FINAL SAFETY EVALUATION REPORT

NAC INTERNATIONAL, INC.

MAGNASTOR DRY CASK STORAGE SYSTEM

DOCKET NO. 72-1031

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MODEL NO. MAGNASTOR
NAC INTERNATIONAL, INC.
CERTIFICATE OF COMPLIANCE NO. 1031

SUMMARY

By letter dated August 6, 2007, NAC International (NAC) re-submitted an application to the U. S. 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 system is a canister-based dry cask storage system with a 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.

NAC originally submitted an application for the MAGNASTOR system on August 31, 2004, and subsequently withdrew that application by letter dated January 26, 2007. The NRC staff documented the results of its partial technical review of the initial MAGNASTOR application in a preliminary staff evaluation, dated July 24, 2007. In that evaluation, the staff indicated that although the partial findings did not provide a complete basis for the approval of the proposed MAGNASTOR system, those findings and supporting information could be referenced in a future application. NAC resubmitted the MAGNASTOR application on August 6, 2007, and provided supplemental information by letters dated September 26, 2007, and January 24, March 7, March 14, April 8, April 18, June 2, June 16, June 24, July 9, September 12, and September 18, 2008.

The staff’s technical review of NAC’s resubmitted application and supplemental information was conducted in accordance with 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. The staff determined that the MAGNASTOR system meets the requirements of 10 CFR Part 72, and that any users of the system will be able to meet the applicable requirements of 10 CFR Part 20.

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 MAGNASTOR Safety Analysis Report (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 1.3-1 and 1.3-2 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 non-mechanistic tip-over 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 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 then 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 opens the transfer cask doors, 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 15 of this safety evaluation report.

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. Steel filler rods must be unirradiated. The design conditions and approved contents are specified in the Certificate of Compliance and the Appendices (Technical Specifications) 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 done 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 Part 72, Subpart G.

The licensee (a reactor licensee under 10 CFR Part 50), or its contractor, may construct an independent spent fuel storage installation (ISFSI) at the reactor site, and may conduct MAGNASTOR system 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 for 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 safety evaluation report.

F1.3 Specifications for the spent fuel to be stored in the MAGNASTOR system are provided in Section 1.4 of the SAR. Detailed characteristics of the spent fuel are presented in Tables 2.2-1 and 2.2-2 of the SAR, and requirements on the approved contents are specified in Appendix B to the proposed Certificate of Compliance.

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 Chapter 1 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 the dry cask storage review guidance 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 in 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 undamaged 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 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 Part 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, maintains the fuel cladding and concrete cask component temperatures below their design limits. The thermal analysis for the MAGNASTOR system is reviewed in Section 4.0 of this safety evaluation report.

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, or 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 tip-over 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 conditions, or off-normal and accident events. 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 ^{10}B 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 testing and maintenance programs 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 the SAR 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 conditions and 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 into 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 provides 87 loading positions for BWR fuel assemblies. SAR Table 1.3-2 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 71160-561 depicts the 24 equally spaced 3-inch-wide s-beam standoffs welded to the inner liner to provide lateral support to the TSC during side impact events. SAR 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 bricks 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 conditions and off-normal and accident-level events. 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 parameter 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.

<u>Flood</u>. 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.

<u>Earthquake</u>. 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 tip-over, as presented in SAR Section 3.7.3.4, for the peak storage pad horizontal acceleration of 0.37g and corresponding vertical acceleration of 0.25g, is reviewed in Section 3.5.3.

<u>Snow and Ice</u>. 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 associated with cask drop and tip-over 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 and Strength Capacity Criteria

Table 2.3-3 of the SAR lists the structural evaluation criteria for the TSC. The stress allowables are based on ASME Code, Section III, Subsections NB and NG, for the canister body and fuel basket, respectively.

SAR Section 2.3.5.1 considers strength capacity reduction factors, in accordance with ACI 349, for evaluating concrete cask strength capacities.

As described in Section 2.3.5.3 of the SAR, 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 nonredundant 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 maximum under-the-hook dry weight at 213,000 lbs is enveloped by the 240,000 lbs used for the vertical lifting evaluation in SAR Section 3.4.3.3. 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 tip-over 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. Transient impact responses of the concrete cask during the cask tip-over and 24-inch vertical drop accidents are calculated with LS-DYNA, including potential for geometric instability of the fuel basket tube array, crushing of the concrete cask pedestal, and load transfer between the neutron absorber plate and its retainer and the associated weld posts.

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 tip-over 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 responses 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 tip-over event. Section 3.10.9 presents the three-dimensional (3-D) ANSYS TSC-basket interaction model to calculate the bounding TSC shell radial deformations used for evaluation of design margins of the fuel basket tube array against potential geometric instability during the cask tip-over accident. Along with the corresponding analyses and results, details of these models are reviewed, as appropriate, in individual sections of this safety evaluation report.

3.1.4.3 Design Margins

For stress evaluation, the SAR considers factors of safety defined as the ratios of the at-temperature stress allowables and the corresponding calculated stresses. Factors of safety are also defined as the ratios of the allowables and the calculated structural performance indices such as material plastic strains and Nelson stud pull-out forces. For buckling evaluation of the axially loaded members such as basket tube side walls, indices are calculated through an interaction equation approach, considering the combined effects of axial compressions and bending moments. A factor of safety equal to or greater than unity ensures adequate structural design margin for the entities being evaluated. These design margin characterizations are acceptable.

To evaluate potential geometric instability of the fuel basket tube array during the cask tip-over accident, SAR Section 3.10.6 considers a side impact loading that is 1.5 times the design basis value to show that the fuel tubes will retain their initial geometric configuration and all the pin-slot connections remain engaged after the tip-over accident. While there is no additional SAR analysis for a much higher impact loading for causing global tube reconfiguration or eventual disengagement of the pin-slot connections, the staff believes that the criterion of the 1.5 times design basis loading provides a reasonable basis for demonstrating design margins against fuel basket geometric stability.

3.1.5 General Standards for Cask Design

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 Section 8.0 of this SER)

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 air pads or by means of two embedded lug assemblies separated180° 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 a dynamic 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.

The SAR also notes the use of four air pads, one placed in each cask inlet, for the movement of the concrete cask. On the basis of a minimum interface area of 5,700 in^2, the bearing stress is calculated to be less than 60 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 with a safety factor of 5 on ultimate strength, 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 single three-legged sling and 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.

Using a half-symmetry finite element model for the TSC, the SAR evaluates 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 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 lift meets the stress design factor criteria of NUREG-0612 and ANSI N14.6 for nonredundant load paths.

3.1.5.3.3 Transfer Cask Lift

Drawing 71160-560 and Section 3.10.5 of the SAR 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^o 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 primary membrane-plus-bending stress intensity in the trunnion is 3.79 ksi, which corresponds to a stress ratio of 8.1 against the yield strength and a large stress ratio against the ultimate strength of the A350 Grade LF 2 carbon steel. This meets the intent of stress design factor criteria of NUREG-0612 and ANSI N14.6 for nonredundant load paths, and is acceptable. SAR Table 3.4.3-2 summarizes 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 stress ratios 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 analysis of 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 Section 8.0 of this safety evaluation report.

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. For thermal stress analysis, the segmented 3-D quarter-symmetry models of Figures 3.10.1-7 and 3.10.2-7 are 47 inches and 43 inches long, 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 boundary sides 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 48.2 ksi and 17.5 ksi, which are below the at-temperature allowable of $3S_m$ or 62.7 ksi at 755°F, for the fuel tube and basket support weldments, respectively. The SAR also evaluates a maximum shear load of 3.5 ksi in the basket attachment bosses, which corresponds to the factor of safety of 3.03. For differential thermal expansion consideration, 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.

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 components 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 38.4 ksi in the neutron absorber retainer strip, which may develop when restrained from thermal growth by the weld posts attached to the fuel tube. The calculated stress, which applies to both the PWR and BWR configurations, is below the allowable of 46.5 ksi, 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 and finite element analyses 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.

The stress performance associated with handling and thermal conditions is reviewed in Section 3.2.1.1 of this evaluation with acceptable 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 0.707g and 1.5g 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 1.1g 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. For the second case of normal internal pressure of 110 psig with off-normal handling, the computed minimum factor of safety of 1.27, per Service Level C, primary membrane-plus-bending stress category, is also acceptable.

Fuel Basket. SAR Section 3.6.2 performs fuel basket evaluation for the off-normal operating events with inertial loadings of 1.5g vertical and 0.707g transverse. The finite element analysis results show large factors of safety for both the fuel tube and support weldment on the basis of the ASME Section III, Service Level C stress intensity limits. This is acceptable.

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 106°F 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 applicable to various loading scenarios, including a pressure on the TSC bottom to simulate the TSC content dead 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, for the accidents associated with conditions of the accident pressurization, 24-inch cask drop, and cask tip-over. For the accident pressurization, the minimum 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 assessment that the TSC is not adversely 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 a 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 to model the pedestal weldments, including the 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 considered 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 kips 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 and is approximately 60% of the original, and is acceptable. Considering also the dynamic load factor effect, the maximum decelerations of the TSC for the upper-bound weight and lower-bound weight TSC are determined to be 19.6g and 25.2g, 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 60g, which bounds the maximum calculated deceleration of 25.2g reviewed above, to perform a stress analysis and buckling evaluation of the canister body.

The analyses are performed using 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 3.71 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 60g inertial load, the previously approved NAC-UMS TSC fabricated with the same A-240 Grade 304L stainless steel meets the buckling interaction equations criteria with large margins, per the ASME Code Case N 284-1 provisions. Therefore, the staff has a reasonable basis to agree with the SAR conclusion that the TSC will not buckle due to a 24-inch cask vertical drop.

Fuel Baskets. SAR Section 3.7.2.1.1 considers a 60g 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. 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 assembly in resisting the axial load against the TSC bottom plate, is demonstrated to exceed the maximum tributary load of 23.6 kips. 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.

SAR Drawing 71160-551 depicts the general assembly of neutron absorber plates attached to four sides of a PWR fuel tube. SAR Drawing 71160-571 provides design details of the neutron absorber plate and its stainless steel retainer strip attached to the tube wall through an array of weld posts. Considering a pair of holes in the neutron absorber plate, which are located at the plate end and not slotted to enable proper assembly, the SAR evaluates the performance of the neutron absorber and weld posts in resisting the in-plane shearing force associated with the 60g axial inertia force. On the basis of the at-temperature, 350°F, tensile strength of 5.38 ksi for the neutron absorber, the resulting factor of safety is 1.89. This ensures that the neutron absorber will continue to maintain its analyzed configuration after the vertical cask drop accident, and is acceptable.

For the BWR neutron absorber attachment design, SAR Section 3.7.2.2.1 presents stress analyses similar to those for the PWR fuel basket with acceptable results.

3.4.3 Concrete Cask Tip-over

SAR Section 3.10.4.4 presents the finite element models for determining rigid body decelerations of the concrete cask during a tip-over 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; 26.6g vs. 26.4g peak at the axial location of the basket top, and 29.6g vs. 29.5g at the TSC top. By considering appropriate dynamic load factors with respect to the peak cask decelerations, SAR Table 3.7.3-4 lists the amplified decelerations as applicable to evaluating the TSC, and the PWR and BWR fuel baskets, under the 0° and 45° drop orientations. The resulting side-impact bounding g-loads are 32.2g and 29.6g 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 tip-over accident.

3.4.3.1 Transportable Storage Canister

Canister Body. 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 exceeds the peak amplified deceleration of 32.2g, at the top of the canister closure lid, and 1g 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 direction as a cosine distribution over a 21° arc from the impact centerline. 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 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.

Fuel Baskets. For the tip-over accident, the inertia load of fuel assemblies is supported in the transverse direction by an assembly of square fuel tubes held in a right-circular cylinder configuration by the side and corner support weldments that are bolted to the outer fuel tubes. SAR Sections 3.10.1.1 and 3.10.2.1 describe the load paths which include tube pin-slot connections, contacts between tube corner flats, and bolted boss connections between the outer tubes and support weldments, for the PWR and BWR baskets, respectively. Since the pin-slot connections allow relative displacements between tubes, which may cause them to become disengaged to result in potential geometric instability of the basket, the SAR evaluates both the structural integrity and the geometric stability performances of the basket.

Fuel Basket - Structural Integrity. SAR Section 3.10.1.2.3 presents the 3-D periodic plastic models for performing ANSYS stress analyses of the PWR basket for the 0° and 45° basket drop orientations. The models consisting of ANSYS SOLID45, SHELL43, SHELL63, CONTAC52, CONTAC173, TARGE170, LINK10, and COMBIN40 elements are capable of simulating interfaces, including gaps and bolt/boss joints, among basket components in calculating stresses in the basket components undergoing inelastic material behavior. Section 3.10.1.3.3 describes the boundary conditions for the analyses, including a bounding side impact load of 35g and the CONTAC52 elements to simulate the interface of the basket and the canister shell inside the concrete cask. Section 3.7.2.1.2 summarizes the analysis results for the PWR basket components, which are reviewed as follows.

For the fuel tubes, considering the ASME Code, Section III, Appendix F, at-temperature stress allowables, the SAR notes that the critical stress locations occur in the tube corners, and the minimum factors of safety are 1.16 and 1.40 for the respective primary membrane and primary membrane-plus-bending stress intensity categories. With a quality factor commensurate with the weld examination procedure for the longitudinal seam weld joining two tube halves, the maximum membrane and membrane-plus-bending stress intensities are calculated to be 8.4 ksi and 25.7 ksi, respectively, which are less than the allowables and are acceptable. The evaluation of tube wall buckling is performed per the NUREG/CR-6322 approach, considering combined axial compression and bending. The two interaction equations are satisfied, and the fuel tube is demonstrated capable of resisting side wall buckling with respective factors of safety of 1.12 and 1.34.

SAR Tables 3.7.2-2, -3, and -4 provide summaries of maximum stress intensities and corresponding factors of safety for the corner weldment mounting plate, corner weldment support bar, and side weldment, respectively. The minimum factors of safety are all greater than unity, on the basis of the Appendix F at-temperature stress allowables. Considering the finite element analysis results, the SAR evaluates bolting designs for attaching the fuel tubes to the support weldments at 16 circumferential locations. The evaluations include shear in the bolt thread and bending of the washers and capability of the bolt under combined tensile and shear stresses to demonstrate that the support weldments have adequate strength for maintaining structural integrity of the basket assembly.

SAR Figure 3.7.2-3 depicts details of the LS-DYNA model for evaluating the neutron absorber and the retainer assembly subject to a side impact loading of 60g, which envelops the maximum tip-over deceleration loading of 35g. The model considers slotted holes in the neutron absorber plate and its stainless steel retainer strip with conical pockets to receive the short steel posts, which are, in turn, welded to the tube wall. Considering inelastic material properties at 700^{o} F for the stainless steel strip and the neutron absorber, the SAR calculates a localized strain of less than 3.3% for the retainer strip. This ensures that the retainer strip remains engaged with the weld post during and after the tip-over accident.

The staff reviewed the BWR basket evaluations of SAR Section 3.7.2.2.2. Similar to those for the PWR basket reviewed above, the staff concurs with the SAR conclusion that the BWR basket is capable of maintaining its structural integrity for the tip-over accident.

<u>Fuel Basket - Geometric Stability</u>. SAR Section 3.10.6 notes that the basket geometric configuration is maintained by three features of basket component design: (1) the side and corner support weldments bolted to the fuel tubes at the basket periphery; (2) the pin-slot connections between adjacent fuel tubes; and (3) the connector pin assemblies at both ends of the basket. To demonstrate geometric stability of the basket, in the context of its deformation performance, the SAR evaluation focuses on ensuring the fuel tubes retain their initial geometric configuration and all the pin-slot connections remain engaged during and after the tip-over accident. The evaluation is accomplished by examining transient dynamic analyses of the basket models. Considering the eight pin-slot connections placed between adjacent fuel tubes with a 20-inch center-to-center axial spacing, the SAR follows common practices and uses a periodic 10-inch thick segment representation for a complete basket assembly. Figures 3.10.6-2 thru 3.10.6-10 depict the full or half-symmetry LS-DYNA models constructed primarily with brick and shell elements and surface-to-surface contact conditions for the six PWR (0^{o}, 18^{o}, 22.5^{o}, 27^{o}, 34^{o}, and 43^{o}) and three (0^{o}, 22.5^{o}, and 45^{o}) BWR basket orientations to capture the worst-case basket deformations. The models consider key basket design features that could result in basket deformations most susceptible to lead to geometric instability. These include gaps between adjacent tubes and those between the support weldments and the fuel tubes, between the basket and the canister, and between the canister and the concrete cask. Using the SAR Section 3.10.9 ANSYS quasi-static analyses of the complete TSC-basket assemblies, the periodic models consider the most deformed parts of the canister and prescribe maximum profiles for basket assembly deformation. These boundary conditions are implemented by redefining the geometry of the cask liner inner surfaces in the periodic model to correspond to the maximum shell deformations determined from the ANSYS analysis results. This is

conservative and acceptable since the maximum shell deformation occurs at a small section near the middle of the canister and is considered constant for the entire impact response history.

For the design margin evaluation, the SAR considers a side impact loading that is 1.5 times the design basis value to show that fuel tubes will retain their initial geometric configuration and all the pin-slot connections remain engaged after the tip-over accident. The load factor of 1.5 is applied to both the cask liner displacement profiles and the Figure 3.7.3-3 cask tip-over deceleration time history imposed on the liner plate for performing LS-DYNA transient dynamic analysis. Based on the basket assembly process and tolerance, a bounding gap of 0.025 inch, as opposed to the permitted 0.016 inch, is also incorporated at selected locations as baseline to maximize effects of these gaps on basket deformation. SAR Tables 3.10.6-3 and -4 summarize results of maximum gap changes at pin-slot connections for the seven PWR and four BWR basket analysis cases, respectively. The maximum instantaneous gap changes are 0.233 inch for the PWR basket and 0.305 for the BWR basket, both with the 22.5^o drop orientation. As displayed in the time-history plots, in Figures 3.10.6-18 through -22, permanent gap openings at key basket locations are determined to be less than 0.15 inches and 0.10 inch for the governing cases for the respective PWR and BWR basket. The staff reviewed these results and concurs with the SAR conclusion that the pin-slot connections remain engaged with a design load margin greater than 1.5.

SAR Figure 3.10.7-1 presents the LS-DYNA models of a single fuel tube for calculating permanent deformations of fuel tubes for the tip-over accident. These secondary analyses impose displacement time histories along the tube diagonal direction, considering the displacements obtained from analyzing the basket assembles. The SAR computes the maximum permanent tube diagonal displacements of 0.008 inch and 0.004 inch for the PWR and BWR fuel tubes, respectively. These tube geometry changes are minimal and are less than 1% of the initial configurations. This demonstrates that the fuel tubes continue to retain their initial configuration to satisfy a fuel basket geometric stability performance criterion.

As part of the stability evaluation for the BWR and PWR baskets, SAR Section 3.10.8 evaluates the strength performance of the pin-slot connections using the LS-DYNA transient analyses of periodic fuel basket models. For a side impact loading that is three times the design basis, the SAR computes the maximum plastic strains of 16.5% and 15.4% in the respective PWR and BWR tube slots. The corresponding strains are 15.4% and 8.4% in the pins for the most stressed pin-slots of the baskets. The strains are below the ultimate true strain of 21% for the SA 537 carbon steel. This ensures that pin-slots will not fracture to result in basket instability with large design margin.

The staff notes that the applicant did not perform an analysis with a load factor sufficient to cause eventual disengagement of the pin-slot connections. However, the staff believes that the criterion of applying a loading 1.5 times the design basis provides a reasonable basis for characterizing the design margin to ensure adequate performance of the fuel baskets against geometric instability.

3.4.4 Fuel Rod Rupture

SAR Section 3.8.3 evaluates cladding degradation temperature limits and concludes that maximum fuel cladding temperatures are below the limits for all design conditions of storage.

For cladding integrity associated with the 24-inch drop of the concrete cask during handling and transferring operation, Section 3.8.1 presents a fuel rod buckling evaluation, using LS-DYNA transient impact analyses, to demonstrate structural performance for the PWR fuel. The evaluation considers a number of fuel types to cover bounding modeling parameters. This includes clad mechanical and cross-section properties, reduced clad thickness for oxide layers, which could be associated with the high burnup fuel, missing grid spacers, bowed rods, gap between fuel assembly and fuel tube wall, and fuel rod to pedestal interface acceleration time history with varied pulse amplitude and duration. Other common model attributes, which apply to all cases, involve finite element representations for clad, grid spacer, fuel tube wall, increased clad density to compensate for fuel pellet weight, and an initial downward velocity of 136 inch/sec for all nodes in the model. For the five cases analyzed, the case using the minimum cross-section in conjunction with the 60-inch spacing for the missing grid condition is bounding. The analysis demonstrates adequate cladding structural integrity since fuel rods will not buckle and the maximum fuel clad stress intensity of 41.9 ksi is much below the clad yield strength of about 78 ksi. For the BWR fuel, because of its substantially smaller slenderness ratio L/r, which governs fuel rod buckling performance, than that of the PWR fuel, the staff agrees with the Section 3.8.2 conclusion that no further fuel rod evaluation is required.

SAR Section 3.8.4 evaluates cladding integrity for a 60g side drop. This deceleration bounds that experienced in the concrete cask tip-over accident in which the maximum deceleration of 26.6g occurs at the top of the basket. Figure 3.8.4-1 depicts details of the ANSYS model, including missing grid spacers and CONTAC52 elements to allow a maximum fuel rod lateral displacement of 2.33 in, for a quasi-static analysis. Considering section modulus Z and grid spacer span, three fuel rods, which represent limiting configurations, are analyzed. The results show a maximum stress of 48.1 ksi, for the WE 15x15 fuel, with the margin of safety of 0.45 against the at-temperature yield strength of 69.6 ksi.

On the basis of the above, the staff concludes that fuel rod will not rupture during the design basis cask drop and tip-over accidents as the cladding will maintain its integrity.

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 tip-over, 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 maximum pad surface horizontal motion of less than 0.41g. 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 tip-over for the design earthquake defined by a maximum storage pad horizontal motion of 0.37g (0.41/0.37 = 1.1) with corresponding vertical motion of 0.25g (0.37 x 0.67 = 0.25g). 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. This will be a requirement of Appendix A to the Certificate of Compliance, “Technical Specifications and Design Features for the MAGNASTOR System,” TS 4.3.1.i.

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:

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 conditions, and off-normal, accident and natural phenomena events.

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

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

F3.4 The structural evaluation of the MAGNASTOR cask and all SSCs important to safety demonstrates with reasonable assurance that the confinement of radioactive material will be maintained under normal conditions and off-normal and credible accident events.

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 conditions and off-normal and accident events. 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 conditions and off-normal and accident events.

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 conditions and off-normal and accident events, including loading and transfer of the SNF. This includes confirmation that the thermal design of the cask has been evaluated using acceptable analytical methods.

4.1 Spent Fuel Cladding

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 1058°F (570°C). Thermal cycles during system drying operations that exceed 117°F (65°C) will be restricted to no more than 10 cycles for spent fuel with burnup greater than 45 GWd/MTU, as required by Technical Specification 5.2.c, in Appendix A of the CoC. The thermal cycling criterion is an alternative to ISG-11 that has been justified as explained in Chapter 8, “Materials Evaluation,” of the SAR. The staff found this alternative acceptable, as stated in Section 8.0 of this SER.

Oxidants are removed from the canister by the vacuum drying process. The proposed canister dryness verification is to hold an internal pressure of 10 torr (1333 Pa) for 10 minutes with the canister isolated from the vacuum pump and the pump turned off. Upon successful completion of the dryness verification, the vacuum pump is restarted and the canister continues to be evacuated until the NUREG-1536 recommended pressure of less than 3 torr is reached. The applicant stated that the continued reduction in cavity pressure from 10 torr to less than 3 torr removes any residual noncondensable and oxidizing gases to a level of less than 1 mole. The canister is then backfilled with high purity helium (99.995%) to a positive pressure. The final canister internal atmosphere is a positive pressure of high purity helium that contains less than 1 mole of oxidizing gases. The residual oxidizing gas concentration is less than 0.25 volume %, as recommended in NUREG-1536.

4.2 Cask System Thermal Design

4.2.1 Design Features

Section 4.1 of the MAGNASTOR SAR discusses the thermal evaluation of the TSC, concrete cask, and 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 of the SAR. 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.

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.

4.2.2 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, as specified in Appendix B to the CoC (Technical Specifications - Approved Contents) Table B2-1, item I.F. 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. The applicant found that the calculated maximum fuel temperature was the same for both uniform and preferential loading patterns. The thermal evaluation is based on preferential loading since this configuration maximizes the TSC single assembly heat load. The BWR fuel basket can accommodate 87 BWR fuel assemblies with a uniform design basis total heat load of 33 kW, or 379 watts per assembly. To increase allowed assembly enrichments over those determined for the 87-assembly basket configuration, an optional 82-assembly loading pattern may be used. The required fuel assembly locations in the 82-assembly pattern are shown in Figure 2.2-2 of the SAR and in Appendix B TS Figure B2-2.

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 of the SAR.

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 1058°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. A summary of the thermal evaluation results for normal conditions of storage is provided in Table 4.4-3 of the SAR, for the PWR and the BWR cases, and the maximum fuel cladding temperatures for the different phases of the transfer operations are presented in Tables 4.4-5 through 4.4-16 of the SAR. 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 acceptable.

4.3 Thermal Model Specifications

4.3.1 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 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. A gap is considered between the side and corner weldments and the TSC shell for analysis purposes. Heat transfer across this 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. The staff found the description of the models acceptable.

4.3.2 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 acceptable.

4.3.3 Boundary Conditions and Thermal Loads

The applicant described the conditions and loads in Section 4.4 of the SAR. A summary of the MAGNASTOR thermal design conditions for storage is provided in Table 4.1-1 of the SAR. The MAGNASTOR spent fuel storage system is designed for a normal maximum average annual temperature of 76°F (24.4°C), off-normal severe heat temperature of 106°F (41.1°C), off-normal severe cold temperature of -40°F (-40°C), and accident extreme heat of 133°F (56.1°C). Solar insolation is considered in the model. The incident solar energy is applied on the concrete cask outer surfaces based on 24-hour averaged values. Natural convection heat transfer at the outer surfaces of the concrete cask is evaluated by using heat transfer correlations for vertical and horizontal plates. Radiation heat transfer to the environment is evaluated in the analysis model by calculating an equivalent radiation heat transfer coefficient. The staff found the description of boundary conditions and thermal loads acceptable.

4.3.4 Normal Storage Conditions

Section 4.4 of the SAR describes the finite element and finite volume methods used to evaluate the thermal performance of MAGNASTOR for normal conditions of storage. The general-purpose finite element analysis program ANSYS is used to perform analyses requiring radiation and conduction. The Computational Fluid 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. A two-dimensional (2-D) axisymmetric model is used to perform the thermal evaluation of the concrete cask and the TSC using CFD analyses. The fuel basket, spent fuel, and neutron absorber are modeled as homogeneous regions with effective thermal properties. The concrete cask air inlet and outlets are modeled using equivalent dimensions that extend around the concrete cask periphery. The air flow in the vertical annulus between the TSC and concrete cask is modeled as transitional turbulent flow using the k-ω turbulence model (Reference 1). Inside the TSC, helium flow is modeled as laminar flow. The fuel basket region is divided into three sections to reflect the location of the active fuel region, and the regions above and below the active fuel. The FLUENT porous media model is used to represent the basket regions. The resistance to flow due to the fuel pins and the fuel assembly grids is represented in terms of a pressure drop included in the momentum equation for each cell in the model associated with porous media. The inertial and viscous flow resistance factors are determined through detailed CFD analyses of bounding PWR and BWR fuel bundles, including the fuel spacer grid. Details of the procedures to calculate the porous media parameters are provided in SAR Section 4.8.2. The staff found the description of the analysis models acceptable.

4.3.5 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) drying phase where vacuum drying is used to remove moisture from the TSC; (3) helium backfill phase when the TSC closure is completed and the transfer cask annulus flow system is operating; and (4) operation of loading the helium-backfilled TSC into the concrete cask without the transfer cask annulus flow system operating.

The applicant performed analyses of the TSC inside the transfer cask for operations involving two options for cooling the TSC after the TSC is backfilled and closed. The two options include operations for 24-hour and 7-hour cooling times. The use of 24-hour cooling time allows for a maximum time for vacuum drying (24 hours) and a maximum time (22 hours) to transfer the TSC to the concrete cask. The use of 7-hour helium cooling time allows for a maximum time of 15 hours of vacuum drying for the maximum decay heat (35.5 kW for the PWR case) and 8 hours to transfer the TSC to the concrete cask. The staff found the description of the analysis models acceptable.

4.3.5.1 Operations Involving 24-Hour Cooling

Evaluation of the Water Phase

The TSC is represented by a FLUENT 2-D axisymmetric model which includes the TSC shell, lid, and bottom plate, basket fuel and neutron absorber. For the condition of water in the TSC, no contribution due to radiation was considered. The applicant claimed that since the maximum water temperature in the TSC is significantly below 212°F, the water is expected to remain in the liquid state, and the use of properties for the liquid state is acceptable. To keep the maximum water temperature in the TSC cavity below 212°F, water is circulated through the annulus between the TSC and the transfer cask. Circulating water through this annular gap was included in the TSC 2-D axisymmetric model. The applicant's CFD analysis for this configuration resulted in a maximum TSC outer surface temperature of about 113°F. To account for uncertainties in the analysis due to modeling assumptions and numerical errors, the annulus cooling water discharging through the upper fill lines is monitored per operating procedures described in the SAR. Specifically Step 29 of Section 9.1.1 of the SAR states that adequate water flow is maintained to keep the outlet water temperature equal or less than 113°F. This value is a critical parameter when using the applicant's TSC 2-D axisymmetric analysis model to calculate the TSC temperature distribution; therefore, the operating procedure should retain this specific temperature restriction.

The transfer cask (TC) and water annulus between the cask and the TSC are also included in the thermal model. The applicant stated that the TC is represented by effective properties calculated for both the radial and axial directions. In the radial direction, the analysis treats the four different cask wall materials as being in series, and in the axial direction, as being in parallel.

Evaluation of Drying Phase

During the vacuum drying phase, convection is not considered in the TSC cavity region. The applicant stated that helium thermal properties of conduction are assumed during the low pressure drying process because, per the operating procedures described in SAR Chapter 9, pressurized helium is used to remove the water from the TSC in preparation for drying the TSC cavity using the vacuum drying methods.

The applicant developed a 3-D, 1/8th symmetry model to perform the vacuum drying analysis. The model does not include the canister lid and bottom plate. Adiabatic boundary conditions are assumed on the bottom and top of the TSC. Heat is rejected from the TSC outer shell to the annulus circulating water. Circulating water is not included in the model and a fixed temperature is applied to the TSC outer wall in the analysis.

Evaluation of Helium Phase

The applicant performed transient analyses to determine the maximum temperature following helium backfill for heat loads greater than 25 kW for PWR fuel and greater than 29 kW for BWR fuel. The analyses were performed using the same 2-D FLUENT model used for the water phase condition. The initial temperature field of the transient evaluation to simulate the helium backfill condition is obtained from the analysis results at the end of the vacuum drying process (3-D ANSYS results) for the respective heat load.

Evaluation of Moving the TSC into the Concrete Cask

The applicant considered four conditions for this configuration for both PWR fuel (25 and 35.5 kW heat loads) and BWR fuel (25 and 33 kW heat loads). The initial conditions are obtained from steady state analyses for the helium phase.

4.3.5.2 Operations Involving Minimum Cooling Time

For this case, the TSC in the transfer cask is also subjected to four separate conditions: water phase, drying phase, helium phase, and transfer of the TSC to the concrete cask. The helium phase is reduced to 7 hours for heat loads greater than 25 kW and to zero hours for heat loads equal to, or less than, 25 kW for PWR fuel. For the BWR fuel, the helium phase is reduced to 6 hours for heat loads greater than 25 kW, and to zero hours for heat loads equal to, or less than, 25 kW. The applicable time limits for both PWR and BWR fuel for this configuration are presented in Tables 4.4.15 and 4.4.16 of the SAR.

The applicant stated that regardless of the time in vacuum drying during the loading operation, the response of the canister and transfer cask in the water phase (inside the TSC) is not affected.

4.3.6 Off-Normal Storage Events

For off-normal storage events, the applicant analyzed severe ambient temperature conditions (106°F and -40°F) and half-blocked air inlet conditions. Design basis heat loads were used in the evaluation of the concrete cask and the TSC. As shown in the SAR, the component temperatures and TSC internal pressures are within allowable values for the off-normal storage events. The staff found the descriptions of the off-normal events and analyses results acceptable.

4.3.7 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 results acceptable.

4.3.7.1 Blocked Vent Condition

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 (76°F) per Table 4.1-1 of the SAR. 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, 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. The staff found the description and blocked vent analysis acceptable.

4.3.7.2 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-inch 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 at a temperature of 1475°F. 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 bounds 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 76°F per Table 4.1-1 of the SAR 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 1475°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 76°F per Table 4.1-1 of the SAR. 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 acceptable.

4.3.7.3 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 133°F is used. The maximum calculated temperatures of the principal PWR and BWR cask components, with the corresponding allowable temperatures, are provided in SAR Section 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 acceptable.

4.4 Pressure Analyses

The applicant described the pressure analyses in Sections 4.4.4 and 4.6.4 of the SAR. 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 containing 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 applicant calculated a maximum normal condition pressure for a TSC of 104 psig. The calculated maximum pressure of 104 psig allows for a 6 psig tolerance on the TSC helium backfill prior to reaching the 110 psig system pressure used in SAR Chapter 3 normal condition structural evaluation. The staff found the applicant’s pressure analyses acceptable.

4.5 Temperature Calculations

The applicant described the component temperature calculations in Sections 4.4.3 and 4.4.4 of the SAR. The staff found the calculations acceptable.

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. The maximum component temperature results presented in this table (including fuel cladding temperatures) are all below allowable limits for both PWR and BWR spent fuel types. The applicant noted that these temperatures are based on an average annual ambient temperature of 76°F at sea level. Site-specific conditions (ambient temperature, site elevation, air density at the inlet vents, etc.) are to be evaluated by the cask user, per 10 CFR 72.212, to assure that component temperatures will remain below their allowable limits.

Transfer Condition

The maximum component temperatures for MAGNASTOR during the transfer operation are reported in SAR Section 4.4.3 and Tables 4.4-5 through 4.4-16. 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. All time-dependent and steady-state temperatures are below allowable limits during all transfer phases.

4.6 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 included 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 also developed a 3-D FLUENT model of the 37-PWR basket using the applicant's simplified geometry to perform confirmatory vacuum drying analysis. The simplified geometry consisted of a 3-D finite volume one-eighth model for a 166-inch long canister loaded with 37 PWR fuel assemblies. The staff used the same assumptions as compared to the applicant's ANSYS 3-D finite element model. The top and bottom portions of the basket and canister are neglected in the model with analyzed uniform heat load of 35.5 kW assuming a uniform basket initial temperature (including fuel contents) of 130°F and a uniform canister outer shell temperature of 113°F. All the material properties were taken from the updated SAR. The staff's calculated maximum temperatures for vacuum drying were higher than values obtained by the applicant but did not exceed any allowable limit.

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 conditions, transfer, and accident events, are acceptable.

4.7 Evaluation Findings

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

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

F4.3 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.

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 has 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 has reasonable assurance that the temperatures of the cask components and the cask pressures under normal conditions and accident events were determined correctly [10 CFR 72.122].

F4.7 The staff concluded 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 provides 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.

4.8 References

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

5.0 SHIELDING EVALUATION

The objective of the shielding review is to evaluate whether the MAGNASTOR dry cask storage system (DCSS) meets the radiation protection requirements set forth in 10 CFR Part 72 and 10 CFR Part 20, and whether the design and operation of the DCSS follow the ALARA principle. This review includes the radiation source term determination and the radiation shielding design for all credible normal conditions and off-normal and accident events encountered during loading, handling, on-site transfer, storage, and retrieval. This review also includes verification of computer code benchmarks and the computer modeling of the cask system for shielding analyses.

The staff's review also considered the acceptance criteria specified in Section 5 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems." The staff's review was performed based on information provided in the MAGNASTOR SAR Revision 2, June 2008. The following sections summarize the staff's findings and conclusions.

5.1 System Description

The MAGNASTOR DCSS is designed to store only undamaged PWR and BWR spent fuel assemblies with initial enrichments of 1.3 wt% to 5.0 wt% and burnup of 10 GWd/MTU to 60 GWd/MTU. Spent fuel assemblies with unenriched uranium blankets are also acceptable contents, provided that the length of each blanket is not greater than six inches (Appendix B Technical Specifications, Table B2-1, item I.E and Table B2-8, item I.G).

Spent fuel assemblies with various burnups are placed into transportable storage canisters (TSCs) in conformance with the limits on total canister heat load. Preferential loading patterns also may be used to accommodate the need for loading PWR assemblies with heat loads up to 1200 watts per assembly, provided that the total canister heat load is within the established limits for the contents.

5.2 Source Specification

To determine the bounding radiation source terms of the fuel assemblies to be loaded in the MAGNASTOR system, the spent fuel assemblies are sorted into groups according to the assembly types, i.e., PWR or BWR, and fuel and hardware masses. A hypothetical bounding fuel assembly is created for each assembly type. Each hypothetical assembly is based on the maximum fuel and hardware masses and presents a conservative bounding value of fuel and hardware mass of that group. Table 5.2.3-1 and Table 5.2.3-2 provide the essential characteristics of the fuel assemblies to be loaded in the MAGNASTOR system.

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

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

- Average assembly burnup from 10 GWd/MTU to 60 GWd/MTU
- Fuel initial enrichment from 1.3 wt% to 5.0 wt%
- Cooling time from 4 years to 90 years (nonfuel hardware is evaluated at cooling times down to 2 years).

A maximum burnup of 62.5 GWd/MTU is used in the SAS2H fuel assembly depletion analysis. Appropriate peaking factors, i.e., 1.08 for PWR fuel and 1.22 for BWR fuel, were applied to the source term in the fuel region calculated using SAS2H, to account for the burnup peaking in the middle portion of the fuel assembly. However, based on data published in NUREG/CR-6801, the peaking factor for PWR fuel should be 1.108 rather than 1.08. The applicant addressed the staff's concern on this issue and revised the SAR to specify that the system users (licensees) should take into consideration the burnup profiles for site-specific fuel loading to ensure that the required dose limits are met.

Recognizing that the SAS2H depletion analysis code is only benchmarked to 46.6 GWd/MTU for PWR fuel assemblies and to 57 GWd/MTU for BWR fuel assemblies, the applicant added an extra 5% safety margin to the calculated source terms for the proposed loading of spent fuel assemblies with burnup ranging from 46 GWd/MTU to 60 GWd/MTU for PWR fuels, and 57 to 60 GWd/MTU for BWR fuels. The staff considers this extra safety margin sufficient to account for the uncertainties involved in the burnup extrapolation, based on various publications such as NUREG/CR-6701, NUREG/CR-6801, and NUREG/CR-6802.

Gamma Source

The gamma radiation contribution to the source term for the shielding calculation comes from two sources: spent fuel (actinides and fission products), and activated hardware (both fuel assembly and nonfuel assembly components). The hardware activation is assumed to be an equivalent of 0.8 grams of ^{60}Co per every 1000 grams of non-zirconium structural materials. Other activated nonfuel components to be considered include control element assemblies, reactor control component assemblies, burnable poison rod assemblies, and thimble plugs. The burnable poison rod assemblies are assumed to be depleted in the core for three cycles and the thimble plugs are assumed to have an average exposure of 180 GWd/MTU.

The applicant used average enrichment in the source term calculation to represent fuel assemblies containing natural uranium blankets. To assess the validity of this approach, the applicant provided explicit evaluations for the gamma and neutron source terms from the fuel assemblies containing six inches of natural uranium blankets at both ends. The results show that the average enrichment approach underestimates the gamma source term by 1% in comparison with that of the corresponding explicit model of the fuel assembly with natural uranium blankets not greater than six inches. However, the results of the staff's explicit model for a fuel assembly with greater than six-inch natural uranium blankets show that the average enrichment approach underestimates the total source term by as much as 10%. Therefore, the average enrichment approach, in general, is not acceptable because this approach cannot capture the three-dimensional effect of the skewed neutron flux, and hence the burnup distributions, in a natural-uranium blanketed fuel assembly. However, this approach is sufficient as a first order approximation for specific situations such as fuel assemblies with natural uranium blankets of six inches or less at each end. As such, users of the MAGNASTOR system are only permitted to load fuel assemblies having natural uranium blankets not greater than six (6) inches (Appendix B Technical Specifications, Table B2-1, item I.E and Table B2-8, item I.G).

Neutron Source

The neutrons in spent fuel assemblies are produced mainly by actinides with spontaneous fissions and (α, n) reactions. The subcritical neutron multiplication inside the cask system also is included in the neutron source term with the well established steady-state neutron population for a subcritical system with a constant neutron source, as expressed in the following equation:

$$N(t) = S_0 / (1 - k_{eff})$$

The applicant states that the k_{eff} value used in this equation is 0.4 for a dry cask.

In addition, the applicant also demonstrated through examples that the neutron dose rate for the dry cask condition bounds that for a flooded or partially flooded transfer cask. The staff examined these calculations and found that the applicant's conclusion is acceptable.

Bounding Gamma and Neutron Spectrum

A 22-group spectrum is employed for the gamma source term. A 28-group spectrum is employed for the neutron source term. Table 5.2.3-3 and Table 5.2.3-5 provide the gamma and neutron spectra, respectively. To perform bounding analyses, the applicant grouped the gamma and neutron source terms based on the energy distribution of the source terms and their associated assembly type, initial enrichment, burnup, and cooling times. Table 5.2.3-6 and Table 5.2.3-7 provide the source term strength data for these groups.

Axial Burnup Profile

The applicant demonstrated in Section 5.6 of the SAR that fuel with burnup in excess of 30 GWd/MTU produces the maximum dose rates. An axial uniform peaking factor is used in calculating the source term. The peaking factors are 1.08 for PWR assemblies based on calculated data from the Seabrook and Maine Yankee plants and measured Turkey Point gamma data. The peaking factor is 1.22 for BWR assemblies based on calculated data from the Columbia Generating Station.

The data published in NUREG/CR-6801, however, indicate that the appropriate peaking factor is 1.108 for PWR spent fuel, and there is no publically available data for BWR burnup profile. Based on these facts, the staff considers the use of these specific burnup peaking factors acceptable, in conjunction with Appendix A Technical Specification 5.5.3, which requires that the licensee (system user) perform an analysis to confirm that the dose limits of 10 CFR 72.104(a) will be met under actual site conditions, considering the number of casks and actual fuel contents.

Axial Source Profile

The applicant introduced a function to relate fuel assembly burnup with the corresponding gamma and neutron source strengths as:

$$r = \frac{1}{H}\int B^{b} dz$$

Where H is the fuel assembly height and B is the fuel assembly axial burnup profile. The value of parameter b is 1.0 for gamma source and 4.22 for neutrons.

With the above equation, a scaling factor “r” is calculated for each fuel assembly type; BWR and PWR. This scaling factor relates the source terms to the average fuel assembly burnup.

5.3 Model Specification

The applicant calculated the dose rates for the transfer cask using a “response function” method. This method estimates the dose rates for different fuel loadings by interpolation of the results from MCNP calculations. The applicant did not provide a detailed technical basis nor a reference for this approach. The applicant stated that the “response function” method is based on MCNP shielding analyses, and provided three example calculations for each fuel assembly type, i.e., PWR or BWR, as requested by the staff.

Although the applicant has demonstrated via specific examples that the response function method produces results that match the results of the MCNP code, it is important to note that the response function does not account for the material dependence of the particle transport problem and, therefore, cannot be generally applied. The validity of the response functions generated by the MCNP code must be obtained and closely examined for each specific cask design.

In addition, the MCNP shielding models used by the applicant for the transfer and concrete casks employed the fresh fuel assumption, i.e., the isotopic compositions of the spent fuel assemblies in the casks are the same as those of the corresponding fresh fuel. Although this assumption may be acceptable for low burnup spent fuel, its use for high burnup fuel is subject to greater uncertainty because the composition of the fuel assembly changes substantially when the fuel is extensively depleted. The substantial actinides and fission products in high burnup spent fuel result in greater contributions to the neutron and gamma sources as a result of spontaneous fissions and secondary neutrons and gamma. The staff has determined that the applicant’s analysis is acceptable for the MAGNASTOR system; however, the acceptability of the fresh fuel assumption, when applied to other high burnup fuel, will be considered on a case-by-case basis.

The radiation safety and shielding effectiveness of the storage system is evaluated using the three-dimensional Monte Carlo method computer code MCNP5. In the MCNP5 model, the fuel assembly is divided into five regions. Source terms from fuel and hardware in each region are homogenized into the regional volumes as uniformly distributed sources. The transfer and concrete casks, including air inlet and outlet paths, are explicitly modeled for shielding and particle streaming.

The ISFSI site boundary dose rates are estimated using a modified version of the SKYSHINE-III computer code, NAC-CASC. The surface radiation currents of the concrete cask calculated by the MCNP5 code are used as the input to the NAC-CASC computer code. The energy and angular spectrum of the radiation emitted from the concrete storage casks are retained when source terms are converted from the MCNP5 output to the NAC-CASC input. It should be noted that, because the NAC-CASC methodology has an intrinsic dependency on the air density, the licensee/user of the MAGNASTOR system shall consider the influence of the site-specific air density in performing the analysis required by Appendix A Technical Specification 5.5.3.

NAC-CASC explicitly calculates cask self-shielding based on the cask geometry and arrangement of the cask array. A particle tracing technique is utilized. In this technique, for a given source location on the cask surface and direction cosines for the source emission, geometric tests are made to determine if any adjacent casks are in the path of the emission. If so, tracking of this particle is terminated because the probability is very small for the particle to contribute to the air scatter dose. Given the thickness of the concrete wall and the diameter of the concrete storage cask, the staff finds this approximation acceptable because only a small fraction of the particles hitting the concrete wall will scatter away from the concrete cask surface. Therefore, the contribution to the total radiation dose by the particles that are scattered from the cask is insignificant.

In the NAC-CASC model, the concrete casks are treated as “black” bodies when modeling the cask shadowing effect. This assumes that radiation emitted from the surface of one cask, which subsequently hits an adjacent cask, will not have a significant contribution to the site boundary dose rate because of the thickness of the cask concrete.

The key shielding features of the TSC, concrete storage cask, and the transfer cask are listed in Tables 5.5.5-1, 5.5.5-2, and 5.5.5-3, respectively. The radial and axial shielding of the TSC, the transfer cask, and the storage cask are all modeled in MCNP5 explicitly except for the source terms. The ISFSI is modeled as a 10 x 2 array of 20 storage casks and the site boundary radiation dose rates are calculated using the NAC-CASC.

In addition, the dose rate contribution from particle and gaseous radioactive materials released from the contaminants on the surface of the TSC is included using the formula provided in Regulatory Guides 1.109 and 1.145.

The SAR provides detailed material density data in Tables 5.5.5-7 and 5.5.5-8 for the different regions of the TSC, transfer cask, and the concrete storage casks.

5.4 Shielding Evaluation and Dose Results

The MAGNASTOR system is designed with a single-length transfer cask and a single-length concrete storage cask. The dose rates are calculated based on a bounding heat load of 37 kW per TSC containing 37 PWR fuel assemblies or 35 kW per TSC containing 87 BWR fuel assemblies. These bounding heat load values provide a convenient way of determining the load pattern of the TSC because they are a measure of the combination of initial fuel enrichment, assembly burnup, and cooling time.

The transfer cask is made of two cylindrical steel shells connected by solid steel top and bottom forgings. A lead gamma shield and a solid borated polymer neutron shield are enclosed between the two steel shells. The applicant performed three-dimensional gamma and neutron shielding analyses for the transfer cask under different operations. All dose rate evaluations assume that all loading operations are performed with a dry canister, even though the majority of the operations, in particular closure lid welding, are performed with the TSC cavity filled with water. This assumption is conservative, since the presence of the water in the TSC provides additional shielding and would result in a net decrease in dose rate. However, the applicant's analyses did take credit for the use of the weld platform during TSC closure activities, which provides 6 inches of steel as auxiliary shielding.

The concrete storage cask is used to hold the TSC. The concrete cask consists of a body and a lid that are made of concrete with steel reinforcement bars. There are air inlets and outlets on the body of the concrete cask for heat removal. The center cavity of the cask is for the placement of the TSC. The lid provides a closure to the cask body once the TSC is loaded in the cavity. The air inlets and outlets are axially offset from the source regions to minimize the neutron and gamma streaming.

The applicant evaluated the source terms for fuel assemblies with natural or depleted uranium blankets using the SAS2H assembly depletion code. Since the SAS2H code is only a one-dimensional code and cannot model the natural uranium blanketed fuel assemblies explicitly, the applicant used the average ^{235}U enrichment to calculate the source terms for fuel assemblies of this type. Hence, the staff believes that the applicant's evaluation results presented in Section 5.8.10 of the SAR may underpredict the source term for the natural uranium blanketed fuel assemblies. The staff's independent evaluation using the TRITON code, a 3-D Monte Carlo transport theory-based code, found that the applicant's approach may underestimate the total source term (gamma + neutron) by up to 10 percent for fuel assemblies with 12 inches of natural uranium blankets at both ends. However, the error is smaller (2~3 percent) for a 6-inch natural uranium blanket. The applicant agreed to limit the loading to assemblies containing natural uranium blankets that are not greater than six (6) inches in the Appendix B Technical Specifications, Table B2-1, item I.E and Table B2-8, item I.G.

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

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

For the given source distribution and spectra, the applicant used the NAC-CASC code, which calculates the dose rates at locations of interest using a combination of precalculated transmission and reflection data and a Monte Carlo technique to integrate over the source direction and energy.

The applicant used the flux-to-dose rate conversion factors of the ANSI/ANS 6.1.1-1977 standard. The staff finds this version of the flux-to-dose rate conversion factors acceptable based on the guidance of NUREG-1536. SAR Figures 5.6.5-1 and 5.6.5-2 provide the calculated bounding dose rates at different heights along the cask axial direction and different locations along the radial direction of the concrete storage cask. Figures 5.6.5-3 and 5.6.5-4 provide the calculated bounding dose rates at different cask air outlet and inlet locations. The maximum dose rates identified by the applicant exist at the top surface of the cask, approximately 85 to 100 cm from the central axis (Figure 5.6.5-2); and at the cask bottom air inlet (Figure 5.6.5-4).

For the transfer cask, the bounding cask dose rates at different distances from the cask center are presented in Figures 5.6.5-5, 5.6.5-6, and 5.6.5-7. The side surface dose rate peaks at the center of the fuel region. The dose rate at the top surface of the transfer cask peaks at 90 cm from the center where the transfer cask to TSC gap is located. The dose rate at the bottom surface of the transfer cask peaks at 20 cm from the center.

Radiation doses from the TSC surface contaminants are also calculated using the methodology described in Regulatory Guide 1.109. Table 5.6.5-3 provides the calculated results. The data show that TSC surface contaminants do not make a significant contribution to the dose at the site boundary. The staff finds this conclusion acceptable.

Based on the heat limits of 37 kW per PWR cask and 35 kW per BWR cask, the applicant developed minimum cooling time requirements for each allowable fuel type group based on the combination of initial enrichment, fuel type, and cooling time.

Section 5.8.3 of the SAR describes the shielding model and evaluation results, with loading tables and cooling time requirements for the 37-PWR assembly system. The dose rates for the transfer cask for the bounding PWR spent fuel characteristics are listed in the following table:

Surface	Fuel Type	Cooling Time (yrs)	Assembly Average Burnup (GWd/MTU)	Initial Enrichment (wt % ^{235}U)	Maximum Dose Rate (mrem/hr)	Average Dose Rate (mrem/hr)
Radial	14a	5.6	44	2.5	1,069	693
Top	14b	5.7	44	2.5	439	163
Bottom	14b	5.7	44	2.5	6,193	3,108

Nonfuel components, including PWR BPRA hardware and thimble plugs, are included in the dose rate calculations. The minimal cooling times for allowable PWR nonfuel components for given exposures are in SAR Tables 5.8.5-3 and 5.8.5-5.

The only nonfuel components included in the BWR dose rate calculations are the control element assemblies. The cooling times for allowable BWR nonfuel components for given exposures are discussed in SAR Section 5.8.6.

In order to load fuel assemblies with heat loads greater than 1 kW, a three-zone, preferential loading pattern is proposed (i.e., inner, middle, and outer zones). In this proposed preferential loading pattern, assemblies with higher heat loads up to 1200 watts per fuel assembly will be loaded in the middle zone. The total heat load of the TSC is kept the same as that of a corresponding uniform loading pattern. SAR Table 5.8.7-1 demonstrates that the maximum calculated dose rates for the uniform loading pattern bound those for the preferential loading pattern for both the transfer cask and concrete storage cask.

The maximum surface dose rates for the concrete storage cask are presented in Table 5.8.3-6 in the SAR. The maximum dose rates at the side, top, and possible particle streaming paths (air inlet and outlet ports) are 77 mrem/hr, 379 mrem/hr, 448 mrem/hr, and 41 mrem/hr respectively.

Section 5.8.4 of the SAR provides details of the shielding evaluation results, with loading tables and cooling time requirements for the 87-assembly BWR system. A curve of dose rate versus distance to the center of the ISFSI is provided for the system. Contours of the controlled area boundaries needed to meet the annual dose requirement of 10 CFR 72.104(a) are provided in Figure 5.8.3-16 and Figure 5.8.4-16 for a 2x10 PWR cask array and a 2x10 BWR cask array, respectively.

The staff noted that, for the bounding 2x10 concrete cask array, the dose at a controlled area boundary in the range of 1300 to 1600 feet from the center of the ISFSI would correspond to the regulatory limit on annual dose to a member of the public from normal operations. Therefore, the MAGNASTOR system user must perform a site-specific analysis, as required by Appendix A Technical Specification 5.5.3, to verify compliance with 10 CFR 72.104(a). This analysis should take into consideration factors such as the actual fuel characteristics, total number of casks, cask array configuration, topography, atmospheric conditions, and engineering features that are part of the bases of the shielding analyses.

5.5 Confirmatory Review and Analysis

The staff reviewed the applicant's shielding analysis and found it acceptable. The maximum dose rates meet the limits defined by 10 CFR Part 72. The staff reviewed the radiation shielding evaluations, including the calculations of the sources and the dose rates for the transfer cask and the concrete casks, at the boundary of the ISFSI controlled area. The staff independently calculated source terms for the bounding PWR and BWR fuel assemblies using combinations of different enrichments, burnups, and cooling times. The staff also performed confirmatory analyses of the dose rates for the transfer and storage casks. The staff finds the applicant's determination of the bounding dose rates for all proposed payloads as defined in Tables 5.8.3-6 and 5.8.4-8 to be acceptable. The applicant has demonstrated and the staff concurs that the

MAGNASTOR dry cask storage system meets the radiation protection requirements of 10 CFR 72.104 and 72.126.

The staff reviewed the applicant's dose rate calculations and finds that the approaches and methodologies used in these calculations, and the results, are acceptable for the MAGNASTOR system design. However, users of the MAGNASTOR system shall perform additional evaluations and analyses, as required by 10 CFR 72.212 and Appendix A TS 5.5.3, to properly account for site-specific characteristics, such as meteorological conditions, topographical features, and actual fuel parameters, as these factors may affect the calculation of off-site dose to a member of the public.

5.6 Evaluation Findings

F5.1 Chapter 5 of the MAGNASTOR SAR sufficiently describes the shielding design bases and design criteria for the structures, systems, and components important to safety.

F5.2 The MAGNASTOR system radiation shielding and confinement features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, 10 CFR 72.106, 10 CFR 72.126, and 10 CFR 72.236(d).

F5.3 The staff concludes that the shielding and radiation protection design features of the MAGNASTOR system, including the concrete cask, the transfer cask, and the TSC, are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The evaluation of the shielding and radiation protection design features provides reasonable assurance that the MAGNASTOR system will provide safe storage of spent fuel. This finding is based on a review that considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, the applicant's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

6.0 Criticality Evaluation

The criticality review ensures that the contents will remain subcritical under all credible normal conditions and off-normal and accident events 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 application).

Only those features of the MAGNASTOR system design 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 conditions and off-normal and accident events 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(a), 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 8C, June 2008.

6.1 Criticality Design Criteria and Features

The major components of the MAGNASTOR system are a transportable storage canister (TSC), a concrete storage cask, and a lead-shielded transfer cask. Criticality safety in the system design is provided by a combination of fissile mass controls, geometry control, fixed neutron absorbers in the basket, and, for the PWR fuel, dissolved boron in the water used to flood the canister. The TSC contains either a basket that holds 37 PWR fuel assemblies or a basket that 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. A minimum dissolved boron concentration that must be maintained in the water in the canister during loading and unloading of the PWR fuel 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 finds that they are consistent with the description of the design and contents given in Chapters 1 and 2 of the SAR. 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 located in Appendix B of the Technical Specifications. The allowed contents are limited to fuel that is undamaged and has cladding made from zirconium-based alloys only. Damaged fuel is defined in the Technical Specifications as fuel that cannot fulfill its fuel-specific or system-related function. The definition provides further clarification of conditions that preclude the fuel from fulfilling its fuel-specific or system-related function. These conditions include cladding breaches that have the potential for release of a significant amount of fuel particles and impairment of the assembly's structural integrity, which would allow reconfiguration of the fuel assembly geometry during normal conditions, or off-normal or accident events. Missing fuel rods in an assembly must be replaced by a solid dummy rod of equal or greater displacement before loading.

6.3 Model Specifications

The key modeling assumptions used by the applicant are: 1) fresh, undamaged, 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; 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 composite absorber plates.

The applicant provided sample input files for criticality calculations with PWR and BWR contents, for the loaded TSC in the transfer cask and in the concrete cask (PWR sample input files), and the 87-assembly and 82-assembly baskets (BWR sample input files). Staff reviewed these input files to verify the use of the modeling assumptions, as well as the most reactive fuel characteristics and basket configuration.

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, as well as the TSC-overpack annulus, 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 that maximize the effective neutron multiplication factor, 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 (BWR fuel), 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 nonfuel 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 nonfuel 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. Analyses with inserts did not include inserts in the PWR instrument tubes; therefore, the Technical Specifications restrict inserts in assemblies such that an assembly may not contain inserts in the instrument tube and the guide tubes concurrently (i.e. inserts may be in either the guide tubes only or in the instrument tube only). Since the sensitivity to the guide tube thickness was found to be very small, this dimension is not included in the fuel parameter specifications; however, the number of guide tubes is retained. These bounding conditions are included in the final design calculations used to set limits on the allowed maximum initial enrichments.

A minimum limit on the fuel tube pitch in the basket is included in the Technical Specifications, which is the fuel tube pitch used in the criticality analyses. The use of this pitch assumes that this pitch, which is a fabrication limit, will be maintained under accident events. The applicant indicates that there is some permanent set, or deformation, that results from the tip-over accident; however, the deformation is quite small (0.008 inches for the PWR basket and 0.004 inches for the BWR basket), less than half of the tolerance on the tube interface width. Further, the structural evaluation indicates that this deformation is a localized (both axially and radially) effect from the tip-over accident. Therefore, based upon the limited extent of permanent deformation in the design, as proposed in the application, and conservatisms in the analysis and risk-informed considerations, the staff finds the use of the Technical Specification limit on tube pitch to be acceptable for the applicant's criticality analysis for spent fuel storage conditions.

The staff considered 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, accepted a limit on the maximum pellet diameter only.

In response to RAIs, the applicant modeled the basket with the optional peripheral poison plates (see SAR Drawing Nos. 71160-575, Rev. 6; 71160-599, Rev. 5, and 71160-600, Rev. 3) removed/replaced by aluminum plates and with the new arrangement of poison plate weld posts. The applicant also states in the SAR that this configuration was used when determining the maximum allowed initial enrichment for each fuel type.

In the 82-assembly BWR configuration, five of the center basket cells which form an "X" pattern may not contain fuel assemblies. Table B2-8 and Figure B2-2 of Appendix B of the Technical

Specifications describe these five designated nonfuel locations. The TS require that the weldments that block the designated nonfuel locations be in place prior to the use of the 82-assembly basket configuration. Procedures for loading the 82-assembly basket also include a step to verify compliance with this condition.

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

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 a comprehensive program of qualification and acceptance testing, as set forth in Sections 10.1.6.4.5 and 10.1.6.4.6 of the SAR. The staff's evaluation of the qualification and acceptance testing program is provided in Section 8 of this SER.

The minimum areal density of ^{10}B required in the fabricated 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. The minimum effective areal densities are 0.036g $^{10}B/cm^2$ in the PWR basket and 0.027g $^{10}B/cm^2$ in the BWR basket.

Specifications for the minimum boron concentrations in the water during wet loading and unloading of the PWR basket are given in Table B2-3 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_{eff} 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 combination of parameter changes in the final analysis that is compared against the upper subcritical limit 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 Subcritical Limit (USL) when loaded with the allowed contents as specified in the SAR and proposed Technical Specifications.

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

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 atom ratio, 6) soluble boron concentration, 7) spacing between fuel assemblies, 8) ^{10}B 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 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 that did exist for 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 that accounted for the near flat trends in the other parameters and resulted in a constant USL value. This constant USL value is the lowest value derived from correlations calculated with the program USLSTATS and results from the correlation for the fuel rod diameter.

As part of its revision of the benchmark analysis, the applicant added data in each parameter trend analysis from a group of 186 benchmark experiments that had not been initially considered, stating that the initial analyses had not considered all the applicable data. This modification translated into data from 183 of the experiments being included (and 3 being discarded) in each parameter analysis except for the cluster gap (fuel assembly spacing), for which only 137 experiments were determined applicable. The applicant provided justification as to the applicability of the data presently included with each parameter analysis.

The staff reviewed the modified benchmark analysis, including the descriptions of the included experiments and justification of applicability provided by the applicant. In its evaluation of the benchmark analysis, the staff noted that not all applicable experiments (based upon the applicant's method of determining applicability) were considered for the cluster gap trend analysis. Specifically, it appears that experiments listing the number of clusters as two-dimensional arrays, such as 3x3 and 5x5 (see SAR Table 6.7.7-1), should have been included. However, the staff determined that the trend analysis without these additional data points is conservative.

The staff also observed that a number of experiments were included in the absorber plate ^{10}B density analysis that are not applicable to this parameter. These experiments used absorber plates with different absorber materials, such as cadmium and copper, which are not representative of the MAGNASTOR system's poison plates, and therefore should not be included. The applicant subsequently provided a calculation that removed the non-Boron based experiments. The modified calculation resulted in an insignificant effect on the USL and no effect on the maximum enrichments of the proposed contents.

The staff examined the applicant's trend analysis for the soluble boron concentration, particularly the interpolation inherent in the current analysis over a large range of boron concentrations, a lack of data in the concentration range of the PWR analyses, and the addition of a very large number of data points at zero ppm boron concentration. The applicant evaluated trends that excluded the few data points near the 5000 ppm concentration, or the zero ppm concentration data, or both sets of data. Exclusion of only the few data points near 5000 ppm did not impact the analysis USL. Correlations excluding just the zero ppm data, or both the zero ppm data and the 5000 ppm data, resulted in a minimum USL that is less than the analysis USL. However, the applicant argued that the additional zero ppm data are needed to arrive at a high confidence USL, particularly for the BWR analyses that are at this range of soluble boron. Regarding the range of boron concentrations covered in the PWR design analyses, the applicant stated that there is nothing in the open literature that indicates the code bias would increase in this range. Upon further review of the experiments, the staff also questioned the applicability of the data near 5000 ppm, since the experiment descriptions indicate that the borated solution was confined to a region of the experiment not containing fuel, a configuration that is different from that in which the MAGNASTOR system would be used. However, the staff notes that an analysis excluding both sets of data would indicate a trend toward smaller biases in the range of the PWR design analyses. Also, based upon the lack of strong trends in the other parameter analyses, the staff does not expect a strong trend to exist in the soluble boron parameter resulting in an increasing bias if there were additional data available beyond 1500 ppm. Further, there is no basis for excluding the additional zero ppm data as not applicable for this parameter trend analysis. However, the staff cautions that for any potential changes to this analysis, only the most relevant experiments (i.e., those with the greatest similarity to the cask configuration) should be applied, as an excessive amount of data at one location may skew the trend analysis in a nonconservative manner.

The staff also notes that the range of the cask analysis may significantly extend beyond the applicable range of the EALCF analysis data. However, based upon the trends for the other parameters and the trend currently determined for the EALCF, the staff does not expect a significant trend that would result in an increasing bias.

Based upon its review, the staff finds that, though there are some uncertainties regarding some aspects of the benchmark analysis, the analysis and the resulting USL are acceptable for the criticality design of the MAGNASTOR as proposed in the current application. This finding is based upon the small impact on the analysis USL and lack of impact on the maximum enrichments of the proposed contents (for the absorber plate trend analysis), the overall lack of significant trends for the several parameters (in considering the anticipated trend behavior for the boron concentration and EALCF), the nature of trends derived from currently included data (for boron concentration and EALCF), and risk-informed considerations. The staff notes, however, that the acceptability of the benchmark analysis may need to be reevaluated if any changes are made to the contents or cask design.

The applicant reviewed benchmark input files for modeling consistency with cask models and the choice of code options. The applicant stated that this review did not indicate any trends resulting from the use of particular modeling code options (e.g., using the UNIVERSE structure versus a single universe for an entire model).

6.5 Criticality Evaluation Summary

The applicant used three-dimensional calculation 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 calculation models for the normal conditions and the off-normal and accident events are the same.

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 and the 238-group (ENDF/B-V) cross-section sets in SCALE. The staff's confirmatory analyses included both PWR and BWR baskets, several 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 the staff's results fell below the acceptance criterion of 0.95 for k_{eff}.

6.6 Evaluation Findings

Based upon a review of the information presented in the application and independent, confirmatory analyses, the staff makes the following findings:

F6.1 Structures, systems and components important to criticality safety are described in sufficient detail in Chapters 1, 2 and 6 of the SAR to enable an evaluation of their effectiveness.

F6.2 The MAGNASTOR cask system, including the TSC, the concrete storage cask and the transfer cask, is designed to be subcritical under all credible conditions.

F6.3 The criticality design is based upon favorable geometry, fixed neutron poisons (boron-based neutron absorber plates) and, for PWR fuel assembly contents, soluble boron in the spent fuel pool. Based upon the structural evaluation (see Section 3 of this SER), the design geometry will be maintained under all credible design-basis conditions, with only very limited deformation under design-basis accidents that has an insignificant impact on system reactivity. Based upon the materials evaluation (see Section 8 of this SER), the neutron absorber plates will perform their function effectively and will be able to do so for the 20-year storage period with no credible way to lose their efficacy; therefore, there is no need to provide a positive means to verify continued efficacy as required by 10 CFR 72.124(b).

F6.4 The analysis and evaluation of the criticality design and performance have demonstrated that the cask will enable the storage of spent fuel for a minimum of 20 years with an adequate margin of safety.

F6.5 The criticality design features for the MAGNASTOR cask system are in compliance with 10 CFR 72 and the applicable design criteria have been satisfied. The evaluation of the criticality design provides reasonable assurance that the MAGNASTOR cask system will allow safe storage of spent fuel. This finding is reached based upon a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, appropriate risk-informed considerations, and accepted engineering practices.

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), as resubmitted on August 6, 2007, and as subsequently revised by letters through September 18, 2008.

7.1 Confinement Boundary

The MAGNASTOR confinement boundary consists of a welded stainless steel transportable storage canister (TSC). Note that the TSC design has not yet been submitted by the applicant, nor approved by the NRC, for transport in accordance with 10 CFR Part 71. The TSC 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, a 2¾-inch thick bottom plate, and a 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 (¾-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 assembly 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, midplane, 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. The Code acceptance criterion for the field hydrostatic pressure test is "no visible leakage." For the proposed test, leakage would be readily visible from the closure weld, but would not be visible from the shell welds, since the TSC is located within the transfer cask when the pressure test is performed. However, the staff accepts the previously performed shop helium leakage test of the canister assembly (as specified in Section 10.1.3 and Table 2.1-2 of the SAR) as reasonable assurance that the shell is free from flaws that would cause any leakage. SAR Table 2.1-2 describes the exception and justification for not meeting the Code leakage acceptance criterion associated with performing a hydrostatic pressure test on the entire confinement boundary. This table lists all of the alternatives to the ASME Code requirements approved by the staff for the MAGNASTOR system, and is explicitly referenced in Appendix A TS 4.2.1.

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 provides 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 are not examined by a multilayer liquid penetrant examination, and are potentially under pressure, they do not qualify for the ISG-15 test exception and are leak tested 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 events 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 of storage (see SAR Section 4.4.3), 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 the lid-to-shell 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 review of information on the confinement design 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. This finding in the confinement review area is contingent upon the acceptability of the thermal analyses needed to demonstrate that material temperature limits will not be exceeded, as described in Section 4 of this safety evaluation report.

F7.4 The confinement boundary integrity will be ensured through: (1) a hydrostatic test of the lid-to-shell 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 will be 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 72.122(a), (b), (h) and (l), and 72.236(a),(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 mechanical assembly of carbon steel fuel compartment boxes, designed to accommodate PWR and BWR fuel assemblies. 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 weldments), 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. The fracture toughness evaluation is discussed in Section 8.2 of this safety evaluation report.

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) A36 steel, a commonly used steel for structural applications, and ASTM A615 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 A588, low alloy steel, while the trunnions and shield doors are primarily fabricated from ASTM A350, 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 Materials

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 Appendix A Technical Specification 4.1.1, appropriate qualification and acceptance testing will be used to ensure that the neutron absorbers have the minimum specified ^{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 the 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 –40°F. Based on Regulatory Guide 7.11, the minimum temperature for use is 40°F above the transition temperature, with no credit taken for heat produced by the contents of the transfer cask. Consequently, the applicant has stated that a minimum ambient temperature of 0°F 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, 0°F, 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 techniques 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 fuel tubes and weldments and is applied in accordance with ASTM B 733. Adhesion of the nickel coating to the carbon steel components 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 closure 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 finds 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 either the Keeler and Long or a Carboline epoxy enamel paint coating is 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 to the inert atmosphere in the TSC.

To ensure that the safety hazards associated with the ignition of hydrogen gas are mitigated, the procedures of 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, 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 4.1.1 of the Appendix A Technical Specifications. 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 that 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 Damaged Fuel

The applicant provided a detailed definition of “damaged fuel” following the guidelines in Interim Staff Guidance-1 (ISG-1), Revision 2, “Damaged Fuel.” This included definitions of “assembly defect,” “breached spent fuel rod,” “intact fuel,” and “grossly breached fuel.” The definition allows assemblies with a missing or defective grid strap to be considered undamaged. It also addresses the use of visual examination only by methods that allow the fuel surface to be seen, and only to determine if a breach is gross. The definition of damaged fuel is acceptable to the staff.

8.10.3 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.

8.10.4 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 affect 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 finds that there will not be excessive stress on the cladding leading to fuel rod degradation if a reflood of the cask is required.

8.10.5 Vacuum Drying

The drying process proposed by the applicant differs from that recommended in NUREG-1536. Instead of the recommended pump down to 3 torr before isolating the valve and looking for a pressure rise over 30 minutes, the applicant proposes to pump down to 10 torr (half the water vapor pressure at 22.2°C), and isolate for 10 minutes. Since the isolation time required is so dependent on the location of the water in the cask, the time is acceptable. The applicant provided a clarifying restatement of the guidelines on thermal cycling provided in ISG-11 Rev 3. The fuel will be limited to no more than 10 cycles having a temperature drop greater than 65°C during the drying process. Based on elimination of water to prevent corrosion of internal components, and the prevention of degradation of the cladding due to cycling, the proposed drying method is acceptable to the staff.

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 evaluation of their effectiveness.

F.8.2 The design of the TSC and the selection of materials adequately protect the spent fuel cladding against degradation that might otherwise lead to gross rupture. This finding in the materials review area is contingent on the thermal analyses demonstrating that material temperature limits will not be exceeded, as described in Section 4 of this safety evaluation report.

F.8.3 The TSC employs only noncombustible materials that 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 EVALUATION

Chapter 9 of the MAGNASTOR SAR describes the operating procedures for loading spent fuel, for removing a loaded TSC from a concrete cask, and for the wet unloading of fuel from a TSC. The procedures described in the SAR provide general guidance; the system user (reactor licensee) will develop more detailed, site-specific procedures for the actual loading, handling, transfer, storage and unloading of the system. These general and site-specific procedures will comply with the conditions of the Certificate of Compliance, and specifically, with Section 5.2 of the Appendix A Technical Specifications, “TSC Loading, Unloading, and Preparation Program.”

9.1 Cask Loading

In preparation for cask loading, the operating procedures in Chapter 9 of the SAR include provisions to ensure that the transfer cask, TSC, and concrete cask are acceptable for use and properly positioned. The procedures require inspection and cleaning of the TSC and fuel basket, and cleaning and decontaminating the transfer cask and other equipment as necessary. When the 82 BWR assembly basket configuration is selected, the procedures require verification that the center cell weldment and upper weldments with blocking straps are present, so that fuel cannot be loaded in the five designated nonfuel basket locations.

9.1.1 ALARA

The design of the MAGNASTOR system is intended to minimize radiation exposure to workers by providing sufficient shielding and limiting the potential for radioactive contamination on component surfaces. In addition, the procedures described in Chapter 9 of the SAR incorporate ALARA principles and practices. These include exposure and contamination controls, and the use of temporary shielding. The staging and material composition of any supplemental shielding must be evaluated by the user/licensee as part of its ALARA program, and any temporary shielding must also be evaluated for potential interaction or interference with the MAGNASTOR system components. Further evaluation of ALARA is found in Section 11 of this safety evaluation report.

9.1.2 Fuel Selection and TSC Loading

The loading procedures described in Section 9.1.1 of the SAR provide instructions to operating personnel to ensure that fuel assemblies are loaded correctly into the TSC. The fuel assemblies shall be selected in compliance with the Approved Contents specified in Appendix B to the CoC. Also, the boron concentration limits in the spent fuel pool water, the fuel loading patterns, and the transfer cask temperature, as required by the Technical Specifications, must be verified. Independent verification of correct fuel assembly selection and placement within the TSC basket is also required.

9.1.3 Draining, Drying, Filling and Pressurization

Chapter 9 of the SAR clearly describes the draining, drying, filling and pressurization procedures for the MAGNASTOR TSC that will provide reasonable assurance that moisture in the TSC will be minimized and that the fuel will be stored in an inert atmosphere.

The procedures of Section 9.1.1 allow the use of the annulus circulating water cooling system during loading operations and instruct the operators to follow the TS LCO 3.1.1 requirements on vacuum drying and TSC transfer times. With this system in use, there is no time limit for completion of the draining of the TSC. However, if the system is not used, or becomes unavailable, operators are instructed to monitor water temperature and take appropriate actions to ensure that adequate cooling of the TSC is provided.

The loading procedures specify that only approximately 70 gallons of water will initially be drained from the MAGNASTOR TSC prior to welding of the closure lid, to ensure that the fuel will not be exposed to air. Prior to and during welding, the hydrogen concentration in the TSC air space is monitored to ensure that a combustible concentration will not be reached. When canister draindown is resumed, helium will be used to assist the removal of water from the TSC, and to ensure that the fuel rods are not exposed to air. The staff has previously noted that rapid oxidation of fuel pellets or fuel fragments can occur if a fuel cladding breach (such as a pinhole) already exists, and may cause significant swelling of the fuel pellets and fragments, which could result in gross fuel cladding breaches. Therefore, the use of an inert gas such as helium will prevent loss of retrievability or an inadequately analyzed configuration from a shielding and criticality perspective. The staff reviewed the procedures in SAR Section 9.1.1, and finds these procedures acceptable for this application.

9.1.4 Welding and Sealing

Welding and sealing operations of the MAGNASTOR TSCs are similar to those previously approved by the staff for other canister-based NAC storage systems. The procedures described in Chapter 9 of the SAR ensure that the TSC welds will be appropriately applied, examined, and tested to verify integrity of the confinement boundary.

9.2 Cask Handling, Transfer and Storage Operations

All handling and transfer activities applicable to moving the loaded MAGNATOR TSC to the storage location will be governed by Appendix A TS 5.2, "TSC Loading, Unloading, and Preparation Program." All postulated events are bounded by the analyses in Chapter 12 of the SAR. Monitoring operations include daily surveillances of the concrete cask air outlet temperatures, or visual inspection of the inlets and outlets, to ensure adequate heat removal, in accordance with Appendix A TS 3.1.2 requirements.

Occupational and public exposures are estimated in Chapter 11 of the SAR. Each cask user will need to develop detailed cask handling and storage procedures that incorporate ALARA objectives of their site-specific radiation protection program in accordance with Appendix A TS 5.5.

9.3 Cask Unloading

Detailed unloading procedures must be developed by each MAGNASTOR system user, consistent with the descriptions in Section 9.3 of the SAR and the requirements of Appendix A TS 5.2.

Section 9.3 of the SAR provides unloading procedures similar to those previously approved by the staff for use with other NAC storage systems. The procedures provide for verification that the boron content for the fill water for the TSC conforms to the specifications of Appendix A TS 3.2.1. The procedures also require monitoring for hydrogen during cutting operations.

Section 9.3 of the SAR includes steps to obtain a sample of the TSC atmosphere and to check the gaseous inventory. To control the potential for release of any built up fission gases (indicative of degraded fuel), the procedures specify that a venting system should be used that is connected to a HEPA filter, or to the plant off-gas system. Nitrogen is used to purge any residual radioactive gas from the TSC.

9.4 Evaluation Findings

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

F9.2 The design features and operating procedures for the MAGNASTOR system provide for retrieval of the spent fuel for further processing or disposal as required.

F9.3 The MAGNASTOR system design and general operating procedures facilitate decontamination. Only routine decontamination will be necessary after the cask is removed from the spent fuel pool.

F9.4 No significant radioactive wastes, nor effluents, are generated during loading, transfer or storage operations associated with the MAGNASTOR system. The processing of any contaminated water or equipment will be governed by the 10 CFR Part 50 license conditions.

F9.5 The technical bases for the general operating procedures described in the SAR are adequate to protect health and minimize danger to life and property. Detailed procedures will need to be developed and evaluated by the cask user on a site-specific basis.

F9.6 Section 11 of this safety evaluation report assesses the radiological protection measures and operational restrictions to meet the limits of 10 CFR Part 20. Additional site-specific restrictions may also be established by the cask user/licensee.

F9.7 The staff concludes that the generic procedures and guidance for the operation of the MAGNASTOR system are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the operating procedure descriptions provided in the SAR offers reasonable assurance that the system will enable safe storage of spent fuel. This finding is based on a review that considered the regulations, appropriate regulatory guides, applicable codes and standards, and accepted practices.

10.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAMS

The objective of the staff's review is to ensure that the applicant's SAR includes the appropriate acceptance tests and maintenance programs for the dry cask storage system. The applicant addressed this area in Chapter 10 of the MAGNASTOR system SAR, "Acceptance Criteria and Maintenance Program." The staff considered the review guidance specified in Section 9.0 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems." The staff's review was performed based on information provided in the MAGNASTOR SAR through Revision 2 (June 2008). The following sections summarize the staff's findings and conclusions.

10.1 Acceptance Criteria and Tests

The applicant has indicated that the MAGNASTOR system is classified as important-to-safety and, therefore, the structures, systems, and components (SSCs) are designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with an appropriate quality assurance program. The controls, inspections and tests applied to the system are intended to ensure that the system will perform its required safety functions during normal conditions and off-normal and accident events to maintain confinement of radioactive material, maintain subcriticality, adequately transfer decay heat from the radioactive material contents, and limit radiation exposure to workers and the public.

10.1.1 Visual Inspection and Nondestructive Examination

Chapter 2 of the SAR specifies the applicable design criteria, codes, and standards for the performance of fabrication, inspecting and testing of system components. Section 10.1.1 of the SAR provides an extensive list of the fabrication controls and inspections to be performed. These include:

a) Materials of construction for the MAGNASTOR system are identified on the license drawings and shall be procured with certification and supporting documentation as required by the ASME Code, Section II, when applicable; and the requirements of ASME Code, Section III, Subsection NB and Subsection NG, when applicable.

b) Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to the applicable Code specification and traceability markings, as applicable. The TSC confinement boundary materials shall also be inspected per the requirements of ASME Code Section III, Subsection NB-2500.

c) The confinement boundary shall be fabricated and inspected in accordance with ASME Code, Section III, Subsection NB, with the code alternatives as listed in SAR Chapter 2, Table 2.1-2. The TSC fuel basket and basket supports shall be fabricated and inspected in accordance with the ASME Code, Section III, Subsection NG, with the alternatives listed in Table 2.1-2. The staff reviewed these alternatives, and the corresponding justifications, and found them to be acceptable.

Steel components of the transfer and concrete casks shall meet applicable ASTM specifications and will be fabricated in accordance with ANSI N14.6 (transfer cask) and ASME Code, Section

VIII, or ANSI/AWS D.1.1 (concrete cask). Inspections and NDE of the transfer cask shall be in accordance with ASME Code, Section III, Subsection NF. Inspections of the welded steel components of the concrete cask shall be in accordance with ASME Code, Section VIII or ANSI/AWS D.1.1.

ASME Code welding shall be performed using welders and weld procedures qualified in accordance with ASME Code, Section IX and the ASME Code, Section III subsection applicable to the component (e.g., NB, NG or NF). ANSI/AWS code welding may be performed using welders and procedures qualified in accordance with the applicable AWS requirements or in accordance with Section IX of the ASME Code.

Construction and inspection of the concrete component of the concrete cask shall be performed in accordance with the applicable sections and requirements of ACI-318.

The nondestructive examination (NDE) of weldments for the various MAGNASTOR system components (TSC confinement boundary, fuel basket and supports, concrete cask structural steel, and transfer cask) is well characterized in Section 10.1.1 of the SAR. Standard NDE symbols and notations are used in the license drawings in Section 1.8 of the SAR. Inspections of these components will consist of visual examination (VT), liquid penetrant (PT), radiographic examination (RT) and ultrasonic examination (UT), in accordance with the applicable codes and standards, as specified in SAR Section 10.1.1. In addition, inspection and nondestructive examination personnel shall be qualified in accordance with the requirements of SNT-TC-1A.

The applicant has also committed to performing visual and dimensional inspections on the neutron absorber materials after manufacturing, to verify the acceptability of the physical characteristics and mechanical properties.

10.1.2 Structural and Pressure Testing

Section 10.1.2 of the SAR describes the structural testing to be conducted on the load-bearing components of the transfer cask and concrete cask, and the pressure testing of the TSC. Following completion of fabrication, the load-bearing components of the transfer cask, including the lifting trunnions, shield doors, and rails, will be load tested in accordance with written and approved procedures, consistent with applicable Codes and standards, to verify their structural integrity to lift and retain the design loads. The concrete cask lifting lugs and anchors will be similarly tested, as described in Section 10.1.2.2 of the SAR. A hydrostatic pressure test of the TSC shall be performed, following completion of the closure lid-to-TSC shell weld after fuel loading, in accordance with ASME Code, Section III, Subsection NB, NB-6000 requirements as described in Sections 9.1.1 and 10.1.2.3 of the SAR. The minimum test pressure of 130 psig (125% of the normal operating pressure) shall be applied to the drain port connection for a minimum of 10 minutes. There shall be no loss in pressure or visible water leakage from the closure lid weld during the 10-minute test period. The staff finds these structural tests acceptable for the designated system components.

10.1.3 Leakage Testing

The applicant described the leakage tests to be performed in Section 10.1.3 of the SAR. The

TSC confinement boundary is defined as the TSC shell weldment, closure lid, and vent and drain port covers. The TSC shell weldment and, separately, the vent and drain port covers, shall be leakage tested using the evacuated envelope method as described in ASME Code, Section V, Article 10, and ANSI N14.5 to confirm that the total leakage rate meets the criteria to be considered leaktight. Based on the confinement system materials, welding requirements and inspection methods, leakage testing of the closure lid is not required.

If helium leakage is detected during the tests, the area of leakage shall be identified and repaired in accordance with the ASME Code, Section III, Subsection NB, NB-4450. The helium leakage test shall be performed again to the original test acceptance criteria.

Technical Specification 5.2. of Appendix A to the proposed Certificate of Compliance for the MAGNASTOR system requires the cask user to establish a program to implement the SAR Chapter 9 requirements for loading fuel and preparing the TSC for storage. The applicable procedures direct the performance of the helium leakage tests described above. In addition, Appendix A TS 5.2.e. requires the user to verify the integrity of the inner port cover welds in accordance with the procedures in SAR Section 9.1.1., which direct the performance of a helium leak test on those welds.

The staff finds the proposed leakage tests for the MAGNASTOR system and the corresponding TS requirements to perform these tests acceptable.

10.1.4 Neutron Absorber Tests

Testing of the neutron absorber materials to be used in the MAGNASTOR system is described in Section 10.1.6 of the SAR. Technical Specification 4.1.1.b. states that, “Acceptance and qualification testing of neutron absorber material shall be in accordance with Sections 10.1.6.4.5, 10.1.6.4.6, and 10.1.6.4.7. These sections in the FSAR are hereby incorporated into the MAGNASTOR CoC.” Therefore, prior NRC approval is required before any changes can be made to these sections of the FSAR. In addition to these TS requirements, the applicant described in Section 10.1.6.4.4 the thermal conductivity and structural testing of the neutron absorber materials to be conducted to demonstrate that the materials can perform the necessary safety functions in service.

There are three types of neutron absorbers commonly used in spent fuel storage and transport system fuel basket design, including the MAGNASTOR TSC basket. They are BORAL® (a trademarked material), boron carbide-aluminum metal matrix composites (MMC), and borated aluminum alloy. The fabrication of the material is controlled to provide a uniform boron carbide distribution and to meet the ^{10}B areal density design requirements.

Acceptance Tests

Acceptance tests are conducted on production lots of the neutron absorber material to determine if selected specified characteristics have been satisfied, such that the lot can be accepted for use. The neutron absorber minimum total ^{10}B areal density is discussed in Section 10.1.6.1 and specified in the license drawings in Section 1.8 of the SAR.

The applicant's acceptance testing program is intended to support the 75% ^{10}B content credited in the criticality analysis for the BORAL® plates. Likewise, the acceptance program is intended to support the 90% ^{10}B content credited in the criticality analysis for the borated aluminum and the boron carbide metal matrix composite plates.

The staff finds the acceptance tests for the neutron absorber material, as defined in Section 10.1.6.4.5 of the SAR and as required by Appendix A TS 4.1.1.b., to be acceptable for this application.

Qualification Tests

Qualification testing is described in Section 10.1.6.4.6. These tests are used to demonstrate the suitability and durability of each neutron absorber material 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, including a change in the material supplier. The staff reviewed the design requirements, tests for durability (e.g., corrosion and thermal damage), and testing to demonstrate the ^{10}B uniformity. Important portions of these qualification tests are captured in SAR Section 10.1.6.4.6. The staff finds the qualification tests for the neutron absorber material defined in SAR Section 10.1.6.4.6, as required by Appendix A TS 4.1.1.b., to be acceptable for this application.

10.2 Maintenance Program

The applicant describes a conceptual maintenance program in Section 10.2 of the SAR. A generic maintenance program will be defined in an operations manual, which will be provided to system users. The operations manual will provide instructions for the inspection, testing, and component replacement required to ensure continued safe and effective operation and handling of the MAGNASTOR system. System users will develop site-specific maintenance programs and documents.

The MAGNASTOR system is totally passive by design, which results in a minimal inspection and maintenance program for the lifetime of the system. The routine maintenance requirements and schedule are shown in Table 10.2-1 of the SAR, and include concrete surface condition inspections and repairs, and reapplication of corrosion-inhibiting coatings on accessible external carbon steel surfaces, as needed. Maintenance activities for the MAGNASTOR shall be performed under the user's approved quality assurance (QA) program.

10.3 Evaluation Findings

F10.1 SSCs important to safety will be designed, fabricated, erected, tested, and maintained to quality standards commensurate with the importance to safety of the function they are intended to perform. Chapter 2 of the SAR specifies the applicable design criteria, codes, and standards for the performance of fabrication, inspecting and testing of system components.

F10.2 The TSC confinement boundary will be fabricated, inspected, and tested in accordance with appropriate Codes and standards, to ensure that it does not exhibit any defects that could significantly reduce its effectiveness. These tests will include a hydrostatic pressure test of the TSC.

F10.3 The nondestructive examination (NDE) of weldments for the various MAGNASTOR SSCs is described in Section 10.1.1 of the SAR, and will be performed by qualified personnel in accordance with the ASME Code.

F10.4 Section 10.1.6 of the SAR describes the applicant’s proposed program for acceptance testing and qualification of the neutron absorber material in the TSC. The staff finds the acceptance and qualification testing program, as required by Appendix A TS 4.1.1.b., to be acceptable for this application.

F10.5 Each TSC and concrete cask will be marked with a model number and identification number, and each concrete cask will also be marked with empty weight and date of loading. The license drawings in SAR Section 1.8 provide the marking instructions.

F10.6 The staff concludes that the acceptance tests and maintenance program for the MAGNASTOR TSC are in compliance with 10 CFR Part 72 and that the applicable acceptance criteria have been satisfied. The evaluation of the acceptance tests and maintenance program provides reasonable assurance that the cask system will allow safe storage of spent fuel throughout its licensed or certified term. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

11.0 RADIATION PROTECTION EVALUATION

The staff reviewed the radiation protection design features, design criteria, and the operating procedures for the MAGNASTOR system to ensure that radiation exposures to workers and to members of the public will meet the regulatory dose requirements of 10 CFR Part 20, 10 CFR 72.104(a), and 10 CFR 72.106(b), and that system design and operation are consistent with the principle of maintaining radiation exposures as low as is reasonably achievable (ALARA). In conducting its review, the staff followed the guidance discussed in Section 10 of NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems."

11.1 Radiation Protection Design Criteria and Design Features

11.1.1 Design Criteria

The radiological protection design criteria are defined by the limits and requirements of 10 CFR Part 20 and 10 CFR Part 72. The applicant proposed Technical Specifications (TS) to provide added assurance that these limits will be met. The Appendix B TS (Approved Contents) define the acceptable fuel characteristics and loading patterns, to ensure that the fuel assemblies to be loaded into the TSC are properly identified and conform to the bounding assumptions used in the applicant's shielding evaluation. The Appendix A TS also establish a radiation protection program (TS 5.5), which requires evaluations, controls and monitoring to ensure that all applicable regulatory requirements will be met by the cask user. Appendix A TS 3.3.1 specifies the maximum allowable surface dose rates for the exterior of the concrete cask, to be measured at specified locations. Appendix A TS 4.1.3 (Design Features) provides design requirements for the transfer cask to further ensure that the applicable dose rate limits will be met.

11.1.2 Design Features

Chapter 5 and Section 11.1.2 of the MAGNASTOR SAR describe the design features of the system that provide radiation protection to operational personnel and members of the public. These design features include the following:

- Material selection and surface preparation to facilitate decontamination
- Operating procedures and controls to minimize TSC contamination during loading
- Substantial shielding; thick steel and concrete shell for the storage cask, and steel, lead and neutron absorber for the transfer cask
- Nonplanar design of the concrete cask inlet and outlet vents to minimize radiation from particle streaming
- Passive system design to minimize maintenance and surveillance that reduce occupational exposure

The staff evaluated the radiation protection design features and design criteria for the MAGNASTOR system and found them acceptable. The applicant's descriptions in the SAR provide reasonable assurance that the MAGNASTOR system can meet the regulatory requirements governing radiation protection in 10 CFR Part 20 and 10 CFR Part 72. Sections 5, 7, and 9 of the SER discuss the staff's evaluations of the shielding features, confinement systems, and operating procedures, respectively.

11.2 Occupational Exposures

Chapter 9 of the SAR discusses the operating procedures that a MAGNASTOR system user will follow for fuel loading, welding and decontamination of the TSC, moving the TSC from the transfer cask to the concrete storage cask, and fuel unloading. Section 11.3 of the SAR discusses occupational exposure. The applicant determined radiation exposure rates at various work locations using the MCNP5 code (for calculations involving a single transfer cask or concrete cask), and the NAC-CASC code (for a concrete storage cask array). The applicant provided estimated occupational doses for workers during different operations in Tables 11.3-1 and 11.3-2 of the SAR.

The estimated occupational doses are based on the MAGNASTOR system operating procedures and operational experience in loading other canister-based, dry cask storage systems. The applicant's dose estimate indicates that the total occupational doses in loading a TSC with design basis BWR or PWR fuel into a concrete storage cask are approximately 0.9 person-rem and 0.7 person-rem, respectively. Annual worker exposures for routine surveillance and maintenance for a 2x10 cask array are estimated to be approximately 34 mrem. The staff reviewed these collective dose estimates and finds them reasonable, pursuant to the requirements defined in 10 CFR 20.1207. In practice, users of the MAGNASTOR system will perform ALARA evaluations based in part on these estimates, but which will also account for site-specific conditions, such as design features, location of work stations, equipment staging, plant configuration and layout, and the use of temporary shielding. Thus, the actual occupational exposures at a given site may be higher or lower than the applicant's generic estimates.

11.3 Exposures to the Public

Chapter 5 of the SAR presents the calculated direct radiation dose rates from a single concrete cask and a 2x10 array of casks loaded with design basis fuel. Figures 5.8.3-14 and 5.8.4-14 provide the estimated annual dose as a function of distance for a single PWR or BWR cask, respectively. Figures 5.8.3-15 and 5.8.4-15 provide the estimated annual dose as a function of distance for a 2x10 array of PWR or BWR casks, respectively. Figure 5.8.3-16 (PWR 2x10 cask array) and Figure 5.8.4-16 (BWR 2x10 cask array) show the contours of the controlled area boundaries necessary to meet the regulatory limit of 25 mrem/yr for dose to a member of the public. These calculations assume an exposure resulting from 100 percent occupancy at the controlled area boundary by a member of the public for 365 days (8,760 hours). Based on the applicant's calculations, the staff notes that these boundaries may need to be established at distances greater than 400 meters from the center of the ISFSI (cask array). The system user must perform a site-specific evaluation, as required by 10 CFR 72.212(b) and Appendix A TS 5.5.3, in order to establish an appropriate controlled area boundary to demonstrate compliance with 10 CFR 72.104(a). The actual doses to individuals beyond the controlled area boundary will depend on several site-specific conditions, such as fuel characteristics, cask array configurations, topography, and use of engineered features (e.g., berm). Appendix A TS 4.3.1.e establishes additional requirements on engineered features such as berms or shield walls, if relied upon to meet the requirements of 10 CFR 72.104(a). In addition, 10 CFR 72.104(a) requires the ISFSI licensee to account for contributions from other fuel cycle activities, such as reactor operations, in calculating total dose to a member of the public. Consequently, final determination of compliance with 10 CFR 72.104(a) is the responsibility of each ISFSI licensee. The staff found that the MAGNASTOR system design provides reasonable assurance that compliance with 10 CFR 72.104(a) can be achieved by each user of the system.

The general licensee will also have an established radiation protection program as required by 10 CFR Part 20, Subpart B, and will demonstrate compliance with dose limits to individual members of the public, as required in 10 CFR Part 20, Subpart D by evaluations and measurements.

The staff evaluated the applicant’s estimates of dose to the public during normal conditions and off-normal and accident events and found them acceptable. The primary dose pathway to individuals beyond the controlled area is from direct radiation (including skyshine). The TSC is leaktight and the confinement function is not affected by normal conditions or off-normal events, design-basis accidents, or natural phenomena events; thus there is no release of contents for any credible scenario. For a design basis accident involving a tornado missile, it is postulated that the concrete cask shielding is reduced in the area of the missile impact, but the canister remains intact. SAR Table 5.1.3-2 provides the concrete cask maximum surface dose rates for normal and accident conditions, and as discussed in Section 12.2.11.5, the calculated accident dose rates would result in an exposure to a member of the public at the controlled area boundary well below the 5 rem limit for accidents specified in 10 CFR 72.106(b). Based on that information, the staff has reasonable assurance that the effects of direct radiation from bounding design basis accidents and natural phenomena will be below the regulatory limits in 10 CFR 72.106(b).

11.4 ALARA

Chapters 5, 7, and 11 of the SAR describe how the MAGNASTOR system radiation protection design features and design criteria address ALARA requirements, consistent with 10 CFR Part 20. Each general licensee will apply its existing site-specific ALARA policies, procedures, and practices for cask operations to ensure that personnel exposure requirements in 10 CFR Part 20 are met. Each system user will have to consider the use of this canister with respect to their particular ALARA implementation philosophy.

The staff evaluated the applicant’s ALARA assessment for the MAGNASTOR system and found it acceptable. Section 9 of this SER discusses the staff’s evaluation of the operating procedures with respect to ALARA principles and practices. Operational ALARA policies, procedures, and practices are the responsibility of the site licensee, as required by 10 CFR Part 20. In addition, the TS establish requirements and a radiation protection program, which sets dose limits and surface contamination limits to ensure that occupational exposures are maintained ALARA.

11.5 Evaluation Findings

F11.1 The MAGNASTOR system SAR sufficiently describes the radiation protection design bases and design criteria for the structures, systems, and components important to safety.

F11.2 The MAGNASTOR dry cask storage system provides radiation shielding and confinement features that are sufficient to meet the requirements of 10 CFR 72.104, and 10 CFR 72.106.

F11.3 The occupational radiation exposures provided in the SAR satisfy the limits in 10 CFR Part 20 and meet the objective of maintaining exposures ALARA.

F11.4 The staff concludes that the design of the radiation protection system of the MAGNASTOR system is in compliance with 10 CFR Part 72 and the applicable design and acceptance criteria have been satisfied. The evaluation of the radiation protection system design provides reasonable assurance that the MAGNASTOR system will provide safe storage of spent fuel. This finding is based on a review that considered the regulation itself, the appropriate regulatory guides, applicable codes and standards, the applicant's analyses, the staff's confirmatory analyses, and acceptable engineering practices.

12.0 ACCIDENT ANALYSIS EVALUATION

The purpose of the staff's review of the accident analyses is to evaluate the applicant's identification of hazards, and the summary analyses of the MAGNASTOR system's response to off-normal and accident or design-basis events. This review ensures that the applicant has conducted thorough accident analyses that identify all credible accidents, correctly assess the safety performance of the cask system with respect to the various safety functions, and meet all applicable regulatory requirements. The accident analyses are presented in Chapter 12 of the SAR.

12.1 Off-Normal Conditions

Off-normal events are those designated as Design Event II, as defined by ANSI/ANS 57.9-1992. These events can be described as infrequent, but can be expected to occur on the order of once per year. The MAGNASTOR system off-normal events are described in Section 12.1 of the SAR. The off-normal events identified and analyzed for the MAGNASTOR system include high and low ambient temperatures (106°F and -40°F), blockage of one-half of the concrete cask air inlets, off-normal TSC handling loads, failure of optional temperature monitoring instrumentation, and a small release of radioactive particulate from the TSC exterior surface. None of these events is expected to have any radiological impact to a member of the public. Corrective actions for certain of these events may result in some additional occupational exposure (for example, removal of debris from the air inlets), but any such exposures are expected to be well below regulatory limits. The staff finds the applicant's identification and analysis of off-normal events acceptable.

12.2 Accident Events and Natural Phenomena

Accident events and conditions are those designated as Design Events III and IV, as defined by ANSI/ANS 57.9-1992. These events are 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. They include human-induced, low probability events and natural phenomena. The applicant provided analyses to demonstrate the adequacy of the MAGNASTOR system design to accommodate the postulated accidents described in Section 12.2 of the SAR. The events addressed by the applicant include the following postulated accident conditions.

12.2.1 Accidental Pressurization of the TSC

This event involves the pressurization of the loaded canister due to the hypothetical concurrent failure of all fuel rods. As discussed in Section 3.4.1 of this SER, the analysis of this event demonstrates that the peak accident pressure of 201 psig is well below the TSC design pressure of 250 psig; thus, there are no adverse consequences to the TSC and no release of radiation from this event.

12.2.2 Full Blockage of Concrete Cask Air Inlets

The MAGNASTOR system has been analyzed for the complete blockage of the concrete cask air inlet openings; the evaluation of this event is presented in Section 4.6.3 of the SAR and is summarized in Section 12.2.13. This hypothetical accident scenario is not considered to be credible, as the complete blockage of all four inlets is highly unlikely, even for the design basis flood or earthquake events. However, this event is analyzed to establish a bounding case.

The resulting loss of convective cooling due to the complete blockage of all four air inlet pathways leads to rapid heat-up of the TSC and the concrete cask. The thermal conditions for this event are analyzed and discussed in Section 4.3.7.1 of this SER. There are no adverse effects, nor significant off-site dose consequences resulting from this accident scenario, provided that the debris is removed from at least two air inlet vents within 58 hours to ensure sufficient cooling to prevent TSC over-pressurization.

There is no significant off-site dose associated with this event, as confinement and shielding are unaffected. The on-site dose received by workers from this accident is estimated to be no more than 0.5 man-rem, for the removal of debris from all four air inlets and the base of the concrete cask. The staff finds the applicant’s analysis of this event acceptable.

12.2.3 Accidental Cask Drop

The design basis drop accident for the MAGNASTOR system is a 24-inch drop of the loaded concrete cask onto the concrete storage pad. Appendix A TS 4.3.1.h. restricts the lift height of a loaded concrete cask to 24 inches. The detailed analyses of this event are provided in Chapter 3, and a summary is provided in Section 12.2.4 of the SAR. The staff’s evaluation of the applicant’s analysis of the 24-inch concrete cask drop accident is presented in Section 3.4.2 of this SER. The staff concludes that all MAGNASTOR system components, as well as the fuel rods, will continue to perform their safety functions for this event, and there will be no radiological consequences from this event.

12.2.4 Fire/Explosion

The fire accident analysis is presented in Section 4.6.2 and summarized in Section 12.2.6 of the SAR. The fire is postulated to be caused by ignition of flammable material at the ISFSI, or of transport vehicle fuel. The physical design of the MAGNASTOR system and licensee administrative controls will limit the quantity of flammable material at the ISFSI, and the quantity of fuel in the transport vehicle will be limited to no more than 50 gallons, as required by Appendix A TS 5.2.h. Licensees/users will evaluate the site-specific equipment to be used at the ISFSI and determine whether any additional controls are required. With these controls and limits in place, any potential fire would be of very short duration. The staff evaluated the applicant’s analysis for this event in Section 4.3.7.2 of this SER and found the fire analysis acceptable.

The applicant’s discussion of explosion hazards is provided in Section 12.2.5 of the SAR. The applicant states that the maximum external cask pressure of 22 psig associated with a flooding event would bound the maximum external cask pressure resulting from any postulated explosion event. Similar to the fire event, the physical design of the cask system and the imposition of site administrative controls will limit the potential for an explosion event to affect a storage cask at the ISFSI. The staff finds the applicant’s analysis of the explosion event acceptable. No off-site radiological impacts are expected to result from fire or explosion events. Some additional dose to workers may be incurred in responding to or recovering from such events, but such doses are not expected to be substantial.

12.2.5 Lightning

The applicant described the potential impact of a lightning strike on a loaded concrete cask in Section 12.2.10 of the SAR. The physical properties of the concrete cask, including its design and mass, are such that only the cask surface would be affected by a lightning strike. The concrete would not overheat and the TSC containing the spent fuel would not be affected. No significant radiological impacts are expected from this event, as only some minor spalling of concrete and thus only a minor effect on cask shielding would likely occur. The staff finds the applicant's analysis for this event acceptable.

12.2.6 Flood

The analysis of a postulated flooding event is presented in Section 3.7.3.3 and summarized in Section 12.2.9 of the SAR. A maximum water depth of 50 feet and a maximum velocity of 15 feet per second are assumed in the analysis. The staff's evaluation of the concrete cask's ability to withstand the effects of flooding, in combination with other design loadings, is in Section 3.5.1 of this SER. The staff agrees with the applicant's determination that a flooding event will not result in cask tip-over, and that allowable stresses on the concrete cask will not be exceeded when accounting for the additional flood loading. In addition, the radiological impacts due to flooding of the concrete cask are negligible, since the TSC remains intact and the confinement boundary is maintained.

12.2.7 Seismic Events

The analysis of a postulated seismic event is presented in Section 3.7.3.4 and summarized in Section 12.2.8 of the SAR. The staff's evaluation of the applicant's analysis is in Section 3.5.3 of this SER. The staff agrees with the applicant's conclusion that the MAGNASTOR storage system is stable against tip-over for the design earthquake defined by a maximum storage pad horizontal motion of 0.37g, with corresponding vertical motion of 0.25g. Appendix A TS 4.3.1.i will require the cask user to verify these limits, and also will require the user to verify that, during the design earthquake, the casks will not slide off the concrete storage pad and that potential impacts (g-load) between casks are bounded by the cask tip-over analysis in the FSAR.

Because the MAGNASTOR system components are designed and analyzed to withstand the design basis earthquake accident, no radiation is released and there is no increased dose to the public due to this event.

12.2.8 Tornado Wind and Tornado Missiles

The analyses of the effects of a postulated tornado, including those from tornado-generated missiles, are presented in Section 3.7.3.2 and summarized in Section 12.2.11 of the SAR. The staff's evaluation of the applicant's analysis is in Section 3.5.2 of this SER. The MAGNASTOR system is designed and analyzed to the criteria specified in NUREG-0800 and NRC Regulatory

Guide 1.76. The applicant's analyses assume a maximum tornado wind velocity of 360 miles per hour and a spectrum of tornado-driven missiles, including a one-inch diameter steel sphere, a 280-lb., 8-inch armor piercing artillery shell, and a 4000-pound automobile with a 20 square foot frontal area moving at 126 miles per hour.

The staff agrees with the applicant's determination that a tornado wind speed of 360 mph will not result in concrete cask tip-over, nor exceed the allowable stresses in the cask. The staff also agrees with the applicant's conclusion that the concrete cask has sufficient capacity to withstand the effects of the full spectrum of tornado missiles analyzed. Therefore, the TSC confinement boundary will remain intact for all postulated tornado events. Damage to the concrete cask from tornado-induced missiles could cause a reduction in its shielding effectiveness; however, any resulting increase in radiation exposure to an individual at the controlled area boundary is expected to be well below the 5 rem limit for accidents required by 10 CFR 72.106(b).

12.2.9 Cask Tip-over Event

The analysis of a hypothetical cask tip-over event is presented in Sections 3.7.3.7 and 3.10.1.3.3, and summarized in Section 12.2.12 of the SAR. The staff's evaluation of the applicant's analysis is in Section 3.4.3 of this SER. The hypothetical concrete cask tip-over is a nonmechanistic accident that provides a bounding case for accident analysis purposes. None of the design basis accidents analyzed for the MAGNASTOR system results in a cask tip-over event.

The staff concurs with the applicant's conclusion that the resulting stress intensities on the MAGNASTOR system components (TSC, fuel basket and concrete cask) are all within the allowable stress intensities, with sufficient margin, for the analyzed tip-over event. The staff also concurs with the applicant's conclusion that the fuel basket will maintain structural integrity and geometric stability for the tip-over accident. Additionally, the staff concludes that fuel rods will not rupture during the design basis cask drop and tip-over accidents, as the fuel cladding will maintain its integrity for these events.

Dose rates would increase as a result of exposing the bottom of the concrete cask in a tip-over event. Corrective actions would be necessary to upright the cask, and/or to add supplemental shielding to minimize additional radiation dose to workers and to the public. In the staff's judgment, sufficient time and means will be available to limit the increase in radiation exposure to workers and to ensure that the regulatory limits for accidents in 10 CFR 72.106(b) for exposure to an individual at the controlled area boundary are met.

12.3 Evaluation Findings

F12.1 Structures, systems, and components of the MAGNASTOR system are adequate to prevent accidents and to mitigate the consequences of accidents and natural phenomena events that do occur.

F12.2 The applicant has evaluated the MAGNASTOR system to demonstrate that it will reasonably maintain confinement of radioactive material under credible accident conditions.

F12.3 An accident or natural phenomena event will not preclude the ready retrieval of spent fuel for further processing or disposal.

F12.4 The spent fuel will be maintained in a subcritical condition under accident conditions. Neither off-normal nor accident conditions will result in a dose to an individual outside the controlled area that exceeds the limits of 10 CFR 72.104(a) or 72.106(b), respectively.

F12.5 The staff concludes that the accident design criteria for the MAGNASTOR system are in compliance with 10 CFR Part 72 and the accident design and acceptance criteria have been satisfied. The applicant's accident evaluation of the cask adequately demonstrates that it will provide for safe storage of spent fuel during credible accident situations. This finding is reached on the basis of a review that considered independent confirmatory calculations, the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

13.0 CONDITIONS FOR CASK USE —TECHNICAL SPECIFICATIONS

In this section, the staff evaluated the proposed operating controls and limits, (the Technical Specifications, or TS), including their bases and the applicant's justification for the conditions of use for the MAGNASTOR system.

The conditions for use and TS define the conditions that are deemed necessary for safe MAGNASTOR system use. Specifically, they define operating limits and controls, monitoring instruments and control settings, surveillance requirements, design features, and administrative controls considered necessary to ensure safe operation of the MAGNASTOR system. As such, these conditions for use and TS are included in the MAGNASTOR Certificate of Compliance.

13.1 Conditions for Use

The conditions for use of the MAGNASTOR system were considered by NRC staff in accordance with guidance provided in NUREG-1745, "Standard Format and Content for 10 CFR Part 72 Cask Certificates of Compliance." The conditions were derived from analysis and evaluations provided in the MAGNASTOR SAR and pertain to the design, construction and operation of the system.

13.2 Technical Specifications

Section 13 of the SAR describes the TS required to ensure that the MAGNASTOR system is operated safely. The TS impose certain, more detailed, requirements for the design, construction, and operation of the MAGNASTOR system by a reactor licensee using a general license for an independent spent fuel storage installation in accordance with 10 CFR Part 72. The TS for the MAGNASTOR system, as approved by the staff, are contained in Appendices A and B to the Certificate of Compliance and address the following areas:

- Use and Application (Appendix A)
- Approved Contents (Appendix B)
- Limiting Condition for Operation Applicability and Surveillance Requirement Applicability (Appendix A)
- Design Features (Appendix A)
- Administrative Controls and Programs (Appendix A)

Table 13-1 of this SER lists the TS to be implemented for the MAGNASTOR system.

13.3 Evaluation Findings

F13.1 Table 13-1 of the SER lists the TSs for the use of the MAGNASTOR system. These TSs are incorporated as appendices to the Certificate of Compliance.

F13.2 The staff concludes that the conditions for use of the MAGNASTOR system identify necessary TSs to satisfy 10 CFR Part 72, and that the applicable acceptance criteria have been satisfied. The TSs provide reasonable assurance that the cask system will provide for safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted practices.

TABLE 13-1
MAGNASTOR System Technical Specifications

Appendix A – Technical Specifications and Design Features

- 1.0 Use and Application
    - 1.1 Definitions
    - 1.2 Logical Connectors
    - 1.3 Completion Times
    - 1.4 Frequency

- 2.0 [Reserved]

- 3.0 Limiting Condition For Operation (LCO) Applicability
- 3.0 Surveillance Requirement (SR) Applicability
    - 3.1 MAGNASTOR System Integrity
        - 3.1.1 Transportable Storage Canister (TSC)
        - 3.1.2 Concrete Cask Heat Removal System
    - 3.2 MAGNASTOR System Criticality Control For PWR Fuel
        - 3.2.1 Dissolved Boron Concentration
    - 3.3 MAGNASTOR System Radiation Protection
        - 3.3.1 Concrete Cask Maximum Surface Dose Rate

- 4.0 Design Features
    - 4.1 Design Features Significant to Safety
        - 4.1.1 Criticality Control
        - 4.1.2 Fuel Cladding Integrity
        - 4.1.3 Transfer Cask Shielding
    - 4.2 Codes and Standards
        - 4.2.1 Alternatives to Codes, Standards, and Criteria
        - 4.2.2 Construction/Fabrication Alternatives to Codes, Standards, and Criteria
    - 4.3 Site-Specific Parameters and Analyses
        - 4.3.1 Design Basis Specific Parameters and Analyses
    - 4.4 TSC Handling and Transfer Facility

- 5.0 Administrative Controls and Programs
    - 5.1 Radioactive Effluent Control Program
    - 5.2 TSC Loading, Unloading, and Preparation Program
    - 5.3 Transport Evaluation Program
    - 5.4 ISFSI Operations Program
    - 5.5 Radiation Protection Program
    - 5.6 Special Requirements for the First System Placed in Service
    - 5.7 Training Program
    - 5.8 Pre-operational Testing and Training Exercises

Appendix B – Approved Contents

- 1.0 Fuel Specifications and Loading Conditions
- 2.0 Fuel to Be Stored in the MAGNASTOR System

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. NAC described its quality assurance (QA) program in Chapter 14 of the MAGNASTOR SAR.

The NRC staff has previously reviewed and approved the NAC QA program. The staff has also performed inspections of the NAC QA program and found that it met regulatory requirements. Therefore, the staff did not reevaluate this area in its review of the MAGNASTOR application.

15.0 DECOMMISSIONING EVALUATION

The purpose of this review is to evaluate the applicant's conceptual decommissioning plan to assess whether the cask system is designed to facilitate decommissioning of the ISFSI after the spent fuel has been transferred to the Department of Energy facility or another location for storage or reprocessing. The applicable 10 CFR Part 72 requirement for decommissioning is 10 CFR 72.236(i).

15.1 Decommissioning Features

The NRC staff reviewed the decommissioning description in Chapter 15 of the MAGNASTOR SAR. The principal elements of the MAGNSTOR system that may require decommissioning are the concrete cask and the TSC. The concrete cask is not expected to become surface contaminated, as it will not come in direct contact with radioactive materials. The TSC is designed to be suitable for permanent disposal in a geologic repository. The TSC and concrete cask are designed to preclude the release of any radioactive materials and contamination to the environment, throughout the service period. Therefore, associated structures, such as the ISFSI pad, security fence and building, and supporting utility fixtures should not require any decontamination and could be reused or disposed of as clean waste materials.

In the event that the concrete cask becomes contaminated through incidental contact with other contaminated surfaces, such contamination would likely be limited to the inner carbon steel lined surfaces of the cask, and standard decontamination techniques could be applied, as needed. The applicant estimated residual activity levels of the concrete cask materials. If such activation of the cask materials was detected, the estimated levels would be very low and the materials would likely qualify for near-surface burial in a low-level waste disposal site.

If the spent fuel contents are ultimately removed from the TSC, the canister would likely have some fixed and removable surface contamination. The carbon steel components would be subjected to decontamination techniques to reduce such contamination, and the TSC could likely be disposed of as low-level waste. Activation of the TSC materials is expected to be minimal. In this scenario, surveys for any residual fuel particulates will be conducted by the licensee, and any particulate detected will be appropriately disposed of.

15.2 Evaluation Findings

The MAGNASTOR system design includes adequate provisions for decontamination and decommissioning. Chapter 15 of the MAGNASTOR SAR describes the practices to be used for decontaminating the system components and disposing of all residual radioactive materials after the spent fuel has been removed. This information provides reasonable assurance that users of the system will be able to conduct decommissioning in a manner that adequately protects the health and safety of the public.

The staff finds that the design of the MAGNASTOR system and the consideration of its decommissioning features meet the applicable requirements of 10 CFR Part 72. This evaluation provides reasonable assurance that the system will support the safe storage of spent fuel and the safe handling and disposal of radioactive materials. This finding is reached on the basis of a review that considered the regulation itself and accepted engineering practices.

16.0 CONCLUSION

The staff performed a detailed safety evaluation of the application for a 10 CFR Part 72 Certificate of Compliance for the MAGNASTOR System. The staff performed the review in accordance with the guidance in NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” dated January 1997. Based on the statements and representations contained in the application and the MAGNASTOR Safety Analysis Report, and the conditions established in the Certificate of Compliance and its Appendices (Technical Specifications), the staff concludes that the MAGNASTOR System meets the requirements of 10 CFR Part 72.

Issued with Certificate of Compliance No. 1031, on February 4, 2009