July 24, 2007

Mr. Anthony L. Patko
Director, Licensing
Engineering
NAC International, Inc.
3930 East Jones Bridge Road
Norcross, GA 30092

SUBJECT: NAC INTERNATIONAL MAGNASTOR SPENT FUEL STORAGE SYSTEM - PRELIMINARY STAFF EVALUATION (TAC NO. L23764)

Dear Mr. Patko:

On August 31, 2004, NAC International (NAC) submitted an application to the U.S. Nuclear Regulatory Commission (NRC), for a Certificate of Compliance (CoC) for a new dry cask storage system, the MAGNASTOR System, in accordance with 10 CFR Part 72. Following the issuance of two Requests for Additional Information (RAIs), and staff review of the responses, the NRC staff met with NAC in January 2007 to provide a summary of the staff's remaining open issues regarding the MAGNASTOR application.

By letter dated January 26, 2007, NAC informed the NRC staff of its withdrawal of the MAGNASTOR application, and its intent to resubmit the application, upon revising it to address the remaining open issues identified by the staff. By letter dated February 15, 2007, the NRC staff acknowledged NAC's withdrawal of the MAGNASTOR application, further described the remaining open issues from its review, and committed to document the complete review findings in a staff evaluation report.

The issuance of the NRC staff evaluation has been delayed, due to unanticipated staff turnover and the emergence of several higher priority actions. Although we have not yet completed the documentation of our staff evaluation, we are providing the enclosed preliminary staff evaluation to NAC at this time, in order to provide you with as much of the information regarding the staff's previous review findings as possible, prior to your resubmittal of the MAGNASTOR application.

The preliminary staff evaluation (Sections 1 through 4 and 6 through 9) addresses most of the technical areas analyzed in the MAGNASTOR Safety Analysis Report. In particular, Sections 3 and 4 summarize the staff's findings in the structural and thermal areas, respectively. These are the technical review areas in which the NRC staff identified the most significant open issues, including the structural analysis for the MAGNASTOR fuel basket design, as documented in our February 15, 2007, letter to you. The preliminary staff evaluation also highlights the areas where the staff was unable to make a technical and safety finding, based on our review of the information previously submitted.

The intent of the staff's evaluation is to document its review of the previous MAGNASTOR application and supporting information to the extent possible. However, the information contained in the enclosed preliminary staff evaluation should not be considered a comprehensive or complete Safety Evaluation Report of the MAGNASTOR design. The enclosed preliminary staff evaluation will serve as a future reference for both NAC and the NRC staff, relative to your anticipated resubmittal of the MAGNASTOR application, and it is to facilitate future NRC review. The extent to which this information can be relied upon in a future review will depend on NAC's ability to minimize changes to the application materials that might affect the staff's review findings. If any aspect of the design is modified or changed, or if the supporting analyses or documentation are revised (except for those previously identified open issues), any findings and conclusions reached by the staff in this evaluation will be reconsidered, as appropriate, in a subsequent review. Based on our recent meeting with your staff to discuss your planned resubmittal of the MAGNASTOR application, we note that NAC does not intend to make any design changes to the MAGNASTOR system. In that meeting, you also described how you intend to revise the SAR and supporting documentation to address the review issues previously identified by the staff.

We intend to complete our preliminary staff evaluation and issue the remaining sections (Sections 5 and 10 through 15) in the near future. Please refer to Docket No. 72-1031 and TAC No. L23764 in future correspondence related to this action. If you have any questions regarding our review, you may contact me at (301) 492-3319.

Sincerely,

/RA/

James R. Hall, Senior Project Manager
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Docket No. 72-1031
TAC No. L23764

Enclosure: Preliminary Staff Evaluation of MAGNASTOR Storage System enclosed preliminary staff evaluation will serve as a future reference for both NAC and the NRC staff, relative to your anticipated resubmittal of the MAGNASTOR application, and it is to facilitate future NRC review. The extent to which this information can be relied upon in a future review will depend on NAC's ability to minimize changes to the application materials that might affect the staff's review findings. If any aspect of the design is modified or changed, or if the supporting analyses or documentation are revised (except for those previously identified open issues), any findings and conclusions reached by the staff in this evaluation will be reconsidered, as appropriate, in a subsequent review. Based on our recent meeting with your staff to discuss your planned resubmittal of the MAGNASTOR application, we note that NAC does not intend to make any design changes to the MAGNASTOR system. In that meeting, you also described how you intend to revise the SAR and supporting documentation to address the review issues previously identified by the staff.

We intend to complete our preliminary staff evaluation and issue the remaining sections (Sections 5 and 10 through 15) in the near future. Please refer to Docket No. 72-1031 and TAC No. L23764 in future correspondence related to this action. If you have any questions regarding our review, you may contact me at (301) 492-3319.

Sincerely,

/RA/

James R. Hall, Senior Project Manager
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Docket No. 72-1031
TAC No. L23764

Enclosure: Preliminary Staff Evaluation of MAGNASTOR Storage System

DISTRIBUTION: NMSS R/F, BWhite, APessin, OGC, RParkhill, AHansen, DTang, CWithee, JSolis, REinziger, MCall

C:\FileNet\ML072050416.wpd

OFC	SFST	E	SFST	C	SFST		SFST	E	SFST		SFST	
NAME	JRHall		MDeBose		LCampbell:BC		GBjorkman: BC		MWaters: BC		RNelson: BC	
DATE	07 /23/07		07/23/07		07/23/07		07/23/07		07/24/07		07/23/07	

C = COVER N = NO COPY E = E-MAIL

OFFICIAL RECORD COPY

Enclosure

NRC PRELIMINARY STAFF EVALUATION

OF THE NAC INTERNATIONAL

MAGNASTOR DRY CASK STORAGE SYSTEM

DOCKET NO. 72-1031

NRC PRELIMINARY STAFF EVALUATION
MAGNASTOR SYSTEM
NAC INTERNATIONAL

SUMMARY

By letter dated August 31, 2004, NAC International (NAC) submitted an application to the United States Nuclear Regulatory Commission (NRC) for approval of the MAGNASTOR spent fuel dry cask storage system, in accordance with U.S. Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste and Reactor-Related Greater than Class C Waste," Title 10, Part 72 (10 CFR Part 72). The MAGNASTOR application proposes a cask system with a storage capacity of up to 37 pressurized water reactor (PWR) or 87 boiling water reactor (BWR) spent fuel assemblies. The NRC staff has assigned Docket No. 72-1031 to this application.

The NRC staff performed a technical review of the MAGNASTOR application and issued formal requests for additional information (RAIs) on May 23, 2005, and on April 6, 2006. NAC's responses to the RAIs were submitted on September 29, 2005, and August 25, 2006, respectively. Over the course of its review, the NRC staff had extensive interactions with NAC, including several meetings, numerous teleconferences, and the review of supplemental information submitted by letters dated October 25, 2004, January 31, March 16, November 15, and December 16, 2005, February 9, April 3, May 8, September 26,and October 19, 2006. Despite these extensive interactions, the NRC staff was unable to make the necessary safety findings on certain issues to support issuance of a CoC based on the information provided up to that time. These issues primarily involved the methods used by NAC for the structural analysis of the unique canister basket design, and several aspects of the thermal analysis for cask loading and transfer activities. NRC discussed these issues with NAC in a public meeting on January 12, 2007. Subsequently, in a letter dated January 26, 2007, NAC requested that the MAGNASTOR system design be withdrawn from consideration for approval, and informed the NRC of its intent to resubmit the application, upon revising it to address the remaining open issues identified by the staff. The NRC acknowledged NAC's request, and provided written summaries of those issues by letter dated February 15, 2007. In that letter, the NRC staff indicated its intent to document its review of the MAGNASTOR application in a staff evaluation report, to address both those areas where a regulatory finding could be made, and those areas where insufficient information was identified.

The staff has documented some of its technical review and findings on the safety-related aspects of the previous MAGNASTOR application in this preliminary staff evaluation. The staff's technical review was carried out according to the applicable NRC regulations in 10 CFR Part 72 for the independent storage of spent fuel and 10 CFR Part 20 for radiation protection. The staff performed its review using the guidance in NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," other applicable regulatory guides, and interim staff guidance documents. This preliminary evaluation documents the staff's review of the MAGNASTOR system, based on the information provided up to the time the staff discontinued its review in December 2006. Those sections of this preliminary evaluation for which the staff has not yet completed the documentation of its evaluation are so noted. This staff evaluation covers the application materials pertinent to the MAGNASTOR system design and procedures, as

described in the Safety Analysis Report (SAR) though Revision 6D, submitted in September 2006. The evaluation considers the staff's RAIs and NAC's responses, as well as the supplemental information referenced above. The evaluation summarizes any identified outstanding issues and indicates where the staff was unable to make a regulatory finding, such as in the area of the structural analysis for the unique fuel basket design. It should be noted that the findings stated at the end of certain chapters are predicated on the acceptable resolution of outstanding technical issues; for example, acceptance of the criticality analyses is based on the presumption that the structural analysis demonstrates that the fuel geometry is maintained. It should be further noted that any changes to the analyses previously reviewed by the staff will require additional review and could affect any findings documented in this report. Therefore, this preliminary staff evaluation does not provide a complete basis for the approval of the proposed MAGNASTOR dry cask storage system, but may be referenced in a future application.

1.0 GENERAL DESCRIPTION

The objective of the review of the general description of the MAGNASTOR dry cask storage system is to ensure that NAC International provided a description that is adequate to familiarize reviewers and other interested parties with the pertinent features of the system.

1.1 General Description and Operational Features

Section 1.3 of the SAR provides a general description of the MAGNASTOR system. It is a spent fuel dry storage system consisting of a concrete cask and a welded stainless steel canister (the transportable storage canister, or TSC) with a welded closure to safely store spent fuel. In the storage configuration, the TSC is placed in the central cavity of the concrete cask. The concrete cask provides structural protection, radiation shielding, and internal airflow paths that remove the decay heat from the TSC contents by natural air circulation. The concrete cask also provides protection during storage for the TSC against adverse environmental conditions. The system is designed to accommodate both the storage and transport of pressurized water reactor (PWR) and boiling water reactor (BWR) spent fuel (although the transportation feature is not considered part of this application and was not reviewed by the staff). The MAGNASTOR system is designed to store up to 37 PWR or up to 87 BWR spent fuel assemblies in each TSC in separate fuel basket assemblies. In addition to the TSC and the concrete cask, the other principal component of the MAGNASTOR system is the transfer cask. The transfer cask is used to move the TSC between the workstations during TSC loading and preparation activities, and to transfer the TSC to or from the concrete cask.

1.1.1 Transportable Storage Canister (TSC)

The TSC provides the confinement boundary for the stored fuel. The major components of the TSC assembly are the shell, base plate, closure lid, closure ring, and redundant port covers for the vent and drain ports. The stainless steel TSC assembly holds the fuel basket structure and confines the contents. The welded stainless steel bottom plate, welded closure lid, closure ring, and redundant port covers prevent the release of contents under normal conditions and off-normal or accident events.

Each TSC contains either a PWR or BWR fuel basket, which positions and supports the stored fuel. The fuel basket assembly provides the structural support and a heat transfer path for the fuel assemblies, while maintaining a subcritical configuration for all of the evaluated normal conditions and off-normal or accident events.

The TSC component dimensions and materials of fabrication, and the overall dimensions and design parameters for the two lengths of TSCs are provided in Tables 1-1 and 1-2 of the SAR, respectively. The TSC stainless steel shell and bottom plate are dual-certified Type 304/304L. The closure lid, closure ring and port covers are Type 304 stainless steel.

The structural components of both the PWR and BWR fuel baskets are fabricated from carbon steel, and the assembled basket is coated with electroless nickel plating to minimize corrosion and combustible gas generation. The principal dimensions and materials of fabrication of the fuel basket are provided in Table 1.3-1 of the SAR.

1.1.2 Storage Cask

The MAGNASTOR concrete storage cask provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the TSC during long-term storage. The concrete cask is the storage overpack for the TSC and it is designed to hold both lengths of TSCs. The principal dimensions and materials of fabrication of the concrete cask are shown in Table 1.3-1 of the SAR.

The concrete cask is a reinforced concrete structure with a structural steel inner liner and base. The reinforced concrete wall and steel liner provide the neutron and gamma radiation shielding for the stored spent fuel. Inner and outer reinforcing steel (rebar) assemblies are encased within the concrete. The reinforced concrete wall provides the structural strength to protect the TSC and its contents in natural phenomena events such as tornado wind loading and wind-driven missiles and during nonmechanistic tipover events. A carbon steel and concrete lid is bolted to the top of the concrete cask. The lid reduces skyshine radiation and provides a cover to protect the TSC from the environment and postulated tornado missiles.

1.1.3 Transfer Cask

The transfer cask is designed, fabricated, and tested to meet the requirements of ANSI N14.6 as a special lifting device. The transfer cask provides biological shielding and structural protection for a loaded TSC, and is used to lift and move the TSC between workstations. The transfer cask also provides shielding during the vertical transfer of a TSC into a concrete cask or a transport cask. Table 1.3-1 of the SAR provides the principal dimensions and materials of fabrication of the transfer cask.

The transfer cask is primarily made from low alloy steel, and incorporates a lead gamma shield and a solid borated polymer neutron shield. The transfer cask has retractable bottom shield doors, which are closed and secured during TSC loading and handling operations. After placement of the transfer cask on the concrete cask, the doors are retracted using hydraulic cylinders and a hydraulic supply. The TSC is then lowered into a concrete cask for storage. The transfer cask is provided with a number of additional penetrations to allow a cooling medium (water, air, inert gas) to be circulated through the cask annulus during TSC loading and preparation activities, as needed.

1.1.4 Basic Operation

The basic sequence of operations for the MAGNASTOR system is as follows: (1) the transfer cask, with the TSC inside, is lowered into the spent fuel pool and the TSC is loaded with spent fuel; (2) the transfer cask and loaded TSC are removed from the spent fuel pool and placed in the cask preparation workstation, where the TSC is welded closed, drained, dried, inspected, and backfilled with an inert gas; (3) the transfer cask is moved to the location of the concrete storage cask, placed on top of the concrete cask, the transfer adapter is opened, and the TSC is lowered into the concrete cask; and (4) the concrete cask is moved to its designated location on the storage pad.

1.2 Drawings

Section 1.8 of the SAR contains the drawings for the MAGNASTOR system, which include drawings of the structures, systems, and components important to safety. Specific structures, systems, and components are evaluated in Sections 3 through 14 of the staff evaluation.

1.3 MAGNASTOR Contents

Section 1.4 of the SAR describes the proposed contents for the MAGNASTOR system. The system is designed to store up to 37 PWR fuel assemblies or up to 87 BWR fuel assemblies in a pressurized helium atmosphere. PWR fuel assemblies may be stored with inserted burnable poison rod assemblies, thimble plugs or control element assemblies. Stainless steel rod inserts for guide tube dashpots may also be inserted. BWR fuel assemblies may be stored with or without channels. Assemblies may contain solid filler rods or burnable absorber rods replacing fuel rods in the assembly lattice. Steel filler rods must be unirradiated. The design content conditions are to be specified in the Certificate of Compliance for the MAGNASTOR system.

1.4 Organizational Roles and Responsibilities

Section 1.5 of the SAR describes the qualifications and the experience of the applicant, NAC International. All design, analysis, licensing, and procurement activities will be performed by NAC in accordance with its approved Quality Assurance Program, as described in Chapter 14 of the SAR. Fabrication of the steel components will be by qualified vendors. A qualified concrete contractor will perform construction of the concrete casks. All vendors and contractors will be selected and their performance monitored in accordance with the NAC Quality Assurance Program. All MAGNASTOR fabrication and assembly activities will be performed in accordance with quality assurance programs meeting the requirements of 10 CFR 72, Subpart G.

The licensee, or its contractor, may perform construction of the ISFSI and conduct MAGNASTOR loading operations on site in accordance with the licensee’s quality assurance program, as appropriate. The licensee will perform decommissioning of the ISFSI in accordance with the licensee’s quality assurance program.

1.5 Evaluation Findings

Based on the NRC staff's review of information provided relevant to the MAGNASTOR system, the staff determined the following:

F1.1 A general description and discussion of the MAGNASTOR system is presented in Chapter 1 of the SAR, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations.

F1.2 Drawings for structures, systems, and components important to safety presented in Section 1.8 of the SAR were reviewed. Details of specific structures, systems, and components are evaluated in Sections 3 through 15 of this staff evaluation.

F1.3 Specifications for the spent fuel to be stored in the MAGNASTOR system are provided in Section 1.4 of the SAR. Detailed specifications for the spent fuel are presented in Tables 1-A-1, 1-A-2, 2.2-1 and 2.2-2 of the SAR, and Appendix B to the proposed Certificate of Compliance in Chapter 13 of the SAR.

F1.4 The technical qualifications of the applicant to engage in the proposed activities are identified in Section 1.5 of the SAR.

F1.5 The quality assurance (QA) program and implementing procedures are described in Chapter 14 of the SAR.

F1.6 The staff concludes that the information presented in this chapter of the SAR satisfies the general description requirements under 10 CFR Part 72. This determination is based on a review that considered the regulation itself, Regulatory Guide 3.61, and accepted dry cask storage practices detailed in NUREG-1536.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

The objective of evaluating the principal design criteria related to the structures, systems, and components important to safety is to ensure that they comply with the relevant general design criteria established in 10 CFR Part 72.

2.1 Structures, Systems, and Components Important to Safety

The principal design criteria for the MAGNASTOR system are presented in Chapter 2 of the SAR, and are specifically listed in Table 2.1-1. The MAGNASTOR system is classified as important-to-safety and, therefore, the structures, systems, and components (SSCs) of the system are designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality assurance program. Each major component of the system is classified with respect to its function and corresponding potential effect on safety. The safety classifications for the SSCs are provided Table 2.4-1 of the SAR and are based on the guidance in NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety," February 1996.

2.2 Design Bases for Structures, Systems, and Components Important to Safety

The MAGNASTOR system design criteria summary describes the allowed range of spent fuel configurations and characteristics, the enveloping conditions of use, and the bounding environmental conditions and natural phenomena.

2.2.1 Spent Fuel Specifications

The MAGNASTOR system is designed to store up to 37 PWR, or up to 87 BWR intact spent fuel assemblies, contained within a TSC. The assemblies of each type are also divided into 2 categories of PWR and BWR fuel based on the length of the assemblies. Detailed specifications for each category of fuel assemblies are provided in Tables 1-A-1, 1-A-2, 2.2-1 and 2.2-2 of the SAR. These include the maximum enrichment, maximum decay heat, maximum average burnup, minimum cooling time, and detailed physical fuel assembly parameters. The limiting fuel specifications are based on the fuel parameters considered in the structural, thermal, shielding, criticality, and confinement analyses.

2.2.2 External Conditions

Section 2.3 of the SAR identifies the bounding site environmental conditions and natural phenomena for which the MAGNASTOR system is analyzed. These conditions include the consideration of the effects of tornado and wind loadings, impact of tornado-generated missiles, floods, seismic events, snow and ice loadings, and temperature extremes.

2.3 Design Criteria for Safety Protection Systems

In addition to the MAGNASTOR system design criteria summarized in SAR Table 2.1-1, ASME Code alternatives are specified for selected components in Table 2.1-2. Analyzed load combinations for the concrete cask and the TSC are listed in Tables 2.3-1 and 2.3-2, respectively, and the structural design criteria used for TSC components are provided in Table 2.3-3.

2.3.1 General

Each major component of the MAGNASTOR system is classified with respect to its function and corresponding potential effect on public safety. The safety classifications for the major system components are designated in Table 2.4-1 of the SAR, in accordance with Regulatory Guide 7.10. The safety classification is based on review of the component's function and the assessment of the consequences of its failure, consistent with the guidelines of NUREG/CR-6407. The safety classification categories are defined as follows:

> Category A - Components critical to safe operation whose failure or malfunction could directly result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.
>
> Category B - Components with major impact on safe operations whose failure or malfunction could indirectly result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.
>
> Category C - Components whose failure would not significantly reduce the packaging effectiveness and would not likely result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.

2.3.2 Structural

The structural analysis for the MAGNASTOR system is presented in Chapter 3 of the SAR. The MAGNASTOR components are designed to meet the structural requirements for confinement of contents, criticality control, heat dissipation, radiological shielding, and contents retrievability required by 10 CFR 72 for the design basis normal conditions, off-normal, and accident events. The design basis off-normal and accident conditions analyzed for the MAGNASTOR system are identified in Sections 12.1 and 12.2 of the SAR, respectively.

2.3.3 Thermal

The thermal analysis is presented in Chapter 4 of the SAR. The MAGNASTOR system is designed to passively reject decay heat when in its storage configuration at the ISFSI. The natural circulation of air inside the concrete storage cask, in conjunction with radiative heat transfer from the TSC surface, maintain the fuel cladding and concrete cask component temperatures below their design limits. The MAGNASTOR thermal analysis is reviewed in Section 4.0 of this staff evaluation.

2.3.4 Shielding/Confinement/Radiation Protection

The shielding, confinement, and radiation protection analyses for the MAGNASTOR system are presented in Chapters 5, 7, and 11 of the SAR. Shielding is provided for in the design of the concrete cask, transfer cask and TSC. Confinement is provided by the TSC, which has a welded closure. The TSC vessel provides a boundary with no credible leakage to prevent the release of solid, volatile, and gaseous radioactive material. There are no evaluated normal conditions, nor off-normal or accident events that result in damage to the TSC that would produce a breach in the confinement boundary. Neither normal conditions of operation, nor off-normal events preclude retrieval of the TSC for transport and ultimate disposal. The TSC is designed to withstand accident conditions, including a 24-inch end drop in the concrete cask and a tipover of the concrete cask, without precluding the subsequent removal of the fuel (i.e., the fuel tubes do not deform such that they bind the fuel assemblies). The TSC's confinement function is verified through pressure testing, helium leakage testing, and weld examinations. Radiation exposure is mitigated by the neutron and gamma shielding and by operational procedures.

2.3.5 Criticality

The criticality analysis is presented in Chapter 6 of the SAR. The design criterion for criticality safety is that the effective neutron multiplication factor, including statistical biases and uncertainties, does not exceed 0.95 under normal, off-normal and accident conditions. The design features relied upon to prevent criticality are the fuel basket geometry and permanent neutron-absorbing materials. The continued efficacy of the neutron-absorbing materials over a 20-year storage period is assured by the design of the system. The boron-10 neutron absorbing material in the TSC will not be significantly depleted, due to the relatively low neutron flux experienced during the storage period.

2.3.6 Operating Procedures

Generic operating procedures are described in Chapter 9 of the SAR. This chapter outlines the loading, unloading, and recovery operations and provides the basis and general guidance for more detailed, site-specific procedures.

2.3.7 Acceptance Tests and Maintenance

The acceptance test and maintenance program are presented in Chapter 10 of the SAR. This chapter specifies the workmanship inspections, the acceptance test program, and the applicable inspection and test acceptance criteria to be implemented for the fabrication, use, and maintenance of the MAGNASTOR system. Those inspections and tests will provide assurance that MAGNASTOR components are fabricated, inspected, tested, accepted for use, and maintained under the conditions specified in this Safety Analysis Report and the Certificate of Compliance.

2.3.8 Decommissioning

Decommissioning considerations for the MAGNASTOR system are summarized in Section 2.5 of the SAR, and described further in Chapter 15.0 of the SAR. Decommissioning of MAGNASTOR will involve removing the TSC by offsite transport and disassembling the concrete cask. It is expected that the concrete will be broken up and the steel components segmented to reduce volume. The concrete and carbon steel are not expected to be surface-contaminated and no significant activation is expected. If necessary, the TSC could be decommissioned following unloading by decontaminating the inside surfaces, and segmenting the shell and closure plates. The remnants of the TSC and concrete cask could then be shipped to a suitable disposal facility.

2.4 Evaluation Findings

Based on the NRC staff's review of information provided in the MAGNASTOR system application, the staff finds the following:

F2.1 The staff concludes that the principal design criteria for the MAGNASTOR system are acceptable with regard to demonstrating compliance with the regulatory requirements of 10 CFR Part 72.

3.0 STRUCTURAL EVALUATION

This section evaluates the structural design of the MAGNASTOR storage system. Structural design features and design criteria are reviewed together with an evaluation of the analyses performed to demonstrate structural acceptability of the system under normal, off-normal, accident, and natural phenomena events.

3.1 Structural Design Features and Design Criteria

3.1.1 Structural Design Features

Chapter 1 of the SAR provides a general description of the MAGNASTOR system consisting of three principal components: (1) the transportable storage canister (TSC, or canister); (2) the concrete cask (cask); and (3) the transfer cask. Based on canister length and arrangement of the fuel basket tube array, the system is configured to store up to 37 PWR or 87 BWR fuel assemblies. Major structural design features of these components are as follows.

3.1.1.1 Transportable Storage Canister

Canister Body. The stainless steel TSC body features a 1/2-inch thick circular cylindrical shell, a 2.75-inch thick welded bottom plate, a 9-inch thick closure lid, a closure ring, and redundant covers for the vent and drain ports. SAR Table 1.3-2 lists physical design parameters of the TSCs at two overall lengths of 184.8 inches and 191.8 inches, with a common outside diameter of 72 inches.

Fuel Basket. The carbon steel fuel basket inside the canister body is comprised of an array of square fuel tubes joined on the interior by the pin-to-slot connections, and at the peripheral points, attached by bolting to an assembly of side and corner weldments that form a circular cross section for emplacement in the canister. The fuel tubes function as individual cells, as well as sidewalls for the developed cells for fuel assemblies. Together with the side and corner weldments, which also serve partially as sidewalls, twenty-one 9.76-inch square tubes provide 37 PWR fuel loading positions. Similarly, an array of forty-five 6.59-inch square tubes provide 87 loading positions for BWR fuel assemblies. SAR Table 1.3-1 lists physical design parameters of the fuel baskets, including a common basket assembly diameter of 70.76 inches and two basket lengths at about 172.5 inches and 179.5 inches each.

3.1.1.2 Concrete Cask

The concrete cask, as a storage overpack of cylindrical reinforced concrete wall construction with a 1.75-inch thick carbon steel inner liner, is closed at the top by a carbon steel and concrete lid assembly. The lid reduces skyshine radiation and provides a cover to protect the TSC from the environment. The concrete wall serves as a structural protective barrier for the TSC and its contents in natural phenomena events, such as tornado wind and wind-driven missiles. SAR Drawing 71160-562 depicts the 24 equally spaced 3 inch-wide s-beam standoffs welded to the inner liner to provide lateral support to the TSC. Table 1.3-1 lists physical design parameters of the 225.3-inches tall concrete cask with an outside diameter of 136 inches and a concrete wall thickness of 26.5 inches.

3.1.1.3 Transfer Cask

Drawing 71160-560 of the SAR depicts the double-walled, circular cylindrical construction of the transfer cask used for lifting and moving the TSC between workstations and for loading the TSC into the concrete cask. The transfer cask, with lead gamma shield blocks and NS-4-FR neutron shield sandwiched between the low alloy steel shell walls, is equipped with a set of retractable shield doors at the cask bottom and two lifting trunnions at the top. It also incorporates three retaining blocks, pin-locked in place, to prevent a loaded TSC from being inadvertently lifted through its top opening. SAR Table 1.3-1 lists the major physical design parameters of the 197.6-inches tall transfer cask, including an outer and inner shell diameter of 88 inches and 74.5 inches, respectively.

3.1.2 Structural Design Criteria

Sections 2.1 and 2.3 of the SAR present the structural design criteria for the MAGNASTOR system. The criteria define, in general, the applicable codes and standards, individual loads as related to environmental conditions and natural phenomenon events, load combinations, and stress allowables, for normal, off-normal, and accident-level conditions. As reviewed below, the structural design criteria are consistent with those of NUREG-1536, and are acceptable.

3.1.2.1 Codes and Standards

The canister body, as a confinement boundary, is designed per American Society of Mechanical Engineers (ASME) Code, Section III, Subsection NB. The fuel basket component stresses are evaluated in accordance with ASME Code, Section III, Subsection NG and, for buckling, with NUREG/CR-6322. The concrete cask is designed and constructed to the American Concrete Institute (ACI) 349 and 318 requirements, respectively. American National Standards Institute (ANSI) N14.6 and NUREG-0612 are used for evaluating the transfer cask lifting trunnions and the bottom shield door assembly. The ANSI/American Nuclear Society (ANS) 57.9, or equivalent, standard is considered for loads and load combinations.

The application of codes and standards for the MAGNASTOR system is consistent with the guidance provided in NUREG-1536, and is acceptable.

3.1.2.2 Site Environmental and Natural Phenomenon Loads

Section 2.3 of the SAR presents the site environmental conditions and natural phenomenon loads used in the design basis analyses of the MAGNASTOR system. These conditions and loads, which can be considered by general licensees for site parameters evaluations, are reviewed below.

<u>Tornado Missiles and Wind</u>. SAR Section 2.3.1 presents the tornado missile and wind loading characteristics. The design basis tornado wind is in accordance with the Regulatory Guide 1.76, Region I, tornado with a maximum rotational wind speed of 290 mph and a translational speed of 70 mph for a maximum combined speed of 360 mph.

SAR Section 2.3.1.3 lists, per NUREG-0800, Section 3.5.1.4, Spectrum I, three types of tornado missiles that could impact the cask at normal incidence: (1) a massive deformable missile of 4,000 lbs, (2) a penetration missile of 280 lbs, and (3) a protective barrier missile of a 1-inch diameter solid steel sphere. The SAR assumes that each missile is to impact the concrete cask horizontally at a speed of 126 mph per hour, which is 35% of the maximum combined speed of 360 mph. For missile impact in the vertical direction, the SAR assumes a missile speed of 88.2 miles per hour, which is 70% of the speed of a horizontal missile. Structural effects of tornado missiles and wind on the cask system, as presented in SAR Section 3.7.3.2, are reviewed in Section 3.5.2 of this evaluation.

Flood. SAR Section 2.3.2 considers a design basis flood water velocity of 15 ft per second and a flood water depth of 50 ft for evaluating the MAGNASTOR system. For a 50-ft head, a hydrostatic pressure of 22 psi is exerted on the TSC and concrete cask. At a velocity of 15 feet per second, the drag force applied on the submerged cask is used to evaluate the factor of safety against overturning of the concrete cask. The hydrostatic pressure and drag force effects on the cask system, as presented in SAR Section 3.7.1.4 and 3.7.3.3, are reviewed in Section 3.5.1 of this evaluation.

Earthquake. SAR Section 2.3.3 considers peak accelerations at the top surface of the concrete storage pad to establish the design basis earthquake for which the loaded MAGNASTOR concrete cask must be shown not to tip over. The cask performance, including stability against tipover, as presented in SAR Section 3.7.3.4, for the peak storage pad horizontal acceleration of 0.37 g and corresponding vertical acceleration of 0.25 g, are reviewed in Section 3.5.3.

Snow and Ice. SAR Section 2.3.4 considers the ANSI/American Society of Civil Engineers (ASCE) 7-93 snow load criteria. On the basis of the exposure, thermal, and importance factors, a design basis snow and ice load of 100.8 psf is established for the concrete cask. The effect of this snow load is bounded by that of applying the weight of the loaded transfer cask to the top of the concrete cask, which is acceptable. As a result, no additional structural evaluation of the concrete cask is necessary for the snow and ice load.

3.1.2.3 Load Combinations

Section 2.3.5 of the SAR presents the load cases for evaluating combined load effects on the structural performance of the MAGNASTOR system. In addition to the environmental conditions and natural phenomenon events, the loads considered include the dead weight, live load, thermal effects, internal pressure, handling load, and loads associate with cask drop and tipover accidents. SAR Table 2.3-1 summarizes the load combinations for the concrete cask, which are consistent with those of ANSI/ANS 57.9. SAR Table 2.3-2 lists the load combinations for the TSC and the fuel basket.

3.1.2.4 Stress Allowables

Table 2.3-3 of the SAR lists the structural evaluation criteria for the TSC and components. The stress allowables are based on ASME Code, Section III, Subsections NB and NG, for the canister body and fuel basket, respectively. **For the basket fuel tubes, however, the staff believes that NAC has not provided sufficient bases, as described in SAR Section 3.10 in using the von Mises stress as an exception to the stress intensity criterion in evaluating stress performance.**

SAR Section 2.3.5.1 considers strength reduction factors, in accordance with ACI 349, for the concrete cask evaluation.

As described in Section 2.3.5.3, the transfer cask, as a special lifting device, meets the provisions of ANSI N14.6 and NUREG-0612 for the handling of heavy loads. This requires that stresses in the two trunnions, in a non-redundant lift configuration, be evaluated for six times and ten times the weight of a fully loaded transfer cask against the yield and ultimate strengths, respectively.

3.1.3 Weights and Centers of Gravity

SAR Table 3.2.1-1 lists the weights of individual components and relevant centers of gravity for the MAGNASTOR system under various operating configurations. For the transfer cask, the heaviest under-the-hook dry weight at 213,000 lbs is enveloped by the wet weight of 229,500 lbs used for the vertical lifting evaluation. The weights of the loaded concrete casks and corresponding centers of gravity provide the basis for selecting a bounding configuration with the least resistance to tipover for the cask seismic stability evaluation.

3.1.4 Supplemental Data

3.1.4.1 Finite Element Analysis Codes

The SAR uses two general purpose finite element codes, ANSYS and LS-DYNA, which are commercially available, to perform structural analyses of the MAGNASTOR system. Stresses in the canister, fuel basket, transfer cask, and concrete cask are generally analyzed with ANSYS. Impact responses of the concrete cask during the cask tipover and 24-inch vertical drop accidents are calculated with LS-DYNA. Additionally, LS-DYNA is used to evaluate special cask performance features, including potential for geometric instability of the fuel tube array, crushing of the concrete cask pedestal, and load transfer between the neutron absorber plate and its retainer and the associated weld posts during the concrete cask tipover accident.

3.1.4.2 Finite Element Structural Analysis Models

SAR Sections 3.10.1 and 3.10.2 provide details for the PWR and BWR fuel basket ANSYS finite element models, respectively. Section 3.10.3 provides the TSC ANSYS finite element model common to both the PWR and BWR spent fuel storage application. Section 3.10.4 presents the ANSYS finite element models for the concrete cask lift and thermal stress evaluations. Also presented therein are the LS-DYNA finite element models for analyzing the concrete cask 24-inch vertical drop and the tipover accidents. Section 3.10.5 provides a description of the transfer cask ANSYS finite element model. As described in Sections 3.10.6 thru 3.10.8, LS-DYNA finite element fuel basket models are used for analyzing transient response of the fuel baskets, including evaluation of potential geometric instability of the fuel tube array and plastic strains and deformations incurred in the fuel tube pin-to-slot connections during the cask tipover event. The model details are reviewed, along with the corresponding analyses and results, in the appropriate sections of this staff evaluation.

3.1.4.3 Design Margins

In the stress evaluation, the SAR defines the stress margin or margin of safety as the ratio of the stress allowable and the calculated stress minus one, for which the at-temperature stress allowables are considered. Positive margins demonstrate structural acceptability for the component sections being evaluated. The SAR also uses factors of safety defined as the ratios of the allowable and the calculated structural performance indices such as material plastic strains and Nelson stud pull-out forces. A factor of safety equal to or greater than unity ensures adequate structural performance for the entities being evaluated. These design margin characterizations are acceptable.

3.1.5 General Standards for Cask

The design features of the MAGNASTOR system for meeting general cask design standards, including maintaining positive closure and allowing safe lift operations, are reviewed as follows.

3.1.5.1 Chemical and Galvanic Reactions (See Chapter 8 of this SE)

3.1.5.2 Positive Closure

The TSC has a closure ring welded on top of the 0.5-inch J-groove weld joining the closure lid to the canister shell. The vent and drain penetrations, through the closure lid to the canister cavity, have welded redundant port covers to provide double-welded confinement boundaries. These design features preclude inadvertent opening, thereby ensuring positive closure of the TSC.

3.1.5.3 Lifting Devices Analysis

SAR Section 3.4.3 evaluates the various lifting devices and components of the MAGNASTOR system. The concrete cask is lifted by means of two embedded lug assemblies separated180^{o} apart at the top of the concrete cask body. The loaded and closed TSC is lifted with two three-legged slings, through the six hoist rings threaded into the closure lid. The transfer cask is lifted with two trunnions. The structural performance of these lifting devices is evaluated as follows.

3.1.5.3.1 Concrete Cask Lift

Section 3.4.3.1 of the SAR demonstrates the lift capability of concrete cask components, including the lifting lug assembly, the pedestal, and the corresponding Nelson studs for transmitting the weight of the loaded TSC through the pedestal to the concrete cask base plate weldment.

Each lug assembly, which is anchored in concrete for an embedment length of more than 65.5 inches, is fabricated with a pair of 7.6-inch wide by 2-inch thick carbon steel plates interconnected by intermediate spacers and a base plate. As an alternative to this standard design, SAR Drawings 71160-561 and -590 show a reconfigured lift lug assembly to allow the segmented concrete cask to be lifted by attaching a removable upper lift lug assembly to the embedded lower lug assembly to facilitate lifting. The strength of the lift lug is evaluated by the same approach as that for the previously approved NAC-UMS cask system, including using the Air Force Flight Dynamics Laboratory "Stress Analysis Manual," AFFDL-TR-69-42, to compute stresses in the lifting lugs and the ANSI N14.6 allowable stress of the lesser of $S_y/3$ and $S_u/5$.

SAR Figure 3.10.4-1 shows the quarter-symmetry finite element analysis model for the concrete cask lifting evaluation. Considering the loaded TSC weight of 120,000 lbs and an impact load factor of 1.1, the model is used to compute the pedestal component internal forces and stresses, including stresses in key weld joints and forces exerted on the Nelson studs. The SAR states that the maximum stresses in the pedestal stand occur in the support rails. The corresponding minimum factor of safety of 1.14 is related to the combined membrane-plus-bending stress intensity allowable of 28.95 ksi of the A-36 steel. The stresses in key weld joints are shown to be within the allowables. The calculated maximum load on a single Nelson stud is 17,145 lbs, which is less than the pullout strength of 24,438 lbs, based on the cask concrete compressive strength of 3,800 psi, and is acceptable.

3.1.5.3.2 Transportable Storage Canister Lift

SAR Section 3.4.3.2 evaluates structural performance of the hoist rings, the TSC closure lid, and the weld that joins the closure lid to the shell for lifting a design basis loaded TSC of 120,000 lbs. Six hoist rings, each at a rated capacity of 50,000 lbs or ultimate capacity of 150,000 lbs, are used with two three-legged slings for the redundant lift of the TSC. The SAR calculates a minimum sling length of 43.1 inches to ensure that the rated hoist ring capability is not exceeded. Considering a thread engagement length of 2 inches, the SAR calculates the shear stress of the enclosure lid bolt hole thread. The resulting stress design factors of safety are 3.7 and 9.1 against the yield and ultimate strengths, respectively, which meet the criteria of NUREG-0612 and ANSI N14.6 for redundant lifting systems. Thus, the staff concurs with the SAR conclusion that the minimum thread engagement of 2 inches is adequate.

The SAR models the upper portion of the TSC in evaluating the enclosure lid and its weld joining the TSC shell. The hoist ring force on the structural lid is simulated with a three-point lifting configuration, and appropriate modeling consideration is given to the boundary condition associated with the truncated canister model and the anticipated symmetric stress distribution. The SAR calculates a maximum stress intensity of 1,481 psi in the lid-to-shell weld and 1,516 psi in the canister shell. The maximum TSC shell stress of 1,516 psi corresponds to the design factors of safety of 12 and 42, which are greater than 3 and 5, against the yield and ultimate strengths, respectively. As a result, the staff concurs with the SAR conclusion that the TSC lift meets the stress design factor of safety criteria of NUREG-0612 and ANSI N14.6 for non-redundant load paths.

3.1.5.3.3 Transfer Cask Lift

SAR Figure 71160-560 and Section 3.10.5 depict design details of the transfer cask comprised of three major sections: (1) the top 14-inch high by 7.5-inch thick solid ring made of carbon steel, (2) the middle 180.5-inch long cask body consisting of a steel inner shell, a lead layer, a neutron shield layer, and a steel outer shell, and (3) the bottom 12-inch high by 7.5-inch thick solid carbon steel ring to which a pair of rails are welded to accommodate the shield doors. Two 9-inch diameter trunnions, which bore through the top ring at 180° apart and are partial penetration welded to both the inner and outer faces of the ring, serve as lift points. SAR

Figure 3.10.5-1 presents the quarter-symmetry three-dimensional (3-D) finite element model of the complete cask defined by the three sections. At a bounding weight of 240,000 lbs, which envelops the design weight of 230,000 lbs of the loaded transfer cask, the model enables computation of stress intensities at all critical locations in the transfer cask. SAR Table 3.4.3-1 summarizes the calculated stresses and associated factors of safety for seven cross-sectional locations of the trunnion and top ring. The maximum bending stress in the trunnion is 3.79 ksi, which corresponds to the factors of safety of 8.1 and 18.5 against the respective yield and ultimate strengths of the A350 Grade LF 2 carbon steel and satisfies the stress design factor of safety criteria of NUREG-0612 and ANSI N14.6 for non-redundant load paths. SAR Table 3.4.3-2 summaries the calculated stress intensities for the most critically stressed locations in the inner and outer shells, as well as the bottom ring, and indicates that the calculated factors of safety are large for all locations, and are, therefore, acceptable.

The SAR evaluates other load bearing components of the transfer cask for the loading conditions against the stress allowables commensurate with the postulated design events. The shield door and rail assemblies at the bottom of the transfer cask are shown to have stress design factors larger than 6 and 10 against the yield and ultimate strengths, respectively. The evaluation also includes the bolted-in-place retainer rod and block assemblies, which meet the ASME Code Service Level C stress limits, in the event of inadvertent lift of the transfer cask by the TSC.

On the basis of the above evaluation, the staff concurs with the SAR conclusion that the transfer cask is structurally adequate in meeting the stress design factor of safety criteria of NUREG-0612 and ANSI N14.6.

3.2 Normal Operating Conditions

3.2.1 Hot and Cold Temperature Effects

The SAR thermal performance of the MAGNASTOR system is reviewed in Section 4 of this evaluation. This section reviews stress performance resulting from the pressure and thermal loadings, including differential thermal expansion effects. The cold temperature effects on brittle fracture of the system are evaluated in Chapter 8 of this evaluation.

3.2.1.1 Internal Pressures and Temperatures

SAR Section 2.3.6 establishes the design basis ambient temperatures of 76°, 106°, -40°, and 133°F for the normal, off-normal severe heat, off-normal severe cold, and accident extreme heat conditions, respectively. SAR Section 4.4.4 calculates, for normal conditions, a maximum canister internal pressure of 104 psig for both the PWR and BWR fuel applications. This provides the basis for applying a bounding internal pressure of 110 psi for the canister structural analysis.

SAR Section 3.10.3 presents the TSC finite element model and applicable boundary conditions for various loading conditions, including nodal temperatures at key locations, which envelop the TSC temperature gradients for normal and other operating conditions, for the thermal analysis. SAR Table 3.5.1-1 lists the maximum thermal stress intensity of 13.05 ksi, which occurs at the center of the canister bottom plate. For pressure and pressure plus handling loads, Tables

3.5.1-2 and 3.5.1-3 present the stress intensities and associated margins for primary membrane and primary membrane-plus- primary bending stress categories, respectively. The minimum factor of safety is 1.23, which is greater than unity, and therefore acceptable.

SAR Sections 3.10.1 and 3.10.2 present the fuel basket ANSYS finite element models and applicable boundary conditions for various loading conditions, including nodal temperatures at key locations, for the PWR and BWR baskets, respectively. The segmented 3-D quarter-symmetry models are 47 inches and 43 inches long **(these dimensions should be verified by NAC and clarified in the updated SAR, due to inconsistent descriptions)**, with one end restrained, for the respective PWR and BWR fuel baskets. For each basket, five cases of symmetric temperature boundary conditions are evaluated, for which temperatures at four locations are considered to envelop the maximum temperatures as well as the maximum temperature gradients in the axial and radial directions of the basket. Section 3.5.2.1 evaluates thermal stresses for the PWR fuel basket. With a maximum handling stress of 0.1 ksi superimposed, the maximum combined stresses are 48.1 ksi and 17.4 ksi, which are below the at-temperature allowable of $3S_m$ or 62.4 ksi at 700°F, for the fuel tube and basket support weldments, respectively. As similarly calculated in Section 3.5.2.2, the corresponding combined stresses are 28.5 ksi and 8.5 ksi for the BWR basket, which are acceptable.

SAR Section 3.10.4.2 describes the thermal stress analyses of the concrete cask. As depicted in Figures 3.10.4-2 and 3.10.4-4, the 3-D ANSYS stress analysis model, which represents one of the 56 periodic radial sections with identical rebars, is modified from the thermal analysis model. The model consisting of SOLID45, LINK8, COMBIN14, and CONTAC52 structural elements is capable of simulating the rebar/concrete and concrete/steel liner interactions. As summarized in Section 3.5.3.1, for a bounding temperature profile corresponding to the off-normal ambient condition of 106°F, the maximum calculated rebar stress is 19.1 ksi. The maximum concrete compressive and tensile stresses are calculated to be 1.0 ksi and 0.1 ksi, respectively, which are below the allowables, and therefore acceptable.

The staff reviewed the SAR approaches to applying thermal and pressure loadings for the MAGNASTOR system structural analyses and concludes that the analyses follow acceptable engineering practices with acceptable results.

3.2.1.2 Differential Thermal Expansion

SAR Section 3.5.2 recognizes the temperature difference between the center and the outer radius of the fuel basket. Based on the initial axial gap allowance of 0.08 inches between adjacent fuel tube connector pins at the basket ends, the applicant determined that no thermal stresses are produced by the axial expansion of the baskets. By considering differences in thermal expansion between the carbon and the stainless steels, the applicant calculated a maximum thermal stress of 37,350 psi in the neutron absorber retainer strip, which may develop when restrained from thermal growth by the weld posts attached to the fuel tube. That stress is below the allowable of 47,700 psi, and is acceptable.

3.2.2 MAGNASTOR System Components Structural Analysis

In the following sections, the staff evaluates the SAR Section 3.5 analyses of the structural performance of the MAGNASTOR system components under normal operating conditions.

3.2.2.1 Transportable Storage Canister

Canister Body. SAR Figures 3.10.3-1 and -2 depict the half-symmetry 3-D finite element model of the TSC body, consisting of the ANSYS SOLID45 elements for the canister shell, bottom plate, and closure lid for analyzing effects of individual and combined thermal, dead, maximum internal pressure, and handling loads. An internal TSC pressure of 110 psig, which envelops the maximum internal pressure of 104 psig, is assumed in combination with the TSC lift for which a pressure representing the weight of the fuel and basket is applied to the TSC bottom. As noted in SAR Section 3.10.3, temperatures at six key locations on the canisters which envelop the normal (76°F ambient temperature) and off-normal (106° and -40°F ambient temperatures), storage and transfer temperature conditions for all TSC operations are considered in the thermal stress analysis.

SAR Table 3.5.1-1 summarizes the maximum canister thermal stresses under the normal operating conditions. SAR Tables 3.5.1-2 , -3 and -4 present the respective canister primary membrane, primary membrane-plus-bending, and primary plus secondary stress results. The SAR reports a minimum stress factor of safety of 1.23, which occurs in the canister shell slightly above the bottom plate, for the pressure plus handling condition, and this factor of safety is acceptable. Since the canister body satisfies the six operating conditions depicted in ASME Code, Section III, Subsection NB, Article NB-4222.6, the staff agrees with the NAC conclusion that no fatigue analysis is needed for the TSC.

Fuel Baskets. Classical hand calculations are used to evaluate stresses for various components of the fuel tube array and side/corner weldment assemblies of the BWR and PWR fuel baskets. For the dead load and vertical lift handling, the SAR reports the bearing stresses, with large factors of safety, of the connector pins against the canister bottom plates and those at the intersection of the connector pin assembly and the fuel tubes

Thermal stresses in the PWR fuel basket are calculated using a 3-D quarter-symmetry ANSYS finite element model described in SAR Section 3.10.1.2. The model, representing the top or bottom **45** inches **(this dimension should be verified and consistently described in the revised SAR**) of the basket, is used to calculate thermal stresses in the basket assembly, considering bounding thermal gradients in the axial and radial directions. The thermal stresses are combined with the maximum stresses associated with the normal handling condition. With the at-temperature stress intensity limit of $3S_m$, or 62.7 ksi for the SA 537 Class 1 steel at 755°F, the SAR reports the factors of safety of 1.3 and 3.38 for the fuel tube and the support weldments, respectively. The ANSYS analysis shows a maximum shear load of 3.5 ksi in the basket attachment bosses, which corresponds to a factor of safety of 3.03. The SAR notes the axial average temperature at the basket center of 521°F, and at the outer radius of 454°F, which produce no axial thermal stresses in either the fuel tubes or connector pin assembly because of the nominal stacking gap of 0.08 inch between the two adjacent connector pins. Hand calculations also show a maximum thermal stress of 38.4 ksi, which is acceptable, in the neutron absorber retainer weld post resulting from differential thermal expansion of the SA-240 stainless steel neutron absorber retainer strip and the SA-537 carbon steel fuel tube when the basket temperature rises from 70°F ambient to the bounding 755°F.

For the BWR fuel basket, SAR Section 3.5.2.2 presents stress analyses similar to those for the PWR fuel basket with acceptable stress results.

3.2.2.2 Concrete Cask

SAR Section 3.10.4.1 presents the ANSYS quarter-symmetry finite element model for the concrete cask pedestal, including LINK8 elements to model the Nelson studs and CONTAC52 elements to model the interfaces where components are not welded together. Considering the 56 equally spaced vertical rebars close to the outer surface of the concrete shell, the thermal stress analysis uses a vertical slice of concrete shell, at 1/56th of the concrete cask along its circumference, for determining force interactions among the concrete shell, inner steel liner, and hoop and vertical rebars. SAR Section 3.5.3 evaluates the structural performance of the concrete cask for the normal condition dead, live, wind, and differential thermal expansion loads, using the finite element analyses and classical hand calculations. Tables 3.5.3-1, -2, and -3 summarize concrete stresses in the cask axial and circumferential directions under various load combinations. The calculated maximum compressive stress of 1,332 psi is much less than the allowable of 2,660 psi, based on a strength reduction factor of 0.7 for the concrete compressive strength of 3,800 psi at 300°F. For an off-normal bounding temperature of 106°F, which envelops the normal condition temperature of 76°F, Section 3.5.3.1 reports a maximum rebar tensile stress of 19.1 ksi, a concrete compressive stress of 1.0 ksi, and a concrete tensile stress of 0.1 ksi, which are all within the allowables.

3.3 Off-Normal Events

SAR Section 3.6 defines off-normal environmental events as ambient temperature conditions of -40°F with no solar load, 106°F with solar load, and half-blockage of the concrete cask air inlets. For the off-normal handling involving the insertion of the TSC into the concrete cask, removal of the TSC from the concrete cask, or removal from the transfer cask, handling loads are defined as the inertia forces of 0.707 g and 1.5 g applied concurrently in the respective cask horizontal and vertical directions. Similar to those for the normal operating conditions, classical hand calculations and finite element models are used to analyze the MAGNASTOR system components.

3.3.1 Transportable Storage Canister

Canister Body. As reviewed in Section 3.2.2.1, the temperature gradients used in examining the TSC normal operating condition bound the off-normal condition. Therefore, the staff agrees with the SAR conclusion that the maximum thermal stresses for the off-normal severe ambient temperature event are bounded by those presented in SAR Table 3.5.1-1 and are acceptable.

SAR Section 3.6.1.2 examines two off-normal load combinations for the TSC. For the case of off-normal internal pressure with normal handling, in addition to the bounding temperature for thermal stresses, load application includes a bounding internal pressure of 130 psig applied on all canister internal surfaces and an inertial force of 1.1 g in the axial direction to simulate normal handling of the loaded TSC. The computed minimum factor of safety is 1.18, shown as the ASME Section III Service Level B primary membrane-plus-bending stress category.

Fuel Basket. The inertial loading for the off-normal handling event is a 1.5 g vertical acceleration and a 0.707 g transverse acceleration. **As noted in Section 3.4.3 of this evaluation, the staff is unable to make a positive finding on the fuel basket design subject to a side impact similar to that associated with a cask tipover event.**

3.3.2 Concrete Cask

SAR Section 3.6.3 notes that the thermal stress evaluation for normal conditions for the concrete cask considers the 106ºF ambient condition thermal gradient, which is the off-normal event. Therefore, the staff agrees with the SAR conclusion that all thermal stress analyses of the concrete cask performed for the normal operating conditions are applicable to those for the off-normal operating events, and are acceptable.

3.4 Storage Accident Events

SAR Section 3.7 presents analyses of the MAGNASTOR system components for storage accident events. In the following, the staff reviews the effects of accident events on the structural performance of individual system components.

3.4.1 Accident Pressurization

Canister Body. SAR Section 4.4.4 calculates a maximum accident canister internal pressure of 158 psig assuming a 100% fuel rod failure, which is less than the bounding internal pressure of 250 psig used for evaluating accident pressurization of the TSC. SAR Section 3.10.3 presents the finite element model and boundary conditions for the analyses, which include applying a pressure load to the TSC bottom to simulate the TSC content weight of 90,000 lb. SAR Tables 3.7.1-1 and -2 list the resulting TSC primary membrane and primary membrane-plus-bending stresses, respectively. The minimum stress factor of safety of 1.59, shown as associated with a primary membrane-plus-bending stress category, occurs in the canister shell slightly above the TSC bottom plate, which is acceptable. Hence, the staff concurs with the SAR conclusion that the TSC is not significantly affected by the increase in internal pressure that results from the accident pressurization related to the hypothetical rupture of all PWR or BWR rods in the TSC.

3.4.2 Concrete Cask 24-inch End-Drop

3.4.2.1 Concrete Crush

SAR Section 3.7.3.6 uses an energy balance method similar to that for the previously approved NAC-UMS system to estimate the bottom-end drop impact deformation of the concrete cask. The cylindrical concrete portion of the cask is assumed to crush squarely onto an infinitely rigid surface. By equating the total cask potential energy to the energy dissipated through concrete crushing, the SAR calculates a maximum concrete crush depth of 0.13 inches. The staff reviewed the approach and agrees with the SAR conclusion that the crush will not result in any significant damage to the steel liner plate to impair its functionality during the 24-inch cask end-drop accident.

3.4.2.2 Pedestal Crush

SAR Section 3.10.4.3 presents LS-DYNA analysis to determine the TSC deceleration and corresponding deformation of the pedestal upon concrete cask bottom-end drop onto an unyielding surface. SAR Figure 3.10.4-5 depicts the quarter-symmetry finite element model with the 4-node shell elements for the pedestal weldments, including air inlet and pedestal support rails. The loaded TSC and the weight of the inner liner plate are modeled with the 8-

node solid elements located on the TSC bottom plate and above the air inlet duct top, respectively. A piece-wise linear stress-strain curve obtained from the Atlas of Stress-Strain Curves is used for the A-36 steel subject to large deformations. SAR Section 3.7.3.6 presents the analysis results of using the upper bound TSC weight of 105,000 lbs to calculate the maximum pedestal deformation and a lower bound weight of 60,000 lbs to calculate the maximum TSC deceleration. The maximum vertical displacement of the air inlet is calculated to be 1.46 inches, which leaves a minimum inlet opening of 2.9 inches to bound the condition associated with the loss of one-half of the air inlets, as an off-normal event. Considering also the dynamic load factor effect, the maximum deceleration of the TSC for the upper-bound weight and lower-bound weight TSC are determined to be 19.6 g and 25.2 g, respectively. The SAR states that the maximum strain in the pedestal is 15.4%, which is less than the ultimate strain of 25% for the A-36 steel. On this basis, the staff agrees with the SAR conclusion that the pedestal is not expected to rupture during the cask 24-inch vertical drop event.

3.4.2.3 Transportable Storage Canister

Canister Body. SAR Section 3.7.1.2 considers an axial inertial load of 60 g, which bounds the maximum calculated deceleration of 25.2 g reviewed above, to perform a stress analysis and buckling evaluation of the canister body.

The analyses use the same 3-D half-symmetry finite element model reviewed previously for the normal conditions application, and a concurrent normal internal pressure of 110 psig is applied to all inner surfaces of the TSC. As listed in SAR Tables 3.7.1-1 and -2 for the respective primary membrane and primary membrane-plus-bending stresses, the minimum factor of safety of 3.37 occurs in the lower TSC shell for the primary membrane stress category.

SAR Section 3.7.1.2.2 determines that the maximum longitudinal compressive stress of 9.3 ksi in the TSC is considerably below the critical buckling stress of 34.5 ksi based on a stress analysis handbook formula. The 1/2-inch thick, 72-inch diameter, and 191.8-inch long TSC has a shell thickness and canister length identical to that of the 67-inch diameter NAC-UMS transportable storage canister. The staff notes that, for the same 60 g inertial load, the previously approved NAC-UMS TSC fabricated with the same A-240 Grade 304L stainless steel is shown to satisfy the buckling interaction equations with large margins, per the ASME Code Case N 284-1 provisions. Therefore, the staff has a reasonable basis to agree with the MAGNASTOR SAR conclusion that the TSC will not buckle as a result of the 24-inch cask vertical drop.

Fuel Baskets. SAR Section 3.7.2.1.1 considers a 60 g axial inertial force, and relies on classical hand calculations to demonstrate adequate at-temperature structural performance of the PWR fuel basket components. The calculated membrane stress of 5.6 ksi for the 9.76-inch square by 5/16-inch thick tube is below the at-temperature 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 (**Note the discrepancy in identifying an ultimate strength of 68.1 ksi at 700°F for the tipover evaluation**). The maximum membrane stress in the corner and side weldments of 43.8 ksi is also less than the at-temperature allowable of 47.9 ksi for the same SA-537 Class 1 steel. The combined bearing and shear capability of 25.3 kips, for the connecting pin weld in resisting the axial load against the TSC bottom plate, is demonstrated to exceed the maximum tributary load of 23.6 ksi. The bounding axial load of 42.2 kips on the basket connection pin is less than the calculated Euler buckling load of 106 kips for the 3/4-inch diameter by 3-inch long connecting pin of the SA-240 Type 304 stainless steel. The weld post is determined to be capable of retaining the 0.015-inch thick stainless steel retainer sheet that functions to encase and attach the neutron absorber plate to the basket tube wall. The staff finds this analysis acceptable.

SAR Section 3.7.2.2.1 considers the same approaches and criteria as those reviewed above, to demonstrate that the BWR fuel basket components are structurally adequate for resisting a canister static equivalent axial load of 60 g. The staff agrees that analysis for the BWR fuel basket components is acceptable.

3.4.3 Concrete Cask Tipover

SAR Section 3.10.4.4 presents the finite element models for determining rigid body decelerations of the concrete cask during a tipover event. Two half-symmetry models of the combined concrete cask, concrete pad, and soil subgrade systems are analyzed using the LS-DYNA computer code. SAR Figures 3.7.3-3 and -4 present, for the respective configurations of the standard and the oversized pads, the raw and low-pass filtered time-history responses of the cask for two cask locations. For the model parameters considered, the peak cask deceleration, after filtering, is demonstrated to be insensitive to the pad size variation; 26.6 g vs. 26.4 g peak at the location of the basket top, and 29.6 g vs. 29.5 g at the TSC top. By considering appropriate dynamic load factors to the peak cask decelerations, SAR Table 3.3.3-4 lists the amplified decelerations as applicable to evaluating the TSC, and the PWR and BWR fuel baskets, under the 0^{o} and 45^{o} drop orientations. The resulting side-impact bounding g-loads are 29.6 g and 32.2 g for the locations at the top of the TSC lid and top of the fuel basket, respectively. For the analysis presented, the staff notes that the approaches to model parameters, including soil and concrete material properties, pad and soil configurations, and boundary conditions are similar to those for the previously approved NAC-UMS cask system. As a result, the staff has a reasonable basis to conclude that the amplified decelerations are applicable to the subsequent cask components analyses. In the following, the staff reviews the load application and structural performance of the cask system components associated with the cask tipover accident.

3.4.3.1 Transportable Storage Canister

<u>Canister Body</u>. For the bounding combination of geometry and loading that envelops the PWR and BWR TSCs, SAR Section 3.10.3 considers a tapered variation of side impact inertial load of 40 g, which bounds the peak amplified deceleration of 32.2 g, at the top of the canister closure lid and 1 g at the base of the concrete cask for the TSC stress analysis. The SAR states that the inertia load associated with the 90,000 lbs content weight is represented as an equivalent static pressure applied on the interior surface of the TSC shell and is applied along the circumferential in a cosine distribution over a 21^{o} arc from the impact center line. SAR Table 3.7.1-1 summarizes the primary membrane stress results for the most critical location, which coincides with the weld joining the closure lid to the canister shell. The maximum stress intensity of 29.05 ksi is less than the allowable of 34.72 ksi with a stress factor of safety of 1.20 (34.72/29.05 = 1.2). SAR Table 3.7.1-2 summarizes results for the primary membrane-plus-bending stress category for the most critically stressed location, which occurs at about the mid-height of the canister shell. The calculated stress intensity of 59.06 ksi is less than the allowable of 63.75 ksi, and is acceptable.

<u>Fuel Baskets</u>. **While the stress results as reviewed above are conservatively calculated with the simulated pressure-equivalent loading distributed only over a 21° arc from the impact center line and along the canister circumferential direction, the load distribution assumption, nevertheless, may not have lent itself to a realistic estimate of the cross sectional deformation, or ovalization, of the canister.**

In evaluating the fuel basket geometric instability potential resulting from the concrete cask tipover accident, SAR Section 3.10.6 notes that the maximum canister shell displacements determined by the quasi-static ANSYS are used as the displacement boundary condition in the LS-DYNA finite element model. However, since the pressure distribution to simulate the inertia effects tends to underestimate the canister shell ovalization potential, the staff believes that some unattainable physical constraint may have been introduced to the model, thereby, rendering the computed results non-conservative. As a result, the staff is unable to make a positive finding on the adequacy of the basket in maintaining its geometric stability during the tipover accident. No further review is performed of the fuel baskets until the basket geometric stability issue is properly addressed by the applicant.

3.4.4 Fuel Rod Rupture

The TSC is designed to remain leaktight in a storage configuration. Because of this design feature, the structural integrity of the fuel rod cladding is not considered in the evaluation of the confinement of radioactive material under accident conditions. Under normal and off-normal conditions, since the effects of pressure, thermal, and mechanical loadings on gross rupture of fuel rods are negligible, the staff has reasonable assurance that the spent fuel rods can readily be retrieved for further processing or disposal. The spent fuel assemblies may be subject to an axial impact associated with a 24-inch cask vertical drop accident. In accordance with NRC's Interim Staff Guidance (ISG) No. 3, however, the 10 CFR 72.122(l) provision on fuel retrievability does not apply to post-accident recovery, and the fuel rod rupture need not be addressed for this accident

3.5 Natural Phenomena Events

3.5.1 Flood

The 50-foot design basis water depth corresponds to a hydrostatic pressure of 22 psig on the 227-inch tall concrete cask. SAR Section 3.7.1.4 states that the TSC is evaluated for an internal pressure of 110 psig for normal conditions. The hydrostatic pressure of 22 psig exerted by the 50-foot depth of water has the effect of reducing the TSC differential pressure from 110 psig to 88 psig (110 - 22 = 88 psig) with reduced stresses in the TSC and is, therefore, acceptable. SAR Section 3.7.3.3 considers the buoyancy and the drag force associated with the flood water velocity and determines that a water velocity of 21.9 ft/sec is required to overturn the concrete cask. This corresponds to a factor of safety of 1.46 against overturning of the concrete cask, based on the design basis flood water velocity of 15 ft/sec (21.9/15 = 1.46). The maximum stress in the concrete due to the drag force is calculated to be 17.2 psi tension and compression, which is insignificant for the concrete with the compressive strength of 3,800 psi.

3.5.2 Tornado Wind and Tornado-Driven Missiles

SAR Section 3.7.3.2 evaluates the structural performance of the MAGNASTOR system under the design basis tornado winds and tornado-driven missiles, including the design wind pressure calculation in accordance with ANSI/ASCE 7-93. Local damage to the concrete cask shell is assessed using a formula developed in Report NSS 5-940, A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects, and the concrete shear capacity is evaluated, per ACI 349-85.

At a tornado wind speed of 360 mph, the SAR calculates an effective pressure load of 36.1 kips as applied on the concrete cask. This results in a factor of safety of 2.44 against overturning, considering only two-thirds of the dead load is effective, per ASCE 7-93, for developing the stabilizing moment for the free standing concrete cask. The maximum stress in the concrete due to the wind pressure drag force is calculated to be 19.1 psi tension or compression, which is insignificant for the concrete with the compressive strength of 3,800 psi. This is acceptable. Furthermore, the staff agrees with the SAR assessment that a detailed analysis of the TSC is not needed for the impact of a 1-inch diameter steel sphere missile, which cannot directly enter the concrete cask interior to hit the TSC.

The SAR calculates a penetration depth of 5.82 inches for a 280 lb, 8-inch diameter armor piercing shell traveling at 185 ft/sec and determines that scabbing will not occur in the 26.51-inch thick concrete shell. For the same armor piercing shell impacting the 3/4-inch carbon steel top plate of the 6.75-inch deep lid assembly, the SAR determines that a 0.65-inch steel cover plate is adequate in preventing plate perforation with a factor of safety of 1.15 (0.75/0.65 = 1.15).

Under the high energy deformable missile of 4,000 lbs impacting the concrete cask at 126 mph, the SAR computes a cask rotation of 4.5 degrees. The corresponding restoring moment after missile impact is calculated to be 1.04 $\times 10^6$ ft-lbs, which is greater than the tornado wind moment of 3.38 $\times 10^5$ ft-lbs. Considering an impact force of 508.8 kips associated with the 4,000-lb missile impacting flush with the top of the concrete shell, the SAR estimates a required concrete cross section area of 1.3 ft^2, which is less than the available concrete area of 20 ft^2 to resist shear failure, and is acceptable. Therefore, the staff concurs with the SAR conclusion that the concrete shell alone has sufficient capacity to withstand the high energy missile impact force.

3.5.3 Earthquake

SAR Section 3.7.3.4 evaluates seismic stability of the concrete cask against tipover, assuming that, at the surface of a storage pad, the peak vertical acceleration is two-thirds of the horizontal acceleration. Considering the restoring moment against the overturning moment and the seismic input combination criteria of ASCE 4-86, "Seismic Analysis of Safety-related Nuclear Structures," the SAR determines that the concrete cask will not overturn for the a maximum pad surface horizontal motion of less than 0.41 g. On this basis, the staff agrees with the SAR conclusion that, after including a 1.1 factor of safety, the MAGNASTOR storage system is stable against tipover for the design earthquake defined by a maximum storage pad horizontal motion of 0.37 g (0.41/0.37 = 1.1) with corresponding vertical motion of 0.25 g (0.37 x 0.67 = 0.25 g).

The SAR has not evaluated the conditions for which the concrete cask can be demonstrated seismically stable against sliding for a design earthquake. As such, in deploying the MAGNASTOR system, the cask user should demonstrate that, during the design earthquake, the casks will not slide off the concrete storage pad. In accordance with the NUREG-1536 guidance, the user should also demonstrate that impacts between casks are precluded or are considered as an accident event for which the cask must be shown to be structurally adequate.

By considering a bounding seismic load of 0.5 g in the horizontal and 0.5 g in the vertical direction, the SAR uses conservative assumptions to calculate the maximum compressive stress of 138 psi in the concrete, which is acceptable for the cask with the concrete compressive strength of 3,800 psi.

3.5.4 Snow and Ice

The maximum snow load of about 10,000 lbs applied at the concrete cask top is much smaller than the loaded transfer cask weight as a live load of 230,000 lbs used in evaluating its effects on the concrete cask. Therefore, the staff concludes that the snow and ice load effects are negligible.

3.6 Evaluation Findings

The NRC staff reviewed the SAR evaluation of the structural performance of the MAGNASTOR system for compliance with 10 CFR Part 72. The review considered the regulation, appropriate Regulatory Guides, applicable codes and standards, and accepted engineering practices. Based on the NRC staff's review of information provided in the MAGNASTOR system application, the staff finds the following:

The NRC staff concludes that, with the exception to the performance of the fuel baskets during the cask tipover event, the MAGNASTOR system will allow safe storage of spent fuel on the basis of the findings as follows.

F3.1 The SAR 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, nor off-normal, conditions analyzed will result in damage to the system that will prevent retrieval of the stored spent nuclear fuel. However, this finding in the structural review area is contingent upon the acceptable resolution of thermal analyses needed to demonstrate that material temperature limits will not be exceeded, as described in Section 4 of this staff evaluation.

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 Staff evaluation.

F3.4 The MAGNASTOR cask and all SSCs important to safety are evaluated to demonstrate with reasonable assurance that they will maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

4.0 THERMAL EVALUATION

The objective 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, off-normal and accident conditions. This objective includes confirmation that the temperatures of the fuel cladding will be within acceptable limits throughout the transfer and storage periods to protect the cladding against degradation, which could lead to gross rupture, during normal, off-normal, and accident conditions.

NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” Section 4.0, “Thermal Evaluation,” and Interim Staff Guidance document ISG-11, Revision 3, specify the review criteria to be used by NRC staff in performing technical evaluations of applications under 10 CFR Part 72. The purpose of the review is to confirm that the application provides sufficient assurance that the cask system is designed to prevent fuel cladding degradation under normal, off-normal and accident conditions, including loading and transfer of the SNF. This includes confirmation that the thermal design of the cask has been evaluated using acceptable analytical methods. This preliminary staff evaluation is based on the MAGNASTOR application, as updated through Revision 6D of the SAR (September 2006). The staff has identified three deficiencies in the updated SAR as further discussed in this section. Consequently, the staff has not approved the thermal evaluation for the MAGNASTOR system.

4.0.1 Thermal Cycling During Vacuum Drying

The staff has determined that the applicant has not demonstrated, at this time, that the temperature differential criterion of ISG-11, Revision 3, will be met for all operating conditions described in the MAGNASTOR SAR, as updated. Specifically, the vacuum drying time limits in Table 9.1.3 of the SAR may not ensure that the maximum cladding temperature differential of 117°F will be met if thermal cycling (repeated heatup/cooldown cycles) occurs during vacuum drying operations. The 117°F temperature criterion is based upon limiting the degree of super-saturation required for the precipitation of hydrides and subsequent cladding failures, during short thermal cycles. The operating procedures and vacuum drying times described in Chapter 9 of the SAR do not appear to address this criterion. In addition, Table 4.4-4 of the SAR presents the predicted maximum fuel cladding temperatures for the different transfer phases during canister loading and preparation activities. This table shows that the vacuum phase peak temperature is 715°F, the helium phase peak temperature is 487°F, and the canister loading into the storage cask phase peak temperature is 690°F. Thus, the analyses appear to indicate that the temperature differential criterion of ISG-11, Revision 3, could be exceeded during normal operation, potentially affecting cladding integrity.

The SAR should provide appropriate supporting analyses to demonstrate with reasonable assurance that this limit will not be exceeded, given the description of the various loading operations and the proposed vacuum drying times in Chapters 8 and 9 of the SAR. The staff will make a final determination on the acceptability of the analyses for thermal cycling during vacuum drying for MAGNASTOR once this deficiency is addressed in an updated SAR.

4.0.2 Transfer Cask Heat-Up Rate

Section 4.4.1.5 of the MAGNASTOR SAR describes the applicant's thermal evaluation for moving the loaded canister from the transfer cask to the storage cask. The SAR indicates that during this phase, operations are time-limited, as only natural convection is relied upon to ensure that the fuel cladding is maintained at acceptable temperatures. The applicant compares this phase to the case of the canister in the concrete storage cask, with all vents blocked, and indicates that the peak fuel clad temperature calculated for the latter case is bounding for the canister in the transfer cask.

The NRC staff finds that the applicant has not sufficiently demonstrated, at this time, that the results of the concrete storage cask blocked-vent configuration conservatively represent the heat-up rate of spent fuel for all cases during transfer of the TSC from the transfer cask into the storage cask. The heat-up rate is important in determining the allowable completion times for transfer without exceeding short-term cladding temperature limits. The SAR needs to include a comparison of heat-up rates using separate transfer cask and storage cask thermal models to demonstrate that the blocked-vent storage cask scenario is bounding for all cases; or, alternatively, a specific analysis of the transfer cask thermal behavior could be performed. A comparison of the thermal conductivities of the transfer and storage casks is not sufficient by itself, because other complex phenomena and properties of both casks, such as cask heat capacities, need to be considered in the thermal performance analyses. The staff will make a final determination on the acceptability of the transfer cask heat-up rate analysis for MAGNASTOR once this deficiency is addressed in an updated SAR.

4.0.3 Drying Criteria and Bases for MAGNASTOR Drying Systems

In conjunction with the two issues discussed above, the SAR needs to be revised to clarify the bases for: (1) the vacuum drying pressure criteria; (2) the helium drying dew point and temperature criteria; and (3) the Pressurized Helium Drying System functional description and acceptance testing. NAC provided an information supplement on November 28, 2006, that generally addressed these issues. The technical bases provided within this information supplement should be incorporated into the SAR, as appropriate. The staff will make a final determination on the acceptability of the drying criteria and bases for MAGNASTOR once this deficiency is addressed in an updated SAR.

4.1 Cask System Thermal Design

4.1.1 Design Features

Section 4.1 of the MAGNASTOR SAR discusses the thermal evaluation of the TSC, concrete cask, and a transfer cask. For the interim storage configuration, the fuel is loaded in a basket structure positioned within the TSC. The TSC is placed in the concrete cask, which provides passive radiation shielding, structural protection and natural convection cooling. The thermal performance of the concrete cask containing a loaded TSC with design basis fuel, and the performance of the transfer cask containing a loaded TSC with design basis fuel are evaluated in this section. The thermal evaluation considers normal conditions and off-normal and accident events of storage. Each of these conditions can be described in terms of the environmental temperature, use of solar insolation, and the condition of the air inlets as shown in Table 4.1-1. For the transfer operation evaluation, a separate model, including the optional use of a TSC cooling system is used, or no additional annulus cooling is used. The evaluation of the different phases of the transfer operation is accomplished by altering the properties of the medium in the canister to correspond to water, helium or vacuum. Additional information is provided in this SAR section.

In order for the heat from the stored spent fuel assemblies to be rejected to the ambient via the concrete cask or the transfer cask, the decay heat from the spent fuel assemblies must be transferred to the TSC surface. The MAGNASTOR baskets for the PWR and the BWR fuel assemblies rely on all three heat transfer modes—radiation, conduction, and convection—to transfer the heat to the TSC surface. The basket design enhances convective heat transfer. Helium is used as the backfill gas in the TSC, because its thermal conductivity is better than other allowable backfill gases. Since the basket is comprised of full-length carbon steel tubes, it provides a significant path for conduction heat transfer. Radiation is a significant mode of heat transfer in the fuel region and between the outer surface of the basket and the TSC shell.

The significant thermal design feature of the concrete cask is the passive convective airflow around the outside of the TSC. Cool (ambient) air enters at the bottom of the concrete cask through four air inlets. Heated air exits through the four air outlets in the upper concrete cask body. Radiant heat transfer occurs from the TSC shell to the concrete cask liner, which then transmits heat to the annular airflow. Conduction through the concrete cask, although not significant, is included in the analytical model. Natural circulation of air through the concrete cask annulus, in conjunction with radiation from the TSC surface, maintains the fuel cladding temperature and all component temperatures below their design limits.

4.1.2 Design Criteria

The MAGNASTOR design basis heat load is 35.5 kW for 37 PWR fuel assemblies. The PWR fuel basket can accommodate a uniform heat load of 959 W per assembly, or a preferential pattern. The preferential loading pattern 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. This configuration enhances convection, while not incurring the penalty from the maximum heat-generating assemblies being in the center of the basket region. The BWR fuel basket can accommodate 87 fuel assemblies with a uniform design basis total heat load of 33 kW, or 379 watts per assembly.

The thermal evaluation applied different component temperature limits and allowable stress limits for long-term conditions versus short-term conditions. Normal storage is considered to be a long-term condition. Off-normal and accident events are considered to be short-term conditions. Thermal evaluations are performed for the design basis PWR and BWR fuels for all design conditions. The maximum allowable material temperatures for long-term and short-term conditions are provided in Table 4.1-2.

During normal conditions of storage and off-normal and accident events, the concrete cask must reject the decay heat from the TSC to the environment without exceeding the system components' temperature limits. In addition, to ensure fuel rod integrity for normal conditions of storage, the spent fuel must be maintained at a sufficiently low temperature in an inert atmosphere to preclude thermally-induced fuel rod cladding deterioration. To preclude fuel degradation, the maximum cladding temperature under normal conditions of storage and canister transfer operations is limited to 752°F (400°C) per ISG-11. The maximum cladding temperature for off-normal and accident events is limited to 1,058°F (570°C). For the structural components of the storage system, the thermally-induced stresses, in combination with pressure and mechanical load stresses, are limited to the material allowable stress levels. Thermal evaluations for normal conditions of storage and canister transfer operations are presented in SAR Section 4.4. The finite element method is used to compute the effective properties for the basket and fuel region. The thermal solutions for the concrete cask and transfer cask are obtained using finite volume methodology. Thermal models used in the evaluation of normal and transfer conditions are described in a later Section. A summary of the thermal evaluation results for normal conditions of storage is provided in Table 4.4-3, for the PWR and the BWR cases and the maximum fuel cladding temperatures for the different phases of the transfer operations are presented in Table 4.4-4. Thermal evaluation results for off-normal and accident events are also presented in SAR Sections 4.5 and 4.6. The results demonstrate that the calculated temperatures are less than the allowable fuel cladding and component temperatures for all normal storage conditions and for short-term events.

The staff found the description of the cask system thermal design generally acceptable, except for the identified deficiencies with the analyses related to transfer conditions, as it relates to satisfying ISG-11 criteria, as described in Section 4.0 of this staff evaluation. The staff will make a final determination on the acceptability once these deficiencies are addressed in an updated SAR.

4.2 Thermal Model Specifications

4.2.1 Model Configuration

Analysis models used for the thermal evaluation of both the PWR and BWR design configurations are described in SAR Section 4.4.1. As stated by the applicant, the methodology conservatively reflects the heat transfer performance provided by the MAGNASTOR design. The designs for both the PWR and the BWR fuel systems utilize the same method of passive heat rejection to transfer the decay heat from the fuel assemblies to the ambient environment. The TSC is a closed system, whereas the concrete cask and the transfer cask are open to the environment. Internal to the TSC, the decay heat is transferred from the fuel assemblies 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 and BWR 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. 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 downcomer regions formed between the TSC shell and the basket side weldments. The gas exiting the downcomer 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 downcomer 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. 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 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. Additionally, radiation contributes to the heat being transferred from the outer basket surface to the TSC shell. Additional information is provided in the SAR.

The staff found the description of the models generally acceptable, except for the identified deficiencies with the analyses related to transfer conditions and canister drying, as described in Section 4.0 of this Staff evaluation. The staff will make a final determination on the acceptability of these analyses once the deficiencies are addressed in an updated SAR.

4.2.2 Material Properties

Material properties used in the analytical model are separated into two categories. One category represents materials specified in the design that are explicitly represented in the model and are tabulated in SAR Chapter 8. The second category represents effective properties of the basket and fuel region, which are calculated using the thermal models presented in SAR Section 4.4.1.

The staff found the material properties used by the applicant in the thermal analyses to be generally acceptable. The staff will document its final evaluation pending an update to the SAR to address deficiencies described in Section 4.0 of this staff evaluation.

4.2.3 Boundary Conditions and Thermal Loads

The applicant described the conditions and loads in Section 4.4 of the SAR. Analysis results are displayed in several tables. The staff found the description of bounding conditions and thermal loads generally acceptable, except for the assumptions regarding transfer cask heat-up rate as described in Section 4.0.2 of this Staff evaluation. The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

4.2.3.1 Normal Storage Conditions

The applicant described the conditions in Section 4.4 of the SAR. The finite element and finite volume methods are 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 Dynamic (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 motion of fluid, as well as by the specification of a film coefficient for a surface boundary condition.

The staff found the descriptions and analyses generally acceptable. The staff will document its final evaluation pending an update to the SAR to address deficiencies described in Section 4.0 of this Staff evaluation.

4.2.3.2 Transfer Conditions

The applicant described the thermal analysis for transfer conditions in Section 4.4.1.5 of the SAR. During the transfer condition, the TSC in the transfer cask is subjected to four separate conditions: (1) water phase when the lid is being welded to the TSC; (2) the drying phase in which pressurized helium drying or vacuum drying can be used to remove moisture from the TSC; (3) the helium backfill phase when the TSC closure is completed and the transfer cask annulus flow system is operating; and (4) the operation of loading the helium-backfilled TSC into the concrete cask without the transfer cask annulus flow system operating. The staff found the descriptions generally acceptable. However, the staff has identified deficiencies with the analyses related to transfer conditions and canister drying, as described in Section 4.0 of this evaluation. The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

4.2.3.3 Accident Conditions

SAR Section 4.6 presents the evaluations of the thermal behavior for accident design events, which address very low probability events that might occur once during the lifetime of the ISFSI or hypothetical 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 SAR Section 4.6.4. The concrete cask and TSC model described in SAR Section 4.4.1.1 is used for the evaluation of the concrete cask and TSC for these thermal accident events.

The staff found the descriptions of the accident conditions and analyses generally acceptable. The staff will document its final evaluation pending an update to the SAR to address deficiencies described in Section 4.0 of this evaluation.

4.2.3.3.1 Blocked Vent Conditions

SAR Section 4.6.3 evaluates the concrete cask for the transient condition of full blockage of the air inlets at the normal storage condition temperature (100°F). The accident temperature conditions are evaluated using the concrete cask and TSC thermal models described in SAR Section 4.4.1.1. The transient analysis assumes initial normal storage conditions, with the sudden loss of convective cooling of the TSC. This is simulated by removing the inlet and outlet conditions from the model. Heat is then rejected from the TSC to the concrete cask liner only by radiation and convection. The loss of convective cooling to the ambient environment results in a sustained heat-up of the TSC and its contents and the concrete cask. The maximum fuel cladding temperature, maximum basket temperature, and the maximum concrete bulk temperature remain less than the allowable accident temperatures for approximately 72 hours after the initiation of the event. However, the internal pressure in the TSC cavity will reach the analyzed maximum pressure condition of 250 psig in approximately 58 hours after the initiation of a complete blockage event. The evaluation demonstrates that there are no adverse consequences due to this accident, provided that debris is cleared from at least two air inlets within 58 hours, based on the steady state evaluation of the half-blocked air inlet condition in SAR Section 4.5.

An analyzed blockage of all cask inlets and outlets is described in SAR Section 4.6.3. Full solar insolation was applied in addition to the design basis heat load. Since the cask is postulated to be buried, all convective cooling is lost, but conductive cooling from the exterior surface of the cask is considered. As an added conservatism, solar insolation was considered which would not be applicable for a buried cask.

The staff found the description and blocked vent analyses generally acceptable. The staff will document its final evaluation pending an update to the SAR to address deficiencies described in Section 4.0 of this evaluation.

4.2.3.3.2 Fire

As stated in SAR Section 4.6.2, fire may be caused by ignition of flammable material or by an accident involving a transport vehicle. While it is possible that a transport vehicle could cause a fire while transferring a loaded storage cask at the ISFSI, this fire will be confined to the vehicle and will be rapidly extinguished by the persons performing the transfer operations or by the site fire crew. Fuel in the fuel tanks of the concrete cask transport vehicle and/or prime mover (maximum 50 gallons) is the only flammable liquid that could be near a concrete cask, and potentially at, or above, the elevation of the surface on which the cask is supported. The fuel carried by other onsite vehicles or by other equipment used for ISFSI operations and maintenance, such as air compressors or electrical generators, is considered not to be within the proximity of a loaded cask on the ISFSI pad. Site-specific analysis of fire hazards will evaluate the specific equipment used at the ISFSI and determine any additional controls required. The analyzed area is a 15x15-foot square, less the 136 in-diameter footprint of the concrete cask, corresponding to the center-to-center distance of the concrete casks on the ISFSI pad.

With a burning rate of 5 in/hr, the fire would continue for 7.2 minutes, based on the stated assumptions. The fire accident evaluation in this section conservatively considers an 8-minute fire. The temperature of the fire is taken to be 1,475°F, which is specified for the fire accident event in 10 CFR 71.73(c) [3]. The fire condition is an accident event and is initiated with the concrete cask in a normal operating steady-state condition. To determine the maximum temperatures of the concrete cask components, the two-dimensional axisymmetric model of the concrete cask and TSC for the PWR configuration described in SAR Section 4.4.1.1 is used to perform a transient analysis. The PWR configuration is considered to bound the BWR configuration due to the higher initial temperatures of the normal condition.

The initial condition of the fire accident transient analysis is based on the steady-state analysis results for the normal condition of storage, which corresponds to an ambient temperature of 100°F in conjunction with solar insolation (as specified in SAR Section 4.4.1.1). The fire condition is implemented by applying a boundary temperature condition of 1,475°F at the air inlet and the lower surface of the steel plate forming the top of the air inlet for eight minutes. This boundary condition temperature is applied as a stepped boundary condition. During the eight-minute fire, solar insolation is also applied to the outer surface of the concrete cask. At the end of the eight minutes, the temperature at the inlet is reset to the ambient temperature of 100°F. The cooldown phase is continued for an additional 10.7 hours to observe the maximum TSC shell temperature and the average temperature of the TSC contents.

The staff found the description of the fire analyses generally acceptable. The staff will make a final determination on the acceptability once the major deficiencies are addressed in an updated SAR.

4.2.3.3.3 Cask Heatup Analysis

SAR Section 4.6.1 evaluates the concrete cask and the TSC for the accident event of an ambient temperature of 133°F. A steady state condition is considered in the thermal evaluation of the system for this accident event. Using the same methods and thermal models described in Section 4.4.1.1 for the normal conditions of storage, thermal evaluations are performed for the concrete cask and the TSC with its contents for this accident condition. All boundary conditions in the model are the same as those used for the normal condition evaluation, except that an ambient temperature of 133ºF is used. The maximum calculated temperatures of the principal PWR and BWR cask components, with the corresponding allowable temperatures, are provided on SAR page 4.6-1. This evaluation shows that the component temperatures are within the allowable temperatures for the extreme ambient temperature conditions.

The staff found the analysis generally acceptable. The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

4.3 Pressure Analyses

The applicant described the pressure analyses in Sections 4.6.4 and 4.4.4 of the SAR. The staff found the analyses generally acceptable, except for the identified deficiencies with the analyses related to transfer conditions and canister drying, as described in Section 4.0 of this evaluation.

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 and backfill gases, 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.

Maximum internal pressures are determined for the BWR fuel in the same manner as those documented for the TSC containing PWR fuel. Primary differences for the BWR evaluations, versus those for the PWR, include a rod backfill gas pressure of 132 psig, a maximum burnup of 60,000 MWd/MTU used to generate fission gases, and the absence of neutron poison gases (no nonfuel hardware in the BWR system). The 132 psig rod backfill pressure used in this analysis is significantly higher than the 6 atmosphere (g) maximum pressure reported in open literature. Free volumes, without fuel assemblies, in the TSC containing BWR fuel types are 9,900 and 10,300 liters.

The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

4.3.1 Temperature Calculations

The applicant described the calculations in Sections 4.4.3 and 4.4.4 of the SAR. The staff found the calculations generally acceptable, except for the identified deficiencies with the analyses related to transfer conditions and canister drying, as described in Section 4.0 of this staff evaluation. The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

Normal Conditions of Storage

The temperature distribution and maximum component temperatures for MAGNASTOR for normal conditions of storage are provided in SAR Section 4.4. System components containing PWR and BWR fuels are addressed separately. The temperature distributions for the BWR design basis fuel are similar to those of the PWR design basis fuel and are, therefore, not presented. The temperature distribution for the concrete cask and the TSC containing the PWR design basis fuel for normal conditions of storage, with a uniform heat load, is shown in SAR Figure 4.4-14. The air velocity distribution in the annulus between the TSC and the concrete cask liner for the normal conditions of storage for PWR fuel is shown in Figure 4.4-15. The maximum component temperatures for the normal conditions of storage for the PWR and BWR design basis fuel are shown in SAR Table 4.4-3.

Transfer Condition

The maximum component temperatures for MAGNASTOR during the transfer operation are reported in SAR Section 4.4.3. Since the PWR fuel configuration is considered to be bounding, it is conservative to identify these temperature results for the PWR fuel design basis heat load as the maximum temperatures for the BWR fuel design basis heat load. 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 to be 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 (or the alternative cooling methods) maintains the canister shell at a temperature significantly lower than the temperature corresponding to the normal conditions of storage. Additional information is provided in the applicant’s SAR.

4.3.2 Confirmatory Analyses

The staff reviewed the applicant’s models and calculation options to determine the adequacy of the proposed MAGNASTOR thermal design. Additionally, the staff performed selected confirmatory analyses using the FLUENT finite volume computational fluid dynamics (CFD) code, as an independent evaluation of the thermal analysis and modeling options presented in the applicant’s SAR.

Specifically, the staff's confirmatory evaluation focused on the applicant's modeling options that have the greatest influence and impact on the calculated results. Some of the modeling options the staff considered were the use of a porous media to represent the fuel basket and fuel compartments as homogenized regions characterized only by viscous and inertial resistance coefficients (Ref. 1). Also, the staff independently performed confirmatory analysis and validation to confirm the applicant's assumption on the flow regime used to characterize the air flow through the annular gap between the TSC and the concrete cask. The staff also performed selected scoping calculations to confirm the adequacy of the effective thermal conductivity model proposed by the applicant in the SAR. Based on the review of the applicant's thermal analysis and the staff's own confirmatory analysis, the staff concluded the following regarding applicant's modeling options:

Use of the porous media approach to represent the fuel compartments and fuel basket is acceptable, provided the porous media parameters to characterize the flow are carefully implemented and calculated based on explicit three-dimensional (3-D) flow characterization of the bounding fuel assembly geometry. The staff developed 3-D CFD models to represent the fuel assembly bounding geometry and used two approaches to calculate the flow resistance parameters: pressure drop method and shear stress method. Both methods were applied for sections without flow area changes (i.e. no contractions or expansions). Both approaches are related and should lead to the same values.

The air flow in the inlet and outlet vents and annular gap between the TSC and the concrete inner shell is expected to be in the transitional regime. It is therefore necessary to specify an appropriate turbulence model for the air flow in order to obtain accurate predictions of local velocities and temperatures in the air stream, and local wall temperatures on the surfaces of the annulus and inlet/outlet vent structures. Based on the applicant's calculation and staff's validation efforts, the staff concluded that the flow in the air annular gap is found to be in the transitional region of turbulence. Only turbulence models that are capable of dealing with this region of the flow regime are appropriate for the thermal analysis of ventilated storage casks of the MAGNASTOR design.

The staff's confirmatory calculation of effective thermal conductivity resulted in values that were on the same order of magnitude as compared to the applicant's calculated values. Therefore, the staff has reasonable assurance that the calculated temperatures and associated modeling approach for normal, transfer, and accident conditions, is generally acceptable, except for the identified deficiencies with the analyses related to transfer conditions and canister drying, as described in Section 4.0 of this staff evaluation. The staff will make a final determination on the acceptability once the deficiencies are addressed in an updated SAR.

4.4 Evaluation Findings and Conclusions

F4.1 SSCs important to safety are described in sufficient detail in SAR Sections 1, 2 and 4 to enable an evaluation of their thermal effectiveness [10 CFR 72.24(c)(3)].

F4.2 The staff does not have at this time 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 Through the analysis, staff developed reasonable assurance that the MAGNASTOR system is designed with a heat-removal capability having testability and reliability consistent with its importance to safety [10 CFR 72.128(a)(4)].

F4.4 By analysis, the staff has reasonable assurance that the decay heat loads were determined appropriately and accurately reflect the burnup, cooling times, and initial enrichments specified [10 CFR 72.122].

F4.5 By analysis, the staff does not have at this time reasonable assurance that the MAGNASTOR system provides adequate heat removal capacity without active cooling systems [10 CFR 72.236(f)].

F4.6 By analysis, the staff does not have at this time reasonable assurance that the temperatures of the cask components and the cask pressures under normal and accident conditions were determined correctly [10 CFR 72.122].

F4.7 The staff has not concluded at this time that the thermal design of the MAGNASTOR system as described in the SAR is in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design does not provide at this time reasonable assurance that the MAGNASTOR system will allow safe storage of spent fuel for a certified life of 20 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.

4.5 References

1. FLUENT 6.3 User's Guide. Fluent Inc. September 29, 2006.

5.0 SHIELDING EVALUATION

The NRC staff has not yet documented its evaluation in this area.

6.0 Criticality Evaluation

The criticality review ensures that the contents will remain subcritical under all credible normal, off-normal, and accident conditions encountered during handling, packaging, transfer, and storage. These objectives include a review of the criticality design criteria (including control features and fuel specifications), a verification and review of the configuration and material properties for the MAGNASTOR, and a review of the criticality analyses including computer programs, benchmark comparisons, and multiplication factors calculated in this request.

The applicant requested approval of a new storage system for spent commercial reactor fuel assemblies containing uranium dioxide. Only those features 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 meets the following regulatory requirements: 10 CFR 72.124(a), 72.124(b), 72.236(c), and 72.236(g). The staff's review also involved a determination on whether the cask system fulfills the acceptance criteria listed in Section 6 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems." Since the applicant only requested approval to use the MAGNASTOR system for dry storage of spent fuel, no information or statements in the SAR regarding the adequacy of the system for the transport of spent fuel were reviewed or evaluated.

The staff's conclusions, summarized below, are based on information provided in the MAGNASTOR SAR, through Revision 6D, September 2006.

6.1 Criticality Design Criteria and Features

The major components of the MAGNASTOR system are the transportable storage canister (TSC), the concrete storage cask and the lead-shielded transfer cask. Criticality safety in the system design is provided by a combination of fissile mass controls, geometry control (which has not yet been demonstrated, as discussed in Section 3 of this evaluation), fixed neutron absorbers in the basket, and for the PWR fuel, dissolved boron in the water used to flood the canister during fuel loading. The TSC contains either a basket which holds 37 PWR fuel assemblies or a basket which holds 87 BWR fuel assemblies (the BWR basket has 89 cell locations but two are occupied by the drain and vent apparatus). 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. Fissile mass control is provided by limiting the enrichment of the uranium in the fuel assemblies. During loading and unloading of the PWR fuel, a minimum dissolved boron concentration in the water used to flood the canister is specified, depending on the fuel assembly type and the initial enrichment of the fuel loaded. For the BWR fuel, 87 or 82 fuel assemblies are allowed to be stored in the canister, depending on the fuel assembly type and initial enrichment. In the 82 BWR assembly configuration, five of the basket's central cell locations may not contain fuel assemblies.

The staff reviewed the applicant's model descriptions and assumptions, and has not yet determined that they are consistent with the description of the design and contents given in Chapters 1 and 2 of the SAR, pending revised information as identified in Section 6.6 of this evaluation. The staff reviewed the SAR and proposed technical specifications to ensure that the fuel specifications important to criticality safety are included.

6.2 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 and 20 BWR 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 divided into two groups. One group is located in Appendix B of the Technical Specifications and the other group is located in Appendix A to Chapter 1 of the SAR. Section 2.1 of Appendix A to the Technical Specifications, "Approved Contents," lists the fuel parameters and characteristics that are in each of these two groups. The applicant proposed that those parameters listed in the Technical Specifications are more significant to criticality safety and thus could only be changed by an amendment to the Certificate of Compliance (if granted); while those parameters located in the SAR could be changed by the approval of the NRC under the process described in Section 2.2 of Appendix A to the Technical Specifications.

The allowed contents are limited to fuel that is not damaged (intact) and has cladding made from zirconium based alloys only. Damaged fuel is defined in the Technical Specifications as fuel with cladding breaches that have the potential for release of a significant amount of fuel particles or fuel with impaired 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 rod of equal or greater displacement before loading.

The applicant's proposal for which fuel characteristics are specified in the Technical Specifications versus the SAR included a consideration of the guidance in the NRC's NUREG-1745 on standardized technical specifications and the staff finds the proposal generally acceptable.

6.3 Model Specifications

The staff has not formally reviewed the criticality code input files discussed with the applicant; these files need to be formally submitted as part of the revised application.

The key modeling assumptions used by the applicant are: 1) fresh, intact, unburned fuel, 2) fuel pellet density at 96% of theoretical, 3) homogeneous, peak-planar average enrichment in the BWR fuel, 4) no major fuel assembly hardware except for fuel channels, 5) fuel assemblies and the basket do not deform significantly in accidents (structural performance has not yet been demonstrated), 6) no integral burnable poisons, and 7) 75% credit for the ^{10}B content in BORAL and 90% credit for the ^{10}B content in the borated aluminum and metallic matrix composites.

6.3.1 Configuration

The applicant modeled a flooded TSC in the transfer cask and a TSC in the concrete overpack when the exterior of the overpack is flooded by water.

Using the key modeling assumptions listed in Section 6.3 above, the applicant performed sensitivity analyses to determine the fuel rod, fuel assembly, and basket parameter values which maximized k_{eff}. Sensitivity to variations in the following parameters was evaluated: pellet-to-clad gap flooding condition, fuel pellet outer diameter (OD), fuel rod OD, fuel rod clad thickness, fuel rod pitch, channel thickness (BWRs), 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.

As a result of these analyses, the applicant established the following bounding conditions: fresh water flooding in the pellet-to-clad gap, maximum pellet OD, minimum fuel rod OD, minimum clad thickness, maximum fuel rod pitch, maximum channel thickness, minimum fuel tube cross section, maximum fuel tube thickness, maximum poison plate thickness, minimum poison plate width, all fuel assemblies shifted toward the basket center, and full density water in the TSC with no significance to partial flooding, and full water density outside the transfer cask. 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 very small, this dimension was not included in the fuel parameter specifications, but the number of guide tubes was retained. These bounding conditions were included in the final design calculations used to set limits on the allowed maximum initial enrichments.

A minimum limit on the fuel tube pitch in the basket is included in the Technical Specifications, but it has not been demonstrated that this limit will be maintained under the accident conditions. Also, the revised application needs to provide a sample input file and confirm that the minimum specified tube pitch was used in the calculations relied upon to determine the allowed maximum enrichments for each fuel type.

The staff questioned whether a minimum pellet OD should be specified in addition to a maximum OD. Sensitivity analyses on this parameter showed mixed results depending on the specific fuel type, particularly when the gap is dry or contains borated water. Although the final design calculations assumed the more reactive case of a fresh water flooded gap, the staff considered a dry gap to be more likely, and based on risk-informed considerations, finds that a limit on the maximum pellet diameter only is acceptable.

In response to the staff's RAIs, the applicant modeled the basket with the optional peripheral poison plates removed and with the new arrangement of poison plate weld posts. The revised SAR should include a statement to confirm that this configuration was used when determining the maximum allowed initial enrichment for each fuel type.

In the 82 BWR configuration, five of the center basket cells which form an "X" pattern may not contain fuel assemblies.

6.3.2 Material Properties

The applicant's analysis used the values from the SCALE 4.4 standard composition library for the stainless steel and carbon steel components in the cask's structure.

The design includes the option of three different absorber plate materials (i.e., Boral, borated aluminum alloy, and borated metal matrix composite (MMC)) for use in the MAGNASTOR basket. Boral is given credit for 75% of its ^{10}B content, and both the borated aluminum alloy and the borated MMC are given credit for 90% of their ^{10}B content. To justify the higher credit for ^{10}B content given to the borated aluminum alloy and MMC, the applicant will subject plates made of these materials to an extensive and comprehensive program of qualification and acceptance testing. This specification and acceptance testing of the absorber sheets is discussed further in Section 8 of this staff evaluation.

The minimum areal density of ^{10}B required in the absorber plates is determined from the effective areal density used in the criticality analysis and the percent credit of ^{10}B content given for the specific material. These areal densities are 0.036 g $^{10}B/cm^2$ in the PWR basket and 0.027 g $^{10}B/cm^2$ in the BWR basket.

Specifications for the minimum boron concentrations in the water during wet loading and unloading of PWR basket are given in Table 2-3 of Appendix B to the Technical Specifications as a function of initial uranium enrichment.

6.4 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 of combinations of these parameters did significantly affect system reactivity. The applicant captured these effects by using the most reactive combinations of parameter changes in the final analysis that is compared against the USL for each hybrid assembly.

6.4.1 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 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.

6.4.2 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 SAR and proposed Technical Specifications (TS).

Final calculations were performed with the parameter values which maximize k_{eff} and all values were lower than the applicable USL, although a number of assemblies had a maximum k_{eff} that nearly equaled the USL (the margin was less than a single standard deviation). This conclusion hinges on a confirmation of the applicant's incorporation of modifications to the poison plates (both attachment scheme and number of plates present) and the minimum fuel tube pitch into the final criticality analysis.

6.4.3 Benchmark Comparisons

The applicant selected 186 benchmark experiments from the International Handbook of Evaluated Criticality Safety Benchmark Experiments. The benchmark data were tested for parametric trends with respect to the following variables: 1) ^{235}U enrichment, 2) fuel rod pitch, 3) fuel pellet outer diameter, 4) fuel rod outer diameter, 5) hydrogen-to-uranium ratio, 6) soluble boron concentration, 7) spacing between fuel assemblies, 8) boron-10 density in the absorber plates, and 9) energy of average neutron lethargy causing fission (EALCF).

While no statistically significant bias trends were found for any of the parameters, the applicant initially proposed using the trend line for the parameter with the highest correlation coefficient (EALCF) when determining the upper subcritical limit (USL) for the calculated values of k_{eff}. Although this is in keeping with the recommendations in NUREG/CR-6361, the staff noted that the trends which did exist for the most of the other parameters were nearly flat. The staff further observed that using the trend line for EALCF to establish the USL would artificially raise the USL at higher values of EALCF. In view of the staff's determination, the applicant used a revised method which accounted for the near flat trends in the other parameters and resulted in a constant USL value.

The revised application should clarify how the data points used in the final trend evaluations for the nine different parameters above were selected. The previous application did not provide a sufficient explanation.

The applicant reviewed benchmark input files for modeling consistency with cask models and the choice of code options.

6.5 Criticality Evaluation Summary

The applicant used three-dimensional calculational models in its criticality analyses. Sketches of the models are given in the SAR as discussed above. The models are based on the engineering drawings in the SAR. The design-basis, off-normal and accident events do not affect the design of the cask from a criticality standpoint. Therefore, the calculational models for the normal, off-normal, and accident conditions are the same. The final resolution of the structural issues may change this criticality evaluation.

The staff used the CSAS/KENO-VI codes in the SCALE suite of analytical codes to perform confirmatory analyses. These calculations used the 44-group cross-section set in SCALE and ran 500,000 neutron histories. The confirmatory analyses included both PWR and BWR baskets, different fuel types, and several boron concentration and enrichment combinations. The results of the staff's confirmatory calculations were bounded by or in close agreement with the applicant's results. All of staff's results fell below the acceptance criterion of 0.95 for k_{eff}.

This conclusion is based on the current state of the review and may change, pending the applicant's resolution of structural issues.

6.6 Evaluation Findings

The staff is unable to make formal findings in the criticality area based on the information provided to date. The applicant must submit a revised SAR to resolve the identified structural issues, as well as the criticality analysis issues specified in the NRC's letter dated February 15, 2007, before the staff can complete its criticality evaluation.

7.0 CONFINEMENT EVALUATION

The staff reviewed the MAGNASTOR system confinement features and capabilities to ensure that any radiological releases to the environment will be within the limits established in 10 CFR Part 72, and that the spent fuel cladding will be protected against degradation that might lead to gross ruptures during storage, as required in 10 CFR 72.122(h)(1). This application was also reviewed to determine whether the MAGNASTOR system fulfills the acceptance criteria listed in Section 7 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," and applicable Interim Staff Guidance (ISG) documents. The staff's conclusions are based on information provided in the MAGNASTOR system Safety Analysis Report (SAR).

7.1 Confinement Boundary

The MAGNASTOR confinement boundary consists of a welded stainless steel transportable storage canister (TSC). Note that the TSC has not yet been submitted nor approved for transport. It is designed to preclude release of radioactive material for all design basis conditions, including preventing failure from maximum internal pressure.

The TSC is a welded ductile stainless steel canister, composed of a ½ inch thick cylindrical shell, 2-3/4 inch thick bottom plate, and 9 inch thick closure lid. The closure lid meets the redundant sealing requirements of 10 CFR 72.236(e) by having a welded closure ring (3/4 inch thick) behind the lid to shell weld, and the vent and drain port covers have dual welded plates (each ½ inch thick).

7.1.1 Confinement Vessel

All welds except for the closure lid are full penetration and volumetrically examined. The closure lid to shell weld is a partial penetration weld and is liquid penetrant examined on its root, mid-plane, and final surfaces . The closure ring is attached to the lid and shell via two partial penetration welds that have their final surface liquid penetrant examined. The port cover plates are beveled seal welds and are liquid penetrant examined on their final surface.

Other testing is performed on the confinement boundary to ensure its integrity. During manufacture, the canister assembly (i.e. shell and bottom plate) is leak tested to the ANSI 14.5-1997 leaktight criterion of 10^{-7} ref cm^3/sec. Subsequent to making the closure lid to shell weld, but prior to installing the closure ring, a hydrostatic pressure test is performed to a minimum pressure of 130 psig, in accordance with Subsection NB of the ASME Code.

In accordance with ISG-18, no leak test is to be performed on the closure lid to shell weld because it is a multiple pass weld of ductile stainless steel material made in accordance with the guidance in ISG-15 and it is not pressurized at the time of welding. However, this exception from leak testing does not apply to the welds for the port cover plates that could potentially be under pressure. Therefore, the port cover plates are leak tested to the leaktight criteria.

A confinement boundary with no leakage is necessary for preventing release of radioactive material and for containing the pressurized helium gas in the canister for the removal of decay heat from the fuel by natural convection.

7.1.2 Confinement Penetrations

The cylindrical confinement boundary is welded in its entirety. However, beneath the redundant port cover plates for the vent and drain lines are quick disconnect valves that are used to drain, dry, and pressurize the canister with helium. These valves are not part of the confinement boundary, but are employed to facilitate the aforementioned operations.

7.1.3 Seals and Welds

There are no bolted seal closures of any kind used in the confinement boundary for the MAGNASTOR system.

All welding is done in accordance with Subsection NB-4000 of the ASME Code, with exceptions listed in Table 2.1-2 of the SAR. Weld procedures, welders and welding machine operators shall be qualified per ASME Code Section IX. Shop and field examinations of the confinement boundary shall be performed by personnel qualified in accordance with American Society of Nondestructive Testing Recommended Practice SNT-TC-IA.

Specific weld examinations and tests are described in above Section 7.1.1.

7.1.4 Closure

Closure of the canister consists of installing the closure lid, followed by the port cover plates and finally the closure ring. This design allows for redundant sealing of the confinement system, as required by 10 CFR 72.236(e).

7.2 Requirements for the Normal Conditions of Storage

The normal conditions of storage include transfer operations and expected environmental conditions associated with placement of the canister within the concrete cask on the storage pad.

7.2.1 Release of Radioactive Material

Since the confinement boundary is an all welded canister in accordance with ISG-15, the presumption of no credible leakage is also met, providing the criteria of ISG-18 are satisfied. Therefore, no radioactive material is released. However, since the port cover plates are only single layered seal welds that aren’t examined by a multilayer liquid penetrate examination and are potentially under pressure, they do not qualify for the ISG-15 test exception and are leaktested to the leaktight criteria.

7.2.2 Pressurization of the Confinement Vessel

The staff reviewed and independently calculated the maximum normal pressure in the vessel; based upon estimates of the moles of gas in the canister (assuming 1% cladding failure), free volume within the canister, and using the NAC calculated bulk average gas temperature of 467°F. This staff calculation verified the maximum normal operating pressure of 110 psig, based upon the validity of the assumed bulk average gas temperature. A similar review of the off normal conditions was performed and resulted in a maximum pressure of 114 psig, assuming a 10% rod failure based on a canister backfill temperature of 485°F. Note that per the applicant's thermal analysis, the transfer operation gas temperatures are bounded by the normal conditions (see SAR Tables 4.4-3 and 4.4-4), since an active cooling system is employed during transfer operations.

7.3 Confinement Requirements for Accident Conditions

As the confinement system is designed and tested to leaktight criteria (except for shell to lid closure weld, which meets the criteria for test exception in ISG-15), no radiological release is postulated for design basis accident conditions. Also, the pressure rise in the canister resulting principally from an assumed 100% failure of cladding is shown to be less than the canister's accident pressure rating of 250 psig.

7.4 Evaluation Findings

Based on the NRC staff's confinement review of information provided in the NAC MAGNASTOR application, the staff finds the following:

F7.1 Chapter 7 of the SAR describes the MAGNASTOR system confinement structures, systems, and components important to safety in sufficient detail to permit evaluation of their effectiveness.

F7.2 The design of the MAGNASTOR Transportable Storage Canister (TSC) provides a redundant sealing system for the confinement system.

F7.3 The design of the MAGNASTOR TSC adequately protects the spent fuel cladding against degradation that might otherwise lead to gross ruptures. However; this finding in the confinement review area is contingent upon the acceptable resolution of thermal analyses needed to demonstrate that material temperature limits will not be exceeded, as described in Section 4 of this staff evaluation.

F7.4 Confinement boundary integrity will be ensured through: (1) a hydrostatic test of the shell to lid closure weld to provide additional assurance as to the weld's structural integrity commensurate with the other confinement boundary welds; (2) operating procedures and technical specifications requiring shut down of the vacuum pump to ensure an accurate canister vacuum pressure rise test; and (3) leak testing of the port covers.

F7.5 The staff concludes that the MAGNASTOR confinement boundary has been designed and tested to satisfy all the applicable confinement requirements of 10 CFR Part 72.

8.0 MATERIALS EVALUATION

8.1 Material Selection

The applicant provided a general description of the materials of construction in the MAGNASTOR SAR, Sections 1.1, 1.2, 1.3, 2.1, 3.1, and 8.1. Additional information regarding the materials, fabrication details and testing programs can be found in SAR Section 10.1. The staff reviewed the information contained in these sections; and the information presented in the SAR drawings, to determine whether the MAGNASTOR system meets the requirements of 10 CFR 72.24(c) (3) and (4), 72.122(a), (b), (h) and (I), and 72.236(g) and (h).

The following aspects were reviewed: materials selection (i.e., steel to be used and absorbers to be used in the cask); brittle fracture; applicable codes and standards; weld design and specifications; corrosion (i.e., environmental; chemical and galvanic; and uniform and localized corrosion), and cladding integrity. Additionally, staff verified that materials selections are appropriate for the environmental conditions to be encountered during loading, unloading, transfer and storage operations (i.e., vacuum drying of the canister).

8.1.1 Structural Materials

Structural components of the MAGNASTOR TSC (shell, bottom plate, closure lid, and port covers) are fabricated from austenitic stainless steel (ASME SA 240, Type 304/304L). The applicant may use ASME 182, Type 304 stainless steel as a substitute material for the SA240 Type 304 stainless steel for the closure lid, provided that the SA182 material has yield strength and ultimate strength greater than, or equal to, those of the SA240 material. These types of steels were selected because of their strength, ductility, resistance to corrosion and metallurgical stability. Because there is no ductile-to-brittle transition temperature in the range of temperatures expected to be encountered for this steel, its susceptibility to brittle fracture is negligible. The staff concludes that the selection of these materials for the TSC meets the regulatory requirements.

The TSC basket is a welded assembly of carbon steel fuel compartment boxes, designed to accommodate PWR and BWR fuel assemblies. The sections of the steel fuel compartments are fusion welded to structural plates, sandwiched between the box sections. The fuel basket is primarily fabricated from carbon steel. The major materials of construction used in the fabrication of the fuel baskets are as follows: ASME SA 537, Class 1 carbon steel (for the basket supports, plates and gussets), and ASME SA 537, Class 1, carbon Steel for the fuel tubes. The carbon steels used in the fuel baskets are selected based on their strength and thermal conductivity. The staff reviewed the open literature for these materials and concluded that these materials are also acceptable for use in the TSC. See the discussion in Section 8.2 of this staff evaluation for the fracture toughness evaluation.

The reinforced concrete cask structure is designed to provide environmental protection and radiological shielding for the TSC. The main structural components of the concrete cask are fabricated with reinforced concrete and carbon steel. The concrete cask's components are fabricated from American Society for Testing and Materials (ASTM) A 36 steel, a commonly used steel for structural applications, and ASTM A 615 reinforcing steel. The concrete to be used for fabrication is ASTM C150 Type II Portland Cement. The applicant has specified a minimum compressive strength and density of 4000 psi and 145 lb/ft^3, respectively. Based on the information provided in the SAR and the staff's independent evaluation, the staff concludes that the concrete materials meet the requirements of ACI 318, and the materials comprising the concrete cask are suitable for structural support, shielding, and protection of the TSC from environmental conditions.

The transfer cask is primarily a shielding cask used to handle the TSC. The transfer cask structural components for the inner and outer shells are fabricated from ASTM A 588, low alloy steel, while the trunnions and shield doors are primarily fabricated from ASTM A 350, low alloy steel. These types of steel are common structural materials. The staff concludes that this steel is suitable for use in the transfer cask.

Note that the shielding of the cask incorporates a multiwall (steel/lead/NS-4-FR/steel) design. The lead and NS-4-FR have been previously evaluated by the staff and are found to be acceptable for this application. NS-4-FR is an epoxy resin material for neutron shielding applications.

8.1.2 Nonstructural Material

Criticality control in the PWR and BWR TSC basket is achieved by including neutron absorbers (also called poisons). The neutron absorber plates provide criticality control and a heat conduction path from the fuel assemblies to the canister shell. Neutron poison plates are composed of: 1) a borated aluminum alloy, 2) a boron carbide aluminum metal matrix composite, or 3) Boral. In accordance with SAR Sections 8.8 and 10.1.6 and the Technical Specifications, appropriate qualification and acceptance testing will be used to ensure that the neutron absorbers have the minimum specified ^{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) will be fabricated from materials that can perform well under all conditions of service during the license period. The lead 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 concludes that the selection of neutron absorbers and shielding materials will ensure that these materials will be sufficiently durable during service life of the cask. More detailed discussion on the qualification and acceptance testing of these materials is provided in Section 8.9 of this staff evaluation.

8.2 Fracture Toughness

The TSC structural material is austenitic stainless steel. 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, carbon steel. The applicant has stated 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 applicant has also stated 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-2331(a)(1) at a Lowest Service Temperature (LST) of -40°F. The staff has concluded that the impact resistance for this component is acceptable for this application, based on the guidance provided in Regulatory Guides 7.00 and 7.12.

The structural components of the transfer cask are fabricated from low alloy carbon steels selected based on their low-temperature fracture toughness. The nil ductility transition temperature for these steels is established as –40ºF. Based on Regulatory Guide 7.11 [1], the minimum temperature for use is 40ºF above the transition temperature, with no credit taken for heat produced by the contents of the transfer cask. Consequently, the applicant has stated that a minimum ambient temperature of 0ºF for use of the transfer cask is to be established. This condition is administratively controlled by procedure and is consistent with the analysis. Since the use of the transfer cask is restricted to conditions when the surrounding air temperature is greater than, or equal to, 0ºF, the applicant has concluded that impact testing of the transfer cask materials is not required. The staff has reviewed the information contained in Regulatory Guide 7.11 and finds the applicant's assessment acceptable.

8.3 Applicable Codes and Standards

The principal codes and standards applied to MAGNASTOR components are the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, the American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI). Code materials meeting the requirements of these codes and/or standards conform to acceptable chemical and physical properties and are produced using controlled processes and procedures. 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 and standards are appropriate for the material control of the components.

The staff also reviewed and evaluated the Alternatives to the ASME Code relating to the TSC closure. The staff finds the proposed alternatives for the MAGNASTOR system acceptable for this application.

8.4 Material Properties

SAR Tables 8.3-1 through 8.3-28 provide mechanical and physical property data for the major structural materials, including stainless steels, carbon steel, bolting materials, concrete, and shielding material. The applicant provided additional material properties in response to a request for additional information on irradiated data used to evaluate high burnup fuel performance while in storage. 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 allowables, 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 and appropriate for the expected load conditions (e.g., hot or cold temperature, wet or dry conditions) during the proposed storage period for the MAGNASTOR system.

8.5 Weld Design and Specification

The TSC materials of construction (e.g., stainless steel) are readily weldable using commonly available welding techniques. The TSC shell assembly is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB of the ASME Code. The circumferential and longitudinal shell plate weld seams are multi-layer full penetration welds. The use of an experienced fabricator will ensure that the process chosen for fabrication will yield a durable canister. The TSC welds were well-characterized on the license drawings, and standard welding symbols and notations in accordance with American Welding Society (AWS) Standard A2.4, "Standard Symbols for Welding, Brazing, and Nondestructive Examination" were used.

The staff concludes that the welded joints of the TSC, concrete cask, and transfer cask will meet the requirements of the ASME Code, AWS Code, and the guidance contained in Interim Staff Guidance-15 (ISG-15), "Materials Evaluation." In addition, the staff finds the Alternatives to the ASME Code acceptable for the closure lid-to-shell weld inspection using liquid penetrant technique performed in accordance with ASME Code, Section V, Article 6.

8.6 Bolting Materials

The TSC is an all-welded canister; as such, there are no bolting materials.

8.7 Coatings

The exposed surfaces of carbon steel and concrete components of MAGNASTOR are coated with specially designed and applied coating systems. The coatings are provided to reduce corrosion of exposed carbon steel surfaces, to minimize adverse reactions between dissimilar materials, and to minimize adverse interactions of components with their operating environment during in-pool loading, dry transfer and storage. The details on the various types of coating systems utilized on MAGNASTOR components are discussed in the following sections.

8.7.1 Electroless Nickel

The PWR and BWR fuel baskets are fabricated primarily of carbon steel. The carbon steel components are coated with an electroless nickel coating to prevent oxidation and corrosion while exposed to the pool water. This nickel coating is a nickel/phosphorus metallic alloy that can be deposited uniformly on all exposed surfaces of the support disk and is applied in accordance with ASTM B 733. Adhesion of the nickel coating to the carbon steel disk is assured by cleaning the carbon steel surfaces in accordance with ASTM B 733 prior to application of the coating.

This coating is not expected to react with the spent fuel pool water or to produce unsafe levels of flammable gas. However, operating procedures identified in SAR Sections 9.1 and 9.3, which specify that the user monitor the concentration of hydrogen gas during welding or cutting operations on the shield lid welds, ensure that accumulation of flammable gases is negligible. If flammable gases are detected at concentrations above 2.4% in air at anytime during these operations, the gas will be removed by flushing the suspect regions with ambient air or an inert gas before continuation of the operations. The staff has evaluated this coating and the ASTM standard mentioned above and find both acceptable for this application.

8.7.2 Other Coating Systems

All of the exposed carbon surfaces of the transfer cask and concrete casks will be coated with either a Keeler and Long or a Carboline epoxy enamel coating. This coating will protect the steel from excessive oxidation and facilitate decontamination of the surfaces. Based on the manufacturing data sheets for these two coatings, the staff concludes that the use of the Keeler and Long or a Carboline epoxy enamel paint coatings are acceptable for this application.

8.8 Corrosion Reactions

In Section 8.10 of the SAR, the applicant evaluated whether chemical, galvanic or other reactions among the materials and environment would occur. The staff reviewed the design drawings and applicable sections of the SAR to evaluate the effects, if any, of intimate contact between various materials in the TSC system materials of construction during all phases of operation. In particular, 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 TSC is primarily fabricated with stainless steel. The staff finds that in this dry, inert environment, the TSC components are not expected to react with one another or with the cover gas. Further, oxidation or corrosion of the fuel cladding and the TSC internal components will effectively be eliminated during storage due a inert atmosphere in the TSC.

To ensure that the safety hazards associated with the ignition of hydrogen gas are mitigated, the procedures of SAR Section 9.1 are employed to monitor the concentration of hydrogen gas during any welding or cutting operations. The staff concludes 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 aluminum with the spent fuel pool water will not impact the ability of the neutron absorbers to perform their intended function, since the loss of aluminum metal is negligible.

The staff also reviewed and evaluated the corrosion properties of the ASTM A615/A615M, Grade 60 reinforcing bar material used in the concrete cask. Although the chemical composition of this material limits its environmental use, the cask sits vertically above ground and the bar material is completely encased in the concrete; therefore, corrosion of the rebar is negligible.

8.9 Neutron Absorber Tests

The MAGNASTOR system utilizes sheets of neutron absorber material that are attached to the sides of the spent fuel storage locations in the fuel baskets, as discussed in Section 8.8 and 10.1.6 of the SAR. The materials and dimensions of the neutron absorber sheets are defined on license drawings. There are three types of neutron absorbers (also called poisons) used in the MAGNASTOR TSC basket. They are BORAL, boron carbide-aluminum metal matrix composite (i.e., Metamic), and borated aluminum alloy.

8.9.1 Inspections

After manufacture, each sheet of neutron absorber material will be visually and dimensionally inspected for damage, embedded foreign material, and dimensional compliance. The neutron absorber sheets are intended to be defect/damage free.

8.9.2 Acceptance Tests

Acceptance tests are conducted on production material to determine if selected specified characteristics have been satisfied, such that the lot can be accepted for use.

Determination of neutron absorber material acceptance shall be performed by neutron attenuation testing. Neutron attenuation testing of the final product or the coupons shall compare the results with those for calibrated standards composed of a homogeneous ^{10}B compound. Other calibrated standards may be used, but those standards must be shown to be equivalent to a homogeneous standard. These tests shall include a statistical sample of finished product or test coupons taken from each lot of material to verify the presence, uniform distribution, and the minimum areal density of ^{10}B. Alternative test methods for neutron attenuation may include chemical analysis or radiography, or a combination of these two methods, provided the alternate methods have been benchmarked (validated or calibrated) to neutron attenuation testing results and have adequate precision to confirm absorber efficacy.

The ^{10}B areal density is measured using a collimated thermal neutron beam of up to 1.2 cm diameter. A beam size greater than 1.2 cm diameter, but no larger than 1.7 cm diameter, may be used if computations are performed to demonstrate that the calculated k_{eff} of the system is still below the calculated Upper Subcritical Limit (USL) of the system, assuming defect areas the same area as the beam.

The neutron absorbers' minimum total ^{10}B areal densities are specified in Section 13 of the SAR. The acceptance program that the applicant will conduct supports crediting 75% in the criticality analysis and ensuring the presence of the ^{10}B content specified for fabrication of the BORAL plates. Likewise, the acceptance program supports crediting 90% in the criticality analysis and ensuring the presence of the ^{10}B content specified for fabrication of the borated aluminum and the boron carbide metal matrix composite plates. The staff finds these tests acceptable for this application.

Test locations/coupons shall be well distributed throughout the lot of material, particularly in the areas most likely to contain variances in thickness, and shall not contain unacceptable defects that could inhibit accurate physical and test measurements.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level (also expressed as 95/95 level) or better.

8.9.3 Qualification Tests

Qualification tests are used to demonstrate suitability and durability for a specific application.

The applicant presented specifications that will be used to qualify a new borated material or changes to an existing borated material. Qualification testing is required for: (1) neutron absorber material specifications not previously qualified; (2) neutron absorber material specifications previously qualified, but manufactured by a new supplier; and (3) neutron absorber material specifications previously qualified, but with changes in key process controls. Key process controls for producing the neutron absorber material used for qualification testing shall be the same as those to be used for commercial production. Qualification testing shall demonstrate consistency between lots (2 minimum). The applicant has stated that nonconforming material shall be evaluated within the NAC International Quality Assurance Program.

The staff reviewed the design requirements, testing for durability (e.g., corrosion and thermal damage), and testing to demonstrate the ^{10}B uniformity. The staff finds the qualification tests acceptable for this application.

8.10 Cladding Integrity

The staff verified that the cladding temperatures for each fuel type proposed for storage are below the temperature limits which would preclude cladding damage that could lead to gross rupture.

The staff reviewed the discussion on material temperature limits with respect to the following regulatory requirements:

- 10 CFR §72.122(h)(1) requires the spent fuel cladding to be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage.

8.10.1 Fuel Properties

The thermal properties (i.e., conductivity, emissivity, and specific heat of the cladding) have been evaluated and found to be within acceptable ranges for this application. The mechanical properties for the high burnup fuel were verified against the staff's data base of mechanical properties of irradiated Zircaloy.

The applicant has created a number of hybrid fuel assemblies that have characteristics that bound the characteristics of a particular class of fuel; for example, one hybrid for all Westinghouse 17 x 17 assemblies. The characteristics, such as cladding thickness, pellet diameter, etc. were randomly verified and found to be accurate.

8.10.2 Oxidation of Spent Fuel

During loading operations, the water level in the TSC will be lowered (blown down) by about 70 gallons to facilitate lid welding. The lowering of the water level will not expose the spent fuel rods to an air atmosphere, thereby assuring that there is no inadvertent oxidation of the fuel rods during this operation. The technical specifications also require that the licensee ensure that fuel cladding oxidation does not occur during this stage.

8.10.3 Temperature Limits and Re-flood Analysis

For the fuel assemblies, the allowable temperature limits are based on Interim Staff Guidance-11, (ISG-11), Revision 3 (U.S. Nuclear Regulatory Commission, November, 2003). The 400°C maximum temperature recommended in ISG-11 limits mechanisms that can lead to breach of the cladding under normal storage. The applicant should note that the phenomenon known as hydride reorientation may occur in high burnup fuel during storage and change the cladding's material properties. This change may effect the potential performance of the cladding during future transportation.

Steps for unloading the cask in the pool are specified in the operating procedures. These steps are based on an analysis of the temperatures in the cask and maximum thermal gradients established in the fuel during the process. Initial water entering the cask flashes to steam and removes additional heat from the cavity. Water continues to be slowly introduced, limiting the thermal gradients to less than 1°F. The staff accepts the applicant's analysis and does not believe there will be excessive stress on the cladding leading to fuel rod degradation if a reflood of the cask is required.

8.10.4 Vacuum Drying

In Section 4 of this staff evaluation, the staff identified insufficient information regarding the vacuum drying procedures for this application. Pending further clarification of these procedures, the staff cannot make a finding concerning their adequacy at this time

8.11 Evaluation Findings

F.8.1 The SAR describes the materials that are used for structures, systems, and components (SSCs) important to safety and the suitability of those materials for their intended functions in sufficient detail to facilitate evacuation of their effectiveness.

F.8.2 The design of the TSC and the selection of materials adequately protects the spent fuel cladding against degradation that might otherwise lead to gross rupture. However; this finding in the materials review area is contingent upon the acceptable resolution of thermal analyses needed to demonstrate that material temperature limits will not be exceeded, as described in Section 4 of this staff evaluation.

F.8.3 The TSC employs only noncombustible materials which will help maintain safety control functions.

F.8.4 The materials that comprise the TSC will maintain their mechanical properties during all conditions of operation.

F.8.5 The TSC employs materials that are compatible with wet and dry spent fuel loading and unloading operations and facilities. These materials are not expected to degrade over time, or react with one another, during any conditions of storage.

9.0 OPERATING PROCEDURES

The NRC staff has not yet documented its evaluation in this area.

10.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAMS

The NRC staff has not yet documented its evaluation in this area.

11.0 RADIATION PROTECTION EVALUATION

The NRC staff has not yet documented its evaluation in this area.

12.0 ACCIDENT ANALYSIS EVALUATION

The NRC staff has not yet documented its evaluation in this area.

13.0 CONDITIONS FOR CASK USE —TECHNICAL SPECIFICATIONS

The NRC staff has not yet documented its evaluation in this area.

14.0 QUALITY ASSURANCE EVALUATION

The purpose of this review and evaluation is to determine whether NAC has a quality assurance (QA) program that complies with the requirements of 10 CFR Part 72, Subpart G. The staff has previously reviewed and accepted the NAC QA program. The staff has performed inspections of the QA program and found that it met regulatory requirements. Therefore, the staff did not reevaluate this area.

15.0 DECOMMISSIONING EVALUATION

The NRC staff has not yet documented its evaluation in this area.