NAC INTERNATIONAL

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February 4, 2011

U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852-2738

Attn: Document Control Desk

Subject: Submission of NAC International Response to the NRC Request for Supplemental Information Re. Amendment 3 Request for the U.S. Nuclear Regulatory Commission Certificate of Compliance No. 1031 for the NAC International MAGNASTOR® Cask System

Docket No. 72-1031, TAC No. L24470

References:
1. U.S. Nuclear Regulatory Commission (NRC) Certificate of Compliance (CoC) No. 1031 for the MAGNASTOR Cask System, Amendment No. 1, August 30, 2010
2. Request to Amend CoC No. 1031 (MAGNASTOR Amendment 3), NAC International, August 26 2010
3. Request for Supplemental Information Certificate of Compliance (CoC) No. 1031 Amendment 3 (TAC No. L24470), US NRC, October 29, 2010

In response to Reference 3, NAC International (NAC) herewith submits the supplemental information requested by the NRC technical review team.

This submittal consists of the following documents:

- Eight copies of NAC's response to the Request for Supplemental Information (RSI), Reference 3, including a list of 72.48 changes that constitute the bases for the Amendment 3 Application.
- Eight copies of MAGNASTOR FSAR changed pages (Revision 11A) in response to RSI 5-1, including the List of Effective Pages and text flow pages. See Note below.
- Two copies of two (2) NAC Proprietary Calculations and eight copies of the proprietary response to RSI 3-1 (one page), packaged in a separate sealed envelope marked "NAC Proprietary Information."
- Proprietary Affidavit.

Note: On the Revision 11A changed pages, the notation of Amendment 1, Amendment 2, Amendment 3 and 74.48 changes remained unchanged for easy insertion into the base document (MAGNASTOR Revision 10B). The additional text in response to RSI 5-1 is identified by a revision bar in the margin. Upon final approval of Amendment 3, the Revision 10B and Revision 11A changed pages will be incorporated into the next MAGNASTOR FSAR update.

NMSS01

ED20110021

If you have any comments or questions, please contact me on my direct line at 678-328-1274.

Sincerely,

Anthony L Patko

Anthony L. Patko
Director, Licensing
Engineering

Enclosures

NAC INTERNATIONAL

NAC INTERNATIONAL
AFFIDAVIT PURSUANT TO 10 CFR 2.390

John J Butler (Affiant), Vice President, Finance, of NAC International, hereinafter referred to as NAC, at 3930 East Jones Bridge Road, Norcross, Georgia 30092, being duly sworn, deposes and says that:

1. Affiant has reviewed the information described in Item 2 and is personally familiar with the trade secrets and privileged information contained therein, and is authorized to request its withholding.

2. The information to be withheld includes the following NAC Proprietary Information that is being provided to support the technical review of NAC's Request for an Amendment of Certificate of Compliance (CoC) No. 1031 for the NAC International MAGNASTOR® Cask System.

   - Response to RSI 3-1 (Structural Evaluation), Page 5 of 11, NAC International Response to the US NRC Request for Supplemental Information for MAGNASTOR Cask System Amendment Request No. 3.

   - NAC International Calculations
     - Calculation No. 71160-3140, "MAGNASTOR VCC/PWR Canister with Damaged Fuel Cans Thermal Evaluation," Revision 0, including Data Files on 1 CD
     - Calculation No. 71160-3127, "Determination of Flow Resistance for PWR Basket with Damaged Fuel Cans," Revision 0, including Data Files on 1 CD

   The above calculations and data files are the result of detailed analyses performed by NAC and are being used for the MAGNASTOR Amendment 3 request. NAC is the owner of the information contained in the above documents. Thus, all of the above identified information is considered NAC Proprietary Information.

3. NAC makes this application for withholding of proprietary information based upon the exemption from disclosure set forth in: the Freedom of Information Act ("FOIA"); 5 USC Sec. 552(b)(4) and the Trade Secrets Act; 18 USC Sec. 1905; and NRC Regulations 10 CFR Part 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial financial information obtained from a person, and privileged or confidential" (Exemption 4). The information for which exemption from disclosure is herein sought is all "confidential commercial information," and some portions may also qualify under the narrower definition of "trade secret," within the meanings assigned to those terms for purposes of FOIA Exemption 4.

4. Examples of categories of information that fit into the definition of proprietary information are:

   a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by competitors of NAC, without license from NAC, constitutes a competitive economic advantage over other companies.

   b. Information that, if used by a competitor, would reduce their expenditure of resources or improve their competitive position in the design, manufacture, shipment, installation, assurance of quality or licensing of a similar product.

   c. Information that reveals cost or price information, production capacities, budget levels or commercial strategies of NAC, its customers, or its suppliers.

   d. Information that reveals aspects of past, present or future NAC customer-funded development plans and programs of potential commercial value to NAC.

e. Information that discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information that is sought to be withheld is considered to be proprietary for the reasons set forth in Items 4.a, 4.b, and 4.d.

5. The information to be withheld is being transmitted to the NRC in confidence.

6. The information sought to be withheld, including that compiled from many sources, is of a sort customarily held in confidence by NAC, and is, in fact, so held. This information has, to the best of my knowledge and belief, consistently been held in confidence by NAC. No public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements, which provide for maintenance of the information in confidence. Its initial designation as proprietary information and the subsequent steps taken to prevent its unauthorized disclosure are as set forth in Items 7 and 8 following.

7. Initial approval of proprietary treatment of a document/information is made by the Vice President, Engineering, the Project Manager, the Licensing Specialist, or the Director, Licensing – the persons most likely to know the value and sensitivity of the information in relation to industry knowledge. Access to proprietary documents within NAC is limited via "controlled distribution" to individuals on a "need to know" basis. The procedure for external release of NAC proprietary documents typically requires the approval of the Project Manager based on a review of the documents for technical content, competitive effect and accuracy of the proprietary designation. Disclosures of proprietary documents outside of NAC are limited to regulatory agencies, customers and potential customers and their agents, suppliers, licensees and contractors with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

8. NAC has invested a significant amount of time and money in the research, development, engineering and analytical costs to develop the information that is sought to be withheld as proprietary. This information is considered to be proprietary because it contains detailed descriptions of analytical approaches, methodologies, technical data and/or evaluation results not available elsewhere. The precise value of the expertise required to develop the proprietary information is difficult to quantify, but it is clearly substantial.

9. Public disclosure of the information to be withheld is likely to cause substantial harm to the competitive position of NAC, as the owner of the information, and reduce or eliminate the availability of profit-making opportunities. The proprietary information is part of NAC's comprehensive spent fuel storage and transport technology base, and its commercial value extends beyond the original development cost to include the development of the expertise to determine and apply the appropriate

evaluation process. The value of this proprietary information and the competitive advantage that it provides to NAC would be lost if the information were disclosed to the public. Making such information available to other parties, including competitors, without their having to make similar investments of time, labor and money would provide competitors with an unfair advantage and deprive NAC of the opportunity to seek an adequate return on its large investment.

STATE OF GEORGIA, COUNTY OF GWINNETT

Mr. John J. Butler, being duly sworn, deposes and says:

That he has read the foregoing affidavit and the matters stated herein are true and correct to the best of his knowledge, information and belief.

Executed at Norcross, Georgia, this 4th day of February 2011.

John J. Butler
Vice President, Finance
NAC International

Subscribed and sworn before me this 4 day of FEBRUARY, 2011.

Notary Public

JEFF D ANDERSON
MY COMMISSION EXPIRES
NOTARY PUBLIC
SEPTEMBER 5, 2013
FORSYTH COUNTY, GEORGIA

NAC INTERNATIONAL

NONPROPRIETARY RESPONSE TO THE

UNITED STATES
NUCLEAR REGULATORY COMMISSION

REQUEST FOR SUPPLEMENTAL INFORMATION

OCTOBER 29, 2010

FOR MAGNASTOR® CASK SYSTEM AMENDMENT REQUEST NO. 3 TO REVISE CONTENTS TO INCLUDE PWR DAMAGED FUEL CONTAINED IN DAMAGED FUEL CANS AND TO INCLUDE FUEL ASSEMBLY AVERAGE BURNUP UP TO 70 GWd/MTU

(TAC NO. L24470, DOCKET NO. 72-1031)

FEBRUARY 4, 2011

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NAC INTERNATIONAL RESPONSE TO REQUEST FOR SUPPLEMENTAL INFORMATION

RSI 0-1

Concerning the dependency between Amendment 3 and the identified 10 CFR 72.48 changes:

1. Provide clarification for what and how Amendment 3 is dependent on the 10 CFR 72.48 changes identified in the SAR.
2. Clarify whether or not these 10 CFR 72.48 changes have been integrated into the design before the Amendment 3 request.

This information is needed in order for the staff to proceed to the detailed technical review. This Request for Supplemental Information is made in accordance with Section 3.1.3 of the Office Instruction SFST-14, Rev. 0, "Acceptance Review Process."

<u>NAC International Response</u>

1. The 72.48 changes that constitute bases for the Amendment 3 application have been tabulated in Attachment 1. A brief explanation is provided as to how Amendment 3 is dependent on each 72.48 change. Please see Attachment 1.
2. All 72.48 changes incorporated into the SAR, Revision 10B, have been integrated into the MAGNASTOR design prior to the Amendment 3 request.

NAC INTERNATIONAL RESPONSE TO REQUEST FOR SUPPLEMENTAL INFORMATION

RSI 1-1 (General Description)

Provide license drawing 71160-556.

On page 1.8-1 of the SAR Revision 10B, the list of license drawings seems to indicate that license drawing 71160-556 is part of the design basis that the current amendment is based upon. This drawing, however, does not seem to be presented in the application.

This information is needed in accordance with Section 3.1.3 of the Office Instruction SFST-14, Rev. 0, "Acceptance Review Process."

<u>NAC International Response</u>

The drawing list provided on page 1.8-1 of SAR, Revision 10B, is a complete listing of the MAGNASTOR license drawings. All drawings that were revised/generated and submitted for approval with the Amendment 3 request are marked on the list with a revision bar in the right margin. Drawings that are not relevant to the Amendment 3 request were not included in the package. License drawing 71160-556, Revision 1, titled "Assembly, MAGNASTOR Transfer Cask (MTC), Stainless Steel," is not a basis for the current amendment request and, therefore, it was not included.

The MAGNASTOR FSAR, Revision 1, submitted January 7, 2011, contains a complete set of all current MAGNASTOR license drawings, including the above-mentioned drawing.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

RSI 3-1 (Structural Evaluation)

For the pressurized water reactor (PWR) basket and PWR damaged fuel basket with alternate pin-slot connections other than that approved for the original CoC, provide: (1) a basket stability evaluation and (2) a basket pin-slot stress evaluation for the concrete cask tip-over accident condition. For the evaluations performed, submit appropriate finite element analysis input and output files for staff review.

The staff expects that the basket stress and stability evaluations similar to those presented in SAR Sections 3.10.1, 3.10.6, and 3.10.8 for the original CoC be provided for review to meet the 10 CFR 72.122(b) requirements. The analysis input and output files should be submitted per USNRC Spent Fuel Storage and Transportation Division Interim Staff Guidance No. 21 (ISG-21), "Computational Modeling Software," for staff review.

This information is needed to comply with 10 CFR 72.11(a).

NAC International Response

[redacted]

[redacted]

[redacted]

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

RSI 4-1 (Thermal Evaluation)

Provide the FLUENT CFD analysis and ANSYS analysis input and output files so that staff may complete the thermal analysis for the application.

Staff reviewed the application per the acceptance review process established in SFST, Office Instruction (OI) No. 14. Per this OI, one of the important keys is to have the computer files necessary to complete the analysis/review. Thus far, the applicant has not supplied the FLUENT and ANSYS input and output files for the review. The analysis input and output files should be submitted per USNRC Spent Fuel Storage and Transportation Division Interim Staff Guidance No. 21 (ISG-21), "Computational Modeling Software," for staff review.

This information is needed to comply with 10 CFR 72.11(a).

NAC International Response

The TSC thermal evaluations for all MAGNASTOR configurations are contained in Section 4.4.1.1 under the paragraph titled "Modeling of the TSC" (pages 4.4-7 through 4.4-10 of MAGNASTOR SAR Revision 10B). In Amendment 3, the evaluation for the PWR damaged fuel configuration was added to the evaluations for the standard PWR and BWR intact fuel configurations. The following two proprietary calculations, including the computer models for the PWR damaged fuel configuration, are included with NAC's response to this RSI in a separate sealed envelope marked "NAC Proprietary Information":

"MAGNASTOR VCC/PWR Canister with Damaged Fuel Cans Thermal Evaluation" – Calculation No. 71160-3140, Revision 0, including data files on one CD

"Determination of Flow Resistance for PWR Basket with Damaged Fuel Cans" – Calculation No. 3127, Revision 0, including data files on one CD

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

RSI 5-1 (Shielding Evaluation)

Provide technical bases or validation for using the SAS2H code to calculate the gamma and neutron source terms of the fuel with burnup up to 70 GWd/MTU.

Amendment 3 to the MAGNASTOR design requests to increase the allowable burnup of the fuel assemblies to 70 GWd/MTU. However, the SAS2H code of the SCALE 4.4 package used in the source term calculations has not been validated to 70 GWd/MTU. The statements in the NUREG/CR-6701 (Review of Technical Issues Related to Predicting Isotopic Compositions and Source Terms for High-Burnup LWR Fuel), "In this demonstration the sensitivity profiles were calculated for a generic LWR fuel assembly having an initial enrichment of 3.0-wt % ^{235}U. The depletion calculations were performed using a nominal power of 35 MW/t and extended to a maximum burnup of 75 GWd/t. The results presented here are only intended as a demonstration to illustrate typical trends in the sensitivity coefficients for several important data parameters with burnup," which the applicant quoted in the SAR, do not appear to be appropriate for use as a basis for code validation. Review of the NUREG-CR-6701 indicates that the statements in Appendix A of NUREG/CR-6701 were for sensitivity study rather than for code validation. NUREG/CR-6701 also shows that the fuel sample with maximum burnup of 73 GWd/MTU was taken from a reconstituted fuel assembly and the value is for peak rod burnup. The corresponding fuel assembly burnup is about 60 GWd/MTU (peak burnup/pellet power peaking factor/rod peaking factor = $73/1.1/1.1 \approx 60$).

Staff consulted the technical staff at Oak Ridge National Laboratory, the developer of the code, on the validation issue of SAS2H. The answer is that SAS2H has never been validated to 70 GWd/MTU burnup. Statements made in NUREG/CR-6701 clearly indicate that the sample from H. B. Robinson was merely used for illustration of the sensitivity study. As such, the code version used for the assembly depletion analysis may not be adequate for this application. The applicant is requested to provide technical basis for the adequacy of using the SAS2H code for calculations of the source terms for the contents with burnup up to 70 GWd/MTU. An independent validation, including trend analysis, of the code versus fuel burnup may be an acceptable approach to resolve this concern.

This information is needed in order for the staff to proceed to the review. This information is needed in accordance with Section 3.1.3 of the Office Instruction SFST-14, Rev. 0, "Acceptance Review Process."

NAC International Response to RSI 5-1

NAC contacted technical staff at Oak Ridge National Laboratory to determine availability of SAS2H validation documents or experimental benchmarks for isotope/source generation of very high burnup fuel. While no benchmark documents were indicated to be available for SAS2H, a recent publication (NUREG/CR-7012, January 2011) contains the required information for SCALE/TRITON. TRITON is the 2-D/3-D neutron transport replacement for the 1-D SAS2H sequence in the SCALE package. In the NUREG studies, TRITON was executed using the 44-group library and the NITWAL option making the method, with the exception of the neutron transport solution, very similar to that employed by NAC for MAGNASTOR with SAS2H. Trends in isotope generation versus burnup are expected to be related to cross-section and processing effects, not neutron transport solution, with cross-section and processing being identical in the sequences used by SAS2H and TRITON (NITAWL option). Therefore, no trending in SAS2H results versus burnup is expected. To confirm this conclusion, NAC generated SAS2H models to cases selected from NUREG/CR-7012 and confirmed by independent validation calculation that no significant trending exists within the code at the requested burnup range (as validated up to 79 GWd/MTU).

The following text is added within Section 5.2 of the SAR.

"NUREG/CR-7012 contains the summary of various NUREGs that document publicly available (and in the case of the MARIBU, commercially protected) comparisons of experimental to code-generated isotope compositions based on the TRITON sequence of SCALE. Burnups included in the NUREG are very high burnups and cover a range of 8 to 79 GWd/MTU. The NUREG compares isotopes relevant to burnup credit, radiation protection and heat generation, and waste management. The comparison relies on the TRITON with NITWAL rather than the newer CENTRM sequence. Beyond the transport solution, which used NEWT in TRITON for a 2-D solution rather than XSDRNPM in SAS2H for a 1-D solution, the NUREG and MAGNASTOR analysis methods are very similar and are not expected to show divergent results in the analysis trend versus burnup. The conclusion in NUREG/CR-7012 is that there is no code bias trend of the depletion-generated isotopics and sources versus burnup level. In particular, there is no significant trend for very high burnup fuel. While absolute differences between SAS2H and TRITON are expected due to neutron transport method differences, trending is not expected for SAS2H. This conclusion is confirmed by reevaluating cases from NUREG/CR-7012 with the SAS2H sequence. In particular, cases documented in detail within NUREG/CR-6968, NAC International Response to RSI 5-1 (cont'd)

MORE CLOSELY

NUREG/CR-6969 and NUREG/CR-7013 are evaluated using SAS2H. SAS2H modeled cases go up to 79 GWd/MTU. Similarly to the NUREG TRITON cases, the SAS2H result differences from experimental data are ~~closer~~ related to uncertainties within the experimental data (e.g., isotope measurement, depletion model inputs) and the uniqueness of the geometry or material composition (e.g., Gd poisoned fuel rods) than to burnup levels. There was no significant trending of the SAS2H results as a function of fuel burnup. As such, the SAS2H/44GROUPNDF5 sequence is applicable to the high burnup fuel evaluated."

Revised pages for SAR Section 5.2 are included with this response.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

Observation

In addition to the Request for Supplemental Information, the staff finds that the following item is necessary for the staff to complete its review of the application. This item, if not addressed now, will likely result in a Request for Additional Information (RAI) during the process of technical review. The applicant, however, is not required to respond to this observation at this time, nor is it part of the acceptance review.

Observation-1

The source spectra for gamma and neutron source terms for the high burnup fuels were not included in the SAR. In general, the source spectra are necessary information for the staff to determine if the application meets the regulatory requirements of the cask shielding design. This information is missing in the SAR. The applicant may consider submitting this information.

<u>NAC International Response</u>

The bounding spectrum is presented in SAR Section 5.2 consistent with the initial licensing evaluation of the MAGNASTOR system. This includes high burnup fuel (> 45 GWd/MTU) where bounding (i.e., transfer cask radial). Thousands of spectra, including many high burnup state points, are generated within the analysis as represented by the allowed fuel type, maximum burnup, minimum initial enrichment and cool time matrix. Many of these state points will result in similar dose rates. If a specific state point is of particular interest to the NRC review staff, NAC can provide the requested data, but NAC does not find it practical to provide all generated high burnup spectrums within the FSAR.

**NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION**

Observation-2

The staff notes that the combinations of various boron-10 contents in the poison plates and the required soluble boron concentrations associated with these different poison plate boron-10 loadings are part of the Amendment 2 requests. Therefore, the review of Amendment 3 design modifications is dependent on the outcome of the Amendment 2 review. As a result, it would be impossible for the staff to determine if Amendment 3 modifications will meet the regulatory requirements of the cask criticality safety unless the staff reviews also the modification requests of Amendment 2. As such, the review of Amendment 3 is dependent upon the quick resolutions of the technical issues, if any, of the Amendment 2 review.

For effective use of the staff's time and resources, it is prudent to point out that the review of Amendment 3 should be suspended if the review of Amendment 2 necessitates a second RAI.

NAC International Response

The damaged fuel configurations were independently evaluated at each of the poison plate and soluble boron combinations and are, therefore, not strictly dependent on Amendment 2 from a damaged fuel review. As the models used in the Amendment 3 damaged fuel analysis were based on the undamaged basket models across all absorber and soluble boron combinations, the data was included in the Amendment 3 submittal.

MAGNASTOR Amendment 2 review by the staff is complete and resulted in no outstanding technical issues. Amendment 2 has been in Rulemaking since December 6, 2010.

Attachment 1

List of MAGNASTOR 10 CFR 72.48 Changes that Constitute the Bases for the Amendment 3 Application

February 4, 2011

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Chapter 1				
Page 1.3-2	DCR(L) 71160-FSAR-0F NAC-09-MAG-010	2nd, 3rd & 4th paragraphs – revised to include descriptions of the four TSC configurations	Yes	As modified by Amendment 3 text addressing the closure ring alternate designs.
Page 1.3-3	DCR(L) 71160-FSAR-0F NAC-09-MAG-010	1st paragraph – added "confinement boundary" 2nd paragraph – changed "Table 1.3-3" to "Table 1.3-2" (two tables were combined & subsequently renumbered) PWR Fuel Basket subheading, 1st paragraph, 2nd sentence – changed "Table 1.3-2" to "Table 1.3-1" (two tables were combined & subsequently renumbered)	Yes	As modified by Amendment 3 text; however, mostly editorial.
Page 1.8-1	DCR(L) 71160-FSAR-0V NAC-10-MAG-016 DCR(L) 71160-FSAR-0AE NAC-10-MAG-043 DCR(L) 71160-FSAR-0AR NAC-10-MAG-64	Drawing revisions incorporated as shown. One drawing, 71160-551, has a proprietary version & a non-proprietary version.	Yes	As included in Amendment 3 application, Revision 10B.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Chapter 2 – no changes				
Chapter 3				
Page 3.2.2, Table 3.2.1-1	DCR(L) 71160-FSAR-0D NAC-09-MAG-008 DCR(L) 71160-FSAR-0AG NAC-10-MAG-045	Table revised throughout to add various concrete cask & transfer cask configurations	Yes	This contains the weight for the DF configuration.
Page 3.5-8	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	1st partial paragraph & following equations revised to reflect the bearing stress on the fuel tube and the factor of safety	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.5-9	DCR(L) 71160-FSAR-0AA NAC-10-MAG-030	Revised factor of safety for bearing, ksi & material	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.5-11	DCR(L) 71160-FSAR-0U NAC-10-MAG-008	Revised factors of safety, ksi & material	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.5-12	DCR(L) 71160-FSAR-0U NAC-10-MAG-008	Revised ksi & material	Yes	The evaluation in this section bounds the PWR DF configuration.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 3.5-13	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	Thermal Stress Evaluation subheading, 1st paragraph, 1st sentence – changed "(Section 3.10.1.2)" to "(Section 3.10.1.2.2"; added new 3rd & 4th sentences; 3rd paragraph, 1st sentence – changed "521°F" to "550°F"; 2nd sentence – changed "454 °F" to "450°F"; revised the equations following 3rd paragraph	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.5-14	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	1st paragraph, 3rd sentence – changed "0.08-inch gap" to "0.10-inch gap"; 5th sentence – revised throughout; changed dimension in figure from "0.08" to "0.10 in."	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.5-14	DCR(L) 71160-FSAR-0U NAC-10-MAG-008	Revised factor of safety, ksi & material	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.6-5	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	Section 3.6.2.1, PWR Fuel Basket, 3rd paragraph, 2nd sentence – added "Figure 3.10.1-22 and Figure 3.10.1-23"; added new 5th sentence	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.6-6	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	Revised bottom 2 rows of table at top of page; 1st paragraph, last sentence – revised throughout along with the following equation, bearing area & factor of safety	Yes	The evaluation in this section bounds the PWR DF configuration.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 3.6-7	DCR(L) 71160-FSAR-0B NAC-09-MAG-006	Revised 1st equation & yield strength	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.6-7	DCR(L) 71160-FSAR-0AA NAC-10-MAG-030	Revised factor of safety equation & yield strength	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.6-7	DCR(L) 71160-FSAR-0AD NAC-10-MAG-042	Revised last paragraph to bound tensile load & clarify bounding shear load	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.7-7	DCR(L) 71160-FSAR-0AK NAC-10-MAG-050	Revised critical buckling load equation (superseded changes made by DCR(L) 71160-FSAR-0B)	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.7-8	DCR(L) 71160-FSAR-0AK NAC-10-MAG-050	Revised factor of safety at top of page (superseded changes made by DCR(L) 71160-FSAR-0B)	Yes	The evaluation in this section bounds the PWR DF configuration.
Page 3.7-14	DCR(L) 71160-FSAR-0AJ NAC-10-MAG-049	Last paragraph, 3rd sentence – changed "strain of 3.3%" to "strain of 2.1%"; 4th sentence – changed "3.3 percent" to "2.1 percent"; 6th sentence – changed "0.06 inch" to "0.05 inch"	Yes	2nd paragraph, 1st sentence – changed "35.8 ksi" to "33.8 ksi"; changed following factor of safety
Page 3.7-15	DCR(L) 71160-FSAR-0AJ NAC-10-MAG-049	1st paragraph, 1st sentence – changed "35.8 ksi" to "33.8 ksi"; changed following factor of safety; 2nd paragraph, 1st sentence – changed "74 pounds" to "47 pounds"; changed factor of safety	Yes	2nd paragraph, 1st sentence – changed "35.8 ksi" to "33.8 ksi"; changed following factor of safety

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Chapter 4				
Page 4.4-32	DCR(L) 71160-FSAR-0AI NAC-10-MAG-047	Maximum Internal Pressure for the TSC Containing PWR Fuel subheading, 1st paragraph, 2nd sentence – revised to include IFBA as content	Yes	DFC analysis used IFBA baseline established by DCR.
Page 4.4-33 & 4.4-34	DCR(L) 71160-FSAR-0AI NAC-10-MAG-047	Added new paragraph to include IFBA as content	Yes	DFC analysis used IFBA baseline established by DCR.
Page 4.4-34	DCR(L) 71160-FSAR-0AI NAC-10-MAG-047	1st full paragraph, 5th sentence – changed "10,000 and 10,400 liters" to "9,900 and 10,300 liters", 6th sentence – added "but do account for axial spacers"	Yes	DFC analysis used IFBA baseline established by DCR.
Chapter 5				
Page 5-1	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Section 5, Shielding Evaluation – added new 4th paragraph to address the two transfer cask and three concrete cask configurations	Yes	Revised for PWR undamaged fuel basket related cask changes (i.e., augmented shield concrete cask and stainless steel).
Page 5-1	Editorial correction	Section 5, Shielding Evaluation , new 4th paragraph, 3rd sentence – changed "(segmented—CC1 and one piece—CC2)" to "(one piece—CC1 and segmented—CC2)"	Yes	DFC analysis applicable to all cask configurations. Cask configurations are included in the generic discussion and undamaged basket sections. DFC section concentrates on basket differences.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 5-2	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Continuation of new paragraph to address the two transfer cask and three concrete cask configurations; old 3rd paragraph (minus 1st sentence) becomes 1st full paragraph on this page	Yes	Revised for PWR undamaged fuel basket related cask changes (i.e., augmented shield concrete cask and stainless steel).
Page 5.8.9-7, Table 5.8.9-2	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Deleted burnups greater than 45 GWd/MTU from this table	Yes	Tables applicable to both undamaged and DFC configuration.
Page 5.8.9-12, Table 5.8.9-3	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Deleted burnups greater than 45 GWd/MTU from this table	Yes	Tables applicable to both undamaged and DFC configuration.
Page 5.8.9-17, Table 5.8.9-4	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Deleted burnups greater than 45 GWd/MTU from this table	Yes	Tables applicable to both undamaged and DFC configuration.
Page 5.8.9-22, Table 5.8.9-5	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Deleted burnups greater than 45 GWd/MTU from this table	Yes	Tables applicable to both undamaged and DFC configuration.
Pages 5.8.9-23 thru 5.8.9-35, Table 5.8.9-6	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number (formerly Table 5.8.11-1)	Yes	Tables applicable to both undamaged and DFC configuration
Pages 5.8.9-36 thru 5.8.9-48, Table 5.8.9-7	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number (formerly Table 5.8.11-2)	Yes	Tables applicable to both undamaged and DFC configuration
Pages 5.8.9-49 thru 5.8.9-61, Table 5.8.9-8	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number (formerly Table 5.8.11-3)	Yes	Tables applicable to both undamaged and DFC configuration

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Pages 5.8.9-62 thru 5.8.9-74, Table 5.8.9-9	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number (formerly Table 5.8.11-4)	Yes	Tables applicable to both undamaged and DFC configuration
Page 5.8.9-75	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Section 5.8.9.2, BWR, 1st paragraph – revised throughout; 2nd paragraph, 1st sentence – changed "Table 5.8.9-6" to "Table 5.8.9-10"; last sentence – deleted "in Table 5.8.9-7"	Yes	Tables applicable to both undamaged and DFC configuration
Page 5.8.9-76, Table 5.8.9-10	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number	Yes	Tables applicable to both undamaged and DFC configuration
Pages 5.8.9-77 thru 5.8.9-81, Table 5.8.9-11	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number & deleted burnups greater than 45 GWd/MTU from this table	Yes	Tables applicable to both undamaged and DFC configuration
Pages 5.8.9-82 thru 5.8.9-89, Table 5.8.9-12	DCR(L) 71160-FSAR-0H NAC-09-MAG-020	Revised table number (formerly Table 5.8.11-5)	Yes	Tables applicable to both undamaged and DFC configuration
Chapter 6				
Page 6.4-2	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Section 6.4.2.1, Fabrication Tolerances, 7th sentence – revised throughout	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-1	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Section 6.7.3.1, Optimum System Configuration – added new last 2 paragraphs to address adequacy of the revised thickness tolerance of the neutron absorber sheets	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 6.7.3-4	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Neutron Absorber and Tube Modifications subheading -- revised subheading & added Phase 1 Design Modifications 2nd paragraph – added new 3rd sentence; 3rd paragraph – added "in Section 6.7.3.2"; added new subsection titled Phase 2 Design Modifications	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-5	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Remainder of new subsection titled Phase 2 Design Modifications; added new subsection titled Phase 3 Design Modifications	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-11, Figures 6.7.3-4 & 6.7.3-5	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Added 2 new figures	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-12, Figures 6.7.3-6 & 6.7.3-7	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Added 2 new figures	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-18, Table 6.7.3-6	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Revised table title & also 2 column titles	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 6.7.3-19, Tables 6.7.3-7 & 6.7.3-8	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Added 2 new tables	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-20, Table 6.7.3-9	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Added new table	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-21, Table 6.7.3-10	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Revised table number	Yes	Justifies that basis for DFC analysis (most reactive configuration) is not affected by changes implemented in undamaged basket. The changed configuration is applied to the damaged fuel basket.
Page 6.7.3-22, Table 6.7.3-11	DCR(L) 71160-FSAR-0P NAC-09-MAG-045	Revised table number	Yes	Result of adding previous tables
Chapter 7 – no changes				
Chapter 8				
Page 8.1-2	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Added "MTC1" to materials used in the transfer cask fabrication introduction; added new section for materials used in the MTC2 transfer cask fabrication	Yes	New material properties were used in the DF analysis.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 8.1-3	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Section 8.1.1, Fracture Toughness, 1st sentence – added "except for the shield plate and shield plate bolts of the composite closure lid assembly"; added new 3rd sentence, 3rd paragraph, 1st, 3rd & 5th sentences – added "MTC1" in 4 places; added 2 new sentences to end of paragraph to address MTC2 transfer cask	Yes	New material properties were used in the DF analysis.
Page 8.3-2, Table 8.3-2	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Added new table	Yes	New material properties were used in the DF analysis.
Page 8.3-7, Tables 8.3-10 & 8.3-11	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Added 2 new tables with footnotes; one subsequently deleted	Yes	New material properties were used in the DF analysis.
Page 8.3-8, Tables 8.3-12 & 8.3-13	DCR(L) 711606-FSAR-0U NAC-10-MAG-008	Revised table title & added a Note to table	Yes	New material properties were used in the DF analysis.
Page 8.3-9 Table 8.3-14	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Added new table with footnotes	Yes	New material properties were used in the DF analysis.
Page 8.3-9, Table 8.3-14	DCR(L) 71160-FSAR-0AP NAC-10-MAG-061	Revised table title & revised table throughout	Yes	New material properties were used in the DF analysis.
Page 8.3-15, Table 8.3-27	DCR(L) 71160-FSAR-0N NAC-10-MAG-015	Revised PWR row of table	Yes	New material properties were used in the DF analysis.

Chapter/Page/ Figure/Table	Source of Change: DCR(L)/72.48	Description of Change	Basis for Amendment No. 3 (Y/N)	Comments/Clarification
Page 8.3-17, Tables 8.3-31, 8.3-32 & 8.3-33	DCR(L) 71160-FSAR-0N NAC-10-MAG-015	Added footnote e to Conductivity row of table & added footnote e to bottom of page	Yes	New material properties were used in the DF analysis.
Chapter 9 – no changes				
Chapter 10				
Page 10.1-1	DCR(L) 71160-FSAR-0M NAC-09-MAG-041	Section 10.1.1, Visual Inspection and Nondestructive Examination, Item a) – added "Subsection NF [4]"	Yes	As applicable, Subsection NF of ASME Code, Section III
Chapter 11 – no changes				
Chapter 12 – no changes				
Chapter 13 – no changes				
Chapter 14 – no changes				
Chapter 15 – no changes				

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MAGNASTOR®

(Modular Advanced Generation Nuclear All-purpose STORage)

FINAL SAFETY ANALYSIS REPORT

NONPROPRIETARY VERSION

Docket No. 72-1031

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5.2 Source Specification

To generate radiation and thermal source terms, the PWR and BWR fuel assembly types are surveyed and grouped by primary characteristics critical to shielding and source term evaluations. Critical criteria are the basic reactor type in which the fuel assembly operated, fuel mass (MTU), and hardware mass. For each assembly group, a hybrid assembly is generated. The hybrid assembly contains the maximum fuel mass and hardware masses of any assembly within the group. This combination leads to a conservative source term in each TSC. The critical characteristics are listed in Table 5.2.3-1 for PWR assemblies and Table 5.2.3-2 for BWR assemblies. Fuel assembly hardware quantities for nonzirconium-based hardware are included in Section 5.8.1. This hardware may contribute significantly to cask surface dose rates as a result of ^{59}Co activation. Refer to Section 5.8.1 for the geometry aspects and hardware quantities of the evaluated PWR and BWR fuel assembly hybrids.

The SAS2H code sequence [5] of the SCALE 4.4 package [6] with the 44-group ENDF/B-V cross-section libraries [7] is used to generate source terms for the shielding analysis. SAS2H includes an XSDRNPM [8] neutronics model of the fuel assembly and the ORIGEN-S code [9] for fuel depletion and source term calculations. Source terms are generated for both UO_2 fuel and fuel assembly hardware.

The 44-group library (44GROUPNDF5) is composed primarily of ENDF/B-V cross-sections with ENDF/B-VI data for a limited number of isotopes (e.g., ^{154}Eu and ^{155}Eu). The cross-section set is collapsed using an LWR spectrum. References 31 through 35 contain extensive SAS2H validation for PWR burnups up to 47 GWd/MTU and BWR burnups up to 57 GWd/MTU. As indicated in the reference documentation, the combination of the SCALE 4.4 SAS2H sequence and the 44 GROUPNDF5 cross-section library is applicable to LWR fuel assembly source term generation for high burnup fuel.

Open literature validations of the SCALE SAS2H/44 group library versus experimental data do not extend to the system allowable assembly average burnup of 70 GWd/MTU for PWR systems and 60 GWd/MTU for the BWR system. Studies performed in NUREG/CR-6701 (Appendix A and Appendix B) [36] indicate no analysis trends in system sensitivity for LWR SAS2H/44GROUPNDF5 evaluations up to a burnup of 75 GWd/MTU.

NUREG/CR-7012 contains the summary of various NUREGs that document publicly available (and in the case of the MARIBU, commercially protected) comparisons of experimental to code-generated isotope compositions based on the TRITON sequence of SCALE. Burnups included in the NUREG are very high burnups and cover a range of 8 to 79 GWd/MTU. The NUREG compares isotopes relevant to burnup credit, radiation protection and heat generation, and waste management. The comparison relies on the TRITON with NITWAL rather than the newer CENTRM sequence. Beyond the transport solution, which used NEWT in TRITON for a 2-D solution rather than XSDRNPM in SAS2H for a 1-D solution, the NUREG and MAGNASTOR analysis methods are very similar and are not expected to show divergent results in the analysis trend versus burnup. The conclusion in NUREG/CR-7012 is that there is no code bias trend of the depletion-generated isotopics and sources versus burnup level. In particular, there is no significant trend for very high burnup fuel. While absolute differences between SAS2H and TRITON are expected due to neutron transport method differences, trending is not expected for SAS2H. This conclusion is confirmed by reevaluating cases from NUREG/CR-7012 with the SAS2H sequence. In particular, cases documented in detail within NUREG/CR-6968, NUREG/CR-6969 and NUREG/CR-7013 are evaluated using SAS2H. SAS2H modeled cases go up to 79 GWd/MTU. Similarly to the NUREG TRITON cases, the SAS2H result differences from experimental data are closer related to uncertainties within the experimental data (e.g., isotope measurement, depletion model inputs) and the uniqueness of the geometry or material composition (e.g., Gd poisoned fuel rods) than to burnup levels. There was no significant trending of the SAS2H results as a function of fuel burnup. As such, the SAS2H/44GROUPNDF5 sequence is applicable to the high burnup fuel evaluated.

Source terms are generated on an assembly average burnup basis using SAS2H and are adjusted to reflect the burnup profile as discussed in Section 5.3 and Section 5.4.

Due to the limited experimental PWR and BWR data available for the SAS2H sequence as applied to high burnup (> 45 GWd/MTU) fuel assemblies, a 5% decrement in heat load is applied at the high burnup fuel levels. The heat load decrement implies an extension in minimum cool time required for high burnup fuel and provides additional margin to account for any uncertainties in the source generation method. Note that this reduction will also reduce neutron and gamma source terms below those previously discussed in Section 5.1.

Site boundary evaluations are based on 40 kW (PWR) and 38 kW (BWR), rather than the 35.5 kW (PWR) and 33 kW (BWR) allowed payloads, providing significant margin in site exposures. The 5% margin high burnup fuel allowed levels are equivalent to 33.72 kW (PWR) and 31.35 kW (BWR) and provides further margin to the calculated site boundary exposures.

The hardware activation is calculated by light element transmutation using the in-core neutron flux spectrum produced by the SAS2H neutronics model. The effects of axial flux spectrum and magnitude variation on hardware activation are estimated by flux ratios determined from empirical data [11]. Refer to Section 5.8.1 for the in-core reactor primary system properties required for burnup calculations for the PWR and BWR systems. Refer to Section 5.8.8.1 for sample PWR and BWR SAS2H input files.

Rather than determining a single cool time, assembly average burnup, and initial enrichment combination acceptable for all payloads, source terms are produced in the following range.

- Assembly average burnup from 10,000 MWd/MTU to 70,000 MWd/MTU (PWR) or 60,000 MWd/MTU (BWR)
- Assembly average initial enrichment 1.3 wt% ^{235}U to 4.9 wt% ^{235}U
- Cool time from 4 years to 90 years (nonfuel hardware is evaluated at cool times down to two years)

5.2.1 Gamma Source

The gamma source term of the spent nuclear fuel assembly is composed of a fuel gamma source, fission product and actinide sources, and a light element activation source primarily associated with fuel hardware. Spectra are initially produced in the default 18-group energy spectrum of ORIGEN-S at reactor shutdown. The source is then decayed and rebinned into the 22-energy group gamma structure shown in Table 5.2.3-3. The 22-group structure shown is the default MCBEND [12] structure and provides improved binning at the ^{60}Co energy lines. Source generation and rebin are accomplished in the same computer run using the SCALE 4.4 stacked input file structure.

The light element gamma spectra contain contributions primarily from ^{60}Co due to the activation of stainless steel or inconel hardware components. Hardware activation is based on an assembly average nonzirconium alloy structural material ^{59}Co level of 0.8 g/kg. Minor dose contributions result from the hardware ^{59}Ni and ^{58}Fe activation and activation of the zirconium alloy clad impurities. The nonzirconium alloy hardware gamma spectral distribution is determined by the irradiation of 1 kg of material (modeled as stainless steel) in the in-core flux spectrum produced by the SAS2H neutronics calculation. Activated fuel assembly hardware source term magnitudes are determined by multiplying the source strength from the 1 kg SAS2H run by the total mass of nonzirconium in the active fuel, plenum, and end-fitting regions and then multiplying this result by a regional flux activation ratio. This regional flux ratio accounts for the effects of both magnitude and spectrum variation on hardware activation. The following list provides the flux ratios for the various source regions.

Region	Generic PWR	CE16×16 PWR	B&W PWR	Generic BWR
Upper-End Fitting	0.10	0.05	0.10	0.10
Upper Plenum	0.20	0.20	0.20	0.20
Fuel	1.00	1.00	1.00	1.00
Lower Plenum	N/A	N/A	0.20	N/A
Lower-End Fitting	0.20	0.20	0.10	0.15

Additional gamma source is produced by nonfuel hardware included in the PWR system evaluation. Included nonfuel hardware components are reactor control element assemblies (e.g., CEAs and RCCAs), burnable poison rod assemblies (e.g., BPRAs and wet annular burnable absorbers [WABAs]), thimble plugs (also referred to as guide tube plugs or flow mixers), reconstituted fuel assemblies with activated stainless steel fuel replacement rods, and HFRAs. Table 5.2.3-4 contains the activated nonfuel hardware mass by core type for BPRAs, thimble plugs, stainless steel rods, and HFRAs. Combustion Engineering (CE) cores employ integral absorber rods that replace some fuel rods. Assuming all lattice locations are filled with fuel rods bounds the in-lattice absorber rods. Refer to Sections 5.8.5, 5.8.6, and 5.8.13 for more information on the nonfuel components.

Source term calculations are based on a maximum three-cycle exposure for BPRAs and a multicycle exposure equivalent to 180 GWd/MTU burnup for thimble plugs and reactor control elements (e.g., guide tube plugs and nozzle region hardware). Actual BPRA exposure may be in more than three cycles, but is conservatively modeled by the three-cycle approach (i.e., no down time between additional cycles is included in the model). Exposure of the stainless steel fuel replacement rods is limited to 32.5 GWd/MTU, as the rods were inserted after at least one cycle of assembly depletion has occurred. The steel rods are designed to replace fuel rods that were removed for examination or due to failure. To limit the effects of steel activation on cask dose rates, reconstituted fuel assemblies with activated stainless steel fuel replacement rods may be loaded in any basket location, provided the number of replacement rods is limited to five per assembly and one assembly per cask. Unirradiated (i.e., no in-core use) replacement rods are not limited in quantity per assembly or assemblies per cask.

HFRAs may be loaded in the basket at a maximum exposure of 4.0 GWd/MTU per HFRA at a minimum cool time of 16 years.

Activation of the nonfuel hardware is treated identical to that of the fuel assembly hardware, including the use of flux factors to account for the location of the activated material in relation to the full (100%) in-core flux employed in the SAS2H depletion calculations.

5.2.2 Neutron Source

Light water reactor spent fuel neutron sources result from actinide spontaneous fission and from (α,n) reactions. The isotopes ^{242}Cm and ^{244}Cm characteristically produce all but a few percent of the spontaneous fission neutrons and (α,n) source. The next largest contribution is from (α,n) reactions in ^{238}Pu. The neutron spectra for each emission type are included in the ORIGEN-S nuclear data libraries of the SCALE 4.4 code package. Similar to the gamma spectrum, the neutron energy spectrum is decayed and rebinned into the MCBEND [12] default neutron structure using ORIGEN-S. The MCBEND neutron spectrum is listed in Table 5.2.3-5.

The MCBEND neutron energy spectrum is employed for consistency with the MCBEND gamma spectrum chosen for its enhanced grouping around the ^{60}Co energy lines. All shielding evaluations are performed with MCNP.

Neutron shielding evaluations for fissile material must account for subcritical multiplication (neutron production) inside the system being evaluated. This subcritical multiplication is taken into account by a scale factor applied to the dose results. While MCNP contains the option to directly account for the subcritical neutron multiplication, the homogenization of the fuel assembly and application of the weight window acceleration method could result in inefficient and possibly erroneous results. Code biasing is set to optimize the speed at which cask surface dose rates are obtained. Thermal energy neutrons within the fuel region are not likely to escape the shielded storage system and tend to be biased out of the evaluation. However, the thermal neutrons account for a significant portion of the subcritical multiplication. Removing the thermal neutrons from the system by biasing for cask surface dose, therefore, has the potential to bias the subcritical neutron multiplication. To account for subcritical multiplication, the neutron source rates are scaled by a subcritical multiplication factor based on the system multiplication factor, k_{eff}:

$$\text{Scale Factor} = \frac{1}{1 - k_{eff}}$$

For dry cask conditions, the system k_{eff} is taken as 0.4, with a resulting scale factor of 1.67. While the fresh fuel dry cask system reactivity is calculated slightly over 0.4 in Chapter 6, 0.4 bounds TSCs loaded with spent fuel.

Primary and secondary source/neutron source assemblies (NSAs) have a neutron source magnitude similar to that of an irradiated fuel assembly (i.e., 1×10^8 to 1×10^9 n/sec). Neutron sources may be loaded in one of the center nine basket locations. The number of neutron sources/NSAs is limited to one per assembly and one per basket. Further detail is provided in

Section 5.8.13.1. Hardware portions of NSAs may also contribute gamma source. Applying thimble plug and/or BPRA restrictions on ^{60}Co content via burnup/cool time or curie limits, as appropriate, (see Section 5.8.13) ensures that the NSA non-neutron source hardware is bounded.

5.2.3 Bounding Gamma and Neutron Spectrum

The shielding evaluations are performed using a response function approach (see Sections 5.6 and 5.8.2). Allowable cool time, initial enrichment, and maximum assembly average burnup are provided for a range of fuel assembly designs. Fuel assembly source spectra for the cases (fuel type, initial enrichment, burnup and cool time) producing the maximum radial transfer and storage cask dose rates are shown in Table 5.2.3-6 for the gamma source and in Table 5.2.3-7 for the neutron source. Maximum radial storage cask dose rates were obtained from PWR fuel, while maximum transfer cask dose rates were calculated for BWR fuel. Therefore, in Table 5.2.3-6 and Table 5.2.3-7 PWR data is presented for the storage cask, while BWR data is shown for the transfer cask. Fuel gamma sources in the tables are expressed on a per-assembly basis, while the hardware (nonzirconium alloy) source is expressed on a per-kilogram basis.

Table 5.2.3-1 Key PWR Fuel Assembly Characteristics

Fuel Type	CE	WE	WE	B&W	CE	WE	B&W
Label	14a	14b	15a	15b	16a	17a	17b
Array	14x14	14x14	15x15	15x15	16x16	17x17	17x17
Nominal Number of Fuel Rods	176	179	204	208	236	264	264
Fuel Mass [MTU]	0.4115	0.4144	0.4671	0.4807	0.4463	0.4671	0.4681

Table 5.2.3-2 Key BWR Fuel Assembly Characteristics

Fuel Type	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/2-3	BWR/4-6	BWR/4-6
Label	07a	07b	08a	08b	09a	09b	10a
Array	7x7	7x7	8x8	8x8	9x9	9x9	10x10
Number of Fuel Rods	49	49	63	64	79	79	92
Fuel Mass (MTU)	0.1985	0.2037	0.1855	0.1996	0.1723	0.1979	0.1946

Table 5.2.3-3 22-Group Gamma Energy Spectrum

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.200E+01	1.400E+01	1.300E+01
2	1.000E+01	1.200E+01	1.100E+01
3	8.000E+00	1.000E+01	9.000E+00
4	6.500E+00	8.000E+00	7.250E+00
5	5.000E+00	6.500E+00	5.750E+00
6	4.000E+00	5.000E+00	4.500E+00
7	3.000E+00	4.000E+00	3.500E+00
8	2.500E+00	3.000E+00	2.750E+00
9	2.000E+00	2.500E+00	2.250E+00
10	1.660E+00	2.000E+00	1.830E+00
11	1.440E+00	1.660E+00	1.550E+00
12	1.220E+00	1.440E+00	1.330E+00
13	1.000E+00	1.220E+00	1.110E+00
14	8.000E-01	1.000E+00	9.000E-01
15	6.000E-01	8.000E-01	7.000E-01
16	4.000E-01	6.000E-01	5.000E-01
17	3.000E-01	4.000E-01	3.500E-01
18	2.000E-01	3.000E-01	2.500E-01
19	1.000E-01	2.000E-01	1.500E-01
20	5.000E-02	1.000E-01	7.500E-02
21	2.000E-02	5.000E-02	3.500E-02
22	1.000E-02	2.000E-02	1.500E-02

Table 5.2.3-4 Bounding Regional Nonfuel Hardware Masses

Assembly	Component	Regional Masses [kg]		
		Upper Nozzle	Upper Plenum	Active Fuel
Westinghouse 14×14	Thimble Plug SS	2.12	2.18	0
	BPRA SS	2.41	2.07	9.22
Westinghouse 15×15	Thimble Plug SS	2.19	2.72	0
	BPRA SS	2.47	2.18	11.39
	HFRA Hafnium	--	--	70.45
	Reconstituted Assembly SS	--	--	13.90
Westinghouse 17×17	Thimble Plug SS	2.73	3.16	0
	BPRA SS	3.04	2.85	10.995
B&W 15×15	Thimble Plug SS	3.641	3.41	0
	BPRA SS	3.602	0	0
B&W 17×17	Thimble Plug SS	3.641	3.41	0
	BPRA SS	3.602	0	0

Table 5.2.3-5 28-Group Neutron Energy Spectrum

Group	E Lower [MeV]	E Upper [MeV]	E Average [MeV]
1	1.360E+01	1.460E+01	1.410E+01
2	1.250E+01	1.360E+01	1.305E+01
3	1.125E+01	1.250E+01	1.188E+01
4	1.000E+01	1.125E+01	1.063E+01
5	8.250E+00	1.000E+01	9.125E+00
6	7.000E+00	8.250E+00	7.625E+00
7	6.070E+00	7.000E+00	6.535E+00
8	4.720E+00	6.070E+00	5.395E+00
9	3.680E+00	4.720E+00	4.200E+00
10	2.870E+00	3.680E+00	3.275E+00
11	1.740E+00	2.870E+00	2.305E+00
12	6.400E-01	1.740E+00	1.190E+00
13	3.900E-01	6.400E-01	5.150E-01
14	1.100E-01	3.900E-01	2.500E-01
15	6.740E-02	1.100E-01	8.870E-02
16	2.480E-02	6.740E-02	4.610E-02
17	9.120E-03	2.480E-02	1.696E-02
18	2.950E-03	9.120E-03	6.035E-03
19	9.610E-04	2.950E-03	1.956E-03
20	3.540E-04	9.610E-04	6.575E-04
21	1.660E-04	3.540E-04	2.600E-04
22	4.810E-05	1.660E-04	1.071E-04
23	1.600E-05	4.810E-05	3.205E-05
24	4.000E-06	1.600E-05	1.000E-05
25	1.500E-06	4.000E-06	2.750E-06
26	5.500E-07	1.500E-06	1.025E-06
27	7.090E-08	5.500E-07	3.105E-07
28	1.000E-11	7.090E-08	3.546E-08

Table 5.2.3-6 Gamma Source Spectrum – Maximum Radial Dose Rate Configuration

Cask	Storage		Transfer	
Fuel Type	PWR		BWR	
Burnup[a]	32,500 MWd/MTU		59,000 MWd/MTU	
Cool Time	4.1 yrs		9.6 yrs	
Initial Enrichment	2.1 wt%		3.1 wt%	
Group	[γ/sec/assy]	[γ/sec/kg]	[γ/sec/assy]	[γ/sec/kg]
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	7.4804E+03	0.0000E+00	1.1750E+04	0.0000E+00
3	1.4468E+05	0.0000E+00	2.2725E+05	0.0000E+00
4	6.8141E+05	0.0000E+00	1.0703E+06	0.0000E+00
5	3.4736E+06	0.0000E+00	5.4555E+06	0.0000E+00
6	8.6551E+06	0.0000E+00	1.3593E+07	0.0000E+00
7	1.6921E+10	1.7267E-15	2.0472E+08	5.2053E-15
8	1.3579E+11	6.8687E+04	1.4196E+09	4.6465E+04
9	4.1272E+12	4.4297E+07	1.8591E+10	2.9966E+07
10	1.7127E+12	9.8431E+03	5.1315E+10	2.0805E-05
11	5.6468E+12	1.1778E+01	8.2650E+11	7.9652E+00
12	4.6708E+13	4.1963E+12	1.2763E+13	2.8387E+12
13	4.5444E+13	4.4232E+12	7.0545E+12	2.9922E+12
14	2.9488E+14	9.5781E+10	4.1222E+13	1.0028E+09
15	1.9045E+15	7.8101E+06	8.3149E+14	5.2829E+06
16	7.5264E+14	2.3127E+07	8.0768E+13	1.5212E+07
17	7.0043E+13	3.5580E+08	1.4734E+13	2.4069E+08
18	9.5410E+13	2.7118E+08	2.2731E+13	1.8345E+08
19	3.3810E+14	5.4614E+09	7.7551E+13	3.6945E+09
20	4.0250E+14	2.2637E+10	1.0662E+14	1.5314E+10
21	8.7664E+14	6.4740E+10	2.6099E+14	4.3935E+10
22	6.2752E+14	7.6843E+10	1.9082E+14	5.2571E+10
Total	5.4660E+15	8.8857E+12	1.6476E+15	5.9479E+12

[a] Assembly average

Table 5.2.3-7 Neutron Source Spectrum – Maximum Radial Dose Rate Configuration

Cask	Storage	Transfer
Fuel Type	PWR	BWR
Burnup[a]	32,500 MWd/MTU	59,000 MWd/MTU
Cool Time	*4.1* yrs	9.6 yrs
Initial Enrichment	2.1 wt%	3.1 wt%
Group	[n/sec/assy]	[n/sec/assy]
1	0.000E+00	0.000E+00
2	*1.665E+04*	*2.615E+04*
3	*6.937E+04*	*1.090E+05*
4	*2.304E+05*	*3.620E+05*
5	*7.229E+05*	*1.135E+06*
6	*1.941E+06*	*3.049E+06*
7	*3.350E+06*	*5.262E+06*
8	*1.121E+07*	*1.761E+07*
9	*1.903E+07*	*2.982E+07*
10	*2.566E+07*	*3.998E+07*
11	*6.098E+07*	*9.508E+07*
12	*9.534E+07*	*1.495E+08*
13	*2.484E+07*	*3.901E+07*
14	*8.618E+06*	*1.353E+07*
15	*2.045E+02*	*2.452E+02*
16	0.000E+00	0.000E+00
17	0.000E+00	0.000E+00
18	0.000E+00	0.000E+00
19	0.000E+00	0.000E+00
20	0.000E+00	0.000E+00
21	0.000E+00	0.000E+00
22	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00
24	0.000E+00	0.000E+00
25	0.000E+00	0.000E+00
26	0.000E+00	0.000E+00
27	0.000E+00	0.000E+00
28	0.000E+00	0.000E+00
Total	*2.520E+08*	*3.945E+08*

[a] Assembly average