SAFETY EVALUATION REPORT

NAC INTERNATIONAL, INC.

Modular Advanced Generation Nuclear All-purpose Storage (MAGNASTOR®) DRY CASK STORAGE SYSTEM

CERTIFICATE OF COMPLIANCE NO. 1031

AMENDMENT NO. 3

DOCKET NO. 72-1031

Table of Contents

Summary

This Safety Evaluation Report (SER) documents the staff's review and evaluation of an amendment to Certificate of Compliance (CoC) No. 1031 for the Modular Advanced Generation Nuclear All-purpose Storage (MAGNASTOR®) spent fuel dry cask storage system. By application dated August 26, 2010 (Agency-wide Documents Access and Management System (ADAMS) accession number ML102420569), the cask vendor, NAC International, Inc. (hereafter, NAC), submitted a request to the U.S. Nuclear Regulatory Commission (NRC) in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 72.244 to amend CoC No. 1031. NAC supplemented its request on the following dates: February 4, 2011 (ML11138A224), February 16, 2011 (ML110480498), August 15, 2011 (ML11229A701), October 3, 2011 (ML11287A020), March 21, 2012 (ML12082A219), March 30, 2012 (ML12094A056), April 6, 2012 (ML12104A025) and April 22, 2013 (ML13114A137). This amendment revises the authorized contents to include the following pressurized water reactor (PWR):

- damaged fuel contained in damaged fuel cans (DFCs) that are placed in a damaged fuel (DF) basket assembly;
- intact fuel assemblies with nonfuel hardware per the expanded definition in this application; and
- intact fuel assemblies with up to five activated stainless steel fuel replacement rods at a maximum burnup/exposure of 32.5 GWd/MTU.

This amendment also revises Paragraph 4.3.1 (i), Appendix A, "Technical Specifications and Design Features for the MAGNASTOR® System," to clarify that the maximum design basis earthquake accelerations of 0.37g in the horizontal direction (without cask sliding) and 0.25g in the vertical direction at the independent spent fuel storage installation (ISFSI) pad top surface do not result in cask tip-over. As part of the response to the NRC request for additional information (RAI) (ML11287A020), NAC withdrew the request to increase the allowable burnup of the fuel contents to 70 GWd/MTU.

To support this amendment request, NAC submitted the MAGNASTOR® Final Safety Analysis Report (FSAR) Revisions 10B, 11A, 11B and 12A. The amendment request affects FSAR Chapters 1 through 13 and the Technical Specifications: Appendix A, "Technical Specifications and Design Features for the MAGNASTOR® System" and Appendix B, "Approved Contents for the MAGNASTOR® System." The amendment request also includes nine (9) new license drawings depicting the design of the damaged fuel can (DFC) and the damaged fuel (DF) basket assembly. Ten (10) license drawings referenced in this amendment have been revised via the 10 CFR 72.48 determination process.

All changes incorporated in the FSAR via the 10 CFR 72.48 determination process are shown in ***bold italic*** lettering. FSAR changes, noted by ***bold italics*** text, incorporated by the applicant through the 10 CFR 72.48 process are not part of this amendment request. Therefore, changes made under the 10 CFR 72.48 process were not evaluated by the NRC staff as part of this amendment request and are not formally authorized as part of this certification action for the MAGNASTOR® dry cask storage system. The FSAR change pages also include information that was the subject of MAGNASTOR® Amendments 1 and 2, which, at the time of this submittal, were both ongoing licensing efforts. The Amendment 1 information is identified in the FSAR change pages by **single underline** and the Amendment 2 information is identified by **double underline**.

The NRC staff reviewed the amendment and supplements to the amendment using the guidance document NUREG-1536, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” Rev. 1, dated July 2010. Based on the statements and representations in the application, as supplemented, and the conditions specified in the CoC and technical specifications (TS), the staff concluded that the MAGNASTOR® dry cask storage system design with the requested changes meets the requirements of 10 CFR Part 72.

1.0 General Description

1.1 Terminology

Several definitions in the terminology section of the FSAR were deleted, modified, or added. For example, the applicant deleted the definition for “peak average burnup.” “Assembly average burnup” is an example of a modified definition. The modified definition accounts for the reactor record, nominal, value. Other definitions that were modified include contents; damaged fuel (DF); MAGNASTOR® System; spent nuclear fuel; transfer cask lifting trunnions; transportable storage canister (TSC) closure lid; and undamaged fuel. The definition for “damaged fuel can (DFC)” is new and “nonfuel hardware” has an expanded definition. Staff finds the new terminology acceptable.

1.2 Introduction

This amendment would revise authorized contents to include pressurized water reactor (PWR) damaged fuel contained in DFCs that are placed in a DF basket assembly. The system is designed to store up to four DFCs in the DF basket assembly. The DF basket assembly also has a capacity of up to thirty-seven (37) undamaged PWR fuel assemblies, including four DFC locations. 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. A DFC may not contain a fuel assembly that includes core components.

For PWR fuel, the inclusion of nonfuel assembly hardware can increase an assembly’s overall length, resulting in the need to use the longer TSC. Fuel assembly spacers may be used in a given TSC to facilitate the loading of fuel assemblies. A DFC spacer may be required for damaged fuel cans to ensure the proper design function of the DFC.

PWR fuel assemblies may be stored with nonfuel hardware. Nonfuel hardware stored in a damaged or undamaged fuel assembly placed into a DFC is limited to steel rod inserts for guide tube dashpots, guide tube anchors, and instrument tube tie components or other similar devices.

1.3 MAGNASTOR® System Description and Operational Features

FSAR Section 1.3 provides a general description of the MAGNASTOR® dry cask storage system components (TSC; fuel baskets; concrete cask; transfer cask; and DFC) and operational features. The changes to the MAGNASTOR® system and operational features per this amendment request are described in the following paragraphs.

1.3.1 MAGNASTOR® Components

In this amendment request, the auxiliary equipment generally needed to use the MAGNASTOR® system was modified to include hydrostatic testing in the preparation of the TSC and contents for storage.

1.3.1.1 Transportable Storage Canister (TSC)

An editorial correction was made to the sentence changing “welded closure lid” to “welded TSC weldment.” Closure ring alternative designs for all four TSC configurations are defined on the applicable drawings.

1.3.1.2 Fuel Baskets

Editorial changes were made in FSAR Section 1.3.1.2. The applicant changed “Following coating” to “Following plating” in the sentence: “Following plating of the structural components, the neutron absorber panels and the stainless steel retainers installed on the basket structure as shown on the License Drawings.” The applicant added to FSAR Table 1.3-1 the principal dimensions and materials of fabrication of the PWR damaged fuel cans (shown below).

Design Characteristic	Nominal Value (in)[a]	Material
# of Fuel Tubes/Fuel Loading Positions (PWR)	21/37	
DFC Corner Support Weldment		
Inner-Formed Plate	1.125	Carbon Steel
Outer-Formed Plate	0.75	Carbon Steel
Ridge Gusset	0.75	Carbon Steel
Damaged Fuel Can Wall		
Tube Body	0.048	Stainless Steel
Side Plate	0.15	Stainless Steel

[a] Thickness unless otherwise indicated.

The applicant added the sentence “Spacers may be used to facilitate the loading of the spent fuel assemblies, or damaged fuel cans, during storage operations.”

PWR Fuel Basket

The applicant added a new paragraph for the PWR fuel basket section to describe the damaged fuel cans in the damaged fuel basket assembly, as follows. “The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. The arrangement of tubes and fuel positions is the same as in the standard fuel basket, but the design of each of the four corner support weldments is modified with additional structural support to provide an enlarged position for a damaged fuel can at the outermost corners of the fuel basket. Each damaged fuel can location has a nominal 9.80-in square opening. A damaged fuel can or an undamaged fuel assembly may be loaded in a damaged fuel can corner location.”

1.3.1.3 Transfer Cask

In the following sentence the applicant changed, “may be” to “is”. “During TSC closure, clean or demineralized spent fuel pool water is circulated through these penetrations into the annulus region to minimize component temperatures and improve canister preparation time limits." The applicant deleted the word "auxiliary" from the sentence: "The annulus circulating water system can be utilized through completion of TSC activities." The applicant added the words "and disconnected" to the sentence: "The annulus circulating water system is turned off and disconnected prior to movement of the transfer cask for TSC transfer operations into the concrete cask."

1.3.1.4 Damaged Fuel Can

The applicant added the new FSAR Section 1.3.1.5, Damaged Fuel Can, which states the following. "The MAGNASTOR® Damaged Fuel Can (DFC), shown in License Drawings 71160-601 and 71160-602, is provided to accommodate damaged WE 15x15, WE 17x17, and B&W 15x15 fuel assemblies. The DFC may also contain the WE 15x15, WE 17x17, and B&W 15x15 fuel assemblies in an undamaged condition or fuel debris equivalent to one PWR fuel assembly. Up to four DFCs may be loaded, one into each outer corner, in the MAGNASTOR® DF Basket Assembly.

The primary function of the DFC is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the TSC cavity. In normal operation, the DFC is in a vertical orientation.

The DFC is fabricated from Type 304 stainless steel and has an 8.7-in square inside dimension. The DFC may be provided in two lengths: an overall length of 166.9 inches with a nominal cavity length of 164.0 inches (WE 15x15 or WE 17x17 fuel assemblies only), or an overall length of 171.8 inches with a nominal cavity length of 169.0 inches (primarily B&W 15x15 fuel assemblies, but WE 15x15 or WE 17x17 fuel assemblies may be accommodated with a fuel assembly spacer to limit axial movement). For the shorter DFC, a DFC spacer is used to provide an overall height of DFC and spacer of 171.5 inches. The side plates that form the upper end of the DFC are 0.15-in thick and the tube body walls are 0.048-in thick (18-gage sheet). The DFC lid plate and bottom thicknesses total 11/16 (0.688) inch and the lid overall height is 2.32 inches. The DFC bottom plate thickness is 5/8 (0.625) inch. The DFC lid and bottom include screened drain holes."

1.3.2 Operational Features

FSAR Chapter 9 presents detailed generic step-by-step operating procedures for the loading and transferring of the MAGNASTOR® system. The applicant modified FSAR Section 1.3.2, list of major loading activities, by including two new bullets (i.e., the third and eleventh bullet in the list of major loading activities, as shown below):

- Load the selected spent fuel assemblies and damaged fuel cans (if applicable) into the TSC.
- Vacuum dry the TSC cavity. Verify cavity dryness.

1.4 MAGNASTOR® Contents

In this amendment request, significant revisions appear in this section of the FSAR. The changes to the first sentence are chiefly editorial; however, the phrase "in a pressurized helium atmosphere" has been deleted. Added to this section is the change to include damaged fuel cans, as follows: "The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. 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." Nonfuel hardware replaces "burnable poison rod assemblies, thimble plugs or control element assemblies. Stainless steel rod inserts for guide tube dashpots…" in the description for what contents may be stored with PWR fuel assemblies. The previously approved "Steel filler rods must be unirradiated" has been changed to "Irradiated (i.e., activated during in-core operation) steel filler rods are limited to five rods per assembly and there may be no more than one assembly with irradiated rods per TSC." The previously approved "Assemblies may contain unenriched axial end blankets" has been changed, deleting "unenriched" from the sentence stating instead that assemblies may contain axial end blankets. The applicant adds the sentence "Axial end blankets may be low enriched, be unenriched, and/or contain annular fuel pellets" in this amendment request.

The staff reviewed the editorial changes and finds that these editorial changes have no adverse impact to the safety of the cask design. Staff also finds that the new contents are acceptable because the applicable regulatory requirements in 10 CFR 72.236 continues to be met.

1.5 Identification of Agents and Contractors

In this section of the FSAR, the applicant updated the information on the number of transportation and/or storage systems that NAC has completed fabrication of or has under construction. The information provided covers the past fifteen (15) years.

1.6 MAGNASTOR® License Drawings

FSAR Section 1.8 contains the drawings for the MAGNASTOR® system, which include drawings of the structures, systems, and components important to safety. The drawings of the damaged fuel can (assembly, details, and spacer), neutron absorber retainer for DF corner weldment, DF (corner weldment, basket assembly, shell weldment, and closure lid), and basket drawings are associated with Amendment 3. These changes to the design are evaluated in Sections 3 through 9 of this SER. FSAR Revision 11B page 1.8-1 includes updated revision numbers for license drawings 71160-551 to Rev. 9P and 9NP (via 72.48), and 71160-673 to Rev. 1.

1.7 Evaluation Findings

Based on the information presented in FSAR Chapter 1, "General Information", the staff concludes that the requirements in10 CFR 72.2(a)(1), (b); 72.122(a), (h)(1); 72.230(a); and 72.236(a), (c), (h), and (m) continues to be satisfied. This finding is reached on the basis of a review that considered the regulation itself, Regulatory Guide 3.61, and accepted practices. Thus, based on the NRC staff's review of information provided for Amendment 3 for the MAGNASTOR® system, the staff determines the following:

F1.1 Drawings for structures, systems, and components (SSCs) important to safety are presented in FSAR Section 1.8. A listing of those drawings (including dates and revision numbers) relied upon as a basis for approval also appears in FSAR Section 1.8. Details of specific SSCs are evaluated in Sections 3 through 8 of this safety evaluation report.

F1.2 Specifications for the spent nuclear fuel (SNF) to be stored in the dry storage system (DSS) are provided in FSAR Section 1.4. Additional details concerning these specifications are presented in Chapter 1 of both the FSAR and SER.

F1.3 The MAGNASTOR® dry cask storage system is not yet certified under 10 CFR Part 71 for use in transportation.

2.0 Principal Design Criteria

The majority of changes made by the applicant to this FSAR Chapter are editorial.

Editorial changes to FSAR Chapter 2

- Page 2-1 - revised 2nd sentence to include damaged PWR fuel assemblies
- Page 2.1-1, Section 2.1, 2nd paragraph – deleted “spent” & added “damaged fuel cans”
- Page 2.1-3, Table 2.1-2 - added “damaged fuel can” in two places in last column of first row
- Page 2.1-4, Table 2.1-2 - added “damaged fuel can” in 1st & last columns of last row
- Page 2.1-4, revised the “Exception, Justification, and Compensatory Measures” cell in the second row to remove the “ref” when referring to helium leak rate testing
- Page 2.1-5, Table 2.1-2 - last column revised throughout
- Page 2.2-1, Section 2.2, 1st paragraph – made former 1st paragraph into two paragraphs by inserting detailed content description into paragraph one; new 3rd paragraph – revised throughout; 4th paragraph - revised last sentence; Section 2.2.1 - deleted last sentence of 1st paragraph
- Page 2.2-2, 1st full paragraph, first line – new paragraph (used to be part of paragraph 2, Section 2.2.1, added new 2nd & 5th sentences; 2nd full paragraph (used to be part of paragraph 2, Section 2.2.1) – revised throughout; last paragraph – revised 1st sentence and added new last sentence
- Page 2.2-6 - added new Figure 2.2-3, DF Basket Assembly Configuration for PWR Fuel with Damaged Fuel Can Locations
- Page 2.2-7, Table 2.2-1 – revised the numbers in the “Max Assembly Average Burnup” row to remove assembly average burnup higher than 60 GWd/MTU; the numbers have been replaced due to the withdrawal of the request to increase the licensed fuel burnup limit to 70 GWd/MTU.
- Page 2.3-5, Section 2.3.5.2 – 1st paragraph, 2nd sentence - added reference to damaged fuel can
- Page 2.4-3, Section 2.4.4 – revised throughout
- Page 2.4-4, Section 2.4.6.1, 1st paragraph, 3rd sentence – changed “attracts” to “captures”; 6th sentence - changed “(registered trademark of AAR Advanced Structures)” to “(registered trademark of Ceredyne, Inc.)”
- Page 2.4-6, Section 2.4.10, 1st paragraph, 1st sentence - added “vacuum drying, cooling, helium backfill”
- Page 2.4-8, Table 2.4-1, 1st row - deleted duplicate listing of drawing “71160-584”; 2nd row - added damaged fuel can and basket drawing numbers to 2nd column

2.1 MAGNASTOR® System Design Criteria

The changes the applicant made in FSAR Section 2.1 were editorial. For example, in the second paragraph the word “spent” was deleted as a descriptor for the fuel baskets. The phrase “damaged fuel cans” was added to the list for approved alternatives to the ASME Code for the design procurement, fabrication, inspection, and testing. The phrase “damaged fuel can” was also inserted in the column labeled “Exception, Justification and Compensatory Measures” of FSAR Table 2.1-2. The last two entries in FSAR Table 2.1-2 were modified to include damaged fuel can in both the first column (i.e., component) and the last column, "Exception, Justification and Compensatory Measures."

The staff reviewed the editorial changes and finds that these editorial changes have no adverse impact to safety of the cask design.

2.2 Spent Fuel to be Stored

MAGNASTOR® contents are described in FSAR Section 2.2 and SER Section 1.4.

2.2.1 PWR Fuel Evaluation

In FSAR section 2.2.1, the applicant rearranged text moving the sentence "Uniform and preferential loading patterns are allowed in the PWR basket" to this section and added the text "and in the damaged fuel (DF) basket assembly" to the end of the sentence. The applicant also moved the sentence "The preferential loading pattern permits peak heat loads of 1.20 kW" to this section. Throughout this section, as appropriate, the applicant added the following new sentences:

- "The fuel basket configuration for PWR fuel with damaged fuel cans is shown in Figure 2.2-3."
- "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."
- "As noted in Table 2.2-1, the evaluation of PWR fuel assemblies includes nonfuel hardware."
- "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 unirradiated steel inserts."

These changes are evaluated in this SER.

2.3 Design Criteria for Environmental Conditions and Natural Phenomena

<u>Load Combinations and Design Strength – TSC and Fuel Basket</u>

The applicant editorial change inserted "damaged fuel can" in the sentence describing the design of the TSC in accordance with the ASME Code, Section III, Subsection NB.

2.4 Safety Protection Systems

<u>Protection by Equipment</u>

The applicant revised text in this section as follows. "The important-to-safety equipment employed in the handling of MAGNASTOR® are the lifting yoke and the crane hook extension (where required) used to lift the transfer cask. The lifting yoke and the crane hook extension are designed, fabricated and tested in accordance with ANSI N14.6 as a special lifting device as defined in NUREG-0612. The lifting yoke and the crane hook extension are proof load tested to 300% or 150% (for facilities not requiring single failure-proof criteria) of its design load when fabricated. Following the load test, the bolted connections are disassembled and the components are inspected for deformation. The transfer cask, lifting yoke and crane hook extension are inspected for visible defects prior to each use."

Control Methods for Prevention of Criticality

The applicant changed "attracts" to "captures" in the sentence "The fixed neutron absorber captures thermal neutrons that are moderated in the water surrounding the fuel." The applicant changed the registered trademark of AAR Advanced Structures® Boral to Ceredyne® Boral.

Auxiliary Structures

The applicant made an editorial change by adding the text "vacuum drying, cooling, helium backfill" to the sentence "The loading, welding, vacuum drying, cooling, helium backfill transfer, and transport of MAGNASTOR® require the use of auxiliary equipment as described in Chapter 9."

The aforementioned changes are evaluated in this SER.

2.5 Evaluation Findings

The staff concludes that the principal design criteria for the MAGNASTOR® system are acceptable with regard to meeting the regulatory requirements of 10 CFR Part 72. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. A more detailed evaluation of the design criteria and an assessment of compliance with those criteria are presented in Chapters 3 through 14 of the SER.

F2.1 The FSAR and docketed materials adequately identify and characterize the SNF to be stored in the DSS in conformance with the requirements in 10 CFR 72.236.

F2.2 The FSAR and docketed materials relating to the design bases and criteria for criticality safety meet the regulatory requirements in 10 CFR 72.124(a) and (b).

F2.3 The FSAR and docketed materials relating to the design bases and criteria for shielding, confinement, radiation protection, and ALARA considerations meet the regulatory requirements in 10 CFR 72.104(a) and (b); 10 CFR 72.106(b); 10 CFR 72.122(a), (b), (c), (f), (h)(1), (h)(4), and (i); 10 CFR 72.126(a).

3.0 Structural Evaluation

There are a number of structural design changes introduced, via the 10 CFR 72.48 change process, to the MAGNASTOR® storage system since its initial certification to afford fabrication and deployment flexibility. These changes include:

(1) Optional use of a composite closure lid assembly of stainless and carbon steels for the transportable storage canister (TSC);
(2) Adding a longer MAGNASTOR® transfer cask (MTC2) to the system with different materials of construction for the outer shell; and
(3) Adding a longer concrete cask (CC) design with reduced wall thickness but increased liner plate thickness of the wall.

This license amendment request (LAR) adds to the MAGNASTOR® system a PWR damaged fuel (DF) basket to allow loading of the damaged fuel can (DFC) at four corner basket locations. It also seeks to clarify the Technical Specifications provision defining the design earthquake acceleration for an ISFSI pad. In the following, the staff reviews the structural performance of the added design features other than those associated with the 10 CFR 72.48 changes. Since the system design bases and acceptance criteria of the initial certification remain applicable, the staff's review focuses primarily on the FSAR implementation of structural evaluation assumptions and the results of the analysis for the PWR DF basket and the DFC for the applicable loading conditions.

3.1 Structural Design Features and Design Criteria

3.1.1 Structural Design Features

<u>PWR DF Basket</u>

The standard PWR fuel basket, as initially certified, is comprised of an array of twenty-one square fuel tubes, which are joined at the interior by the pin-to-slot connections, and at the peripheral, attached by bolting to the side and corner weldment assemblies to form a circular cross section for the TSC emplacement. The fuel tubes with a nominal 8.76-inch square opening function as individual cells as well as sidewalls for the developed cells with a nominal 8.86-inch square. Together with the side and corner weldments, which also serve partially as cell sidewalls, the standard PWR basket provides 37 fuel loading positions.

FSAR Drawing 71160-675 presents design details of the PWR DF basket fabricated with seventeen, instead of twenty-one, independent fuel tubes. The basket configuration is essentially the same as that of the standard PWR fuel basket that allow 37 fuel loading positions. The primary deviation from the standard PWR basket is that, in addition to providing support to the interior fuel tubes, each of the four corner weldments is modified to include an enlarged opening of 9.80-inch square (nominal) for loading a DFC insertion into the PWR DF basket.

<u>Damaged Fuel Can (DFC)</u>

FSAR License Drawings 71160-601 and 71160-602 depict design details of the MAGNASTOR® DFC. The Type 304 stainless steel DFC is configured with an 18-gauge shell tube body, a bottom plate, and a top closure assembly with screened openings to allow gaseous and liquid media to escape. The tube body has an 8.7-inch square inside dimension and may be provided in two lengths: an overall length of 166.9 inches and 171.8 inches with a nominal 164-inch and 169-inch long cavity, respectively. As noted in FSAR Section 1.3.1.5 and License Drawing 71160-673, for the shorter DFC, a 5.5-inch high DFC spacer is used to provide an overall height of DFC and spacer of 171.5 inches to ensure its proper positioning inside the TSC cavity.

3.1.2 Structural Design Criteria

The structural design criteria, including codes and standards, site environmental and natural phenomenon loads, and load combinations as presented in FSAR Sections 2.1 and 2.3 remain applicable to the added structural features of the MAGNASTOR® system and require no further review.

3.2 Review of Structural Analysis

In the FSAR the structural performance of the PWR DF basket and the DFC are evaluated by both hand calculations and finite element analyses, as appropriate. FSAR Section 3.10.1.5 provides a summary description of the finite element models for analyzing the PWR DF basket for various loading conditions, including the off-normal TSC handling, thermal stress, and concrete cask tip-over accident conditions. The analysis models are essentially identical to those for the initially certified standard PWR fuel basket except that appropriate modeling details are introduced to recognize physical attributes of the corner weldment specific to the PWR DF basket. In the following, the staff reviews structural performance of the PWR DF basket and the DFC for the loadings associated with normal and off-normal handling conditions as well as the concrete cask 24-inch end-drop and the tip-over accidents.

3.2.1 PWR Damaged Fuel Basket

3.2.1.1 Normal Handling Condition

FSAR Section 3.5.2.2 presents the structural performance analysis of the PWR DF basket for the normal handling condition. Assuming a bounding basket weight of 25,000 lbs evenly distributed on the 17 tubes, the axial stress in the fuel tube and the bearing stresses as exerted by the connector pin assembly to the fuel tube and the TSC bottom plate are all determined to have large stress margins, which is acceptable. Using a bounding weight of 2,450 lbs for both the corner and side weldments, the governing TSC bottom plate bearing stress at the three contact points is calculated to be 0.7 ksi, which is much less than the at-temperature yield strength of 20.7 ksi. Similarly, the FSAR Section 3.5.2.1 evaluation of the bolting between the support weldments and the fuel tube array for the initially certified basket is considered to envelop that of the PWR DF basket configuration. The FSAR evaluates thermal stress of the PWR DF basket components, including the neutron absorbers, by noting that they are bounded by those presented in FSAR Section 3.5.2.1 for the initially certified PWR basket. These evaluations demonstrate acceptable structural performance of the PWR DF basket for the normal handling condition.

3.2.1.2 Off-Normal Handling Condition

FSAR Section 3.6.2.2 analyzes the PWR DF basket for a concurrent inertial loading of 1.5 g vertical and 0.707 g transverse. This loading is postulated to be associated with the off-normal handling events involving the insertion of the TSC into the concrete cask, removal of the TSC from the concrete cask, or removal of the TSC from the transfer cask. The finite element analysis results show a minimum factor of safety of 2.47 for the basket fuel tube and large factors of safety for the support weldments, on the basis of the ASME Section III, Service Level C, stress intensity limits. The evaluation also addresses the bolting between the support weldments and the fuel tube array as well as bearing stresses at the interfaces between the connector pin and the fuel tube and between the connector pin assembly and the TSC bottom plate. It follows the same approaches as those for the normal handling condition; the stress results are acceptable.

3.2.1.3 Concrete Cask 24-Inch End-Drop Accident

FSAR Section 3.7.2.1.2 continues to consider a bounding axial inertial force of 60 g and rely on classical hand calculations to demonstrate adequate structural performance of the PWR DF basket components under the 24-inch end-drop accident. For a bounding basket weight of 25,000 lbs carried by 17 tubes, the FSAR calculates a membrane stress of 7.7 ksi in the 9.76-inch square by 5/16-inch thick fuel tube. This is below the at-temperature stress allowable of 47.9 ksi, or 0.7 S_u, where S_u is the ultimate strength of 68.4 ksi at 700°F for the SA-537, Class 1 steel. The governing membrane stress of 36.2 ksi in the corner and side weldments is also less than the at-temperature allowable of 47.9 ksi for the same SA-537, Class 1 steel. The bounding axial load of 46.9 kips on the connector pin assembly is determined to be less than the calculated Euler buckling load of 112.3 kips for the ¾-inch diameter by 3-inch long pin with an at-temperature Young's modulus of 27.3 x 10^6 psi. These evaluations demonstrate acceptable structural performance of the PWR DF basket for the concrete cask 24-inch end-drop accident condition.

3.2.1.4 Concrete Cask Tip-over Accident

Fuel Basket - Structural Integrity

FSAR Section 3.10.1.5.3 presents the three-dimensional (3-D) periodic plastic models for performing ANSYS stress analysis of the PWR DF basket for the 0° and 45° basket drop orientations. The finite element models, as depicted in FSAR Figures 3.10.1-17 and -18, are essentially the same as those for the standard PWR fuel basket, including a 35-g side-impact force boundary condition and a displacement boundary simulated by the CONTAC52 elements for the interface between the basket and the canister shell supported by the concrete cask wall liner. The models deviate slightly from those for the standard PWR fuel basket models. The SHELL43 elastic-plastic elements replace the SHELL63 elements for the ridge gussets of the modified corner weldment. Additionally, with continuing implementation of the CONTAC52, CONTA173, TARGE170, LINK10 and COMBIN40 elements, the models are capable of simulating interface conditions among basket components, including gaps and bolt/boss joints, for calculating stresses in the components undergoing inelastic material behavior. FSAR Section 3.7.2.1.4 presents analysis results for the PWR DF basket components, which are reviewed as follows.

For the fuel tubes evaluated with the ASME Code, Section III, Appendix F, at-temperature stress allowables, the FSAR notes that the critical stress locations occur at tube corners and the minimum factors of safety are 1.14 and 1.39 for the primary membrane and primary membrane-plus-bending stress intensity categories, respectively. With a 0.65 weld quality factor commensurate with the weld examination procedure for the longitudinal seam weld joining two tube halves, the maximum membrane and membrane-plus-bending stress intensities in the weld are calculated to be 9.3 ksi and 25.6 ksi, respectively, which are less than the allowables and are acceptable.

For the respective 0° and 45° basket drop orientations, Tables 3.7.2-11 and -12 provide summaries of maximum stress intensities for the corner weldment plates with a minimum factor of safety of 1.74. The results for the corner weldment ridge gussets are presented in Tables 3.7.2-13 and -14 with a minimum factor of safety of 2.30. The stress results for the side weldment are presented in Tables 3.7.2-15 and -16. The minimum factors of safety for membrane and membrane-plus-bending stress intensities are 6.56 and 2.13, respectively. On the attachment between fuel tubes and support weldments, the FSAR notes that the evaluations presented in Sections 3.7.2.1.3 and 3.7.2.1.4 for the standard PWR fuel basket bounds that of the PWR DF basket configuration. This provides reasonable assurance for the staff to conclude that the stress performance of the PWR DF basket assembly is adequate.

Buckling capability of the fuel tube sidewall is evaluated per the NUREG/CR-6322 approach, considering the combined axial compression and bending. For a maximum compression of 28.8 kip and a maximum bending of 4.81 inch-kip, the fuel tube wall is demonstrated to be capable of resisting buckling failure by satisfying interaction Equations 31 and 32 with the factors of safety of 1.33 and 1.56, respectively.

Consistent with the approach used for the standard PWR fuel basket, the FSAR considers fuel tube deformations and fuel cell dimension changes to determine a minimum clearance of 0.24 inch and 0.10 inch between the tube wall and the fuel assembly for the manufactured tubes and the developed tubes, respectively, for the 35-g side impact loading. As a comparison, the FSAR notes that clearance between the DFC tube and the damaged fuel assembly is bounded by those associated with the standard PWR baskets, which is acceptable.

To evaluate structural performance of the neutron absorber and its retainer subject to a bounding side impact loading of 60 g, the LS-DYNA model depicted in FSAR Figure 3.7.2-3 for the standard PWR fuel basket is modified slightly to account for the increased neutron absorber thickness from 0.125 inch to 0.145 inch. The model includes slotted holes in the neutron absorber plate and its stainless steel retainer strip with conical pockets to receive the short steel posts, which are, in turn, welded to the tube wall. Considering inelastic material properties at 700°F for the stainless steel strip and the neutron absorber, the FSAR calculates a maximum localized strain of less than 2.2%, which is minimal and much below the elongation limit, for the retainer strip. This demonstrates that the retainer strip remains engaged with the weld post during and after the tip-over accident. The calculated peak force of 57 lbs on the weld post is much smaller than the weld capacity of 812 lbs.

Fuel Basket - Geometric Stability

FSAR Section 3.10.6 evaluates the geometric stability of the basket assembly to ensure that the fuel tubes retain their initial geometric configuration and all of the pin-to-slot connections remain engaged after the tip-over accident. The FSAR notes that the PWR DF basket configuration replaces the standard corner weldment and independent corner fuel tube with a much stiffer integrated welded corner weldment and oversized fuel tube assembly. As a result, the staff has reasonable assurance to conclude that the structural stability performance of the standard PWR basket bounds that of the PWR DF basket and there is no need to perform additional analysis to demonstrate geometric stability of the PWR DF basket.

3.2.2 Damaged Fuel Can

FSAR Section 3.4.3.4 presents the structural analysis of the DFC for lifting operation. The welds and key components, including the tube shell side plates and bottom plate, are shown to have large stress margins. For the stresses introduced to the lifting slots during lifting operation, the calculated von Mises and tensile stresses all have factors of safety greater than three against the material yield strength. This demonstrates acceptable structural performance.

FSAR Section 3.10.10 performs the structural evaluation of the DFC in accordance with the ASME Code, Section III, Subsection NG, provisions for normal and accident conditions of storage.

For the normal condition of storage, the 90 psi compressive stress incurred by the DFC dead weight in the tube wall is much less than the primary membrane stress of 15,800 psi.

The FSAR considers an axial force of 9,000 lbs, which corresponds to a 60-g bounding deceleration of the concrete cask 24-inch end-drop accident, to calculate a primary membrane stress intensity of 5,357 psi in the tube wall. This stress is much less than the at-temperature allowable of 37,920 psi (2.4 S_m = 2.4 x 15,800 = 37,920) for the SA-240, Type 304 stainless steel. The same 9,000-lb axial force is also shown to be much less than the buckling capacity of 44,000 lbs for the DFC tube wall.

FSAR Section 3.10.10.1 notes that the majority of the DFC tube is contained within the PWR DF basket corner support weldment and no significant bending stress is introduced into the tube body. For the longer DFC, however, the FSAR recognizes that the last 0.2 inch of the tube body plus the 3.8-inch side plates are unsupported past the end of the tube in the side impact associated with the concrete cask tip-over accident. Considering also the distributed damaged fuel and on the basis of the cantilever beam response, the FSAR computes the maximum bending and shear stresses in the tube wall to obtain a corresponding primary membrane-plus-bending stress intensity of 7,130 psi. It is significantly less than the at-temperature allowable of 56,880 psi (3.6 S_m = 3.6 x 15,800 = 56,880) of the SA-240, Type 304 stainless steel tube body.

FSAR Drawing 71160-673 depicts design details of the 5.5-inch tall DFC spacer used to provide an overall height of 171.5 inches for the short DFC and its spacer for proper emplacement within the canister cavity. FSAR Section 3.10.10.2 calculates a maximum compressive stress of 214 psi in the spacer under the normal condition of storage for the combined dead weight of 1,765 lbs. For the 60-g end-drop inertia force with a 10% dynamic load factor, the resulting maximum compressive stress of 11.7 ksi in the spacer is below the buckling capability of 41.04 ksi (2.4 S_m = 2.4 x 17.1 = 41.04). This is acceptable.

3.2.3 Technical Specification Changes

3.2.3.1 Weight per Storage Location

The fuel assembly weight limit per storage location, specified as Allowable Contents in Technical Specification (TS), Table B2-1, of the initial certification, is equal or less than 1,680 lbs, including nonfuel-bearing components. The amendment request proposes to replace the TS provision to read, “Weight per Storage Location to be less than 1,765 lb, including SNF Assembly, NONFUEL HARDWARE, and fuel spacers.”

FSAR Section 3.10.6.4 evaluates the effect of the proposed TS contents weight change per storage location on the geometric stability of the standard PWR basket by noting that:

(1) the total contents weight continues to be limited by the initially approved weight of 62,160 lbs (37 x 1,680 = 62,160) and
(2) the maximum allowable contents weight in an individual storage location of 1,765 lbs, as proposed, amounts to about 5% weight increase.

Since the basket structural behavior is governed by the total contents weight, which remains bounded by the initially approved weight, the above assessment on total contents weight adequately demonstrates the basket structural performance. Therefore, the staff has reasonable assurance to conclude that the small variation in the contents weight in each storage location has a negligible effect on the basket stability performance, which provides the basis for the proposed TS change.

3.2.3.2 Design Basis Earthquake Accelerations

The initially approved Technical Specifications (Appendix A) 4.3.1(i) provides that “[t]he maximum design basis earthquake at the ISFSI pad top surface to prevent cask tip-over is equal to, or less than, 0.37g in the horizontal direction and equal to, or less than, 0.25g in the vertical direction.” These earthquake acceleration levels are the design basis site-specific parameters that require verification by the user of the MAGNASTOR® system. The license amendment request proposes, however, to clarify the subject part of the TS to read, “Maximum design basis earthquake accelerations of 0.37g in the horizontal direction (without cask sliding) and 0.25g in the vertical direction at the ISFSI pad top surface do not result in cask tip-over.”

In evaluating the revised TS language, the staff also considers the cask earthquake performance acceptance criteria specified in the second part of TS 4.3.1(i). TS 4.3.1(i) states, “Site-specific cask sliding is permitted with validation by the cask user that the cask does not slide off the pad and that the g-load resulting from the collision of two sliding casks remains to be bounded by the cask tip-over accident condition analysis presented in Chapter 3 of the FSAR.” The revised TS accounts for the cask earthquake performance criteria consistent with guidance provided in Section 3, “Structural Evaluation,” of NUREG-1536. Therefore, the staff concludes that the proposed revision clarifies the provision for implementation by the MAGNASTOR® system user in verifying the site-specific earthquake acceleration parameters.

3.3 Evaluation Findings

On the basis of the above review, the staff has reasonable assurance to conclude that the added design features, including the PWR DF basket and the DFC, will not adversely affect the structural performance of the MAGNASTOR® dry cask storage system to continue to meet the requirements of 10 CFR 72.24(c)(3), 10 CFR 72.44(c), and 10 CFR 72.122(b). Specifically, the structural evaluation demonstrates that the MAGNASTOR® system will continue to meet the relevant requirements as follows:

F3.1 The FSAR describes the SSCs important to safety in sufficient detail to enable an evaluation of the structural performance of the MAGNASTOR system's capability to accommodate the combined loads of the normal, off normal, and accident conditions and the natural phenomena events.

F3.2 The MAGNASTOR system is designed to allow ready retrieval of spent nuclear fuel for further processing or disposal. No normal, or off-normal, conditions analyzed will result in damage to the system that will prevent retrieval of the stored spent nuclear fuel. This finding in the structural review area is contingent upon the acceptability of thermal analyses needed to demonstrate that material temperature limits will not be exceeded, as discussed in Section 4 of this safety evaluation report.

F3.3 The MAGNASTOR system is designed and fabricated so that its structural performance is adequate for maintaining the spent fuel subcritical under normal, off-normal, and credible accident conditions. Additional criticality evaluations are discussed in Section 6 of this safety evaluation report.

4.0 Thermal Evaluation

The goal of the thermal review is to ensure that the MAGNASTOR® storage system components and fuel material temperatures will remain within the allowable values for normal and off-normal conditions and accident events for the newly designed DFCs and DF baskets.

4.1 Cask System Thermal Design

4.1.1 Design Criteria – Damaged Fuel Cans and Damaged Fuel Baskets

For PWR fuel, the MAGNASTOR® design basis heat load is 35.5 kW. The fuel loading in the 37 PWR fuel basket may be up to 37 undamaged PWR fuel assemblies or in the DF basket assembly up to four damaged fuel cans and up to 33 undamaged fuel assemblies. As shown in FSAR Figure 2.2-3 and License Drawing 71160-675, the DFC locations are at the four outer corners of the DF basket assembly. Both the PWR fuel basket and the DF basket assembly can accommodate a uniform heat load of 959 W per assembly, or a preferential loading pattern as shown in FSAR Figure 4.1-1. The preferential loading pattern identified in FSAR Figure 4.1-1 defines three values of heat generation that place the fuel assemblies with the maximum heat generation rate in an intermediate region of fuel storage locations. Analyses are performed using the two-dimensional axisymmetric model with the same fluid resistances and material properties for both the preferential and uniform loading patterns. The applicant found that the maximum fuel temperatures were 5 °F apart due to a localized bounding temperature response due to the localized increased heat generation for the preferential loading configuration.

Thermal evaluations for normal conditions of storage and canister transfer operations are presented in FSAR Section 4.4. The finite element method is used to compute the effective properties for the basket, neutron absorber, and fuel region. The thermal solutions for the concrete cask and transfer cask are obtained using finite element and finite volume methodologies. Thermal models used in the evaluation of normal and transfer conditions are described in FSAR Section 4.4.1. A summary of the thermal evaluation results for normal conditions of storage is provided in Table 4.4-3 for the PWR fuel. The odd numbered FSAR Tables 4.4-5 through Table 4.4-13 contain the maximum fuel cladding temperatures for the different phases of the transfer operations for the PWR cases. The results of the thermal evaluation performed by the applicant for off-normal and accident events are presented in Sections 4.5 and 4.6 of the FSAR, respectively. Comparison of the evaluation results, conducted by the staff, shows that the standard PWR basket evaluation bounds that of the DF basket assembly. The results demonstrate that the calculated temperatures are less than the allowable fuel cladding and component temperatures for all normal (long-term) storage conditions and for short-term events. Therefore, the staff found the description of the cask system thermal design acceptable because the description satisfies the requirements in 10 CFR 72.122(h)(1), 72.122(l), 72.236(b), 72.236(f), 72.236(g), and 72.236(h).

4.2 Thermal Model Specifications

4.2.1 Model Configuration

Analysis models used for the thermal evaluation of the PWR design configurations (with the damaged fuel cans) is described in FSAR Section 4.4. The methodology inherent in the models, stated by the applicant, conservatively reflects the heat transfer performance provided by the MAGNASTOR® design. The designs for the PWR fuel system utilize the same method of passive heat rejection to transfer the decay heat from the fuel assemblies (and the damaged fuel cans, as applicable) to the ambient environment.

The transportable storage canister (TSC) is a closed system, whereas the concrete cask and the transfer cask are open to the environment. Internal to the TSC, decay heat is transferred from the fuel assemblies, or the DFCs, in each of the fuel tubes to the TSC shell by three modes of heat transfer: convection, conduction, and radiation. The fuel baskets designed for PWR fuel assemblies permit the helium backfill gas to flow up the fuel tubes containing the fuel assemblies and carry the heat away from the fuel assemblies.

Note that no helium flow is considered in the basket slots containing damaged fuel cans. The region in the TSC just above the fuel basket allows the helium to flow upward from the fuel tubes to combine and flow through the down corner regions formed between the TSC shell and the basket side weldments. The gas exiting the down corner regions at the bottom of the fuel basket enters a region below the basket tubes. The flow of the helium upward in the fuel basket and downward in the down comer regions is driven by the buoyancy forces created by the effect of the heated helium rising up through the fuel tubes. To increase the buoyancy force, the density of the helium is increased by raising the helium backfill pressure. Since the fuel tubes are full-length carbon steel tubes, they provide a path for conduction of heat. While the tubes are not welded together, the effect of the gap between the tubes is mitigated by the use of the helium backfill. The side and corner weldments of the fuel basket, which support the fuel basket during a side impact, also provide a path of heat conduction. The effective properties for the DF basket assembly are determined using the same methodology as used for the standard PWR basket, except for the modification to the model, as listed:

(1) A 1/4-section model is used as shown in FSAR Figure 4.4-22.
(2) The contents of the DFC locations in the DF basket assembly are conservatively modeled as helium, which has a lower conductivity.
(3) Thermal conductivities of the steel plates forming the basket corner slot in the model are factored to reflect the actual plate thickness.

The damaged fuel (DF) basket assembly corner weldment with thicker carbon steel plates provides a more effective path of heat conduction than does the standard PWR basket assembly. While a gap is considered between the side and corner weldments and the TSC shell for analysis purposes, the heat transfer across the gap is provided by the radiation from the weldments and conduction through the helium gap to the TSC shell. Radiation is also a mode of heat transfer, which allows heat from the interior of the fuel assembly to be transferred to the outer pins of the fuel assembly. Additionally, since the fuel assemblies are assumed by the applicant to be in the center of each fuel tube, radiation also contributes to the heat transfer from each fuel assembly to the fuel tube wall. Radiation is also taken into account for all gaps, such as those between the tubes. Radiation contributes to the heat being transferred from the outer basket surface to the TSC shell. Staff found the description of the models to be acceptable because the description satisfies the requirements in 10 CFR 72.122(h)(1), 72.122(l), 72.236(b), 72.236(f), 72.236(g), and 72.236(h).

4.2.2 Material Properties

Material properties used in the analytical models are separated into two categories. One category represents materials specified in the design that are explicitly represented in the model and are tabulated in FSAR Chapter 8. The second category represents effective properties of the neutron absorbers and fuel region, which are calculated using the thermal models presented in FSAR Section 4.4.1. Staff found the material properties used by the applicant in the thermal analyses to be acceptable based on the requirements stated in 10 CFR 72.236.

4.2.3 Normal Storage Conditions

FSAR Section 4.4 describes the finite element and finite volume methods used to evaluate the thermal performance of MAGNASTOR® for normal conditions of storage. The general-purpose finite element analysis program, ANSYS®, is used to perform analyses requiring radiation and conduction. The computational fluid dynamics (CFD) program FLUENT, which is based on finite volume methods, is used to perform analysis that includes conduction, radiation, and convection. In FLUENT, convection of heat is simulated through the motion of fluid, as well as by the specification of a film coefficient for a surface boundary condition. A two-dimensional (2-D) axisymmetric model is used to perform the thermal evaluation of the concrete cask and the TSC using CFD analyses. The applicant validated their code through the study of mesh sensitivity, mentioned in FSAR Section 4.4.1.5. As shown in FSAR Figure 4.4-1, the 2-D axisymmetric concrete cask and TSC model includes the following:

- Concrete cask, including lid, liner, pedestal and stand;
- Air in the air inlets, the annulus and the air outlet;
- TSC shell, lid and bottom plate;
- Basket with fuel (including damaged fuel cans, as applicable) and neutron absorber; and
- Helium internal to the TSC.

The fuel basket, fuel and neutron absorber are modeled as homogeneous regions with effective properties. The effective thermal conductivities for the TSC internals in the radial and axial directions are determined using the 2-D models as detailed in FSAR Section 4.4.1.2. The 2-D axisymmetric concrete cask and TSC model is used to perform CFD analyses to determine the component temperature, the mass flow rate, velocity and temperature of the airflow in the annulus region, and for the helium flow internal to the TSC. Since the concrete cask and its components are contained in the model, the temperature distributions in the concrete and the concrete cask steel liner are also determined. The models used for the thermal evaluation are explained in greater detail in FSAR Section 4.4.1.1. Staff found the description of the analysis models and the models themselves acceptable based on the requirements stated in 10 CFR 72.122(h)(1), 72.122(l), 72.236(b), 72.236(f), 72.236(g), and 72.236(h).

4.2.4 Transfer Conditions

4.2.4.1 Operations Involving Minimum Cooling Time

Evaluation of TSC Loaded with Damaged Fuel Basket Assembly

The flow resistance for a single zone DF basket assembly is slightly lower than the flow resistance for the standard PWR basket. The thicker side plates forming the basket corner slots for the damaged fuel can enhance the basket assembly conductance in the basket axial direction. Therefore, the thermal analysis results for the standard PWR basket bound the results for the DF basket assembly, as demonstrated by three representative analyses performed for the DF basket assembly for the transfer condition. Maximum fuel temperatures for all three analyses for the DF basket assembly are lower than those for the standard PWR basket. The three analyses are:

(1) For the water phase, the 35.5 kW steady-state case (FLUENT CFD analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell;

(2) For the drying phase, the 25 kW steady-state case (ANSYS analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell;

(3) For the drying phase, the 35.5kW transient case (ANSYS analysis) with helium inside the canister and water in the annulus between the canister and the transfer cask inner shell.

Cases with helium inside the canister are selected because they yield higher fuel temperatures than cases with water inside the canister. Staff reviewed the analysis models and found the description of the analysis models and the models themselves acceptable because the description and the models satisfy the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.2.5 Off-Normal Storage Events

The concrete cask and TSC model described in FSAR Section 4.4.1.1 evaluates the concrete cask and TSC for the off-normal events: severe ambient temperature conditions (106°F (41°C) and -40°F (-40°C)) and the half-blocked air inlets condition. The evaluation of the off-normal events for variations in the ambient temperature only requires a change to the boundary condition temperature. For the half-blocked air inlets condition, the air inlet condition is modified to permit only half of the airflow into the inlet. The design basis heat loads of 35.5 kW are used in the evaluations of the concrete cask and TSC containing PWR fuels.

As shown in FSAR Sections 4.4.1 and 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the DF basket assembly for normal conditions due to the higher thermal conductivity of the DF basket assembly. This conclusion is valid for the off-normal conditions due to higher thermal conductivity. The principal component temperatures for each of the off-normal events, discussed previously, are summarized in tables found in FSAR Section

4.5 along with the allowable temperatures. Note that the maximum fuel cladding temperatures are conservatively used as the maximum fuel basket temperatures. As the tables show, the component temperatures for the concrete cask and TSC containing PWR fuels are within the allowable values for the off-normal storage events. Staff found the descriptions of the off-normal events and the results of the analyses to be acceptable because the descriptions and the results satisfy the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.2.6 Accident Events

FSAR Section 4.6 presents the evaluations of the thermal behavior for design basis accident (DBA) events, which address very low probability events that might occur once during the lifetime of the ISFSI or DBA events that are postulated because their consequences may result in the maximum potential impact on the surrounding environment. Three thermal accident events are evaluated in this section: maximum anticipated heat load, fire accident, and full blockage of the air inlets. The maximum TSC internal pressure for the bounding accident conditions is evaluated in FSAR Section 4.6.4.

As shown in FSAR Sections 4.4.1 and 4.4.3, the analysis results for the standard PWR basket bound the analysis results for the DF basket assembly for normal conditions due to the higher thermal conductivity of the DF basket assembly. This conclusion is valid for the accident conditions for the same reasons. Staff found the descriptions of the accident conditions and the results of the analyses to be acceptable because the descriptions and the results satisfy the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.3 Pressure Analyses

FSAR Sections 4.4.4 and 4.6.4 describe the pressure analyses performed by the applicant. The internal pressure of a TSC containing PWR fuel assemblies is a function of fuel type, burnup, initial enrichment, cool time, fuel condition (failure fraction), presence, or absence of nonfuel hardware, TSC length, and the backfill gases in the TSC. Gases included in the pressure evaluation of a TSC containing PWR fuel include fuel rod fission, decay, backfill gases and integral fuel burnable absorber (IFBA) generated gas, gas generated by the nonfuel hardware components (assembly control components contain boron as the absorber material), and TSC backfill gases. Each of the PWR fuel types is separately evaluated to determine a bounding pressure for a TSC containing PWR fuel assemblies. Evaluations, done by the applicant, are performed for all contents in the standard basket (undamaged fuel) and in the damaged fuel basket configuration. The damaged fuel basket represents a bounding configuration due to the additional volume displacement by the thicker corner weldment plates and the presence of the DFC canisters themselves.

The calculated maximum pressure of 104 psig allows for a 6-psig tolerance on the TSC helium backfill prior to reaching the 110-psig system pressure employed in the FSAR Chapter 3 structural evaluations under normal condition. Significantly, higher-pressure margins exist in the off-normal and accident pressures. Off-normal and accident pressures were calculated at 112 psig (10% fuel failure and off-normal thermal conditions) and 226 psig (100% fuel failure, see FSAR Section 4.6.4) and are conservatively bounded by the 130 psig off-normal and 250 psig accident condition pressures that were employed in the structural calculations. Staff found the pressure analyses, provided by the applicant, acceptable because the analyses satisfy the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.4 Temperature Calculations

The applicant described the component temperature calculations in FSAR Sections 4.4.3 and 4.4.4. The staff found the calculations acceptable because the calculations satisfy the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.4.1 Normal Conditions of Storage: PWR Configuration with DF Basket Assembly

The thermal evaluation for the concrete cask loaded with a TSC containing a DF basket assembly in storage conditions is performed based on configuration concrete cask 3 (CC3) using the 2-D axisymmetric FLUENT CFD models described in FSAR Section 4.4.1.1. Staff considered the following three cases listed by the applicant:

Case 1: The active fuel region is modeled as a single porous zone with a single lumped resistance coefficient. The uniform loading heat generation rate (based on a total heat load of 35.5 kW) is applied to the active fuel region. The calculated maximum fuel temperature is 704°F (373°C).

Case 2: The active fuel region is modeled as two parallel porous zones radially, with a resistance coefficient for the outer zone of 16 basket slots (which include the four-damaged fuel can slots) and a separate resistance coefficient for the inner zone of 21 basket slots. The uniform loading heat generation rate is applied to the active fuel region. The calculated maximum fuel temperature is 707°F (375°C).

Case 3: The active fuel region is modeled the same way as in Case 2. The uniform loading heat generation rate is considered for the standard fuel assemblies. The decay heat is considered to be concentrated at the lower 103 inches of the active fuel region based on a 50% compaction ratio of debris for the four damaged fuel can slots. The calculated maximum fuel temperature is 709°F (376°C).

The maximum fuel temperatures from the Case 1 through Case 3 analyses are lower than the maximum fuel temperature (718°F (381°C)) for the corresponding standard PWR basket, as shown in FSAR Table 4.4-3. Therefore, the standard PWR basket analyses bound those for the damaged fuel basket assembly. This approach is acceptable to the staff because it satisfies the regulatory requirements 10 CFR 72.122 and 10 CFR 72.236.

4.4.2 Transfer Condition

The maximum component temperatures for MAGNASTOR® during the transfer operation are reported in FSAR Section 4.4.3 and Tables 4.4-5 through 4.4-16. The transfer operation is comprised of four separate phases: the water phase, the drying phase, the helium phase, and the TSC loading phase. The only phases considered to be limited by time are vacuum drying of the TSC and the final phase of loading the TSC into the concrete cask. The reason that indefinite time limits are permitted for the water phase, the helium-drying phase, and the helium phase is the normal use of the transfer cask annulus cooling water system, partially submerged loading conditions, or equivalent immersion system. The transfer annulus cooling system is considered an operational convenience, since the transfer cask can be placed back into the spent fuel pool at any point in time during the transfer operation without resulting in thermal shock to the transfer cask system. The annulus cooling water system maintains the canister shell at a temperature significantly lower than the temperature corresponding to the normal conditions of storage. All time-dependent and steady state temperatures are below allowable limits during all transfer phases. This information is presented in the tables mentioned at the beginning of this section.

4.5 Staff Analyses

Staff reviewed the applicant's models and calculation options to assess the adequacy of MAGNASTOR's proposed design and to make certain that the fuel cladding temperature does not exceed values specified in the FSAR. Additionally, staff examined the applicant's ability to apply the necessary boundary conditions, heat loads, and other conditions for each of the respective cases. After staff reviewed the models, verified that the applicant met best practices for the models, implemented modeling assumptions properly, and reviewed the results listed in the FSAR versus what their models generated that did not exceed the fuel cladding maximum limiting temperatures for normal, vacuum drying, off-normal, transfer, and accident conditions; staff has reasonable assurance that the fuel cladding will maintain integrity within the above stated conditions based on the staff's evaluation findings.

4.6 Evaluation Findings

F4.1 Structure, systems and components (SSCs) important to safety are described in sufficient detail in FSAR Chapters 1, 2 and 4 to enable an evaluation of their thermal effectiveness [10 CFR 72.236(b)].

F4.2 The staff has reasonable assurance that the spent fuel cladding will be protected against degradation that leads to gross ruptures by maintaining the clad temperature below maximum allowable limits and by providing an inert environment in the cask cavity [10 CFR 72.122(h)(1)].

F4.3 Based on the staff's review of the applicant's analysis, the staff has reasonable assurance that the MAGNASTOR® system is designed with a heat-removal capability having testability and reliability consistent with its importance to safety.

F4.4 The staff concluded that the thermal design of the MAGNASTOR® system, as described in the FSAR, complies with 10 CFR 72.122 and 10 CFR 72.236, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the MAGNASTOR® system will allow safe storage of spent fuel for a certified life of 40 years. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

5.0 Confinement Evaluation

With the contents revised, the staff reviewed the confinement system to ensure that the confinement features/capabilities are not affected and any radiological releases to the environment are still within the limits established in 10 CFR Part 72. The staff also reviewed the application to determine whether the MAGNASTOR® system meets the acceptance criteria listed in NUREG-1536.

5.1 Confinement System

MAGNASTOR® is a dry storage system consisting of a concrete cask and a welded stainless steel transportable storage canister (TSC) with a welded closure to safely store the spent fuel. TSCs have four configurations designated TSC1 through TSC4. TSC1 and TSC2 include a standard 9-inch thick forged stainless steel closure lid assembly. TSC3 and TSC4 include a composite closure lid assembly consisting of a 4-inch stainless closure lid which is defined as the confinement boundary and a 5-inch thick carbon steel shield plate which is not recognized as the confinement boundary. TSC closure lid lifting holes (2-1/4 inch deep) are machined at the forging top surface. Therefore, the minimum machined thicknesses of the closure lid, (subtracting the depth of machined penetration), are 6-3/4 inches thick for the standard TSC1 and TSC2 closure lid assembly and 1-3/4 inches thick for the composite TSC3 and TSC4 closure lid assembly.

As specified in FSAR Section 7.1.1, the TSC shell is a rolled type 304/304L stainless steel canister joined by full penetration welds and is closed at the bottom end by a circular plate joined by a full penetration weld. The closure lid-to-TSC shell weld is a partial penetration weld examined by liquid penetration (PT) at its root, mid-plane, and final surfaces, in accordance with ISG-18. The closure ring is attached to the lid and shell via two partial penetration welds that have their final surface PT-examined. The closure ring provides the redundant sealing to the confinement system as required by 10 CFR 72.236(e).

The vent and drain port penetrations are closed with inner port covers that are partial-penetration welded with each final surface PT-examined, and both vent and drain port inner cover welds are helium leak tested to verify the absence of helium leakage past the inner port cover welds in the field. Both vent and drain port are further closed with outer port covers that are welded to the closure lid to provide the double weld redundant sealing of the confinement system. The outer port cover weld final surfaces are inspected by PT-examination in the field.

Subsequent to making the closure lid-to-shell weld, but prior to installing the closure ring, the user will perform a hydrostatic pressure test on the TSC vessel with a minimum pressure of 130 psig for a minimum of 10 minutes. The staff confirmed that the minimum test pressure of 130 psig is 125% of the normal operating pressure of 104 psig, in accordance with Subsection NB of the ASME Code.

5.2 Leakage Rate Testing

In order to demonstrate compliance with confinement requirements and dose limits in 10 CFR 72.104 and 10 CFR 72.106, the applicant determined that leakage from the canister systems is not credible. The applicant specified the following tests to verify confinement integrity, such as leak test, liquid penetration test (PT), ultrasonic examination (UT), and pressure tests. The applicant also specified leakage tests for each TSC configuration.

5.2.1 TSC Shell, Bottom Plate, All Joining Confinement Welds, Vent/Drain Port Covers (TSC1~TSC4)

In FSAR Section 7.1.1, the applicant specifies that during fabrication, TSC shell, bottom plate and the joining welds are shop helium leak tested to the leaktight criterion of 1.0 x 10^{-7} ref-cm^3/sec or 2.0x10^{-7} cm^3/sec (helium) and a minimum test sensitivity of 1.0 x 10^{-7} cm^3/sec (helium), in accordance with the ANSI 14.5 leaktight standard using the evacuated envelope test method. The test envelope will be installed around the TSC enclosing all of the TSC shell confinement welds and filled with 99.995% (minimum) pure helium to an acceptance concentration.

The vent and drain port penetrations are closed with inner port covers. The welds of the port covers are helium leak tested. The applicant states the lid-to-shell weld (the closure weld) is excluded from the leak testing but will fabricate and test the welds in accordance with ISG-18.

5.2.2 Composite Closure Lid Assembly (TSC3 and TSC4)

The applicant will update FSAR Sections 7 and 10 to specify that during fabrication, the 4-inch thick closure lid, as a part of the composite closure lid assembly for TSC3 and TSC4, are shop helium leakage tested because of the overlap of partial penetration tapped holes and reduced effective thickness of the composite closure lid due to these partial penetration tapped holes. The helium leakage test of the 4-inch thick TSC3/TSC4 closure lid will be performed alone following completion of all fabrication and machining processes (final diameter, lid and shield plate bolt holes installed, and vent/drain ports machined) but before final assembly with the 5-inch thick shield plate as part of the final acceptance test program. The lid is tested to leaktight criterion of 1.0x10^{-7} ref-cm^3/sec or 2.0x10^{-7} cm^3/sec (helium) and a minimum test sensitivity of 1.0 x 10^{-7} cm^3/sec (helium), in accordance with the ANSI 14.5 leaktight standard, as detailed in FSAR Section 10.

5.2.3 Standard Closure Lid Assembly (TSC1 and TSC2)

(a) <u>Review on Material Characteristics</u>

The applicant did not specify leak testing of the TSC1/TSC2 9-inch thick stainless steel forged closure lid. The applicant described the lid material characteristics and performance to demonstrate that leakage through the material is not credible. Compared to other candidate metals, the stainless steel has excellent resistance to stain or rust due to its chromium content, good corrosion resistance due to its cubic-centered structure and better resistance to cracking and pitting in most environments. These characteristics also prevent permeation of the inert gas (e.g., helium) through the 9-inch thick stainless steel closure lid. The applicant specified that the stainless steel SA240/SA236, used to fabricate the MAGNASTOR® closure lid, will meet the specifications developed by the American Society for Testing and Materials (ASTM) with regard to mechanical properties such as toughness and corrosion resistance.

The applicant stated that the closure lid material is procured, inspected, and accepted in accordance with the ASME Code, Section III, Subsection NB-2000 requirements including the testing specified in NB-2500, which specifies ultrasonic examination (UT) of the forging to detect material discontinuities, voids, and imperfections in the base material. The staff concludes that the required non-destructive evaluation (NDE) testing will help provide quality assurance as one of the proofs in verifying the material property of stainless steel used for the closure lid and demonstrates compliance with 10 CFR 72.236.

(b) Review on Welding Process
When performing the lid-to-shell welding, it is likely that the base metal of the stainless steel closure lid located in the heat affected zone could experience temperature below its melting point, but high enough to change the microstructure and alter the material properties.

The applicant stated that the lid-to-shell weld is a partial penetration weld progressively examined at the root, midplane, and final surface by liquid penetration (PT) examination. Following the NDE of the closure lid-to-shell weld, the TSC cavity is re-flooded and the TSC vessel and closure lid assembly are hydrostatically pressure tested as described in the Operating Procedures and Acceptance Program and as required by the QA program.

The staff reviewed the examination procedure and determined that instead of full penetration welding, the partial penetration shell-to-lid welding should have limited or negligible heat effect to the base metal of the 9-inch thick closure lid. The staff also notes the PT-examination of the final weld surfaces will cover not only the fusion zone of the welds, but also the heat affected zone of the base metal. Therefore, PT should be able to detect any adverse defects near the surface or in the heat affected zone of the closure lid and, therefore, prevent the 9-inch thick closure lid from confinement degradation caused by the welding operation.

(c) Review on Stainless Steel Forging Process
The applicant described in the FSAR that the MAGNASTOR® TSC1/TSC2 fabricates a single piece 9-inch thick stainless steel (SA240/SA336) closure lid by forging process. The forging process has effects on the material that are beneficial to the integrity of the single piece closure lid. The metal flow that occurs during the forging process results in the redistribution of inclusions and crystallographic re-orientation of the grain structure. Inclusions and grains are re-oriented in a direction that is parallel to the exterior surface of the lid (i.e., perpendicular to a potential leak path). This grain orientation reduces the potential for microscopic flaws to extend or grow through the thickness of the closure lid forging.

Forging is a manufacturing process for forming the metal into a desired shape by using localized compressive forces and producing a piece that is stronger than an equivalent cast or machined part. As the lid metal (SA240/SA236) of the MAGNASTOR® cask is shaped by the forging process, its internal grain deforms to follow the general shape of the part without rupture. As a result, the grain is continuous throughout the base metal, giving rise to a lid with improved strength characteristics and reduced micro-porosity. The staff recognizes that the forging process may cause surface defects as a result of excessive working at too low a temperature or at too high a temperature. However, the surface defects should not affect the confinement capability of a 9-inch stainless steel closure lid because the surface defect has a very limited effect on the 9-inch thick lid.

The applicant stated that no fabrication or machining steps, performed on the closure lid, would introduce a potential through thickness leakage path or introduction of a 'stringer' from the TSC cavity to the atmosphere through the closure lid. The staff accepts this statement because when compared to a forging process, stringers are more likely to be produced through plate casting, and orientation of the stringer is perpendicular to the potential leak path developed in the closure lid which prevents gas leakage through the closure lid. In addition, the thickness of the forged lid is 9 inches, which is a significant thickness that provides reasonable assurance that a potential flow through the entire thickness is very unlikely.

(d) Operating Experience/QA Program
The applicant provided an analysis of operating experience and its QA program for the TSC assembly design and maintenance activities for all TSC1-TSC4. The applicant will procure and fabricate the confinement components (including the closure lid) per the requirements of the ASME B&PV Code under NAC's quality assurance program approved by NRC (Docket No. 72-1031). The applicant stated in RAI responses 1 and 2 that the existing operating experience supports a conclusion regarding the integrity of the base material of thick ASME, Section II stainless steel forgings used for confinement closure of the MAGNASTOR® canisters. The applicant stated that more than 250 NAC storage system shield lids (five to seven-inch stainless steel forgings) have been helium leak tested in accordance with ANSI N14.5-1997 methods using an evacuated envelope test. As a result, the helium leak testing has been successfully completed without the detection of a single leakage through the shield lid base material to a minimum leakage test sensitivity of $<1 \times 10^{-7}$ cm^3/sec (helium).

The staff reviewed the applicant's analyses of operating experience and approved quality control procedures, and finds that, compared to the historical testing of 5 to 7 inch thick stainless steel closures of similar characteristics to the TSC1 and TSC-2, the 9-inch thick stainless steel closure lid of TSC1 and TSC2 provide adequate assurance to exhibit no credible leakage at the ANSI-N14.5 leaktight standard.

To ensure the confinement effectiveness and consider the aging effects, the staff notes that the MAGNASTOR® system (TSC1-TSC4) must be designed and fabricated to store the spent fuel safely for a minimum of 20 years and permit maintenance as required. In accordance with maintenance plans described in the Technical Specifications, the cask user must provide sufficient inspection to ascertain that there are no defects that could significantly reduce the confinement effectiveness, in compliance with 10 CFR 72.236.

(e) Confirmatory Analysis (Calculation of Leak Path in MAGNASTOR® casks in Amendment 3)
The staff performed confirmatory analyses to approximate equivalent leak path dimensions that may be associated with various leakage rates and compared them with the grain size and the gap between the grain boundaries of stainless steel. The staff used two extremely conservative cases that the gas in the canister will leak through the leak paths distributed at the 100% surface area (the entire lid surface area) or distributed at 10% surface area of the 9-inch thick stainless steel closure lid. The confirmatory analysis takes many parameters into account (such as decay heat, TSC free volume, helium molecular weight, maximum TSC gas pressure, maximum TSC gas temperature, lid surface area, and lid thickness).

Considering many conservative assumptions (e.g., maximum pressure, maximum temperature, leaktight and greater lid area for leakage (10% and 100%)), the staff concludes that with the cask leaktight, any radiological releases to the environment would still be within the limits specified in 10 CFR 72.104 and 10 CFR 72.106. This conclusion takes into consideration the hypothetical leakage rates and the hypothetical leak path dimensions associated with the natural grain size and the gap between the grain boundaries of stainless steel to provide added confidence. Staff's engineering judgment is that for confinement to limit the release of radioactive material from the canister, the basis for not testing the 9-inch thick metal is the same as the basis for accepting leaktight or dose limits regulated in 10 CFR Part 72 in a practical sense – limiting the leakage path size such that there is no credible leakage of the radioactive material. The material qualification of the 9-inch thick forged stainless steel closure lid in the MAGNASTOR® design provides reasonable assurance to confinement effectiveness in compliance with 10 CFR 72.236(j) and (l).

5.2.4 Confinement Evaluations

Based on the staff's confinement evaluation, the staff concludes that the confinement design of the MAGNASTOR® cask satisfies the confinement requirements of 10 CFR 72.236 under normal, off-normal, and accident conditions.

The staff evaluated the material characteristics, fabrication process, operating experience, defect-related reports, and QA program described by the applicant. The staff also performed confirmatory analyses on hypothetical leakage rates and leak path sizes. The staff considered it acceptable that the standard 9-inch thick forged stainless steel closure lid assembly, with cask heat loads of 35.5 kW for PWR fuel, provides adequate confinement effectiveness and provides reasonable assurance that there is no credible leakage through the closure lid material. The applicant's design is a sufficient alternative approach to helium leak testing. The staff determined that the design, material qualification, and fabrication process of the TSC1/TSC2, 9-inch thick stainless steel forged lid provides reasonable assurance for demonstrating confinement effectiveness of the closure lid in accordance with acceptance criteria in Interim Staff Guidance (ISG)-25 and in compliance with 10 CFR Part 72 regulatory requirements. Staff determined that the configuration and material characteristics of the TSC3/TSC4 4-inch thick composite lids do not provide sufficient evidence to preclude the need for a helium leakage test to demonstrate confinement effectiveness.

The staff notes that this finding is only valid for the specific 9-inch forged steel configuration and cask operating conditions specified for TSC1 and TSC2 of the MAGNASTOR® system. The robust materials characteristics and significant 9-inch thickness provides adequate assurance of no credible leakage. Staff's evaluation does not constitute a generic assessment or approval for precluding helium leakage tests for other types of lid configurations. In addition, the staff reaffirms that the configuration and material characteristics of the base material of the canister walls, bottom plate, and weldments do not preclude the need for helium leakage tests.

<u>Limitations and Conditions in TS and CoC</u>

Specific limitations and conditions are specified for approval of this Amendment and use of the MAGNASTOR® system. These limitations and features are specified in CoC or TS as conditions of use for the MAGNASTOR® system.

1) The TSC shell, bottom plate, all confinement welds, vent and drain port covers of all TSCs and the composite closure lid of TSC3 and TSC4 shall be fabrication helium leak-tested in accordance with ANSI N14.5 to leaktight criterion.
2) The closure lid shall be helium leak-tested during fabrication (in accordance with ANSI N14.5 to leaktight criterion), if it is constructed with a lid thickness less than 9 inches (nominal).

5.3 Evaluation Findings

F5.1 The staff concludes that the design of the confinement system of the MAGNASTOR® Amendment 3 is in compliance with 10 CFR 72.236 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the confinement system design provides reasonable assurance that the MAGNASTOR® system will allow safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, the applicant's analysis, and the staff's confirmatory analysis, and accepted engineering practices.

6.0 Shielding Evaluation

The staff's review considered the acceptance criteria specified in Section 6 of NUREG-1536. The staff's review was performed based on information provided in the MAGNASTOR® FSAR Revision 10B, August 2010; Revision 11A, September 2011; and Revision 11B, October 2011. The following section summarizes the staff's findings and conclusions.

The applicant requests design modification to the MAGNASTOR® dry cask storage system (DCSS) to safely store up to 37 undamaged PWR fuel assemblies with initial enrichments of 1.3 wt% to 5.0 wt% U-235 and burnups of 10 GWd/MTU to 60 GWd/MTU; and to store up to four damaged fuel cans (DFCs) in the DF basket assembly. The DF basket assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. PWR spent fuel assemblies may contain nonfuel hardware (Appendix B Technical Specifications, Table B2-5). The applicant also requests to store nonfuel hardware in PWR assemblies.

Nonfuel hardware components are reactor control element assemblies (e.g., CEAs and RCCAs), burnable poison rod assemblies (e.g., BPRAs and wet annular burnable absorbers [WABAs]), thimble plugs (also referred to as guide tube plugs or flow mixers), neutron source assemblies, and HFRAs.

The MAGNASTOR® system is modified with two transfer cask and three concrete cask configurations. The transfer casks for PWR fuels are made of either carbon steel or stainless steel shells. Concrete casks are designed in a standard shielding configuration with a 1.75-inch liner and an augmented shielding configuration with a 3-inch liner, an increased lid thickness and additional shielding at the air inlets. Canisters may be sealed with either an all stainless steel closure lid or a composite carbon steel and stainless steel lid assembly.

Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. The DFC slots are locations 4, 8, 30 and 34 in FSAR Figure 5.8.12-10. To ensure that the worst-case configuration is considered, the applicant evaluated two damaged fuel scenarios. The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. This scenario is modeled by filling the fuel assembly interstitial volume with UO_2 and increasing the fuel neutron, gamma and n-gamma source consistent with this increase in mass. In a comparison of dose rate profiles for the 37 undamaged fuel assembly results and 33 undamaged and four damaged fuel assemblies, the applicant demonstrates that the damaged fuel model dose rates are less due to the increase in self-shielding from the four damaged fuel assemblies, compensating for the increase in source strength.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end-fitting region of the fuel assembly, filling all the modeled void space. However, no credit is taken for the reduction in the lower end fitting hardware dose rate due to the added UO_2 mass and self-shielding nor for the reduction in fuel mass migrated from the active fuel region. In this case, the transfer cask bottom surface dose rates increase due to the addition of damaged fuel. The transfer cask bottom axial dose rate increase is 35 mrem/hr, increasing the bottom axial dose rate by approximately 0.6 percent. Radial dose rates for PWR fuel increase. Damaged fuel dose rates are computed using the carbon steel transfer cask, as it produces higher dose rates than the stainless steel transfer cask due to the higher density of stainless steel versus carbon steel. Damaged fuel maximum dose rates in the carbon steel transfer cask are summarized in FSAR Table 5.1.3-7. Both of these scenarios are evaluated for the concrete cask. The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. In a comparison of dose rate profiles for the 37-assembly undamaged fuel results and 33 undamaged and four damaged assemblies, the applicant demonstrates that the damaged fuel model dose rates are less due to the increase in self-shielding from the four damaged fuel assemblies compensating for the increase in source strength. In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end-fitting region of the fuel assembly, filling all the modeled void space. In this case, concrete cask inlet dose rates increase due to the addition of damaged fuel. The concrete cask inlet dose rate increase is 38 mrem/hr, increasing the inlet dose rate by approximately 9 percent. Damaged fuel dose rates are computed using the standard concrete cask, as it produces higher dose rates than the augmented shield concrete cask. Damaged fuel maximum dose rates in the standard concrete cask are summarized in FSAR Table 5.1.3-8.

To determine the bounding radiation source terms of the fuel assemblies to be loaded in the MAGNASTOR® system, the spent fuel assemblies are sorted into groups according to the assembly type and fuel and hardware masses. A hypothetical bounding fuel assembly is created for each assembly type. Each hypothetical assembly is based on the maximum fuel and hardware masses and presents a conservative bounding value of fuel and hardware mass of that group. FSAR Table 5.2.3-1 provides the essential characteristics of the fuel assemblies to be loaded in the MAGNASTOR® system for PWR assemblies.

The applicant used the SAS2H sequence of the SCALE 4.4 computer code system to evaluate the source terms of each spent fuel assembly group. The 44GROUPNDF5 library, which is composed primarily of ENDF/B-V cross-sections with limited ENDF/B-VI data for a limited number of isotopes, is employed to improve the calculation accuracy.

The source terms for the various proposed spent fuel assemblies are evaluated for the following ranges:

- Fuel initial enrichment from 1.3 wt% to 4.9 wt%
- Cooling time from 4 years to 90 years (nonfuel hardware is evaluated at cooling times down to 2 years)

For the average assembly burnup from 10 GWd/MTU to 60 GWd/MTU, the applicant added an extra 5% safety margin to the calculated source terms for 60 GWd/MTU for PWR fuels, as approved in previous amendments.

The applicant's source term calculations for non-fuel hardware are based on a maximum three-cycle exposure for BPRAs and a multi-cycle exposure equivalent to 180 GWd/MTU burnup for thimble plugs and reactor control elements (e.g., guide tube plugs and nozzle region hardware). Actual BPRA exposure may be in more than three cycles, but is conservatively modeled by the three-cycle approach (i.e., no down time between additional cycles is included in the model).

Exposure of the stainless steel fuel replacement rods is limited to 32.5 GWd/MTU, as the rods were inserted after at least one cycle of assembly depletion occurred. The steel rods are designed to replace fuel rods that were removed for examination or due to failure. To limit the effects of steel activation on cask dose rates, reconstituted fuel assemblies with activated stainless steel fuel replacement rods may be loaded in any basket location provided the number of replacement rods is limited to five per assembly and one assembly per cask. Unirradiated (i.e., no in-core use) replacement rods are not limited in quantity per assembly or assemblies per cask. HFRAs may be loaded in the basket at a maximum exposure of 4.0 GWd/MTU per HFRA at a minimum cool time of 16 years.

The applicant's shielding analyses used a five-region source term that represents homogenized spent fuel assembly upper and lower fittings, upper and lower plenums, and one active fuel region. The dose rates for the transfer cask and the storage concrete cask are performed using the three-dimensional Monte Carlo method code MCNP5. There is no design basis off-normal or accident event that will affect the shielding performance of the transfer cask.

No auxiliary shielding is considered in the concrete cask shielding evaluation. All components related to the safety performance of the cask are explicitly modeled. The possible radioactive material releases from the contaminants on the surfaces of the TSC are explicitly calculated and included in the dose rate evaluation results. FSAR Table 5.1.3-1 provides a summary of the maximum dose rates at the side, top, and bottom of the transfer cask, and FSAR Table 5.1.3-2 provides a summary of the maximum dose rates at the side and top of the concrete storage cask. FSAR Table 5.1.3-3 lists the bounding payload type at various locations on the transfer cask and the concrete cask where radiation dose rates are evaluated. FSAR Table 5.1.3-7 summarizes the transfer cask maximum dose rates for 35.5 kW PWR damaged fuel. FSAR Table 5.1.5-7 summarizes the concrete cask maximum dose rates for 35.5 kW PWR damaged fuel.

The staff reviewed the assumptions, modeling, and calculations presented in the FSAR and found them acceptable. The evaluation of the shielding and radiation protection design features provides reasonable assurance that the MAGNASTOR® system will provide safe storage of spent fuel. This finding is based on a review that considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, the applicant's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

6.1 Evaluation Findings

F6.1 FSAR Section 6 sufficiently describes the shielding design bases and design criteria for the structures, systems, and components important to safety.

F6.2 The MAGNASTOR® system radiation shielding and confinement features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, 10 CFR 72.106, 10 CFR 72.126, and 10 CFR 72.236(d).

F6.3 The staff concludes that the shielding and radiation protection design features of the MAGNASTOR® system, including the concrete cask, the transfer cask, and the TSC, are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied.

7.0 Criticality Evaluation

Staff reviewed the amendment request to determine whether the MAGNASTOR® system will maintain its contents in a subcritical manner under all credible normal conditions and off-normal accident events encountered during handling, packaging, transfer, and storage. Only those features of the amendment request that affect the criticality safety of the system are discussed in this section. The staff reviewed the MAGNASTOR® criticality safety analysis to ensure that all credible normal, off-normal, and accident conditions have been identified and their potential consequences on criticality considered such that the MAGNASTOR® dry cask storage system meets the regulatory requirements in 10 CFR 72.124 and 10 CFR 72.236.

The staff's conclusions, summarized below, are based on information provided in the MAGNASTOR® FSAR.

7.1 Criticality Design Criteria and Features

The major components of the MAGNASTOR® system are a transportable storage canister (TSC), a concrete storage cask, and a lead-shielded transfer cask. Criticality safety in the system design is provided by a combination of fissile mass controls, geometry control, fixed neutron absorbers in the basket, and for the PWR fuel, dissolved boron in the water used to flood the canister. The TSC contains a basket that holds 37 PWR fuel assemblies. The fixed neutron absorber sheets are attached to the walls of the fuel assembly tubes and are positioned between each of the fuel assemblies in the basket. For PWR fuel, a minimum dissolved boron concentration is maintained during loading and unloading operations depending on the fuel assembly type and the initial enrichment of the fuel loaded.

This amendment includes a new basket assembly design for storing damaged PWR fuel. The damaged fuel (DF) basket assembly can store up to four damaged fuel cans (DFCs) in the four corner basket locations and has a capacity of an additional undamaged PWR fuel assemblies, when using the DFCs. The DFC provides a screened container to prevent gross fissile material release into the TSC cavity from failed fuel rod cladding. 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.

The staff reviewed the applicant's model descriptions and assumptions and finds that they are consistent with the description of the design and contents given in FSAR Chapters 1 and 2.

The staff reviewed FSAR Chapters 1, 2, and 6 of Amendment 3, and verified that the design criteria and features important to criticality safety are clearly identified and adequately described. The staff also verified that the FSAR contains engineering drawings, figures, and tables that are sufficiently detailed to support an in-depth staff evaluation. Based on its review, the staff concludes that the applicant has satisfied the regulatory requirements in 10 CFR 72.24 and 10 CFR 72.236.

Additionally, the staff verified that the design-basis off-normal and postulated accident events would not have an adverse effect on the design features important to criticality safety. FSAR Chapter 3 shows that the basket will remain intact during all normal, off-normal, and accident conditions. Based on the information provided in the FSAR, the staff concludes that the

MAGNASTOR spent fuel dry cask storage system meets the double contingency requirements in 10 CFR 72.124(a).

7.2 Fuel Specifications

The applicant grouped the proposed inventory of allowed spent fuel into generic fuel types and established bounding values on the key parameters for each generic type. This classification resulted in 12 PWR types. Criticality analyses to establish enrichment limits were performed for each generic fuel type.

The fuel rod and assembly specifications that define the allowable contents are located in Appendix B of the Technical Specifications. The allowed contents are limited to fuel that has cladding made from zirconium-based alloys only. Damaged fuel may be stored if contained in a DFC. Damaged fuel is defined in the Technical Specifications as fuel that cannot fulfill its fuel-specific or system-related function. The definition provides further clarification of conditions that preclude the fuel from fulfilling its fuel-specific or system-related function. These conditions include cladding breaches that have the potential for release of a significant amount of fuel particles and impairment of the assembly's structural integrity which would allow reconfiguration of the fuel assembly geometry during the normal, off-normal or accident conditions. Missing fuel rods in an assembly must be replaced by a solid dummy rod of equal or greater displacement before loading. The NRC staff reviewed the FSAR and proposed technical specifications to ensure that the fuel specifications important to criticality safety are included.

7.3 Model Specifications

The original application analysis for the MAGNASTOR® system evaluated storage of undamaged PWR fuel assemblies. This amendment adds damaged fuel to the allowable contents when storing PWR fuel.

The key modeling assumptions used by the applicant are:

(1) undamaged, fresh (unburned) fuel;
(2) fuel pellet density at 96% of theoretical;
(3) all non-fuel components placed into the guide tubes are specifically addressed;
(4) fuel assemblies and the basket do not deform significantly in accidents;
(5) no integral burnable poisons; and
(6) 75% credit for the ^{10}B content in Boral and 90% credit for the ^{10}B content in the borated aluminum and metallic matrix composite (MMC) absorber plates, as was used in the previous analysis.

In addition, the applicant modeled borated plates using conservative thickness tolerances for the PWR absorber plates. Modeling assumptions specific for the analytical damaged fuel models are:

(1) DFC heterogeneous fuel material located axially lined up with the undamaged fuel material, and
(2) tolerances on the 1.125-inch thick DFC inner formed plate and on the 0.750-inch thick DFC outer formed plate are not modeled.

The applicant provided sample input files for calculations related to including damaged fuel in the allowable contents when storing PWR fuel. Staff reviewed the information submitted by the applicant, as required by 10 CFR 72.24, and concluded that the information is adequate for staff evaluation.

7.3.1 Configuration

Using the key modeling assumptions listed in Section 7.3 above, the applicant performed sensitivity analyses to determine the fuel rod, fuel assembly, and basket parameter values that maximize k_{eff}. Sensitivity to variations in the following parameters was evaluated:

- pellet-to-clad gap flooded with borated water and fresh water,
- fuel pellet outer diameter (OD),
- fuel rod OD,
- fuel rod clad thickness,
- fuel rod pitch,
- basket fuel tube cross section and thickness,
- neutron absorber sheet width and thickness,
- eccentric fuel assembly position in the basket tubes,
- water density and partial flooding inside the TSC,
- water density outside the transfer cask,
- presence of non-fuel hardware inserts in the PWR guide tubes, and
- guide tube OD and thickness.

Based the results of these analyses, the applicant determined that a cask with the following conditions attains the most reactive configuration:

- fresh water flooded pellet-to-clad gap,
- fuel assembly with maximum pellet OD,
- fuel assembly with minimum fuel rod OD,
- fuel assembly with minimum clad thickness,
- fuel assembly with maximum fuel rod pitch,
- basket with minimum fuel tube cross section,
- basket with maximum fuel tube thickness,
- basket with maximum poison plate thickness,
- basket with minimum poison plate width,
- all fuel assemblies shifted toward the basket center,
- TSC flooded with full density water, and
- transfer cask reflected with 30cm full density water.

Because the effect of non-fuel inserts in the PWR guide tubes varies depending on the level of dissolved boron in the spent fuel pool water, the applicant performed calculations for both cases of inserts or no inserts and applied the case with the lower allowed enrichment. Since the sensitivity to the guide tube thickness was found to be very small, this dimension is not included in the fuel parameter specifications; however, the number of guide tubes is retained. These bounding conditions are included in the final design calculations used to set limits on the allowed maximum initial enrichments.

Starting with the most reactive basket configuration determined for undamaged fuel, the applicant evaluated various damaged fuel configurations. Each DFC configuration was evaluated with effective ^{10}B contents of 0.036, 0.030, and 0.027 g/cm^2 for the absorber sheets and with and without inserts in the fuel assembly guide tubes. Use of the maximum reactivity configuration for undamaged fuel as the baseline is appropriate because it maintains the most reactive configuration of the 33 undamaged fuel assemblies and minimizes the separation between the damaged fuel assemblies and the rest of the payload.

Maximum enrichments for payloads of 33 undamaged and four damaged PWR fuel assemblies in the MAGNASTOR® system were determined with effective ^{10}B contents of 0.036, 0.030, and 0.027 g/cm^2 for the absorber sheets. Three damaged fuel configurations were evaluated. In the first configuration (undamaged assembly case), undamaged fuel was loaded into a DFC to demonstrate the effect of the additional stainless steel from the DFC and the DFC corner weldments. In the second configuration (unclad array case), damaged fuel was postulated to lose its cladding and the array was modeled at an increased pitch. The maximum size array fills the DFC cross-sectional area. In the third configuration (mixture case), mixtures of fuel and water simulated small fuel rubble inside the DFC. The mixture case modeled a homogenized mixture of fuel and moderator up to various heights of the DFC cavity.

The applicant studied three scenarios with respect to moderator density: preferentially flooded DFC, partially flooded cask, and homogenized fuel/moderator mixture. In the preferentially flooded DFC scenario, the DFC was assumed to vary in moderator density with a wet and dry canister. A study on the effect of moderator density in a cask with homogenized fuel/moderator mixture was also performed to ensure that the homogenized mixture remains under-moderated.

For the undamaged assembly case with all 37 assemblies modeled as undamaged at their limiting enrichments (see FSAR Section 6.7.3.2), the DFC has no statistically significant effect on system reactivity. Similar to results for the undamaged fuel basket evaluations, the presence or absence of the inserts has no statistically significant effect on system criticality safety. However, because the enrichment limits established for the undamaged fuel basket resulted in some enrichment/soluble boron/fuel type combinations exceeding the USL, the applicant reduced the enrichment for these combinations. The maximum required reduction in enrichment for all combinations to remain below the USL is 0.1 wt.% U-235 from the fuel enrichment limits established for the undamaged fuel basket.

The MAGNASTOR® system design allows loading of undamaged fuel assemblies into the four designated DFC locations in the DF basket assembly without the use of a DFC. The difference between this configuration and undamaged fuel in the DFC evaluated previously in this section is the presence of the 0.048-inch thick DFC wall. Given that the 1.125-inch inner wall plate separates DFC content from adjacent assemblies in both models, statistically resolvable reactivity differences was observed between models with and without a DFC. Evaluating each primary array type at 0.036 and 0.027 g/cm^2 boron (^{10}B) concentration in the absorber sheets, with minimum (1500 ppm) and maximum (2500ppm) borated water concentrations, resulted in no statistically significant change in system reactivity. All cases remained under the USL. Loading of undamaged fuel into the four designated DFC locations in the DF basket assembly without a DFC is, therefore, acceptable. This conclusion is acceptable because the 1000 ppm soluble boron suppresses the effect of difference in the boron loadings of poison plates

For the unclad array case, damaged fuel is postulated to lose its cladding and pellets are allowed to separate. As PWR assemblies are typically under moderated, the removal of cladding, in conjunction with pitch variations, has the potential to increase system reactivity. Pellet array pitch is allowed to increase until it fills the DFC opening. Clad removal and pitch modification affects system reactivity by varying moderator between fuel rods, therefore, changing neutron thermalization and utilization, while simultaneously varying the neutron absorber quantity in the form of soluble boron in the moderator. These are offsetting phenomena (i.e., increasing pitch increases the borated moderator quantity between fuel rods, which improves thermalization of fast fission neutron for absorption in the fuel, while also increasing the ^{10}B absorber quantity between rods and thereby reducing thermal neutron flux). As shown in Table 6.7.8-2, at a 2250 ppm soluble boron, the result show that there is no statistically resolvable trend of system reactivity versus various pellet pitch, i.e., the nominal assembly design pitch, the maximum pitch allowed by the DFC opening, or the average pitch between nominal and maximum. As lower soluble boron shifts the trend towards increasing system reactivity as a function of increasing pitch, maximum pitch is applied to the remaining pellet evaluations. Similar to the undamaged fuel assembly in the DFC evaluation, the loose pellets study results in no statistically significant change in system reactivity.

Included in the damaged fuel definition are fuel assemblies with fuel rods removed and not replaced by either fuel rods or inert rods. As the physical change in the system is similar to that of the clad removal and pitch evaluation, i.e., increasing the moderator quantity while adding absorber in the form of soluble boron, with the additional negative reactivity effect of removing fissile material, this configuration is bounded by the reactivity of the undamaged fuel in the basket.

For the mixture case, mixtures were designed to fill various heights of the DFC and simulate small fuel rubble inside the canister. Mixtures were assumed to fill the DFC from the DFC bottom plate up, which places fissile material below the neutron absorber (maximum exposure is less than 3 inches). Conservatively, the water-fuel mixture was modeled not to contain soluble boron. The fuel mixture studies model fuel material at various material fractions, expressed as mixture height (i.e., fuel/water mixture height in DFC). At the lower bound, the material is modeled at a mixture height of 50% of the DFC (50% of DFC cavity height is 214 cm, which presents 40% collapse for a 144-inch [366-cm] typical active fuel height). At the upper bound, the fuel water mixture fills the DFC cavity. Mixtures are evaluated at 10% height increments. Each fuel type is evaluated as a function of mixture height at each effective absorber level, with and without the non-fuel insert in the undamaged fuel guide tube. Sample results for each primary fuel assembly array (e.g., WE15HI) at three of the soluble boron concentrations are listed in Table 6.7.8-5 with effective ^{10}B contents of 0.036 g/cm^2 for the absorber sheet. As demonstrated in this table, variations in the maximum allowed enrichments are within statistical range but do exhibit a slight increase in reactivity resulting from the geometry and material change associated with the debris/mixture in the DFC. Maximum reactivity, allowed enrichments, and percent cavity height are summarized in Table 6.7.8-6 and Table 6.7.8-7 for the 0.036 g/cm^2 ^{10}B absorber with and without insert. Similar tables are constructed for the remaining absorber options to determine a complete matrix of allowable enrichments. With the exception of the BW15H4 hybrid at the 0.027 g/cm^2 ^{10}B effective absorber sheet density and 2500 ppm soluble boron, all loading combinations are found to be below the USL with either no or a 0.1% ^{235}U reduction in initial enrichment. The BW15H4 hybrid required a 0.2 wt.% ^{235}U reduction at the 2500 ppm soluble boron, 0.027 g/cm^2 ^{10}B sheet, state point.

PWR fuel assemblies may include non-fuel 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 chapter. Nonfuel components, such as thimble plugs, may not reach into the active fuel region and do not have a significant effect on system reactivity. Inserts are modeled as neutronically transparent zirconium alloy.

Typically, WE and B&W instruments are accessed from the bottom of the assembly. The instrument tube is, therefore, not readily accessible for loading non-fuel hardware when considering an assembly loaded into a TSC. Therefore, all baseline analysis by the applicant was based on inserts (modeled as zirconium alloy filled tubes) located in the guide tubes with the instrument tube filled by TSC moderator. CE type fuels were excepted from this modeling approach as all five guide tubes (which may also be referred to as four guide tubes and one instrument tube) were filled with zirconium alloy in the "insert" models.

The number of guide tubes in the fuel assembly models ranges from 16 to 24, depending on the array size of the affected assemblies versus a single instrument tube in each assembly. As the baseline analysis resulted in only small differences in reactivity between the insert and no-insert configuration, the addition of one filled tube (removal of moderator containing soluble boron) does not change system reactivity to a statistically resolvable extent. All bounding enrichment, soluble boron, and neutron absorber sheet content combinations were run for each fuel model hybrid with inserts in the guide tubes and with inserts in the guide tube and instrument tube. The results show that inserting zirconium alloy in the guide tube and instrument tube under the insert condition has an insignificant effect on system reactivity and meets system criticality limits.

PWR fuel assemblies may also contain axial end-blankets. These blankets are typically 6-to 8-inch long regions of low enriched or natural uranium oxide. Blankets may be constructed from solid fuel pellets, identical in geometry to fuel "midplane", or be annular in configuration (i.e., contain a central void). Solid pellets of lower than midplane enrichment present less fissile material while not increasing potential moderator volume and therefore lower system reactivity. Annular pellets have the potential to increase system reactivity due to increased unborated moderator under flooded rod conditions. Although the improved moderation may compensate for the reduced fissile material quantity, the blankets are in the axial high neutron leakage basket locations, and the effect on system reactivity is assumed to be negligible. This was confirmed by sample calculations by the applicant using a 12-inch fully (midplane) enriched annular end-blanket WE17H1 hybrid at low and high soluble boron concentrations. Therefore, annular end-blankets represent an allowable MAGNASTOR® payload.

For each of the fuel types, with and without non-fuel inserts in the active fuel region of the undamaged assemblies, several combinations of minimum soluble boron and maximum initial enrichments were determined. The allowable loadings for damaged fuel were documented in Table 6.1.1-6. Table 6.1.1-2 included the allowable loadings for undamaged fuel. Specifications for the loading and unloading of the PWR basket are given in Table B2-4 of the Technical Specifications, Appendix B as a function of initial uranium enrichment and neutron absorber sheet effective areal ^{10}B density.

Based on the results discussed previously, limiting ^{235}U enrichments for effective ^{10}B loadings of 0.036, 0.030 and 0.027 g/cm^2 are summarized in Table 6.7.8-10. The listed enrichments bound undamaged fuel assemblies with and without non-fuel inserts. Non-fuel inserts are not expected to be loaded into DFCs.

Staff reviewed the modeling configuration and assumptions and finds that they are appropriate and consistent with the design described in Chapters 1 and 2 of the FSAR. This finding is based on staff's structural evaluation findings (see SER Section 3) that the basket will be geometrically stable, the fuel will maintain its integrity and will not deform, and that any significant amount of permanent deformation of the fuel basket resulting from accident conditions is localized radially to only a few fuel tubes on the basket periphery and axially to only a small length of the affected fuel tubes.

7.3.2 Material Properties

The applicant's analysis used the material composition values from the SCALE 4.4 library for the stainless steel and carbon steel components in the cask's structure. No changes were made to the material properties as a result of this amendment.

7.4 Criticality Analysis

In general, the applicant's analysis demonstrated that system k-effective was not significantly affected by changes to individual system or fuel assembly parameters. However, changes to combinations of these parameters did significantly affect system reactivity. The applicant captured these effects by using the most reactive combination of parameter changes in the final analysis that is compared against the USL for each hybrid assembly.

7.4.1 Computer Programs

The applicant used the MCNP5 three-dimensional Monte Carlo code with continuous neutron energy cross-sections. The MCNP code was developed by the Los Alamos National Laboratory for performing criticality analyses and is considered to be appropriate for this particular design and these fuel types.

The applicant used the MCNP's SDEF source definition card to ensure proper initial sampling of the fission source and to accelerate code convergence. Furthermore, the statistical error in MCNP is kept within ±0.2%. The applicant also confirmed that all fissile material in the cask was sampled and that the results passed MCNP's built-in statistical checks.

7.4.2 Neutron Multiplication Factor

The applicant performed calculations showing that the MAGNASTOR® system will meet the design criterion of k_{eff} + 2 sigma $\leq$ Upper Sub-critical Limit (USL) when loaded with the allowed contents as specified in the FSAR and proposed Technical Specifications (TS).

The applicant performed final calculations with the parameter values that maximize k_{eff}, and all results were lower than the applicable USL, though a number of assemblies had a maximum k_{eff} that nearly equaled the USL (the margin was less than a single standard deviation). These final calculations also incorporate the modifications to the poison plates (both the attachment scheme and the number of plates present) and the minimum fuel tube pitch (specified in the TS).

7.4.3 Benchmark Comparisons

This amendment did not require any new benchmark analyses.

7.5 Criticality Evaluation Summary

The applicant used three-dimensional calculation models in its criticality analyses. Sketches of the models are given in the FSAR, as discussed above. The models are based on the engineering drawings in the FSAR. The design-basis off-normal and accident events do not affect the design of the cask from a criticality standpoint. Therefore, the calculation models for the normal, off-normal, and accident conditions are the same.

NRC staff used the CSAS/KENO-VI codes in the SCALE suite of analytical codes to perform confirmatory analyses using the 44-group and the 238-group (ENDF/B-V) cross-section sets. The staff's confirmatory analyses included PWR baskets, several fuel types, and several boron concentration and enrichment combinations in order to verify that the damaged fuel configurations were adequately modeled by the applicant. The results of the staff's confirmatory calculations were bounded by or in close agreement with the applicant's results. All of the staff's results fell below the acceptance criterion of k_{eff} less than 0.95.

7.6 Evaluation Findings

The staff concludes that the criticality design features for the MAGNASTOR® spent fuel dry cask storage system are in compliance with the requirements in 10 CFR 72.24, 10 CFR 72.40, 10 CFR 72.124, and 10 CFR 72.236(c). Staff also concludes that the applicable design and acceptance criteria have been satisfied. The evaluation of the criticality safety of the cask design provides reasonable assurance that the MAGNASTOR® spent fuel dry cask storage system will allow safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices. Specifically, the nuclear criticality safety evaluation demonstrates that the MAGNASTOR® spent fuel dry cask storage system will continue to meet the relevant regulatory requirements as follows:

F7.1 Structures, systems, and components important to criticality safety are described in sufficient detail in the FSAR to enable an evaluation of their effectiveness.

F7.2 The cask and its spent fuel transfer systems are designed to be subcritical under all credible conditions.

F7.3 The criticality design is based on favorable geometry, fixed neutron poisons, and soluble poisons of the spent fuel pool. An appraisal of the fixed neutron poisons has shown that they will remain effective for the term requested in the CoC application and there is no credible way for the fixed neutron poisons to significantly degrade during the requested term in the CoC application; therefore, there is no need to provide a positive means to verify their continued efficacy as required by 10 CFR 72.124(b).

F7.4 The analysis and evaluation of the criticality design and performance have demonstrated that the cask will enable the storage of spent fuel for the term requested in the CoC application.

8.0 Materials Evaluation

8.1 Material Selection

Materials of construction are provided in the MAGNASTOR® Final Safety Analysis Report (FSAR) in Sections 1, 2, 3, and 8. Acceptance criteria, testing and maintenance can be found in FSAR Section 10. The staff reviewed the information contained in these sections and the information presented in the FSAR drawings to determine whether the MAGNASTOR® system meets the requirements of 10 CFR 72.122(a), (b), (h) and (I), and 10 CFR 72.236(a),(g) and (h).

8.1.1 Structural Materials

Transportable Storage Canister (TSC):

Structural components of the MAGNASTOR® TSC (shell, bottom plate, closure lid/ring, and port covers) are fabricated from austenitic stainless steel (SS), American Society of Mechanical Engineers (ASME) SA240, Type 304/304L. ASME SA182, Type 304 SS is an acceptable substitute material for the SA240, Type 304 SS for the closure lid material. These types of SS were selected because of their strength, ductility and resistance to corrosion. Further, susceptibility to brittle fracture is negligible as no steep ductile-to-brittle transition temperature is experienced for the range of temperatures expected to be encountered. The staff finds that the materials for the TSC are acceptable and meet regulatory requirements of 10 CFR 72.122(a).

The major materials of construction used in the fabrication of the fuel baskets are as follows: ASME SA 537, Class 1 carbon steel (CS) for the basket weldments, and ASME SA 537, Class 1, CS for the fuel tubes. The CS used in the fuel baskets are selected based on their strength and thermal conductivity. The staff finds that these materials are also acceptable for use in the TSC in accordance with 10 CFR 72.122(a).

The main structural components of the concrete cask are fabricated with reinforced concrete and CS. The concrete cask components are fabricated from American Society for Testing and Materials (ASTM) A36 steel, structural applications, and ASTM A615 reinforcing steel. The concrete to be used for fabrication is ASTM C150 Type II Portland Cement. The staff concludes that the concrete materials meet the requirements of the American Concrete Institute (ACI) 318. Also, the materials comprising the concrete cask are suitable for structural support, shielding, and protection of the TSC from environmental conditions. Staff's conclusions are based on the information provided in the FSAR and the staff's independent evaluation.

Transfer Cask (TC):

The TC is primarily a shielding cask used to handle the TSC. The TC structural components for the inner and outer shells are fabricated from ASTM A588, low alloy steel, while the trunnions and shield doors are primarily fabricated from ASTM A350, low alloy steel. The top and bottom forgings are fabricated from ASTM A516, Grade 70 CS (pressure vessels). These types of steel are common structural materials. The staff finds that these steels are suitable for use in the transfer cask because they satisfy the requirements in 10 CFR 72.122(a).

Note that the shielding of the cask incorporates a multiwall (steel/lead/NS-4-FR/steel) design. NS-4-FR (solid, borated, hydrogenous synthetic polymer with neutron absorption capabilities similar to those of borated water) is an epoxy resin material for neutron shielding applications. The staff finds, based on its evaluation, that this material is acceptable and meets the requirements of 10 CFR 72.122(a).

8.1.2 Nonstructural Materials

Criticality control in the PWR TSC basket is achieved by including neutron absorbers (poisons). Neutron poison plates are composed of borated aluminum (Al) alloy, boron carbide Al metal matrix composite, or Boral. In accordance with FSAR Sections 8, 10 and Appendix A Technical Specification 4.1.1, appropriate qualification and acceptance testing will be used to ensure that the neutron absorbers have the minimum specified boron 10 (^{10}B) loading (content), as well as uniformity and effectiveness for the MAGNASTOR® system.

Neutron absorbers and gamma shields (ASTM B29, Standard Specification for Refined Lead (Pb)) will be fabricated from materials that can perform well under all conditions of service during the license period. The Pb and steel shells of the transfer cask provide shielding between the TSC and the exterior surface of the TC for the attenuation of gamma radiation. The staff finds the neutron absorbers and shielding materials are acceptable based on the above discussion and meets the requirements in 10 CFR 72.124(b).

8.2 Fracture Toughness

The TSC structural material is austenitic stainless steel (SS). In accordance with ASME Code, Section III, Subsection NB, Article NB-2311, these materials do not require testing for fracture toughness.

The fuel basket is comprised of welded tubes and supports primarily fabricated from ASME Code SA537, Class 1, CS. The FSAR states that the fuel basket materials will meet ASME Code, Section III, Subsection NG, Article NG-2300 requirements for impact tests and will be tested in accordance with paragraph NG-2320. The FSAR also states that a procurement/fabrication specification will describe fracture toughness testing of these materials for each heat of material subjected to the equivalent forming/bending process or heat-treated condition. Acceptance values shall be per ASTM A370, Section 26.1, with values meeting the requirements of Table NG-2332(a)-1 at a Lowest Service Temperature (LST) of -40°F (-40°C).

The staff finds that the impact resistance for this component is acceptable for this application, based on the guidance provided in Regulatory Guide (RG) - 7.11. The structural components of the transfer cask are fabricated from low alloy CS selected based on their low-temperature fracture toughness. The nil ductility transition temperature for these steels is established as -40°C (-40°F). Based on RG-7.11, the minimum temperature for use is 40°F above the transition temperature, with no credit taken for heat produced by the contents of the transfer cask.

Consequently, the FSAR states that a minimum ambient temperature of 0°F (-17.8°C) for use of the transfer cask is to be established and administratively controlled by procedure. The staff finds impact testing of transfer cask structural material is not required based on the above discussion, guidance in RG - 7.11 and that the transfer cask will be limited to conditions of operation greater than or equal to 0 °F.

8.3 Applicable Codes and Standards

Code materials conform to acceptable chemical and mechanical properties. The TSC steel components and associated weld filler materials are procured in accordance with the ASME Code, Section III, Subsection NB requirements, except as listed in the Code. The staff finds that the identified codes, standards and proposed alternatives meet the requirements in 10 CFR 72.24(c)(4).

8.4 Material Properties

FSAR Tables 8.3-1 through 8.3-33 provide mechanical and physical property data for the major structural materials, including SS, CS, bolting materials, concrete, and shielding material. Most of the values in the tables were obtained from ASME Code, Section II, Part D; however, some of the values were obtained from other acceptable references. The staff independently verified the temperature-dependent values for the stress allowable, modulus of elasticity, Poisson's ratio, weight density, and coefficient of thermal expansion. The staff also used other technical references to verify material properties (e.g., high burnup fuel cladding). The staff concludes that the material properties are acceptable based on the discussion above and meet the requirements in 10 CFR 72.24(c)(3).

8.5 Corrosion Reactions

FSAR Section 8.10, evaluates whether chemical, galvanic or other reactions among the materials and environment would occur. The staff evaluated whether these contacts could initiate a significant chemical or galvanic reaction that could result in corrosion or combustible gas generation. Pursuant to NRC Bulletin 96-04, a review of the TSC system, its contents and operating environments has been performed to confirm that no operation (e.g., short term loading/unloading or long-term storage) will produce adverse chemical or galvanic reactions.

The staff finds that in this dry, inert environment, the TSC SS components are not expected to react with one another or with the cover gas, since galvanic corrosion requires dissimilar metals and an electrolyte. Further, oxidation or corrosion of the fuel cladding and the TSC internal components will effectively be eliminated during storage due to the inert atmosphere in the TSC. To ensure that the safety hazards associated with the ignition of hydrogen gas are mitigated, the procedures of FSAR Section 9 are employed to monitor the concentration of hydrogen gas during any welding or cutting operations. The staff finds that these procedures are adequate to prevent ignition of any hydrogen gas that may be generated during welding operations. Further, the potential reaction of the Al with the spent fuel pool water will not impact the ability of the neutron absorbers to perform their intended function, as the loss of Al metal is negligible.

8.6 Evaluation Findings

F8.1 The applicant has met the requirements of 10 CFR 72.24(c)(3). The FSAR describes the materials that are used for structures, systems, and components important to safety and the suitability of those materials for their intended functions in sufficient detail to evaluate their effectiveness.

F8.2 The applicant has met the requirements of 10 CFR 72.122(h)(1) and 10 CFR 72.236(h). The design of the TSC and the selection of materials adequately protect the spent fuel cladding against degradation that might otherwise lead to gross rupture. This finding is contingent on the thermal analyses demonstrating that material temperature limits will not be exceeded, as described in Section 4 of this SER.

F8.3 The applicant has met the requirements of 10 CFR 72.236(g). The materials that comprise the TSC will sustain their mechanical properties during all conditions of operation.

F8.4 The applicant has met the requirements of 10 CFR 72.236(h). The TSC employs materials that are compatible with wet and dry spent fuel loading and unloading operations. These materials are not anticipated to degrade over time and/or react with one another during any conditions of storage.

9.0 Operating Procedures Evaluation

9.1 Loading MAGNASTOR®

The applicant added the text, “Up to four damaged fuel cans (DFCs) containing damaged or undamaged PWR fuel assemblies or PWR fuel debris may be loaded in a TSC with a DF basket assembly, as authorized in the Approved Contents provisions of the CoC. Undamaged fuel assemblies may be loaded directly (i.e., without a DFC) into DFC locations in the DF basket assembly.”

9.1.1 Loading and Closing the TSC

This section describes the sequence of operations to load and close the TSC in preparation for transferring the TSC to the concrete cask.

To Step 7 in the sequence the applicant added the following text to the note: “Appendix A” and “(not applicable to the stainless steel MTC2 design)”. The note reads – “The temperature of the transfer cask (surrounding ambient air temperature) must be verified to be at or above the minimum operating temperature of 0 °F, per Section 4.3.1.f of Appendix A of the Technical Specifications (not applicable to the stainless steel MTC2 design).”

To Step 8 in the sequence, the applicant added the word “optional” to the text. The note reads – “An optional protective cover, attached to the bottom of the transfer cask, may be used to prevent imbedding contaminated particles in the shield doors and door rails.” Since the shielding design of the cask does not take credit for this protective cover, the staff determined that this is good ALARA practice but the use of it is not required.

The applicant added two new notes to Step 15 in the sequence. The first note reads – “Up to four DFCs containing authorized PWR contents may be loaded in a TSC with a DF Basket Assembly. A DFC spacer is required to be positioned in the designated DF Basket Assembly corner locations for the shorter length DFCs. Independently, visually verify proper placement and correct orientation of each required DFC spacer.” The second note to Step 15 reads – “At the option of the user, install fuel assembly spacers for the axial positioning of the PWR fuel assembly types to be loaded. Verify spacer identification and install fuel spacers in each intended fuel loading location based on the fuel spacer plan prepared, which is based on the fuel assembly inventory and nonfuel hardware to be loaded. Independently, visually verify proper placement and correct orientation of each required fuel spacer”.

The applicant added the text “(and DFC, as applicable)” to Step 16 and changed “identification” to “identifications.” Step 16 reads – “Visually verify the fuel assembly (and DFC, as applicable) identifications to confirm the serial numbers match the approved fuel-loading pattern.”

The applicant added Caution text to Step 20 in the sequence: “Caution: Following closure lid installation, there is a thermal time limit of 19 hours to begin the Auxiliary Circulating Water System (ACWS), or approved alternative annulus flow system operation, and to begin temperature measurement of the MTC annulus outlet flow to verify MTC outlet temperature is maintained <113 °F. If ACWS flow cannot be initiated in the time allowed, return the MTC to the spent fuel pool and remove the closure lid to allow cooling by the spent fuel pool water."

The applicant revised Step 28 of the sequence to read, "Install the annulus circulating water cooling system, or alternative annulus flush/cooling system, to the lower and upper annulus fill lines."

The applicant's editorial change to the note to Step 29 consisted of changing the text in the first sentence from "completion" to "initiation". The third sentence was also revised. "(Step 29: Initiate clean water flow into the transfer cask lower fill lines with annulus water discharging through the upper fill lines. Ensure water flow is maintained to keep the outlet water temperature ≤113 °F.)" The revised first sentence in the note reads, "With the annulus circulating water cooling system operating, there is no time limit through initiation of the draining of the TSC. However, if the circulating water cooling system is not utilized or becomes nonoperational, measure the cavity water temperature every 2 hours. If TSC preparation operations through draining are not completed prior to the cavity water temperature reaching 200 °F, a cooling water flow will be established through the cavity to lower the water temperature to <130 °F prior to the start of draining, or the TSC shall be returned to the spent fuel pool within 2 hours and maintained with the TSC submerged for a minimum cooling period of 24 hours, or the annulus circulating water cooling system operation is initiated."

The word "female" was removed from the first and second sentences of Step 33 of the sequence to read, "Insert the drain line with a quick-connector attached through the drain port opening and into the basket drain port sleeve. Remove the quick-disconnect and any contaminated water displaced from the cavity."

The order of Steps 45 and 46 were reversed and the text "and allows venting of gases from the cavity" was added to the new Step 46. Step 45 reads, "Perform visual and liquid penetrant (PT) examinations of the root pass and record the results." Step 46 reads, "Remove the H_2 detector from the vent line while ensuring the TSC cavity vent line remains installed and allows venting of gases from the cavity."

The applicant added a new note to Step 50, "(Install and tack the closure ring in position in the closure lid-to-TSC shell weld groove.)". The Note reads, "Depending on the operational loading procedure and intended minimum helium backfill time (per LCO 3.1.1) to be utilized, the closure ring installation, welding and NDE sequence can be performed following final helium mass backfill (i.e., after Step 60)."

The modified note to Step 52, "(Remove the water from the TSC using one of the following methods: drain down using a suction pump with a pressurized helium cover gas; or blow down using pressurized helium gas. Ensure the totalizer in the drain line is reset to zero prior to the start of draining.)" reads as follows: "Note: Fuel rods shall not be exposed to air during canister draining operations. Record the start time of TSC draining operations. The maximum drying times of LCO 3.1.1 are based on the total time from start of TSC draining through completion of helium backfilling of the TSC cavity."

The applicant modified the notes to Step 59, "(Dry the TSC cavity using vacuum drying methods as follows.)" by adding the text "or equivalent annulus cooling/flush system" to the first note; and changed the first sentence of the third note from "7 bar, gauge" to "103 psig". Note 1 reads: "Ensure heat load dependent vacuum drying time limits are not exceeded so that fuel cladding temperatures are maintained below 752 °F. Vacuum drying cycle time limits in LCO 3.1.1 are based on utilizing the annulus circulating water cooling system or equivalent annulus cooling/flush system”. Note 3 reads: “If the dryness verification is not met within the first vacuum drying cycle time as defined in LCO 3.1.1, the TSC shall be backfilled with helium to 103 psig and cooled by the annulus circulating water cooling system or by placement in the spent fuel pool for a 24-hour (+1, -0) period. After the cooling period, subsequent drying cycle operations can continue for the times indicated in LCO 3.1.1. Drying cycles and cooling periods may be continued until the TSC cavity passes the dryness verification per LCO 3.1.1. For fuel burnup greater than 45 GWd/MTU, the number of cooling cycles is limited to ten.”

In Step 60 c, the text “100 (+5, -0) psig” was changed to “90 (+5, -0) psig.” Step 60 c now reads “Set the helium bottle regulator to 90 (+5,-0) psig.”

Step 69, “The annulus circulating water cooling system or equivalent annulus cooling/flush system will be utilized throughout the TSC closing operations until the minimum helium backfill time is satisfied (see LCO 3.1.1). Drain the TSC/transfer cask annulus by stopping annulus circulating water flow to the annulus and connecting one or more drain lines to the lower annulus fill ports. Once the annulus is drained, deflate the top and bottom annulus seals. Note the time the annulus circulating water cooling system flow is terminated. Remove the temporary plugs or ensure that a minimum of four annulus fill lines are open in the base of the transfer cask” was modified.” The first sentence was made into two sentences and the first sentence was revised throughout. A new last sentence was added. In the note, the first sentence was deleted “or completing the helium backfill if the annulus circulating water cooling system is not used” and two new sentences for clarity were added to the note. The note now reads, “The time duration of the sequence of operations from stopping the annulus circulating water cooling system through completion of TSC transfer into the concrete cask shall not exceed the transfer time limits in LCO 3.1.1. If the TSC transfer to the concrete cask cannot be completed in the defined time period, the transfer operation will be suspended and the TSC shall be cooled down for a minimum of six hours prior to restarting minimum helium backfill cooling time and TSC transfer operations. The second, and subsequent, minimum helium backfill time and maximum TSC transfer time shall be limited to the heat load specific cooling and specific transfer times in the maximum TSC transfer Tables 1.B and 1.D of LCO 3.1.1. For PWR fuel, the 24-hour minimum helium backfill time is followed by a maximum TSC transfer time of 48 hours for heat loads ≤ 25 kW or 22 hours for heat loads ≤ 35.5 kW.”

The note “Utilize high temperature-resistant slings (≤ 350 °F)” was added to Step 71, “(Install the six swivel hoist rings into the six threaded holes in the closure lid if TSC transfer is to be performed by two sets of redundant slings. Torque the hoist rings to the manufacturer's recommended value.)”

9.1.2 Transporting and Placing the Loaded Concrete Cask

This FSAR section describes the general procedures for moving a loaded concrete cask to the ISFSI pad using either a vertical cask transporter or a flat-bed transport vehicle.

9.1.2.1 Flat-bed Transport Vehicle Loaded with the Closed Concrete Cask

The applicant added a note to Step 17: “Lower the concrete cask into position by deflating and removing the four air pads. Note: Ensure that air pads are not installed longer than eight hours to complete the concrete cask transfer.”

Table 9.1-2 Threaded Component Torque Values

The applicant revised the torque values for threaded components in Table 9.1-2.

9.2 Removing the Loaded TSC from a Concrete Cask

The applicant added new notes to Steps 3 and 6, as shown below.

Step 3: For concrete casks to be transported on a flat-bed vehicle, install an air pad rig set in the inlets. Inflate the air pads and move concrete cask onto the vehicle deck.)

Note: Ensure that air pads are not installed longer than eight hours to complete concrete cask transfer.

Step 6: Install the six hoist rings into the canister closure lid threaded holes. Remove shield ring, if installed.

Note: Utilize high temperature-resistant slings (≤ 350 °F).

The applicant revised the last two sentences of the following paragraph throughout: "After the transfer cask with the loaded TSC is in, or adjacent to, the facility, the operational sequence to load another concrete cask is performed in accordance with the procedures in Section 9.1.2. Note that the amount of time that a loaded TSC can remain in the transfer cask without cooling is limited to 11 hours from the time the TSC is removed from the concrete cask. Internal or external cooling of the TSC is required to be initiated within 11 hours as described in Section 9.3."

9.3 Wet Unloading a TSC

The applicant added a new note to Step 12: "Attach the cooldown system to the vent and drain connections. Note: Initial TSC cooling can be provided by an external TSC cooling system prior to port cover removal in order to satisfy the 11-hour maximum transfer time without cooling operations."

The applicant added the text "or equivalent annulus cooling/flush system" to the note of Step 17: "Terminate cooling water flow and disconnect the cooldown system from the drain and vent ports. Install a vent line to the vent port. Note: Cooling of the TSC using the annulus circulating water system or equivalent annulus cooling/flush system may be required to assure cavity water boiling will not occur during closure lid weld removal operations per Section 9.1.1."

9.4 Evaluation Findings

The staff concludes that the generic procedures and guidance for the operation of the MAGNASTOR® system are in compliance with 10 CFR Part 72 (i.e., 10 CFR 72.104(b), (c); 10 CFR 72.122(f), (h)(1), and (l); 10 CFR 72.212(b)(9); 10 CFR 72.234(f); 10 CFR 72.236(c); and 10 CFR 72.236(h), and (i)) and that the applicable acceptance criteria have been satisfied. The evaluation of the operating procedure descriptions provided in the FSAR offers reasonable assurance that the cask will enable safe storage of spent fuel. This finding is based on a review that considered the regulations, appropriate regulatory guides, applicable codes and standards, and accepted practices.

The applicant did not provide details for loading the damaged fuel into the Damaged Fuel Can in the FSAR. The staff considers that the operation of canning damaged fuel may be performed before the ISFSI loading campaign. Therefore, licensees can develop the procedures for the canning operation separately, as needed.

F9.1 The MAGNASTOR® system is compatible with wet loading and unloading. General procedure descriptions for these operations are summarized in Chapter 9 of the applicant's FSAR. Detailed procedures will need to be developed and evaluated on a site-specific basis.

F9.2 The content of the general operating procedures described in the FSAR are adequate to protect health and minimize damage to life and property. Detailed procedures will need to be developed and approved on a site-specific basis.

F9.3 The radiation protection chapter of this SER assesses the operational restrictions to meet the limits of 10 CFR Part 20. Additional site-specific restrictions may also be established by the site licensee.

10.0 Acceptance Tests and Maintenance Program Evaluation

10.1 Acceptance Criteria

The applicant made editorial changes in this section and added a new paragraph for load testing of the damaged fuel can.

10.1.1 Visual Inspection and Nondestructive Examination

Steps a) through n) of FSAR Section 10.1.1 outline the fabrication controls and inspections to be performed to assure compliance with the FSAR and the license drawings. Editorial changes made by the applicant to Step i) involved changing “fuel basket and basket supports” to “fuel baskets, DFCs and basket supports.”

Step i) now reads, “Visual examinations of the welds of the fuel baskets, DFCs and basket supports shall be performed in accordance with ASME Code, Section V, Articles 1 and 9, with acceptance per Section III, Subsection NG, Article NG-5360. The fuel tube welds shall be magnetic particle examined (MT) in accordance with ASME Code, Section V, Articles 1, 7 and 25, with acceptance criteria per Section III, Subsection NG, Article NG-5340. Repairs to fuel basket welds shall be performed in accordance with ASME Code, Section III, Subsection NG, Article NG-4450, and the welds reinspected per the original acceptance criteria applicable to the examination method.”

10.1.2 Structural and Pressure Tests

10.1.2.1 Load Testing of Damaged Fuel Can (DFC)

The new FSAR Section (10.1.2.4) describes how to qualify the design of the MAGNASTOR® DFC. The first DFC to be provided to a user shall be load tested to 150% of the total weight of the DFC plus the heaviest contents to be loaded in the DFC. The test load on the DFC shall be applied and held for a minimum of 10 minutes. Following completion of the load test, all load bearing welds and surfaces shall be visually inspected for permanent deformation, galling or cracking. Load bearing welds shall be inspected using liquid penetrant examination in accordance with ASME Code, Section V, Article 6. Acceptance criteria shall be in accordance with ASME Code, Section III, NG-5350.

Any evidence of permanent deformation, cracking or galling of load bearing surfaces, or unacceptable liquid penetrant examination results shall be cause for rejection, repair, reperformance of the load test and reexamination of the DFC.

10.1.2.1 Cask Identification

The applicant performed an editorial change to FSAR Section 10.1.8. The second sentence was changed by adding “system” to the sentence, “Each concrete cask will additionally be marked for empty system weight and date of loading.”

10.2 Maintenance Program

In FSAR Table 10.2-1, the frequency for the visual inspection of the MTC1 transfer cask in the MAGNASTOR® maintenance program schedule was changed to quarterly while transfer cask is in operation, or prior to returning the transfer cask to service.

10.3 Evaluation Findings

The staff concludes that the acceptance tests and maintenance program for the MAGNASTOR® system are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the acceptance tests and maintenance program provides reasonable assurance that the cask will allow safe storage of spent fuel throughout its licensed or certified term. This finding is reached on the basis of a review that considered appropriate regulatory guides, applicable codes and standards, accepted practices, and the regulation itself (i.e., 10 CFR 72.82(d); 10 CFR 72.122(a), (f); and 10 CFR 72.236(g), (j), (k) and (l)).

F10.1 FSAR Chapter 10 describes the applicant's proposed program for preoperational testing and initial operations of the MAGNASTOR® system. FSAR Chapter 10 discusses the proposed maintenance program.

F10.2 The licensee will examine and/or test the MAGNASTOR® system to ensure that it does not exhibit any defects that could significantly reduce its confinement effectiveness. Chapter 10 of the FSAR describes this inspection and testing.

F10.3 The applicant/licensee will mark the DSS with a data plate indicating its model number, unique identification number, and empty weight. Drawing 71160-556, Rev 2 (Detail 18) in FSAR Chapter 1 illustrates this plate data.

11.0 Radiation Protection Evaluation

11.1 Estimated Dose Due to Loading Operations

In FSAR Section 11.3.1, the applicant added a new sentence to the first paragraph that reads, "Similarly, PWR exposures presented for undamaged fuel bound those of damaged fuel due to the negligible contribution from damaged fuel to cask surface dose rates near the top of the cask, which is the predominant exposure location for accumulation of occupational dose." The staff did not make in-depth assessment on the accuracy of this determination because the difference is not safety significant.

11.2 Estimated Dose Due to Remote Operations

No change was made in this section of the FSAR.

11.3 Evaluation Findings

The staff reviewed the changes in radiation protection presented in the FSAR and finds that these changes are editorial and they have no adverse impact to safety of the cask design.

12.0 Accident Analysis Evaluation

12.1 Off-Normal Events

12.1.1 Severe Ambient Temperature Events (106°F and -40°F)

12.1.1.1 Analysis of Severe Ambient Temperature Event

The following new paragraph was added to FSAR Section 12.1.1.3. "As shown in Section 4.4.1 and Section 4.4.3, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons the temperature results for the severe ambient temperature events are also bounded."

12.1.2 Blockage of One-Half of the Air Inlets

12.1.2.1 Analysis of One-Half of the Air Inlets Blockage Event

The following new paragraph was added to FSAR Section 12.1.2.3. "As shown in Section 4.4.1 and Section 4.4.3 of the FSAR, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons the temperature results for the blockage of one-half of the air inlets event are also bounded."

12.2 Accidents and Natural Phenomena

12.2.1 Accident Pressurization

12.2.1.1 Analysis of Accident Pressurization

Analysis of this accident involves calculation of the maximum TSC internal pressure and the resulting stresses. The maximum TSC pressure is calculated by adding the releasable quantity of fill and fission gas in the fuel assemblies, BPRA gases, and the subsequent calculation of pressure in the TSC, if these gases are added to the helium backfill pressure already present in the TSC (see Section 4.6). The analysis shows that the maximum TSC pressure for the 100% fuel failure assumption is 226 psig (PWR)." The TSC pressure for the 100% fuel failure was changed from 201 psig to 226 psig.

12.2.2 Fire Accident

12.2.2.1 Analysis of Fire

The following new paragraph was added to FSAR Section 12.2.6.3. "As shown in Section 4.4.1 and Section 4.4.3 of the FSAR, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons the temperature results for the fire accident condition are also bounded."

12.2.3 Maximum Anticipated Heat Load (133°F Ambient Temperature)

12.2.3.1 Analysis of Maximum Anticipated Heat Load

The following new paragraph was added to FSAR Section 12.2.7.3. "As shown in Section 4.4.1 and Section 4.4.3 of the FSAR, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons the temperature results for the maximum anticipated heat load event are also bounded."

12.2.4 Full Blockage of the Concrete Cask Air Inlets

12.2.4.1 Analysis of Full Blockage

The following new paragraph was added to FSAR Section 12.2.13.3. "As shown in Section 4.4.1 and Section 4.4.3 of the FSAR, the thermal analysis temperature results for the standard PWR basket bound the temperature results for the damaged fuel basket for normal operating conditions due to the higher thermal conductivity of the damaged fuel basket. For the same reasons the temperature results for the full blockage of the concrete cask air inlets event are also bounded."

12.3 Evaluation Findings

The staff concludes that the accident design criteria for the MAGNASTOR® system are in compliance with 10 CFR 72.122, 10 CFR 72.124, and 10 CFR 72.236, the design basis accidents and acceptance criterion. The applicant's accident evaluation of the cask adequately demonstrates that it will provide for safe storage of SNF during design basis accidents. This finding is reached on the basis of a review that considered independent confirmatory calculations, the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

F12.1 Tables 13.2-13.4 in Chapter 13 of the SER list the changes to the Technical Specifications for the MAGNASTOR® system.

13.0 Technical Specifications and Operating Controls and Limits Evaluation

Listed below are the changes to the Technical Specifications, Appendix A and Appendix B, of MAGNASTOR® FSAR, Revision 10B, 11A, 11B and 12A. In accordance with the proposed Appendix A and Appendix B Technical Specification changes, Appendix C, Technical Specification Bases for the MAGNASTOR® system, Chapter 13 of the MAGNASTOR® FSAR (including the Table of Contents), is being revised as follows:

TABLE 13.1 – Changes to Chapter 13 of the MAGNASTOR® FSAR

Page	Change
13 C-1	Section 1.0, 1st paragraph – added "and the approved contents provided in Appendix B"
13 C-2	Section 2.1, BACKGROUND – added new 1st paragraph to describe system contents; 2nd paragraph, 1st sentence – revised to capitalize definitions used; 2nd sentence – changed "fuel" to "SNF"; last paragraph – changed "Table 2-1 and 2-8" to "Tables B2-1 through B2-24"; APPLICABLE SAFETY ANALYSES – changed "fuel" to "SNF" in two places
13 C-3	APPROVED CONTENTS – added "2.1.1"; 1st paragraph, 1st, 2nd & 3rd sentences – changed "fuel" to "SNF" in each sentence; 3rd sentence – changed "Tables 2-2 through 2-7 and Tables 2-9 through 2-12" to "Tables B2-2 through B2-8 and Tables B2-10 through B2-24"; added new Section 2.1.2; APPROVED CONTENT LIMITS AND VIOLATIONS, 1st paragraph – changed "fuel" to "SNF" in four places; 2nd paragraph, 1st sentence – added "Operations Center"
13 C-12	LCO, 2nd paragraph, 1st sentence – revised throughout; 2nd sentence – changed "these Tables" to "Table 1.B and 1D"; last sentence – changed "second and fourth Tables of Section 1 limits" to "Table 1 .B and 1D values for maximum transfer time limits"
13 C-17	ACTIONS – added "AND"
13 C-19	Section 3.2.1, BACKGROUND, 1st paragraph – capitalized "NONFUEL HARDWARE"; APPLICABLE SAFETY ANALYSIS – changed "fuel" to "SNF" in two places; LCO, 1st paragraph – changed "fuel" to "SNF"; 2nd paragraph – changed "fuel" to "SNF"
13 C-20	APPLICABILITY – changed "fuel" to "SNF"; ACTIONS, 2nd paragraph – changed "fuel" to "SNF"; added "AND"; SURVEILLANCE REQUIREMENTS – CHANGED "fuel" to "SNF" & deleted "requiring boron credit"
13 C-21	SURVEILLANCE REQUIREMENTS, last paragraph – changed "fuel" to "SNF" in two places
13 C-23	ACTIONS, A.1 – changed "fuel" to "SNF" in four places; added "AND"; A.2 – changed "fuel" to "SNF"
13 C-24	SURVEILLANCE REQUIREMENTS - changed "beginning" to "commencement"

TABLE 13.2 Technical Specifications, Appendix A: Proposed Changes

Page	Change
Global	Updated the footer to Amendment 3
Global	Added “continued” at end of page, where appropriate
A-1	Updated Amendment 2 to Amendment 3
A-2	Updated table of contents page numbers due to text flow changes
A1-1	Deleted definition of “Assembly Defect”; “Burnup” definition revised throughout; added “a)” and “b)”
A1-1	Added definition of Composite Closure Lid
A1-2	For “Damaged Fuel” definition, made SPENT NUCLEAR FUEL all caps; item 2, added “SNF” & “stainless steel or zirconium”; note after item 3.3, added “SNF”; note after item 4, capitalized BREACHED SPENT FUEL RODs & added “SPENT”; deleted old item 5 & added a new one to describe FUEL DEBRIS
A1-3	Added definitions of “Damaged Fuel Can (DFC)” & “Fuel Debris”; deleted definition of “Intact Fuel (Assembly or Rod)”; for “Loading Operations,” changed to read: “end when the TSC is lowered into a CONCRETE CASK”; for “MAGNASTOR SYSTEM, added “(MAGNASTOR)” and revised definition throughout
A1-4	Added definition of “Nonfuel Hardware”
A1-5	Added definition of “Spent Nuclear Fuel (SNF)”; deleted definition of “Standard Fuel”; revised “Storage Operations” definition throughout; revised “Transportable Storage Canister (TSC)” definition throughout
A1-6	For “Undamaged Fuel” definition, changed “spent nuclear fuel” to “SNF” in two places; capitalized BREACHED SPENT FUEL RODS; “Unloading Operations” definition revised throughout
A3-3	Changed “duration from” to “durations covering”
A3-3 thru A3-4	LCO 3.1.1, Transportable Storage Canister (TSC) – revised throughout
A3-6	Removed Condition D, including associated required actions and completion times
A3-7	Removed Surveillance Requirement SR 3.1.1.3, including frequency
A3-12	SR 3.3.1.1 – “Frequency” column, inserted “before or after placement”
A4-1	4.1.1 – added new Note after item d)
A4-2	First line – added “carbon steel or stainless”
A4-2	4.1.4 – “vent and drain port covers of TSCs (TSC1-TSC4) and the composite closure lid of TSC3 and TSC4” has been deleted and “COMPOSITE CLOSURE LID” has been added to the first sentence. In the second sentence, “of TSC1 and TSC2” has been deleted, and “(nominal)” has been added.
A4-3	4.3.1 – item d), changed “fuel tank” to “fuel tank(s)” & added “a total” to last line; item f), added new 2nd sentence; item i), added “without cask sliding” & deleted “or less than” in two places
A4-4	Added “or for utilizing an external crane structure integral to a 10 CFR 50 licensed facility”
A4-6	4.4 – item b., deleted “flammable liquid” and added “fuel”
A5-1	Section 5.2 – item a., added new 2nd sentence; item c., first sentence, inserted “including TRANSFER OPERATIONS”
A5-3	Section 5.2 – item h., deleted “flammable liquid” and added “fuel”

TABLE 13.3 Editorial Changes Based On As-Published Amendment 2

Page	Change
A1-1	Editorial correction – Added missing subsection numbering 1.1
A1-7	Editorial correction – Added missing subsection numbering 1.2
A1-9	Editorial correction – Added missing subsection numbering 1.3
A1-13	Editorial correction – Added missing subsection numbering 1.4
A4-2	Editorial correction – Added missing subsection numbering 4.2 and added "(continued)" at the end of the page

TABLE 13.4 Proposed Technical Specifications, Appendix B, Changes

Page	Change
Global	Updated the footer to Amendment 3
Global	Added “continued” at end of page, where appropriate
B-1	Updated Amendment 2 to Amendment 3
B-2	Updated table of contents page numbers due to new figures, Table B2-5 title change, and text flow changes
B1-1	Replaced former first sentence with a new paragraph describing MAGNASTOR SYSTEM allowable contents
B2-1	Revised throughout
B2-2	Revised throughout to add “SNF”; item “c”, added “1)” for preferential loading and added “2) Uniform Loading: ≤ 959 watts”; updated item “f” to “Weight Per Storage Location (lbs.)” and changed weight value, and added, “SNF assembly”; added item “g” to define total canister contents weight
B2-3	Revised items “C.”, “D.”, “E.”, “F.”, and “G.” throughout; added items “H.”, “I.”, and “J.”
B2-4 thru B2-6	Table B2-1 – added three new pages to table to describe the TSC with DF Basket Assembly
B2-7	Updated Table B2-2 by replacing values on “Max Weight Per Storage Location” row with “See Note 1”; added new Note 1; deleted third bullet
B2-8	Added Note below Table B2-3
B2-10	Table B2-5 – revised table title and table column titles; added “SNF” to Note in four places
B2-11	Tables B2-6 and B2-7 – revised table titles; Table B2-8, first column, changed “(see Figure B2-1)” to “(see Figure B2-2)”
B2-12	Figure B2-1 – added new figure to depict PWR basket schematic
B2-13	Figure B2-2 – revised figure title and number & added note under figure
B2-14	Figure B2-3 – added new figure to show schematic of DF basket assembly
B2-15 thru B2-16	Table B2-9 – revised throughout
B2-17	Table B2-10 – revised table title
B2-18	Table B2-11 – revised table title & footnote 1; added note for Amendment 2 changes
B2-19	Table B2-12 – revised table title
B2-22	Figure B2-6 – revised figure number
B2-23	Table B2-13 – added “SNF” to table title**;** Table B2-14 – added “SNF” to table title

Table B2-4 was modified to include two sections. The upper section’s title was changed to "TSC with Undamaged PWR Fuel Basket Assembly Max. Initial Enrichment (wt% 235U)" from "Max. Initial Enrichment (wt% 235U)". The bottom section is titled "TSC with Damaged PWR Fuel Basket Assembly Max. Initial Enrichment (wt% 235U)". For the upper section of the revised table, the first 5 entries starting from the top of column 3, which is for an absorber with 0.036 ^{10}B g/cm^2 and a soluble boron concentration of 2000 ppm, have been corrected. The values are revised from 4.0% to the values presented in MAGNASTOR FSAR Revision 4, Table 6.7.3-11. The bottom section of the revised table contains the maximum initial enrichment values presented in MAGNASTOR Amendment 3 submittal 10B FSAR changed page 6.7.8-90, Table 6.7.8-10.

13.1 Evaluation Findings

F13.1 The staff concludes that the conditions for use for MAGNASTOR® system identify necessary technical specifications to satisfy 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The proposed technical specifications provide reasonable assurance that the DSS will allow safe storage of SNF. This finding is based on the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

14.0 Quality Assurance Evaluation

The modifications requested by NAC have not altered the staff's previous quality assurance evaluation of the MAGNASTOR® cask system. Therefore, the staff did not reevaluate this area for the amendment request.

15.0 Conclusion

The staff performed a detailed safety evaluation of the application for an amendment to the 10 CFR Part 72 Certificate of Compliance for the MAGNASTOR® system. The staff performed the review in accordance with the guidance in NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility," Rev. 1, dated July 2010. Based on the statements and representations contained in the application; the MAGNASTOR® Final Safety Analysis Report, as supplemented by Revision 10B, Revision 11A, Revision 11B, Revision 12A; the letter of March 30, 2012; and the conditions established in the Certificate of Compliance and its Appendices (Technical Specifications), the staff concludes that these changes do not affect the ability of the MAGNASTOR® system to meet the requirements of 10 CFR Part 72.

Issued with Certificate of Compliance No. 1031, Amendment No. 3,
on July 25, 2013 .