ENG.20080213.0005

BSC	Design Calculation or Analysis Cover Sheet *Complete only applicable items.*	1. QA: QA 2. Page 1

3. System	4. Document Identifier
DOE and Commercial Waste Package	000-00C-DS00-01200-000-00A
5. Title	
WHF and RF Thermal Evaluation	
6. Group	
Thermal/Structural Analysis and Engineering/Mechanical	
7. Document Status Designation	
☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded	
8. Notes/Comments	
N/A	

	Attachments	Total Number of Pages
I	Thermal Conductivity Values	2
II	Average Wall Temperatures from Room 1023 of CRCF-1 in Normal Conditions	1
III	CD	N/A

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	35	35	Matthew Hinds entire document except Table 1 and Section 6.5 2/12/08 Steven McNiven Steven Simner Table 1 2/13/08 Delwin Mecham Section 6.5 2/12/08	Bryan Dunlap entire document except Table 1 2/12/08 Daryl Lopez Table 1 for Daryl Lopez 2/13/08	for Michael Anderson Delwin Mecham entire document except Table 1 2/13/08 Maurice LaFountain Table 1 2-13-08	Michael Anderson entire document except Table 1 2/13/08 Hadi Jalali Table 1 02/13/08

DISCLAIMER

CONTENTS

TABLES

FIGURES

ACRONYMS

AO	aging overpack
CRCF	Canister Receipt and Closure Facility
CTM	canister transfer machine
DPC	dual-purpose canister
ITS	Important to Safety
NRC	U.S. Nuclear Regulatory Commission
PWR	pressurized water reactor
RF	Receipt Facility
SAR	Safety Analysis Report
SNF	spent nuclear fuel
STC	shielded transfer cask
TAD	transportation, aging, and disposal canister
TC	transfer cask
WHF	Wet Handling Facility
YMP	Yucca Mountain Project

1. PURPOSE

The purpose of this analysis is to estimate the peak fuel assembly cladding temperature within the transportation casks that will be received in the WHF and RF, and to compare this value with established temperature limits. Thermally limiting scenarios are evaluated for both normal and off-normal operating conditions, with the off-normal condition defined as a loss of active ventilation.

A second purpose of this analysis is to identify a specific room in the surface facilities as thermally limiting of all the rooms, with respect to the potentially highest temperatures on the concrete walls. The thermal response of the walls due to radiative heat transfer from the casks inside is judged based on the interior geometry of each room. The rooms are compared on the basis of their dimensions, as well as the distance of the walls to standard positioning of casks inside.

The aging overpack is not included in this analysis, as it has not yet been designed. According to the current mechanical equipment envelope for the aging overpack design (Ref. 2.2.16), it will be designed with vent openings, aiding in ventilation heat dissipation.

The shielded transfer casks and the shield bell of the canister transfer machine are not included in this analysis, as they have not yet been designed.

2. REFERENCES

2.1 PROJECT PROCEDURES/DIRECTIVES

2.1.1 EG-PRO-3DP-G04B-00037, Rev. 10. *Calculations and Analyses*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071018.0001

2.1.2 IT-PRO-0011, Revision 7, ICN 0. *Software Management.* Las Vegas, NV: BSC. ACC: DOC.20070905.0007

2.1.3 ORD (Office of Repository Development) 2007. *Repository Project Management Automation Plan.* 000-PLN-MGR0-00200-000-00E. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: ENG.20070326.0019

2.2 DESIGN INPUTS

2.2.1 BSC (Bechtel SAIC Company) 2007. *Thermal Evaluation of the CRCF-1 Lower Transfer Room Cells.* 060-00C-DS00-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071002.0053

2.2.2 ASME (American Society of Mechanical Engineers) 2001. *2001 ASME Boiler and Pressure Vessel Code (includes 2002 addenda).* New York, New York: American Society of Mechanical Engineers. TIC: 251425

2.2.3 Incropera, F.P. and DeWitt, D.P. 1996. *Introduction to Heat Transfer.* 3rd Edition. New York, New York: John Wiley & Sons. ISBN: 0-471-30458-1. TIC: 241057

2.2.4 Thompson, T.C. 2003. "NAC-STC Safety Analysis Report, Revision 14." Letter from T.C. Thompson (NAC International) to the NRC, June 18, 2003, with enclosures. TIC: 255255 [DIRS: 169362]

2.2.5 Haynes International 1997. Hastelloy C-22 Alloy. Kokomo, Indiana: Haynes International. TIC: 238121 [DIRS: 100896]

2.2.6 BSC (Bechtel SAIC Company) 2007. *Basis of Design for the TAD Canister-Based Repository Design Concept.* 000-3DR-MGR0-00300-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071002.0042; ENG.20071108.0002; ENG.20071109.0001; ENG.20071120.0023; ENG.20071126.0049; ENG.20071214.0009; ENG.20071213.0005; ENG.20071227.0018; ENG.20080207.0004; ENG.20080212.0003.

2.2.7 BSC (Bechtel SAIC Company) 2007. *Wet Handling Facility General Arrangement Legend and General Notes.* 050-P10-WH00-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071206.0031

2.2.8 BSC (Bechtel SAIC Company) 2007. *Wet Handling Facility General Arrangement Ground Floor Plan.* 050-P10-WH00-00102-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071206.0032; ENG.20071226.0001; ENG.20080121.0014; ENG.20080121.0015.

2.2.9 BSC (Bechtel SAIC Company) 2007. *Wet Handling Facility General Arrangement Plan Below El +40'–0".* 050-P10-WH00-00103-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071206.0033; ENG.20071226.0002.

2.2.10 BSC (Bechtel SAIC Company) 2007. *Wet Handling Facility General Arrangement Sections F and G.* 050-P10-WH00-00110-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071206.0040

2.2.11 BSC (Bechtel SAIC Company) 2007. *Receipt Facility General Arrangement Legend and General Notes.* 200-P10-RF00-00101-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071212.0010

2.2.12 BSC (Bechtel SAIC Company) 2007. *Receipt Facility General Arrangement Ground Floor Plan.* 200-P10-RF00-00102-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071212.0011; ENG.20080122.0012.

2.2.13 BSC (Bechtel SAIC Company) 2007. *Receipt Facility General Arrangement Second Floor Plan.* 200-P10-RF00-00103-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071212.0012

2.2.14 BSC (Bechtel SAIC Company) 2007. *Receipt Facility General Arrangement Sections A and B.* 200-P10-RF00-00106-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071212.0015

2.2.15 BSC (Bechtel SAIC Company) 2007. *Receipt Facility General Arrangement Sections C and D.* 200-P10-RF00-00107-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071212.0016

2.2.16 BSC (Bechtel SAIC Company) 2007. *Aging Facility Vertical DPC Aging Overpack*. 170-MJ0-HAC0-00201-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070928.0032

2.2.17 NAC (Nuclear Assurance Corporation) 2004. "NAC-STC NAC Storage Transport Cask, Revision 15." Volume 1 of *Safety Analysis Report.* Docket No. 71-9235. Norcross, Georgia: NAC International. TIC: 257644 [DIRS: 175039]

2.2.18 NAC (Nuclear Assurance Corporation) 2002. *Safety Analysis Report for the NAC-UMS Universal Transport Cask.* Revision 1. EA790-SAR-001. Docket No. 71-9270. Volume 1. Norcross, Georgia: Nuclear Assurance Corporation International. TIC: 257643 [DIRS: 175038]

2.2.19 Holtec International 2003. *Storage, Transport, and Repository Cask Systems, (Hi-Star Cask System) Safety Analysis Report, 10 CFR 71, Docket 71-9261.* HI-951251, Rev. 10. [Marlton, New Jersey]: Holtec International. ACC: MOL.20050119.0271 [DIRS: 172633]

2.2.20 Chopra, U.B. 2003. "Application for Renewal of NUHOMS® Certificate of Compliance (CoC) No. 9255 for the NUHOMS MP187 Package and Submittal of a Consolidated SAR for the NUHOMS® MP187 Package, Revision 17." Letter from U.B. Chopra (Transnuclear) to M.J. Ross-Lee (NRC), August 4, 2003, NUH05-03-01, with enclosures. TIC: 257825. [DIRS: 175448]

2.2.21 Mason, M. 2001. "NUHOMS-MP197 Transport Packaging Safety Analysis Report." Letter from M. Mason (Transnuclear) to E.W. Brach (NRC), May 2, 2001, E-21135, with enclosures. TIC: 255258. [DIRS: 179205]

2.2.22 Transnuclear 2001. *TN-68 Transport Packaging Safety Analysis Report, Revision 4.* Hawthorne, New York: Transnuclear. TIC: 254025 [DIRS: 160746]

2.2.23 BNFL Fuel Solutions 2003. *FuelSolutions™ TS125 Transportation Cask Safety Analysis Report, Revision 5.* Document No. WSNF-120. Docket No. 71-9276. Campbell, California: BNFL Fuel Solutions. TIC: 257634 [DIRS: 175040]

2.2.24 Sisley, S.E. 2002. "Transportation License Application for the FuelSolutions™ System (TAC No. L23311) Submittal of the FuelSolutions™ Transportation SARs, Revision 3." Letter from S.E. Sisley (BNFL) to U.S. Nuclear Regulatory Commission, April 11, 2002, BFS/NRC 02-011, Docket No. 71-9276, File No. CMPC.0006.3, with enclosures. TIC: 255246. [DIRS: 170407]

2.2.25 Sisley, S.E. 2002. "Transportation License Application for the FuelSolutions™ System (TAC No. L23311), Submittal of the FuelSolution™ Transportation SARs, Revision 3." Letter from S.E. Sisley (BNFL) to the NRC, April 11, 2002, BFS/NRC 02-011, with enclosures. TIC: 255245. [DIRS: 171545]

2.2.26 FLUENT V. 6.0.12. 2003. HP-UX 11.00. STN: 10550-6.0.12-00. [DIRS 163001]

Information from Safety Analysis Reports of shipping cask vendors (Refs. 2.2.4, 2.2.17, 2.2.18, 2.2.19, 2.2.20, 2.2.21, 2.2.22, 2.2.23, and 2.2.25) was used as direct input to this calculation. Therefore, these are suitable for use in this calculation. Information from other shipping cask vendors (Ref. 2.2.24) is used as indirect input to this calculation.

2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

None. However, this calculation will be used as supporting information for the YMP License Application.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 WHF Room Dimensions, Names, and Numbers

The WHF room dimensions, names, and numbers used are assumed to be the same as those indicated in References 2.2.7, 2.2.8, 2.2.9 and 2.2.10, and are assumed to be the same as the final definitive design.

Rationale: The design is preliminary, and will require verification upon the final definitive design.

3.1.2 RF Room Dimensions, Names, and Numbers

The RF room dimensions, names, and numbers used are assumed to be the same as those indicated in References 2.2.11, 2.2.12, 2.2.13, 2.2.14 and 2.2.15, and are assumed to be the same as the final definitive design.

Rationale: The design is preliminary, and will require verification upon the final definitive design.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Heat Transfer Effect

In the comparison of thermal resistance across the walls of each cask in Section 6.1, heat transfer is represented as steady-state, one-dimensional conduction only. In the comparison of thermal resistance across the wall of the TS-125 cask due to a change in fill gas in the canister-cask gap in Section 6.3.2, heat transfer is represented as steady-state, one-dimensional conduction only through the solid layers, with conduction and radiation in parallel through the gap.

Rationale: Neglecting transient effects, axial conduction, and convective heat transfer greatly simplifies the calculation, and produces defensibly conservative results.

3.2.2 Constant Thermal Conductivity

All thermal conductivity values are assumed to be constant over the range of temperature analyzed.

Rationale: This simplifies the calculation, and the small changes in thermal conductivity over the relevant temperatures would have a minimal impact on results.

3.2.3 Thermal Performance of Transportation Casks

Of the casks which may be received in the WHF or RF (Sections 5.2.1.1.4 and 6.2.1.1.3 of Ref. 2.2.6, respectively), the rail transportation casks are included in this analysis (NAC-STC, NAC-UMS, Hi-Star 100, MP-187, MP-197, TN-68 and TS-125), and the truck transportation casks are not (GA-4, GA-9 and NAC-LWT).

The TAD transportation cask is not included in this analysis. The TAD transportation cask has not yet been designed. However, it is assumed that it will be designed to comply with applicable temperature limits.

Rationale: The rail transportation casks listed above each contain a significantly greater number of fuel assemblies than the truck transportation casks. This means the rail casks possess a higher generated thermal power than, and therefore bound the thermal performance of, the truck transportation casks.

3.2.4 Gap Between Canister and Cask Wall

It is assumed that the canister and inside cask wall do not touch, whether in a horizontal orientation (as in the transportation licensing basis) or in a vertical orientation (as in surface facility unloading conditions).

Rationale: Whether in horizontal or vertical orientation, contact between the canister and inner cask wall is expected. This greatly aids in conductive heat transfer through the cask wall. However, in order to avoid the uncertainty involved in quantifying the effect of conductive heat transfer through a contact surface, the calculation is greatly simplified with the assumption of no physical contact. This is a conservative simplification, since combined conductive and radiative heat transfer through a fill gas is less effective at dissipating heat than conduction through a contact surface between two metals.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037 (Ref. 2.1.1). The WHF and RF structures are classified as ITS in the *Basis of Design for the TAD Canister-Based Repository Design Concept* (Ref. 2.2.6, Sections 5.1.2 and 6.1.2 respectively). Therefore, the approved version of this document is designated as QA: QA.

4.2 USE OF SOFTWARE

The commercially available Microsoft Excel 2003 spreadsheet code is used to perform simple calculations in Sections 6.1 and 6.3.2. Use of Microsoft Excel in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Ref. 2.1.2, Section 1.2). Microsoft Excel 2003 is listed in the Repository Project Management Automation Plan (Ref. 2.1.3, Table 6-1). Microsoft Excel 2003 was executed on a PC running the Microsoft Windows XP Professional operating system. Hand calculations were performed for simple problems and to verify Excel spreadsheet results.

FLUENT Version 6.0.12 software (Ref. 2.2.26), which is identified by the Software Tracking Number 10550-6.0.12-00, was used to extract the information in Attachment II from electronic files on DVD-ROM attached to Ref. 2.2.1. The files contain results from a qualified FLUENT calculation documented in Ref. 2.2.1. However, in this calculation using the software simply to extract information from existing results files constitutes Level 2 usage, as defined in IT-PRO-0011 (Ref. 2.1.2, Attachment 12). FLUENT was executed on the following Hewlett-Packard (HP) 9000 Series workstation running operating system HP-UX 11.00: Central Processing Unit (CPU) Name: Portnoy, Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) Tag Number: 150691. Access to, and use of, the code for this calculation was granted by Software Configuration Management in accordance with the appropriate procedures. The information extracted using FLUENT was visually verified.

4.3 METHOD

Of the transportation casks that will be received in the WHF and RF (per Ref. 2.2.6, Sections 5.2.1.1.4 and 6.2.1.1.3 respectively), the thermally limiting cask is identified through a comparison on the bases of the maximum thermal power each cask is licensed to contain, as well as the resistance to heat dissipation across each cask wall. The thermal resistance of the cask wall is determined with a one-dimensional steady-state conduction heat transfer representation.

4.3.1 Normal Conditions of Cask Unloading

For the purpose of this calculation, the normal condition of cask unloading is conservatively defined as the following. In Room 1023 of CRCF-1, the cask is oriented vertically and its lid is removed, releasing the helium in the gap between the canister and cask. All rooms in the WHF and RF, in which a loaded cask is expected, are considered thermally bounded by Room 1023 of CRCF-1. The cask is allowed to achieve thermal equilibrium, with active cooling from ventilation in the room.

The peak cladding temperature of a fuel assembly contained in the thermally limiting transportation cask, as calculated in the SAR for the cask, is used as a reference. The difference in canister shell temperature between the transportation licensing scenario and the normal scenario of cask unloading is conservatively evaluated using a one-dimensional steady-state conduction-only calculation through the cask solid layers. For the gap between the canister and cask, a conductive and radiative heat transfer calculation is included, to account for the presence of the fill gas. The calculated difference in canister shell temperature is assumed to be the same as the difference in peak fuel assembly temperature within the canister, relative to the transportation licensing case. This value is added to the peak fuel assembly temperature from the thermally limiting transportation cask SAR to yield the expected peak fuel assembly temperature in a cask subject to normal unloading conditions. This value is then compared to the established limit of 400 °C (Ref. 2.2.6, Section 11.2.2.4).

4.3.2 Off-Normal Conditions of Cask Unloading

The off-normal condition of cask unloading is defined as a failure of the ventilation system, resulting in the absence of forced convection cooling. Ref. 2.2.1 contains a calculation of surface temperatures in Room 1023 of CRCF-1, in the normal condition scenario with ventilation, as well as in the off-normal scenario of a loss of ventilation for 30 days. The difference in these temperatures is applied to the cask outer surface temperature in the licensing scenario. When re-calculated with the same simplified cask representation as in Section 4.3.1, a new canister shell temperature for the off-normal condition is approximated. Applying the difference of normal and off-normal canister shell temperatures to the peak cladding temperature, yields the peak cladding temperature for the off-normal condition. The estimated peak fuel assembly cladding temperature in the off-normal condition is then compared to the established limit of 570 °C (Ref. 2.2.6, Section 11.2.2.4).

4.3.3 Concrete Wall Temperature Comparison

To identify the thermally limiting room in the surface facilities in terms of concrete wall temperature, the rooms are compared on the basis of their dimensions, as well as the distance of the walls to standard positioning of casks or canisters inside. The layouts of the WHF and RF are each evaluated to determine the locations of casks or canisters relative to the walls under normal operating conditions.

5. ATTACHMENTS

ATTACHMENT I	Thermal Conductivity Values [2 pages]
ATTACHMENT II	Average Wall Temperatures from Room 1023 of CRCF-1 in Normal Conditions
ATTACHMENT III	CD, contains spreadsheet file `trans_cask_02_11_2008.xls`

6. CALCULATION

6.1 SELECTION OF A THERMALLY LIMITING TRANSPORTATION CASK

In order to identify the thermally limiting (potentially hottest) transportation cask to be received in the WHF or the RF, the seven rail casks listed in Table 1 (see Assumption 3.2.3) are compared on the following two bases:

1) the maximum thermal power with which each has been licensed to ship, and
2) the resistance to heat dissipation through the cask wall

Conservatively assuming all heat is transferred radially outward, the product of the thermal resistance across the cask wall and the maximum thermal power generated within the cask will yield a representative temperature drop expected across the composite cask wall. Assuming only one-dimensional, steady-state, conduction heat transfer through the solid layers of the wall, the thermal resistance of each layer is defined by the following (Ref. 2.2.3, p. 92) (see Assumption 3.2.1):

$$R_c \equiv \frac{\Delta T}{Q} = \frac{\ln(r_o/r_i)}{2\pi L_{act} k} \qquad \text{Equation 1}$$

where:
- R_c = thermal resistance to conductive heat transfer (K/W)
- ΔT = temperature drop across the layer (°C)
- Q = total thermal power generated (W)
- L_{act} = axial active heat-generating length = 150 in. (3.81 m) (Ref. 2.2.25, p. 3.1-6)
- r_i = inner radius of the layer (m)
- r_o = outer radius of the layer (m)
- k = thermal conductivity within the layer (W/m/K)

Figure 1 shows the equivalent thermal circuit representing the solid layers of the cask wall. The thermal resistance to conductive heat transfer through the entire composite wall is the sum of the values for each of the four layers (Ref. 2.2.3, p. 78). Since all the casks listed in Table 1 have similar helium-filled gaps between the canister and the inner shell of the transportation cask, and since these temperature values are only used to compare the casks, the insulating effect of the gap between the canister and cask wall is neglected. The insulating effect of any gaps between solid layers within the cask wall is also neglected. This calculation is performed in the spreadsheet file `trans_casks_02_11_2008.xls`, included on CD Attachment III.

As shown in Table 1, the FuelSolutions TS-125 transportation cask has the highest representative temperature drop, and is therefore selected as the thermally limiting transportation cask.

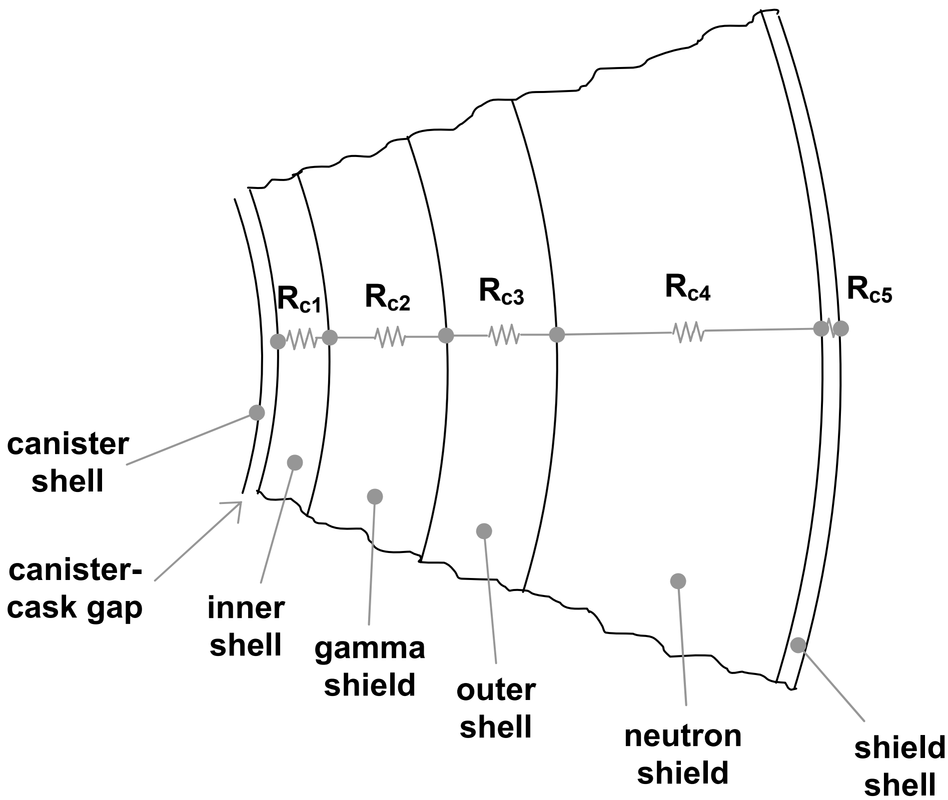

Figure 1. Representative transportation cask wall, showing effective thermal circuit.

Table 1. Transportation cask comparison

Cask Type (see Assumption 3.2.3)	Cask Dimensions (in.)			Cask Wall Materials and Dimensions (in.)					Reference	Effective Thermal Resistance (K/W)	Maximum Thermal Power (kW)	Repres-entative ΔT (C)
	Inner Diameter	Outer Diameter	Overall Length	Inner Shell	Gamma Shield	Outer Shell	Neutron Shield	Shield Shell				
NAC-STC	71.00	99.10	193.00	Type 304 SS 1.50	Lead 3.7	Type 304 SS 2.65	NS-4-FR composite (see Table 6) 5.5	Type 304 SS 0.25	Ref. 2.2.17, Sections 1.2 and 1.3.2	1.13e-3	22.1	25.0
NAC-UMS	67.61	92.90	209.30	Type 304 SS 2.00	Lead 2.75	Type 304 SS 2.8	NS-4-FR composite (see Table 6) 4.5	Type 304 SS 0.25	Ref. 2.2.18, Sections 1.2 and 1.3.2	1.01e-3	20	20.2
Hi-Star 100	68.56	96.00	203.25	SA-203E 2.50	SA-516 Gr. 70 6.00	N/A	Holtite-A composite (see Table 6) 4.72	SA-515 Gr. 70 0.50	Ref. 2.2.19, Sections 1.2 and 1.4	1.60e-3	20	32.0
MP-187	68.00	92.50	201.50	XM-19 SS 1.25	Lead 4.00	XM-19 SS 2.50	NS-3 composite (see Table 6) 4.31	304 SS 0.19	Ref. 2.2.20, Sections 1.2 and 1.3.2	3.32e-3	13.5	44.8
MP-197	68.00	91.50	208.00	XM-19 SS 1.25	Lead 3.25	316 SS 2.50	Borated Polyester composite (see Attachment I) 4.56	304 SS 0.19	Ref. 2.2.21, Sections 1.2 and 1.4	1.58e-3	15.9	25.2
TN-68*	69.50	98.00	197.25	SA-203E 1.50	SA-266 Cl. 2 6.00	N/A	Borated Polyester composite (see Attachment I) 6.00	SA-516 Gr. 70 0.75	Ref. 2.2.22, Sections 1.2 and 1.4	1.41e-3	21.2	30.0
TS-125	67.00	94.20	210.40	XM-19 SS 1.50	Lead 3.25	XM-19 SS 2.65	NS-4-FR composite (see Table 6) 6.00	SA-516 Gr. 70 0.19	Ref. 2.2.23, Sections 1.2 and 1.3	4.20e-3	22	92.5

* As described in Section 6.4.1.2, operations in the WHF and RF include removing the lid of transportation casks containing DPCs, allowing the helium fill gas to be replaced with air which has a significantly lower thermal conductivity, thereby resulting in higher internal temperatures. Transportation casks containing bare SNF (such as the TN-68 cask) also contain helium fill gas, but upon receipt in the WHF these casks are filled with water (prior to transfer into the WHF pool), which subsequently expels and replaces the helium gas. As such transportation casks with bare SNF are not subject to the same air-filled bounding conditions as the transportation casks loaded with DPCs.

6.2 TRANSPORTATION CASK LICENSING BASIS

The thermally limiting transportation cask received in the WHF and RF is a FuelSolutions TS-125 rail transportation cask. To represent the interior of the cask, a FuelSolutions W21 dual-purpose canister is selected. Of the FuelSolutions W21 and W74 dual-purpose canister types the TS-125 cask is licensed to ship, the W21 canister is selected because it contains the majority of PWR fuel assembly types (Ref. 2.2.25, pp. 1.2-21 through 1.2-26; Ref. 2.2.24, pp. 1.2-25 through 1.2-27). The following summarizes the thermally limiting calculation case in the SAR for the FuelSolutions W21 canister, as shipped in a TS-125 transportation cask (Ref. 2.2.25):

- three-dimensional finite element representation
- 22 kW thermal power within
- horizontal orientation
- 100 °F (38 °C) bulk air temperature used to represent free convection heat transfer from the outer surface of the transportation cask
- 100 °F (38 °C) external temperature used to represent radiative heat transfer from the outer surface of the transportation cask
- direct sunlight (insolation considered)
- convection cells in the helium fill gas of the W21 canister itself
- helium fill gas in the gap between the canister and the cask
- canister and cask are assumed not to be in physical contact, even though a horizontal orientation guarantees a significant contact surface

According to the SAR, these conditions result in the following temperatures:

- 200 °F transportation cask outer surface temperature (Ref. 2.2.25, p. 3.4-32)
- 464 °F canister shell temperature (Ref. 2.2.25, p. 3.4-16)
- 343.1 °C peak fuel assembly cladding temperature within the canister (Ref. 2.2.25, p. 3.4-16)

6.3 CASK WALL REPRESENTATION

The difference in peak fuel assembly cladding temperature between the transportation license basis scenario as represented in the SAR of the W21 canister and the received casks placed in Room 1023 can be conservatively estimated with the same one-dimensional steady-state calculation used in Section 6.1, with the inclusion of conductive and radiative heat transfer across the canister-cask gap, to account for the presence of the fill gas. This calculation is performed in the spreadsheet file `trans_casks_02_11_2008.xls`, included on CD Attachment III, and is graphically shown in Figure 2.

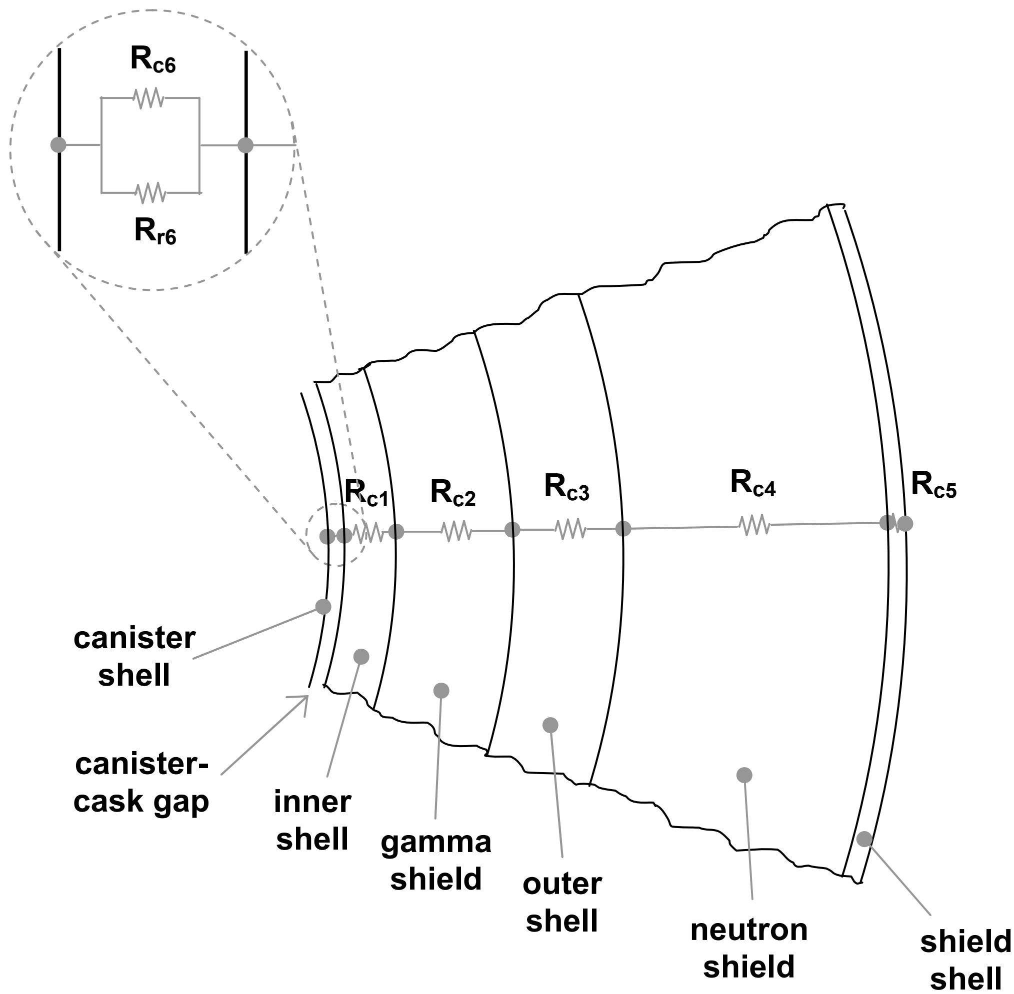

Figure 2. Representative transportation cask wall, showing effective thermal circuit (gap included)

In the solid layers of the composite cask wall, one-dimensional conductive heat transfer is represented by Equation 2 (Ref. 2.2.3, p. 99):

$$T_i = T_o + \frac{Q \cdot PF}{2\pi L_{act} k} \cdot \ln\left(\frac{r_o}{r_i}\right) \qquad \text{Equation 2}$$

where:
T_i = temperature on inner surface of layer (solid or gas) (°C)
T_o = temperature on outer surface of layer (solid or gas) (°C)
Q = total fuel assembly thermal power generation (W)
PF = fuel assembly axial power peaking factor
L_{act} = active thermal power-generating length (m)
k = thermal conductivity of solid wall (W/m/K)
r_o = outer radius of solid wall (m)
r_i = inner radius of solid wall (m)

In the gap between the canister and cask, radiative heat transfer is represented by Equation 3 (Ref. 2.2.3, p. 699), which is solved concurrently with Equation 2:

$$T_i = \left\{T_o^{\,4} + \frac{Q \cdot PF}{2\pi L_{act} r_i \sigma} \cdot \left[\frac{1}{\varepsilon_i} + \frac{1-\varepsilon_o}{\varepsilon_o} \cdot \left(\frac{r_i}{r_o}\right)\right]\right\}^{\frac{1}{4}} \qquad \text{Equation 3}$$

where:
ε_o = emissivity on outer surface
ε_i = emissivity on inner surface
σ = Stefan-Boltzmann constant = 5.67e-8 $W/m^2/K^4$

Given the outer surface temperature, an inner surface temperature value is numerically determined through resolution of the total heat transfer across the gap into conductive and radiative components.

6.3.1 Benchmark with FuelSolutions W21 canister SAR Results

The canister shell temperature determined with the one-dimensional calculation method described above, representing helium in the canister-cask gap, is compared with the canister shell temperature given in the SAR for the FuelSolutions W21 canister. The TS-125 cask dimensions and materials from Table 1 were used, along with the following information, as input to the calculation of canister shell temperature in Attachment II:

fuel assembly axial power peaking factor	1.095	(Ref. 2.2.25, p. 3.1-8)
active fuel length	150 in. (3.81 m)	(Ref. 2.2.25, p. 3.1-6)
outer surface temperature	200 °F (93.33 °C)	(Ref. 2.2.25, p. 3.4-32)

emissivity of inner surface of gap	0.4	(Ref. 2.2.23, p. 3.2-5; Ref. 2.2.25, p. 3.4-5)
emissivity of outer surface of gap	0.4	(Ref. 2.2.23, p. 3.2-5; Ref. 2.2.25, p. 3.4-5)

The canister shell temperature calculated in Attachment III with helium in the canister-cask gap is 246.4 °C (475.5 °F). In the SAR, the calculated canister shell temperature is 464 °F (Ref. 2.2.25, p. 3.4-16). The ~12 °F difference between the two values validates this method for the purpose of demonstrating a change in effective resistance to heat dissipation through the cask wall.

6.4 CASK UNLOADING: NORMAL CONDITION (WITH VENTILATION)

A conservative estimate is made of the peak fuel assembly cladding temperature occurring within the W21 canister subject to normal conditions of unloading from the TS-125 cask in the WHF and RF. Using the peak fuel assembly temperature value from the licensing basis calculation in the W21 SAR as a reference temperature, the peak fuel assembly temperature occurring during normal conditions of cask unloading is determined through a comparison of the transportation licensing basis scenario and the normal conditions of cask unloading. For the purpose of this calculation, the normal condition of cask unloading is defined as the following:

- In Room 1023 of CRCF-1, the cask is oriented vertically and its lid is removed, releasing the helium in the gap between the canister and cask. All rooms in the WHF or RF are considered thermally bounded by Room 1023 of CRCF-1, since it is the smallest room that accomodates transportation casks, which leads to higher temperatures on interior radiating surfaces (Ref. 2.2.1, p. 38).

- The cask is then allowed to achieve thermal equilibrium, with active cooling from ventilation in the room.

The differences between the transportation licensing basis and the normal condition of cask unloading are enumerated in Sections 6.4.1 and 6.4.2, along with the net effect of each on cask outer surface temperature, canister shell temperature, and/or peak fuel assembly cladding temperature. Effects that are known to be beneficial (resulting in lower temperatures in the normal conditions of cask unloading than in the licensing basis scenario) are not quantified, and therefore not included in the result. Detrimental effects (resulting in higher temperatures in the normal conditions of cask unloading than in the licensing basis scenario) are conservatively bounded using simplifying assumptions. The end result therefore represents multiple conservative factors.

6.4.1 Normal Conditions: Detrimental Effects Represented

6.4.1.1 Radiative heat transfer from the outer surface of the transportation cask

In the transportation licensing basis calculation, radiative heat transfer is represented between the cask outer surface and an ambient temperature of 100 °F (38 °C).

In order to represent radiative heat transfer from the cask outer surface in the normal condition of cask unloading, an average wall temperature is taken from Ref. 2.2.1. Wall temperatures are extracted from the following FLUENT results files from Ref. 2.2.1, Attachment V, DVD 1 of 2:

```
crcf_1022_1023_18000_2451.cas
crcf_1022_1023_18000_2451.dat
crcf_1022_1023_25000_3287.cas
crcf_1022_1023_25000_3287.dat
```

The average temperatures (K) on each of the six walls of Room 1023 of CRCF-1 (depicted on pp. 40 and 69 of Ref. 2.2.1) in the 18 kW case and the 25 kW case are listed in Attachment II. Converting to (°F), the average of all six walls in the 18 kW case is 106.6 °F, and the average of all six walls in the 25 kW case is 117.4 °F. Interpolating between the two to approximate the value that would result from a 22 kW case, yields an average wall temperature of about 113 °F.

Radiative heat transfer therefore occurs between the cask outer surface and an ambient environment at an average of 113 °F, which is 13 °F hotter than the ambient environment in the transportation licensing scenario.

To produce a simple bounding result (higher temperatures than in reality), the cask outer surface temperature taken from the transportation licensing case is therefore increased by 13 °F and applied as the cask outer surface temperature in this calculation. The actual cask outer surface temperature will be significantly lower. Using this adjusted cask outer surface temperature, a new higher canister shell temperature is calculated in the spreadsheet file. The difference between this canister shell temperature and the canister shell temperature from the benchmark of the transportation licensing case is then assumed to be the difference in peak fuel assembly cladding temperature within the canister, due to the increased temperature on the outer surface of the cask. The approximate net difference in cask outer surface temperature, canister shell temperature, and peak fuel assembly cladding temperature due to this effect are listed in Table 2.

6.4.1.2 Fill gas in the gap between canister and cask

Casks containing DPCs are licensed to ship with a helium backfill gas to provide adequate thermal conductivity, in addition to a chemically inert environment, between the cask wall and the DPC within. Normal operations in the WHF and RF include the removal of the cask lid, allowing the helium to be replaced by air which has a significantly lower thermal conductivity than helium, resulting in a higher resistance to heat dissipation.

In the spreadsheet file in Attachment III, the helium fill gas is replaced with air, and a new higher canister shell temperature is calculated. The difference between this canister shell temperature and the canister shell temperature from the benchmark of the transportation licensing case is then assumed to be the difference in peak fuel assembly cladding temperature within the canister, due to the change from helium to air in the canister-cask gap. The approximate net difference in cask outer surface temperature, canister shell temperature, and peak fuel assembly cladding temperature due to this effect are listed in Table 2.

6.4.2 Normal Conditions: Beneficial Effects Neglected

6.4.2.1 Free convection heat transfer from the outer surface of the transportation cask

The transportation licensing basis calculation accounted for the effect of free convection heat dissipation from the cask outer surface to a bulk air temperature of 100 °F (38 °C). According to p. 63 of Ref. 2.2.1, the average air temperature in Room 1023 of CRCF-1 is 89.5 °F (31.9 °C), which in the normal condition of cask unloading would provide greater heat dissipation through free convection heat transfer than the air temperature of 100 °F in the licensing case. However, since the same cask outer surface temperature from the licensing case is applied to the outer surface of the cask in this calculation (with the addition of 13 °F, as explained in Section 6.4.2.4), the increased heat dissipation resulting from free convection to the lower indoor air temperature is not represented. A realistically lower surface temperature should be explicitly calculated in the future from a three-dimensional finite element calculation representing all three heat transfer modes.

6.4.2.2 Forced convection heat transfer from the outer surface of the transportation cask

The transportation licensing basis calculation did not represent heat dissipation from the outer surface of the cask through forced convection due to wind. There will be active cooling by ventilation in the normal condition of cask unloading, resulting in lower temperatures in the normal condition of cask unloading than in the transportation licensing basis. However, since the same cask outer surface temperature from the licensing case is applied to the outer surface of the cask in this calculation (with the addition of 13 °F, as explained in Section 6.4.2.4), the increased heat dissipation resulting from active cooling by ventilation is not represented. A realistically lower surface temperature should be explicitly calculated in the future from a three-dimensional finite element calculation representing all three heat transfer modes.

6.4.2.3 Insolation (direct sunlight)

In the transportation licensing basis calculation the cask is subject to heat flux from the sun. In this calculation the cask is inside the building, therefore no insolation heat flux is applicable. However, since the same cask outer surface temperature from the licensing case is applied to the outer surface of the cask in this calculation (with the addition of 13 °F, as explained in Section 6.4.2.4), effectively the insolation heat flux is still being applied. A realistically lower surface temperature should be explicitly calculated in the future from a three-dimensional finite element calculation representing all three heat transfer modes.

6.4.2.4 Radiative heat transfer from the outer surface of the transportation cask

In the transportation licensing basis calculation, radiative heat transfer was represented between the cask outer surface and an ambient temperature of 100 °F (38 °C). As described in Section 6.4.1.1, the average wall temperature in Room 1023 of CRCF-1 is about 113 °F. The 13 °F difference on the concrete walls is directly applied to the cask outer surface temperature. Although it is necessarily bounding of (higher than) the surface temperature, this approach does not correctly represent radiative heat transfer. A realistically lower surface temperature should be explicitly calculated in the future from a three-dimensional finite element calculation representing all three heat transfer modes.

6.4.2.5 Convective cooling out of the open top of the cask

In the transportation licensing basis the cask lid is attached. In the normal condition of cask unloading the lid is removed, and the cask is vertically oriented, allowing convective cooling out of the open top of the cask. However, since the cask outer surface temperature from the licensing case is applied to the outer surface of the cask in this calculation (with the addition of 13 °F, as explained in Section 6.4.2.4), and the calculation neglects three-dimensional heat transfer, the convective cooling is not represented. Effectively the lid is still on, but the helium in the gap has been replaced with air. The convective cooling effect should be evaluated in the future using a three-dimensional finite element calculation representing all three heat transfer modes.

6.4.2.6 Conductive heat transfer due to physical contact of the canister with the cask wall

Whether in a horizontal or vertical orientation, gravity will ensure physical contact between the canister and the cask wall, in both the normal condition of cask unloading and in the transportation licensing basis scenario. The contact surface thus created will provide a path for conductive heat dissipation through the cask wall. However, in order to avoid the uncertainty involved in quantifying the effect of conductive heat transfer through the contact surface, the calculation is conservatively simplified with the assumption of no physical contact (see Assumption 3.2.4).

To provide more margin to the design limit, this effect should be represented in the future in a three-dimensional finite element calculation including all three heat transfer modes.

6.4.2.7 Linearization of heat transfer effects within the canister

As described in Sections 6.4.1.1 and 6.4.1.2, the difference in canister shell temperature calculated between the cask unloading scenario and the transportation licensing basis scenario is added directly to the peak fuel assembly cladding temperature from the licensing case, to produce the conservative bound of peak fuel assembly cladding temperature expected during loading conditions. However, due to the significant occurrence of all three modes of heat transfer within the canister, including heat generation within the fuel rods, the relationship between canister shell temperature and peak fuel assembly cladding temperature is non-linear, and the resulting increase in peak fuel assembly cladding temperature will necessarily be less than the increase in canister shell temperature.

To provide more margin to the design limit, this effect should be represented in the future in a three-dimensional finite element calculation including all three heat transfer modes.

6.4.2.8 Transient period required to reach thermal equilibrium

Both the normal condition of cask unloading and the transportation licensing basis scenario are presented in a state of thermal equilibrium. From the moment a transportation cask is placed into normal conditions of cask unloading, the maximum peak fuel assembly cladding temperature may not be reached for many hours. If time limits were applied to operations, additional margin to temperature limits could be ensured.

6.4.3 Result for Normal Conditions of Cask Unloading

Applying the detrimental effects described in Section 6.4.1, and neglecting the beneficial effects described in Section 6.4.2, the total conservative difference estimated in Attachment III is +59.8 °C, which when added to 343.1 °C from Section 6.2, results in a peak fuel assembly cladding temperature of 402.9 °C. Since this is very close to the NRC limit of 400 °C (Ref. 2.2.6, Section 11.2.2.4), additional margin may be quantified in the future through detailed analysis of each of the neglected ‘beneficial effects’ listed in Section 6.4.2.

6.5 CASK UNLOADING: OFF-NORMAL CONDITION (LOSS OF VENTILATION)

The off-normal condition of cask unloading is defined as a failure of the ventilation system, resulting in the absence of forced convection cooling. Ref. 2.2.1 contains a calculation of surface temperature on a transfer trolley containing a waste package generating 25 kW. The transfer trolley is represented in Room 1023 of CRCF-1, in normal conditions with ventilation, as well as in the off-normal scenario of loss of ventilation. The difference in the transfer trolley surface temperature in normal and off-normal conditions is 81.5 °C (Ref. 2.2.1, pp. 66 and 87).

To assess the impact of loss of ventilation in this calculation, this 81.5 °C increase is applied to the cask outer surface temperature used in the normal conditions of cask unloading. Since the maximum thermal power allowed in the TS-125 cask is 22 kW, applying the increase in temperature on the surface of the transfer trolley containing a waste package generating 25 kW is conservative. Adding 81.5 °C to the outer surface temperature of the TS-125 cask, then re-calculating in the spreadsheet file, yields a canister shell temperature of 362.1 °C for off-normal conditions, which is 55.9 °C higher than for normal conditions. Applying this difference to the peak fuel assembly cladding temperature calculated for normal conditions yields 402.9 + 55.9 = 458.8 °C for the off-normal condition, well below the NRC peak fuel assembly cladding temperature limit of 570 °C (Ref. 2.2.6, Section 11.2.2.4).

6.6 SUMMARY OF CASK EVALUATION

Table 2 summarizes the results of the cask evaluation. As discussed in Sections 6.4 and 6.5, the beneficial effects (resulting in lower temperatures in the normal conditions of cask unloading than in the licensing basis scenario) are not quantified, and therefore not included in the end result. Detrimental effects (resulting in higher temperatures in the normal conditions of cask unloading than in the licensing basis scenario) are conservatively bounded using simplifying assumptions. The resulting value of peak fuel assembly cladding temperature therefore represents multiple conservative factors, and it is slightly over the prescribed limit. In the future, a three-dimensional finite element representation including all three modes of heat transfer could quantify the beneficial effects enumerated in Section 6.4.2, resulting in a more accurate peak temperature below the limit.

Table 2. Summary of results

	Effect	How assessed in the transportation licensing basis calculation	How assessed in this calculation	Cask Outer Surface Temperature	Canister Surface Temperature	Peak Fuel Assembly Cladding Temperature
			Transportation Licensing Base Case Results	**200 °F (93.3 °C)**	**475.5 °F (246.4 °C)**	**649.6 °F (343.1 °C)**
Normal Conditions	Radiative heat transfer from the outer surface of the transportation cask	Represented between the cask outer surface temperature and an ambient temperature of 100 °F (38 °C)	To produce a simple bounding result (higher temperatures than in reality), the cask outer surface temperature taken from the transportation licensing case is increased by 13 °F and applied as the cask outer surface temperature in this calculation. The actual cask outer surface temperature will be significantly lower. The peak fuel assembly cladding temperature is then re-calculated.	**+ 13 °F (+ 7.2 °C)**	**+ 11.8 °F (+ 6.6 °C)**	**+ 11.8 °F (+ 6.6 °C)**
Normal Conditions	Fill gas in the gap between canister and cask	The gap between the canister and cask is filled with helium	The cask lid is removed, releasing the helium in the canister-cask gap and replacing it with air. Air has a much lower thermal conductivity, resulting in a higher resistance to heat dissipation.	**(no difference)**	**+ 107.6 °F (+ 59.8 °C)**	**+ 107.6 °F (+ 59.8 °C)**
Normal Conditions	Other beneficial effects neglected (see Section 6.4.2)			**— (some number)**	**— (some number)**	**— (some number)**
			Result for Normal Conditions of Cask Unloading	**213 °F (100.5 °C)**	**583.2 °F (306.2 °C)**	**757.2 °F (402.9 °C)**
Off-Normal Conditions	Loss of active cooling by ventilation	(N/A)	The difference between the transfer trolley tube surface temperatures in the normal and off-normal cases in Ref. 2.2.1 is applied to the cask outer surface. The peak fuel assembly cladding temperature is then re-calculated.	**+ 146.7 °F (+ 81.5 °C)**	**+ 95.8 °F (+ 53.2 °C)**	**+ 95.8 °F (+ 53.2 °C)**
Off-Normal Conditions	Loss of active cooling by ventilation	(N/A)	The waste package inside the transfer trolley tube is generating 25 kW, therefore it is conservative to use this temperature on the surface of a cask containing waste form generating 22 kW. However, the transfer trolley tube has a larger outer surface. This is a secondary effect, since the end result is so far below the established off-normal criterion (458.8 °C << 570 °C).	**(secondary effect)**	**(secondary effect)**	**(secondary effect)**
			Result for Off-Normal Conditions of Cask Unloading	**359.7 °F (182.1 °C)**	**683.8 °F (362.1 °C)**	**857.8 °F (458.8 °C)**

6.7 SELECTION OF A THERMALLY LIMITING ROOM FOR CONCRETE WALL THERMAL RESPONSE

The layouts of the WHF and RF were each evaluated to determine the locations of casks under normal operating conditions. Table 3 shows which casks are contained in which rooms in the WHF, and includes rooms dimensions and distance from the center of the cask to the nearest wall. Table 4 shows the same for the RF. Figure 3 and Figure 4 show the layouts for WHF and RF.

Table 5 lists and compares heat transfer parameters at the facility walls for all cases considered in Table 3 and Table 4. It is shown in Table 5 that the distance to the wall for all of the cases considered for the WHF and RF is always greater than the distance to the wall in Room 1022 of CRCF-1. The heat flux in all of the cases is also less than the heat flux in Room 1022 of CRCF-1. Therefore, the results for Room 1022 of CRCF-1 are bounding for concrete thermal response. Reference 2.2.1 concluded that in normal and off-normal conditions there will be local hot spots above the limits on some of the concrete walls, but thermal shields can be used in the final design to obtain satisfactory thermal performance in the affected structures.

Table 3. Waste Form Configuration in WHF

WHF Case	Waste Form	Room Number	Height (ft-in)	Width (ft-in)	Length (ft-in)	Center line to wall (ft-in)
W1	One AO with TAD or DPC (at aging overpack access platform)	1023	44’ 5”	66’	72’	23’
W2	One AO with TAD or DPC (in the cask loading room)	1007	28’	33’	49’	20’
W3	One TC with DPC or one STC with TAD or DPC (in the cask unloading room)	1008	28’	23’	49’	20’ -6”
W4	One STC with DPC (at DPC cutting station)	1016	78’	208’	100’	13’
	One STC with TAD (at TAD closure station)					
	One TC with bare fuel (at preparation station #1)					
W5	One DPC or TAD in the CTM (in the canister transfer room)	2004	66’	114’	53’	20’ -6”

Dimensions taken from Ref. 2.2.7, 2.2.8, 2.2.9, and 2.2.10 (see Assumption 3.1.1)

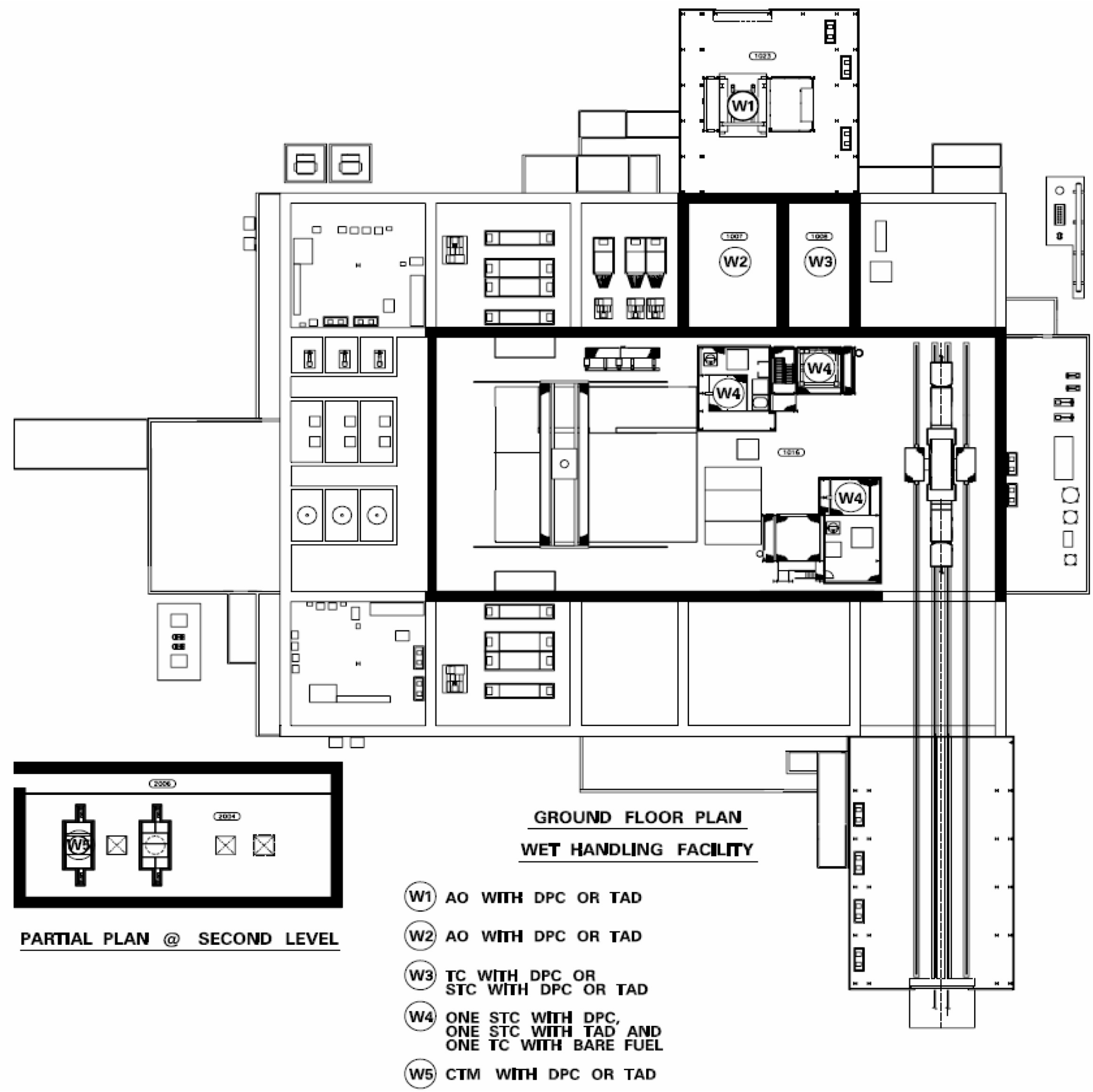

Figure 3. Waste Form Locations in WHF (Ref. 2.2.8)

Table 4. Waste Form Configuration in RF

RF Case	Waste Form	Room Number	Height (ft-in)	Width (ft-in)	Length (ft-in)	Center line to wall (ft-in)
R1	One TC with TAD or DPC (in transportation cask vestibule)	1021A	36’	45’	79’	9’-1”
R2	One TC with TAD or DPC (in transportation cask vestibule annex)	1021	30’-6”	42’	48’	9’-5”
R3	One TC with TAD or DPC (in cask preparation annex)	1017A	30’-6”	28’	42’	9’-5”
R4	One TC with TAD or DPC (in cask preparation room)	1017	70’-6”	70’	87’	20’
R5	One TC with TAD or DPC (in cask unloading room)	1015	28’	37’	37’	15’
R6	One AO with TAD or DPC (in loading room)	1013	28’	37’	42’	15’
R7	One AO with TAD or DPC (in lid bolting room)	1002	62’6”	39’	42’	16’
R8	One AO with TAD or DPC (in site transporter vestibule)	1001	30’-3”	35’	42’	14’
R9	One TAD or DPC in CTM (in canister transfer room)	2007	66’-6”	70’	101’	21’

Dimensions taken from Ref. 2.2.11, 2.2.12, 2.2.13, 2.2.14, and 2.2.15(see Assumption 3.1.2)

Figure 4. Waste Form Locations in RF (Ref. 2.2.12)

Table 5. Comparison of Heat Transfer Parameters at Facility Walls

Case	Facility	Room	Height-(ft)	Width (ft)	Length (ft)	Area (ft^2)	Q (kW)	Q/A (W/ft^2)	CL to Wall (ft)	Q/A ratio (Q/A divided by Q/A for Reference Case)
REFERENCE CASE[a]	CRCF	1022	28	11	28	2800	25	8.929	5.5[b]	1.000
W1	WHF	1023	44.4	66	72	21758.4	25	1.149	23	0.129
W2	WHF	1007	28	33	49	7826	25	3.194	20	0.358
W3	WHF	1008	28	23	49	6286	25	3.977	20.5	0.445
W4	WHF	1016	78	208	100	89648	25	0.279	13	0.031
W5	WHF	2004	66	114	53	34128	25	0.733	20.5	0.082
R1	RF	1021A	36	45	79	16038	25	1.559	9.1	0.175
R2	RF	1021	30.5	42	48	9522	25	2.625	9.4	0.294
R3	RF	1017A	30.5	28	42	6622	25	3.775	9.4	0.423
R4	RF	1017	70.5	70	87	34317	25	0.729	20	0.082
R5	RF	1015	28	37	37	6882	25	3.633	15	0.407
R6	RF	1013	28	37	42	7532	25	3.319	15	0.372
R7	RF	1002	62.5	39	42	13401	25	1.866	16	0.209
R8	RF	1001	30.25	35	42	7598.5	25	3.290	14	0.368
R9	RF	2007	66.66	70	101	36937.72	25	0.677	21	0.076

[a]Data taken from Ref. 2.2.1; Tables 4 & 5

[b]CL distance in CRCF is taken as ½ the room width for room 1022 from Ref. 2.2.1; Table 4

7. CONCLUSIONS

Through identification of a thermally limiting transportation cask, and simplified conservative comparisons of the licensed transportation base case of the cask, the peak fuel assembly cladding temperature occurring within any of the transportation casks expected to be received in the WHF or RF is estimated. Thermally limiting scenarios are evaluated for both normal operating conditions, defined as removal of the cask lid and allowing thermal equilibrium with the indoor environment with active ventilation, and off-normal conditions, defined as the accidental loss of ventilation.

The simplifying assumptions made herein were intended to conservatively bound the comparison between the transportation licensing basis scenario and the normal operating conditions in the surface facilities. A number of significant effects that would otherwise aid in heat dissipation were neglected. The resulting peak fuel assembly cladding temperature value therefore represents multiple conservative factors.

Within the unopened helium-filled cask, the steady-state peak fuel assembly cladding temperature at the maximum rated thermal power of 22 kW is 349.7 °C (from Table 2, representing only the effect of moving the cask indoors), well below the 400 °C limit. When opened, letting air replace helium in the gap between the DPC and the cask, the peak cladding temperature is conservatively shown to reach 402.9 °C, very close to the limit of 400 °C. Significant additional margin is available and will be quantified in the future using a three-dimensional finite element representation including all three modes of heat transfer. This will incorporate the neglected 'beneficial effects' listed in Section 6.4.2, resulting in a more accurate peak temperature below 400 °C.

Through conservative application of differences in surface temperatures in normal and off-normal conditions from existing calculations, the steady-state peak fuel assembly cladding temperature at the maximum rated thermal power of 22 kW in the limiting cask is estimated to be 459 °C during off-normal conditions (the canister-cask gap filled with air, as well as a loss of ventilation), well below the 570 °C limit.

Room 1022 of CRCF-1 is identified as thermally limiting of all rooms in the WHF or RF for the purposes of concrete wall thermal response, due to its size and the expected distance between casks and the walls. This room is thermally limiting for the off-normal condition, in which radiative heat transfer is the only mode with which to dissipate heat from containers inside. However, although this room is still most likely bounding for normal conditions, the ventilation air flow impact will be evaluated further during detailed design to qualify the effect on concrete wall temperature during normal operating conditions. Concrete wall temperatures were shown in Ref. 2.2.1 to exceed established limits in small areas, in normal and off-normal conditions, but thermal shields can be used in the final design to obtain satisfactory thermal performance in the affected structures.

ATTACHMENT I – THERMAL CONDUCTIVITY VALUES

Table 6. Thermal conductivity of cask and canister materials

Material	Thermal Conductivity (W/m/K) (see Assumption 3.2.2)	Reference
304 and 304L SS	14.87	Ref. 2.2.2; Section II, Part D, Table TCD, p. 663 (material group J)
316 SS	14.19	Ref. 2.2.2; Section II, Part D, Table TCD, p. 663 (material group K)
XM-19 SS	11.08	Ref. 2.2.2; Section II, Part D, Table TCD, p. 663 (material group L)
Lead	31.4	Ref. 2.2.3; Table A.1, p. 746
NS-4-FR	0.65	Ref. 2.2.4; Table 3.2-1
Alloy 22	10.1	Ref. 2.2.5, Page 13; this data is from the vendor of Alloy 22, and therefore is suitable for use in this calculation
Aluminum 6061	166	Ref. 2.2.2; Section II, Part D, Table TCD, A96061
A 516 Carbon Steel, SA-515 Gr. 70, SA-516 Gr. 70, SA-266 Cl.2, and SA-203 E	47.04	Ref. 2.2.2; Section II, Part D, Table TCD, p. 662 (material group B), minimum below 300 F
NAC-STC Neutron Shield Structure	7.04	Ref. 2.2.17; Sections 3.3.2, 3.4.1.1.1.3, and Table 3.2-1
NAC-UMS Neutron Shield Structure	7.89	Ref. 2.2.18; Sections 1.2.1.2.1, 3.3.2, 3.4.1.1.1, and Table 3.2-1
Hi-Star 100 Neutron Shield Structure	3.14	Ref. 2.2.19; Sections 1.2.1.4.2, Table 3.4-8, and dwg. 3913 (sheet 6)
MP-187 Neutron Shield Structure	1.47	Ref. 2.2.20; Section 3.2.1.2.1, Tables 3.2-1 and 3.5-5, and dwg. NUH-05-4001 (sheet 6 of 6)
TS-125 Neutron Shield Structure	1.56	Ref. 2.2.23; Sections 1.2.1.1, 3.1.1.1, 3.1.4, Table 3.2-1, and dwg. FS-210 (sheet 3 of 9)

Table 7. Thermal conductivity of fill gases

Fill Gas	Thermal Conductivity (W/m/K)	Reference
Helium	0.204	Ref. 2.2.3, p. 759 (@ 450 K)
Air	0.037	Ref. 2.2.3, p. 757 (@ 450 K)

Calculation of Effective Thermal Conductivities for MP-197 and TN-68

Effective thermal conductivity values for the MP-197 and TN-68 neutron shielding structures are not available in references but can be calculated as follows.

The MP-197 cask has 0.12-inch aluminum fins spaced 6 inches apart (Ref. 2.2.21; dwg. 1093-71-5). The TN-68 cask has 0.12-inch aluminum fins spaced about 5 inches apart (Ref. 2.2.22; Figure 3-1). Thermal conductivity of the NS-4-FR material is taken as 0.65 W/m/K and for aluminum is 166 W/m/K (see Table 6). The effective thermal conductivity is the width-weighted average:

$$k_{eff} = \frac{w_{al}k_{al} + w_{poly}k_{poly}}{w_{al} + w_{poly}}$$

$$k_{eff,\mathrm{MP-197}} = \frac{(6)(0.65) + (0.12)(166)}{6 + 0.12} = 3.89 \;\; W/m/K$$

$$k_{eff,\mathrm{TN-68}} = \frac{(5)(0.65) + (0.12)(166)}{5 + 0.12} = 4.52 \;\; W/m/K$$

ATTACHMENT II – AVERAGE WALL TEMPERATURES FROM ROOM 1023 OF CRCF-1 IN NORMAL CONDITIONS

The following are the average temperature values (K) on each of the six walls of Room 1023 of CRCF-1 during normal loading conditions in the 18 kW case (generated using FLUENT to extract results from Ref. 2.2.1, Attachment V, DVD 1 of 2, files: `crcf_1022_1023_18000_2451.cas` and `crcf_1022_1023_18000_2451.dat`):

```
(cx-gui-do cx-activate-item  "Surface Integrals*PanelButtons*PushButton1(OK)")

           Area-Weighted Average
              Static Temperature                    (k)
-------------------------------- --------------------
                surf_in_1023_clg            313.70963
               surf_in_1023_door            314.58185
                surf_in_1023_flr            313.65637
                  surf_in_1023_n            314.73111
                  surf_in_1023_s            316.65829
                  surf_in_1023_w            314.31488
                             Net            314.57947
(cx-gui-do cx-activate-item "MenuBar*WriteSubMenu*Stop Transcript")
```

The following are the average temperature values (K) on each of the six walls of Room 1023 of CRCF-1 during normal loading conditions in the 25 kW case (generated using FLUENT to extract results from Ref. 2.2.1, Attachment V, DVD 1 of 2, files: `crcf_1022_1023_25000_3287.cas` and `crcf_1022_1023_25000_3287.dat`):

```
(cx-gui-do cx-activate-item "Surface Integrals*PanelButtons*PushButton1(OK)")

           Area-Weighted Average
              Static Temperature                    (k)
-------------------------------- --------------------
                surf_in_1023_clg            319.47464
               surf_in_1023_door            320.68448
                surf_in_1023_flr            319.32687
                  surf_in_1023_n              321.258
                  surf_in_1023_s            323.25537
                  surf_in_1023_w             319.7254
                             Net            320.57968
(cx-gui-do cx-activate-item "MenuBar*WriteSubMenu*Stop Transcript")
```