December 2016

Revision 16B

# MAGNATRAN

(Modular Advanced Generation Nuclear All-purpose TRANsport)

# MAGNATRAN RAI Response Package Submittal

Book 1 of 1

**NON-PROPRIETARY VERSION**

Docket No. 71-9356

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

**Enclosure 1**

# RAI Responses

# No. 71-9356 for the MAGNATRAN Cask

# MAGNATRAN SAR, Revision 16B

# NAC INTERNATIONAL

# RESPONSE TO THE

# UNITED STATES
# NUCLEAR REGULATORY COMMISSION

# PROPRIETARY
# REQUEST FOR ADDITIONAL INFORMATION #4

**September 2016**

# FOR REVIEW OF THE CERTIFICATE OF COMPLIANCE NO. 9356, REVISION NO. 0

# (CoC NO. 9356, DOCKET NO. 71-9356)

**December 2016**

# TABLE OF CONTENTS

Page

# NAC INTERNATIONAL RESPONSE
# TO
# REQUEST FOR ADDITIONAL INFORMATION

## Thermal

3-1. [redacted]

[redacted]

[redacted]

[redacted]

# Enclosure 2

## List of SAR Changes

## No. 71-9356 for the MAGNATRAN Cask

## MAGNATRAN SAR, Revision 16B

## List of Changes for the MAGNATRAN® SAR, RAI Responses

| Chapter/Page/ Figure/Table | Description of Change |
|---|---|
| Note: The List of Effective Pages and the Chapter Table of Contents, List of Figures and List of Tables have been revised accordingly to reflect the list of changes detailed below. | |
| **Chapter 1** | |
| Page 1.3-23 | Modified the first paragraph at the top of the page. |
| Page 1.3-24 | Text flow changes. |
| Page 1.3-25 | Modified list Item 3. |
| Page 1.3-26 | Modified list Item 11.d. |
| Page 1.3-27 thru 1.3-28 | Text flow changes. |
| Page 1.3-29 | Modified list Item 12.e. |
| Page 1.3-30 thru 1.3-32 | Text flow changes. |
| Page 1.3-38 | Modified the last row of Table 1.3-6, deleted one bullet, and added Note 2. |
| Page 1.4-3 thru 1.4-4 | Section 1.4.3 revised for License Drawings. |
| **Chapter 2** | |
| No Changes | |
| **Chapter 3** | |
| Page 3.1-1 | Added a sentence in the middle of the second paragraph of Section 3.1. |
| Page 3.1-2 | Text flow changes |
| Page 3.1-3 | Added a note following Table 3.1-1. |
| Page 3.2-3 | Added a sentence at the bottom of the page in Section 3.2.3. |
| Page 3.2-8 | Modified and added a row to Table 3.2-12; added a row and note to Table 3.2-13. |
| Page 3.4-2 | Deleted text in the second paragraph of Section 3.4.1. |
| Page 3.4-3 | Modified text near the end of the first full paragraph on the page. |
| Page 3.4-4 | Modified the first paragraph of Section 3.4.1.1.1. |
| Page 3.4-5 | Modified the last paragraph on the page. |
| Page 3.4-6 | Modified the first and last paragraphs on the page; deleted text in the middle of the page. |
| Page 3.4-7 | Modified the second paragraph on the page. |
| Page 3.4-8 | Added the last sentence to the first paragraph of Section 3.4.1.1.3. |
| Pages 3.4-9 thru 3.4-12 | Text flow changes. |
| Page 3.4-13 | Added the last sentence to the first paragraph of Section 3.4.1.2.3 at the top of the page. |
| Page 3.4-14 | Deleted the last paragraph of Section 3.4.1.3 near the middle of the page. |
| Page 3.4-15 | Added the second paragraph to Section 3.4.2 in the middle of the page. Deleted text from the third paragraph of Section 3.4.2. |

| Chapter/Page/ Figure/Table | Description of Change |
|---|---|
| Page 3.4-16 | Text flow changes. |
| Page 3.4-17 | Modified the second full paragraph in the middle of the page. |
| Pages 3.4-18 thru 3.4-19 | Text flow changes. |
| Pages 3.4-20 thru 3.4-21 | Replaced Figures 3.4-1 and 3.4-2. |
| Page 3.4-32 | Deleted Figure 3.4-13. |
| Pages 3.4-33 thru 3.4-34 | Modified Tables 3.4-1 and 3.4-2. |
| Page 3.5-4 | Deleted text in the second paragraph of Section 3.5.4. |
| Page 3.5-15 | Modified Table 3.5-1. |
| **Chapter 4** | |
| No Changes | |
| **Chapter 5** | |
| Pages 5.8.14-1 thru 5.8.14-5 | Added new Section 5.8.14, "22 kW PWR Cool Time Tables," which includes new Tables 5.8-58 thru 5.8-61. |
| **Chapter 6** | |
| No Changes | |
| **Chapter 7** | |
| No Changes | |
| **Chapter 8** | |
| Pages 8.1-14 | Replaced the embedded table near the top of the page. |

# Enclosure 3

# List of Drawing Changes

# No. 71-9356 for the MAGNATRAN Cask

# MAGNATRAN SAR, Revision 16B

# List of Drawing Changes, MAGNATRAN SAR, Revision 16B

## Drawing 71160-504, Misc. Details, Transport Cask, MAGNATRAN, Rev. 2

Sheet 1:

1. Zones E5/D5, revised dimension to "(5.90)", was "(5.60)"; revised dimension to "(3.8)", was "(3.6)"; revised dimension to "(7.9)", was "(7.6)"; deleted graphics for the groove notch in the threaded region and the weep hole.

2. Zone E7, deleted graphics for the groove notch in the threaded region and the weep hole.

## Drawing 71160-585, TSC Assembly, MAGNASTOR, Rev. 12

Sheet 1:

1. Revised delta note 10 by adding the following sentence: "Multiple segments from different closure rings of similar size may be used, blending sections at seams.

2. Zone A6, attach a delta note 10 symbol next to item 18 balloon.

3. Zone A5, revise the following statement below Detail A-A to: "(Optional configuration)", was "(Optional configuration of Assy 92 & 93 only)" and add two zone boxes referencing "SH1/F5" and "SH2/F5".

4. Zone A6, add item 5 balloon next to item 17 balloon callout.

5. Modify the Quantity columns of Item 16 within the BOM by replacing all values of "1" with "A/R".

6. Modify the Quantity columns of Item 18 within the BOM by populating all empty columns with the value of "A/R" and remove delta note 10 symbol.

Sheet 2:

7. Zone F5, add zone box referencing "SH1/A5".

8. Zone A6, add zone box referencing "SH3/F5".

9. Zone A8, add delta note 10 symbol next to item 16 balloon.

10. Zone A4, add Zone Box referencing Sheet 3 and Zone E5.

**Drawing 71160-685, DF, TSC Assembly, MAGNASTOR, Rev 6**

Sheet 1:

1. Zone A8, revise Note 3 to Delta Note 3 and revise text as follows: "The closure ring may be field dressed in localized areas to accommodate fit-up to the shell weldment. Extent of localized closure ring field dressing shall maintain minimum weld configuration. Closure ring may be cut into segments prior to installation to assist in fit-up. Multiple segments from different closure rings of similar size may be used, blending sections at seams.", was "The closure ring may be field dressed in localized areas to accommodate fit-up of the closure ring to the shell weldment."

2. Add callout for Delta Note 3 adjacent to Item 9 in B.O.M.

Sheet 2:

3. Zone D8, add delta note 3 symbol next to delta note 6.

**Enclosure 4**

# Supporting Calculations

# No. 71-9356 for the MAGNATRAN Cask

# MAGNATRAN SAR, Revision 16B

## Enclosure 4 Contents

1. 71160-2101, Revision 8
2. 71160-3011, Revision 2
3. 71160-3013, Revision 3
4. 71160-3014, Revision 5
5. 71160-3015, Revision 6

CALCULATIONS WITHHELD IN THEIR ENTIRETY PER 10 CFR 2.390

**Enclosure 5**

# MAGNATRAN SAR

## LOEP and SAR Page Changes

## No. 71-9356 for the MAGNATRAN Cask

## MAGNATRAN SAR, Revision 16B

December 2016

Revision 16B

# MAGNATRAN

(Modular Advanced Generation Nuclear All-purpose TRANsport)

# SAFETY ANALYSIS REPORT

## NON-PROPRIETARY VERSION

Docket No. 71-9356

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

## List of Effective Pages

Chapter 1

Page 1-i thru 1-iii .......................... Revision 15A
Page 1-1 .......................................... Revision 12A
Page 1.1-1 thru 1.1-8...................... Revision 12A
Page 1.2-1 thru 1.2-4...................... Revision 12A
Page 1.2-5 ...................................... Revision 14A
Page 1.3-1 thru 1.3-6...................... Revision 12A
Page 1.3-7 ...................................... Revision 15A
Page 1.3-8 thru 1.3-20.................... Revision 12A
Page 1.3-21 thru 1.3-22.................. Revision 15A
Page 1.3-23 thru 1.3-32.................. Revision 16B
Page 1.3-33 thru 1.3-37.................. Revision 15A
Page 1.3-38 .................................... Revision 16B
Page 1.3-39 thru 1.3-45.................. Revision 15A
Page 1.3-46 .................................... Revision 16A
Page 1.3-47 thru 1.3-51.................. Revision 15A
Page 1.4-1 thru 1.4-2...................... Revision 12A
Page 1.4-3 thru 1.4-4...................... Revision 16B

36 drawings (see Section 1.4.3)

Chapter 2

Page 2-i thru 2-iii .......................... Revision 12A
Page 2-iv thru 2-xxiv ..................... Revision 14A
Page 2-1 .......................................... Revision 12A
Page 2.1-1 ...................................... Revision 12A
Page 2.1.1-1 thru 2.1.1-4................ Revision 12A
Page 2.1.1-5 thru 2.1.1-6................ Revision 15A
Page 2.1.2-1 thru 2.1.2-5................ Revision 12A
Page 2.1.2-6 .................................. Revision 14A
Page 2.1.2-7 .................................. Revision 12A
Page 2.1.2-8 .................................. Revision 14A
Page 2.1.2-9 thru 2.1.2-11.............. Revision 12A
Page 2.1.3-1 thru 2.1.3-2................ Revision 12A
Page 2.1.4-1 thru 2.1.4-5................ Revision 12A
Page 2.2-1 ...................................... Revision 12A
Page 2.2.1-1 thru 2.2.1-17.............. Revision 12A
Page 2.2.2-1 thru 2.2.2-3................ Revision 12A
Page 2.2.2-4 .................................. Revision 14A
Page 2.2.2-5 thru 2.2.2-7................ Revision 12A
Page 2.2.2-8 thru 2.2.2-9................ Revision 14A
Page 2.2.3-1 .................................. Revision 12A
Page 2.3-1 ...................................... Revision 12A
Page 2.3.1-1 .................................. Revision 12A
Page 2.3.2-1 .................................. Revision 12A
Page 2.4-1 thru 2.4-2...................... Revision 12A
Page 2.5-1 ...................................... Revision 12A
Page 2.5.1-1 thru 2.5.1-12.............. Revision 12A
Page 2.5.2-1 thru 2.5.2-2 ............... Revision 12A
Page 2.5.2-3 .................................. Revision 14A
Page 2.5.2-4 thru 2.5.2-5 ............... Revision 12A
Page 2.5.2-6 .................................. Revision 14A
Page 2.5.2-7 thru 2.5.2-19 ............. Revision 12A
Page 2.6-1 ...................................... Revision 12A
Page 2.6.1-1 thru 2.6.1-4 ............... Revision 12A
Page 2.6.1-5 .................................. Revision 14A
Page 2.6.1-6 thru 2.6.1-8 ............... Revision 12A
Page 2.6.1-9 thru 2.6.1-15 ............. Revision 14A
Page 2.6.2-1 .................................. Revision 14A
Page 2.6.2-2 thru 2.6.2-3 ............... Revision 12A
Page 2.6.2-4 thru 2.6.2-10 ............. Revision 14A
Page 2.6.3-1 .................................. Revision 12A
Page 2.6.4-1 thru 2.6.4-2 ............... Revision 12A
Page 2.6.5-1 thru 2.6.5-3 ............... Revision 12A
Page 2.6.5-4 thru 2.6.5-5 ............... Revision 14A
Page 2.6.6-1 .................................. Revision 12A
Page 2.6.7-1 .................................. Revision 12A
Page 2.6.7.1-1 ................................ Revision 12A
Page 2.6.7.1-2 thru 2.6.7.1-4 ......... Revision 14A
Page 2.6.7.1-5 ................................ Revision 12A
Page 2.6.7.1-6 thru 2.6.7.1-8 ......... Revision 14A
Page 2.6.7.1-9 ................................ Revision 12A
Page 2.6.7.2-1 ................................ Revision 12A
Page 2.6.7.2-2 thru 2.6.7.2-4 ......... Revision 14A
Page 2.6.7.2-5 ................................ Revision 12A
Page 2.6.7.3-1 ................................ Revision 12A
Page 2.6.7.3-2 thru 2.6.7.3-4 ......... Revision 14A
Page 2.6.7.3-5 ................................ Revision 12A
Page 2.6.7.3-6 thru 2.6.7.3-8 ......... Revision 14A
Page 2.6.7.4-1 ................................ Revision 12A
Page 2.6.7.5-1 thru 2.6.7.5-7 ......... Revision 14A
Page 2.6.7.5-8 ................................ Revision 15A
Page 2.6.7.5-9 thru 2.6.7.5-18 ....... Revision 14A
Page 2.6.7.5-19 .............................. Revision 15A
Page 2.6.7.5-20 thru 2.6.7.5-34 ..... Revision 14A
Page 2.6.7.6-1 thru 2.6.7.6-5 ......... Revision 12A
Page 2.6.7.7-1 thru 2.6.7.7-15 ....... Revision 12A
Page 2.6.7.7-16 thru 2.6.7.7-17 ..... Revision 14A
Page 2.6.7.7-18 thru 2.6.7.7-19 ..... Revision 12A
Page 2.6.8-1 .................................. Revision 12A
Page 2.6.9-1 .................................. Revision 12A
Page 2.6.10-1 ................................ Revision 12A
Page 2.6.11-1 thru 2.6.11-5 ........... Revision 12A
Page 2.6.12-1 ................................ Revision 15A
Page 2.6.12-2 ................................ Revision 12A
Page 2.6.12.1-1 .............................. Revision 12A

## List of Effective Pages (cont'd)

## List of Effective Pages (cont'd)

## List of Effective Pages (cont'd)

## List of Effective Pages (cont'd)

kW/assembly. Neutron absorber with Type 2 thermal conductivity (see Table 3.2-12) is required for PWR basket with a maximum heat load of 23kW. For the PWR basket with neutron absorbers with Type 1 thermal conductivity (see Table 3.2-12), the heat load is limited to 22 kW, with the individual assembly decay heat limited to 0.595 kW. The bounding thermal evaluations are based on the Westinghouse 17×17 fuel assembly. The minimum cool times are determined based on the maximum decay heat load of the contents and meeting transport dose limits. The fuel assemblies and source terms that produce the maximum dose rates are summarized in Chapter 5.

The DF basket assembly configuration for PWR fuel with damaged fuel can locations is shown in Figure 1.3-4. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly. PWR fuel assemblies loaded in a DFC shall not contain nonfuel hardware, with the exception of instrument tube tie components and steel inserts.

A PWR fuel assembly weight of 1,680 pounds based on a B&W 15×15 fuel assembly with control components inserted, has been structurally evaluated in each location of the PWR fuel basket, equaling a total contents weight of 62,160 lbs. A bounding weight of 1,814 pounds is evaluated for each loaded damaged fuel can in the damaged fuel configuration of the PWR DF fuel basket. A total contents weight of 61,184 lbs is specified for the PWR DF basket to limit the maximum loaded TSC weight to 104,500 lbs. The analyzed contents weight provides the most significant measure of the basket performance. Accordingly, a 5% increase in the maximum weight per undamaged fuel location of 1,765 lbs is permitted while maintaining a maximum contents weight consistent with the basket evaluation.

As noted in Table 1.3-6, PWR fuel assemblies may include nonfuel hardware placed into the fuel assembly guide tubes and/or instrument tube. Nonfuel hardware that is located in the active fuel region is referred to as inserts in this SAR. Nonfuel components, such as thimble plugs, may not reach into the active fuel region and do not have a significant effect on system reactivity.

Westinghouse 15×15 PWR fuel assemblies that have been enhanced to address top nozzle stress corrosion cracking may use nonfuel hardware to prevent the separation of the top nozzle.

### BWR Fuel

The BWR fuel evaluations are based on bounding BWR fuel assembly parameters that maximize the source terms for the shielding evaluations, the reactivity for the criticality evaluations, the decay heat load for the thermal evaluations, and the fuel weight for the structural evaluations. These bounding parameters are selected from the various spent fuel assemblies that are

candidates for loading in the TSC. The bounding fuel assembly values are established based primarily on how the principal parameters are combined, and on the loading conditions or restrictions established for a group of fuel assemblies based on its parameters. Each TSC may contain up to 87 undamaged BWR fuel assemblies. To increase allowed assembly enrichments over those determined for the 87-assembly basket configuration, an optional 82-assembly loading pattern may be used. The required fuel assembly locations in the 82-assembly pattern are shown in Figure 1.3-5.

The limiting parameters of the BWR fuel assemblies authorized for loading in the TSC are shown in Table 1.3-19. The maximum initial enrichment represents the peak planar-average enrichment. The BWR fuel assembly characteristics are summarized by fuel type in Chapter 6. Table 1.3-19 assembly physical information is limited to the critical analysis input of fuel mass, array configuration, and number of fuel rods. These analysis values are key inputs to the shielding and criticality evaluations in Chapters 5 and 6. Lattice parameters dictating system reactivity are detailed in Chapter 6. Enrichment limits are set for each fuel type to produce reactivities at the USL. The maximum decay heat load per TSC for the transport of BWR fuel assemblies is 22.0 kW (0.253 kW/assembly). Only uniform loading is permitted for BWR fuel assemblies. The bounding thermal evaluations are based on the GE 10×10 fuel assembly. The minimum cooling times are determined based on the maximum decay heat load of the contents and meeting transport dose limits.

BWR fuel assemblies may contain partial-length fuel rods. Table 1.3-20 contains the type of BWR assemblies and the number of partial-length rods included in the analysis in this SAR. Locations for the partial-length rods within the lattice are illustrated in Figure 1.3-8.

A bounding BWR fuel assembly weight of 704 pounds based on the maximum weight of GE 7×7 and 8×8 assemblies with channels has been structurally evaluated in each storage location of the BWR basket as well as the two additional locations coinciding with the drain and vent ports, equaling a total contents weight of 62,656 lbs. The analyzed contents weight provides the most significant measure of the basket performance. Accordingly, a 5% increase in the maximum weight per fuel location of 739 lbs is permitted while maintaining a maximum contents weight consistent with the basket evaluation.

As noted in Table 1.3-19, the evaluation of BWR fuel envelops unchanneled assemblies and assemblies with channels up to 120 mils thick.

### GTCC Waste

The GTCC waste to be transported in the MAGNATRAN transport cask consists of sections of core baffle plates and angles, baffle formers, lower core plates and miscellaneous related

hardware associated with these components. The major components are cut into pieces of a size that are loaded into a GTCC waste basket liner. Small residual pieces of GTCC may be loaded into stainless steel strainer baskets for handling. The loaded strainer baskets are stacked in a stainless steel pipe cell that has been placed in the GTCC waste basket liner to retain spacing prior to GTCC initial loading. Any dross material (fines and debris) generated by the cutting operations will be disposed of as low-level radioactive or GTCC waste.

Each GTCC waste basket liner may contain up to 55,000 pounds of GTCC waste including the weight of strainer baskets and pipe spacers. The GTCC waste basket liner is transported in a GTCC TSC with a welded closure lid. The GTCC waste basket liners have twelve 1.0-inch diameter holes in the bottom plate, and outer ring and middle supports under the bottom plate to facilitate free flow drainage from the liner. The GTCC TSC has a sump in the bottom plate, and the closure lid includes a drain tube assembly to enable draining and vacuum drying of the loaded TSC. Consequently, no hydrogen generation occurs as a result of residual water.

The radionuclide composition of the waste was determined based on radiochemical assay of samples and dose rate measurements. The isotope that primarily contributes to the radiological source term is $^{60}Co$. The source terms applied in the evaluation of the GTCC waste are presented in Chapter 5 of this SAR.

### Fuel and GTCC Content Limits

Spent fuel and GTCC waste shipments in the MAGNATRAN shall be subject to the following limits:

1. The maximum contents weight for the MAGNATRAN transport cask shall not exceed 106,000 pounds.
2. The design basis fuel characteristics shall be in accordance with Table 1.3-6 and Table 1.3-19.
3. The total decay heat of the cask cavity contents shall not exceed:
   a. 23 kW for PWR fuel with a uniform loading pattern
   b. 22 kW for PWR fuel loaded in a basket with neutron absorbers having Type 1 thermal conductivity (see Table 3.2-12)
   c. 22 kW for BWR fuel
   d. GTCC waste content, the decay heat limit is 1.7 kW.
4. The total weight of the PWR fuel assemblies in the TSC, including standard nonfuel hardware and spacers (if used), shall not exceed 62,160 pounds.
5. The total weight of the PWR fuel assemblies in the DF PWR TSC, including standard nonfuel hardware and spacers (if used), shall not exceed 61,184 pounds.

6. The total weight of the BWR fuel assemblies in the TSC, including channels (if applicable), shall not exceed 62,656 pounds.
7. GTCC waste consists of solid, irradiated, and contaminated hardware provided the quantity of fissile material does not exceed a Type A quantity and does not exceed the mass limits of 10 CFR 71.15.

   The specific Curie content source of the GTCC shall be limited to:
   a. a maximum of 2.7 Ci $^{60}$Co/lb averaged over GTCC contents
   b. a localized peak 16.1 Ci $^{60}$Co/lb
   c. a total $^{60}$Co activity of 85,760 Ci at transport.

   The maximum allowed weight of this waste is 55,000 lbs.
8. Any number of MAGNATRAN casks may be shipped at one time by rail, ship, barge or heavy-haul vehicle with the exception of a PWR-DF basket with DFC which requires only one cask to be shipped at one time.
9. Radiation levels shall not exceed the requirements of 10 CFR 71.47 and 10 CFR 71.51 for a closed transport vehicle.
10. Surface contamination levels shall not exceed the requirements of 10 CFR 71.87(i)(1).
11. Cask contents transported in a TSC with a PWR fuel basket shall be uranium undamaged PWR fuel assemblies in accordance with the limiting values shown in Table 1.3-6 and Table 1.3-7 and shall meet the following specifications:
    a. Zirconium-based alloy cladding.
    b. Enrichment, post-irradiation cooling time and burnup credit load curves in accordance with Tables 1.3-6, 1.3-8 through 1.3-11, and Figure 1.3-6.
    c. Maximum assembly average burnup shall be ≤ 45,000 MWd/MTU. A fuel assembly with maximum assembly average burnup > 45,000 MWd/MTU shall be treated as damaged fuel and placed in a damaged fuel can for transport.
    d. Decay heat per fuel assembly: 622 watts (includes non-fuel hardware contribution). For the PWR basket with neutron absorbers with Type 1 thermal conductivity (see Table 3.2-12), the decay heat per fuel assembly is limited to 595 watts.
    e. Nominal fresh fuel dimensions: assembly length (in.) ≤ 178.3; assembly width (in.) ≤ 8.54
    f. Fuel assembly weight (lbs.): ≤ 1,765 (including nonfuel hardware and fuel spacers)
    g. Spent fuel contents shall be loaded in accordance with the loading tables in Chapter 5, Section 5.8.3, of this SAR.
    h. Quantity per TSC: up to 37 undamaged PWR fuel assemblies shown in Figure 1.3-6. Figure 1.3-6 indicates the fuel storage locations that shall be empty, at a minimum, when implementing the 36, 35 and 33 loading patterns for burnup credit purposes.

i. Undamaged PWR fuel assemblies may contain nonfuel hardware (NFHW). Fuel assembly lattices not containing the nominal number of fuel rods specified in Table 1.3-7 must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. Fuel assemblies may have stainless steel rods inserted to displace guide tube "dashpot" water. Nonfuel hardware cool times shall be in accordance with Tables 1.3-16 through 1.3-18. Alternatively, the $^{60}$Co curie limits in Table 1.3-17 and Table 1.3-18 may be used to establish site-specific nonfuel hardware constraints. Note that fuel assemblies defined as CE14 and CE16 are not allowed to contain BPRA or TP type nonfuel hardware.

j. Fuel spacers may be used in the TSCs to reduce axial gaps for the spent fuel assemblies and non-fuel hardware.

k. Unenriched and unirradiated (i.e., not inserted in-core) fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted, provided that the nominal length of the blanket is not greater than six inches. An unenriched rod may be used as a replacement rod to return a fuel assembly to an undamaged condition.

l. Reactor control components (RCC) are restricted to fuel storage locations No. 11, 12, 13, 18, 19, 20, 25, 26 and 27 (Figure 1.3-6). Minimum RCC cool times are:

| Minimum Cool Time (years) | Maximum Exposure (GWd/MTU) |
|---|---|
| 10 | 180 |
| 14 | 270 |
| 20 | 360 |

Interpolation is not allowed between data points.

m. One Neutron Source or Neutron Source Assembly (NSA) is permitted to be loaded in a TSC in fuel storage locations No. 11, 12, 13, 18, 19, 20, 25, 26 or 27 (Figure 1.3-6). Neutron source assemblies may contain source rods attached to hardware similar in configuration to guide tube plug devices (thimble plugs) and burnable absorbers, in addition to containing burnable poison rodlets and/or thimble plug rodlets. For NSAs containing absorber rodlets, the BPRA cool time and burnup/exposure or hardware $^{60}$Co curie limit listed in Table 1.3-17 are applied to the neutron sources. NSAs having only thimble plug rodlets require the thimble plug restriction in Table 1.3-18 to be applied. Combination NSAs, containing both thimble plug and burnable absorber rodlets must apply the more limiting of the two minimum cool time/curie limit. Fuel assemblies

loaded with the NSAs must apply the additional cool times listed in Table 1.3-16. Fuel types indicated as CE14 and CE16 are not permitted to be loaded with NSAs.

n. Fuel assemblies may contain any number of unirradiated (i.e., not inserted in-core) nonfuel solid filler fuel replacement rods. Activated stainless steel rods are limited to five per assembly, one assembly per basket, at a maximum steel rod burnup/exposure of 32.5 GWd/MTU. Fuel assemblies with activated stainless steel rods must be cooled either a minimum of 21 years or the Section 5.3 loading table minimum cool time plus one year, whichever is greater.

o. Westinghouse fuel assemblies may contain a hafnium absorber assembly (HFRA) at a maximum burnup/exposure of 4.0 GWd/MTU and a minimum cool time of 16 years. Fuel assemblies loaded with an HFRA must apply the additional cool times listed in Table 1.3-16.

p. Under-burned (assemblies with burnup less than that dictated by the burnup credit loading curve) Westinghouse 15×15 PWR fuel assemblies may be loaded provided that they include Ag-In-Cd full-length RCCAs and are loaded in the basket locations that RCCs are allowed (see item l for RCCA loading). Burnup must be greater than or equal to 12,000 MWd/MTU. Enrichment must be equal to or less than 4.05 wt. % $^{235}$U. The basket must include absorber sheets with an effective $^{10}$B areal density of 0.036 g/cm$^2$. For the loading of low burnup fuel, the RCCAs must be full length (i.e. spider component included). RCCA exposure must be equal to or less than 200,000 MWd/MTU. Any assemblies loaded without an RCCA inserted must meet the burnup credit loading curve for the applicable assembly loading profile.

12. Cask contents transported in a TSC with a DF Basket Assembly shall be uranium undamaged PWR fuel assemblies and damaged fuel (damaged PWR fuel assemblies or PWR fuel debris) in accordance with the limiting values shown in Table 1.3-6 and Table 1.3-7 and shall meet the following specifications:

   a. Zirconium-based alloy cladding.

   b. For the 33 non-DFC fuel locations in the DF Basket Assembly, enrichment, post-irradiation cooling time and burnup credit load curves in accordance with Tables 1.3-6, 1.3-12 through 1.3-15, and Figure 1.3-6 for a TSC with a DF Basket Assembly containing DFCs. For a TSC with a DF Basket Assembly that does not contain any DFCs, the enrichment, post-irradiation cooling time and burnup credit load curves in accordance with Tables 1.3-6, 1.3-8 through 1.3-11, and Figure 1.3-4 may be used for all fuel locations.

c. For the up to four DFC locations in a DF Basket Assembly containing damaged fuel, the damaged fuel shall have a minimum burnup of 5 GWd/MTU, a maximum enrichment of 4.05 wt % $^{235}U$, and a minimum cool time of 15 years.

d. Maximum assembly average burnup shall be ≤ 45,000 MWd/MTU. A fuel assembly with maximum assembly average burnup > 45,000 MWd/MTU shall be treated as damaged fuel and placed in a damaged fuel can for transport.

e. Decay heat per fuel assembly: 622 watts (590.5 watts for burnup > 45,000 MWd/MTU, includes non-fuel hardware contribution). For the PWR basket with neutron absorbers with Type 1 thermal conductivity (see Table 3.2-12), the decay heat per fuel assembly is limited to 595 watts

f. Nominal fresh fuel assembly: length (in.) ≤ 167.0

g. Nominal fresh fuel assembly: width (in.) ≤ 8.54

h. Fuel assembly weight (lbs.): ≤ 1,765 (including nonfuel hardware, DFCs and fuel spacers)

i. Spent fuel contents shall be loaded in accordance with the loading tables in Section 5.8.3 with additional cool time for damaged fuel found in Table 5.8-49 of this SAR. The additional cool time from Table 5.8-49 applies to all assemblies loaded in a damaged fuel TSC with damaged fuel. High burnup fuel is treated as damaged fuel and must apply the damaged fuel delta cool time as applicable.

j. Quantity per TSC: Up to a total of 37 undamaged PWR fuel assemblies, including up to four DFCs containing undamaged PWR fuel assemblies, damaged PWR fuel assemblies, and/or PWR fuel debris loaded in DFC location Nos. 4, 8, 30 and 34, as shown on Figure 1.3-4, for the DF Basket Assembly. Figure 1.3-6 indicates the fuel storage locations that shall be empty, at a minimum, when implementing the 36, 35 and 33 loading patterns for burnup credit purposes.

k. The contents of a DFC must be less than, or equivalent to, one undamaged PWR fuel assembly. PWR fuel assemblies loaded in a DFC shall not contain nonfuel hardware with the exception of instrument tube tie components, guide tube anchors or other similar devices, and steel inserts.

l. Undamaged PWR fuel assemblies not loaded in a DFC may contain nonfuel hardware consistent with Table 1.3-16. Fuel assembly lattices not containing the nominal number of fuel rods specified in Table 1.3-7 must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. Fuel assemblies may have stainless steel rods inserted to displace guide tube "dashpot" water. Nonfuel hardware cool times shall be in accordance with Tables 1.3-16 through 1.3-18.

Alternatively, the $^{60}Co$ curie limits in Tables 1.3-17 and 1.3-18 may be used to establish site-specific nonfuel hardware constraints. Note that fuel assemblies defined as CE14 and CE16 are not allowed to contain BPRA or TP type nonfuel hardware.

m. Fuel spacers may be used in the TSCs to reduce axial gaps for the spent fuel assemblies, non-fuel hardware or damaged fuel cans.

n. Unenriched and unirradiated (i.e., not inserted in-core) fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted, provided that the nominal length of the blanket is not greater than six inches. An unenriched rod may be used as a replacement rod to return a fuel assembly to an undamaged condition.

o. Reactor control components (RCC) are restricted to fuel storage location Nos. 11, 12, 13, 18, 19, 20, 25, 26 and 27 (Figure 1.3-4). Minimum RCC cool times are:

| Minimum Cool Time (years) | Maximum Exposure (GWd/MTU) |
|---|---|
| 10 | 180 |
| 14 | 270 |
| 20 | 360 |

Interpolation is not allowed between data points.

p. One Neutron Source or Neutron Source Assembly (NSA) is permitted to be loaded in a TSC in fuel storage location Nos. 11, 12, 13, 18, 19, 20, 25, 26 or 27 (Figure 1.3-4). Neutron source assemblies may contain source rods attached to hardware similar in configuration to guide tube plug devices (thimble plugs) and burnable absorbers, in addition to containing burnable poison rodlets and/or thimble plug rodlets. For NSAs containing absorber rodlets, the BPRA cool time and burnup/exposure or hardware $^{60}Co$ curie limit listed in Table 1.3-17 are applied to the neutron sources. NSAs having only thimble plug rodlets require the thimble plug restriction in Table 1.3-18 to be applied. Combination NSAs, containing both thimble plug and burnable absorber rodlets must apply the more limiting of the two minimum cool time/curie limit. Fuel assemblies loaded with the NSAs must apply the additional cool times listed in Table 1.3-16. Fuel types indicated as CE14 and CE16 are not permitted to be loaded with NSAs.

q. Fuel assemblies may contain any number of unirradiated (i.e., not inserted in-core) nonfuel solid filler fuel replacement rods. Activated stainless steel rods are limited to five per assembly, one assembly per basket, at a maximum steel rod burnup/exposure of 32.5 GWd/MTU. Fuel assemblies with activated stainless steel rods must be cooled

either a minimum of 21 years or the item 12.i indicated minimum cool time plus one year, whichever is greater.

r. Westinghouse fuel assemblies may contain a hafnium absorber assembly (HFRA) at a maximum burnup/exposure of 4.0 GWd/MTU and a minimum cool time of 16 years. Fuel assemblies loaded with an HFRA must apply the additional cool times listed in Table 1.3-16.

s. Under-burned (assemblies with burnup less than that dictated by the burnup credit loading curve) Westinghouse 15×15 PWR fuel assemblies may be loaded provided that they include Ag-In-Cd full-length RCCAs and are loaded in the basket locations that RCCs are allowed (see item o for RCCA loading). Burnup must be greater than or equal to 12,000 MWd/MTU. Enrichment must be equal to or less than 4.05 wt. % $^{235}$U. The basket must include absorber sheets with an effective $^{10}$B areal density of 0.036 g/cm$^2$. For the loading of low burnup fuel, the RCCAs must be full length (i.e. spider component included). RCCA exposure must be equal to or less than 200,000 MWd/MTU. Any assemblies loaded without an RCCA inserted must meet the burnup credit loading curve for the applicable assembly loading profile.

t. Damaged CE 16×16 fuel assemblies are not to be loaded in the MAGNATRAN system.

13. Cask contents transported in a TSC with a BWR fuel basket shall be uranium undamaged BWR fuel assemblies in accordance with the limiting values shown in Table 1.3-19 and Table 1.3-20 and shall meet the following specifications:

a. Zirconium-based alloy cladding.

b. Enrichment, post-irradiation cooling time and average assembly burnup in accordance with Tables 1.3-19, 1.3-21, and 1.3.-22 and Figures 1.3-5, 1.3-7 and 1.3-8.

c. Decay heat per fuel assembly: uniform loading 253 watts

d. Nominal fresh fuel dimensions: assembly length (in.) ≤ 176.2

e. Assembly width (in.) ≤ 5.52

f. Fuel assembly weight (lbs.) ≤ 739 lbs (including channel and fuel spacers) with a maximum contents weight of 62,656 lbs.

g. Spent fuel contents shall be loaded in accordance with the loading tables in Chapter 5, Section 5.8.4, of this SAR.

h. Quantity per TSC: up to 87 undamaged BWR fuel assemblies as shown in Figure 1.3-7.

i. Allowable fuel assembly locations for the 82-assembly BWR fuel basket configurations are shown in Figure 1.3-5 (location numbering for the 82-assembly basket is the same as that shown for the 87-assembly basket in Figure 1.3-7).

j. Prior to use of the 82-assembly configuration, the center cell weldment and upper weldments with blocking strap must be in place to physically block the designated nonfuel locations (shown in Figure 1.3-5). Less than 82 assemblies may be loaded when implementing the 82-Assembly configuration provided the required fuel storage locations are empty, at a minimum.

k. BWR fuel assemblies may be unchanneled, or channeled with zirconium-based alloy channels.

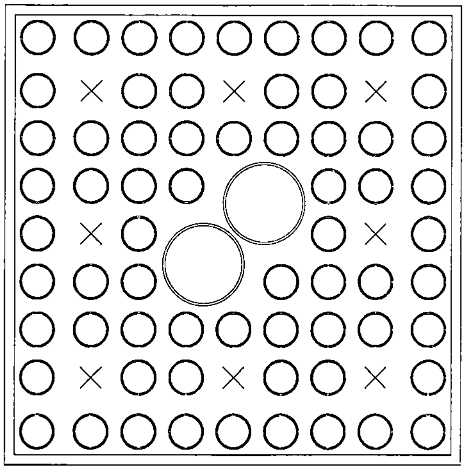
l. BWR fuel assemblies with stainless steel channels are not authorized.

m. Fuel assembly lattices not containing the assembly type-specific nominal number of fuel rods specified in Table 1.3-20 must contain solid, unirradiated, filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces

n. Spacers may be used in the TSCs to fill axial gaps and provide support for the spent fuel assemblies.

o. Unenriched and unirradiated (i.e., not inserted in-core) fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted, provided that the nominal length of the blanket is not greater than six inches.

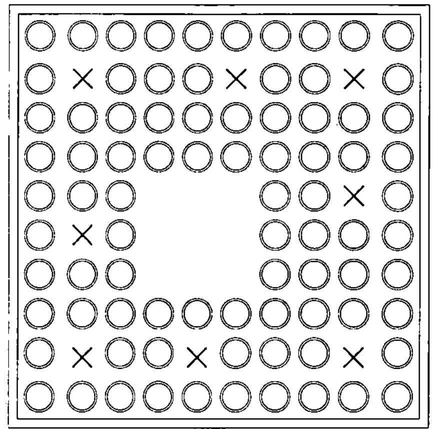
**Figure 1.3-8 BWR Partial Length Fuel Rod Location Sketches**



○ = Fuel Rod Location

× = Partial Rod Location

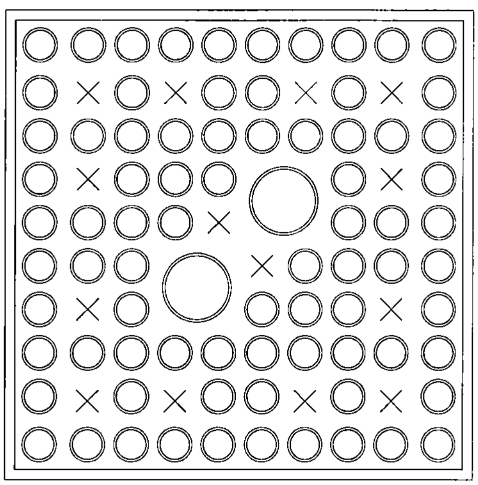
*B9_74A 8 Partial Length Rods*



○ = Fuel Rod Location

× = Partial Rod Location

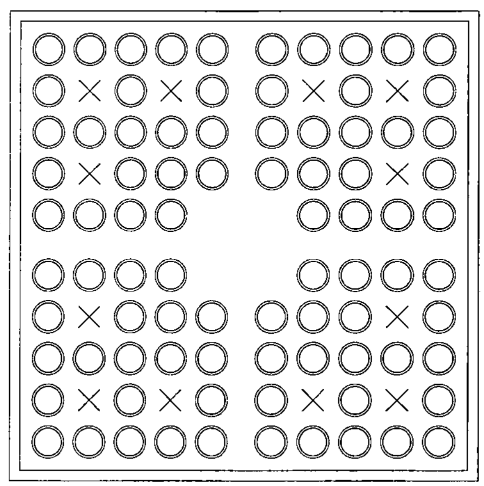
*B10_91A 8 Partial Length Rods*



○ = Fuel Rod Location

× = Partial Rod Location

*B10_92A 14 Partial Length Rods*



○ = Fuel Rod Location

× = Partial Rod Location

*B10_96A 12 Partial Length Rods*

**Table 1.3-6 PWR Fuel Assembly Characteristics**

| Characteristic | Fuel Class | | | | | |
|---|---|---|---|---|---|---|
| | 14×14 | 14×14 | 15×15 | 15×15 | 16×16 | 17×17 |
| Base Fuel Type[a] | CE, SPC | W, SPC | W, SPC | BW, FCF | CE | BW, SPC, W, FCF |
| Max Initial Enrichment (wt% $^{235}U$) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Min Initial Enrichment (wt% $^{235}U$) | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Number of Fuel Rods | 176 | 179 | 204 | 208 | 236 | 264 |
| Max Assembly Average Burnup (MWd/MTU) | 60,000 | 60,000 | 60,000 | 60,000 | 60,000 | 60,000 |
| Min Cool Time (years) | 4 | 4 | 4 | 4 | 4 | 4 |
| Max Weight (lb) per Storage Location | See Note 1 | See Note 1 | See Note 1 | See Note 1 | See Note 1 | See Note 1 |
| Max Decay Heat (Watts) per Fuel Location | See Note 2 | See Note 2 | See Note 2 | See Note 2 | See Note 2 | See Note 2 |

- Fuel cladding is a zirconium-based alloy.
- All reported enrichment values are nominal preirradiation fabrication values.
- Weight includes the weight of nonfuel-bearing components.
- Assemblies may contain nonfuel hardware and/or fuel replacement rods (also referred to as filler rods). Filler rods are considered to be a component of spent nuclear fuel assemblies and not nonfuel hardware. Filler rods may be burnable absorber rods, stainless steel rods or zirconium alloy rods.
- PWR fuel is loaded using burnup credit. Maximum enrichment is as a function of minimum burnup as specified in Chapter 6. Maximum initial enrichment represents the peak fuel rod enrichment for variably-enriched fuel assemblies.
- Spacers may be used to axially position fuel assemblies to facilitate handling.
- All fuel with burnup > 45,000 MWd/MTU is placed into Damaged Fuel Cans (DFC).

**Notes:**

1. Maximum weight per storage location is 1,765 lbs (including nonfuel hardware, DFCs and fuel spacers) with a maximum contents weight of 62,160 lbs for the PWR basket and 61,184 lbs for the DF basket.
2. For PWR baskets with Type 2 thermal conductivity neutron absorbers, the maximum heat load is 622 watts per storage location and PWR baskets with Type 1 thermal conductivity neutron absorbers the maximum heat load is 595 watts per storage location.

[a] Indicates assembly and/or nuclear steam supply system (NSSS) vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor provided that the fuel assembly meets the load limits. Abbreviations are as follows: Westinghouse (W), Combustion Engineering (CE), Siemens Power Corporation (SPC), Babcock and Wilcox (BW), and Framatome Cogema Fuels (FCF).

### 1.4.3 License Drawings

This section presents the list of License Drawings for MAGNATRAN.

| Drawing Number | Title | Revision No. |
|---|---|---|
| 71160-500 | Shipping Configuration, Transport Cask, MAGNATRAN | 1NP |
| 71160-501 | Assembly, Transport Cask, MAGNATRAN | 0 |
| 71160-502 | Transport Cask Body, MAGNATRAN | 4NP |
| 71160-504 | Misc. Details, Transport Cask, MAGNATRAN | 2 |
| 71160-505 | Lid Assembly, Transport Cask, MAGNATRAN | 5NP |
| 71160-506 | Cask Cavity Spacer, MAGNATRAN | 1 |
| 71160-511 | Personnel Barrier, Shipping Configuration, Transport Cask, MAGNATRAN | 1 |
| 71160-512 | Nameplate, MAGNATRAN | 1 |
| 71160-530 | Misc. Details, Impact Limiter, MAGNATRAN | 1 |
| 71160-531 | Impact Limiter, Transport Cask, MAGNATRAN | 2P* |
| 71160-551 | Fuel Tube Assembly, MAGNASTOR – 37 PWR | 10NP |
| 71160-559 | Lifting Trunnion, Transport Cask, MAGNATRAN | 0 |
| 71160-571 | Details, Neutron Absorber, Retainer, MAGNASTOR – 37 PWR | 8 |
| 71160-572 | Details, Neutron Absorber, Retainer, MAGNASTOR – 87 BWR | 8NP |
| 71160-574 | Basket Support Weldments, MAGNASTOR – 37 PWR | 6 |
| 71160-575 | Basket Assembly, MAGNASTOR – 37 PWR | 11NP |
| 71160-581 | Shell Weldment, TSC, MAGNASTOR | 5 |
| 71160-584 | Details, TSC, MAGNASTOR | 8 |
| 71160-585 | TSC Assembly, MAGNASTOR | 12 |
| 71160-591 | Fuel Tube Assembly, MAGNASTOR – 87 BWR | 8NP |
| 71160-598 | Basket Support Weldments, MAGNASTOR – 87 BWR | 7NP |
| 71160-599 | Basket Assembly, MAGNASTOR – 87 BWR | 8NP |
| 71160-600 | Basket Assembly, MAGNASTOR – 82 BWR | 5NP |
| 71160-601 | Damaged Fuel Can (DFC), Assembly, MAGNASTOR | 0 |
| 71160-602 | Damaged Fuel Can (DFC), Details, MAGNASTOR | 1 |

* License drawing is proprietary in its entirety and not included in the non-proprietary version of the SAR. It is included on the List of License Drawings for reference only.

1.4.3 License Drawings (cont'd)

| Drawing Number | Title | Revision No. |
|---|---|---|
| 71160-620 | Top Fuel Spacer, MAGNASTOR | 1P* |
| 71160-671 | Details, Neutron Absorber, Retainer, For DF Corner Weldment, MAGNASTOR – 37 PWR | 0 |
| 71160-673 | Damaged Fuel Can (DFC), Spacer, MAGNASTOR | 1 |
| 71160-674 | DF Corner Weldment, MAGNASTOR | 3NP |
| 71160-675 | DF Basket Assembly, 37 Assembly PWR, MAGNASTOR | 3NP |
| 71160-681 | DF, Shell Weldment, TSC, MAGNASTOR | 1 |
| 71160-684 | Details, DF Closure Lid, MAGNASTOR | 2 |
| 71160-685 | DF, TSC Assembly, MAGNASTOR | 6 |
| 71160-711 | GTCC Waste Basket Liner, MAGNASTOR | 1 |
| 71160-781 | Shell Weldment, GTCC TSC, MAGNASTOR | 1 |
| 71160-785 | GTCC TSC, Assembly, MAGNASTOR | 3 |

| REV | CHANGE |
|---|---|
| 0 | INITIAL ISSUE |
| 1 | INC DCR 0A |
| 2 | INC DCR 1A. |

# Security-Related Information Figure Withheld Under 10 CFR 2.390.

UNLESS OTHERWISE STATED

NEXT ASSEMBLY 71160-501

DRAWING TYPE: LICENSE

| GROUP | NAME | DATE |
|---|---|---|
| | [signature] | 12/13/16 |
| | [signature] | 12-13-16 |
| | [signature] | 12-13-16 |
| | [signature] | 12-13-16 |
| | [signature] | 12/13/16 |
| | [signature] | 12-15-16 |

NAC INTERNATIONAL

MISC. DETAILS, TRANSPORT CASK, MAGNATRAN

PROJECT 71160

DRAWING 504 REV 2

SH 1 OF 1

| REV | CHANGE |
|---|---|
| 0 | INITIAL ISSUE |
| 1 | INC DCR 0A |
| 2 | INC DCR 1A |
| 3 | INC DCR 2A |
| 4 | INC DCR 3A |
| 5 | INC DCR 4A |
| 6 | INC DCR 5A |
| 7 | INC DCR 6A |
| 8 | INC DCR 7A, 7B |
| 9 | INC DCR 8A |
| 10 | INC DCR 9A |
| 11 | INC DCR 10A |
| 12 | INC DCR 11A |

Security-Related Information Figure Withheld Under 10 CFR 2.390.

UNLESS OTHERWISE STATED

NEXT ASSEMBLY: 71160-590/500

DRAWING TYPE: LICENSE

| GROUP | NAME | DATE |
|---|---|---|
| | [signature] | 6-9-16 |
| | [signature] | 6-15-16 |
| | [signature] | 6-15-16 |
| | [signature] | 6-15-16 |
| | [signature] | 6/16/16 |
| | [signature] | 6-16-16 |

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

PROJECT 71160 DRAWING 585 REV 12

SH 1 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

71160

585

12

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

TSC ASSEMBLY, MAGNASTOR

PROJECT 71160

DRAWING 585

REV 12

SH 3 OF 3

| REV | CHANGE |
|---|---|
| 0 | INITIAL ISSUE |
| 1 | INC DCR 0A |
| 2 | INC DCR 1A |
| 3 | INC DCR 2A |
| 4 | INC DCR 3A |
| 5 | INC DCR 4A |
| 6 | INC DCR 5A |

Security-Related Information Figure Withheld Under 10 CFR 2.390.

| | | |
|---|---|---|
| UNLESS OTHERWISE STATED | GROUP | NAME | DATE |
| | | | 6-10-16 |
| | | | 6-15-16 |
| | | | 6-15-16 |
| | | | 6-15-16 |
| NEXT ASSEMBLY 71160-590/501 | | | 6/16/16 |
| DRAWING TYPE LICENSE | | | 6-16-16 |

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160 DRAWING 685 REV 6

SH 1 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160 | DRAWING 685 | REV 6

SH 2 OF 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

NAC INTERNATIONAL

DF, TSC ASSEMBLY, MAGNASTOR

PROJECT 71160

DRAWING 685 REV 6

SH 3 OF 3

# Chapter 3
# Thermal Evaluation

## Table of Contents

## List of Figures

## 3.1 Discussion

The MAGNATRAN transport cask is designed to transport two categories of PWR fuel assemblies, two categories of BWR fuel assemblies, PWR damaged fuel in DFCs and GTCC waste. Two lengths of transportable storage canisters (TSCs), long and short, are designed to transport the two categories of PWR and BWR fuel assemblies. The short TSC is also designed to transport GTCC waste with a maximum heat load of 1.7 kW. A cavity spacer shall be used in the transport cask cavity to axially position the short TSC and limit its potential movement under normal conditions of transport and hypothetical accident conditions. Only the bounding evaluation for the PWR and BWR classes of fuel is reported herein. The bounding case is represented by a configuration consisting of the short canister, short fuel tube, and short fuel assemblies with the lowest effective thermal conductivity. The fuel assemblies are confined within the fuel tubes of the fuel basket. The short fuel basket results in a larger gap between the basket and the canister. The short canister provides the longest space in the bottom and top of the cask cavity. The result is a greater concentration of heat and maximized thermal resistance for rejection of heat through the cavity top and bottom.

The design basis heat loads are 23 kW for up to 37 PWR fuel assemblies and 22 kW for up to 87 BWR fuel assemblies. The individual PWR assembly decay heat is limited to 0.622 kW (including damaged fuel), and the individual BWR assembly decay heat load is limited to 0.253 kW. As shown in Table 3.2-12, there are two types of required effective thermal conductivities for the neutron absorber. For the PWR basket with design basis heat load of 23 kW, Type 2 thermal conductivity of the neutron absorber is required. For the PWR basket with neutron absorbers with Type 1 thermal conductivity, the heat load is limited to 22 kW, with the individual assembly decay heat limited to 0.595 kW. For the BWR basket with design basis heat load, Type 1 thermal conductivity of the neutron absorber is required. As shown in Section 3.4.6, the thermal analysis considers a range of fuel assembly burnup and cool times for both fuel types to establish the allowable cladding temperatures. These limits are used to establish the allowable decay heat loads for fuel having cooling times of five years or more.

The thermal analyses presented in the following sections use helium as the cover gas in the cask cavity and in the TSC.

Heat transfer from the MAGNATRAN transport cask to the environment is by passive means only and no forced cooling is necessary. Conduction and radiation are the means by which heat is transferred from the fuel assemblies to the fuel tubes and through the tubes to the TSC wall and then to the cask cavity inner shell. From the MAGNATRAN transport cask cavity, heat is conducted through the inner shell, the lead (gamma shield) and then through the cask outer shell.

The copper heat transfer fins surrounding the outer shell along most of the cask's length conducts heat to the neutron shield assemblies and the environment. Heat is removed from the surface of the copper and aluminum heat transfer fins by convection and radiation.
Because of the insulating characteristics of the impact limiters, no heat is modeled as being removed from the ends of the cask. The bounding thermal conditions for the analysis required by 10 CFR 71 under normal conditions of transport are presented in Table 3.1-1.

During normal conditions of transport and hypothetical accident conditions, the cask must reject the fuel decay heat to the environment without exceeding the operational temperature ranges of the cask seals or other components important to safety. In addition, to maintain fuel rod integrity for normal conditions of transport, the fuel must be maintained at a sufficiently low temperature in an inert atmosphere such that thermally induced fuel rod cladding deterioration is precluded. Finally, the thermally induced stresses, in combination with pressure and mechanical load stresses, must be below allowable stress levels.

The temperatures for the various components of the fuel, TSC, basket and cask during normal conditions of transport and the hypothetical accident condition fire are calculated by using finite element methods. For the normal conditions of transport and the hypothetical accident conditions, the cask loaded with PWR fuel and the cask loaded with BWR fuel, are analyzed by using separate finite element models. For each fuel configuration, the thermal analyses of the cask for normal conditions of transport are performed by using three-dimensional finite element models of the loaded cask. The cask is transported in a horizontal orientation. These models are described in Section 3.4.1.1 and Section 3.4.1.2. The thermal analyses of the cask for the hypothetical accident fire condition are performed by using three-dimensional models of the cask. These models are described in Section 3.5.1.1.

Results of the thermal analyses of the package are presented in Section 3.4 and Section 3.5. The results demonstrate that the maximum fuel rod cladding temperatures remain below the allowable temperatures for normal conditions of transport and hypothetical accident conditions. The thermally induced stresses, combined with pressure and mechanical load stresses, are within the allowable levels, as demonstrated in Chapter 2.0. Therefore, the cask design and operation are in conformance with temperature and thermal stress criteria.

The temperatures determined in this chapter, and other properties evaluated herein, are used in other analyses included in this Safety Analysis Report. The material properties and allowable stresses at the corresponding component temperatures are used in the structural calculations presented in Chapter 2.0. The structural evaluation of the cask components also incorporates stresses resulting from differential thermal expansion and temperature effects on the cask internal pressure as applicable.

**Table 3.1-1 Thermal Analysis Bounding Conditions – Normal Conditions of Transport**

| Condition | Value |
|---|---|
| Ambient Temperature per 10 CFR 71:<br>Maximum (hot conditions)<br>Minimum (cold conditions and minimum temperature) | <br>100°F<br>-40°F |
| Insolance (for 12 hr per day) per 10 CFR 71:<br>Horizontal Flat Surfaces (facing up)<br>Curved Surfaces | <br>2,950 Btu/ft$^2$<br>1,475 Btu/ft$^2$ |
| PWR Fuel Assembly Decay Heat, Total:<br>PWR Fuel Peaking Factor | 23 kW*<br>1.08 |
| BWR Fuel Assembly Decay Heat, Total:<br>BWR Fuel Peaking Factor | 22 kW<br>1.22 |

* For PWR basket using Type 1 neutron absorber as defined in Table 3.2-12, the heat load is limited to 22 kW

$$q_k = \frac{KA}{g}(T_i - T_j)$$

where:

$g$ = gap distance (between two surfaces defined by nodes i and j)

$K$ = conductivity of gas in gap

$A$ = cross sectional area for heat conduction

By combining the two expressions (for $q_k$ and $q_r$) and factoring out the term $A(T_i - T_j)/g$,

$$Q_t = [g\sigma\varepsilon F(T_i^2 + T_j^2)(T_i+T_j) + K][A(T_i - T_j)/g]$$

or

$$Q_t = K_{eff}A(T_i - T_j)/g$$

where:

$$K_{eff} = g\sigma\varepsilon F(T_i^2 + T_j^2)(T_i+T_j) + K$$

The material conductivity used in the analysis for the elements that constitute the gap includes the heat transfer by both conduction and radiation. Because the gap is small compared with the basket length, the form factor (F) is taken to be unity.

### 3.2.3 Convective Properties

A convective heat transfer coefficient, $h_c$, is associated with each surface where convection operates. The cylindrical surface of the cask and the surface of the heat transfer fins take part in the convection heat removal process because the ends of the cask are thermally "insulated" from the environmental ambient thermal sink by the impact limiters.

The surface is represented by a horizontal cylinder and fins in air. From the Standard Handbook for Mechanical Engineers, Eq. 4.4.12d, Page 4-88, the heat transfer coefficient, $h_c$, is:

$$h_c = 0.19\ \Delta T^{1/3}\ \text{BTU/hr-ft}^2\text{-°F, for } D^3\Delta T > 100$$

where:

$\Delta T$ = temperature difference between surface and air, °F

$D$ = cylinder diameter, ft

For $D = 7.225$ ft and $\Delta T > 100$°F, the value of $D^3\Delta T > 37{,}000$ is significantly larger than 100.

The expression can be converted into:

$$h_c = 0.00132\ \Delta T^{1/3}\ \text{Btu/(hr-in}^2\text{-°F)}$$

Alternatively, the heat transfer coefficient may be determined by the CFD model as presented in Section 3.4.1.3.

**Table 3.2-1 Thermal Properties of Solid Neutron Shield (NS-4-FR)**

| Property (units) | Value |
|---|---|
| Conductivity (Btu/hr-in-°F) | 0.0311 |
| Density (Borated) (lbm/in$^3$) | 0.0589 |
| Density (Nonborated) (lbm/in$^3$) | 0.0607 |
| Specific heat (Btu/lbm-°F) | 0.319 |

**Table 3.2-2 Thermal Properties of Stainless Steel**

| | Type 304 and 304L | | | | |
|---|---|---|---|---|---|
| | Temperature | | | | |
| Property | 100°F | 200°F | 400°F | 550°F | 750°F |
| Conductivity (Btu/hr–in-°F) | 0.725 | 0.775 | 0.867 | 0.925 | 1.000 |
| Density (lbm/in$^3$) | 0.290 | 0.289 | 0.287 | 0.286 | 0.284 |
| Specific Heat (Btu/lbm-°F) | 0.116 | 0.120 | 0.127 | 0.131 | 0.136 |
| Emissivity | ← 0.36 (300°F) → | | | | |

| | Type SA240, Type XM-19 Stainless Steel | | | | | | |
|---|---|---|---|---|---|---|---|
| | Temperature | | | | | | |
| Property | 70°F | 100°F | 200°F | 300°F | 500°F | 700°F | 750°F |
| Conductivity (Btu/hr -in-°F) | 0.533 | 0.550 | 0.592 | 0.642 | 0.733 | 0.825 | 0.842 |
| Emissivity | ← 0.36 → | | | | | | |

Table 3.2-9 Thermal Properties of Copper

| Property | Temperature 32°F | 212°F | 392°F |
|---|---|---|---|
| Conductivity (Btu/hr -in-°F) | 18.6 | 18.3 | 18.0 |
| Density (lbm/in³) | ← 0.32 → | | |
| Specific Heat (Btu/lbm-°F) | ← 0.09 → | | |
| Emissivity | ← 0.65 → | | |

Table 3.2-10 Thermal Properties of Zircaloy and Zircaloy-4 Cladding

| Property | Temperature 392°F | 572°F | 752°F | 932°F |
|---|---|---|---|---|
| Conductivity (Btu/hr -in-°F) | 0.69 | 0.73 | 0.80 | 0.87 |
| Density (lbm/in³) | ← 0.237 → | | | |
| Specific Heat (Btu/lbm-°F) | 0.072 | 0.074 | 0.076 | 0.079 |
| Emissivity | ← 0.75 → | | | |

Table 3.2-11 Thermal Properties of Fuel ($UO_2$)

| Property | Temperature 100°F | 257°F | 482°F | 707°F | 932°F |
|---|---|---|---|---|---|
| Conductivity* (Btu/hr–in-°F) | 0.38 | 0.347 | 0.277 | 0.236 | 0.212 |
| Density (lbm/in³) | ← 0.396 → | | | | |
| Specific Heat (Btu/lbm-°F) | 0.057 | 0.062 | 0.067 | 0.071 | 0.073 |
| Emissivity | ← 0.85 → | | | | |

* 60% of the conductivities are conservatively used in the evaluations for both PWR and BWR configurations.

**Table 3.2-12 Neutron Absorber Material Minimum Effective Thermal Conductivity**

| Neutron Absorber Type* | Minimum Effective Thermal Conductivity - BTU/(hr-in-°F) | | | |
|---|---|---|---|---|
| | Radial | | Axial | |
| | 100°F | 500°F | 100°F | 500°F |
| Type 1 | 1.503 | 1.972 | 3.295 | 3.669 |
| Type 2 | 3.12 | 3.21 | 4.31 | 4.65 |

* Type 1 thermal conductivity for the neutron absorber is required for PWR or BWR baskets with a maximum heat load of 22 kW. Type 2 thermal conductivity is required for PWR baskets with a maximum heat load of 23 kW.

**Table 3.2-13 Gaps in the MAGNATRAN Transport Cask Model**

| Gap Location | Gap (in.) Cask with PWR Fuel Canister | Gap (in.) Cask with BWR Fuel Canister |
|---|---|---|
| Gap between basket slots at corners | 0.01 | 0.01 |
| Gap between canister and cask inner shell | 0.125* | 0.125* |
| Gap between lead gamma shield and inner shell | 0.015 | 0.015 |
| Gap between basket and canister bottom plate | 0.25 | 0.25 |
| Gap between canister bottom plate and cask bottom plate | 5.625 | 5.625 |
| Gap between canister lid and cask lid** | 8.5 | N/A |

* The gap size is 0.125 inch. The TSC in the model is shifted downward to simulate contact with the cask inner shell resulting in a non-uniform gap around the TSC (larger gap at the upper region and smaller gap at the lower region).

** This gap is applicable for the full-length PWR model only.

## 3.4 Thermal Evaluation for Normal Conditions of Transport

The finite element method is used to evaluate the thermal performance of the MAGNATRAN transport cask for normal conditions of transport as specified in 10 CFR 71. The general-purpose finite element analysis program ANSYS is used to perform the finite element evaluations.

The normal conditions of transport used in the thermal evaluation of the cask are as follows:

- Hot Conditions: maximum decay heat generation, ambient temperature = 100°F, solar insolance (solar insolance applied according to Table 3.1-1)
- Cold Conditions: maximum decay heat generation, ambient temperature = -40°F, no solar insolance
- Minimum Temperature Conditions: no decay heat generation, ambient temperature = -40°F, no solar insolance (no analysis is performed for this condition because all component temperatures will be -40°F for steady-state conditions)

The objectives of the cask thermal analyses under normal conditions of transport are as follows:

1. Demonstrate that the cask can safely maintain the design basis temperatures required for fuel cladding integrity under the range of thermal conditions expected during normal conditions
2. Demonstrate that cask components important to safety are maintained within their safe operating temperature ranges
3. Provide thermal input to the structural analyses

The first objective is met by demonstrating that the cask maintains maximum fuel rod cladding temperatures below the allowable temperatures during normal conditions.

The second objective is met by comparing the results of the analyses with the safe operating ranges established in Section 3.3.

The third objective is met by using the results of the thermal analyses (as direct import of ANSYS temperature data, as maximum and minimum component temperatures, or as allowable look-up temperatures) as input to the structural analyses, which demonstrate that the combined load stresses are within allowable limits.

### 3.4.1 Thermal Models

The finite element and finite volume methods are used to evaluate the MAGNATRAN transport cask for exposure to normal conditions of transport as specified in 10 CFR 71. This section describes the finite element and finite volume models used in the thermal evaluation of the cask under normal conditions of transport. Separate three-dimensional finite element models are used to evaluate the cask loaded with PWR fuel and the cask loaded with BWR fuel. A three-dimensional finite volume model of the cask body section is developed to evaluate the convection film coefficients on the cask surface. The analyses for normal conditions of transport consider the transport cask oriented horizontally.

For each fuel-loading configuration, the cask is evaluated for normal conditions of transport using a three-dimensional finite element model of the loaded cask including internal components. The three-dimensional finite element models of the cask/internal components each comprise four parts: basket with fuel assembly; TSC; transport cask body; and gases between components. To model the cask in a horizontal orientation, the fuel basket in each model is modeled in contact with the TSC on one side which, in turn, is in contact with the inner shell of the cask on one side.

Solar insolance, natural convection and thermal radiation boundary conditions based on ambient temperature are applied to the outer surface of the cask (the sections of the cask body covered by the impact limiters are modeled as adiabatic). The three-dimensional finite element model for the cask loaded with PWR fuel is described in Section 3.4.1.1.1. The three-dimensional finite element model for the cask loaded with BWR fuel is described in Section 3.4.1.2.1.

The models of the cask/internal components (both PWR and BWR) are constructed of ANSYS three-dimensional, solid brick, thermal conduction elements (SOLID70) and thermal shell (SHELL57) to model heat conduction/combined conduction and thermal radiation, as well as superelement (MATRIX50) to model thermal radiation.

In the three-dimensional cask models, the fuel assemblies are modeled as homogeneous regions with effective temperature-dependent thermal conductivity. The effective thermal conductivity of the fuel region in the plane perpendicular to the major axis of the cask is determined for each fuel (PWR and BWR) by using two-dimensional finite element models representing the cross-section of a single fuel assembly. The two-dimensional finite element models of the fuel assemblies consist of the $UO_2$ fuel pellets; Zircaloy cladding; and gas between the fuel pellets and cladding and between the fuel rods (fuel pellet/cladding). Heat generation rates (multiplied by the respective peaking factors for each fuel) are applied to the elements representing the $UO_2$ and an isothermal temperature condition is applied to the edges of the model representing the

outer surfaces of the fuel assembly. The effective conductivity of the fuel assembly is then calculated by determining the maximum temperature in the fuel and using a closed form expression for a square with uniform heat generation. The two-dimensional finite element model of the PWR fuel is also described in Section 3.4.1.1.2. The two-dimensional finite element model of the BWR fuel is also described in Section 3.4.1.2.2. The models of the fuel assemblies are constructed of ANSYS two-dimensional thermal elements (PLANE55) to model heat conduction and superelement (MATRIX50) to model thermal radiation. The analyses of the fuel assembly models are steady-state.

Additionally, the neutron absorber regions (between the fuel assembly and the fuel tube) are modeled in the three-dimensional cask models as homogeneous regions by using effective thermal conductivity properties. The effective thermal conductivity of the neutron absorber region is determined for each fuel tube (PWR and BWR) by using two-dimensional finite element models representing the cross-section of a typical fuel tube. A heat flux is applied to the inner face of the composite tube wall while a temperature is applied to the outer face. The change in temperature is then used to calculate the effective thermal conductivity. This method treats the thermal resistance of the different layers as being in series. The effective thermal conductivity for heat condition parallel to the axis of the cask is computed as a weighted average based on the thickness of each layer. The two-dimensional finite element model of the PWR neutron absorber is described in Section 3.4.1.1.3. The two-dimensional finite element model of the BWR neutron absorber is described in Section 3.4.1.2.3. The models of the neutron absorber are constructed of ANSYS two-dimensional thermal elements (PLANE55) to model heat conduction and a superelement (PLANE55 to model heat conduction and LINK31 to model thermal radiation). The analyses of the neutron absorber models are steady-state.

The impact limiters are not explicitly modeled in the cask thermal analyses previously discussed. The cask surfaces covered by the impact limiters are modeled as adiabatic.

A three-dimensional periodic axial section of the cask is modeled using Computational Fluid Dynamic (CFD) code, FLUENT. Natural convection of air surrounding the cask is simulated, and surface temperature and heat flux are determined from the simulation results to determine the convection film coefficients. The average convective film coefficients are determined for eight divisions of the cask outer surface in the circumferential direction in a 180-degree half-symmetry model.

A sensitivity study for convection film coefficients on the cask outer surface for the PWR hot case of normal conditions of transport is performed using the sectional convection film coefficients determined by this model.

### 3.4.1.1 Analytical Models: Cask with PWR Fuel

The thermal analysis of the cask transporting PWR fuel uses three finite element ANSYS models as previously described. A three-dimensional model is employed to evaluate the cask in a horizontal position with the basket in contact with the TSC, which, in turn, is in contact with the cask inner shell. The fuel regions and the fuel tubes with neutron absorber plates in this model are modeled by using effective properties. The effective property of the fuel is determined by a second model, which is a detailed two-dimensional thermal model of the fuel assembly. The effective properties of the fuel tube wall and neutron absorber plate are calculated by using a third model, which is a two-dimensional thermal model of the fuel tube. The three ANSYS thermal models are described in the following paragraphs.

#### 3.4.1.1.1 Three-Dimensional Cask Model: Cask with PWR Fuel

The three-dimensional MAGNATRAN transport cask model is a full-length finite element model (360°) constructed by using ANSYS Revision 16.2. The model considers the fuel assemblies, fuel tubes, basket plates, TSC shell, TSC lid and bottom plate, cask inner shell, lead, outer shell, cask lid and bottom, neutron shield, copper and aluminum cooling fins and neutron shield shell. The gaps between the individual components are also considered. The ANSYS model is shown in Figure 3.4-1. The internal cavity of the TSC in the model contains the active fuel region, the top and bottom end fitting zone of the fuel assemblies, and fuel tubes enclosing the fuel assemblies.

The gas inside the TSC is modeled as helium. The gas inside the cask cavity is modeled as helium because the cavity will be backfilled with helium following fuel loading prior to transport. The finite element model is constructed of ANSYS three-dimensional, solid brick, thermal conduction elements (SOLID70), as well as two-dimensional elements (SHELL57) to model heat conduction/combined conduction and thermal radiation and superelement (MATRIX50) to model thermal radiation. The principal gaps applied to the model are described in Section 3.2.2.3.

Because the TSC is in the horizontal position during transport, the TSC shell is in contact with the inner shell of the cask. Similarly, the basket is in contact with the canister shell. Due to the small diametrical difference between these components, the basket is considered to be in contact with the canister shell in five local regions of the basket support weldment. This is equivalent to an angle of approximately 80° (out of 360°) in the model. Similarly, the canister shell is considered to be in contact with the cask inner shell with a contact angle of approximately 100°.

The contact is simulated by using a thermal conductivity of 2.0 BTU/hr-in-°F for the elements in the contact regions.

Solar insolance and ambient temperature conditions are applied to the cask surface including the surface of the cooling fins. Insolance is used at the exterior surface of the cask and the cooling fins and is based on the amount of insolation required by 10 CFR 71 to be applied over a 12-hr period evaluated in the steady state (applied over 24 hours simulating 12-hour period of solar exposure and 12-hour period of no solar exposure). The heat flux resulting from insolation on a curved surface is calculated as follows:

$$1475 \frac{\text{Btu}}{12\ \text{hr - ft}^2} \times \frac{12\ \text{hr}}{24\ \text{hr}} \times \frac{1\ \text{ft}^2}{144\ \text{in}^2} = 0.427\ \text{Btu/hr-in}^2.$$

The heat flux resulting from insolance is factored by the emissivities of the materials on which the insolance is applied.

The model is analyzed for a steady-state condition to determine the maximum temperatures for the fuel, basket, TSC, cask shells, radial shielding and surface conditions under normal conditions of transport. All material thermal properties are shown in Table 3.2-1 through Table 3.2-12.

The fuel regions (inside tubes) are modeled as homogeneous regions with effective conductivities, determined by the two-dimensional fuel model as described in Section 3.4.1.1.2. The fuel tube and the neutron absorber plate, including gaps on both sides of the neutron absorber sheet and the gap between the stainless steel cladding for neutron absorber and disk, are modeled as one element thick with effective conductivities, as established by using the two-dimensional neutron absorber and tube model discussed in Section 3.4.1.1.3.

The neutron shield assembly of the MAGNATRAN Transport Cask is consisted of NS-4-FR, thermal insulator, and stainless steel shell. The orthotropic effective material properties are computed for the three layers as listed below.

1) 0.125-inch silicone foam
2) 0.125-inch thermal insulator
3) 0.12-inch stainless steel

In the model, radiation heat transfer is considered from the bottom of the fuel region to the top surface of the TSC bottom plate, and from the outer surfaces of the basket to the inner surface of the TSC shell. The radiation from the bottom of the fuel region to the top surface of the TSC bottom plate and the radiation from the top of fuel region to the bottom surface of the TSC lid are modeled by using effective properties as described in Section 3.2.2.1. The radiation from the exterior surfaces of the fuel tubes to the inner surface of the TSC shell is modeled by using ANSYS superelement, MATRIX50.

Radiation at the cask surface to ambient is combined with the convection effect by using the method described in Section 3.2.2.2. The convection heat transfer coefficients at the cask surface are determined using the Cask CFD model as presented in Section 3.4.1.3. Effective emissivities are used for all radiation calculations, with the form factor taken to be unity. Effective emissivity is computed by using the following formula based on corresponding material emissivities:

$$\varepsilon_{eff} = 1/(1/\varepsilon_1 + 1/\varepsilon_2 - 1)$$

Solar insolance is applied to the cask surface for the "Hot" condition (ambient temperature = 100°F). A uniform heat flux is considered for the insolance.

Volumetric heat generation (Btu/hr-inch$^3$) is applied to the active fuel region on the basis of a total heat load of 23 kW, with an active fuel length of 144 inches, and an axial power distribution as shown in Figure 3.4-3.

There are a number of conservative conditions in this three-dimensional cask model:

1. The fuel assembly is conservatively considered to be located at the center of the basket slot. (The fuel assembly will be in contact with the fuel tube on its side since the cask is in the horizontal position during transport. The contact will reduce the maximum component temperature.)
2. Convection heat transfer is conservatively ignored inside the cask and the TSC.
3. The gap between the lead and the cask inner shell is conservatively considered to be 360° around the shell. (A good portion of the lead will be in contact with the inner shell since the cask is in the horizontal position during transport. The contact will reduce the maximum component temperature.)

## Damaged Fuel Configuration

The three-dimensional cask model loaded with PWR fuel assemblies described in this section is modified to simulate the configuration of the cask loaded with PWR fuel assemblies and damaged fuel cans (DFCs). Four damaged fuel cans are loaded in the PWR basket at the locations shown in Figure 3.4-2. The model described in this section is modified for the DFC geometry and the heat load applied to the DFC. A damaged fuel height of 107-inches is determined based on a 50% compaction of the damaged fuel. A damaged fuel length of 103 inches is conservatively used in this modified model. As shown in Figure 3.4-2, the damaged fuel is concentrated at the center (103 inches) in the model, with the material properties conservatively corresponding to the effective properties for the intact fuel assembly. It is conservative to neglect any contact among the fuel debris. The regions below and above the damaged fuel region are conservatively modeled as helium without radiation. The conductance of the DFCs is conservatively not included in the model.

A computed heat generation rate based on the total heat load per canister (23kW), divided by 37 fuel assemblies and a volume corresponding to the 103 inches of damaged fuel, is applied to the damaged fuel regions at the four corner slots of the model.

The thermal evaluation of the MAGNATRAN transport cask loaded with PWR fuel assemblies and DFCs is performed for the normal transport condition (hot conditions, ambient temperature of 100°F). Due to the improved conduction performance of the damaged fuel basket configuration design, the maximum fuel temperature is 28°F lower for the basket loaded with DFCs than for the intact fuel basket configuration (Table 3.4-1). Therefore, the analysis results for the intact fuel configuration, shown in Table 3.4-1, bound the analysis results for the configuration of the basket loaded with DFCs.

**GTCC Configuration**

The MAGNATRAN cask system may contain a TSC with GTCC waste. The maximum heat load for the GTCC configuration is 1.7 kW, which is well below the design basis heat load of 23 kW for the PWR system. Therefore, the thermal analysis results obtained using the three-dimensional cask model with the 23 kW heat load for the PWR system, as described in this Section, bounds those for the GTCC configuration. No further evaluation is required.

#### 3.4.1.1.2 Two-Dimensional Fuel Assembly Model: PWR Fuel

The effective conductivity of the fuel is determined by detailed two-dimensional finite element thermal models of the PWR fuel assembly. The model includes the fuel pellets, cladding, gas between the fuel rods, and gas occupying the gap between the fuel pellets and cladding. Modes of heat transfer modeled include conduction and radiation between individual fuel rods for the steady-state condition. Thermal analyses are performed for PWR 14×14, 15×15, 16×16 and 17×17 fuel assemblies. However, because the PWR 14×14 fuel assembly results in the lowest effective thermal conductivities, only the effective properties of that fuel assembly are used in the cask model presented in Section 3.4.1.1.1.

ANSYS PLANE55 conduction elements and MATRIX50 radiation elements are used to model conduction and radiation. Radiation elements are defined between fuel rods and between the fuel rods and the fuel tube. A typical PWR fuel assembly finite element model is shown in Figure 3.4-4, which corresponds to the 14×14 fuel assembly.

The effective conductivity for the fuel is determined by using an equation defined in the Sandia National Laboratory (SNL) Report SAND90-2406. Conservatively, 60% of the conductivities of fuel pellets ($UO_2$) are used in the models. The equation is used to determine the maximum temperature of a square cross-section of an isotropic homogeneous fuel with a uniform

volumetric heat generation. At the boundary of the square cross-section, the temperature is constrained to be uniform. The expression for the temperature at the center of the fuel is given by:

$$T_c = T_e + 0.29468\,(Qa^2 / K_{eff})$$

where:

$T_c$ = the temperature at the center of the fuel (°F)

$T_e$ = the temperature applied to the exterior of the fuel (°F)

$Q$ = volumetric heat generation rate (Btu/hr-in$^3$)

$a$ = half-length of the square cross-section of the fuel (inch)

$K_{eff}$= effective thermal conductivity for the isotropic homogeneous fuel (Btu/hr-in-°F)

Volumetric heat generation (Btu/hr-in$^3$) based on the design heat load is applied to the pellets. The effective conductivity is determined based on the heat generated and the temperature difference from the center of the model to the edge of the model. Temperature-dependent effective properties are established by performing multiple analyses using different boundary temperatures. The effective conductivity in the axial direction and the effective density of the fuel assembly are calculated on the basis of the material area ratio. The effective specific heat is computed on the basis of a weighted mass average.

### 3.4.1.1.3 Two-Dimensional Neutron Absorber Model: PWR Fuel

The two-dimensional neutron absorber model is used to calculate the effective conductivities of the neutron absorber, and the neutron absorber retainer. These effective conductivities are used in the three-dimensional cask models (Section 3.4.1.1.1). As shown in Figure 3.4-5, the PWR neutron absorber model includes the neutron absorber, the stainless steel retainer, and the gaps between the neutron absorber and the stainless steel retainer and the surface of the fuel tube. Helium is considered in the gap. Note that two types of neutron absorbers are considered (see Table 3.2-12 for the corresponding thermal conductivities).

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the model. The model consists of four layers of conduction elements and two sets of radiation elements that are defined at the gaps (two for each gap). The thickness of the model (x-direction) is the distance measured from the outside surface of the stainless steel retainer to the inside surface of the fuel tube (assuming the neutron absorber is centered between the retainer and the fuel tube, and there is no contact for the length of the basket).

Heat flux is applied at the left side of the model, and the temperature at the right boundary of the model is specified. The heat flux is determined based on the design heat load. The maximum

temperature of the model (at the left boundary) and the temperature difference ($\Delta T$) across the model are calculated by the ANSYS model. The effective conductivity ($K_{xx}$) is determined using the following formula.

$$q = K_{xx} (A/L)\, \Delta T$$

or

$$K_{xx} = q\ L / (A\, \Delta T)$$

where:

$K_{xx}$ = effective conductivity (Btu/hr-in-°F) in X direction (the X direction in Figure 3.4-5)
$q$ = heat rate (Btu/hr)
$A$ = area ($in^2$)
$L$ = length (thickness) of model (in)
$\Delta T$ = temperature difference across the model (°F)

The temperature-dependent conductivity is determined by varying the temperature constraints at one boundary of the model and solving for the temperature difference. The effective conductivity for the parallel path (the Y direction in Figure 3.4-5) is calculated by the following:

$$K_{yy} = \frac{\sum K_i\, t_i}{L}$$

where:

$K_i$ = thermal conductivity of each layer (Btu/hr-in-°F)
$t_i$ = thickness of each layer (in)
$L$ = total length (thickness) of the model (in)

#### 3.4.1.2 Analytical Models: Cask with BWR Fuel

The finite element ANSYS models used in the thermal analysis of the cask transporting BWR fuel are similar to those used in the thermal analysis of the cask transporting PWR fuel discussed in previous sections. A three-dimensional model is employed to evaluate the cask in a horizontal position with the basket in contact with the TSC, which, in turn, is in contact with the cask inner shell. The fuel regions and the fuel tubes with neutron absorber plates are modeled by using effective conductivities. A detailed two-dimensional thermal model of the fuel assembly is used to determine the effective conductivity of the fuel. A two-dimensional thermal model of the fuel tube is used to calculate the effective conductivities of the fuel tube wall and neutron absorber plate. Another two-dimensional thermal model for the fuel tube is used to calculate the effective conductivity of the fuel tube wall with no neutron absorber plate present. These four ANSYS thermal models are described in the following sections.

### 3.4.1.2.1 Three-Dimensional Cask Model: Cask with BWR Fuel

The three dimensional MAGNATRAN transport cask model containing a BWR canister is a half-length finite element model (360°) constructed by using ANSYS Revision 10.0. The model considers the fuel assemblies, fuel tubes, basket plates, TSC shell and bottom plate, cask inner shell, lead, outer shell, neutron shield, copper and aluminum cooling fins, and neutron shield shell. The gaps between the individual components are also considered. The ANSYS model is shown in Figure 3.4-6. The internal cavity of the TSC contains the active fuel region, the bottom end fitting zone of the fuel assemblies, and fuel tubes enclosing the fuel assemblies.

The gas inside the TSC is modeled as helium. The gas inside the cask cavity is modeled as helium, because the cavity will be backfilled with helium following fuel loading prior to transport. The finite element model is constructed of ANSYS three-dimensional, solid brick, thermal conduction elements (SOLID70), as well as two-dimensional elements (SHELL57) to model heat conduction/combined conduction and thermal radiation and Superelement (MATRIX50) to model thermal radiation. The principal gaps applied to the model are described in Section 3.2.2.3.

Because the TSC is in the horizontal position during transport, the elements for the TSC shell are in contact with the inner shell of the cask. Similarly, the basket is in contact with the TSC shell. A 65-degree contact arc is considered for the gaps between the TSC shell and the cask inner shell and a 64-degree arc (five small contact zones) is considered for the gaps between the basket and the TSC shell. The contact is simulated by turning the gap in the contact zones into carbon steel that has high thermal conductivities (in range of 2 Btu/hr-in-°F).

Solar insolance and ambient temperature conditions are applied to the cask surface including the heat fins. Insolance is used at the exterior surface of the cask and the heat fins and is based on the amount of insolation required by 10 CFR 71 to be applied over a 12-hour period evaluated in the steady state (applied over 24 hr simulating 12-hour period of solar exposure and 12-hour period of no solar exposure). The heat flux resulting from insolation on a curved surface is calculated as follows:

$$1475\frac{\text{Btu}}{12\text{ hr - ft}^2} \times \frac{12\text{ hr}}{24\text{ hr}} \times \frac{1\text{ ft}^2}{144\text{ in}^2} = 0.427\text{ Btu/hr-in}^2.$$

The heat flux resulting from solar insolance is factored by the emissivities of the materials on which the insolance is applied.

The model is analyzed to determine the maximum temperatures for the basket, TSC, cask shells, radial shielding, and surface conditions under normal conditions of transport. All material thermal properties are shown in Table 3.2-1 through Table 3.2-12.

The fuel regions (inside tubes) are modeled as homogeneous regions with effective conductivities, determined by the two-dimensional fuel model as described in Section 3.4.1.2.2. The fuel assembly tube and the neutron absorber plate, including gaps on both sides of the neutron absorber sheet and the gap between the stainless steel cladding for neutron absorber and disk, are modeled as one element thick with effective conductivities, as established by using the two-dimensional tube model discussed in Section 3.4.1.2.3.

The neutron shield assemblies of the MAGNATRAN transport cask consist of NS-4-FR, thermal insulator, and stainless steel shells. The orthotropic effective material properties are computed for the three layers as listed below.

1) 0.125-inch silicone foam
2) 0.125-inch thermal insulator
3) 0.12-inch stainless steel

In the model, radiation heat transfer is considered from the bottom of the fuel region to the top surface of the TSC bottom plate, and from the exterior surfaces of the fuel tubes to the inner surface of the TSC shell. The radiation from the bottom of the fuel region to the top surface of the TSC bottom plate is modeled by using effective properties. The radiation from the exterior surfaces of the fuel tubes to the inner surface of the TSC shell is modeled by using ANSYS Superelement, MATRIX50.

Radiation at the cask surface to ambient is combined with the convection effect by using the method described in Section 3.2.2.2. The convection heat transfer coefficient is calculated on the basis of the formula shown in Section 3.2.3. Effective emissivities are used for all radiation calculations, with the form factor taken to be unity. Effective emissivity is computed by using the following formula based on corresponding material emissivities:

$$\varepsilon_{eff} = 1/\left(1/\varepsilon_1 + 1/\varepsilon_2 - 1\right)$$

Solar insolance is applied to the cask surface for the "Hot" condition (ambient temperature = 100°F). A uniform heat flux is considered for the insolance.

Volumetric heat generation (Btu/hr-inch$^3$) is applied to the active fuel region of 87 assemblies on the basis of a total heat load of 22 kW, with an active fuel rod length of 144 inches, and an axial power distribution as shown in Figure 3.4-7.

The conservative conditions in this three-dimensional cask model are identical to those in the cask model for the PWR fuels.

### 3.4.1.2.2 Two-Dimensional Fuel Assembly Model: BWR Fuel

The two-dimensional fuel assembly models include the fuel pellets, cladding, fuel channel, and the helium occupying the space between fuel rods. The media is considered to be helium for transport conditions. The two-dimensional finite element models of the fuel assemblies are used to determine the effective conductivities for the BWR fuel assemblies. The effective conductivities are used in the three-dimensional fuel basket models described in Section 3.4.1.2.1. For the BWR fuel assemblies, four separate types are considered: 7×7, 8×8, 9×9 and 10×10. A fuel channel is considered since it may be present and it will result in bounding fuel cladding temperatures. The effective properties corresponding to the 10×10 BWR fuel assembly type (Table 3.2-11) are used in the cask model as presented in Section 3.4.1.2.1, since the 10×10 fuel has the lowest thermal conductivities.

Modes of heat transfer modeled include conduction and radiation between individual fuel rods for the steady-state condition. ANSYS PLANE55 conduction elements and MATRIX50 radiation elements are used to model conduction and radiation. Radiation elements are defined between fuel rods and between the fuel rods and the fuel channel. The BWR fuel assembly model only considers the region up to the inner surface of the channel, and a typical BWR fuel assembly is shown in Figure 3.4-8, which corresponds to the 10×10 fuel assembly.

The effective conductivity for the fuel is determined by using an equation defined in a Sandia National Laboratory (SNL) Report, as discussed in Section 3.4.1.1.2. Conservatively, 60% of the conductivities of fuel pellets ($UO_2$) are used in the models (Table 3.2-11).

Volumetric heat generation (Btu/hr-in$^3$) based on the design heat load is applied to the pellets. The effective conductivity is determined based on the heat generated and the temperature difference from the center of the model to the edge of the model. Temperature-dependent effective properties are established by performing multiple analyses using different boundary temperatures. The effective conductivity in the axial direction and the effective density of the fuel assembly are calculated on the basis of the material area ratio. The effective specific heat is computed on the basis of a weighted mass average.

### 3.4.1.2.3 Two-Dimensional Neutron Absorber Model: BWR Fuel

The two-dimensional neutron absorber model is used to calculate the effective conductivities of the neutron absorber, the neutron absorber retainer, and the fuel channel. These effective conductivities are used in the three-dimensional cask models (Section 3.4.1.2.1). Two neutron absorber models are required: one with the neutron absorber plate and channel, and one with the channel but without the neutron absorber plate, corresponding to the enveloping configurations

of the 10×10 BWR fuel assembly. Thermal conductivities for the Type 1 neutron absorber, as shown in Table 3.2-12, are used in the models.

ANSYS PLANE55 conduction elements and LINK31 radiation elements are used to construct the model. As shown in Figure 3.4-9, the first BWR neutron absorber model includes the fuel channel, the retainer, the neutron absorber and associated gaps. As shown in Figure 3.4-10, the second BWR neutron absorber model includes the fuel channel and the gap between the fuel channel and the fuel tube surface.

Heat flux is applied at the left side of the model (fuel channel for BWR model), and the temperature at the right boundary of the model is specified. The heat flux is determined based on the design heat load. The maximum temperature of the model (at the left boundary) and the temperature difference (ΔT) across the model are calculated by the ANSYS model. The effective conductivity ($K_{xx}$) is determined using the following formula.

$$q = K_{xx} (A/L)\, \Delta T$$

or

$$K_{xx} = q\ L / (A\, \Delta T)$$

where:

$K_{xx}$ = effective conductivity (Btu/hr-in-°F) in X direction in Figure 3.4-9 and Figure 3.4-10
$q$ = heat rate (Btu/hr)
$A$ = area ($in^2$)
$L$ = length (thickness) of model (in)
$\Delta T$ = temperature difference across the model (°F)

The temperature-dependent conductivity is determined by varying the temperature constraints at one boundary of the model and solving for the temperature difference. The effective conductivity for the parallel path (the Y direction in Figure 3.4-9 and Figure 3.4-10) is calculated by the following:

$$K_{yy} = \frac{\sum K_i\, t_i}{L}$$

where:

$K_i$ = thermal conductivity of each layer (Btu/hr-in-°F)
$t_i$ = thickness of each layer (in)
$L$ = total length (thickness) of the model (in)

### 3.4.1.3 Analytical Models: Cask Periodic CFD Model

As shown in Figure 3.4-11, a three-dimensional periodic axial section of the cask is modeled using the Computational Fluid Dynamic (CFD) code, FLUENT. The model includes the cask outer shell, the neutron shield, the cooling fins and the surrounding air at ambient temperature of 100°F. In the cask axial direction, the model includes one-half the axial length of a fin. Half of the cask (180° in the circumferential direction) is modeled because of symmetry. A close-up section of the mesh is shown in Figure 3.4-12. The model contains 1,647,000 computational cells, with higher concentration of cells near the wall to capture the near-wall velocity and temperature gradients. Transitional k-ω turbulence model is used for the simulation. The mesh ensures that the average y+ is less than 1.0 on the cask surface wall. Natural convection of air surrounding the cask is simulated, and surface temperature and heat flux are determined from the simulation results to determine the convection film coefficients. The average convective film coefficients for eight divisions (180 degrees) of the cask outer surface in the circumferential direction are determined.

The personnel barrier is made from aluminum mesh with a large ratio of open area. Due to the small surface area of the aluminum mesh and the low emissivity of aluminum (0.22), the personnel barrier absorbs an insignificant amount of solar energy or radiant energy from the transport cask. The high percentage of open area allows free flow of the air through the aluminum mesh. The additional flow restriction by the mesh is insignificant; therefore, natural convection is not affected by the personnel barrier. The thermal effect of the personnel barrier on the transport thermal performance is insignificant; therefore, the personal barrier is not explicitly included in the CFD thermal model.

### 3.4.1.4 Test Model

The methods previously described have been used in previous transport cask licensing and are sufficient to show that the MAGNATRAN transport cask meets the criteria set forth in Section 3.4. Therefore, no thermal test model is created.

### 3.4.2 Maximum Temperatures

Using the thermal models described in Section 3.4.1.1 and Section 3.4.1.2, temperatures for the PWR and BWR cask body, TSC, basket, and fuel rod cladding are determined for two normal conditions of transport: (1) maximum decay heat, 100°F ambient temperature, and solar insolance; and (2) maximum decay heat, -40°F ambient temperature, and no insolance. The maximum temperatures of the principal PWR and BWR cask components, TSC, basket

components, and fuel rod cladding are shown in Table 3.4-1 and Table 3.4-2 for the two environmental conditions listed above. For the environmental condition with no decay heat, -40°F ambient temperature, and no insolance, no analysis is necessary because all package temperatures will equilibrate to -40°F. The cask body maximum allowable component temperatures are shown in Section 3.3.2.

As discussed in Section 3.1, for the PWR basket with neutron absorbers with a Type 1 thermal conductivity (see Table 3.2-12), the heat load per cask is limited to 22 kW. Two additional analyses (hot and cold conditions as described above for normal transport conditions) were performed for this PWR configuration (22 kW). The analysis results indicate that the temperatures reported in Tables 3.4-1 and 3.4-2 are bounding.

Note that the O-ring temperatures for the BWR configuration are considered to be bounded by those for the PWR configuration, since the decay heat at the top portion of the cask for the BWR configuration is less than that for the PWR configuration, based on the comparison of maximum decay heat (PWR: 23 kW and BWR: 22 kW) and the fuel assembly axial power distribution (Figure 3.4-3 and Figure 3.4-7).

Based on the temperature profile from the analysis results using the periodic cask CFD model (Figure 3.4-11), the maximum temperature of the personnel barrier is 162°F.

### 3.4.3 Minimum Temperatures

The minimum temperatures of the cask and components occur with no heat load and -40°F. These conditions yield a uniform -40°F temperature throughout the MAGNATRAN transport cask package.

### 3.4.4 Maximum Internal Pressures

In the following sections, the maximum internal pressures for normal conditions of transport are calculated for intact PWR and BWR canisters and for the MAGNATRAN transport cask cavity under the condition of hypothetical canister boundary failure. No normal condition of operation breaches the canister boundary. Gauge pressure inside the cask cavity is, therefore, solely the result of the 1.36 atmosphere (20 psia) cask backfill being adjusted from a conservative backfill temperature of 20°C to cask operating temperature. Maximum normal operating pressure for the cask cavity is calculated to be 23 psig. Conservatively, the cask containment boundary is structurally evaluated based on a hypothetical failure of the canister boundary. The hypothetical canister failure results in a substantial increase in cask cavity pressure. The maximum internal pressures for an intact canister and for the cask cavity, assuming a failed canister, are summarized in Table 3.4-3.

### 3.4.4.1 Maximum Internal Pressure for PWR Fuel Canister and Transport Cask

The internal pressures within the PWR fuel TSC and transport cask are a function of fuel type, fuel condition (failure fraction), burnup, TSC length, and the backfill gases in the TSC and cask cavity. Gases included in the pressure evaluation include rod-fill, rod fission and rod backfill gases, TSC and cask backfill gases and burnable poison generated gases. Each of the fuel types expected to be loaded into the MAGNATRAN transport cask is separately evaluated to arrive at a bounding TSC pressure.

Fission gases include all fuel material generated gases including long-term actinide decay generated helium. Based on detailed SAS2H calculations of the maximum fissile material mass assemblies in each TSC, the quantity of gas generated by the fuel rods rises as burnup and cool time is increased and enrichment is decreased. To assure the maximum gas is available for release, the PWR inventories are extracted from conservatively high 70,000 MWd/MTU burnup cases at an enrichment of 1.9 wt. % $^{235}U$ and a cool time of 40 years. Gases included are all krypton, iodine, and xenon isotopes in addition to helium and tritium ($^{3}H$). Molar quantities for each of the maximum fissile mass assemblies are summarized in Table 3.4-4. Fuel generated gases are scaled by fissile mass to arrive at molar contents of other MAGNATRAN fuel types.

Fuel rod backfill pressure varies significantly between the PWR fuel types. The maximum reported backfill pressure is listed for the Westinghouse 17x17 fuel assembly at 500 psig. With the exception of the B&W fuel assemblies, which are limited to 435 psig, all fuel assemblies evaluated are set to the maximum 500 psig backfill reported for the Westinghouse assembly. Backfill quantities are based on the free volume between the pellet and the clad and the plenum volume. The fuel rod backfill gas temperature is conservatively assumed to have an initial temperature of 68°F.

Burnable poison rod assemblies (BPRAs) placed within the TSC may contribute additional molar gas quantities due to (n, alpha) reactions of fission generated neutrons with $^{10}B$ during in-core operation. $^{10}B$ forms the basis of a portion of the neutron poison population. Other neutron poisons, such as gadolinium and erbium, do not produce a significant amount of helium nuclides (alpha particles) as part of their activation chain. Primary BPRAs in existence include Westinghouse Pyrex (borosilicate glass) and WABA (wet annular burnable absorber) configurations, as well as B&W BPRAs and shim rods employed in CE cores. The CE shim rods replace standard fuel rods to form a complete assembly array. The quantity of helium available for release from the BPRAs is directly related to the initial boron content of the rods and the release fraction of gas from the matrix material in question. Release from either of the low temperature, solid matrix materials is likely to be limited, but no release fractions were

available in open literature. Therefore, a 100% release fraction is assumed based on a boron content of 0.0063 g/cm $^{10}B$ per rod, with the maximum number of rods per assembly. The maximum number of rods is 16 for Westinghouse core 14×14 assemblies, 20 rods for Westinghouse and B&W 15×15 assemblies, and 24 rods for Westinghouse and B&W 17×17 assemblies. The length of the absorber is conservatively taken as the active fuel length. CE core shim rods are modeled at 0.0126 g/cm $^{10}B$ for 16, 12, and 12 rods applied to CE manufactured 14×14, 15×15 and 16×16 cores, respectively.

Fuel rods may contain integral fuel burnable absorbers (IFBAs). The absorber is typically zirconium diboride and, as such, will generate helium gas as part of the neutron capture process. IFBA assemblies are generally used as an alternative or augmentation to BPRA use. The IFBA loading employed in the pressure analysis is based on NUREG-6760 as 2.355 mg $^{10}B$/inch in 156 rods. To bound the presence of both BPRA and IFBA materials in a fuel assembly, when loaded, the cask pressure calculations assume a design basis IFBA loading in the fuel assembly with a design basis BPRA inserted into the assembly guide tubes prior to loading into the system. Rather than accounting for the IFBA rods as an individual component, the pressure calculations double the BPRA gases for non-CE fuel assembly types (bound the combined inventory of IFBA and BPRA based on linear loading and number of rods affected).

Under normal operating conditions, the helium backfill for a TSC containing PWR fuel assemblies is at a bounding maximum average gas temperature of 500°F and a pressure of 103 psig. The cask backfill temperature and pressure are assumed to be 68°F and 1.36 atm. Free volume inside each PWR TSC is listed in Table 3.4-5. Also included are the total TSC and cask free volumes. The listed free volumes do not include fuel assembly components since these components vary for each assembly type and fuel insert, but do account for axial spacers. By subtracting the rod and guide tube volumes and all hardware component volumes from the listed free volume, the free volume of the TSCs including fuel assemblies and a load of 24 BPRAs can be determined. For the Westinghouse BPRAs, the Pyrex volume is employed since it displaces more volume than the WABA rods.

The total pressure for each of the MAGNATRAN payloads is found by calculating the releasable molar quantity of each gas (30% of the fission gas, 100% of the rod backfill, BPRA, IFBA and shim rod gases adjusted for the 3% fuel failure fraction and the TSC and cask backfill gases), and summing the quantities directly. The quantity of gas is then employed in the ideal gas equation in conjunction with the average gas temperature at normal operating conditions to arrive at system pressures. The normal condition average temperature of the gas within the TSC and cask is considered to be 515°F, rounded up from the maximum evaluated normal temperature for both the PWR and BWR fuel of 508°F. Each of the MAGNATRAN PWR fuel types is individually

evaluated for normal condition pressure, and the maximum normal condition PWR fuel TSC and cask pressures are determined to be 114.7 psig and 112.6 psig, respectively. A summary of the maximum pressure in the TSC and in the cask for each PWR TSC length is shown in Table 3.4-3. The table also includes the fuel type producing the listed maximum pressures.

Similarly, the maximum internal pressures are calculated for the DF-PWR TSC and the transport cask. The normal condition pressures are determined to be 114.8 psig and 112.6 psig for the DF-PWR TSC and the cask, respectively (Table 3.4-3).

#### 3.4.4.2 Maximum Internal Pressure for BWR Fuel Canister and Transport Cask

BWR TSC and cask maximum pressures are determined in the same manner as those documented for the PWR cases. Primary differences between PWR and BWR analysis include a rod backfill gas pressure of 132 psig, a maximum burnup of 60,000 MWd/MTU used to generate fission gases, and pressurizing gases are limited to fission gases (including helium actinide decay gas), rod backfill gases, and canister and cask backfill gas. The 132 psig employed in this analysis is significantly higher than the 6 atmosphere maximum pressure reported in open literature. BWR assemblies do not contain an equivalent to the PWR BPRAs and, therefore, do not require $^{10}B$ helium generated gases to be added. Fissile gas inventories for the maximum fissile material assemblies in each of the three BWR lattice configurations (7×7, 8×8, and 9×9) are shown in Table 3.4-6. Free volumes, without fuel components, in MAGNATRAN TSCs are shown in Table 3.4-7. Cask and TSC maximum pressures for each TSC are listed in Table 3.4-3. The maximum normal condition TSC pressure of 112.7 psig is based on a GE 7×7 assembly designed for a BWR/2-3 reactor. Cask maximum pressure for the GE 8×8 fuel is 110.9 psig. Similar fuel masses and displaced volume account for similar system pressures.

### 3.4.5 Maximum Thermal Stresses

The ANSYS program is used to obtain temperatures for use in the structural analyses of Chapter 2.0. These temperatures are presented in Table 3.4-1 and Table 3.4-2. The thermal stress calculations for normal conditions of transport are performed in Sections 2.6.1 and 2.6.2.

### 3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

Results of thermal analysis of the MAGNATRAN transport cask containing PWR and BWR fuel under normal conditions of transport are summarized in Tables 3.4-1 through 3.4-3. The maximum fuel rod cladding temperature is maintained below 752°F (400°C); temperatures of safety-related cask components are maintained within their safe operating ranges; and thermally

induced stresses in combination with pressure and mechanical load stresses are shown in the structural analysis of Chapter 2.0 to be less than the allowable stresses. As shown in Section 3.4.2, the personnel barrier temperature of 162°F is below the allowable temperature of 185°F for exclusive use shipment. Therefore, the MAGNATRAN transport cask can safely transport the design basis fuel under the normal conditions of transport specified in 10 CFR 71.71.

**Figure 3.4-1 Three-Dimensional PWR Cask Finite Element Model**

[redacted]

Figure 3.4-2 Three-Dimensional Model of PWR Cask Loaded with DFC (Intact Fuel and Damaged Fuel Assemblies)

[redacted]

**Figure 3.4-3 Design Basis PWR Fuel Assembly Axial Power Distribution**

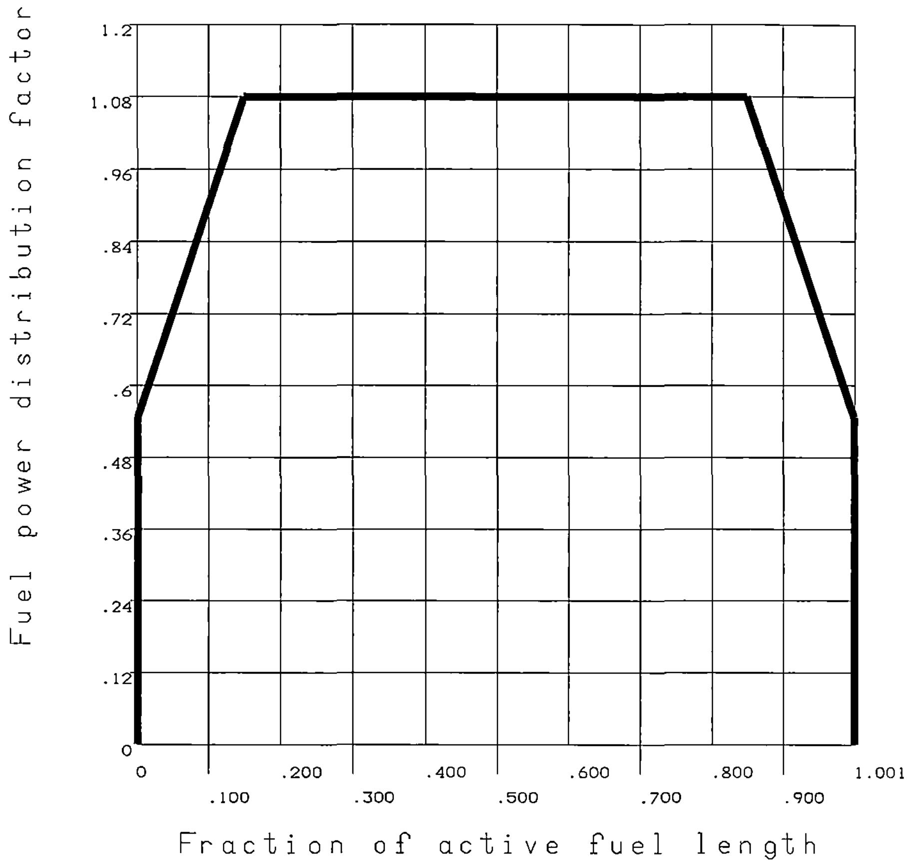


**Figure 3.4-12 Mesh of a Section of the Periodic Cask CFD Model**

[redacted]

Figure 3.4-13 [DELETED]

Table 3.4-1 Maximum Component Temperatures – Normal Conditions of Transport, Maximum Decay Heat, Maximum Ambient Temperature

[redacted]

Table 3.4-2 Maximum Component Temperatures – Normal Conditions of Transport, Maximum Decay Heat, Minimum Ambient Temperature

[redacted]

Table 3.4-3 Maximum Internal Pressures for Transport Under Normal Conditions

[redacted]

An additional fire transient analysis is performed to demonstrate the conservatism of "ΔT method" to determine the maximum temperatures for the fuel and basket components for the fire accident as described at the beginning of this section. A half-length (360°) three-dimensional finite element model corresponding to the top half of the cask and loaded canister (including basket and fuel) for the PWR configuration is used for this transient analysis. The model is based on the three-dimensional models presented in Section 3.4.1.1.1 for the evaluation of normal conditions of transport. The transient analysis is performed for the same three phases as described above and the maximum temperature is 747°F for the fuel and 722°F for the basket, which are significantly lower than the temperatures reported in Table 3.5-1. Therefore, it is conservative to use the 'ΔT method' to determine the maximum temperatures for cask contents for the fire accident.

### 3.5.1.2 Test Model

The thermal analyses presented in Section 3.5-3 demonstrate that the MAGNATRAN transport cask is capable of meeting the design basis temperature requirements under hypothetical accident conditions. The methodology used in this analysis is conservative, consistent with those used in prior transport cask licensing, and sufficient to show that the cask meets the criteria set forth in Section 3.5. Therefore, no thermal test model is created.

## 3.5.2 Package Conditions and Environment

As demonstrated in Chapter 2, the MAGNATRAN transport cask body sustains no major damage as a result of the free drop and puncture events, and the impact limiters remain attached to the cask. Since the pin puncture only results in local damage to the neutron shield, the cask body is modeled in an undamaged configuration.

The emissivity of stainless steel is 0.36. The copper emissivity is 0.65. The aluminum emissivity of 0.22 is conservatively used for the aluminum plates on the cask surface. However, during the 30-min fire portion of the transient analysis, the emissivity is assumed to be 0.9. Also, the emissivity of the fire is assumed to be 1.0.

At the end of the fire, the NS-4-FR in the neutron shield is assumed to be destroyed. The result is a lower conductivity, and thus a greater resistance to heat leaving the cask. The emissivity of stainless steel of 0.36, the emissivity of aluminum of 0.22, and the emissivity of copper of 0.65 are again used, which also provides a greater resistance to heat leaving the cask. The cool-down is analyzed for a period of 64 hours after the end of the fire. At the end of the cool-down period, all cask components have already reached their maximum temperatures and have begun to cool down to their post-fire, steady-state temperatures.

### 3.5.3 Package Temperatures

The ANSYS computer code is used to evaluate the MAGNATRAN transport cask for the hypothetical accident fire. A steady-state initial temperature profile is calculated on the basis of a 100°F ambient temperature and solar insolance and used as initial condition for the 30-min fire transient, which considers exposure of the cask to a 1,475°F radiant environment. This exposure is followed by a 64-hour cool-down period, which considers exposure of the cask to a 100°F ambient temperature and solar insolance.

The safe operating temperature ranges of the components specified in Section 3.3.2 are also evaluated for the fire accident. These components include the metallic containment O-ring seals and lead gamma shielding. The radial neutron shield temperature is not considered to be significant; therefore its loss is assumed in this accident. The shielding consequences of the fire accident on the radial neutron shield are provided in Chapter 5.

The maximum component temperatures during the hypothetical fire accident and cool-down period are provided in Table 3.5-1 (PWR) and Table 3.5-2 (BWR). The tables also show the maximum component temperatures for the fuel cladding, and the lead in the cask body. None of the safety-related components, with the exception of the radial neutron shield, as noted previously, exceeds its safe operating temperature as a result of the fire accident. The temperature histories of the major cask components are shown in Figures 3.5-4 through 3.5-9 for the PWR configuration. The temperature histories of the major cask components for the BWR configuration are not shown due to the similarity of the histories to those for the PWR configuration.

### 3.5.4 Maximum Internal Pressures

The internal pressure analysis requires the calculation of the free volume of the canister, calculation of the releasable quantity of fill and fission gas in the fuel assemblies, BPRA gases, and the subsequent calculation of the pressure in the canister and cask if these gases are added to the backfill helium pressure (initially at 1.36 atm) already present in the TSC and cask (Sections 3.4.1.1 and 3.4.1.2). TSC and cask pressures are determined for the accident condition of 100% fuel failure and maximum temperature. The method employed in the accident analyses is identical to that employed in the normal condition evaluation of Section 3.4.1.

For the accident condition, the gas quantities associated with 100% fuel rod failure are combined with the bounding fire accident average gas temperatures of 670°F to determine the system pressures. The maximum TSC pressure for the 100% fuel rod failure and maximum temperature accident (fire) condition is 276.6 psig (DF-PWR). The maximum transport cask pressure is 256.5 psig (DF-PWR), where the cask pressure assumes the loss of TSC confinement.

Table 3.5-1 Maximum Component Temperatures – Hypothetical Accident Condition Fire Transient (PWR Cask)

[redacted]

Table 3.5-2 Maximum Component Temperatures – Hypothetical Accident Condition Fire Transient (BWR Cask)

[redacted]

# Chapter 5
# Shielding Evaluation

## Table of Contents

## List of Figures

## List of Tables (cont'd)

## List of Tables (cont'd)

### 5.8.14 22 kW PWR Cool Time Tables

PWR cool time tables are calculated for the MAGNATRAN system with a maximum heat load of 22 kW. Dose rates are not recalculated for the 22 kW heat load. All previously calculated dose rates at 23 kW are bounding. For any fuel type, burnup, initial enrichment, and cool time combination allowed at the 23 kW cask heat load (622 W/assembly), additional cool time, and therefore reduced sources, are associated with the reduction to a 22 kW cask heat load (595 W/assembly). Bounding maximum dose rates are therefore documented in Section 5.8.3.

Minimum cool times for cask heat loads of 22 kW or less are documented in Table 5.8-58 and Table 5.8-59. For casks with average assembly enrichment less than 2.1 wt % $^{235}U$ and a burnup less than 30 GWd/MTU, the cool times in table 5.8-58 shall be used. Fuel assembly minimum cool times for assemblies with greater than or equal to 2.1 wt% $^{235}U$ initial average enrichment and assembly average burnup up to 45 GWd/MTU are found in Table 5.8-59. Table 5.8-60 presents minimum cool time for fuel with assembly average burnup greater than 45 GWd/MTU. The cool times in Table 5.8-60, include a reduction in allowable heat load for fuel over 45 GWd/MTU (20.9 kW/cask).

The additional cool time required to load non-fuel hardware is shown in Table 5.8-61.

The requirements for loading damaged fuel and reconstituted fuel assemblies do not change.

**Table 5.8-58 Low Burnup PWR Fuel Loading Table – 22 kW/Cask**

| Max. Assembly Avg. Burnup [MWd/MTU] | Min. Assembly Avg. Initial Enrichment [wt% $^{235}U$] | Minimum Cool Time [Years] |
|---|---|---|
| 10,000 | 1.3 | 4.0 |
| 15,000 | 1.5 | 4.0 |
| 20,000 | 1.7 | 4.5 |
| 25,000 | 1.9 | 5.7 |
| 30,000 | 2.1 | 7.4 |

**Table 5.8-59 Loading Table for PWR Fuel (22 kW/Cask)**

| Minimum Initial Assembly Avg. Enrichment wt % $^{235}$U (E) | Assembly Average Burnup ≤ 30 GWd/MTU Minimum Cooling Time (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | 6.0 | 6.1 | 7.1 | 7.4 | 6.6 | 7.2 | 7.2 |
| 2.3 ≤ E < 2.5 | 5.9 | 6.0 | 7.0 | 7.3 | 6.6 | 7.0 | 7.1 |
| 2.5 ≤ E < 2.7 | 5.9 | 6.0 | 7.0 | 7.2 | 6.5 | 7.0 | 7.0 |
| 2.7 ≤ E < 2.9 | 5.8 | 5.9 | 6.9 | 7.2 | 6.4 | 6.9 | 6.9 |
| 2.9 ≤ E < 3.1 | 5.8 | 5.9 | 6.8 | 7.1 | 6.4 | 6.9 | 6.9 |
| 3.1 ≤ E < 3.3 | 5.7 | 5.8 | 6.8 | 7.0 | 6.3 | 6.9 | 6.9 |
| 3.3 ≤ E < 3.5 | 5.7 | 5.8 | 6.8 | 7.0 | 6.3 | 6.8 | 6.8 |
| 3.5 ≤ E < 3.7 | 5.6 | 5.7 | 6.7 | 7.0 | 6.2 | 6.8 | 6.8 |
| 3.7 ≤ E < 3.9 | 5.6 | 5.7 | 6.7 | 6.9 | 6.2 | 6.7 | 6.7 |
| 3.9 ≤ E < 4.1 | 5.6 | 5.7 | 6.6 | 6.9 | 6.1 | 6.7 | 6.7 |
| 4.1 ≤ E < 4.3 | 5.5 | 5.6 | 6.6 | 6.9 | 6.1 | 6.7 | 6.7 |
| 4.3 ≤ E < 4.5 | 5.5 | 5.6 | 6.6 | 6.8 | 6.0 | 6.6 | 6.6 |
| 4.5 ≤ E < 4.7 | 5.5 | 5.6 | 6.5 | 6.8 | 6.0 | 6.6 | 6.6 |
| 4.7 ≤ E < 4.9 | 5.4 | 5.6 | 6.5 | 6.8 | 6.0 | 6.6 | 6.6 |
| E ≥ 4.9 | 5.4 | 5.5 | 6.5 | 6.7 | 6.0 | 6.6 | 6.6 |
| **Minimum Initial Assembly Avg. Enrichment wt % $^{235}$U (E)** | **30 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)** | | | | | | |
| | **CE 14X14** | **CE 14X14** | **WE 15x15** | **B&W 15x15** | **CE 16X16** | **WE 17X17** | **B&W 17X17** |
| 2.1 ≤ E < 2.3 | - | - | 10.1 | - | - | - | - |
| 2.3 ≤ E < 2.5 | 7.7 | 7.9 | 9.9 | 10.7 | 8.8 | 10.0 | 10.0 |
| 2.5 ≤ E < 2.7 | 7.5 | 7.8 | 9.8 | 10.6 | 8.7 | 9.9 | 9.9 |
| 2.7 ≤ E < 2.9 | 7.4 | 7.7 | 9.7 | 10.4 | 8.6 | 9.7 | 9.7 |
| 2.9 ≤ E < 3.1 | 7.3 | 7.6 | 9.5 | 10.2 | 8.5 | 9.6 | 9.6 |
| 3.1 ≤ E < 3.3 | 7.2 | 7.5 | 9.4 | 10.1 | 8.4 | 9.5 | 9.5 |
| 3.3 ≤ E < 3.5 | 7.2 | 7.4 | 9.3 | 10.0 | 8.3 | 9.4 | 9.4 |
| 3.5 ≤ E < 3.7 | 7.1 | 7.4 | 9.2 | 9.9 | 8.2 | 9.3 | 9.3 |
| 3.7 ≤ E < 3.9 | 7.0 | 7.3 | 9.1 | 9.8 | 8.1 | 9.3 | 9.2 |
| 3.9 ≤ E < 4.1 | 7.0 | 7.2 | 9.1 | 9.7 | 8.1 | 9.1 | 9.2 |
| 4.1 ≤ E < 4.3 | 6.9 | 7.2 | 9.0 | 9.6 | 8.0 | 9.1 | 9.1 |
| 4.3 ≤ E < 4.5 | 6.9 | 7.1 | 9.0 | 9.6 | 8.0 | 9.0 | 9.0 |
| 4.5 ≤ E < 4.7 | 6.9 | 7.0 | 8.9 | 9.5 | 7.9 | 9.0 | 9.0 |
| 4.7 ≤ E < 4.9 | 6.8 | 7.0 | 8.8 | 9.5 | 7.9 | 9.0 | 9.0 |
| E ≥ 4.9 | 6.8 | 7.0 | 8.8 | 9.4 | 7.9 | 8.9 | 8.9 |

Table 5.8-59 Loading Table for PWR Fuel (22 kW/Cask) (continued)

| Minimum Initial Assembly Avg. Enrichment wt % $^{235}U$ (E) | 35 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | - | - | - | - | - | - | - |
| 2.3 ≤ E < 2.5 | - | - | - | - | - | - | - |
| 2.5 ≤ E < 2.7 | 10.7 | 11.9 | 15.2 | 16.6 | 13.1 | 15.4 | 15.4 |
| 2.7 ≤ E < 2.9 | 10.5 | 11.2 | 14.9 | 16.2 | 12.9 | 15.2 | 15.1 |
| 2.9 ≤ E < 3.1 | 10.3 | 11.0 | 14.7 | 16.0 | 12.6 | 14.8 | 14.8 |
| 3.1 ≤ E < 3.3 | 10.1 | 10.8 | 14.4 | 15.8 | 12.4 | 14.7 | 14.7 |
| 3.3 ≤ E < 3.5 | 9.9 | 10.6 | 14.2 | 15.6 | 12.2 | 14.4 | 14.5 |
| 3.5 ≤ E < 3.7 | 9.8 | 10.4 | 14.1 | 15.4 | 12.0 | 14.3 | 14.2 |
| 3.7 ≤ E < 3.9 | 9.7 | 10.3 | 13.9 | 15.3 | 11.9 | 14.2 | 14.1 |
| 3.9 ≤ E < 4.1 | 9.6 | 10.1 | 13.7 | 15.1 | 11.8 | 14.0 | 14.0 |
| 4.1 ≤ E < 4.3 | 9.5 | 10.0 | 13.6 | 15.0 | 11.7 | 13.9 | 13.9 |
| 4.3 ≤ E < 4.5 | 9.4 | 10.0 | 13.5 | 14.8 | 11.6 | 13.7 | 13.8 |
| 4.5 ≤ E < 4.7 | 9.3 | 9.9 | 13.5 | 14.8 | 11.6 | 13.7 | 13.6 |
| 4.7 ≤ E < 4.9 | 9.2 | 9.8 | 13.3 | 14.6 | 11.5 | 13.6 | 13.6 |
| E ≥ 4.9 | 9.2 | 9.7 | 13.3 | 14.5 | 11.5 | 13.5 | 13.5 |
| Minimum Initial Assembly Avg. Enrichment wt % $^{235}U$ (E) | 40 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years) | | | | | | |
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | - | - | - | - | - | - | - |
| 2.3 ≤ E < 2.5 | - | - | - | - | - | - | - |
| 2.5 ≤ E < 2.7 | - | - | - | - | - | - | - |
| 2.7 ≤ E < 2.9 | 15.7 | 19.0 | 21.7 | 23.5 | 19.2 | 22.1 | 22.1 |
| 2.9 ≤ E < 3.1 | 15.3 | 16.7 | 21.4 | 23.2 | 18.8 | 21.8 | 21.8 |
| 3.1 ≤ E < 3.3 | 15.0 | 16.2 | 21.1 | 22.9 | 18.6 | 21.5 | 21.5 |
| 3.3 ≤ E < 3.5 | 14.8 | 15.9 | 20.9 | 22.6 | 18.3 | 21.3 | 21.3 |
| 3.5 ≤ E < 3.7 | 14.5 | 15.7 | 20.7 | 22.4 | 18.0 | 21.1 | 21.0 |
| 3.7 ≤ E < 3.9 | 14.2 | 15.5 | 20.4 | 22.2 | 17.8 | 20.8 | 20.8 |
| 3.9 ≤ E < 4.1 | 14.0 | 15.3 | 20.2 | 22.0 | 17.6 | 20.6 | 20.6 |
| 4.1 ≤ E < 4.3 | 13.9 | 15.0 | 20.0 | 21.8 | 17.5 | 20.5 | 20.4 |
| 4.3 ≤ E < 4.5 | 13.7 | 14.8 | 19.8 | 21.6 | 17.3 | 20.3 | 20.3 |
| 4.5 ≤ E < 4.7 | 13.6 | 14.7 | 19.7 | 21.5 | 17.1 | 20.1 | 20.1 |
| 4.7 ≤ E < 4.9 | 13.5 | 14.5 | 19.6 | 21.3 | 17.0 | 20.0 | 19.9 |
| E ≥ 4.9 | 13.4 | 14.4 | 19.5 | 21.2 | 16.9 | 19.8 | 19.9 |

Table 5.8-60 Loading Table for PWR Fuel (20.9 kW/Cask)

| Minimum Initial Assembly Avg. Enrichment wt % $^{235}U$ (E) | 45 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | - | - | - | - | - | - | - |
| 2.3 ≤ E < 2.5 | - | - | - | - | - | - | - |
| 2.5 ≤ E < 2.7 | - | - | - | - | - | - | - |
| 2.7 ≤ E < 2.9 | - | - | 31.0 | - | - | - | - |
| 2.9 ≤ E < 3.1 | 23.8 | 25.2 | 30.7 | 32.7 | 27.8 | 31.3 | 31.2 |
| 3.1 ≤ E < 3.3 | 23.5 | 24.7 | 30.5 | 32.5 | 27.6 | 31.0 | 31.0 |
| 3.3 ≤ E < 3.5 | 23.2 | 24.4 | 30.2 | 32.2 | 27.4 | 30.8 | 30.8 |
| 3.5 ≤ E < 3.7 | 22.9 | 24.1 | 30.0 | 32.1 | 27.1 | 30.6 | 30.5 |
| 3.7 ≤ E < 3.9 | 22.6 | 23.9 | 29.8 | 31.9 | 27.0 | 30.4 | 30.3 |
| 3.9 ≤ E < 4.1 | 22.4 | 23.6 | 29.6 | 31.7 | 26.8 | 30.2 | 30.1 |
| 4.1 ≤ E < 4.3 | 22.2 | 23.4 | 29.4 | 31.5 | 26.6 | 30.0 | 29.9 |
| 4.3 ≤ E < 4.5 | 22.0 | 23.2 | 29.3 | 31.3 | 26.4 | 29.9 | 29.8 |
| 4.5 ≤ E < 4.7 | 21.8 | 23.0 | 29.1 | 31.2 | 26.2 | 29.7 | 29.6 |
| 4.7 ≤ E < 4.9 | 21.6 | 22.8 | 28.9 | 31.0 | 26.0 | 29.6 | 29.5 |
| E ≥ 4.9 | 21.4 | 22.7 | 28.7 | 30.8 | 25.8 | 29.4 | 29.3 |
| Minimum Initial Assembly Avg. Enrichment wt % $^{235}U$ (E) | 50 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years) | | | | | | |
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | - | - | - | - | - | - | - |
| 2.3 ≤ E < 2.5 | - | - | - | - | - | - | - |
| 2.5 ≤ E < 2.7 | - | - | - | - | - | - | - |
| 2.7 ≤ E < 2.9 | - | - | - | - | - | - | - |
| 2.9 ≤ E < 3.1 | - | - | - | - | - | - | - |
| 3.1 ≤ E < 3.3 | 28.9 | 31.7 | 36.1 | 38.1 | 33.8 | 37.3 | 37.2 |
| 3.3 ≤ E < 3.5 | 28.7 | 30.7 | 35.8 | 38.0 | 33.6 | 37.1 | 37.0 |
| 3.5 ≤ E < 3.7 | 28.3 | 30.4 | 35.7 | 37.8 | 33.4 | 36.9 | 36.8 |
| 3.7 ≤ E < 3.9 | 28.1 | 30.2 | 35.4 | 37.6 | 33.2 | 36.8 | 36.6 |
| 3.9 ≤ E < 4.1 | 27.9 | 29.9 | 35.2 | 37.4 | 33.0 | 36.6 | 36.5 |
| 4.1 ≤ E < 4.3 | 27.6 | 29.7 | 35.1 | 37.3 | 32.9 | 36.4 | 36.3 |
| 4.3 ≤ E < 4.5 | 27.4 | 29.5 | 34.8 | 37.1 | 32.6 | 36.3 | 36.2 |
| 4.5 ≤ E < 4.7 | 27.2 | 29.3 | 34.7 | 37.0 | 32.5 | 36.2 | 36.1 |
| 4.7 ≤ E < 4.9 | 27.1 | 29.1 | 34.6 | 36.8 | 32.3 | 36.0 | 35.9 |
| E ≥ 4.9 | 26.9 | 28.9 | 34.4 | 36.7 | 32.2 | 35.8 | 35.7 |

**Table 5.8-60 Loading Table for PWR Fuel (20.9 kW/Cask) (continued)**

| Minimum Initial Assembly Avg. Enrichment wt % $^{235}$U (E) | 55 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | CE 14X14 | CE 14X14 | WE 15x15 | B&W 15x15 | CE 16X16 | WE 17X17 | B&W 17X17 |
| 2.1 ≤ E < 2.3 | - | - | - | - | - | - | - |
| 2.3 ≤ E < 2.5 | - | - | - | - | - | - | - |
| 2.5 ≤ E < 2.7 | - | - | - | - | - | - | - |
| 2.7 ≤ E < 2.9 | - | - | - | - | - | - | - |
| 2.9 ≤ E < 3.1 | - | - | - | - | - | - | - |
| 3.1 ≤ E < 3.3 | - | - | 41.6 | - | - | - | - |
| 3.3 ≤ E < 3.5 | 34.1 | 37.6 | 41.4 | 43.7 | 38.5 | 42.2 | 42.1 |
| 3.5 ≤ E < 3.7 | 33.8 | 36.1 | 41.3 | 43.5 | 38.3 | 42.0 | 41.9 |
| 3.7 ≤ E < 3.9 | 33.6 | 35.9 | 41.1 | 43.4 | 38.1 | 41.8 | 41.7 |
| 3.9 ≤ E < 4.1 | 33.4 | 35.7 | 41.0 | 43.3 | 37.9 | 41.8 | 41.6 |
| 4.1 ≤ E < 4.3 | 33.2 | 35.5 | 40.8 | 43.1 | 37.8 | 41.6 | 41.5 |
| 4.3 ≤ E < 4.5 | 33.0 | 35.3 | 40.7 | 43.0 | 37.6 | 41.4 | 41.3 |
| 4.5 ≤ E < 4.7 | 32.9 | 35.1 | 40.5 | 42.9 | 37.5 | 41.3 | 41.2 |
| 4.7 ≤ E < 4.9 | 32.7 | 35.0 | 40.4 | 42.8 | 37.3 | 41.2 | 41.1 |
| E ≥ 4.9 | 32.5 | 34.8 | 40.3 | 42.7 | 37.2 | 41.1 | 41.0 |

**Table 5.8-61 Additional Cool Time to Load Non-Fuel Hardware (Reduced Heat Load – 22kW PWR - Configuration)**

| Assembly | BPRA/HFRA* | TP | RCC | NSA |
|---|---|---|---|---|
| CE 14x14 | - | - | 0.4 | 0.4 |
| WE 14x14 | 1.1 | 0.1 | 0.3 | 1.1 |
| WE 15x15 | 1.5 | 0.2 | 7.6 | 1.5 |
| BW 15x15 | 0.1 | 0.2 | 0.3 | 0.2 |
| CE 16x16 | - | - | 0.4 | 0.4 |
| WE 17x17 | 1.5 | 0.2 | 7.3 | 1.5 |
| BW 17x17 | 0.1 | 0.2 | 0.3 | 0.2 |

* HFRAs limited to Westinghouse fuel assemblies only

#### 8.1.5.3.7 Borated Aluminum

Borated aluminum material is a direct chill cast metallurgy product with a uniform fine dispersion of discrete boron particles in a matrix of aluminum. Borated aluminum material is a metallurgically bonded matrix, low porosity product. Borated aluminum is credited with an effectiveness of 90% of the specified minimum areal density of $^{10}B$ in the borated aluminum material based on acceptance and qualification testing of the material as described in Section 8.1.5.3.8 and Section 8.1.5.3.10. Visual inspections of the sheets of borated aluminum material will be based on Aluminum Association recommendations, as applicable—i.e., blisters and/or widespread rough surface conditions such as die chatter or porosity shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores or discoloration are acceptable based on material neutron attenuation and thermal performance not being impacted by minor fabrication anomalies.

#### 8.1.5.3.8 Metal Matrix and Borated Aluminum Neutron Absorber Tests

##### Thermal Conductivity Testing

Thermal conductivity qualification testing of the neutron absorber materials shall conform to ASTM E1225, ASTM E1461, or an equivalent method. The testing shall be performed on test coupons taken from production material. Note that thermal conductivity increases slightly with temperature increases.

- Sampling will initially be one test per lot and may be reduced if the first five tests meet the specified minimum thermal conductivity. Additional tests may be performed on the material from a lot whose test result does not meet the required minimum value, but the lot will be rejected if the mean value of the tests does not meet the required minimum value.

- Upon completion of 25 tests of a single type of neutron absorber material having the same aluminum alloy matrix and boron content (in the same compound), further testing may be terminated if the mean value of all of the test results minus two standard deviations meets the specified minimum thermal conductivity. Similarly, testing may be terminated if the matrix of the material changes to an alloy with a larger coefficient of thermal conductivity, or if the boron compound remains the same, but the boron content is reduced.

In the Chapter 3 thermal analyses, the neutron absorber is evaluated as a 0.125-in nominal thickness sheet for the PWR fuel basket and a 0.10-in nominal thickness sheet for the BWR fuel basket.

The required minimum thermal conductivities for the MAGNASTOR neutron absorbers are as follows:

Minimum Effective Thermal Conductivity - BTU/(hr-in-°F)

| Neutron Absorber Type | Radial | | Axial | |
|---|---|---|---|---|
| | 100°F | 500°F | 100°F | 500°F |
| Type 1 | 1.503 | 1.972 | 3.295 | 3.669 |
| Type 2 | 3.12 | 3.21 | 4.31 | 4.65 |

Note: Type 1 thermal conductivity for Neutron Absorber is required for PWR or BWR basket with a maximum heat load of 22 kW. Type 2 thermal conductivity is required for PWR basket with a maximum heat load of 23 kW.

The neutron absorber thermal acceptance criterion will be based on the nominal sheet thickness. Surface anomalies increase radiation heat transfer and have insignificant influence on thermal conductivity, permitting acceptance of minor surface defects without additional material testing.

Additional thermal conductivity qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum thermal conductivity are available as referenced documentation.

## Yield Strength Testing

Yield strength qualification testing of the neutron absorber shall conform to ASTM Test Method B557/B557M, E8 or E21.

Neutron absorber material yield strength must be equal to or greater than 5 ksi at 70°F consistent with 1100-O aluminum alloy per Table 2.2.1-14. The material yield strength at 700°F from Table 2.2.1-14 is applied as a temperature-independent value for the structural evaluation of the neutron absorber. This yield strength assures that the material will maintain its form when subjected to normal, off-normal and hypothetical accident condition loads.

The neutron absorber yield strength acceptance criterion will be based on the absorber meeting the specified nominal sheet thickness. Control and limitations on the neutron absorber boron content (primary driver to material structural performance) permits acceptance without additional material yield strength acceptance testing.

Additional yield strength qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum yield strength are available as referenced documentation.