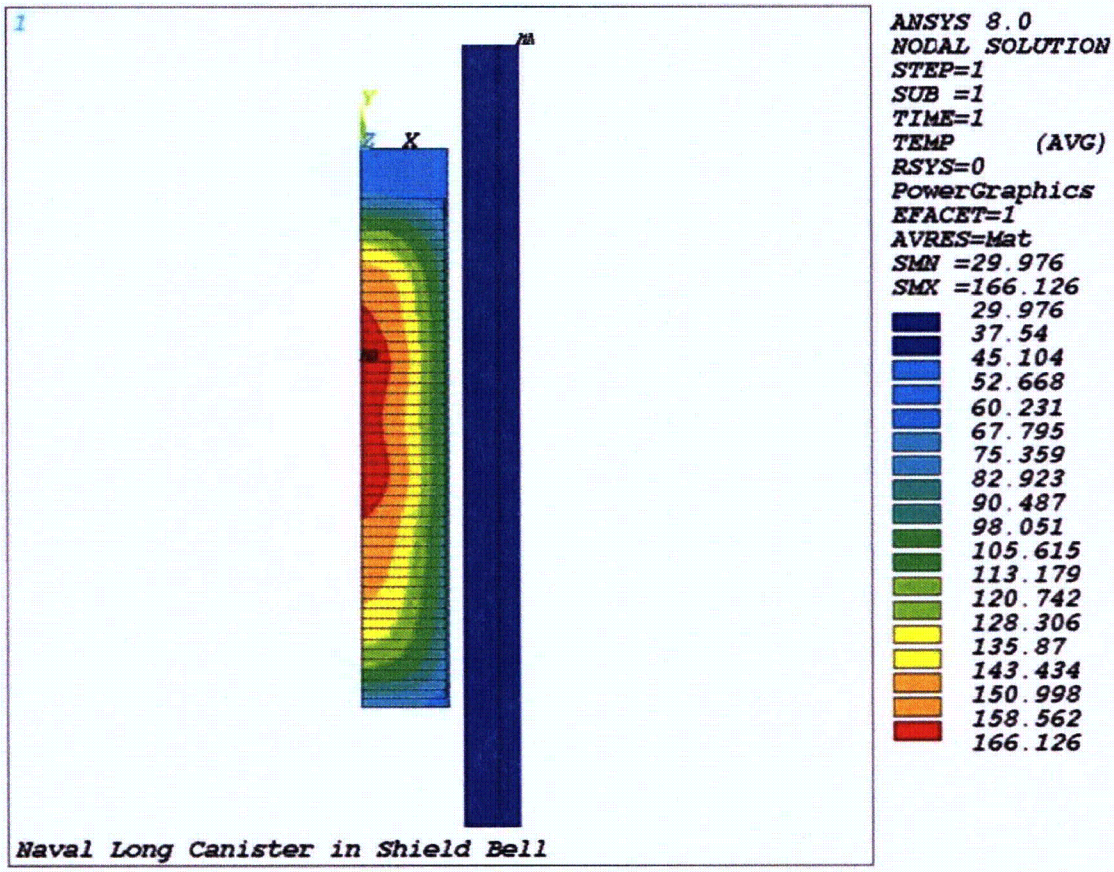


Figure 6. Temperature (°C) Contour of a Naval Long Canister in the Shield Bell – Normal Scenario (Case Long_3-1_3_RC_2_2 – steady state, 3 peaks)

7.2.3 Conclusions and Commentary

In all cases evaluated under normal operating conditions, all thermal criteria are satisfied with significant margin. The peak naval canister surface temperature reached in any of the normal cases was 106.0 °C, falling far below the temperature limit of 400 °F (204.4 °C).

The peak NS-4-FR temperature reached in any of the normal cases was 41.6 °C, falling far below the continuous operating temperature limit of 300 °F (148.9 °C). Note, however, that all results presented assume thermally shunted NS-4-FR shielding material (Assumption 3.1.3). If the shielding material is not as thermally conductive as assumed, the predicted temperatures can be expected to increase.

Significant margin exists in all normal shield bell scenarios.

7.3 MILD OFF-NORMAL SCENARIO RESULTS

7.3.1 Brief Summary

A mild off-normal scenario was modeled in which the the outer surface of the shield bell radiates and convects to an ambient temperature of 116 °F (46.7 °C), the maximum ambient outdoor temperature. Natural convection between the shield bell and the naval canister is modeled with an air temperature of 212 °F (100 °C). The mild off-normal scenario is designed to approximate the thermal response in a minor accident scenario such as a halt in canister transfer operations combined with a loss of HVAC/ventilation in the IHF.

7.3.2 Results

Peak temperature results for the naval long and short canisters under mild off-normal conditions are given in Table 18 and Table 19 respectively.

A graph of the temperatures along the length of the naval long canister surface under mild off-normal conditions (all cases) is presented in Figure 7. A similar graph for the naval short canister surface is presented in Figure 8.

Example temperature contour plots of the naval long canister in the shield bell under normal conditions (Cases Long_2-2_3_RC_4_10 and Long_3-2_3_RC_4_10) are presented in Figure 9 and Figure 10

Table 18. Peak Temperatures of Naval Long Canister in Mild Off-Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Long2-1_3	46.7	100	207.9	140.9	82.9	82.4	76.8
Long2-2_1	46.7	100	118.4	97.6	69.9	69.6	66.2
Long2-2_3	46.7	100	192.0	132.8	79.8	79.3	74.2
Long2-3_5	46.7	100	228.5	150.8	84.9	84.3	78.2
Long3-1_3	46.7	100	205.9	139.7	82.6	82.1	76.6
Long3-2_1	46.7	100	119.1	98.0	70.1	69.7	66.3
Long3-2_3	46.7	100	193.1	133.3	80.1	79.6	74.5
Long3-3_5	46.7	100	226.0	149.6	84.4	83.8	77.8

Table 19. Peak Temperatures of Naval Short Canister in Mild Off-Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Short2-1_3	46.7	100	201.5	141.9	83.1	82.6	76.9
Short2-2_1	46.7	100	115.6	97.2	69.8	69.4	66.0
Short2-2_3	46.7	100	181.9	132.0	79.4	78.9	73.8
Short2-3_5	46.7	100	224.2	152.4	85.7	85.0	78.8
Short3-1_3	46.7	100	201.4	141.9	83.2	82.7	77.0
Short3-2_1	46.7	100	116.5	97.8	69.9	69.6	66.2
Short3-2_3	46.7	100	183.6	132.9	79.8	79.3	74.2
Short3-3_5	46.7	100	222.5	151.6	85.3	84.7	78.6

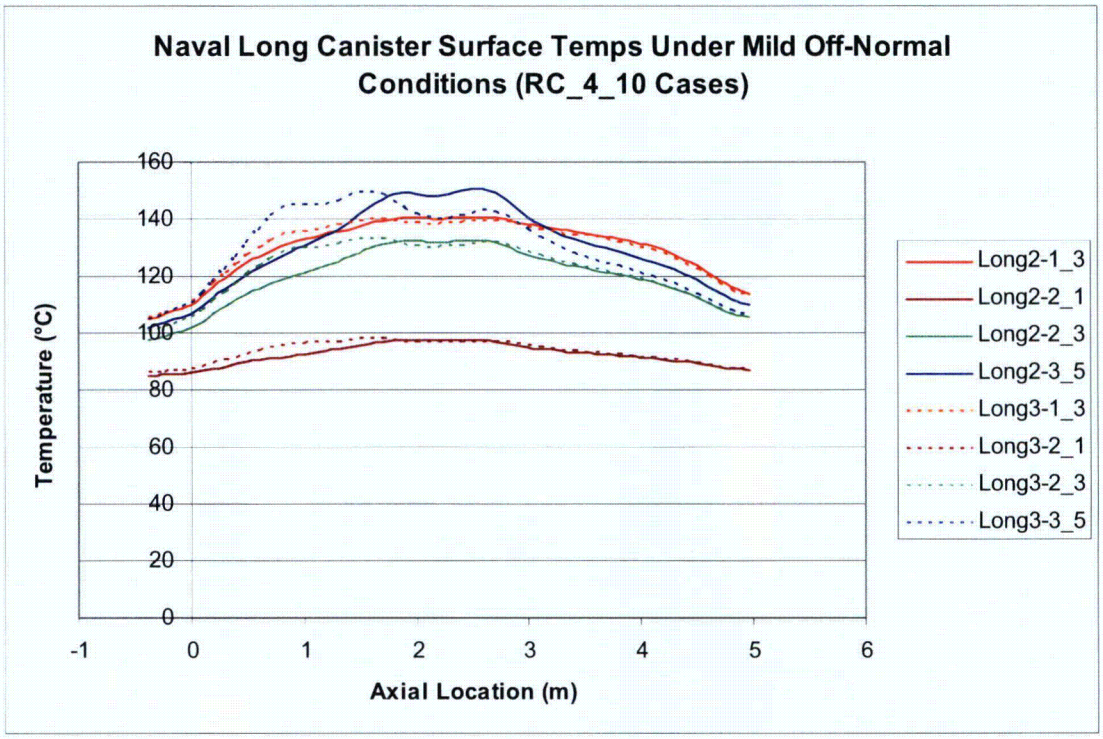


Figure 7. Naval Long SNF Canister Surface Temperature Profiles (°C) – Mild Off-Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Long RC_4_10"

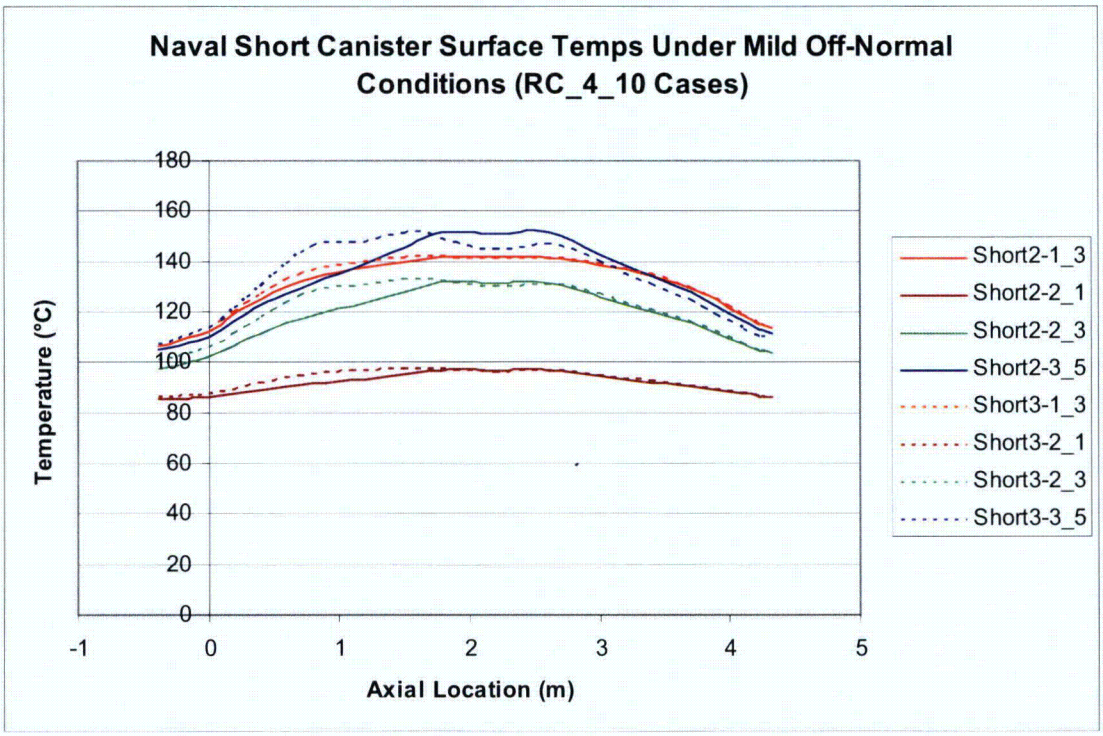


Figure 8. Naval Short SNF Canister Surface Temperature Profiles (°C) – Mild Off-Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Short RC_4_10"

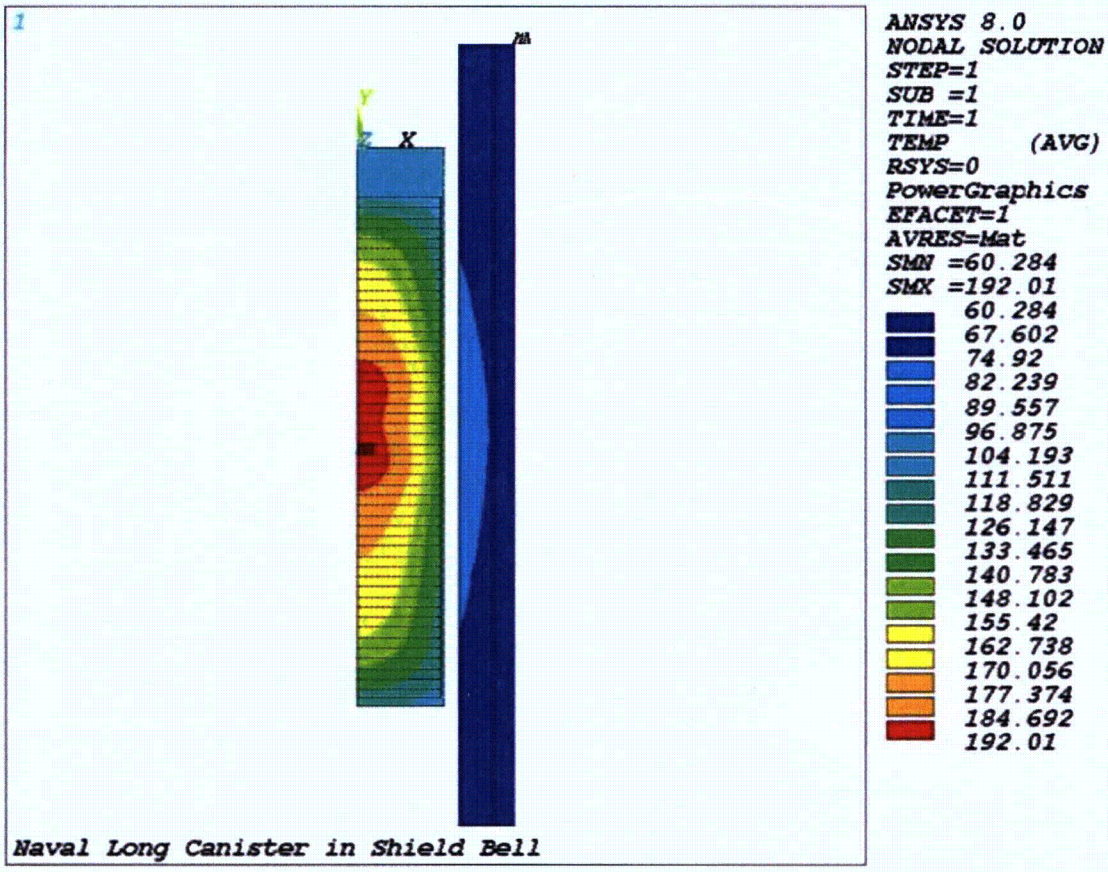


Figure 9. Temperature (°C) Contour of a Naval Long Canister in the Shield Bell – Mild Off-Normal (Case Long_2-2_3_RC_4_10 – steady state, 2 peaks)

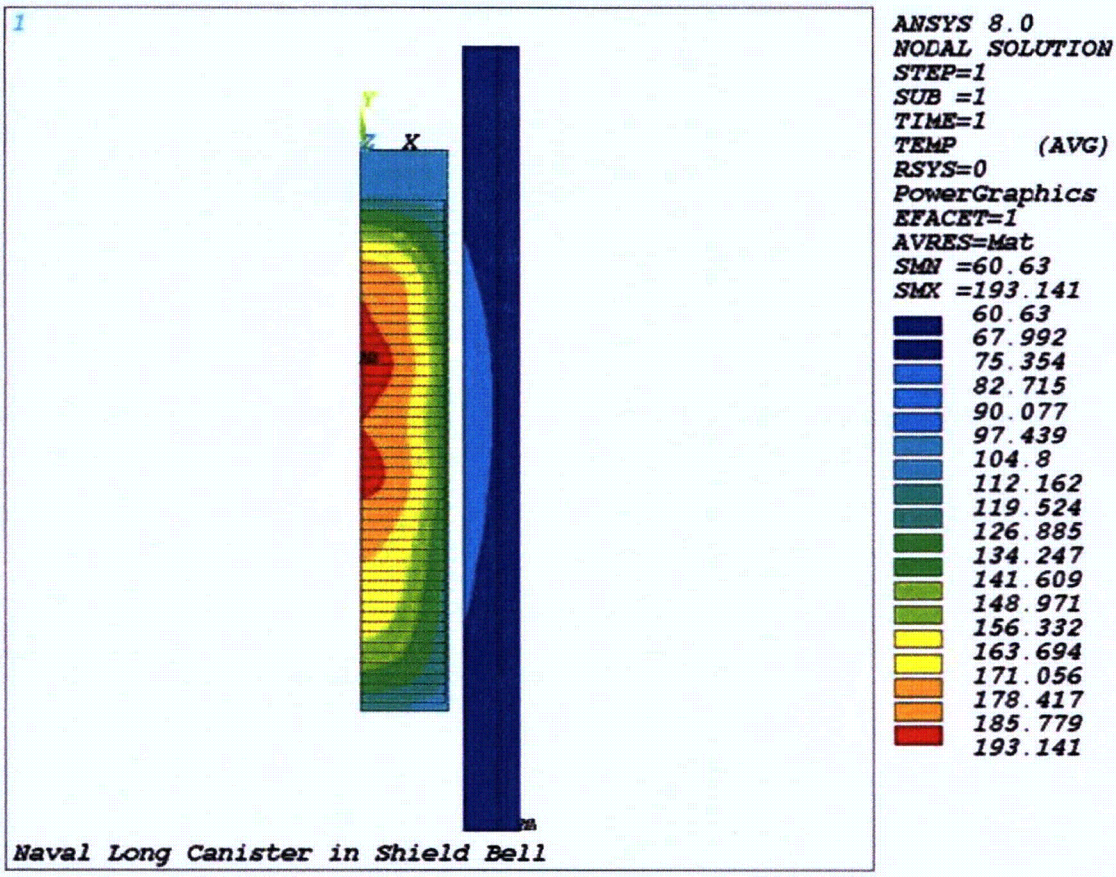


Figure 10. Temperature (°C) Contour of a Naval Long Canister in the Shield Bell – Mild Off-Normal (Case Long_3-2_3_RC_4_10 – steady state, 3 peaks)

7.3.3 Conclusions and Commentary

In all cases evaluated under mild off-normal conditions, all thermal criteria are satisfied with significant margin. The peak naval canister surface temperature reached in any of the mild off-normal cases was 152.4 °C, falling far below the temperature limit of 400 °F (204.4 °C).

The peak NS-4-FR temperature reached in any of the normal cases was 78.8 °C, falling far below the continuous operating temperature limit of 300 °F (148.9 °C). Note, however, that all results presented assume thermally shunted NS-4-FR shielding material (Assumption 3.1.3). If the shielding material is not as thermally conductive as assumed, the predicted temperatures can be expected to increase.

Significant margin exists in all mild off-normal shield bell scenarios.

7.4 EXTREME OFF-NORMAL SCENARIO RESULTS

7.4.1 Brief Summary

An extreme off-normal scenario was modeled in which the the outer surface of the shield bell radiates and convects to an ambient temperature of 212 °F (100 °C), the assumed bounding ambient temperature (Assumption 3.2.6). No convective heat transfer effects are modeled between the shield bell and the naval canister. The extreme off-normal scenario is designed to serve as an overly conservative, bounding case to demonstrate the tremendous degree of margin present in other scenario results.

7.4.2 Results

Peak temperature results for the naval long and short canisters under extreme off-normal conditions are given in Table 20 and Table 21 respectively.

A graph of the temperatures along the length of the naval long canister surface under extreme off-normal conditions (all cases) is presented in Figure 11. A similar graph for the naval short canister surface is presented in Figure 12.

Example temperature contour plots of the naval short canister in the shield bell under normal conditions (Cases Short_2-3_5_RC_10_N and Short_3-3_5_RC_10_N) are presented in Figure 13 and Figure 14

Table 20. Peak Temperatures of Naval Long Canister in Extreme Off-Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Long2-1_3	100	N/A	247.9	190.4	135.3	134.7	128.4
Long2-2_1	100	N/A	152.0	129.8	109.7	109.6	107.9
Long2-2_3	100	N/A	227.7	177.7	128.6	128.1	123.0
Long2-3_5	100	N/A	270.2	202.0	138.8	138.0	130.9
Long3-1_3	100	N/A	244.9	188.8	134.9	134.3	128.2
Long3-2_1	100	N/A	152.8	130.3	110.0	109.9	108.2
Long3-2_3	100	N/A	229.0	178.5	129.3	128.8	123.7
Long3-3_5	100	N/A	267.2	200.3	137.8	137.1	130.3

Table 21. Peak Temperatures of Naval Short Canister in Extreme Off-Normal Scenario

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
Short2-1_3	100	N/A	244.3	191.7	135.6	135.0	128.6
Short2-2_1	100	N/A	145.5	129.0	109.4	109.2	107.6
Short2-2_3	100	N/A	220.2	175.9	127.5	127.0	122.1
Short2-3_5	100	N/A	267.9	204.7	140.2	139.4	132.0
Short3-1_3	100	N/A	244.3	191.7	135.9	135.2	128.8
Short3-2_1	100	N/A	146.8	129.8	109.8	109.6	108.0
Short3-2_3	100	N/A	222.6	177.6	128.5	128.0	123.0
Short3-3_5	100	N/A	266.3	204.1	139.9	139.1	131.9

Note: Grey highlighting indicates exceedance of a thermal limit.

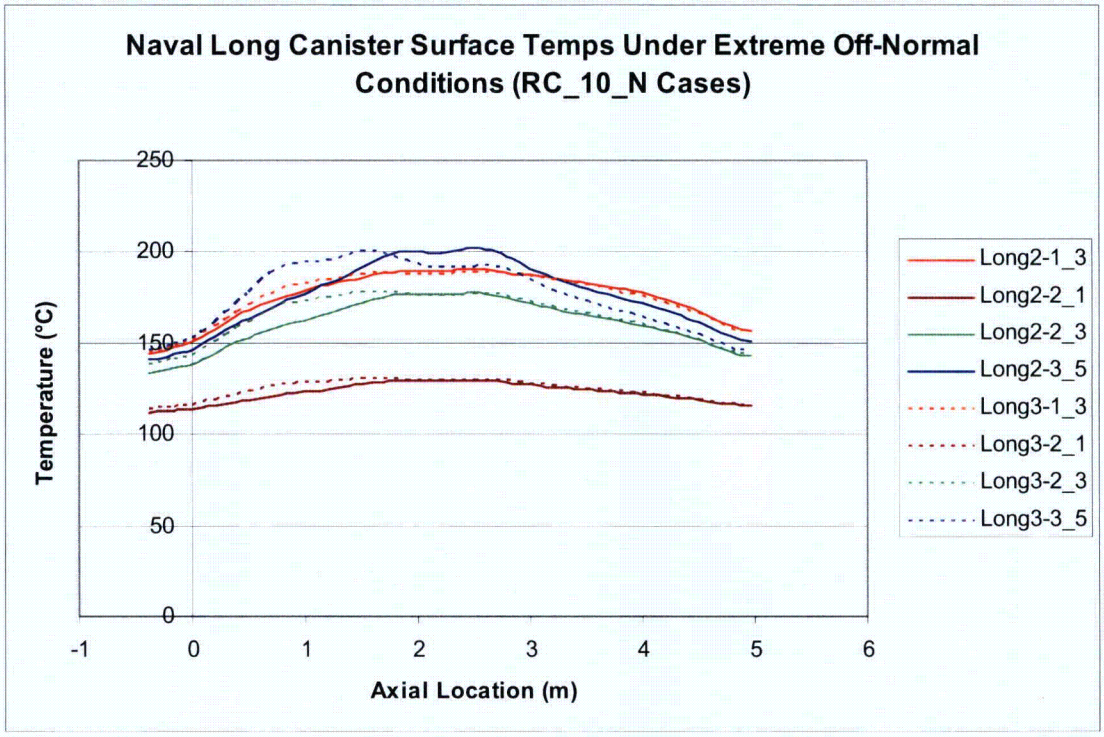


Figure 11. Naval Long SNF Canister Surface Temperature Profiles (°C) - Extreme Off-Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Long RC_10_N"

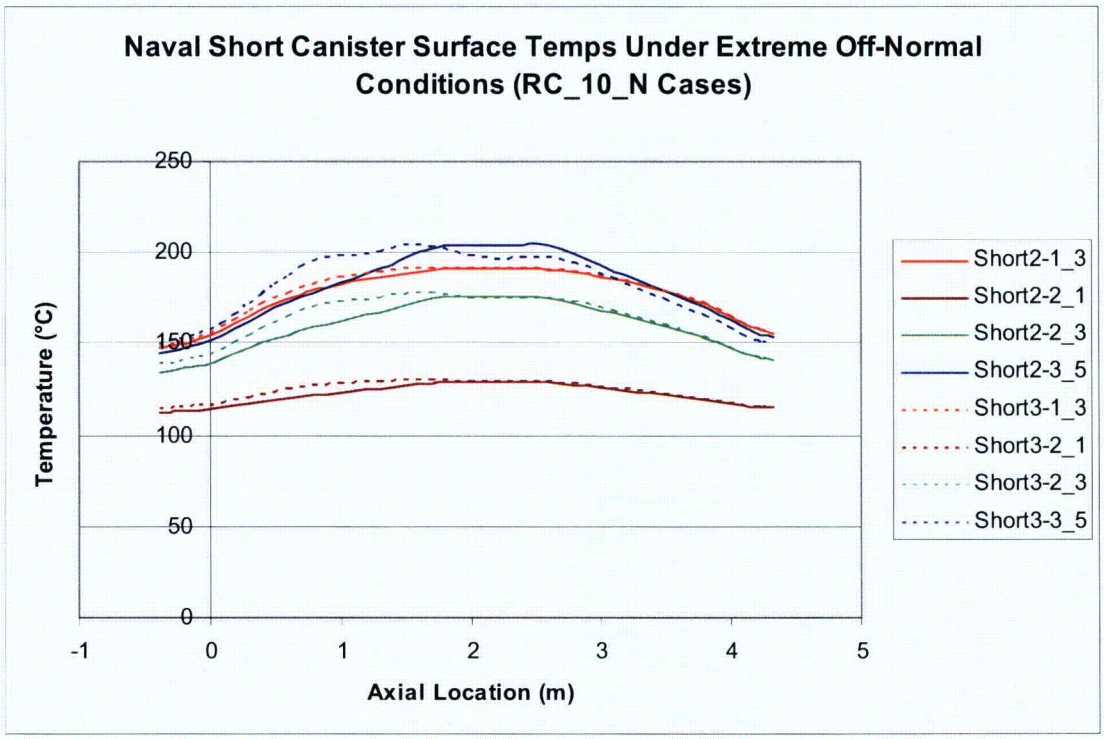


Figure 12. Naval Short SNF Canister Surface Temperature Profiles (°C) - Extreme Off-Normal Conditions
Source: Attachment V, file: *AxialSurfProfiles.xls*, tab: "Short RC_10_N"

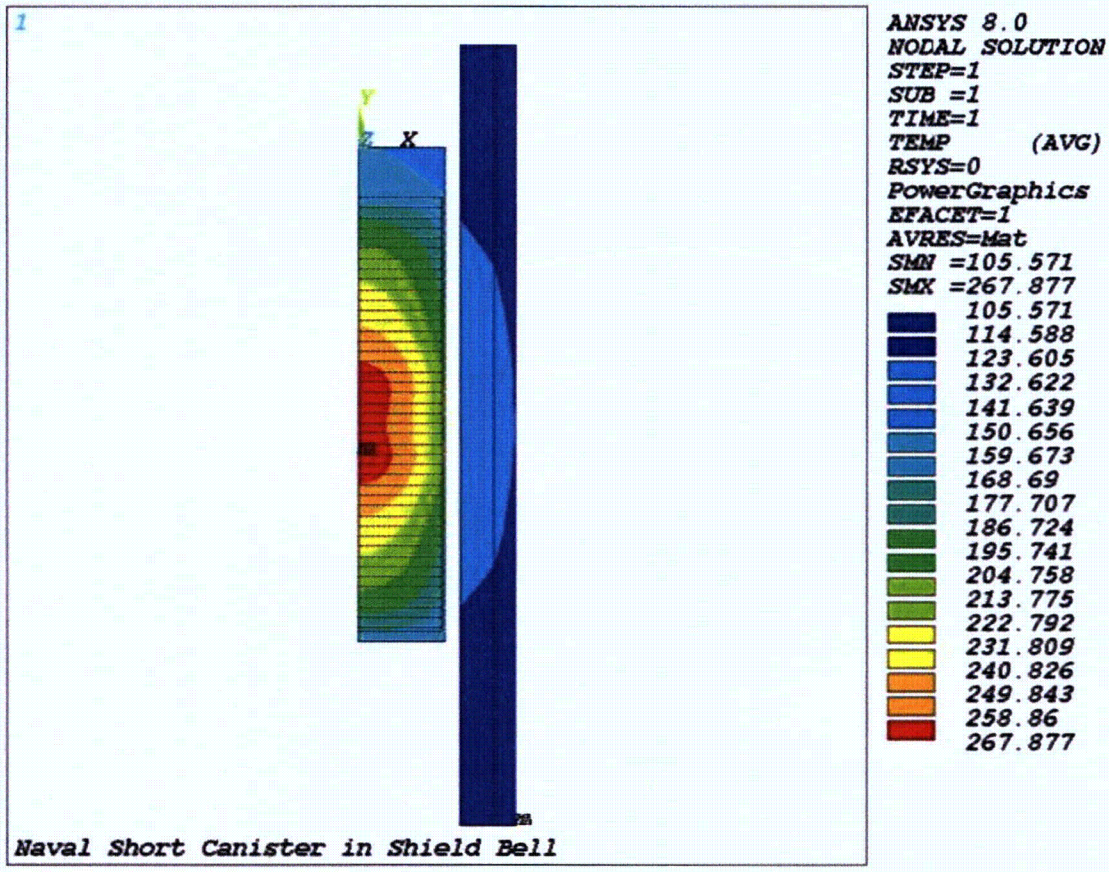


Figure 13. Temperature (°C) Contour of a Naval Short Canister in the Shield Bell – Extreme Off-Normal (Case Short_2-3_5_RC_10_N – steady state, 2 peaks)

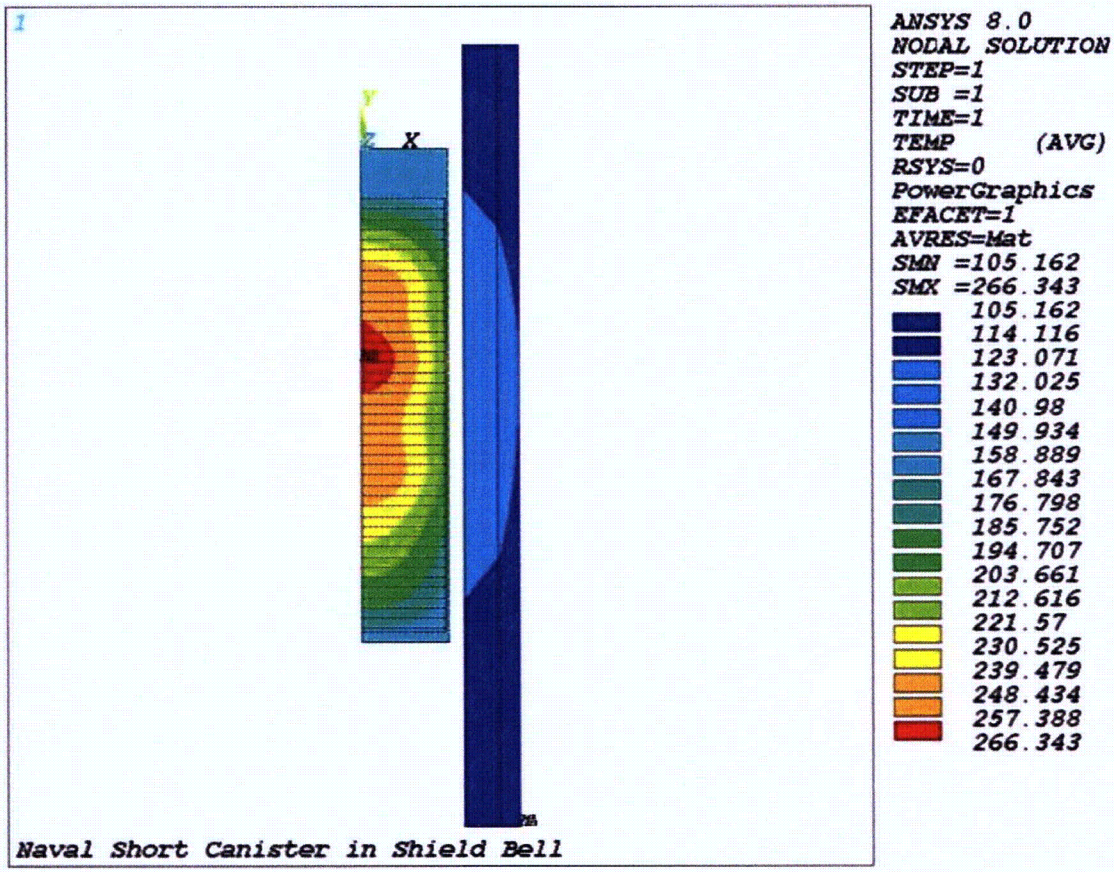


Figure 14. Temperature (°C) Contour of a Naval Short Canister in the Shield Bell – Extreme Off-Normal (Case Short_3-3_5_RC_10_N – steady state, 3 peaks)

7.4.3 Conclusions and Commentary

In all but the most conservative case modeled (Case Short2-3_5_RC_10_N), the naval canister surface remains below its 400°F (204.4°C) temperature limit. By reducing the level of conservatism and including the effects of natural convection on the shield bell outer surface (Case RC_10_NX - see Attachment I, "Pass Case" subsection), even the maximum temperature case satisfies the thermal limit.

The peak NS-4-FR temperature reached in any of the extreme off-normal cases was 132.0 °C, falling far below the continuous operating temperature limit of 300 °F (148.9 °C). Note, however, that all results presented assume thermally shunted NS-4-FR shielding material (Assumption 3.1.3). If the shielding material is not as thermally conductive as assumed, the predicted temperatures can be expected to increase.

7.5 FINAL SUMMARY

Margin exists in all but the most overly conservative shield bell scenarios. For any realistic normal or off-normal conditions, all temperature limits are satisfied.

ATTACHMENT I

SENSITIVITY STUDIES

Because the canister transfer machine design has not been finalized (Assumptions 3.1.1 and 3.1.2), it is still possible that the final shield bell design will be different from that modeled in the main body of this calculation. In this attachment, the thermal impacts of several possible design/scenario modifications are investigated.

Sensitivities investigated include: shield bell diameter, stainless steel emissivity, NS-4-FR removal, extreme off-normal with convection, and a verification case using an alternate radation method.

All sensitivity studies are performed on the naval short canister with heat generation profile case Short2-3_5.

Shield Bell Diameter

Additional normal, mild off-normal, and extreme off-normal cases were run with an enlarged shield bell diameter. All shield bell diameters were increased by a value of 20 inches; all layer thicknesses remained the same as before, as listed in Table 3. All other input parameters remained unchanged.

The increase in the gap between the naval canister and the shield bell inner surface is expected to increase the surface area participating in radiation, and thus lower overall temperatures.

Files for the shield bell diameter sensitivity study are in Attachment V, folder: *\ANSYS\ SensitivityStudies\ BellDiam* .

The results of the shield bell diameter sensitivity study are given in Table 22.

Table 22. Peak Temperatures of Naval Short Canister in Shield Bell Diameter Sensitivity Study

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
RC_2_2B	26.1	26.1	184.1 (-1.6)	103.8 (-2.2)	41.8 (-3.0)	41.5 (-2.9)	39.3 (-2.3)
RC_4_10B	46.7	100	221.7 (-2.4)	149.2 (-3.2)	81.9 (-3.7)	81.4 (-3.6)	76.0 (-2.8)
RC_10_NB	100	N/A	261.4 (-6.5)	196.7 (-8.0)	132.3 (-7.9)	131.7 (-7.7)	126.1 (-5.9)

Note: Values in parentheses indicate the change from the original values due to sensitivity scenario modification.

Increasing the shield bell diameter by 20 inches appears to drop peak naval canister surface temperatures between 2 and 8 °C, with the difference being more pronounced at higher temperatures. The bounding extreme off-normal case which previously exceeded thermal limits is shown to pass with this scenario modification.

SS Emissivity

Additional normal, mild off-normal, and extreme off-normal cases were run with an increased emissivity for stainless steel bodies not including the naval canister surface (i.e., all shield bell surfaces). The emissivity of stainless steel was increased from 0.62 to 0.9. All other input parameters remained unchanged.

The increased emissivity is expected to increase heat transfer from the naval canister to the shield bell, and from the shield bell to the ambient, resulting in lower overall temperatures. Calculations of the alternate effective heat transfer coefficients can be seen in Attachment V, folder: *\Supplemental_Files\ navyCTM_h_calc.xls* , tab: "0.9emis (sensitivity)".

Files for the emissivity sensitivity study are in Attachment V, folder: *\ANSYS\ SensitivityStudies\ Emissivity* .

The results of the emissivity sensitivity study are given in Table 23.

Table 23. Peak Temperatures of Naval Short Canister in SS Emissivity Sensitivity Study

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
RC_2_2E	26.1	26.1	182.1 (-3.6)	101.3 (-4.6)	45.1 (0.4)	44.8 (0.3)	41.5 (-0.1)
RC_4_10E	46.7	100	218.5 (-5.7)	145.5 (-6.9)	84.6 (-1.0)	83.9 (-1.1)	77.0 (-1.8)
RC_10_NE	100	N/A	257.2 (-10.6)	192.2 (-12.5)	136.4 (-3.8)	135.6 (-3.8)	128.0 (-4.0)

Note: Values in parentheses indicate the change from the original values due to sensitivity scenario modification.

Increasing the emissivity of shield bell surfaces to 0.9 appears to drop peak naval canister surface temperatures between 4 and 13 °C, with the difference being more pronounced at higher temperatures. The bounding extreme off-normal case which previously exceeded thermal limits is shown to pass with this scenario modification.

No Poly (NS-4-FR removal)

Additional normal, mild off-normal, and extreme off-normal cases were run with scenario modifications to simulate the removal of the NS-4-FR neutron shielding layer of the shield bell. This is accomplished by increasing the thermal conductivity of NS-4-FR from 6.5 to 1000 W/m-K. All other input parameters remained unchanged.

Because NS-4-FR typically acts as a thermal insulator, the dramatically increased thermal conductivity is expected to lower overall temperatures in the same manner as removal of this shielding layer.

Files for the no poly sensitivity study are in Attachment V, folder: *\ANSYS\ SensitivityStudies\ NoPoly* .

The results of the NS-4-FR removal sensitivity study are given in Table 24.

Table 24. Peak Temperatures of Naval Short Canister in NS-4-FR Removal Sensitivity Study

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR*
RC_2_2K	26.1	26.1	184.7 (-1.1)	104.6 (-1.4)	38.9 (-5.8)	38.6 (-5.9)	35.0 (-6.6)
RC_4_10K	46.7	100	221.7 (-2.5)	149.3 (-3.1)	76.0 (-9.7)	75.3 (-9.8)	67.8 (-10.9)
RC_10_NK	100	N/A	260.8 (-7.1)	196.1 (-8.6)	124.7 (-15.5)	123.9 (-15.5)	115.7 (-16.3)

Note: Values in parentheses indicate the change from the original values due to sensitivity scenario modification.
*The layer listed as "Shield Bell NS-4-FR" is viewed as an extension of the shield bell steel.

Removing the NS-4-FR shielding layer from the shield bell appears to drop peak naval canister surface temperatures between 1 and 9 °C, with the difference being more pronounced at higher temperatures. The bounding extreme off-normal case which previously exceeded thermal limits is shown to pass with this scenario modification.

Pass Case

Because the extreme off-normal case of Short2-3_5 exceeded the naval canister surface thermal limit, a slightly modified case with some conservatism removed was evaluated to ensure expected compliance with thermal limits.

Natural convection effects have been introduced between the naval canister and the shield bell inner surface. The natural convection is to an air temperature of 302 °F (150 °C), an approximate average of the ambient temperature, 212 °F (100 °C), and the naval canister surface temperature. All other input parameters remained unchanged. Calculations of the alternate effective heat transfer coefficients can be seen in Attachment V, folder: *\Supplemental_Files\ navyCTM_h_calc.xls* , tab: "0.62emis (default)".

Files for the pass case sensitivity study are in Attachment V, folder: *\ANSYS\ SensitivityStudies\ PassCase* .

The results of the pass case are given in Table 25.

Table 25. Peak Temperatures of Naval Short Canister in Modified Extreme Off-Normal (Pass Case)

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
RC_10_NX	100	150	257.5 (-10.3)	191.4 (-13.3)	136.7 (-3.4)	136.1 (-3.3)	129.5 (-2.5)

Note: Values in parentheses indicate the change from the original values due to sensitivity scenario modification.

Introducing convective effects (to an air temperature of 150 °C) between the naval canister and shield bell dropped the peak naval canister surface temperature 13.3 °C. This modified extreme off-normal case is shown to meet all thermal requirements.

Space Node Radiation Method

In order to verify the accuracy of the radiation method used in the bulk of this calculation, an alternative radiation method within ANSYS is evaluated. Rather than using an effective heat transfer coefficient to simulate radiation to the ambient, the outer surface of the shield bell is modeled as radiating to a space node at a fixed temperature. Convective effects off the shield bell outer surface are still modeled using an effective heat transfer coefficient. All other input parameters remained unchanged.

If both methods of modeling radiation are viable, results from both should be very close to equal.

Files for the space node verification study are in Attachment V, folder: *\ANSYS\ SensitivityStudies\ SpaceNodeRad* .

The results of the space node radiation cases are given in Table 26.

Table 26. Peak Temperatures of Naval Short Canister in Emissivity Sensitivity Study

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
C_2_2	26.1	26.1	185.8 (-0.008)	106.0 (-0.009)	44.7 (-0.033)	44.4 (-0.033)	41.6 (-0.036)
C_4_10	46.7	100	224.2 (-0.008)	152.4 (-0.018)	85.6 (-0.044)	85.0 (-0.045)	78.7 (-0.049)
C_10_N	100	N/A	267.9 (0.011)	204.7 (0.010)	140.2 (0.025)	139.4 (0.025)	132.0 (0.027)

Note: Values in parentheses indicate the change from the original values due to sensitivity scenario modification.

Results from the "space node method" and the "effective heat transfer coefficient method" were shown to be in very close agreement, with temperature differences between the two methods on the order of 0.01 °C. Therefore both radiation methods are shown to adequately model radiation and to be suitable for use in further work.

ATTACHMENT II

SCOPING CASES

Prior to deciding which boundary condition cases would comprise the "primary cases" presented in the main body of this report, several additional scoping cases were performed to determine the approximate thermal response. Those cases are presented herein. All scoping cases are performed on the naval short canister with heat generation profile case Short2-3_5.

Table 27 lists the scoping cases evaluated (cases selected as "primary cases" are bolded). The results of these cases are presented in Table 28.

All files for the scoping cases can be found in Attachment V, folder: *\ANSYS\ScopingCases* .

Table 27. Scoping Case Listing

Case Number	Outer Boundary Condition	Ambient Temp (°C)	Tube Conv Present?	Tube Conv Temp (°C)
RC_2_2	**Rad + Conv**	**26.1**	**Yes**	**26.1**
RC_2_4	Rad + Conv	26.1	Yes	46.7
RC_2_10	Rad + Conv	26.1	Yes	100
RC_2_N	Rad + Conv	26.1	No	N/A
RC_4_4	Rad + Conv	46.7	Yes	46.7
RC_4_10	**Rad + Conv**	**46.7**	**Yes**	**100**
RC_4_N	Rad + Conv	46.7	No	N/A
RC_10_10	Rad + Conv	100	Yes	100
RC_10_N	**Rad + Conv**	**100**	**No**	**N/A**

Note: All scoping cases performed on heat generation profile case "Short2-3_5" (Cases chosen as primary cases are bolded and discussed further in the main body of the calculation.)

Table 28. Peak Temperatures of Scoping Cases

Case Number	Ambient Temp (°C)	Tube Conv Temp (°C)	Maximum Temperature (°C)				
			Navy Can Core	Navy Can Surface	Guide Sleeve	Shield Bell Steel	Shield Bell NS-4-FR
RC_2_2	**26.1**	**26.1**	185.8	106.0	44.7	44.4	41.6
RC_2_4	26.1	46.7	195.8	118.3	52.9	52.5	48.3
RC_2_10	26.1	100	220.5	148.2	73.6	72.9	65.5
RC_2_N	26.1	(none)	234.6	166.8	74.7	73.9	66.0
RC_4_4	46.7	46.7	199.3	122.6	65.8	65.5	62.5
RC_4_10	**46.7**	**100**	224.2	152.4	85.7	85.0	78.8
RC_4_N	46.7	(none)	242.8	176.3	92.8	92.0	84.2
RC_10_10	100	100	236.0	166.4	119.7	119.4	115.8
RC_10_N	**100**	**(none)**	267.9	204.7	140.2	139.4	132.0

Note: All scoping cases performed on heat generation profile case "Short2-3_5" (Cases chosen as primary cases are bolded and discussed further in the main body of the calculation.)
-Grey highlighting indicates exceedance of a thermal limit.

ATTACHMENT III

NAVAL CANISTER HEAT GENERATION PROFILES

The heat generation data shown in Table 29 through Table 32 were derived from the linear decay heat loads given in Table 1 and Table 2 of Reference 2.2.22.

The linear decay heat (kW/m) from each 0.1-meter segment of the naval SNF canisters was used to calculate the total heat for each segment (kW). If the total heat of the naval SNF canister is greater than 11.8 kW, the total heat is scaled down to 11.8, while holding the peaks constant. The volumetric heat generation for each segment of the naval SNF canister (W/m^3) is calculated by dividing the total heat for each segment (W) by the volume of each segment (m^3, calculated by multiplying the length of each segment by the cross-sectional area of the naval canister minus the 1-inch canister wall thickness).

The details of the derivation of the volumetric heat generation rates can be seen in Attachment V, files: *\Supplemental_Files\ naval_long_canister_heat_gen.xls* and *\Supplemental_Files\ naval_short_canister_heat_gen.xls*.

Table 29. Represented Naval Long SNF Canister Heat Generation Rates with Two Peaks

SNF Segment Length (m)		Volumetric Heat Generation Rate (W/m^3)			
Begin	End	Case 2.3_5	Case 2.2_3	Case 2.1_3	Case 2.2_1
0.00	0.10	920.5	759.0	1093.4	237.2
0.10	0.20	920.5	759.0	1093.4	237.2
0.20	0.30	920.5	759.0	1093.4	237.2
0.30	0.40	920.5	759.0	1093.4	237.2
0.40	0.50	920.5	759.0	1093.4	237.2
0.50	0.60	920.5	759.0	1093.4	237.2
0.60	0.70	920.5	759.0	1093.4	237.2
0.70	0.80	920.5	759.0	1093.4	237.2
0.80	0.90	920.5	759.0	1093.4	237.2
0.90	1.00	920.5	759.0	1093.4	237.2
1.00	1.10	920.5	759.0	1093.4	237.2
1.10	1.20	920.5	759.0	1093.4	237.2
1.20	1.30	920.5	759.0	1093.4	237.2
1.30	1.40	920.5	759.0	1093.4	237.2
1.40	1.50	920.5	759.0	1093.4	237.2
1.50	1.60	1338.9	759.0	1093.4	237.2
1.60	1.70	1673.6	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4
1.80	1.90	2371.9	1423.1	1423.1	474.4
1.90	2.00	1673.6	1423.1	1423.1	474.4

2.00	2.10	1338.9	759.0	1093.4	237.2
2.10	2.20	920.5	759.0	1093.4	237.2
2.20	2.30	920.5	759.0	1093.4	237.2
2.30	2.40	920.5	759.0	1093.4	237.2
2.40	2.50	2371.9	1423.1	1423.1	474.4
2.50	2.60	2371.9	1423.1	1423.1	474.4
2.60	2.70	2371.9	1423.1	1423.1	474.4
2.70	2.80	2371.9	1423.1	1423.1	474.4
2.80	2.90	920.5	759.0	1093.4	237.2
2.90	3.00	920.5	759.0	1093.4	237.2
3.00	3.10	920.5	759.0	1093.4	237.2
3.10	3.20	920.5	759.0	1093.4	237.2
3.20	3.30	920.5	759.0	1093.4	237.2
3.30	3.40	920.5	759.0	1093.4	237.2
3.40	3.50	920.5	759.0	1093.4	237.2
3.50	3.60	920.5	759.0	1093.4	237.2
3.60	3.70	920.5	759.0	1093.4	237.2
3.70	3.80	920.5	759.0	1093.4	237.2
3.80	3.90	920.5	759.0	1093.4	237.2
3.90	4.00	920.5	759.0	1093.4	237.2
4.00	4.10	920.5	759.0	1093.4	237.2
4.10	4.20	920.5	759.0	1093.4	237.2
4.20	4.30	920.5	759.0	1093.4	237.2
4.30	4.40	920.5	759.0	1093.4	237.2
4.40	4.50	920.5	759.0	1093.4	237.2
4.50	4.60	920.5	759.0	1093.4	237.2
4.60	4.70	920.5	759.0	1093.4	237.2
4.70	4.80	920.5	759.0	1093.4	237.2
4.80	4.88	920.5	759.0	1093.4	237.2

Table 30. Represented Naval Long SNF Canister Heat Generation Rates with Three Peaks

SNF Segment Length (m)		**Volumetric Heat Generation Rate (W/m^3)**			
Begin	**End**	**Case 3.3_5**	**Case 3.2_3**	**Case 3.1_3**	**Case 3.2_1**
0.00	0.10	780.6	759.0	1056.7	237.2
0.10	0.20	780.6	759.0	1056.7	237.2
0.20	0.30	780.6	759.0	1056.7	237.2
0.30	0.40	780.6	759.0	1056.7	237.2
0.40	0.50	780.6	759.0	1056.7	237.2
0.50	0.60	780.6	759.0	1056.7	237.2
0.60	0.70	2371.9	1423.1	1423.1	474.4
0.70	0.80	2371.9	1423.1	1423.1	474.4

0.80	0.90	2371.9	1423.1	1423.1	474.4
0.90	1.00	2371.9	1423.1	1423.1	474.4
1.00	1.10	780.6	759.0	1056.7	237.2
1.10	1.20	780.6	759.0	1056.7	237.2
1.20	1.30	780.6	759.0	1056.7	237.2
1.30	1.40	780.6	759.0	1056.7	237.2
1.40	1.50	2371.9	1423.1	1423.1	474.4
1.50	1.60	2371.9	1423.1	1423.1	474.4
1.60	1.70	2371.9	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4
1.80	1.90	780.6	759.0	1056.7	237.2
1.90	2.00	780.6	759.0	1056.7	237.2
2.00	2.10	780.6	759.0	1056.7	237.2
2.10	2.20	780.6	759.0	1056.7	237.2
2.20	2.30	780.6	759.0	1056.7	237.2
2.30	2.40	780.6	759.0	1056.7	237.2
2.40	2.50	1135.5	996.2	1056.7	332.1
2.50	2.60	1419.3	1185.9	1423.1	379.5
2.60	2.70	2371.9	1423.1	1423.1	474.4
2.70	2.80	2371.9	1423.1	1423.1	474.4
2.80	2.90	1419.3	1185.9	1423.1	379.5
2.90	3.00	1135.5	996.2	1056.7	332.1
3.00	3.10	780.6	759.0	1056.7	237.2
3.10	3.20	780.6	759.0	1056.7	237.2
3.20	3.30	780.6	759.0	1056.7	237.2
3.30	3.40	780.6	759.0	1056.7	237.2
3.40	3.50	780.6	759.0	1056.7	237.2
3.50	3.60	780.6	759.0	1056.7	237.2
3.60	3.70	780.6	759.0	1056.7	237.2
3.70	3.80	780.6	759.0	1056.7	237.2
3.80	3.90	780.6	759.0	1056.7	237.2
3.90	4.00	780.6	759.0	1056.7	237.2
4.00	4.10	780.6	759.0	1056.7	237.2
4.10	4.20	780.6	759.0	1056.7	237.2
4.20	4.30	780.6	759.0	1056.7	237.2
4.30	4.40	780.6	759.0	1056.7	237.2
4.40	4.50	780.6	759.0	1056.7	237.2
4.50	4.60	780.6	759.0	1056.7	237.2
4.60	4.70	780.6	759.0	1056.7	237.2
4.70	4.80	780.6	759.0	1056.7	237.2
4.80	4.88	780.6	759.0	1056.7	237.2

Table 31. Represented Naval Short SNF Canister Heat Generation Rates with Two Peaks

SNF Segment Length (m)		Volumetric Heat Generation Rate (W/m^3)			
Begin	End	Case 2.3_5	Case 2.2_3	Case 2.1_3	Case 2.2_1
0.00	0.10	1043.6	759.0	1185.9	237.2
0.10	0.20	1043.6	759.0	1185.9	237.2
0.20	0.30	1043.6	759.0	1185.9	237.2
0.30	0.40	1043.6	759.0	1185.9	237.2
0.40	0.50	1043.6	759.0	1185.9	237.2
0.50	0.60	1043.6	759.0	1185.9	237.2
0.60	0.70	1043.6	759.0	1185.9	237.2
0.70	0.80	1043.6	759.0	1185.9	237.2
0.80	0.90	1043.6	759.0	1185.9	237.2
0.90	1.00	1043.6	759.0	1185.9	237.2
1.00	1.10	1043.6	759.0	1185.9	237.2
1.10	1.20	1043.6	759.0	1185.9	237.2
1.20	1.30	1043.6	759.0	1185.9	237.2
1.30	1.40	1043.6	759.0	1185.9	237.2
1.40	1.50	1043.6	759.0	1185.9	237.2
1.50	1.60	1518.0	759.0	1185.9	237.2
1.60	1.70	1897.5	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4
1.80	1.90	2371.9	1423.1	1423.1	474.4
1.90	2.00	1897.5	1423.1	1423.1	474.4
2.00	2.10	1518.0	759.0	1185.9	237.2
2.10	2.20	1043.6	759.0	1185.9	237.2
2.20	2.30	1043.6	759.0	1185.9	237.2
2.30	2.40	1043.6	759.0	1185.9	237.2
2.40	2.50	2371.9	1423.1	1423.1	474.4
2.50	2.60	2371.9	1423.1	1423.1	474.4
2.60	2.70	2371.9	1423.1	1423.1	474.4
2.70	2.80	2371.9	1423.1	1423.1	474.4
2.80	2.90	1043.6	759.0	1185.9	237.2
2.90	3.00	1043.6	759.0	1185.9	237.2
3.00	3.10	1043.6	759.0	1185.9	237.2
3.10	3.20	1043.6	759.0	1185.9	237.2
3.20	3.30	1043.6	759.0	1185.9	237.2
3.30	3.40	1043.6	759.0	1185.9	237.2
3.40	3.50	1043.6	759.0	1185.9	237.2
3.50	3.60	1043.6	759.0	1185.9	237.2
3.60	3.70	1043.6	759.0	1185.9	237.2
3.70	3.80	1043.6	759.0	1185.9	237.2

3.80	3.90	1043.6	759.0	1185.9	237.2
3.90	4.00	1043.6	759.0	1185.9	237.2
4.00	4.10	1043.6	759.0	1185.9	237.2
4.10	4.20	1043.6	759.0	1185.9	237.2
4.20	4.24	1043.6	759.0	1185.9	237.2

Table 32. Represented Naval Short SNF Canister Heat Generation Rates with Three Peaks

SNF Segment Length (m)		Volumetric Heat Generation Rate (W/m^3)			
Begin	**End**	**Case 3.3_5**	**Case 3.2_3**	**Case 3.1_3**	**Case 3.2_1**
0.00	0.10	923.6	759.0	1185.9	237.2
0.10	0.20	923.6	759.0	1185.9	237.2
0.20	0.30	923.6	759.0	1185.9	237.2
0.30	0.40	923.6	759.0	1185.9	237.2
0.40	0.50	923.6	759.0	1185.9	237.2
0.50	0.60	923.6	759.0	1185.9	237.2
0.60	0.70	2371.9	1423.1	1423.1	474.4
0.70	0.80	2371.9	1423.1	1423.1	474.4
0.80	0.90	2371.9	1423.1	1423.1	474.4
0.90	1.00	2371.9	1423.1	1423.1	474.4
1.00	1.10	923.6	759.0	1185.9	237.2
1.10	1.20	923.6	759.0	1185.9	237.2
1.20	1.30	923.6	759.0	1185.9	237.2
1.30	1.40	923.6	759.0	1185.9	237.2
1.40	1.50	2371.9	1423.1	1423.1	474.4
1.50	1.60	2371.9	1423.1	1423.1	474.4
1.60	1.70	2371.9	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4
1.80	1.90	923.6	759.0	1185.9	237.2
1.90	2.00	923.6	759.0	1185.9	237.2
2.00	2.10	923.6	759.0	1185.9	237.2
2.10	2.20	923.6	759.0	1185.9	237.2
2.20	2.30	923.6	759.0	1185.9	237.2
2.30	2.40	923.6	759.0	1185.9	237.2
2.40	2.50	1343.4	996.2	1185.9	332.1
2.50	2.60	1679.3	1185.9	1423.1	379.5
2.60	2.70	2371.9	1423.1	1423.1	474.4
2.70	2.80	2371.9	1423.1	1423.1	474.4
2.80	2.90	1679.3	1185.9	1423.1	379.5
2.90	3.00	1343.4	996.2	1185.9	332.1
3.00	3.10	923.6	759.0	1185.9	237.2
3.10	3.20	923.6	759.0	1185.9	237.2

3.20	3.30	923.6	759.0	1185.9	237.2
3.30	3.40	923.6	759.0	1185.9	237.2
3.40	3.50	923.6	759.0	1185.9	237.2
3.50	3.60	923.6	759.0	1185.9	237.2
3.60	3.70	923.6	759.0	1185.9	237.2
3.70	3.80	923.6	759.0	1185.9	237.2
3.80	3.90	923.6	759.0	1185.9	237.2
3.90	4.00	923.6	759.0	1185.9	237.2
4.00	4.10	923.6	759.0	1185.9	237.2
4.10	4.20	923.6	759.0	1185.9	237.2
4.20	4.24	923.6	759.0	1185.9	237.2

ATTACHMENT IV

FILE LISTING FOR ATTACHMENT V

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Volume in drive D is CD 1 of 1
 Volume Serial Number is C4C8-9158

 Directory of D:\

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02/18/2009  09:01 AM            22,016 NavyCTMresults.xls
02/19/2009  03:30 PM    <DIR>          Supplemental_Files
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02/18/2009  04:35 PM    <DIR>          RC_2_2
02/18/2009  04:35 PM    <DIR>          RC_4_10
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02/17/2009  03:40 PM             4,607 Long2-2_1_RC_10_N.inp
02/17/2009  05:11 PM           117,884 Long2-2_1_RC_10_N.out
02/09/2009  05:32 PM             1,951 Long2-2_1_RC_10_N.txt
02/17/2009  03:40 PM             4,607 Long2-2_3_RC_10_N.inp
02/17/2009  05:11 PM           117,884 Long2-2_3_RC_10_N.out
02/09/2009  05:32 PM             1,951 Long2-2_3_RC_10_N.txt
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02/17/2009  05:11 PM           118,180 Long2-3_5_RC_10_N.out
02/09/2009  05:32 PM             1,951 Long2-3_5_RC_10_N.txt
02/17/2009  03:40 PM             4,607 Long3-1_3_RC_10_N.inp
02/17/2009  05:11 PM           117,884 Long3-1_3_RC_10_N.out
02/09/2009  05:32 PM             1,951 Long3-1_3_RC_10_N.txt
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02/17/2009  05:11 PM           117,884 Long3-2_1_RC_10_N.out
02/09/2009  05:32 PM             1,951 Long3-2_1_RC_10_N.txt
02/17/2009  03:41 PM             4,607 Long3-2_3_RC_10_N.inp
02/17/2009  05:11 PM           117,884 Long3-2_3_RC_10_N.out
02/09/2009  05:31 PM             1,951 Long3-2_3_RC_10_N.txt
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12/10/2008  10:02 AM             3,383 navy_long_heat_2-2_3.dat
12/10/2008  07:18 AM             3,375 navy_long_heat_2-3_5.dat
12/10/2008  10:50 AM             3,424 navy_long_heat_3-1_3.dat
12/10/2008  10:50 AM             3,375 navy_long_heat_3-2_1.dat
12/10/2008  10:49 AM             3,387 navy_long_heat_3-2_3.dat
12/10/2008  10:48 AM             3,389 navy_long_heat_3-3_5.dat
12/10/2008  10:54 AM             3,138 navy_short_heat_2-1_3.dat
12/10/2008  10:54 AM             3,095 navy_short_heat_2-2_1.dat
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02/18/2009  09:46 AM            1,951 Long3-3_5_RC_2_2.txt
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12/10/2008  10:02 AM            3,383 navy_long_heat_2-2_3.dat
12/10/2008  07:18 AM            3,375 navy_long_heat_2-3_5.dat
12/10/2008  10:50 AM            3,424 navy_long_heat_3-1_3.dat
12/10/2008  10:50 AM            3,375 navy_long_heat_3-2_1.dat
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12/10/2008  10:55 AM            3,109 navy_short_heat_3-3_5.dat
02/17/2009  03:29 PM            4,611 Short2-1_3_RC_2_2.inp
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02/18/2009  09:46 AM            1,813 Short2-1_3_RC_2_2.txt
02/17/2009  03:29 PM            4,611 Short2-2_1_RC_2_2.inp
02/17/2009  05:09 PM          117,969 Short2-2_1_RC_2_2.out
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02/17/2009  03:28 PM            4,611 Short2-2_3_RC_2_2.inp
02/17/2009  05:09 PM          117,969 Short2-2_3_RC_2_2.out
02/18/2009  09:46 AM            1,813 Short2-2_3_RC_2_2.txt
02/17/2009  03:28 PM            4,611 Short2-3_5_RC_2_2.inp
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02/17/2009  05:09 PM          117,969 Short3-1_3_RC_2_2.out
02/18/2009  09:45 AM            1,813 Short3-1_3_RC_2_2.txt
02/17/2009  03:28 PM            4,611 Short3-2_1_RC_2_2.inp
02/17/2009  05:09 PM          117,969 Short3-2_1_RC_2_2.out
02/18/2009  09:45 AM            1,813 Short3-2_1_RC_2_2.txt
02/17/2009  03:28 PM            4,611 Short3-2_3_RC_2_2.inp
02/17/2009  05:09 PM          117,969 Short3-2_3_RC_2_2.out
02/18/2009  09:45 AM            1,813 Short3-2_3_RC_2_2.txt
02/17/2009  03:25 PM            4,611 Short3-3_5_RC_2_2.inp
```

```
02/17/2009  05:09 PM           118,111 Short3-3_5_RC_2_2.out
02/18/2009  09:45 AM             1,813 Short3-3_5_RC_2_2.txt
              67 File(s)      2,099,784 bytes

 Directory of D:\ANSYS\RC_4_10

02/18/2009  04:35 PM    <DIR>          .
02/19/2009  11:09 AM    <DIR>          ..
02/17/2009  03:33 PM             4,609 Long2-1_3_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long2-1_3_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long2-1_3_RC_4_10.txt
02/17/2009  03:34 PM             4,609 Long2-2_1_RC_4_10.inp
02/17/2009  05:10 PM           118,371 Long2-2_1_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long2-2_1_RC_4_10.txt
02/17/2009  03:34 PM             4,609 Long2-2_3_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long2-2_3_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long2-2_3_RC_4_10.txt
02/17/2009  03:34 PM             4,609 Long2-3_5_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long2-3_5_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long2-3_5_RC_4_10.txt
02/17/2009  03:34 PM             4,609 Long3-1_3_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long3-1_3_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long3-1_3_RC_4_10.txt
02/17/2009  03:34 PM             4,609 Long3-2_1_RC_4_10.inp
02/17/2009  05:10 PM           118,371 Long3-2_1_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long3-2_1_RC_4_10.txt
02/17/2009  03:35 PM             4,609 Long3-2_3_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long3-2_3_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long3-2_3_RC_4_10.txt
02/17/2009  03:35 PM             4,609 Long3-3_5_RC_4_10.inp
02/17/2009  05:10 PM           118,655 Long3-3_5_RC_4_10.out
02/09/2009  05:31 PM             1,951 Long3-3_5_RC_4_10.txt
02/17/2009  03:22 PM            15,557 matprops_navy_sb_long.dat
02/17/2009  03:21 PM            15,566 matprops_navy_sb_short.dat
02/17/2009  03:24 PM            19,128 mySteadyAxisMain.inp
12/10/2008  10:05 AM             3,424 navy_long_heat_2-1_3.dat
12/10/2008  10:04 AM             3,424 navy_long_heat_2-2_1.dat
12/10/2008  10:02 AM             3,383 navy_long_heat_2-2_3.dat
12/10/2008  07:18 AM             3,375 navy_long_heat_2-3_5.dat
12/10/2008  10:50 AM             3,424 navy_long_heat_3-1_3.dat
12/10/2008  10:50 AM             3,375 navy_long_heat_3-2_1.dat
12/10/2008  10:49 AM             3,387 navy_long_heat_3-2_3.dat
12/10/2008  10:48 AM             3,389 navy_long_heat_3-3_5.dat
12/10/2008  10:54 AM             3,138 navy_short_heat_2-1_3.dat
12/10/2008  10:54 AM             3,095 navy_short_heat_2-2_1.dat
12/10/2008  10:53 AM             3,103 navy_short_heat_2-2_3.dat
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
12/10/2008  10:56 AM             3,138 navy_short_heat_3-1_3.dat
12/10/2008  10:56 AM             3,095 navy_short_heat_3-2_1.dat
12/10/2008  10:55 AM             3,107 navy_short_heat_3-2_3.dat
12/10/2008  10:55 AM             3,109 navy_short_heat_3-3_5.dat
02/17/2009  03:35 PM             4,610 Short2-1_3_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short2-1_3_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short2-1_3_RC_4_10.txt
02/17/2009  03:35 PM             4,610 Short2-2_1_RC_4_10.inp
02/17/2009  05:10 PM           117,823 Short2-2_1_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short2-2_1_RC_4_10.txt
```

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02/17/2009  03:35 PM             4,610 Short2-2_3_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short2-2_3_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short2-2_3_RC_4_10.txt
02/17/2009  03:36 PM             4,610 Short2-3_5_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short2-3_5_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short2-3_5_RC_4_10.txt
02/17/2009  03:36 PM             4,610 Short3-1_3_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short3-1_3_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short3-1_3_RC_4_10.txt
02/17/2009  03:36 PM             4,610 Short3-2_1_RC_4_10.inp
02/17/2009  05:10 PM           117,823 Short3-2_1_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short3-2_1_RC_4_10.txt
02/17/2009  03:36 PM             4,610 Short3-2_3_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short3-2_3_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short3-2_3_RC_4_10.txt
02/17/2009  03:37 PM             4,610 Short3-3_5_RC_4_10.inp
02/17/2009  05:10 PM           117,965 Short3-3_5_RC_4_10.out
02/18/2009  09:46 AM             1,813 Short3-3_5_RC_4_10.txt
              67 File(s)     2,098,284 bytes

 Directory of D:\ANSYS\ScopingCases

02/19/2009  03:56 PM    <DIR>          .
02/19/2009  11:09 AM    <DIR>          ..
02/17/2009  03:21 PM            15,566 matprops_navy_sb_short.dat
02/17/2009  03:24 PM            19,128 mySteadyAxisMain.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  03:22 PM            13,824 ScopingResults.xls
02/19/2009  11:13 AM             4,608 Short2-3_5_RC_10_10.inp
02/19/2009  01:13 PM           117,831 Short2-3_5_RC_10_10.out
02/19/2009  11:11 AM             4,610 Short2-3_5_RC_2_10.inp
02/19/2009  01:13 PM           117,823 Short2-3_5_RC_2_10.out
02/19/2009  11:11 AM             4,611 Short2-3_5_RC_2_4.inp
02/19/2009  01:13 PM           118,114 Short2-3_5_RC_2_4.out
02/19/2009  11:11 AM             4,610 Short2-3_5_RC_2_N.inp
02/19/2009  01:13 PM           117,911 Short2-3_5_RC_2_N.out
02/19/2009  11:12 AM             4,611 Short2-3_5_RC_4_4.inp
02/19/2009  01:13 PM           118,259 Short2-3_5_RC_4_4.out
02/19/2009  11:12 AM             4,610 Short2-3_5_RC_4_N.inp
02/19/2009  01:13 PM           117,618 Short2-3_5_RC_4_N.out
              16 File(s)        786,829 bytes

 Directory of D:\ANSYS\SensitivityStudies

02/19/2009  04:04 PM    <DIR>          .
02/19/2009  11:09 AM    <DIR>          ..
02/19/2009  01:12 PM    <DIR>          BellDiam
02/19/2009  03:51 PM    <DIR>          Emissivity
02/19/2009  01:13 PM    <DIR>          NoPoly
02/19/2009  02:52 PM    <DIR>          PassCase
02/19/2009  04:04 PM            21,504 SensitivityResults.xls
02/19/2009  01:13 PM    <DIR>          SpaceNodeRad
               1 File(s)         21,504 bytes

 Directory of D:\ANSYS\SensitivityStudies\BellDiam

02/19/2009  01:12 PM    <DIR>          .
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02/19/2009  04:04 PM    <DIR>          ..
02/17/2009  03:21 PM            15,566 matprops_navy_sb_short.dat
02/17/2009  03:24 PM            19,128 mySteadyAxisMain.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  10:02 AM             4,608 Short2-3_5_RC_10_NB.inp
02/19/2009  01:12 PM           117,348 Short2-3_5_RC_10_NB.out
02/19/2009  10:02 AM             4,611 Short2-3_5_RC_2_2B.inp
02/19/2009  01:12 PM           118,120 Short2-3_5_RC_2_2B.out
02/19/2009  10:02 AM             4,610 Short2-3_5_RC_4_10B.inp
02/19/2009  01:12 PM           117,977 Short2-3_5_RC_4_10B.out
               9 File(s)        405,063 bytes

 Directory of D:\ANSYS\SensitivityStudies\Emissivity

02/19/2009  03:51 PM    <DIR>          .
02/19/2009  04:04 PM    <DIR>          ..
02/19/2009  03:46 PM            15,566 matprops_navy_sb_shortE.dat
02/19/2009  03:34 PM            19,148 mySteadyAxisMainE.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  03:48 PM             4,608 Short2-3_5_RC_10_NE.inp
02/19/2009  03:51 PM           117,350 Short2-3_5_RC_10_NE.out
02/19/2009  03:48 PM             4,611 Short2-3_5_RC_2_2E.inp
02/19/2009  03:51 PM           118,122 Short2-3_5_RC_2_2E.out
02/19/2009  03:48 PM             4,610 Short2-3_5_RC_4_10E.inp
02/19/2009  03:51 PM           117,979 Short2-3_5_RC_4_10E.out
               9 File(s)        405,089 bytes

 Directory of D:\ANSYS\SensitivityStudies\NoPoly

02/19/2009  01:13 PM    <DIR>          .
02/19/2009  04:04 PM    <DIR>          ..
02/17/2009  03:21 PM            15,566 matprops_navy_sb_short.dat
02/17/2009  03:24 PM            19,128 mySteadyAxisMain.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  10:04 AM             4,609 Short2-3_5_RC_10_NK.inp
02/19/2009  01:13 PM           117,428 Short2-3_5_RC_10_NK.out
02/19/2009  10:04 AM             4,612 Short2-3_5_RC_2_2K.inp
02/19/2009  01:13 PM           118,200 Short2-3_5_RC_2_2K.out
02/19/2009  10:04 AM             4,611 Short2-3_5_RC_4_10K.inp
02/19/2009  01:13 PM           118,057 Short2-3_5_RC_4_10K.out
               9 File(s)        405,306 bytes

 Directory of D:\ANSYS\SensitivityStudies\PassCase

02/19/2009  02:52 PM    <DIR>          .
02/19/2009  04:04 PM    <DIR>          ..
02/19/2009  02:41 PM            17,978 matprops_navy_sb_shortX.dat
02/19/2009  02:32 PM            19,265 mySteadyAxisMainX.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  02:32 PM             4,596 Short2-3_5_RC_10_NX.inp
02/19/2009  02:52 PM           121,140 Short2-3_5_RC_10_NX.out
               5 File(s)        166,074 bytes

 Directory of D:\ANSYS\SensitivityStudies\SpaceNodeRad

02/19/2009  01:13 PM    <DIR>          .
02/19/2009  04:04 PM    <DIR>          ..
```

```
02/17/2009  03:21 PM            15,566 matprops_navy_sb_short.dat
02/17/2009  03:24 PM            19,128 mySteadyAxisMain.inp
12/10/2008  07:19 AM             3,095 navy_short_heat_2-3_5.dat
02/19/2009  10:32 AM             4,608 Short2-3_5_C_10_N.inp
02/19/2009  01:13 PM           120,964 Short2-3_5_C_10_N.out
02/19/2009  10:32 AM             4,611 Short2-3_5_C_2_2.inp
02/19/2009  01:13 PM           121,298 Short2-3_5_C_2_2.out
02/19/2009  10:32 AM             4,610 Short2-3_5_C_4_10.inp
02/19/2009  01:13 PM           121,155 Short2-3_5_C_4_10.out
               9 File(s)        415,035 bytes

 Directory of D:\Supplemental_Files

02/19/2009  03:30 PM    <DIR>          .
02/26/2009  01:44 PM    <DIR>          ..
11/13/2008  02:31 PM           148,480 naval_long_canister_heat_gen.xls
11/05/2008  10:17 AM           128,000 naval_short_canister_heat_gen.xls
02/19/2009  03:30 PM            51,200 navyCTM_h_calc.xls
09/19/2008  01:44 PM            28,937 NS-4-FR_thermal_properties.xmcd
               4 File(s)        356,617 bytes

     Total Files Listed:
             265 File(s)      9,387,055 bytes
              36 Dir(s)               0 bytes free
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