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 Waste Package	800-00C-DN00-00100-000-00A

5. Title
Thermal Evaluation of Naval Waste Packages in the TEV

6. Group
Thermal Structural Analysis

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☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments
The FLUENT files are checked by Huajun Chen. The balance of the calculation is checked by Daniel Wang.

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	44	I-6	Helen Marr 3/18/09	Daniel Wang 3/18/09 Huajun Chen 3/18/2009	Del Mecham 3/18/09	Michael J. Anderson 3/25/09

ENCLOSURE 4

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.

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FIGURES

Page

TABLES

ACRONYMS

2D	two-dimensional
3D	three-dimensional
BSC	Bechtel SAIC Company, LLC
DVD	Digital Versatile Disc
CPU	central processing unit
CRWMS M & O	Civilian Radioactive Waste Management System Management and Operating Contractor
FEA	finite element analysis
IED	information exchange drawing
ITS	important to safety
ITWI	important to waste isolation
IV	inner vessel
OCB	outer corrosion barrier
SNF	spent nuclear fuel
SS	stainless steel
TEV	transport and emplacement vehicle
WP	waste package
DHLW	defense high level waste
DOE	U. S. Department of Energy

1. PURPOSE

The objective of this calculation is to evaluate the temperatures of the naval waste package and the transport and emplacement vehicle (TEV) during the transportation process from the surface facilities to the emplacement drifts. The scope of the calculation is limited to the naval waste packages in the TEV during normal transportation conditions.

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2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

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 Naval Long and Short Waste Packages

Dimensions and materials of the naval long waste package are assumed to be the same as those indicated in References 2.2.21, 2.2.22, and 2.2.23 and are assumed to be the same as the final definitive design. Dimensions and materials of the Naval Short Waste Package are assumed to be the same as those indicated in References 2.2.16, 2.2.17, and 2.2.18 are assumed to be the same as the final definitive design.

Rationale: The design is preliminary, and will require verification at the completion of the final definitive design.

This assumption is used in Section 6.2.

3.1.2 Dimensions and Materials of the TEV Shielding

Dimensions and materials of the TEV shielding are assumed to be the same as those indicated in Reference 2.2.24. Furthermore, the TEV shielding is assumed to be composed of the following layers of materials (listed from inside to outside): 316 Stainless Steel (SS) (0.5 in thick), depleted uranium (DU) (1.5 in thick), 316 SS (1.5 in thick), NS-4-FR (6 in thick), and 316 SS (0.5 in thick).

Rationale: The design is preliminary, and will require verification at the completion of the final definitive design. These TEV shielding layers and thicknesses are consistent with those given in Section 6.2.1.1 of Reference 2.2.24, except that the inside and middle layers of 316 SS have been swapped, placing the thickest 316 SS layer in the middle. Since this neither has effect on the overall effective thermal resistance across all of the TEV shielding layers or has effect on the NS-4-FR temperature prediction, it is anticipated that this will have no measurable impact on results of this calculation.

This assumption is used in Section 6.2.

3.1.3 Emplacement Height of Waste Packages

The emplacement heights of the naval waste packages, as given in Reference 2.2.19, are assumed to be the same as the final definitive design.

Rationale: The design is preliminary, and will require verification at the completion of the final definitive design.

This assumption is used in Section 6.2.

3.1.4 Effective Thermal Conductivity of NS-4-FR

The thermal conductivity of NS-4-FR (6.46 W/m·K) used in this calculation is ten times the original value.

Rationale: The design is preliminary, and will require verification at the completion of the final definitive design. The neutron shielding material is essentially a thermally insulating material. Heat flow from the waste package to the environment, through the TEV shielding, is limited. It is reasonable to assume that the neutron shielding design will be enhanced by including thermal shunts. Studies (such as Reference 2.2.30) have shown that if thermal shunts in the form of a honeycomb of some conductive material (such as aluminum) penetrate the NS-4-FR, the effective thermal conductivity of the neutron shielding can be increased to values beyond this level.

This assumption is used in Section 6.4.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Representation of the TEV

Only the TEV shielding is represented in the computational models. The main TEV chassis beams, lifting mechanisms, driving mechanisms, and any associated hardware and enclosures are not modeled.

Rationale: This is a simplifying assumption necessary to keep the computational model to a reasonable size. The main chassis beams, lifting mechanisms, driving mechanisms, and associated hardware and enclosures will provide additional heat conduction paths from the shielding surface, and will also provide greater surface area for convection and radiation heat transfer to the environment. Therefore, modeling only the TEV shielding is conservative.

This assumption is used in Section 6.2.

3.2.2 Heat Transfer Modeling Within the Waste Package

Only conduction and radiation heat transfer inside the waste package is assumed.

Rationale: Some natural convective heat transfer will occur in the gaps between inner vessel (IV) and outer corrosion barrier (OCB) and between IV and naval canister. However, in a horizontal emplacement configuration with small gaps, natural convection is minor compared to thermal radiation (at the expected temperatures). Also, the fill gas between the IV and naval canister is helium, which has poor buoyancy (unlike air, for example), and natural convection has a negligible contribution to total heat transfer.

This assumption is used in Section 6.1.

3.2.3 Emplacement Pallets Are Neglected

Conductive heat transfer between the waste packages and the emplacement pallets, and hence through the pallets into the TEV, is neglected.

Rationale: This is a simplifying assumption necessary to keep the computational model to a reasonable size. The waste package pallets have point contact with the waste package in only a few places. Therefore, conduction through the support structure will be limited and can be conservatively neglected.

This assumption is used in Section 6.1.

3.2.4 Treatment of Contacts

The naval canister, waste package IV, and OCB are modeled as floating with no contacts between the components.

Rationale: This is a simplifying assumption necessary to keep the computational model to a reasonable size. This assumption will result in slightly conservative temperature prediction.

This assumption is used in Section 6.1.

3.2.5 Representation of Naval Canister Internals

The naval canister internals are represented as a homogeneous, heat-generating cylinder.

Rationale: The design of the naval canister internals is undisclosed. Since the temperatures of the naval canister internals are not of interest in the calculations, this is acceptable.

This assumption is used in Section 6.1.

3.2.6 Pressure of Helium in the Waste Package

The thermal conductivity of helium at atmospheric pressure is assumed to be representative of the conditions which helium in the waste package will experience.

Rationale: According to p. 255 of Reference 2.2.9, the thermal conductivity of most gasses is pressure independent. Thus, using the thermal conductivity at atmospheric pressure is reasonable. The impact of this assumption is anticipated to be negligible.

This assumption is used in Section 6.4.

3.2.7 Solar Insolation Rate

It is assumed that the solar energy incident on the outer surface of the TEV is equal to 200 cal/cm^2 per 12-hour period on the vertical sides and is equal to 800 cal/cm^2 per 12-hour period on the top and tapered sections.

Rationale: Section 71(c)(1) of Reference 2.2.1 indicates that for flat, horizontal surfaces, the insolation rate is 800 cal/cm^2 per 12-hour period, and that for flat, non-horizontal surfaces, the insolation rate is 200 cal/cm^2 per 12-hour period. Per these criteria, the tapered sections of the TEV shielding should have an insolation value of 200 cal/cm^2 per 12-hour period. Using the higher value of 800 cal/cm^2 per 12-hour period on the tapered sections of the TEV shielding will result in higher temperatures, and therefore is conservative.

This assumption is used in Section 6.3.1.

3.2.8 Naval Waste Package Emplacement Height

The naval waste package emplacement height on the pallet is assumed to be 50.64 inches, which is the same as for the 5-DHLW / DOE SNF waste package (Ref. 2.2.19).

Rationale: The emplacement height for naval waste package is 46.93 inches (Ref. 2.2.19) which is very close to the value for 5-DHLW / DOE SNF waste package. Since the waste package is

assumed floating in the TEV, radiation and conduction inside the TEV will not be affected by the small deviation in emplacement height.

This assumption is used in Section 6.2.

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 waste packages are classified as ITS (important to safety) and ITWI (important to waste isolation) in the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.11, Section 12.1.2). Therefore, the approved version of this document designated as QA: QA.

4.2 USE OF SOFTWARE

The finite volume computer code used for the calculation is FLUENT Version 6.0.12 (Reference 2.2.2), which is identified by the Software Tracking Number 10550-6.0.12-00. Usage of FLUENT Version 6.0.12 in this calculation constitutes Level 1 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). FLUENT Version 6.0.12 is qualified, baselined, and listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1).

The FLUENT Version 6.0.12 evaluations performed in this calculation are fully within the range of the validation performed for FLUENT Version 6.0.12 (Reference 2.2.3). Therefore, FLUENT Version 6.0.12 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 FLUENT analyses are described in Section 6.

Calculations using the FLUENT Version 6.0.12 software were executed on Hewlett-Packard (HP) 9000 Series workstations running operating system HP-UX 11.00.

Commercially available software mesh generator, Gambit Version 2.4.6 is used for creating the meshes in the FLUENT representations. Usage of Gambit Version 2.4.6 in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). Gambit is listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1).

Gambit Version 2.4.6 was executed on Hewlett-Packard (HP) 9000 Series workstations running operating system HP-UX 11.00. The meshes are verified by visual inspection.

Mathcad version 13.0 is used for the calculation of thermal properties and heat transfer coefficients in Attachment II. Usage of Mathcad version 13.0 in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.2, Attachment 4). Mathcad

version 13.0 is listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1).

Mathcad version 13.0 was executed on a PC running the Microsoft Windows XP SP-3 operating system. The results are confirmed by hand calculation.

Microsoft Excel 2003 SP-3, which is a component of Microsoft Office 2003, is used for performing simple calculations and plotting results in Section 7 and Attachment II. 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 is listed in the *Repository Project Management Automation Plan* (Reference 2.1.3, Table 6-1).

Microsoft Excel 2003 SP-3 was executed on a PC running the Microsoft Windows XP SP-2 operating system. The calculations are confirmed by hand calculations, and the plots are confirmed by visual inspection.

All inputs and outputs are located in Attachment II. Note that some of the Fluent files are in .gz format. They are compressed binary files created in HP Unix 11.0 using "gzip" command. The .gz files can be uncompressed using WinZip PC software.

4.3 METHOD

The solution method employed involves three-dimensional (3D) analyses using the commercially available code FLUENT to determine the naval long and short SNF canister surface, waste package, and the TEV shielding temperatures. Steady-state calculations are performed for various naval axial heat generation profiles with consideration of natural convection and no natural convection inside TEV (in the space between TEV inner surface and waste package OCB outer surface). For the cases with natural convection, the unsteady solver is used to aid the convergence of the problem. The problem is solved until it reaches steady state (results are no longer changing with time).

5. LIST OF ATTACHMENTS

Table 1. List of Attachments

Attachment	Description	Number of Pages
I	File Listing for Attachment II	6
II	One (1) DVD	N/A

6. BODY OF CALCULATION

6.1 FLUENT REPRESENTATION

To predict the temperatures of the naval waste package in the TEV, a 3D half symmetry representation is used in the calculations. The representation includes the naval canister, waste package IV and OVB, and TEV shielding materials. The emplacement pallet is ignored in the representation (Assumption 3.2.3). The naval canister, waste package IV and OCB are all modeled as floating. No conduction contacts are considered (Assumption 3.2.4). The naval canister internals are represented as a homogenous heat generating cylinder (Assumption 3.2.5). The helium gaps between the waste package inner vessel and the naval canister; and the air gap between the outer corrosion barrier and the inner vessel are modeled as non-moving gases. Only conduction and radiation are included across the gaps. No natural convection is considered (see Assumption 3.2.2).

Note that the ventilation inlet and outlet are modeled on the TEV shielding. However, they are closed with adiabatic walls to represent a fully sealed enclosure. Figure 1 shows the detailed FLUENT representation.

All the cases are first performed by considering that there is no natural convection inside the TEV. Thus only conduction and radiation are considered, ignoring the effect of natural convection inside the enclosure of TEV (in the space between TEV inner surface and waste package OCB outer surface).

For the cases where the thermal criteria cannot be satisfied with only conduction and radiation inside the TEV enclosure, natural convection is included (in the space between TEV inner surface and waste package OCB outer surface). Overall heat transfer coefficients from natural convection are estimated for the waste package surface and TEV inner surface. The heat transfer coefficient h, is defined as:

$$h = \frac{q''}{T_1 - T_2} \qquad \text{(Equation 1)}$$

where q" = average heat flux on waste package surface or TEV inner surface (W/m^2)

T_1 = average temperature on waste package surface or TEV inner surface (°C)

T_2 = average air temperature (°C)

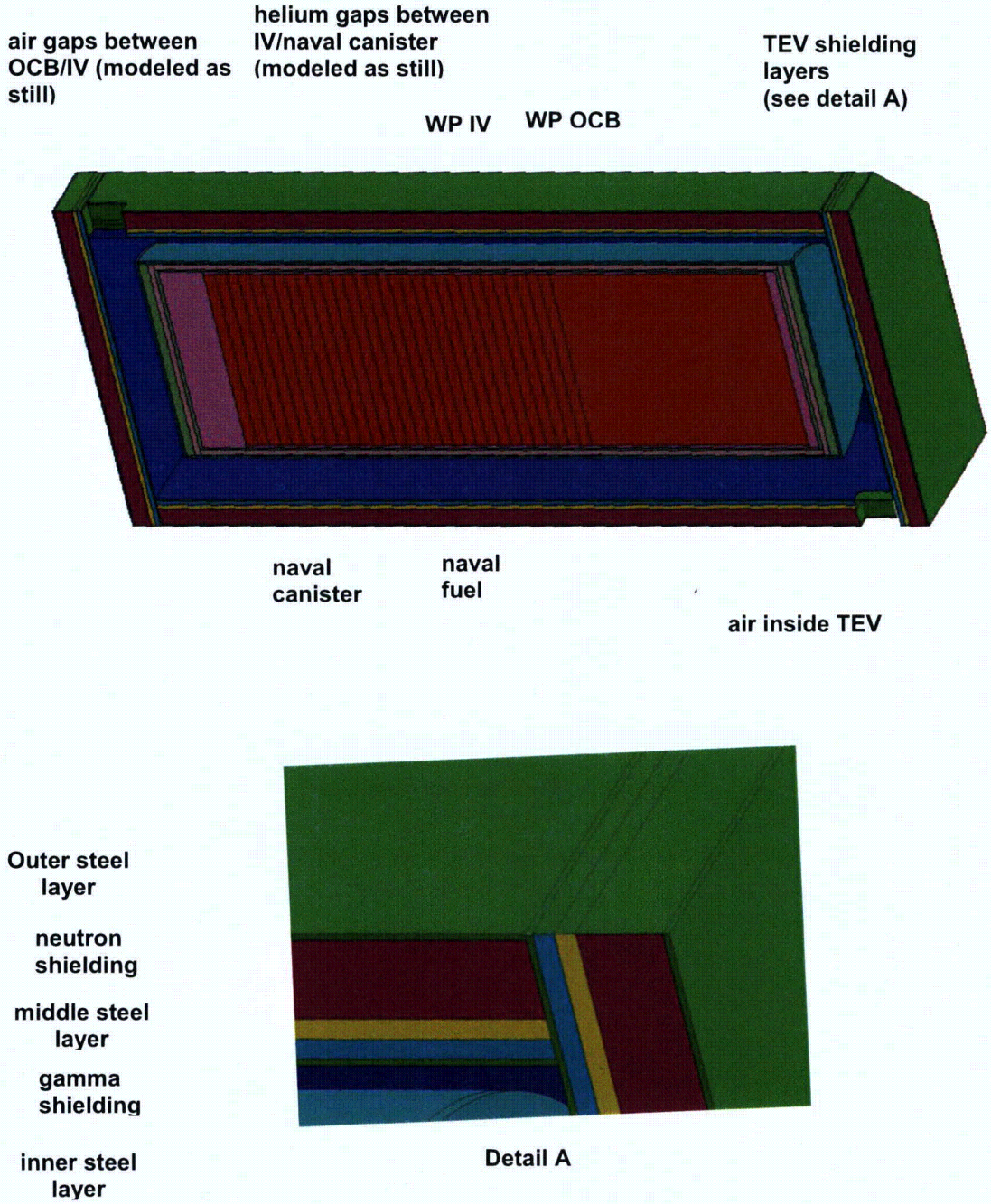

Figure 1. FLUENT Representation

6.2 GEOMETRY

Figure 2 shows a geometric cross section of the waste package in the TEV indicating dimensions relevant to this calculation. Only the TEV shielding is represented in the computational models (Assumption 3.2.1). The key dimensions of the TEV listed in Table 2 are either taken directly from Reference 2.2.24 (Assumption 3.1.2) or derived from Reference 2.2.24. The naval waste

package emplacement height is taken from Reference 2.2.19 (Assumption 3.1.3). The thicknesses of the TEV shielding layers are shown in Table 3 (Assumption 3.1.2).

Table 4 lists the key dimensions used in the waste package representation taken from References 2.2.22 and 2.2.23 for naval long waste package and 2.2.17 and 2.2.18 for naval short waste package (see Assumption 3.1.1).

Table 5 lists the naval canister dimensions taken from References 2.2.10 and 2.2.20.

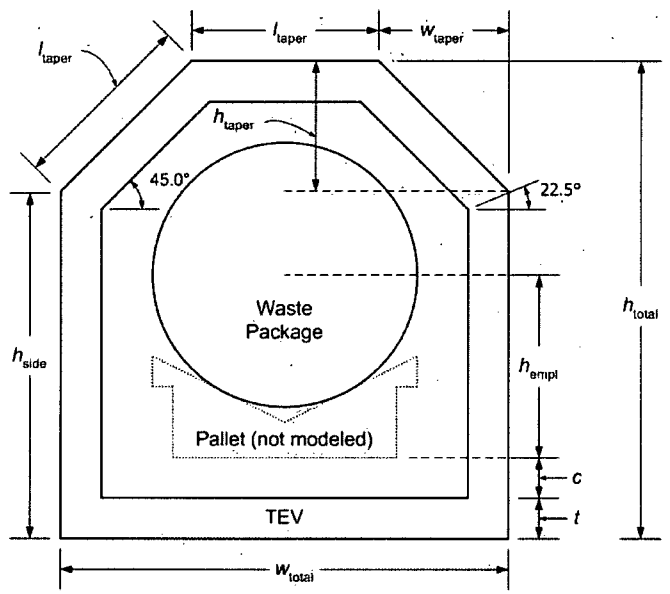

Figure 2. Geometry of Waste Package in the TEV

Table 2. Key TEV Dimensions

Item	Dimension (in)	Dimension (m)	Reference
Total outside length *	272	6.9088	Reference 2.2.24, Section 6.2.3.1
Total outside height (h_{total})	118.49	3.0096	Reference 2.2.24, Section 6.2.3.3
Total outside width (w_{total})	109.70	2.7864	Reference 2.2.24, Section 6.2.3.2
Outside length of tapered sections (l_{taper})	45.5	1.1557	Reference 2.2.24, Section 6.3.3.1.2
Emplacement pallet clearance (c)	2	0.0508	Reference 2.2.24, Section 3.2.1
Total shielding thickness (t)	10	0.254	Reference 2.2.24, Section 6.2.1.1
Waste package emplacement height (h_{empl})	50.64**	1.2861**	Reference 2.2.19

*Not shown in Figure 2

** Value for 5DHLW waste package is used (see Assumption 3.2.8)

Table 3. Shielding Thicknesses

Shielding Name	Material	Thickness		Reference
		(in)	(m)	
TEV Inner Steel Layer	316 Stainless Steel	0.5	0.0127	Reference 2.2.24, Section 6.2.1.1
TEV Gamma Shielding	Depleted Uranium	1.5	0.0381	Reference 2.2.24, Section 6.2.1.1
TEV Middle Steel Shielding Layer	316 Stainless Steel	1.5	0.0381	Reference 2.2.24, Section 6.2.1.1
TEV Neutron Shielding	NS-4-FR	6	0.1524	Reference 2.2.24, Section 6.2.1.1
TEV Outer Steel Layer	316 Stainless Steel	0.5	0.0127	Reference 2.2.24, Section 6.2.1.1

Table 4. Key Naval Waste Package Dimensions

Item		Dimension		Reference
		(in)	(m)	
Outer Corrosion Barrier Outer Length (not including lifting feature and skirt)	naval long	225.07	5.7167	References 2.2.22 and 2.2.23
	naval short	200.07	5.0817	References 2.2.17 and 2.2.18
Outer Corrosion Barrier Top Lid Thickness		1.0	0.0254	References 2.2.22 and 2.2.18
Outer Corrosion Barrier Bottom Lid Thickness		1.0	0.0254	References 2.2.22 and 2.2.18
Outer Corrosion Barrier Outer Diameter		74.08	1.8816	References 2.2.22 and 2.2.17
Outer Corrosion Barrier Inner Diameter		72.08	1.8308	References 2.2.22 and 2.2.17
Inner Vessel Outer Length (not including lip above top lid)		217	5.5118	References 2.2.22, 2.2.23, 2.2.17, and 2.2.18
Inner Vessel Cavity Length	naval long	213	5.4102	Reference 2.2.22
	naval short	188	4.7752	Reference 2.2.17
Inner Vessel Top Lid Thickness		2.0	0.0508	References 2.2.23 and 2.2.18
Inner Vessel Bottom Lid Thickness		2.0	0.0508	References 2.2.23 and 2.2.18
Inner Vessel Outer Diameter		71.70	1.8212	References 2.2.22 and 2.2.17
Inner Vessel Inner Diameter		67.70	1.7196	References 2.2.22 and 2.2.17

Table 5. Naval Canister Dimensions

Item		Dimension (in)	Dimension (m)	Reference
Naval SNF Canister Outer Diameter		66.5	1.6891	Reference 2.2.20, Enclosure 3, p. 2
Naval SNF Canister Top Lid Thickness		15	0.381	Reference 2.2.20, Enclosure 3B, Drawing 6253E73
Naval SNF Canister Bottom Lid Thickness		3.5	0.0889	Reference 2.2.20, Enclosure 3B, Drawing 6253E73
Naval SNF Canister Wall Thickness		1.0	0.0254	Reference 2.2.28
Naval SNF Canister Active Fuel Length	naval long	192.13	4.8801	Reference 2.2.10, Attachment 2, Table 1
	naval short	166.93	4.2400	Reference 2.2.10, Attachment 2, Table 1

Note: Reference 2.2.20 and Reference 2.2.28 are drawings from the supplier of the Naval SNF Canisters and, therefore, are considered appropriate for use in this calculation.

6.3 BOUNDARY CONDITIONS AND HEAT LOADS

The boundary conditions on the TEV exterior include solar energy incident, radiation to the ambient, and convection to the ambient. In this calculation, radiation and natural convection to the ambient are combined using an effective heat transfer coefficient for convenience. There are eight different heat load profiles considered for naval long canisters and eight for naval short canisters. The following sections describe the details of the calculation conditions.

6.3.1 Solar Heat Flux

The solar energy incident on the outer surface of the TEV is equal to 200 cal/cm^2 per 12-hour period on the vertical sides and is equal to 800 cal/cm^2 per 12-hour period on the top and tapered sections (Assumption 3.2.7). No solar incident is counted on the bottom of the TEV. The solar heat flux (q'') into the TEV shielding is calculated using Equation 2,

$$q'' = \alpha G \qquad \text{(Equation 2)}$$

where G is the solar energy incident on the surface, and α is the absorptivity of the outer surface of the TEV (316 SS), which is equal to 0.5 (Reference 2.2.25, Table 12.2).

The solar heat flux is calculated to be 388 W/m^2 on the top and tapered sections of the TEV and 97 W/m^2 on the vertical sides of the TEV (See Reference 2.2.13, Attachment V, file: *solar_heat_flux.xmcd* for calculations).

6.3.2 Combined Radiation and Convection on TEV Exterior

The radiation heat transfer from the TEV outer surface to the ambient can be expressed as:

$$q_r = \sigma\varepsilon A(T_1^4 - T_2^4) \qquad \text{(Equation 3)}$$

where q_r = radiation heat transfer rate (W)
σ = Stefan-Boltzmann constant = 5.67×10^{-8} W/m^2·K^4
ε = surface emissivity
A = surface area (m^2)
T_1 = surface temperature (K)
T_2 = ambient temperature (K)

Equation 2 can be expanded to

$$q_r = \sigma\varepsilon A(T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2) = h_r A(T_1 - T_2) \qquad \text{(Equation 4)}$$

where h_r = effective coefficient for radiation heat transfer (W/m^2·K)

$$= \sigma\varepsilon A(T_1^2 + T_2^2)(T_1 + T_2)$$

The convective heat transfer from the TEV outer surface to the ambient can be expressed as:

$$q_c = h_c A \cdot (T_1 - T_2) \qquad \text{(Equation 5)}$$

The convection heat transfer coefficient (h_c) from the surface of the TEV to the ambient can be approximated by using a horizontal cylinder at room temperature and atmospheric pressure. The average value of the convection heat transfer coefficient, h_c, is correlated by the following equation (Reference 2.2.7, p. 4-88):

$$h_c = 0.19\,(\Delta T)^{1/3} \qquad \text{(Equation 6)}$$

which has units of Btu/hr·ft^2·°F, with ΔT in degrees Fahrenheit, for $D^3\Delta T > 100$ ft^3·°F. Equation 6 can be expressed in SI units as:

$$h_c = 1.3123\,(\Delta T)^{1/3} \qquad \text{(Equation 7)}$$

which has units of W/m^2·K, with ΔT in degrees Kelvin or Celsius.

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

$$q = q_r + q_c = (h_r + h_c)A(T_1 - T_2) \qquad \text{(Equation 8)}$$

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

$$h_{eff} = h_r + h_c \qquad \text{(Equation 9)}$$

The ambient temperature considered for this calculation is set equal to the maximum ambient outdoor temperature of 116 °F (46.7 °C) (Reference 2.2.12, Section 6.1.6). Based on this ambient temperature, the effective heat transfer coefficient for convection/radiation is determined and tabulated in Table 6 (Values are listed in Table 38, Ref. 2.2.13).

Table 6. Effective Heat Transfer Coefficient on TEV Exterior (46.7 °C Ambient Temperature)

TEV Exterior Surface Temperature (°C)	Effective Heat Transfer Coefficient ($W/m^2 \cdot K$)
71.7	9.01
96.7	10.6
121.7	12.0
146.7	13.3
171.7	14.6
196.7	15.9
221.7	17.3
246.7	18.7

6.3.3 Heat Loads

The heat generation of the naval fuel varies axially along the length of the canister. Eight axial profiles for the naval long canister and eight axial profiles for the naval short canister are provided by NNPP (Ref. 2.2.10). Tables 7 and 8 tabulate the linear heat load profiles taken from Ref. 2.2.10. The volumetric heat generation rates for the naval canister internals are calculated and listed in Tables 7 and 8 also. Note that for the cases with heat generation greater than 11.8 kW (Cases 2.3_5, 2.1_3, 3.3_5, and 3.1_3 for both naval long and short canisters), the heat generation profiles are scaled to a total heat generation of 11.8 kW, while keeping the 5.0 kW/m and 3.0 kW/m peaking unchanged.

The scaled total heat for each segment is then divided by the volume of each segment in order to obtain the volumetric heat generation rates as listed in Tables 9 and 10. The details of this derivation can be seen in Attachment II, files: *naval_long_canister_heat_gen.xls* and *naval_short_canister_heat_gen.xls*.

Table 7. Linear Heat Load (kW/m) for Naval SFC with Two Peaks (source: Ref. 2.2.10, Tables 1 and 5)

Segment Length (m)	Linear Heat Loads (kW/m)			
	Case 2.3_5	Case 2.2_3	Case 2.1_3	Case 2.2_1
0.0 to 1.5	2.2	1.6	2.5	0.5
1.5 to 1.6	3.2	1.6	2.5	0.5
1.6 to 1.7	4	3	3	1
1.7 to 1.9	5	3	3	1
1.9 to 2.0	4	3	3	1
2.0 to 2.1	3.2	1.6	2.5	0.5
2.1 to 2.4	2.2	1.6	2.5	0.5
2.4 to 2.8	5	3	3	1
2.8 to Short SFC 4.24	2.2	1.6	2.5	0.5
2.8 to Long SFC 4.88	2.2	1.6	2.5	0.5
Total Heat Generation in Short SFC (kW)	11.57	7.91	11.00	2.52
Total Heat Generation in Long SFC (kW)	12.97	8.92	12.59	2.84

Table 8. Linear Heat Load (kW/m) for Naval SFC with Three Peaks (source: Ref. 2.2.10, Table 2 and Ref. 2.2.31, Table 6)

Segment Length (m)	Linear Heat Loads (kW/m)			
	Case 3.3_5	Case 3.2_3	Case 3.1_3	Case 3.2_1
0.0 to 0.6	2.2	1.6	2.5	0.5
0.6 to 1.0	5	3	3	1
1.0 to 1.4	2.2	1.6	2.5	0.5
1.4 to 1.8	5	3	3	1
1.8 to 2.4	2.2	1.6	2.5	0.5
2.4 to 2.5	3.2	2.1	2.5	0.7
2.5 to 2.6	4	2.5	3	0.8
2.6 to 2.8	5	3	3	1
2.8 to 2.9	4	2.5	3	0.8
2.9 to 3.0	3.2	2.1	2.5	0.7
3.0 to Short SFC 4.24	2.2	1.6	2.5	0.5
3.0 to Long SFC 4.88	2.2	1.6	2.5	0.5
Total Heat Generation in Short SFC (kW)	12.69	8.47	11.20	2.72
Total Heat Generation in Long SFC (kW)	14.09	9.48	12.79	3.04

Table 9. Naval Long SNF Canister Heat Generation Rates

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	Case 3.3_5	Case 3.2_3	Case 3.1_3	Case 3.2_1
0.00	0.10	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.10	0.20	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.20	0.30	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.30	0.40	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.40	0.50	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.50	0.60	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
0.60	0.70	920.5	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
0.70	0.80	920.5	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
0.80	0.90	920.5	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
0.90	1.00	920.5	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
1.00	1.10	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
1.10	1.20	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
1.20	1.30	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
1.30	1.40	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
1.40	1.50	920.5	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
1.50	1.60	1338.9	759.0	1093.4	237.2	2371.9	1423.1	1423.1	474.4
1.60	1.70	1673.6	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
1.80	1.90	2371.9	1423.1	1423.1	474.4	780.6	759.0	1056.7	237.2
1.90	2.00	1673.6	1423.1	1423.1	474.4	780.6	759.0	1056.7	237.2
2.00	2.10	1338.9	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
2.10	2.20	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
2.20	2.30	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
2.30	2.40	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
2.40	2.50	2371.9	1423.1	1423.1	474.4	1135.5	996.2	1056.7	332.1
2.50	2.60	2371.9	1423.1	1423.1	474.4	1419.3	1185.9	1423.1	379.5
2.60	2.70	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
2.70	2.80	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
2.80	2.90	920.5	759.0	1093.4	237.2	1419.3	1185.9	1423.1	379.5
2.90	3.00	920.5	759.0	1093.4	237.2	1135.5	996.2	1056.7	332.1
3.00	3.10	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.10	3.20	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.20	3.30	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.30	3.40	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.40	3.50	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.50	3.60	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.60	3.70	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.70	3.80	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.80	3.90	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
3.90	4.00	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2

4.00	4.10	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.10	4.20	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.20	4.30	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.30	4.40	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.40	4.50	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.50	4.60	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.60	4.70	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.70	4.80	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
4.80	4.88	920.5	759.0	1093.4	237.2	780.6	759.0	1056.7	237.2
Total Heat Generation (kW)		**11.8**	**8.93**	**11.8**	**2.84**	**11.8**	**9.49**	**11.8**	**3.04**

Table 10. Naval Short SNF Canister Heat Generation Rates

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**	**Case 3.3_5**	**Case 3.2_3**	**Case 3.1_3**	**Case 3.2_1**
0.00	0.10	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.10	0.20	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.20	0.30	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.30	0.40	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.40	0.50	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.50	0.60	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
0.60	0.70	1043.6	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
0.70	0.80	1043.6	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
0.80	0.90	1043.6	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
0.90	1.00	1043.6	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
1.00	1.10	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
1.10	1.20	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
1.20	1.30	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
1.30	1.40	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
1.40	1.50	1043.6	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
1.50	1.60	1518.0	759.0	1185.9	237.2	2371.9	1423.1	1423.1	474.4
1.60	1.70	1897.5	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
1.70	1.80	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
1.80	1.90	2371.9	1423.1	1423.1	474.4	923.6	759.0	1185.9	237.2
1.90	2.00	1897.5	1423.1	1423.1	474.4	923.6	759.0	1185.9	237.2
2.00	2.10	1518.0	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
2.10	2.20	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
2.20	2.30	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
2.30	2.40	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
2.40	2.50	2371.9	1423.1	1423.1	474.4	1343.4	996.2	1185.9	332.1
2.50	2.60	2371.9	1423.1	1423.1	474.4	1679.3	1185.9	1423.1	379.5
2.60	2.70	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4

2.70	2.80	2371.9	1423.1	1423.1	474.4	2371.9	1423.1	1423.1	474.4
2.80	2.90	1043.6	759.0	1185.9	237.2	1679.3	1185.9	1423.1	379.5
2.90	3.00	1043.6	759.0	1185.9	237.2	1343.4	996.2	1185.9	332.1
3.00	3.10	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.10	3.20	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.20	3.30	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.30	3.40	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.40	3.50	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.50	3.60	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.60	3.70	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.70	3.80	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.80	3.90	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
3.90	4.00	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.00	4.10	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.10	4.20	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.20	4.30	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.30	4.40	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.40	4.50	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.50	4.60	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.60	4.70	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.70	4.80	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
4.80	4.88	1043.6	759.0	1185.9	237.2	923.6	759.0	1185.9	237.2
Total Heat Generation (kW)		**11.57**	**7.9**	**11.0**	**2.52**	**11.8**	**8.46**	**11.2**	**2.72**

6.4 THERMAL PROPERTIES

Table 11 summarizes the materials used in the FLUENT representations.

Table 11. Materials Used in the FLUENT Representations

Component	Material	Reference
WP Outer Corrosion Barrier	Alloy 22	References 2.2.21 and 2.2.16
WP Inner Vessel	316 Stainless Steel	References 2.2.21 and 2.2.16
Naval SNF Canister Internals	Homogeneous Material	Reference 2.2.20, Enclosure 1
Naval SNF Canister Wall	316L Stainless Steel	Reference 2.2.28
Waste Package Inner Vessel Fill Gas	Helium	Reference 2.2.12, Section 4.9.5.4.2
Gap Between Inner Vessel and Outer Corrosion Barrier	Air	No fill gas is specified. Since this area is allowed to communicate with the environment, it is air.

Gap Between Outer Corrosion Barrier and TEV Shielding	Air	No fill gas is specified. Since this area is allowed to communicate with the environment, it is air.
TEV Inner Steel Layer	316 Stainless Steel	Reference 2.2.24, Section 6.2.1.1
TEV Gamma Shielding	Depleted Uranium	Reference 2.2.24, Section 6.2.1.1
TEV Middle Steel Shielding Layer	316 Stainless Steel	Reference 2.2.24, Section 6.2.1.1
TEV Neutron Shielding	NS-4-FR	Reference 2.2.24, Section 6.2.1.1
TEV Outer Steel Layer	316 Stainless Steel	Reference 2.2.24, Section 6.2.1.1

Table 12 lists the emissivity of Alloy 22. The emissivity is taken from Reference 2.2.15, p. 10-297. Table 13 lists the thermal conductivity of Alloy 22. The values of thermal conductivity are taken from Reference 2.2.27, p. 13. The information cited in Reference 2.2.27 is data from the vendor of Alloy 22, and, therefore, is suitable for use in this calculation.

Table 12. Emissivity of Alloy 22

Emissivity
0.87

Table 13. Thermal Conductivity of Alloy 22

Temperature (°C)	Thermal Conductivity (W/m·K)
48	10.1
100	11.1
200	13.4
300	15.5
400	17.5
500	19.5
600	21.3

Table 14 lists the emissivity of 316 SS and 316L SS. The emissivity is taken from Reference 2.2.7, Table 4.3.2 (median value).

Table 15 lists values of thermal conductivity of 316 SS and 316L SS. Values for thermal conductivity are taken from Reference 2.2.5, Section II, Part D, Table TCD, p. 663 (material group K).

Table 14. Emissivity of 316 SS and 316L SS

Emissivity
0.62

Table 15. Thermal Conductivity of 316 SS and 316L SS

Temperature		Thermal Conductivity	
(°F)	(°C)	(Btu/hr-ft-F)	(W/m-K)
70	21.11	8.2	14.18
100	37.78	8.3	14.35
150	65.56	8.6	14.87
200	93.33	8.8	15.22
250	121.11	9.1	15.74
300	148.89	9.3	16.08
350	176.67	9.5	16.43
400	204.44	9.8	16.95
450	232.22	10.0	17.30
500	260.00	10.2	17.64
550	287.78	10.5	18.16
600	315.56	10.7	18.51
650	343.33	10.9	18.85
700	371.11	11.2	19.37
750	398.89	11.4	19.72
800	426.67	11.6	20.06
850	454.44	11.9	20.58
900	482.22	12.1	20.93
950	510.00	12.3	21.27
1000	537.78	12.5	21.62
1050	565.56	12.8	22.14
1100	593.33	13.0	22.48
1150	621.11	13.2	22.83

The atmospheric pressure of air used in the FLUENT calculations is 88558 Pa. This pressure is obtained by taking the pressure at one atmosphere at sea level (101325 Pa) and multiplying it by the appropriate pressure ratio, 0.874, which is interpolated from Table 11.4.1 of Reference 2.2.7, at an elevation of 3750 ft. Reference 2.2.29, file: *As-Built Met. Sites Spreadsheet.xls*, indicates that the elevation of Site 1 (NTS-60) is approximately 3750 ft. (Note that DTN: MO0708ABS14MSP.000 (Reference 2.2.29) is cited in *IED Surface Facility and Environment* (Reference 2.2.8), and, therefore, is approved and appropriate for the intended use in this calculation).

Table 16 lists the thermal properties of air used in the FLUENT calculations at an atmospheric pressure of 88558 Pa. Values for specific heat, thermal conductivity, and viscosity are taken from Reference 2.2.4, p. 20.59, at standard atmospheric pressure. The density of air at a pressure of 88558 Pa and at the listed temperatures is calculated using the ideal gas law. See Attachment II, file: *density_of_air_at_elevation.xmcd* for detailed calculations of air density.

Table 16. Thermal Properties of Air at Atmospheric Pressure of 88558 Pa

Temperature (°C)	Density (kg/m^3)	Thermal Conductivity (W/m-K)	Specific Heat (J/kg-K)	Viscosity (kg/s-m)
-17.78	1.208	0.0229	1005.6	1.625E-05
-6.67	1.158	0.0237	1005.6	1.682E-05
4.44	1.112	0.0246	1006.0	1.736E-05
15.56	1.069	0.0254	1006.0	1.790E-05
26.67	1.029	0.0261	1006.4	1.844E-05
37.78	0.992	0.0269	1006.9	1.893E-05
48.89	0.958	0.0277	1007.7	1.943E-05
60.00	0.926	0.0284	1008.1	1.997E-05
71.11	0.896	0.0292	1009.0	2.046E-05
82.22	0.868	0.0299	1009.8	2.092E-05
93.33	0.842	0.0306	1010.6	2.141E-05
104.44	0.817	0.0314	1011.9	2.187E-05
115.56	0.794	0.0321	1013.1	2.236E-05
126.67	0.772	0.0328	1014.4	2.282E-05
137.78	0.751	0.0335	1015.7	2.327E-05
148.89	0.731	0.0342	1017.3	2.373E-05
160.00	0.712	0.0349	1018.6	2.414E-05
171.11	0.695	0.0356	1020.3	2.460E-05
182.22	0.678	0.0363	1022.4	2.501E-05
204.44	0.646	0.0377	1026.1	2.588E-05
226.67	0.617	0.0391	1029.9	2.670E-05
248.89	0.591	0.0405	1034.5	2.753E-05
271.11	0.567	0.0418	1039.1	2.832E-05
293.33	0.545	0.0432	1043.7	2.910E-05
315.56	0.524	0.0446	1048.7	2.985E-05
337.78	0.505	0.0459	1053.8	3.063E-05
360.00	0.487	0.0473	1059.2	3.138E-05
382.22	0.471	0.0486	1064.6	3.208E-05
404.44	0.455	0.0499	1069.7	3.282E-05
426.67	0.441	0.0513	1075.1	3.352E-05

Table 17 lists values of thermal conductivity of helium used in the FLUENT calculations, taken from Reference 2.2.4, p. 20.55, at standard atmospheric pressure (Assumption 3.2.6).

Table 17. Thermal Properties of Helium

Temperature (°C)	Thermal Conductivity (W/m-K)
-17.78	0.1396
-6.67	0.1437

4.44	0.1478
15.56	0.1519
26.67	0.1559
37.78	0.1599
48.89	0.1638
60.00	0.1677
71.11	0.1715
82.22	0.1754
93.33	0.1791
115.56	0.1866
137.78	0.1940
160.00	0.2012
182.22	0.2083
204.44	0.2153
226.67	0.2222
248.89	0.2291
271.11	0.2358
293.33	0.2425
315.56	0.2491
337.78	0.2556
360.00	0.2620
382.22	0.2684
404.44	0.2747
426.67	0.2810

Table 18 lists the thermal conductivity of uranium, taken from Reference 2.2.15, page 12-173.

Table 18. Thermal Conductivity of Uranium

Thermal Conductivity (W/m-K)
27.6

The thermal conductivity of NS-4-FR of 0.646 W/m·K, is taken from Table 3.2-1 of Reference 2.2.14 (see Ref. 2.2.13, Attachment IV, file: *\Supplemental_Files\NS-4-FR_thermal_properties.xmcd* for unit conversion). Reference 2.2.14 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. However in this calculation a thermally enhanced value (ten times the original value) (see Table 19) is used (see Assumption 3.1.4)

Table 19. Thermal Conductivity of NS-4-FR (thermally enhanced value)

Thermal Conductivity (W/m-K)
6.46

Table 20 lists the surface emissivity of the naval SNF canister. The emissivity is taken from Reference 2.2.20, Enclosure 1, p. 4. Table 21 lists the effective thermal conductivity of the naval long and short SNF canisters, taken from Reference 2.2.20, Enclosure 1, p. 11.

Table 20. Surface Emissivity of Naval SNF Canister

Emissivity
0.6

Table 21. Thermal Conductivity of Naval SNF Canister

Temperature (°C)	Thermal Conductivity (W/m·K)	Temperature (°C)	Thermal Conductivity (W/m·K)
Naval Long		Naval Short	
77.78	2.45	77.78	2.74
89.61	2.62	89.61	2.94
109.98	2.71	109.98	3.04
129.11	2.90	129.11	3.26
135.20	2.87	135.20	3.21
142.72	2.00	142.72	3.36
155.84	3.12	155.84	3.51
159.20	3.06	159.20	3.43
167.42	3.18	167.42	3.56
167.84	3.26	167.84	3.65
178.75	3.23	178.75	3.62
181.64	3.27	181.64	3.66
184.95	3.28	184.95	3.67
188.03	3.35	188.03	3.76
189.14	3.39	189.14	3.81
193.11	3.38	193.11	3.79
195.20	3.37	195.20	3.78
203.17	3.44	203.17	3.86
204.59	3.46	204.59	3.88
204.97	3.49	204.97	3.91
207.36	3.49	207.36	3.92
219.36	3.58	219.36	4.02
228.56	3.66	228.56	4.10

236.22	3.72	236.22	4.17
239.03	3.74	239.03	4.19
242.72	3.76	242.72	4.22
244.75	3.78	244.75	4.23
279.34	4.00	279.34	4.51

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 appropriate bounding thermal results for design guidance at this time. Limiting heat loads have been used together with nominal conservative assumptions. Future work may quantify the inherent safety margin.

7.1 THERMAL LIMITS

The following thermal limits apply to this calculation:

The naval SNF canister external 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 2.2.6, Section 10.3.2.2).

The waste package surface temperature must not exceed 300°C (572°F) (Ref. 2.2.11, Section 12.2.2.5). This limit applies to both normal and off-normal conditions.

The maximum continuous operating temperature of NS-4-FR (neutron shielding material) is 300 °F or 148.9 °C (Reference 2.2.26, p. II-5). Attachment II of Reference 2.2.26 provides vendor data from a supplier of NS-4-FR, and, therefore, is suitable for use in this calculation.

7.2 RESULTS

Tables 22 and 23 list the peak temperature results of the naval long and short canisters in the TEV. The maximum temperature axial distribution on the naval canisters (on the top of the canister at the symmetry) are listed in Attachment II, files: *Tprofile_long.xls and Tprofile_short.xls*)

For all naval long waste packages in the TEV, the temperatures are below the temperature criteria for different materials even with no credit taken for the natural convection inside the TEV (in the space between TEV inner surface and waste package OCB outer surface). The cases with 5 kW/m peaks (2.3_5 and 3.3_5) have the highest temperatures compared to the ones with 3 kW/m and 1 kW/m peaks.

For the naval short waste package in the TEV, all cases except for the ones with 5 kW/m peak can satisfy the temperature limits without taking credit of natural convection inside TEV (in the

space between TEV inner surface and waste package OCB outer surface). The naval canister surface temperatures for the cases with 5 kW/m peak (2.3_5 and 3.3_5) are slightly above the limit. By including natural circulation inside the TEV, the naval canister temperatures are lowered by 9°C for both cases, which meet the naval canister surface temperature limit of 204.4°C.

The natural convection inside the TEV removes about 23% of the heat generated by the naval canister. The overall heat transfer coefficients on the waste package and TEV inner surface are both around 3 $W/m^2 \cdot K$ (see Attachment II, file: *h_calc.xmcd*).

Figure 3 shows the temperature contours for the naval long waste package in the TEV without natural convection (case 2.3_5). Figures 4 and 5 show the naval long canister temperature distribution.

Figure 6 shows the velocity contours on the symmetry plane for naval short waste package in the TEV (case 2.3_5). Figure 7 displays the velocity contours on a series of cross sections. The maximum air velocity induced by natural convection is about 0.39 m/s.

Figure 8 shows the temperature contours for the naval short waste package in the TEV with natural convection (case 2.3_5). Figures 9 and 10 show the naval short canister temperature distribution.

Table 22. Summary of Maximum Temperatures of Naval Long Canister in the TEV

Naval Heat Load Case	Natural Convection Inside TEV (Yes/No)?	Naval Canister Surface Temperature (°C)	Waste Package Surface (°C)	TEV Shielding Inner Surface (°C)	NS4-FR Inner Surface (°C)	TEV Shielding Outer Surface (°C)
2.3_5	No	204	153	109	108	74
2.2_3	No	173	135	102	101	68
2.1_3	No	191	147	107	106	72
2.2_1	No	110	97	88	88	63
3.3_5	No	202	152	109	107	73
3.2_3	No	175	136	103	102	68
3.1_3	No	189	146	107	106	72
3.2_1	No	110	98	88	88	63

Table 23. Summary of Maximum Temperatures of Naval Short Canister in the TEV

Naval Heat Load Case	Natural Convection Inside TEV (Yes/No)?	Naval Canister Surface Temperature (°C)	Waste Package Surface (°C)	TEV Shielding Inner Surface (°C)	NS4-FR Inner Surface (°C)	TEV Shielding Outer Surface (°C)
2.3_5	No	208*	157	110	109	74
	Yes	199	144	108	107	70
2.2_3	No	171	134	101	100	67
2.1_3	No	193	148	107	106	72

2.2_1	No	109	97	88	88	62
3.3_5	No	205*	154	110	107	74
	Yes	196	142	108	106	70
3.2_3	No	173	135	102	101	68
3.1_3	No	193	148	108	106	73
3.2_1	No	110	97	88	88	62

* exceed limit

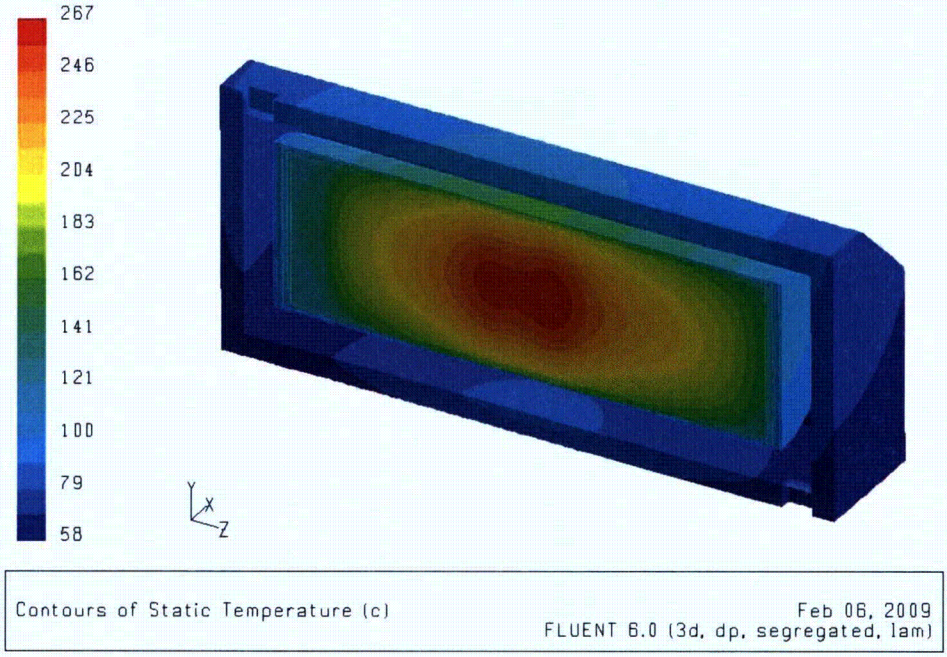

Figure 3. Temperature Contours for Naval Long Waste Package in the TEV (Case 2.3_5)

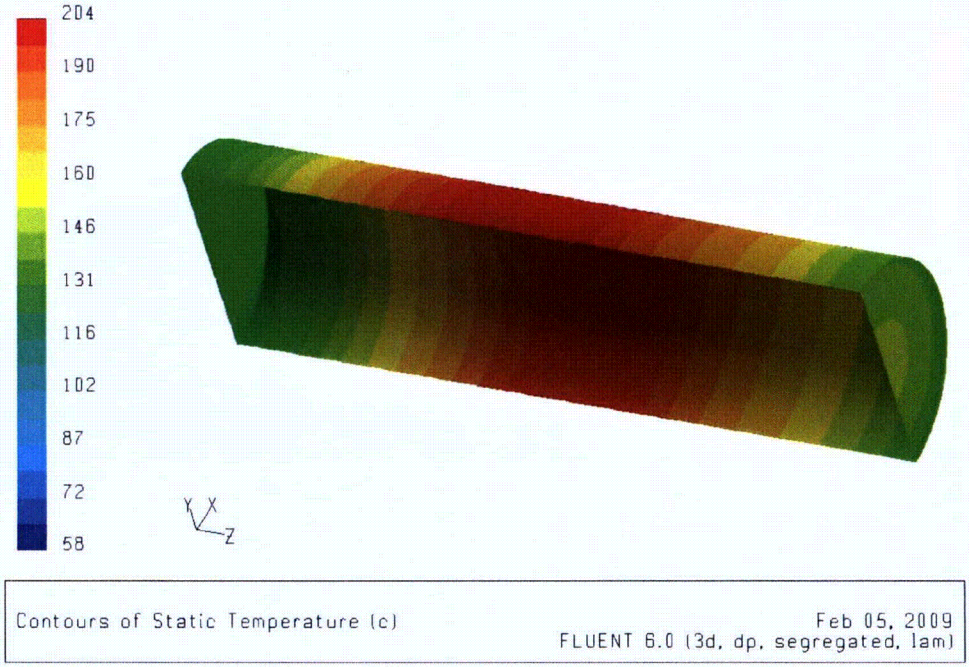

Figure 4. Temperature Contours of the Naval Long Canister Outer Surface (Case 2.3_5)

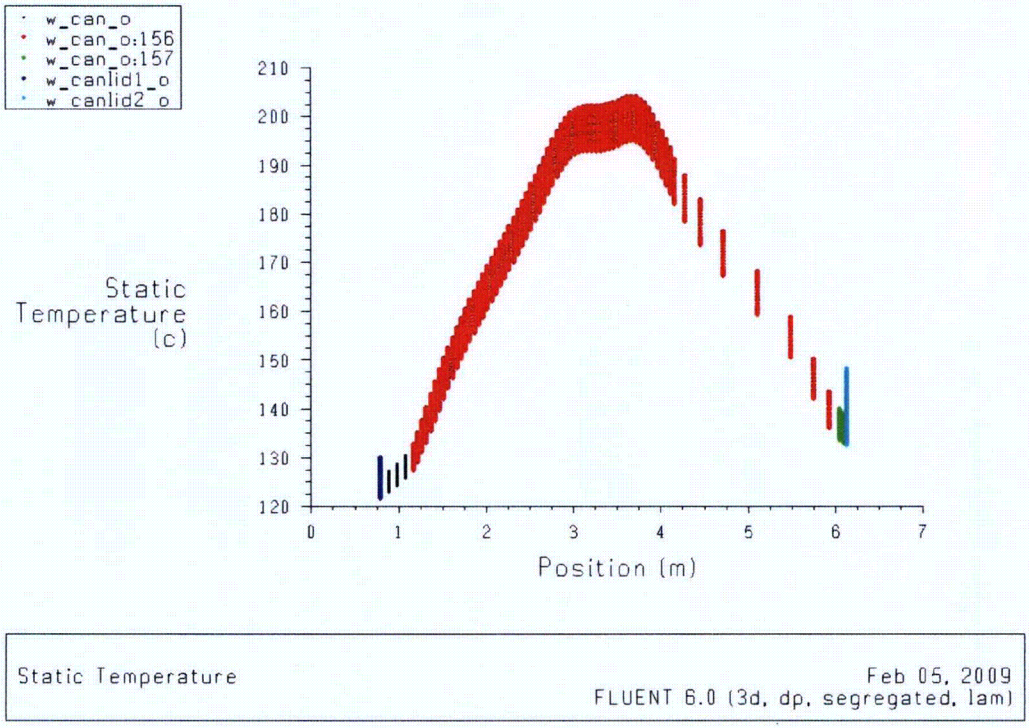

Figure 5. Temperature Distribution along the Length of the Naval Long Canister Outer Surface (Case 2.3_5)

Note: w_can_o:#: canister outer surface w_canlid#_o: canister lid outer surface

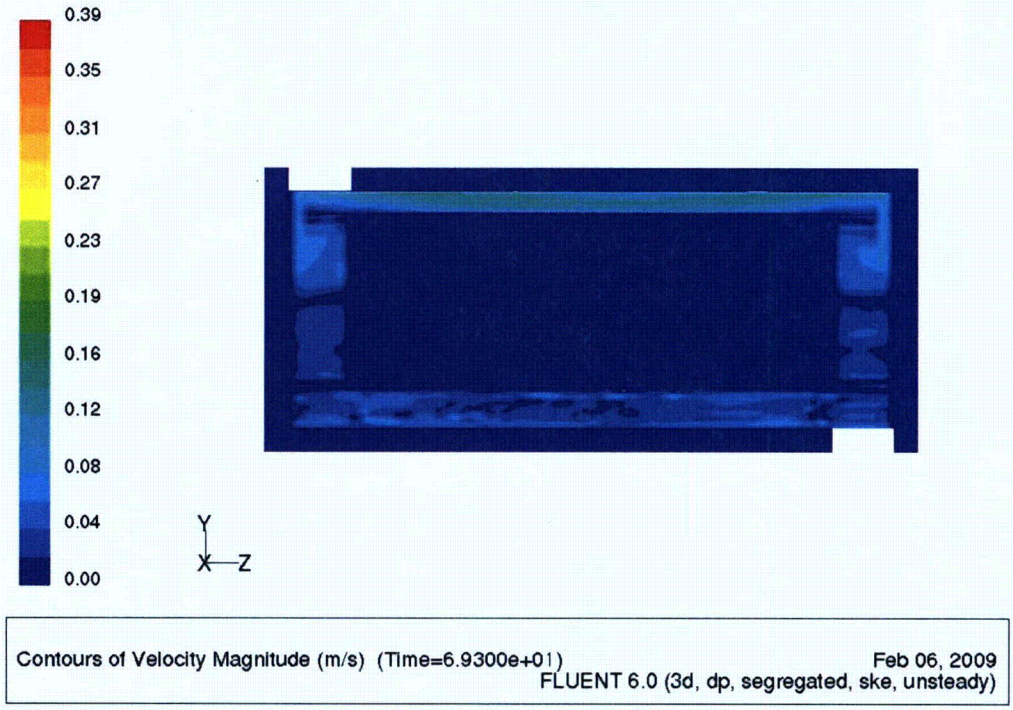

Figure 6. Velocity Contours on the Symmetry Plan for Naval Short Waste Package in the TEV (Case 2.3_5) (time is in seconds)

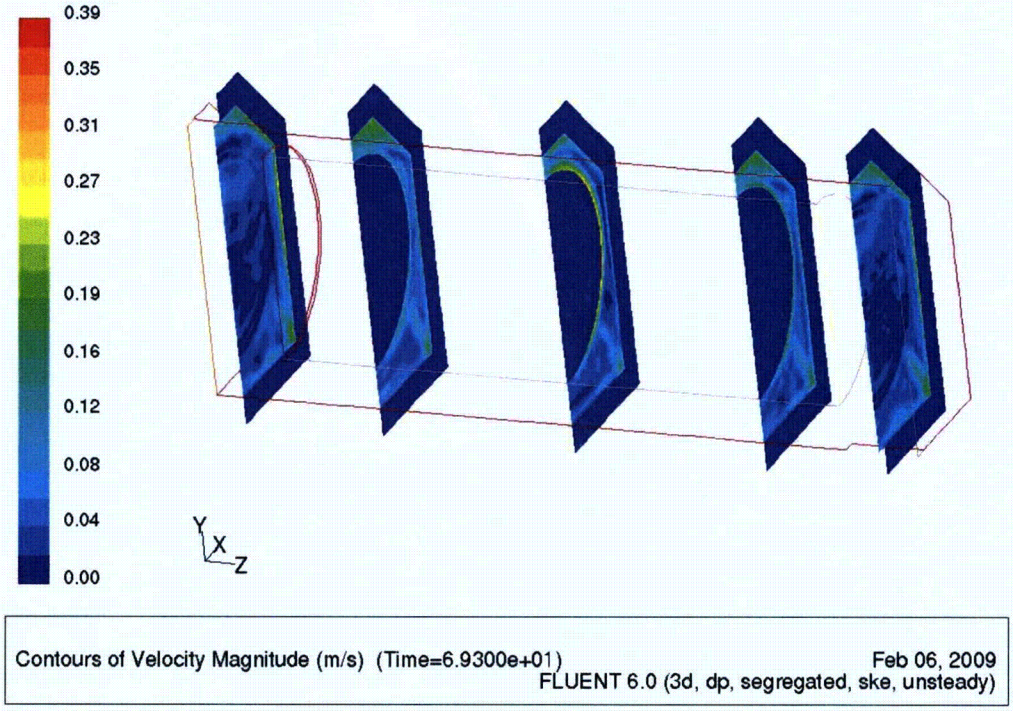

Figure 7. Velocity Contours on the Cross Sections for Naval Short Waste Package in the TEV (Case 2.3_5) (time is in seconds)

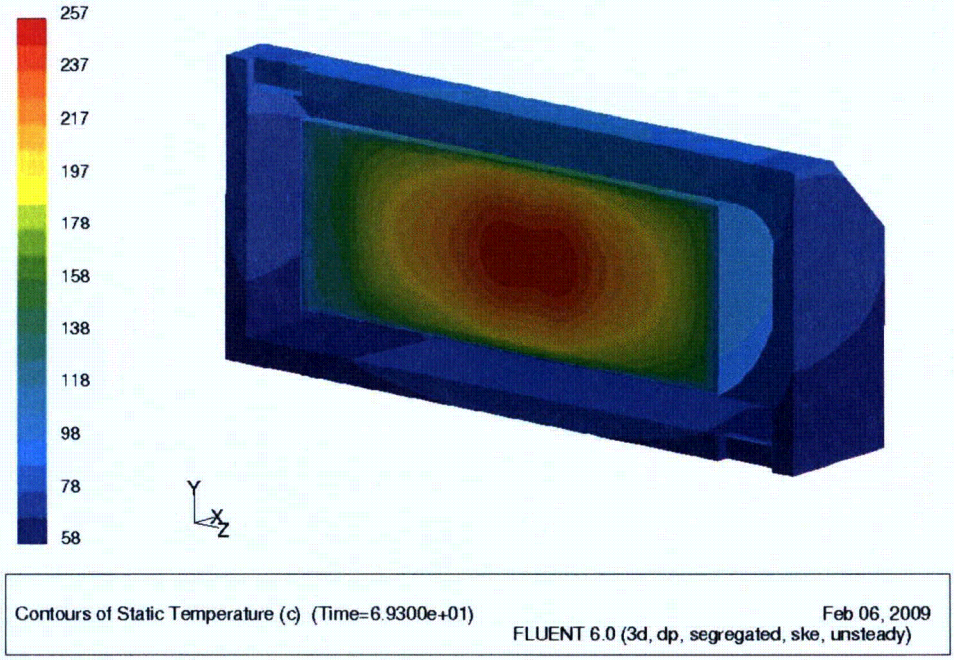

Figure 8. Temperature Contours for Naval Short Waste Package in the TEV- with natural convection (Case 2.3_5) (time is in seconds)

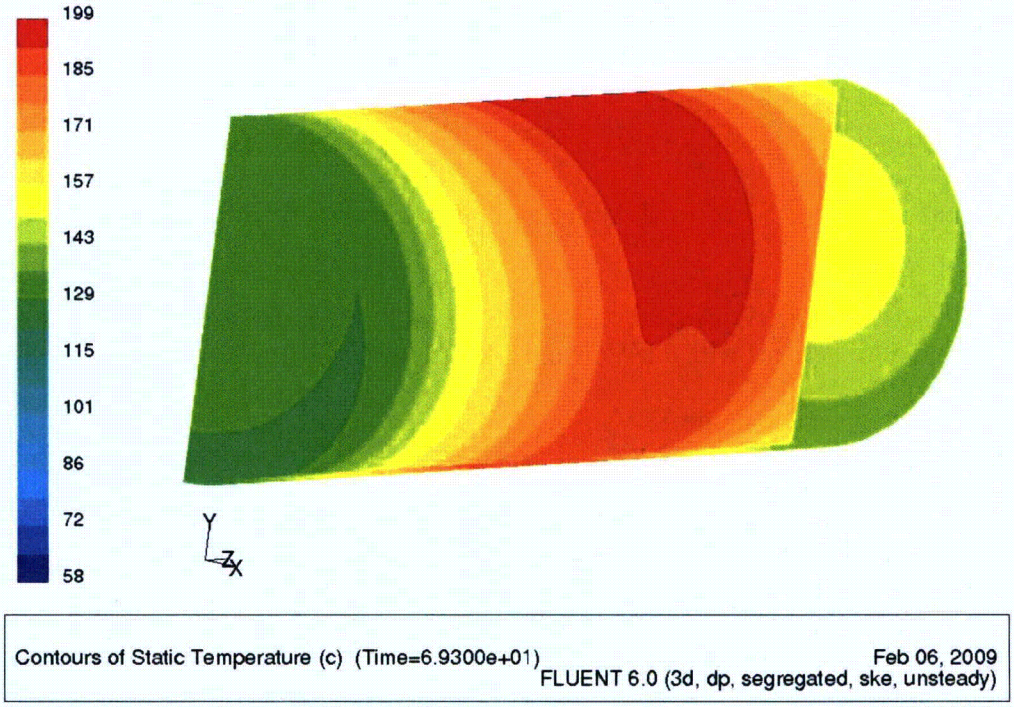

Figure 9. Temperature Contours of the Naval Short Canister Outer Surface – with natural convection (Case 2.3_5) (time is in seconds)

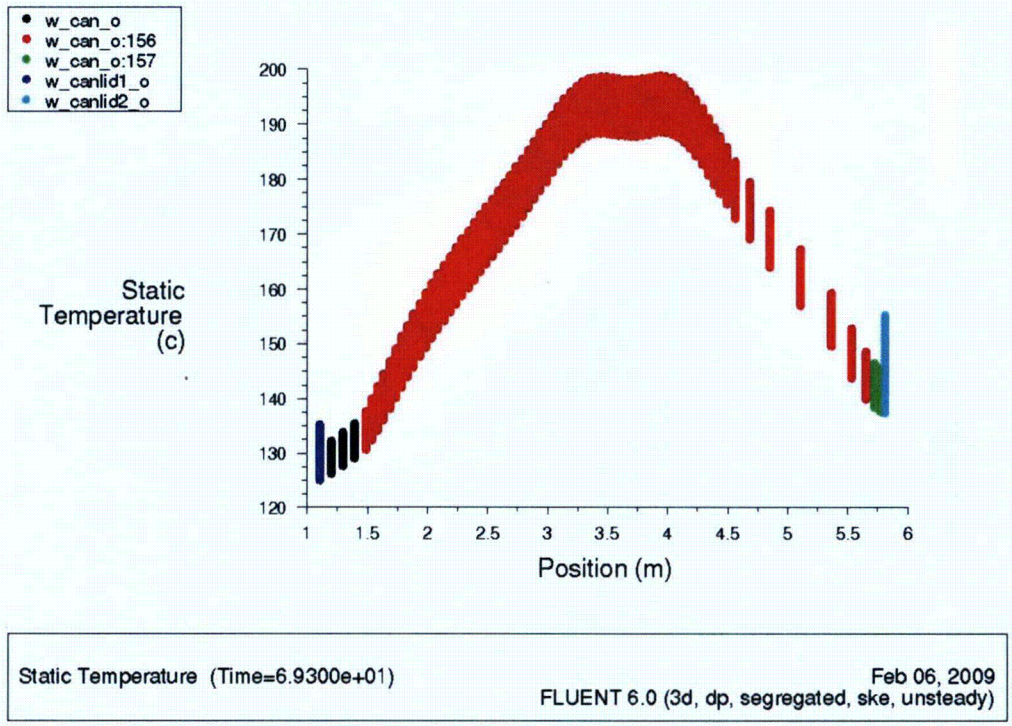

Figure 10. Temperature Distribution along the Length of the Naval Short Canister Outer Surface – with natural convection (Case 2.3_5) (time is in seconds)

Note: w_can_o:#: canister outer surface w_canlid#_o: canister lid outer surface

7.3 CONCLUSIONS

Naval Long Waste Package in the TEV

- All cases satisfy the thermal limits without taking credit of natural convection inside TEV.
- The cases with 5 kW/m peak (Cases 2.3_5 and 3.3_5) have the highest temperatures compared to the ones with 3 kW/m and 1 kW/m peaks.

Naval Short Waste Package in the TEV

- All cases except for the ones with 5 kW/m peak (Cases 2.3_5 and 3.3_5) can satisfy the temperature limits without taking credit of natural convection inside the TEV. The canister temperature limits are satisfied when natural convection is included for Cases 2.3_5 and 3.3_5. The canister temperatures are reduced by 9°C for both cases.
- The natural convection inside the TEV removes about 23% of the heat generated by the naval canister. The overall heat transfer coefficients on the waste package and TEV inner surface are both around 3 $W/m^2 \cdot K$.