TRANSNUCLEAR
AN AREVA COMPANY

February 22, 2007
E-24675

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

Subject: Revision 5 to Application for Amendment 1 to TN-68 CoC 1027
Docket 72-1027, TAC L23802

Gentlemen:

Transnuclear, Inc. herewith submits Revision 5 to its application for Amendment 1 to TN-68 CoC 72-1027. Based on recent discussions with the NRC staff, this revision makes changes Updated Final Safety Analysis Report chapters 4 and 9 to regarding TN-68 cask thermal view factors, and neutron absorber testing, respectively.

Should you or your staff require additional information, please do not hesitate to contact me at 410-910-6930 or Mr. Don Shaw at 410-910-6878.

Sincerely,

Robert Grubb
Senior Vice President - Engineering

cc: Mr. Jose Cuadrado (NRC SFST), with eight printed copies of Enclosures 1 and 2 and one compact disc containing Enclosures 1 and 2, all provided in a separate mailing

cc: (without enclosures)

Jeff Gagne, Transnuclear
David Shortes, Exelon

Enclosures:

1. List of Enclosed UFSAR pages
2. Replacement UFSAR pages

7135 Minstrel Way, Suite 300, Columbia, MD 21045
Phone: 410-910-6900 ◆ Fax: 410-910-6902

NMSS01

List of Enclosed UFSAR pages

List of Enclosed UFSAR pages

- Chapter 4 Table of Contents first page, Rev 0, unchanged (front side of second TOC page)
- Chapter 4 Table of Contents second page, Rev 5, changed due to shifting of Sections 4.10.2 and 4.10.3 (back side of first TOC page)

- Chapter 4 Table of Contents page with List of Tables and List of Figures, Rev 5, changed due to new tables and figures (front side of page 4.1-1)
- 4.1-1, Rev 0, unchanged (back side of page showing Table of Contents page with List of Tables and List of Figures)

- 4.10-2, Rev 5, changed with addition of Section 4.10.1.1 (front side of page 4.10-3)
- 4.10-3, Rev 5, changed with addition of Section 4.10.1.1 (back side of page 4.10-2)

- 4.10-4, Rev 5, changed with addition of Section 4.10.1.1 (front side of page 4.10-5)
- 4.10-5, Rev 5, changed with addition of Section 4.10.1.1 (back side of page 4.10-4)

- 4.10-6, Rev 5, information unchanged but this page was created by addition of Section 4.10.1.1 (front side of page 4.10-7)
- 4.10-7, Rev 5, information unchanged but this page was created by addition of Section 4.10.1.1 (back side of page 4.10-6)

- 4.11-1, Rev 0, unchanged former back side of page 4.10-4 (front side of an intentionally blank page)
- Page annotated "Intentionally Blank" (back side of page 4.11-1)

- 4.12-1, Rev 0, unchanged (front side of page 4.13-1)
- 4.13-1, Rev 5, changed due to addition of Section 4.10.1.1 (back side of page 4.12-1)

- Table 4.10-3, Rev 5, new table referenced from new Section 4.10.1.1 (front side of an intentionally blank page)
- Page annotated "Intentionally Blank" (back side of page 4.11-1)

- Figure 4.10-2, Rev 5, new figure referenced from new Section 4.10.1.1
- The back of Figure 4.10-2 is blank and not annotated, per the previous convention.

- Figure 4.10-3, Rev 5, new figure referenced from new Section 4.10.1.1
- The back of Figure 4.10-3 is blank and not annotated, per the previous convention.

- 9.1-5, Rev 3, unchanged (front side of page 9.1-6)
- 9.1-6, Rev 5, changed regarding neutron absorber testing (back side of page 9.1-5)

- 9.4-1, Rev 0, unchanged (front side of page 9.4-2)
- 9.4-2, Rev 5, changed regarding neutron absorber testing (back side of page 9.4-1)

- 9.4-3, Rev 5, changed regarding neutron absorber testing (front side of page 9.4-4)
- 9.4-4, Rev 3, unchanged (back side of page 9.4-3)

Replacement UFSAR pages

TABLE OF CONTENTS

SECTION PAGE

TABLE OF CONTENTS

SECTION PAGE

LIST OF TABLES

LIST OF FIGURES

CHAPTER 4

THERMAL EVALUATION

4.1 Discussion

The TN-68 cask is designed to passively reject decay heat under normal storage, accident, and loading/unloading conditions while maintaining temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to cask material limits to ensure components perform their intended safety functions;
- Determination of temperature distributions to support the calculation of thermal stresses;
- Determination of maximum cask internal pressures for normal, off-normal, and accident conditions, and
- Determination of the maximum fuel cladding temperature, and to confirm that this temperature will remain sufficiently low to prevent unacceptable degradation of the fuel during storage.

To establish the heat removal capability, several thermal design criteria are established for the system. These are:

- Maximum temperatures of the containment structural components must not adversely affect the containment function.
- A maximum fuel cladding temperature limit of 752°F (400°C) is considered for normal conditions of storage and for short-term storage operations such as vacuum drying. During off-normal storage and accident conditions, the fuel cladding temperature limit is 1058°F (570°C). These limits are based on the NRC recommendations in ISG-11, rev. 3 [1].
- A maximum temperature limit of 536°F (280°C) is set for the Helicoflex seals (double metallic seals) in the containment vessel closure lid to satisfy the leak tight containment function.
- A maximum allowable temperature of 300°F (149°C) is considered for the radial neutron shield. The maximum allowable limit for the top neutron shield is 220°F (104°C) for long term and 300°F (149°C) for short term conditions.
- The minimum and maximum ambient temperatures during handling and storage are -20°F (-29°C) and 115°F (46°C) respectively. In general, all the thermal criteria are associated with maximum temperature limits and not minimum temperatures. All

The cask emitting radiation was represented as a cylinder with a 8.17 ft. diameter and a height of 13.0 ft. The casks receiving the thermal radiation of the emitting cask were represented as planes perpendicular to the line connecting the centerlines of the casks. View factors between casks with more than one intermediate cask between them are negligible.

Considering the labels in Figure 4.10-1, the view factor of an individual cask to the environment can be represented:

$$F_{cask-Environment} = 1 - \begin{bmatrix} 3F_{cask-1} + 2\left(F_{cask-2} + F_{cask-3} + F_{cask-4} + F_{cask-5}\right) + F_{cask-7} \\ + 2\left(F_{cask-8} + F_{cask-9} + F_{cask-10} + F_{cask-11}\right) \\ + 2\left(F_{cask-12} + F_{cask-13} + F_{cask-14} + F_{cask-15}\right) \end{bmatrix}$$

Eq. 4.10-4

It is assumed conservatively, that the radiation exchange between any receiving cask and the emitting cask is not blocked by another receiving member. In this case the view factor of the emitting cask to any receiving cask is maximized, which minimizes the view factor of emitting cask to the environment.

The view factors from the emitting cask to the casks beyond cask 15 (shown in Figure 4.10-1) are less than 0.002, and are not considered in the calculation due to their negligible effect. An ANSYS macro ("viewfactor.mac") is used to calculate the view factors based on equations 4.10-3 and 4.10-4. The results are summarized in Table 4.10-1. The view factor from the emitting cask to the other cask is 0.38.

The resultant view factor from the emitting to environment is:

$F_{Cask-Environment} = 1 - 0.38 = 0.62$

The free convection coefficients are calculated based on the surface shape and position in Section 4.10.3. The above correlations are incorporated in ANSYS model via macros "HTOT_VPL.mac", "HTOT_HPD.mac", and "HTOT_HPU.mac". Air properties reported in Section 4.2 are used in these macros. The macros are provided in Section 4.12.

4.10.1.1 Effects of Concrete Pad on Thermal Radiation from TN-68 Cask

As seen in Figure 4.10-1, the TN-68 casks are stored in two 2 × ∞ storage arrays on concrete pads. The view factor between an emitting cask and the concrete pad was not considered explicitly in the calculation of view factor in Section 4.10.1.

Although the surface temperature of the concrete pad is higher than ambient temperature due to solar radiation and thermal radiation from the casks, it is significantly lower than the cask surface temperature. Therefore, the radiation exchange between the cask and the concrete pad is not eliminated but it is lower than the radiation exchange between the cask and the ambient.

To determine the effects of the cask view factor on the thermal performance of the cask, a two step approach is taken:

1) View factors from the cask to ambient and to the concrete pad are calculated using ray tracing methodology (Radiosity) in ANSYS [12]. These values are compared to the view factor calculated for TN-68 cask described in Section 4.10.1.

2) A sensitivity analysis is performed to evaluate the effects of the view factor on the maximum component temperatures of TN-68 cask. A discussion of the effects on the thermal performance of the components follows, in Section 4.10.1.3.

4.10.1.2 Calculation of TN-68 Cask View Factors

A finite element model of the two 2 × ∞ storage arrays of TN-68 cask is created using ANSYS compute code [12]. This model considers half of the emitting cask and is extended to four complete casks stored in the two 2 × ∞ storage arrays. This model is illustrated in Figure 4.10-2.

The view factors from the emitting cask to the other casks ($F_{e,casks}$) and to the concrete pads ($F_{e,concrete}$) are calculated using the radiosity solver method in ANSYS [12]. The view factor of the emitting cask to ambient ($F_{e,\infty}$) is calculated by subtracting the above view factors from 1.

$$F_{e,\infty} = 1 - \left(F_{e,casks} + F_{e,concrete}\right) \qquad \text{Eq. 4.10-5}$$

The resultant view factors are listed below.

View Factors from Emitting Cask

View Factor	Radiosity Methodology	Eq. 4.10-4 Section. 4.10.1
From emitting cask to receiving casks ($F_{e,casks}$)	0.28	0.38
From emitting cask to concrete pads ($F_{e,concrete}$)	0.18	0 *
From emitting cask to ambient ($F_{e,\infty}$)	0.54	0.62

As seen in the above table, the calculated view factor from the emitting cask to the receiving casks in Section 4.10.1 is larger than the value calculated based on the radiosity methodology. The view factor calculated in Section 4.10.1 could have resulted in a more conservative value for ($F_{e,\infty}$), if the concrete pad temperature were at or close to ambient temperature and the cask view factor to the pads could be ignored.

As discussed above, there is significant thermal radiation exchange between the cask and the concrete pads since the concrete pad temperature is well below the cask surface temperature. Nevertheless, this radiation exchange is conservatively ignored in the calculation of cask to ambient view factor based on Eq. 4.10-5 for radiosity methodology.

* The concrete pads were considered as part of ambient in Section 4.10.1. Under that assumption, the concrete pad temperature remains at or close to ambient.

The view factor of $F_{e,\infty}$ based on radiosity methodology is therefore the conservative, lower bounding value for the view factor of TN-68 cask to ambient. The sensitivity analysis considers the view factor of 0.54 as the lowest bound and 0.62 as the highest bound for the evaluation. In addition, the maximum component temperatures are determined using a view factor of 0.33 to extend the sensitivity analysis.

4.10.1.3 Sensitivity Analysis for View Factors

The thermal model for TN-68 described in Section 4.3.1 is used to evaluate the sensitivity of the cask thermal performance to the view factors considered from the emitting cask to ambient. The view factors for this evaluation are listed below.

View Factors for Sensitivity Analysis

Case No.	1	2	3	4	5
View Factor $F_{e,\infty}$	0.62	0.59	0.57	0.54	0.33

The resultant maximum component temperatures are summarized in Table 4.10-3.

As seen in Table 4.10-3, only the maximum temperature of the radial neutron shield (resin) exceeds the limit for the lowest view factor (case # 4). The average resin temperature at the hottest cross section is 287°F. This temperature is below the 300°F limit. Temperature distributions for the radial neutron shield are shown in Figure 4.10-3 for case # 4.

The average temperature at the hottest cross section of the radial neutron shield for case # 5 is 311°F. The effects of this elevated temperature on the shielding properties of the resin are discussed in Section 4.10.1.4.

The maximum temperature calculated for resin in the top portion of the cask is over-conservative since no radiation exchange is considered between the top shield cover and the protective cover for storage conditions.

The other component temperatures including fuel cladding and seals remain well below the limits for the entire view factor range.

4.10.1.4 Neutron Shielding Resin at Elevated Temperatures

The effect of high temperature on the neutron shielding resin is to drive off gasses, with an associated loss of the main shielding constituent, hydrogen. Transnuclear provided data on the weight reduction of 2 inch diameter × 2 inch high samples at 125°C (257°F) and 155°C (311°F) in Chapter 9A of the TN-32 FSAR [21]. Subsequent testing of larger specimens has demonstrated that damage to the resin is limited to a surface layer about 5 mm deep. The effect of exceeding the resin's service temperature limit by 3°F (11°F under the worst case sensitivity analysis) on the surface nearest to the shield shell is a negligible acceleration of the formation of the damaged layer on this surface. A 5 mm damaged layer is less than 3% of the 5.75 inch thick resin and the resulting impact on the dose rates due to loss of some hydrogen from the damaged layer will be also negligible.

A pressure relief valve is provided in the neutron shield shell to prevent any pressure buildup due to gas release from the resin.

4.10.2 Total heat Transfer Coefficient to Ambient for Fire

The free convection heat transfer in Eq.4.10-1 is replaced with forced convection to analyze the fire accident case. A forced convection value of 4.5 Btu/hr-ft^2-°F (0.03125 Btu/hr-in^2-°F) is considered during the burning time from Reference [15].

The radiation heat transfer coefficient during burning period of the hypothetical fire accident, $h_{r,fire}$, is given by the following equation:

$$h_{r,fire} = \varepsilon_s F_{12}\left[\frac{\sigma\left(\varepsilon_f T_f^{\,2} - T_s^{\,2}\right)}{T_f - T_s}\right] \quad \text{(Btu/hr-ft}^2\text{-°F)} \qquad \text{Eq. 4.10-4}$$

where,

ε_s= surface emissivity =0.8 [14]
ε_f = fire emissivity = 0.9 [14]
F_{12} = view factor from surface to fire = 1
$\sigma = 0.1714 \times 10^{-8}$ Btu/hr-ft^2-°R^4
T_f = surface temperature, 1475°F = 1935°R [14]
T_s = ambient temperature, °R

The calculated total heat transfer coefficients for the outer cask surfaces during the fire are listed in the Table 4.10-1 for various surface temperatures.

4.10.3 Free Convection Coefficients

The free convection coefficients are calculated based on the shape and position of the convective surface using correlations from Reference [4]. The convection correlations are described in the following sections.

4.10.3.1 Vertical Cylinder

Due to the large outer diameter of the cask, the convection coefficient on the cylindrical surface approaches that for a vertical flat plate. The following equations are used to calculate the free convection coefficients.

$$h_c = \frac{Nu\,k}{L}$$

with

L = height of the vertical plate
k = air conductivity

$$Nu = \left[(Nu_l)^m + (Nu_t)^m \right]^{1/m} \quad \text{with} \quad m = 6 \quad \text{for} \quad 1 < Ra < 10^{12}$$

$$Nu_l = \frac{2.8}{\ln(1 + 2.8 / Nu^T)}$$ Nusselt number for fully laminar heat transfer with

$$Nu^T = \overline{C}_l \; Ra^{1/4} \quad , \overline{C}_l = 0.515 \text{ (for gases)}$$

$$Nu_t = C_t^V \; Ra^{1/3}$$ Nusselt number for fully turbulent heat transfer with

$$C_t^V = \frac{0.13 \, \mathrm{Pr}^{0.22}}{(1 + 0.61 \, \mathrm{Pr}^{0.81})^{0.42}}$$

$$Ra = Gr \; \mathrm{Pr} \quad ; \quad Gr = \frac{g \, \beta \, (T_w - T_\infty) \, L^3}{\nu^2}$$

The correlations to calculate the total heat transfer coefficient are incorporated in the ANSYS model via "HTOT_VPL.mac".

4.10.3.2 Horizontal Flat Surfaces Facing Downwards

$$h_c = \frac{Nu \; k}{L}$$

with

L = A/P
A=surface area of heated surface
P= perimeter of the heated surface
k = air conductivity

$$Nu = Nu_l \quad ; \quad Nu_l = \frac{0.527 \, Ra^{1/5}}{[1 + (1.9 / \mathrm{Pr})^{9/10}]^{2/9}}$$

$$Ra = Gr \; \mathrm{Pr} \quad ; \quad Gr = \frac{g \, \beta \, (T_w - T_\infty) \, L^3}{\nu^2}$$

The above correlations are incorporated in ANSYS model via macro "HTOT_HPD.mac"

4.10.3.3 Horizontal Flat Plate Facing Upwards

$$h_c = \frac{Nu \; k}{L}$$

with

L = A/P
A=surface area of heated surface
P= perimeter of the heated surface
k = air conductivity

$$Nu = \left[(Nu_l)^m + (Nu_t)^m \right]^{1/m} \qquad with \quad m = 10 \quad for \quad Ra > 1$$

$$Nu_l = \frac{1.4}{\ln(1 + 1.4 / Nu^T)}$$ Nusselt number for fully laminar heat transfer with

$$Nu^T = 0.835\, \overline{C}_l\, Ra^{1/4} \quad , \overline{C}_l = 0.515 \text{ (for gases)}$$

$$Nu_t = C_t^H\, Ra^{1/3}$$ Nusselt number for fully turbulent heat transfer

$$C_t^H \approx 0.14 \qquad \text{for } \Pr < 100$$

$$Ra = Gr \Pr \quad ; \quad Gr = \frac{g\, \beta\, (T_w - T_\infty)\, L^3}{\nu^2}$$

The above correlations are incorporated in ANSYS model via macro "HTOT_HPU.mac".

4.11 Radial Hot Gap between the Basket Rails and the Cask Inner Shell

An average radial cold gap of 0.17" is considered between the basket and the cask cavity wall for the TN-68 cask, conforming to the gap specification, drawing 972-70-5 note 6. A radial, hot gap of 0.1" at thermal equilibrium is assumed in the ANSYS model for normal storage conditions. To verify this assumption, the radiuses of the inner shell and the basket can be calculated after thermal equilibrium using the following equation:

$$R_{hot} = R_{cold}\ (1+\alpha\ (T_{avg} - 70))$$

α = mean coefficient of thermal expansion
T_{avg} = average component temperature

To calculate the hot radius of the basket, three locations are considered as shown in Figure 4.11-1. Locations I and II consist of stainless steel components of the basket and the aluminum component of the rails. Location III consists of basket and shim, which are stainless steel components only. Since adequate cold gaps are considered between the poison / aluminum plates and the stainless steel structural plates of the basket, the aluminum plates do not have any effect on the thermal growth of the basket.

The hot radius of the basket at locations I and II is calculated as follows:

$$R_{basket,hot,I} = R_{I,SS}(1+\alpha_{SS}\ (T_{avg,SS} - 70)) + R_{I,Al}(1+\alpha_{Al}\ (T_{avg,Al} - 70))$$

$$R_{basket,hot,II} = R_{II,SS}(1+\alpha_{SS}\ (T_{avg,SS} - 70)) + R_{II,Al}(1+\alpha_{Al}\ (T_{avg,Al} - 70))$$

The hot radius at location III is:

$$R_{basket,hot,III} = R_{III,SS}(1+\alpha_{SS}\ (T_{avg,SS} - 70)) + L_{shim}\ (1+\alpha_{SS}\ (T_{avg,shim} - 70))$$

The hot radius of the inner cask shell is:

$$R_{inner\ shell,hot} = R_{inner\ shell}\ (1+\alpha_{shell}\ (T_{avg,shell} - 70))$$

The size of the radial hot gap is calculated as follows:
Hot gap = ($R_{inner\ shell,\ hot}$ - $R_{basket,\ hot}$)

The average temperatures are retrieved from result file of the base model basket at the hottest cross section (71.18≤ Z ≤83.38) for 100°F normal storage conditions using ANSYS [12] command "ETABLE". The ANSYS commands are collected in the file "AvgTempS.mac" in Section 4.12. The calculated hot dimensions are listed in Table 4.11-1.

The assumption of a 0.1" hot gap at thermal equilibrium is conservative, since the hot gaps shown in Table 4.11-1 are smaller than the assumed gap.

Intentionally Blank

4.12 Supplemental Data

4.12.1 ANSYS Macros

This Section provides ANSYS macros utilized to calculate the heat transfer coefficients and the average component temperatures for the TN-68 cask thermal models. These macros are provided as part of a separate proprietary compact disc. A listing of the contents of the compact disc and a brief description of the macros are given below.

File Name	**Description**
HTOT_VPL.mac	Total heat transfer coefficient for vertical surfaces
HTOT_HPD.mac	Total heat transfer coefficient for horizontal, flat surfaces facing downwards
HTOT_HPU.mac	Total heat transfer coefficient for horizontal, flat surfaces facing upwards
AvgGasTemp.mac	Average gas temperature in the cask cavity
AvgTempS.mac	Average basket component temperatures for thermal / structural analyses

4.13 References

1. USNRC, SFPO, Interim Staff Guidance – 11, Rev. 3, "Cladding Considerations for the Transportation and Storage of Spend Fuel"
2. Environmental Conditions for On-Site Hazardous Material Packages, WHC-SD-TP-RPT-004, Westinghouse Hanford Company, 1992
3. Commonwealth Edison, "Typical BWR Average Axial Exposure Profiles", Memorandum NFS:BND:95-083, July 1995
4. Rohsenow, W. M., Hartnett, J. P., Ganic, E. N. , "Handbook of Heat Transfer Fundamentals", 2nd Edition, 1985
5. ASME Boiler and Pressure Vessel Code, Section II, Part D, "Material Properties", 1998 and 2000 addenda
6. Perry, R. H., Chilton, C. H., "Chemical Engineers' Handbook", 5th Edition, 1973
7. Zoldners, N. G., "Thermal Properties of Concrete under Sustained Elevated Temperatures", ACI Publications, Paper SP 25-1, American Concrete Institute, Detroit, MI, 1970
8. Bentz, D. P., "A Computer Model to Predict the Surface Temperature and Time-of-wetness of Concrete Pavements and Bridge Decks", Report # NISTIR 6551, National Institute of Standards and Technology, 2000
9. Siegel, Robert, Howell, R. H., "Thermal Radiation Heat Transfer", 4th Edition, 2002
10. Azzazy Technology Inc., "Emissivity Measurements of 304 Stainless Steel", Report Number ATI-2000-09-601, 2000
11. USNRC, SFPO, NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems - Final Report", 1997
12. ANSYS Computer Code and User's Manuals, Version 6.0, 8.0, and 8.1
13. Viebrock, J. M., Douglas, H. M., "Domestic Light Water Reactor Fuel Design Evolution", Vol. III, Nuclear Assurance Corporation, 1981
14. USNRC, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material", 2004
15. Gregory, J. J., Mata, R., Keltner, N. R., "Thermal Measurements in a Series of Long Pool Fires", SANDIA Report, SAND 85-0196, TTC-0659,1987
16. IAEA Safety Standards, "Regulations for the Safe Transport of Radioactive Material", 1985
17. USNRC, SFPO, NUREG/CR-0497, "A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior", MATPRO - Version II (Revison 2), EG&G Idaho, Inc., TREE-1280, 1981
18. Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE, A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation for Workstations and Personal Computers", NUREG/CR-0200, Rev. 6, ORNL/NUREG/CSD-2/V3/R6
19. SANDIA Report, SAND90-2406, "A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements", 1992
20. Transnuclear, Inc., "Safety Analysis Report, NUHOMS®-MP197 Multipurpose Cask – Transportation Package", Rev. 0, Appendix 3.7.1
21. TN-32, Final Safety Analysis Report, Rev. 3, Docket 72-1021

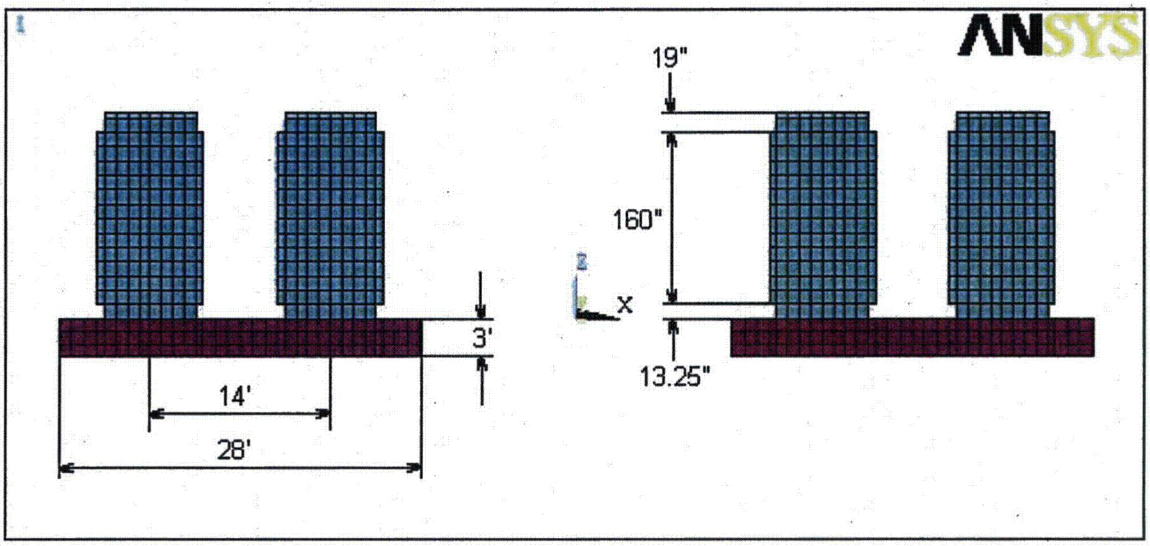
Table 4.10-3
Maximum Component Temperatures for Sensitivity Analysis

	Maximum Temperature (°F)					
Component	**Case 1 [Table 4.3-1]**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Temp Limit (°F)**
Fuel Cladding	622	624	626	628	647	752 [1]
Basket	595	598	600	602	621	
Basket Rails, type 1&2	382	385	387	389	411	
Basket Shim	350	352	354	357	379	
Inner Shell	319	322	324	327	350	
Gamma Shield	314	317	319	321	345	
Radial Neutron Shield	295	298	300	**303**	**327**	300
Top Neutron Shield	211	213	215	217	**235**	220
Cask Outer Surface	255	258	260	263	288	
Cask Lid Seal	212	214	216	217	235	536
Vent & Port Seals	212	214	215	217	235	536

Intentionally Blank

Figure 4.10-2
Finite Element Model for Radiosity Methodology

Front View



Three-Dimensional View

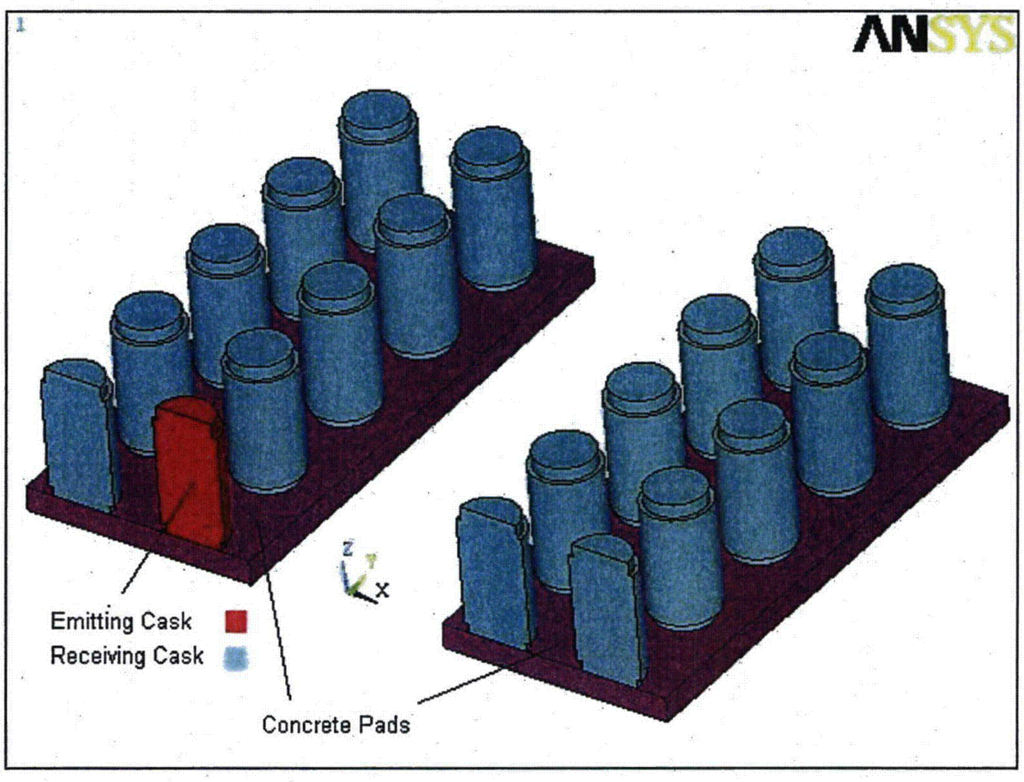
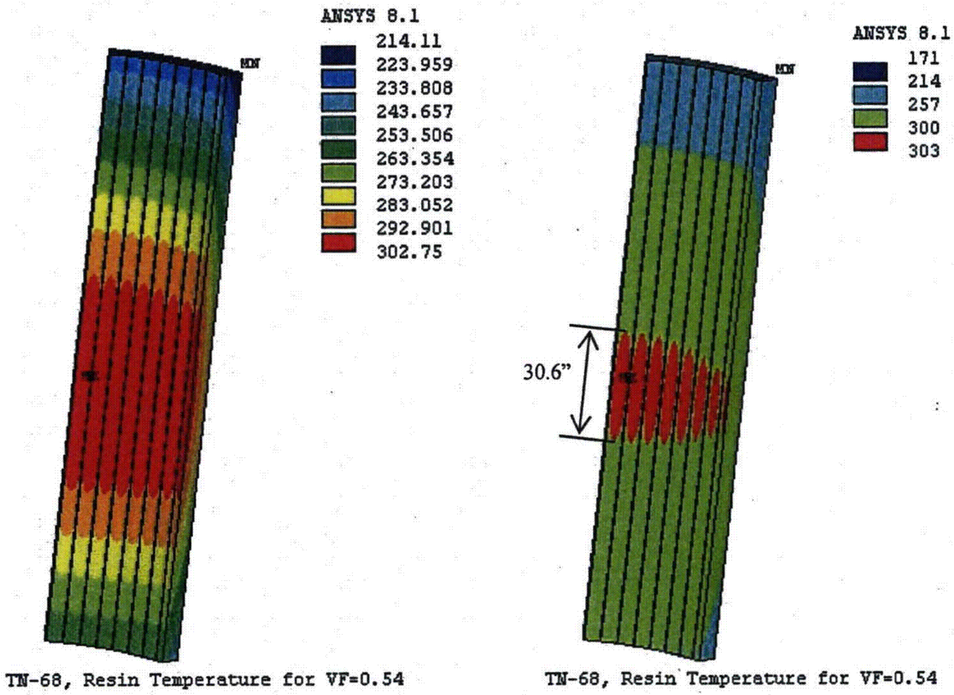


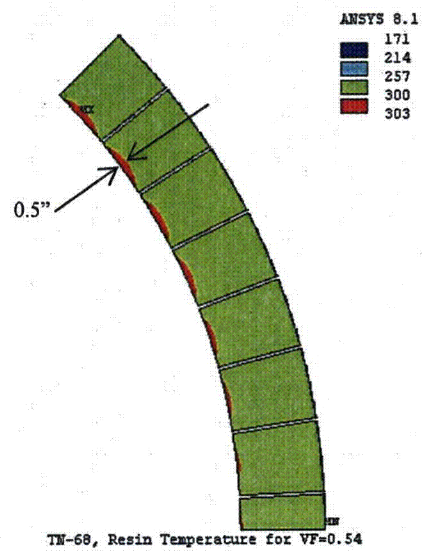
Figure 4.10-3

Temperature Distribution of Radial Neutron Shield Resin for Case # 4

Along Resin Boxes



At Hottest Cross Section



9.1.7.1 Boron Aluminum Alloy (Borated Aluminum)

See the Caution in Section 9.1.7 before deletion or modification to this section.

The material is produced by direct chill (DC) or permanent mold casting with boron occuring as a uniform fine dispersion of discrete AlB_2 or TiB_2 particles in the matrix of aluminum or aluminum alloy. For extruded products, the TiB_2 form of the alloy shall be used. For rolled products, either the AlB_2, the TiB_2, or a hybrid may be used.

Boron is added to the aluminum in the quantity necessary to provide the specified minimum B10 areal density in the final product, with sufficient margin to minimize rejection, typically 10 % excess. The amount required to achieve the specified minimum B10 areal density will depend on whether boron with the natural isotopic distribution of the isotopes B10 and B11, or boron enriched in B10 is used. In no case shall the boron content in the aluminum or aluminum alloy exceed 5% by weight.

The criticality calculations take credit for 90% of the minimum specified B10 areal density of borated aluminum. The basis for this credit is the B10 areal density acceptance testing, which shall be as specified in Section 9.4.2 or 9.5. The specified acceptance testing assures that at any location in the material, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

9.1.7.2 Boron Carbide / Aluminum Metal Matrix Composites (MMC)

See the Caution in Section 9.1.7 before deletion or modification to this section.

The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume.

Prior to use in the TN-68, MMCs shall pass the qualification testing specified in Section 9.4.3, and shall subsequently be subject to the process controls specified in Section 9.4.4.

The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section 9.4.2. The specified acceptance testing assures that at any location in

the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings"[5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described in the following section.

9.1.7.3 Boral®

See the Caution in Section 9.1.7 before deletion or modification to this section.

This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles is approximately 80 microns before and somewhat smaller after rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.

The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®. B10 areal density will be verified by chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on an approximately 1 cm^2 area from the thinnest coupon, typically that taken near one of the corners of the sheet produced from each ingot. If the measured areal density is below that specified, all the material produced from that ingot will be treated as non-conforming. Alternatively, individual pieces cut from the sheet may be accepted if a coupon from the sheet, thinner than any location on the piece in question, has a measured areal density equal to or greater than that specified.

Visual inspections shall verify that the Boral® core is not exposed through the face of the sheet at any location.

9.4 Specification for Neutron Absorbers

9.4.1 Specification for Thermal Conductivity Testing of Neutron Absorbers

Testing shall conform to ASTM E1225[7], ASTM E1461[8], or equivalent method, performed at room temperature on coupons taken from the rolled or extruded production material. Previous testing of borated aluminum and metal matrix composite, Table 9.4-1, shows that thermal conductivity increases slightly with temperature. Initial sampling shall be one test per lot, defined by the heat or ingot, and may be reduced if the first five tests meet the specified minimum thermal conductivity.

If a thermal conductivity test result is below the specified minimum, additional tests may be performed on the material from that lot. If the mean value of those tests falls below the specified minimum (Ch 4, Section 4.2, item 12), the associated lot shall be rejected.

After twenty five tests of a single type of material, with the same aluminum alloy matrix, the same boron content, and the boron appearing in the same phase, e.g., B_4C, TiB_2, or AlB_2, if the mean value of all the test results less two standard deviations meets the specified thermal conductivity, no further testing of that material is required. This exemption may also be applied to the same type of material if the matrix of the material changes to a more thermally conductive alloy (e.g., from 6000 to 1000 series aluminum), or if the boron content is reduced without changing the boron phase.

The thermal analysis in Chapter 4 considers a base model with 0.31" thick neutron absorber. This model gives the bounding values for the maximum component temperatures. The dual plate basket construction alternate model described in Section 4.3.1 assumes a 3/16 inch thick neutron absorber paired with a 1/8 inch thick aluminum 1100 plate to make a total thickness of 0.31". The specified thickness of the neutron absorber may vary, and the thermal conductivity acceptance criterion for the neutron absorber will be based on the nominal thickness specified. To maintain the thermal performance of the basket, the minimum thermal conductivity shall be such that the total thermal conductance (sum of conductivity * thickness) of the neutron absorber and the aluminum 1100 plate shall equal the conductance assumed in the analysis for the base model. Samples of the acceptance criteria for various neutron absorber thicknesses are highlighted in Table 9.4-2.

The aluminum 1100 plate does not need to be tested for thermal conductivity; the material may be credited with the values published in the ASME Code Section II part D.

9.4.2 Specification for Acceptance Testing of Neutron Absorbers by Neutron Transmission

CAUTION *Section 9.4.2 is incorporated by reference into the TN-68 CoC 1027 Technical Specifications (paragraph 4.1.1) and shall not be deleted or altered in any way without a CoC amendment approval from the NRC. The text of this section is shown in bold type to distinguish it from other sections.*

For TN-68 units 01 through 44, Neutron Transmission testing is performed per Section 9.5 of this chapter.

Neutron Transmission acceptance testing procedures shall be subject to approval by the Certificate Holder. Test coupons shall be removed from the rolled or extruded production material at locations that are systematically or probabilistically distributed throughout the lot. Test coupons shall not exhibit physical defects that would not be acceptable in the finished product, or that would preclude an accurate measurement of the coupon's physical thickness.

A lot is defined as all the pieces produced from a single ingot or heat. If this definition results in lot size too small to provide a meaningful statistical analysis of results, an alternate larger lot definition may be used, so long as it results in accumulating material that is uniform for sampling purposes.

The sampling rate for neutron transmission measurements shall be such that there is at least one neutron transmission measurement for each 2000 square inches of final product in each lot.

The B10 areal density is measured using a collimated thermal neutron beam of up to 1.2 centimeter diameter. A beam size greater than 1.2 centimeter diameter but no larger than 1.7 centimeter diameter may be used if computations are performed to demonstrate that the calculated $k_{effective}$ of the system is still below the calculated Upper Subcritical Limit (USL) of the system assuming defect areas the same area as the beam.

The neutron transmission through the test coupons is converted to B10 areal density by comparison with transmission through calibrated standards. These standards are composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.

Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 cm^2.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. The following illustrates one acceptable method.

The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor with 95% probability and 95% confidence[16]. If a goodness-of-fit test demonstrates that the sample comes from a normal population, the value of K for a normal distribution may be used. Otherwise, use a non-parametric (distribution-free) method of determining the one-sided tolerance limit.

Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.

Any plate which is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, so long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness.

Non-conforming material shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

9.4.3 Specification for Qualification Testing of Metal Matrix Composites

9.4.3.1 Applicability and Scope

Metal matrix composites (MMCs) shall consist of fine boron carbide particles in an aluminum or aluminum alloy matrix. The ingot shall be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) or permanent mold casting. In any case, the final MMC product shall have density greater than 98% of theoretical, a metallurgically bonded matrix, and boron carbide content no greater than 40% by volume. Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

Prior to initial use in a spent fuel dry storage or transport system, such MMCs shall be subjected to qualification testing that will verify that the product satisfies the design function. Key process controls shall be identified per Section 9.4.4 so that the production material is equivalent to or better than the qualification test material. Changes to key processes shall be subject to qualification before use of such material in a spent fuel dry storage or transport system.

ASTM test methods and practices are referenced below for guidance. Alternative methods may be used with the approval of the certificate holder.

9.4.3.2 Design Requirements

In order to perform its design functions the product must have at a minimum sufficient strength and ductility for manufacturing and for the normal and accident conditions of the storage/ transport system. This is demonstrated by the tests in Section 9.4.3.4. It must have a uniform distribution of boron carbide. This is demonstrated by the tests in Section 9.4.3.5.

9.4.3.3 Durability

There is no need to include accelerated radiation damage testing in the qualification. Such testing has already been performed on MMCs, and the results confirm what would be expected of materials that fall within the limits of applicability cited above. Metals and ceramics do not experience measurable changes in mechanical properties due to fast neutron fluences typical over the lifetime of spent fuel storage, about 10^{15} neutrons/cm^2.

The need for thermal and corrosion (hydrogen generation) testing shall be evaluated case-by-case based on comparison of the material composition and environmental conditions with previous thermal or corrosion testing of MMCs.