UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION REPORT
NAC INTERNATIONAL
MAGNASTOR® STORAGE SYSTEM
DOCKET NO. 72-1031
AMENDMENT NO. 5

SUMMARY

On December 19, 2013 (see Agencywide Documents Access and Management System (ADAMS) Accession No. ML13361A144), as supplemented on March 19, 2014 (see ADAMS Accession No. ML14079A525), May 15, 2014 (see ADAMS Accession No. ML14140A239), and June 13, 2014 (see ADAMS Accession No. ML14170A032), NAC International (NAC or the applicant) requested approval of an amendment, under the provisions of Title 10, Code of Federal Regulations (10 CFR) Part 72, Subparts K and L, to Certificate of Compliance No. 1031 for the Modular Advanced Generation Nuclear All-purpose STORage (MAGNASTOR®) Dry Cask Storage System. NAC requested the following changes:

- Incorporate Combustion Engineering 16×16 (CE16×16) damaged fuel,
- Revise the contents to state unirradiated (instead of unenriched) BWR fuel assemblies are not authorized for loading,
- Revise the BWR 82-assembly loading profile by adding alternate profile that allows General Electric 14 (GE14) fuel assemblies to be loaded with a maximum enrichment of 4.55 weight percent,
- Include a BWR 86-assembly loading profile that allows General Electric 13 (GE13) fuel assemblies to be loaded with a maximum enrichment of 3.85 weight percent,
- Include a new pressurized-water reactor (PWR) preferential loading profile, which includes 4-zones and retains the maximum currently licensed canister heat load of 35.5 kW,
- Include new cool time tables, specifically for Westinghouse 14×14 (WE14×14) and CE16×16 PWR fuel that allows reduced cool times,
- Include new minimum cool times, specifically for Westinghouse Control Element Assemblies (CEA) and rod cluster control assemblies (RCCAs) down to 2.5 yr,
- Remove the PWR short loading cell callouts that were incorporated into Amendment No. 3,
- Remove statements in Appendix B of the technical specifications for the BWR 82-assembly loading configuration that defines the means by which the empty cells are blocked,
- Remove callouts in figures within Appendix B of the technical specifications that show the canister alignment tick mark,
- Revise the cask surface dose rate shown in Limiting Conditions for Operation (LCO) 3.3.1 from 95 mrem/hour gamma to 120 mrem/hour gamma, and
- Revise Technical Specification, Appendix A, Section 4.3.1(i), to allow a MAGNASTOR® system to be utilized at sites where the design basis earthquake (DBE) acceleration is greater than 0.37g in the horizontal direction and 0.25g in the vertical direction provided that the independent spent fuel storage installation (ISFSI) pad is designed with bollards

that prevent a cask from overturning, sliding into adjacent casks or sliding off the ISFSI pad,

- Revised decay times in Technical Specification, Appendix B Table B2-5 for minimum additional decay time required for the spent fuel when the fuel contains nonfuel hardware.
- Corrected typographical error in two actual boron loadings in Technical Specification 4.1.1(a).

This amendment, when codified through rulemaking, will be denoted as Amendment No. 5 to the certificate of compliance.

In support of the amendment, NAC submitted Revision 13D, Revision 14A, and Revision 14D of the safety analysis report (SAR) for the MAGNASTOR® system. This amendment request is based on MAGNASTOR® final safety analysis report (FSAR) Revision No. 5 and Certificate of Compliance No. 1031, Amendment No. 3. (Although Amendment No. 4 had been submitted, it was not yet effective at the time of this request and therefore, Amendment No. 3 was used as the basis for the review.)

The NRC staff reviewed the amendment request and supplements to the amendment request using guidance in NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” Rev. 1, dated July 2010. For the reasons stated below, and based on the statements and representations in the application, as supplemented, and the conditions specified in the certificate of compliance and technical specifications, the staff concludes that the requested changes meet the requirements of 10 CFR Part 72.

The staff's assessment is based on whether NAC meets the applicable requirements of 10 CFR Part 72 for independent storage of spent fuel. The staff’s assessment focused only on modifications requested in the amendment as supported by the submitted revised SAR and did not reassess previously approved portions of the FSAR or certificates of compliance through Amendment No. 3.

1.0 GENERAL DESCRIPTION

The objective of the review of this chapter is evaluate design changes made to the MAGNASTOR® storage system to ensure that NAC provided a description that is adequate to familiarize reviewers and other interested parties with the pertinent features of the system, including the changes requested.

1.1 Description

The applicant made minor modifications to the description of the storage system. These minor changes do not alter the staff’s previous system general description evaluation of the MAGNASTOR® cask system.

1.2 Evaluation Findings

The applicant’s revisions to the general changes continue to satisfy the requirements for the general description under 10 CFR Part 72 because the description contains sufficient information to allow reviewers and other interested parties to familiarize themselves with pertinent features of the storage system. This finding is reached on the basis of a review that considered the regulation itself and accepted practices. Thus, based on the NRC staff's review

of information provided for Amendment No. 5 for the MAGNASTOR® system, the staff determines the following:

F1.1 Drawings for structures, systems, and components (SSCs) important to safety are presented in the FSAR. Details of specific structures, systems, and components are evaluated in Sections 3 through 9 of this safety evaluation report (SER), as appropriate.

2.0 PRINCIPAL DESIGN CRITERIA EVALUATION

Principal design criteria changes are documented and evaluated in other sections of this SER.

3.0 STRUCTURAL EVALUATION

The applicant proposed revising Technical Specification, Appendix A, Section 4.3.1(i), to allow a MAGNASTOR® system to be utilized at sites which have a DBE acceleration greater than the currently approved accelerations, provided that the ISFSI pad is designed with bollards that prevents a cask from overturning, sliding into adjacent casks or sliding off the ISFSI pad.

3.1 Design-Basis Earthquake Discussion

The current Technical Specification (Appendix A) 4.3.1(i) provides that “The maximum design basis earthquake accelerations of 0.37g in the horizontal direction (without cask sliding) and 0.25g in the vertical direction at the ISFSI pad top surface do not result in cask tip-over.” These earthquake acceleration levels are the design basis bounding parameters that require verification by the user of the MAGNASTOR® system.

Amendment No. 3 further specified a performance acceptance criterion in the second part of Technical Specification 4.3.1(i) that states, “Site-specific cask sliding is permitted with validation by the cask user that the cask does not slide off the pad and that the g-load resulting from the collision of two sliding casks remains to be bounded by the cask tip-over accident condition analysis presented in Chapter 3 of the FSAR.”

This license amendment request proposes to specify an additional performance criteria on TS 4.3.1(i) in the third paragraph that states, “For design basis earthquake accelerations greater than 0.37g in the horizontal direction and 0.25g in the vertical direction at the ISFSI pad top surface, the use of the MAGNASTOR® system is permitted provided the ISFSI pad has bollards and the cask user validates that the cask does not slide off the pad or overturn, g-loads resulting from the cask contacting the bollard is bounded by the cask tip-over accident condition presented in Chapter 3 of the FSAR, and the ISFSI pad and bollards are designed, fabricated and installed such that they are capable of handling the combined loading of the design basis earthquake and any contact between the bollard and cask during the design basis earthquake.”

Although the revised technical specification allows use of the MAGNASTOR® system at a location where the site earthquake parameters are greater than 0.37g in the horizontal direction and 0.25g in the vertical direction at the ISFSI pad top surface, the provision requires the user to demonstrate that no tip-over will result from an earthquake and that impacts between casks and bollards, while allowed, are an accident event for which the cask must be shown to be structurally adequate, and therefore accounts for the cask earthquake performance criterion consistent with guidance provided in Section 3, “Structural Evaluation,” of NUREG-1536. Additionally, the technical specification is consistent with 10 CFR Part 72 paragraph 212.(b)(5)(ii) which requires the cask storage pads and areas be designed to adequately

support the static and dynamic loads of the stored casks, considering the potential amplification of earthquakes through soli-structure interactions, and soil liquefaction potential of other soil instability due to vibratory ground motion. The staff therefore concludes that the proposed revision is an acceptable provision for implementation by potential MAGNASTOR® system users in evaluating the site-specific earthquake acceleration parameters.

3.2 Evaluation Findings

Based on the information provided in the SAR, by reference, and by supporting documentation, the staff finds that the application meets the acceptance criterion specified in NUREG-1536, Rev. 1, with the requested changes.

F3.1 The applicant has met the requirements of 10 CFR 72.236 with regard to inclusion of adequate protection against Environmental Conditions and Natural phenomena.

4.0 THERMAL EVALUATION

The applicant proposed to amend the certificate of the MAGNASTOR® Cask System to incorporate a new four-zone preferential loading pattern for WE14×14 and CE16×16 PWR fuel assemblies, but while maintaining the maximum canister heat loads for both low-burnup and high-burnup fuels.

4.1 Thermal Design

There is no change in the thermal design of the MAGNASTOR® casks in this amendment.

4.2 PWR Minimum Reduced Cool Time Fuel Assembly

Storage Conditions

The proposed PWR fuel preferential loading configuration requests accommodation of up to 37 PWR fuel assemblies with some fuel assemblies at a reduced cooling time using a loading pattern shown in Figure 4-1, and heat load limits as shown in Table 4-1 below. The maximum heat load limits are 35.5 kW for the low burnup fuel (≤ 45 GWd/MTU) and 33.725 kW for the high burnup fuel (> 45 GWd/MTU).

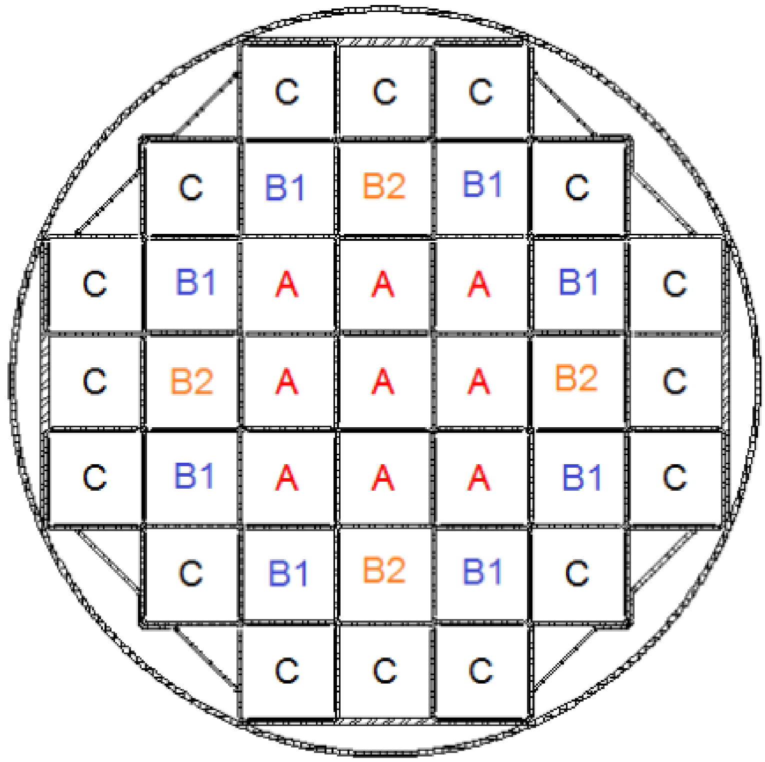

Figure 4-1: PWR Four-Zone Preferential Loading

Table 4-1: PWR Four-Zone Decay Heat Limits

Zone Description	Designator	Heat Load ≤ 45 GWd/MTU [W/assembly]	Heat Load > 45 GWd/MTU [W/assembly]	# Assemblies
Inner Ring	A	513	487	9
Middle Ring	B1	1300	1235	8
	B2	1800	1710	4
Outer Ring	C	830	788	16

4.3 Analytical Methods, Models, and Calculations

The applicant performed thermal analyses using the ANSYS Fluent computational fluid dynamics computer program with the same fluid resistances and material properties for both PWR four-zone preferential loading pattern and previously approved standard PWR basket assembly. The staff reviewed the analyses and found that the material thermal properties of the cask components are unchanged from those in the previous amendments. Because the proposed PWR four-zone loading pattern is only related to heat-load re-distribution and does not affect flow resistance and material properties, and the staff has previously reviewed and

approved the material thermal properties, the staff concludes that the material thermal properties used in the analyses are appropriate for the thermal evaluation.

As shown in the SAR Section 4.4, the applicant calculated the maximum fuel temperature of 698°F for the PWR minimum reduced cool time fuel assembly, which is below the allowable limit of 752°F, as indicated in NUREG-1536 and Interim Staff Guidance No. 11 (ISG-11), Rev. 3, "Cladding Considerations for the Transportation and Storage of Spent Fuel" and is bounded by the maximum fuel temperature of 718°F for the standard PWR fuel assembly, which was approved by the NRC in the previous application. This is because the proposed loading pattern of the PWR minimum reduced cool time fuel configuration significantly removes the heat from the basket center, and consequently reduces the maximum fuel temperature, when compared to the maximum fuel temperature for the standard PWR basket assembly with the same total heat load.

The applicant stated in SAR Sections 4.5 and 4.6, that the bounding conclusion for the normal storage condition is also valid for off-normal and accident storage conditions because of the heat distribution of the preferential loading of the PWR minimum reduced cool time fuel assembly.

The staff reviewed the model assumptions and methodology described in the previous application which was approved by the NRC, the proposed preferential loading pattern of 37 PWR minimum reduced cool time fuel assembly, and the calculated fuel temperatures. Based on the methodology used in the thermal analysis and the applicant's calculated temperature of 698°F, the staff has reasonable assurance that the fuel cladding temperature will be below the limits of 752°F for normal storage conditions, and 1058°F for off-normal and accident storage conditions.

Short-Term Operations

The applicant performed a thermal analysis of vacuum drying condition which is the bounding case for the short-term operations and derived that the maximum fuel temperature of 640°F for the standard PWR fuel assembly bounds the maximum fuel temperature of 630°F for the PWR minimum reduced cool time fuel assembly. Similar to normal and accident conditions above, the applicant indicates that the proposed loading pattern of the PWR minimum reduced cool time fuel configuration significantly removes the heat from the basket center, and consequently reduces the maximum fuel temperature, when compared to the maximum fuel temperature for the standard PWR basket assembly with the same total heat load.

The staff reviewed the thermal evaluation and finds that the proposed loading pattern with the hot fuel located at the outer zone will remove the heat more significantly, and that the calculated temperature of 630°F is far below the limit of 752°F. Therefore, the staff determines that the thermal analysis of the PWR minimum reduced cool time fuel assembly is bounded by the thermal analysis of the standard PWR fuel assembly not only for the vacuum drying operations, but also for other short-term operations. The staff concludes that the proposed loading pattern of the 37 PWR minimum reduced cool time fuel assembly is acceptable per the thermal requirements listed in 10 CFR Part 72.

4.4 Evaluation Findings

F4.1 The applicant's thermal evaluation provides reasonable assurance to verify the fuel cladding temperatures will remain below the allowable temperature limits under normal,

off-normal, and accident conditions when the proposed preferential loading profile (Figure 4.1-2 in SAR) for the 37 PWR minimum reduced cool time fuel basket is used.

The staff concludes that the thermal evaluation of the structures, systems, and components of the MAGNASTOR® storage system are in compliance with 10 CFR Part 72, and that the applicable design and acceptance criteria have been satisfied. The finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes, model assumptions/methodology, and accepted engineering practices.

5.0 SHIELDING EVALUATION

The objective of this review is to verify that the proposed amendment to the MAGNASTOR® design meets the requirements of 10 CFR 72.104 and 10 CFR 72.106 under normal, off-normal and accident conditions. The proposed changes affecting the shielding analysis are: (1) a new PWR preferential loading profile, which includes 4-zones and retains the maximum currently approved canister heat load of 35.5 kW; (2) new cool time tables, specifically for WE14×14 PWR fuel that allows reduced cool times down to 2.5 years, (3) new cool time tables, specifically for CE 16x16 PWR fuel; (4) new minimum cool times, specifically for Westinghouse RCCAs (also known as control element assemblies [CEAs]) down to 2.5 years and CE CEA/RCCAs down to 5.0 years; and (5) corrections to the discrepancies in Table B2-5, "Additional SNF Assembly Cool Time Required to Load NONFUEL HARDWARE," which contained non-conservative additional cooling times for fuel assemblies loaded with an RCCA. In addition, the applicant requested Table B2-5 be expanded to cover the use of the three-zone and four-zone preferential loading patterns with nonfuel hardware.

The staff shielding review evaluated the proposed changes in conjunction with the findings from previous staff analyses to determine they provide adequate protection from the radioactive contents within. This review looked at the methods and calculations employed by NAC to determine the expected gamma and neutron radiation at locations near the cask surface and at specific distances away from the cask.

5.1 Shielding Design Description

5.1.1 Design Criteria

Technical specification dose rate evaluation in the application includes maximum dose rate limits as calculated for a content of design basis fuel as well as procedures to determine whether the dose rate at the prescribed locations exceeds the maximum dose rate limit.

5.1.2 Design Features

According to the application, MAGNASTOR® is a dry storage system consisting of a concrete cask and a welded stainless steel canister with a welded closure to safely store the spent fuel. The system also includes a transfer cask as a shielded lifting device designed to hold the canister during loading operations, transfer operations, and unloading operations.

5.2 Source Specification

The source term in this SAR for the bounding WE14×14 PWR fuel is specified as in previous versions of the SAR, except the minimum cooling time for use in the SAS2H sequence of SCALE 4.4 is 2.5 years versus 4.0 years in previous version of the SAR. The source term for

the bounding Combustion Engineering PWR fuel (CE 16×16) in this SAR remains the same as previous versions of the SAR.

5.3 Shielding Model

No changes were made to the shielding design of the MAGNASTOR® dry storage system as a result of this amendment.

5.4 Shielding Evaluation

The applicant calculated bounding dose rates and developed loading tables for WE14×14 PWR fuel using the MCNP5 computer code. These dose rates and loading tables were for a minimum cool time of 2.5 years at the surfaces of, and 1-ft, 1-m, 2-m, and 4-m away from, the canister and concrete storage cask. Dose rates at the air inlets/outlets were also calculated to provide dose rates at possible streaming paths. Dose rates were calculated based on meeting the maximum cask heat load limit of 35.5 kW. Both uniform heat load and four-zone preferential heat load pattern loading up to 1.8 kW assemblies were evaluated by the applicant for a full cask loading of 37 PWR fuel assemblies. Evaluations were also performed for damaged fuel assembly baskets and revising the minimum cool time required for loading CEAs to 2.5 years from 10 years.

Using the dose response method discussed in previous SAR amendments, the applicant calculated transfer cask dose rates from the canister and concrete cask for all allowed cool time, assembly average burnup, and initial enrichment combinations for the hybrid WE14×14 fuel type. The reduction in minimum cool time to 2.5 years resulted in a new bounding source term for the radial dose rates of the concrete cask. The average radial dose rate at the surface increased to 68 mrem/hr. The previous maximum average dose rate of any uniformly loaded fuel type in the concrete cask was 57 mrem/hr, which was based on an assessment of 4.0 year minimum cool time and 40.0 kW maximum system heat load. For site boundary dose rates, the increased radial dose component can be accounted for by conservatively increasing reported single cask and array yearly dose and exposure values by 20%. This will conservatively neglect the smaller height concrete cask evaluated at the reduced cool time (with the associated lower surface area for emission) and reduced axial dose components versus the 40 kW design basis source. According to the applicant, reducing the minimum cool time to 2.5 years has no impact on the bounding dose rates for the canister or the top, inlet, and outlet detector locations of the concrete cask.

NAC proposed changes to the additional cooling times for RCCAs and some burnable poison absorber assemblies (BPAAs)/hafnium absorber assemblies (HFRAs). NAC utilized previously calculated quantities of activated metal in the control components to re-evaluate the minimum decay time to achieve the maximum decay heat in a fuel assembly containing control components for all fuel assemblies except for the WE14×14 fuel assemblies. Results of these calculations are shown in the SAR in Tables 5.8.5-7 for BPAAs and 5.8.6-6 for RCCAs.

NAC performed more detailed analysis to evaluate decay times for both uniform loading and preferential loadings for nonfuel hardware for WE14×14 and CE 16×16 in Sections 5.9 and 5.10, respectively. For the WE14×14 fuel assemblies, NAC previously assumed the WE14×14 CEA is fully inserted when calculating activated CEA masses (severely overestimating the activated CEA mass). During typical core operation, only the tips of the CEA rods are located within a significant neutron flux field. Rod tips are above the active fuel region at full withdrawal limiting activated regions to the plenum and assembly top regions. The applicant calculated

activation volumes and masses in these regions for the WE14x14 assembly type CEA to more accurately evaluate the heat and dose contribution from the CEAs and to determine additional cool times for the four-zone preferential loading. The results of these calculations for nonfuel hardware in WE14×14 fuel assemblies are shown in Table 5.9.4-1 for BPAAs and TPs, and Table 5.9.5-4 for RCCs.

The results of NAC's calculations for nonfuel hardware in CE16×16 fuel assemblies for the four-zone preferential loading are shown in Table 5.10.4-2 for RCCs. According to the applicant, on the sides of the concrete and transfer casks, the additive dose rate does not affect the maximum dose rates, but at the concrete cask inlets and transfer cask bottom, loading of CEAs significantly increases the maximum dose rates. The maximum decay heat produced by a loading of nine CEAs is 0.17 kW. According to the applicant, an increase in the spent fuel assembly cool time as shown in Table 5.8.6-6 provides the necessary margin to accommodate the CEAs. The applicant states that the strict application of increased cool time without a recalculation of fuel dose rates is conservative, since an increase in cool time will decrease the fuel source term.

In order to envelop fuel assemblies with heat loads higher than 959 W, which is the bounding heat load for uniform loading, the applicant proposed a four-zone preferential loading pattern as shown in Table 4-1 and Figure 4-1, above. Preferential and uniform loading patterns still limit the total cask heat load to 35.5 kW.

According to the applicant, the minimum cool time tables account for potential uncertainties in the source generation abilities of SAS2H at burnups greater than 45 GWd/MTU by reducing allowed heat loads by 5 percent. Fuel assembly loading tables at greater than 45 GWd/MTU are, therefore, generated for a cask heat load of 33.725 kW with preferential (1.71 kW max) and uniform (911 W/assy) heat load patterns. The 5% penalty adjusted four-zone preferential loading pattern is also shown in Table 4-1.

Maximum and average surface dose rates for the preferential pattern are shown in SAR Table 5.9.6-1 with the corresponding limiting results for the uniform pattern. According to the application, the maximum dose rates for the analyzed preferential loading pattern are less than or statistically unchanged from those calculated for a uniform pattern at each detector surface for both casks with the exception of transfer cask bottom dose rates. Maximum transfer cask bottom dose rates are increased minimally (< 7%), but are statistically bounded by the design basis calculations. The concrete cask radial and top axial average dose rates are less than or statistically unchanged in the preferential pattern. The staff has reviewed and confirmed the applicant's calculations and has determined that using the uniform pattern to characterize the restricted area and controlled area boundaries is acceptable because it bounds the preferential loading pattern.

Maximum dose rates for damaged fuel with the four-zone preferential loading are shown in Tables 5.9.9-2 and 5.9.9-4 for the transfer cask and concrete cask, respectively. The applicant explains that, comparing these tables to the maximum dose rates for the uniform loading in Tables 5.8.12-2 and 5.9.9-3 for the transfer and concrete casks, respectively, shows that the only significant increase (i.e., greater than 10%) when compared to previous WE14×14 bounding damaged dose rates is for the radial concrete cask dose. This maximum dose rate of 113.9 mrem/hr is less than the proposed maximum dose in Technical Specification Appendix A LCO 3.3.1.

The applicant performed a similar analysis to the above to develop the new cooling time tables for the CE 16×16 PWR fuel and reduce the minimum cool times for CE CEA/RCCAs down to 5.0 years.

As for nonfuel hardware, as stated in the June 5, 2014, deficiency letter from NAC (ADAMS Accession No. ML14160A856), Table B2-5, "Additional SNF Assembly Cool Time Required to Load NONFUEL HARDWARE," contained non-conservative additional cooling times for fuel assemblies loaded with an RCCA. This was due to the added heat loads of nine RCCAs being distributed across the entire basket instead of just the nine fuel bundles in which the RCCAs were to be placed. As part of the review for this deficiency, the applicant also determined that Table B2-5 needed to be expanded to cover the use of the three-zone and four-zone preferential loading patterns with nonfuel hardware. The applicant made appropriate adjustments to the heat loads to correct the deficiency and expand for use in the preferential loading pattern resulting in a new Table B2-5 which is included in the proposed technical specifications.

5.4.1 Confirmatory Review and Analysis

The staff reviewed the applicant's shielding analysis and found it acceptable because 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. The staff independently calculated source terms for the bounding PWR 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 WE14×14 PWR fuel as defined in Table 5.9.3-1 to be acceptable and within regulatory limits. The staff concludes that the applicant has demonstrated that the MAGNASTOR® dry cask storage system meets the radiation protection requirements of 10 CFR 72.104 and 72.106.

5.5 Evaluation Findings

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

F5.1 Chapter 5 of the MAGNASTOR® SAR describes shielding structures, systems, and components important to safety in sufficient detail to allow evaluation of their effectiveness.

F5.2 Chapter 5 of the MAGNASTOR® SAR provides reasonable assurance that the radiation shielding features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F5.3 Operational restrictions to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106 are the responsibility of the general licensee. The MAGNASTOR® shielding features are designed to assist in meeting these requirements.

Based upon its review, the staff has reasonable assurance that the design of the shielding system for the MAGNASTOR® system, including the concrete cask, the transfer cask, and the CANISTER, 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 in accordance with 10 CFR 72.236(d). 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

Staff reviewed the amendment request to determine whether the MAGNASTOR® system would maintain its contents in a subcritical manner under all credible normal and off-normal conditions of storage and accident events encountered during handling, loading, transfer, and storage. Only those features of the amendment request that affect the criticality safety of the system are discussed in this section of the SER. The staff reviewed the MAGNASTOR® criticality safety analysis to ensure that all credible bounding scenarios have been identified and their potential consequences on criticality considered such that the MAGNASTOR® dry cask storage system meets the regulatory requirements in 10 CFR 72.124 and 10 CFR 72.236. The staff's conclusions, summarized below, are based on information provided in support of the application and supplemental calculations provided to support this amendment.

6.1 Criticality Design Criteria and Features

According to the application, the MAGNASTOR® storage system consists of a storage canister, a concrete storage cask, and a lead-shielded transfer cask. Criticality safety in the system design is provided by a combination of fissile mass and enrichment controls, geometry control, and fixed neutron absorbers in the basket. The application explains that, for the PWR fuel, soluble boron in the water is used to flood the canister. The system is designed to store a fuel basket having up to 37 PWR assemblies or up to 87 BWR assemblies. The system may also contain damaged fuel cans (DFCs) used to accommodate damaged PWR fuel including fuel debris equivalent to one PWR fuel assembly. The system is also designed to store baskets containing 86 and 82 BWR assemblies. The fixed neutron absorber sheets are attached to the walls of the fuel assembly tubes and are positioned between each of the fuel assemblies in the basket. For PWR fuel, a minimum soluble boron concentration is maintained during loading and unloading operations corresponding to the allowable assembly type and the maximum initial enrichment of the fuel being loaded.

The scope of this amendment included a number of revisions and additions pertaining to criticality safety. As part of the proposed amendment, the applicant requested the addition of CE 16×16 damaged fuel (using the DFC). Secondly, the applicant requested that the loading profile for the BWR 82-assembly basket be revised to allow GE14 fuel assemblies with a maximum enrichment of 4.55 weight percent. Thirdly, the applicant requested an additional BWR 86-assembly loading profile be included to allow GE13 fuel with a maximum enrichment of 3.85 weight percent. The applicant incorporated changes into the certificate of compliance and technical specifications to support the proposed revisions and additions included as part of this amendment.

The staff reviewed the applicant's model descriptions and assumptions and finds that they are consistent with the description of the design and contents given in FSAR Chapters 1 and 2 and in the supplemental calculations included as part of this amendment. The staff also verified that the FSAR and related supplemental information contained the relevant figures and tables that are sufficiently detailed to support an in-depth staff evaluation. Based on its review, the staff concludes that the applicant has satisfied the regulatory requirements in 10 CFR 72.236.

6.2 Fuel Specifications

Consistent with Amendment No. 3, the applicant categorized the proposed contents for this amendment based on the specified fuel type and established bounding values on the key parameters for each generic fuel type. Criticality analyses to establish enrichment limits were performed for each generic fuel type. The application limits allowable contents to fuel that has cladding made from zirconium-based alloys, and allows damaged fuel to be stored in the canister if contained in a DFC. NRC staff reviewed the FSAR and proposed technical specifications to ensure that the proposed fuel specifications impacting criticality safety are included.

6.3 Model Specifications

The previous amendments of the application evaluated the storage of damaged and undamaged PWR fuel assemblies and undamaged BWR fuel assemblies within the MAGNASTOR® system. This currently proposed amendment (Amendment No. 5) includes the allowance of the CE 14×14 damaged PWR fuel assembly and two BWR fuel assembly types (GE14 and GE13) with maximum initial enrichments of 4.55 weight percent and 3.85 weight percent, respectively.

The modeling assumptions used by the applicant are unchanged from those previously approved for Amendment No. 3.

6.3.1 Configuration

As specified in the transmittal letter, the applicant is requesting that a CE 16×16 damaged PWR fuel assembly be included among those assembly types already approved under Amendment No. 3. As part of the methodology discussed in Amendment No. 3, the applicant performed a generic criticality evaluation that was used to show that all of the proposed undamaged and damaged PWR fuel assemblies remained below the established upper subcritical limit (USL) of 0.9376. The applicant justified inclusion of the damaged CE16×16 fuel by evaluating the fuel under the same conditions and assumptions used in the Amendment No. 3 analyses for damaged fuel being placed in the DFC. These scenarios included evaluating criticality effects of placing undamaged CE 16×16 fuel into the DFC, evaluating the effects of loose rods having no cladding (damaged fuel), and evaluating a mixture of fuel and water within the DFC. The reactivity effects of missing rods within the assembly and the effects of removing ^{10}B inserts from the fuel basket were also evaluated for the CE 16×16 fuel assembly.

The criticality section of the FSAR only consisted of a generic evaluation and was used to address the fuel assembly types allowed for storage in the MAGNASTOR® storage system. As a result, discussion in the criticality section of the SAR for this amendment was not updated to address inclusion of the CE 16×16 fuel. However, the criticality results from the evaluation of the damaged CE 16×16 fuel were included in the updated portions of Tables 6.7.8-1 through 6.7.8-10 of the SAR. The most reactive results associated with loading of the damaged CE 16×16 fuel yielded $k_{eff} + 2\sigma$ values of 0.93575.

Staff determined this to be acceptable due to the conservative assumptions discussed in the preceding paragraphs being used in the criticality analyses such as assuming loose rods with no cladding and assuming a mixture of fuel and water within the DFC. Additionally, the reactivity results involving the addition of the damaged CE 16×16 fuel were still less than the USL of 0.9376 and were therefore, considered by staff to be acceptable.

Section 6.7.5 of the SAR states, in part, that “characterization studies are based on the 87-assembly basket configuration. For assemblies exceeding the USL at the enrichment specified in the studies either the 86-assembly basket, the 82-assembly basket configurations, or reduced maximum enrichments are required.” As part of this amendment the applicant demonstrated that the reduction in system reactivity resulting from the removal of the center assembly (86-assembly basket) would allow loading of the proposed B9_74A BWR assembly with an initial enrichment of 3.85 wt.%. Likewise, the applicant demonstrated that reduction in system reactivity resulting from the removal of five (5) assemblies from the center and four other locations (alternate 82-assembly basket) would allow the loading of the proposed B10_91A and B10_92A BWR assemblies with an initial enrichment of 4.55 wt.%.

In order to evaluate the addition of GE14 fuel with a maximum enrichment of 4.55 weight percent in the 82-assembly basket and the GE13 fuel with a maximum enrichment of 3.85 weight percent in the 86-assembly basket, the applicant submitted, as part of the response to NRC’s request for additional information No. 6-1, a supplemental criticality calculation (Calculation 71160-6011). The applicant imported the bounding 87-assembly and 82-assembly basket loadings from a previous analysis which was used as the basis for this analysis.

The GE13 BWR fuel was evaluated by loading the 87-assembly basket, with the GE13 (B9_74A) assemblies having a maximum enrichment of 3.85 weight percent and removing the center assembly (86-assembly basket loading). As part of this analysis, some of the peripheral absorber sheets were considered to either be removed or replaced by aluminum (up to 24 absorber sheets). The effects of moderation were evaluated by varying the moderator density within the basket. The 86-assembly basket loading was evaluated for full length as well as partial length rods. The most reactive cases for the full- and partial-length fuel rods in the fuel assemblies yielded $k_{eff} + 2\sigma$ values of 0.93380 and 0.93272, respectively. In all cases involving the 86-assembly basket loadings the reactivity was shown to be below the USL of 0.9376.

The GE14 BWR fuel was evaluated by loading the 82-assembly basket (shown in Figure 6.1.1-1 of the SAR) with the GE14 (B10_91A) assemblies having a maximum enrichment of 4.55 weight percent. The center assembly is removed and the other four empty positions were shifted out from the center as shown in Figure 6.1.1-1 of the SAR (alternate 82-assembly basket loading). As part of this analysis, some of the peripheral absorber sheets were considered to either be removed or replaced by aluminum (up to 16 absorber sheets). The effects of moderation were evaluated by varying the moderator density within the basket. The alternate 82-assembly basket loading was evaluated for full-length as well as partial-length rods. The GE14 (B10_92A) assemblies were evaluated in the same manner. The most reactive cases for the full- and partial–length fuel rods in the fuel assemblies yielded $k_{eff} + 2\sigma$ values of 0.92716 and 0.93220, respectively. In all cases involving the alternate 82-assembly basket loadings the reactivity was shown to be below the USL of 0.9376.

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. Since the MCNP code and cross-section libraries are benchmarked by comparison to a range of critical experiments relevant to light water reactor fuel in storage and transport casks, the staff determined it to be acceptable for this particular design and these fuel types.

6.4.2 Multiplication Factor

The applicant performed calculations showing that the MAGNASTOR® system will meet the design criterion of $k_{eff} + 2\sigma < USL$ when loaded with the authorized contents as specified in the FSAR and proposed technical specifications. The applicant performed final calculations with the parameter values that maximized 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 (i.e., 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 technical specifications). For cases where the maximum k_{eff} exceeds the USL, either the 86-assembly basket configuration, the 82-assembly basket configuration, or reduced maximum enrichments are required for use, as shown in Table B2-12 of the Technical Specifications.

6.4.3 Benchmark Comparisons

This amendment did not require any new benchmark analyses.

6.5 Criticality Evaluation Summary

The applicant used three-dimensional calculation models in its criticality analyses. The models are based on the engineering drawings in the FSAR and previously reviewed models submitted as part of supplemental calculations. The design-basis off-normal and accident events do not affect the design of the cask from a criticality standpoint. Therefore, the calculation models for the normal, off-normal, and accident conditions are the same. NRC staff imported sample input files provided by the applicant to confirm results provided in the supplemental calculations.

6.6 Evaluation Findings

NRC staff reviewed the information provided in Amendment No. 5 of the application and determined that it is in compliance with the requirements in 10 CFR 72.124, and 10 CFR 72.236(c). Staff also determined that the criticality results associated with the evaluation of CE 16×16 damaged PWR fuel and GE13 and GE14 BWR fuel, as described in this application, remain less than the USL of 0.9376 for each of the evaluated cases. The applicant incorporated a number of conservative assumptions and evaluated the fuel over a range of bounding credible scenarios. Limits are imposed for each fuel in regards to the minimum ^{10}B concentration in the absorber sheets, soluble boron concentrations in the pool (for PWR fuel), and allowable enrichments. As a result, staff has reasonable assurance that the MAGNASTOR® spent fuel dry cask storage system containing either the CE 16×16 damaged PWR fuel, or GE14 or GE13 BWR fuel, as described in Amendment No. 5 of the application, will remain safe while in storage. Specifically, the nuclear criticality safety evaluation demonstrates that the MAGNASTOR® spent fuel dry cask storage system will continue to meet the relevant regulatory requirements and the staff finds the following:

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

F6.2 The cask and its spent fuel transfer systems are designed to be subcritical under all credible conditions.

F6.3 The criticality design is based on favorable geometry, fixed neutron poisons, and soluble poisons of the spent fuel pool. An appraisal of the fixed neutron poisons has shown that they will remain effective for the term requested in the application and there is no

credible way for the fixed neutron poisons to significantly degrade during the requested term in the application; therefore, there is no need to provide a positive means to verify their 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 the term requested in the application.

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.

7.0 CONFINEMENT EVALUATION

There were no requested changes in the confinement section and none of the changes requested affect the confinement section.

8.0 MATERIALS EVALUATION

There were no requested changes in the materials of construction and none of the changes requested affect the materials section.

9.0 OPERATING PROCEDURES EVALUATION

The objective of the operating procedures review is to ensure that the application presents acceptable operating sequences, guidance, and generic procedures for key operations for the MAGNASTOR® storage system.

9.1 Cask Loading

The applicant made a minor revision in Section 9.1.1 to account for the three- and four-zone preferential loading patterns to add specific fuel assembly positions for preferential loading in Figure B2-2 of Appendix B to the Technical Specifications.

9.2 Evaluation Findings

Based upon its review, the staff has reasonable assurance that the operating procedures for the MAGNASTOR® storage system are in compliance with 10 CFR Part 72 and the staff finds the following:

F9.1 The content of the general operating procedures described in the SAR are adequate to protect health and minimize damage to life and property. Detailed procedures will need to be developed and approved on a site-specific basis.

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.

10.0 ACCEPTANCE TESTS AND MAINTANANCE PROGRAM EVALUATION

The objective of the acceptance tests and maintenance program review is to ensure that the application includes the appropriate acceptance tests and maintenance programs for the MAGNASTOR® storage system.

10.1 Acceptance Tests – Structural and Pressure Tests

The applicant made a minor modification to more accurately reflect the subsection within the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV), Section III, Subsection NB from NB-6000 to NB-6200 utilized for the pressure test.

10.2 Evaluation Findings

F10.2 Structures, systems, and components (SSCs) important to safety continue to 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 10 of the SAR identifies the safety importance of SSCs, and presents the applicable standards for their design, fabrication, and testing.

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.

11.0 RADIATION PROTECTION EVALUATION

There were no requested radiation protection changes requiring evaluation and none of the changes requested affect the radiation protection section.

12.0 ACCIDENT ANALYSIS EVALUATION

There were no requested accident analysis procedures changes requiring evaluation and none of the changes requested affect the accident analysis section. Other accidents are bounded by previous analyses.

13.0 TECHNICAL SPECIFICATIONS

In addition to the technical specification changes documented and evaluated in previous sections to this SER, the applicant requested an editorial change in Appendix A of the technical specifications to revise the minimum required ^{10}B actual areal density from 0.334 g/cm^2 to 0.0334 g/cm^2 for both borated aluminum alloy and borated metal matrix composite (MMC) for PWR fuel baskets.

13.1 Technical Specifications

By application dated March 22, 2010 (ADAMS Accession No. ML100830445), as supplemented March 30 (ADAMS Accession No. ML100910345), March 31 (ADAMS Accession No. ML100950172), June 8 (ADAMS Accession No. ML101610085), July 1 (ADAMS Accession No. ML102880325), November 10 (ADAMS Accession No. ML103190427), November 19 (ADAMS Accession No. ML103260461), April 22 (ADAMS Accession No. ML11115A146), and May 17, 2011 (ADAMS Accession No. ML11143A101), NAC requested several changes to Certificate of Compliance No. 1031, one of which is "the addition of various ^{10}B areal densities for use with PWR and BWR baskets."

In its application dated March 22, 2010, NAC performed a criticality analysis for PWR baskets and took 90% credit for the ^{10}B in the borated aluminum alloy and borated MMC plates. The

effective ^{10}B density (90% of actual ^{10}B density) that was used in the criticality evaluation was 0.036 g/cm^2, 0.030 g/cm^2, and 0.027 g/cm^2 to ensure criticality safety. Table 13-1 (Table 6.1.1-5 in NAC's application) translated the effective areal density of neutron absorber content to actual required areal density using 90% credit.

Table 13-1: Effective Areal Density as a Function of Absorber Credit

	Effective ^{10}B g/cm^2	75% Credit ^{10}B g/cm^2	90% Credit ^{10}B g/cm^2
PWR	0.036	0.048	0.040
	0.030	0.040	0.0334
	0.027	0.036	0.03
BWR	0.027	0.036	0.030
	0.0225	0.030	0.025
	0.020	0.0267	0.0223

Since the NAC criticality evaluation and the NRC staff's safety evaluation report (ADAMS Accession No. ML120320247) both indicate that the effective areal density used in this case was 0.030 ^{10}B g/cm^2, the NRC staff concludes that the value stipulated in LCO 4.1.1(a) of 0.334 ^{10}B g/cm^2 is a typographical error and should be 0.0334 ^{10}B g/cm^2.

13.2 Evaluation Findings

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

The proposed technical specifications provide reasonable assurance that the cask will allow safe storage of spent fuel. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, accepted practices and the statements and representations in the application.