TRANSNUCLEAR
AN AREVA COMPANY

November 1, 2007
E-25747

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

Subject: Application for Amendment 1 of the NUHOMS® HD Certificate of Compliance No. 1030 for Spent Fuel Storage Casks, Revision 0

Gentlemen:

In accordance with 10 CFR 72.244, Transnuclear, Inc. (TN) herewith submits its application to amend Certificate of Compliance (CoC) 1030 for the NUHOMS® HD System. This application has two main purposes. First the application proposes to allow additional fuel assembly types as authorized contents. Secondly, the application proposes to allow additional control components as authorized contents.

Enclosure 2 of this application provides a description, justification, and evaluation of the amendment changes. Enclosure 3 provides the proposed changes to those Technical Specifications and UFSAR pages. Enclosure 4 provides a list and description of input and output computer files associated with certain thermal and shielding analyses. The files are provided on a compact disk as Enclosure 5. All of these files are proprietary.

This submittal includes proprietary information which may not be used for any purpose other than to support your staff's review of the application. In accordance with 10 CFR 2.390, I am providing an affidavit (Enclosure 1) specifically requesting that you withhold this proprietary information from public disclosure.

Transnuclear, Inc. is in discussions with certain utilities who would need to use the provisions of this amendment in November 2008. Accordingly, TN requests that the staff assign a priority for review of this application consistent with that timing.

Transnuclear looks forward to working with the NRC staff on this amendment application. TN is prepared to meet with the staff to resolve any questions you might have. Should the NRC staff require additional information to support review of this application, please do not hesitate to contact Mr. Don Shaw at 410-910-6878 or me at 410-910-6930.

Sincerely,

Robert Grubb
Senior Vice President - Engineering

7135 Minstrel Way, Suite 300, Columbia, MD 21045
Phone: 410-910-6900 ◆ Fax: 410-910-6902

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cc: Jennifer Davis (NRC SFST) (six paper copies of this cover letter and Enclosures 1 through 4, plus six compact disk copies of Enclosure 5)

Enclosures:

1. Affidavit
2. Description, Justification, and Evaluation of the Amendment 1 Changes
3. Proposed Changes to the NUHOMS® HD Technical Specifications, Amendment 0 and to the NUHOMS® HD System Updated Final Safety Analysis Report, Revision 1
4. Listing of Input/Output Computer Files Provided with this Application
5. Compact disk containing the proprietary computer files listed in Enclosure 4

AFFIDAVIT PURSUANT
TO 10 CFR 2.390

Transnuclear, Inc.)
State of Maryland) SS.
County of Howard)

I, Robert Grubb, depose and say that I am Senior Vice President of Transnuclear, Inc., duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conformance with the provisions of 10 CFR 2.390 of the Commission's regulations for withholding this information.

The information for which proprietary treatment is sought is contained in Enclosure 6 and is listed below:

1. Computer files associated with thermal analysis for the effective conductivity of CE 16x16 fuel,
2. Computer files associated with the bounding criticality analysis for CE 16x16 fuel

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Transnuclear, Inc. in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1) The information sought to be withheld from public disclosure involves the computer files related to the thermal analysis for the effective conductivity of CE 16x16 fuel and the bounding criticality analysis for CE 16x16 fuel, which are owned and have been held in confidence by Transnuclear, Inc.

2) The information is of a type customarily held in confidence by Transnuclear, Inc. and not customarily disclosed to the public. Transnuclear, Inc. has a rational basis for determining the types of information customarily held in confidence by it.

3) The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.390 with the understanding that it is to be received in confidence by the Commission.

4) The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

5) Public disclosure of the information is likely to cause substantial harm to the competitive position of Transnuclear, Inc. because:

a) A similar product is manufactured and sold by competitors of Transnuclear, Inc.

b) Development of this information by Transnuclear, Inc. required expenditure of considerable resources. To the best of my knowledge and belief, a competitor would have to undergo similar expense in generating equivalent information.

c) In order to acquire such information, a competitor would also require considerable time and inconvenience related to the development of a design and analysis of a dry spent fuel storage system.

d) The information required significant effort and expense to obtain the licensing approvals necessary for application of the information. Avoidance of this expense would decrease a competitor's cost in applying the information and marketing the product to which the information is applicable.

e) The information consists of descriptions of the design and analysis of dry spent fuel storage and transportation systems, the application of which provide a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Transnuclear, Inc., take marketing or other actions to improve their product's position or impair the position of Transnuclear, Inc.'s product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

f) In pricing Transnuclear, Inc.'s products and services, significant research, development, engineering, analytical, licensing, quality assurance and other costs and expenses must be included. The ability of Transnuclear, Inc.'s competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.

Further the deponent sayeth not.

Robert Grubb
Senior Vice President, Transnuclear, Inc.

Subscribed and sworn to me before this 1st day of November, 2007.

Notary Public

My Commission Expires 10 / 14 / 2008

DESCRIPTION, JUSTIFICATION AND EVALUATION OF AMENDMENT 1 CHANGES

1.0 INTRODUCTION

The scope of Amendment 1 to CoC 1030 application includes seven separate changes as described in the following paragraphs, plus some editorial corrections, clarifications and simplifications. These changes also result in modifications to the NUHOMS® CoC 1030 Technical Specifications and the associated Bases.

Change No. 1:

Addition of Combustion Engineering (CE) 16x16 class fuel assemblies as authorized contents of the NUHOMS® HD system described in the UFSAR. The NUHOMS® HD System is currently authorized to store CE 14x14, Westinghouse (WE) 15x15 and WE 17x17 classes only.

Change No. 2:

Reduce the minimum ambient temperature from -20 °F to -21 °F.

Change No. 3:

This change seeks to expand the authorized contents of the NUHOMS® HD System to include PWR fuel assemblies with Control Components (CCs, also referred to as Non Fuel Assembly Hardware, NFAH in CoC 1030 Amendment 0) such as Burnable Poison Rod Assemblies (BPRAs), Thimble Rod Assemblies (TPAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster Control Assemblies (RCCAs), Vibration Suppressor Inserts (VSIs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Neutron Source Assemblies (NSAs) and Neutron Sources. All PWR fuel assemblies currently authorized for storage may be stored with CCs.

The NUHOMS® HD System is currently authorized to store three types of CCs, BPRAs, TPAs and VSIs, for the WE 15x15 and WE 17x17 classes only.

Change No. 4:

Reduce the minimum initial enrichment of fuel assemblies from 1.5 wt. % U-235 to 0.2 wt. % U-235.

Change No. 5:

Clarify the requirements of reconstituted fuel assemblies.

Change No. 6:

Addition of requirements to qualify metal matrix composite (MMC) neutron absorbers with integral aluminum cladding.

Change No. 7:

Delete use of nitrogen for draining the water from the DSC and allow only Helium as a cover gas during DSC cavity water removal operations.

2.0 BRIEF DESCRIPTION OF THE CHANGE

2.1 Changes to the NUHOMS® CoC 1030 Technical Specifications with Justification

The proposed changes are indicated by italic text and revision bars.

A brief description for each of the suggested changes to the Technical Specifications with justification is provided in the following paragraphs. Additional justification is not provided for those changes that are changed to provide clarification.

- Simplify the page numbering of the Technical Specifications to include only the level 1 section number. For example, pages will be numbered as 1-1, 1-2, 2-1 etc. and not 1.1-1, 1.2-1 etc. The page numbering for the Tables and Figures remains unchanged. This change improves the readability of the Technical Specifications and corrects an inconsistency in the numbering utilized previously. These changed page numbers are not annotated by revision bars.

- Clarify the definition of DAMAGED FUEL ASSEMBLY and TRANSFER OPERATIONS in Section 1.1.

- Reformat Technical Specification 2.1, "Fuel to be stored in the 32PTH DSC" to present the same information in a more simplified format. Technical Specification 2.1 also includes specific requirement for reconstituted fuel assemblies and control components. CE 16x16 fuel assemblies and an expanded definition of control components is added, consistent with the analyses provided in Chapters 4, 5 and 6. This change improves the readability of the Technical Specifications and also provides specific requirements for reconstituted fuel assemblies and control components.

- Revise paragraph 2.2.3 to change the time available for the report submittal from 30 days to 60 days. Based on the reporting requirements established in the regulation (72.75) which allow of the consideration of safety significance prior to reporting, it is judged that 60 days represents a more appropriate time period.

- Revise Technical Specification title for 3.1.1, including LCO 3.1.1 and associated ACTIONS and SURVEILLANCE REQUIREMENTS to use only Helium for drainage of bulk water. This also eliminates the need to use the three vacuum drying procedures. This revision is justified to enable compliance with ISG-21 and to limit the fuel oxidation. The revised ACTIONS allow for the repair and or replacement of the vacuum drying system components to complete the vacuum drying operations.

- Clarify the Applicability for LCO 3.1.2 and revise associated ACTIONS and SURVEILLANCE REQUIREMENTS to allow for the repair and or replacement of the vacuum drying system components to complete the backfill operations.

- Revise LCO 3.1.3 and associated ACTIONS to clarify the time limits for transfer cask cavity backfill based on "time of draining of the annulus water", consistent with the thermal analysis in Chapter 4. The FREQUENCY requirements are revised to be consistent with the SURVEILLANCE requirements.

- Revise LCO 3.2 and APPLICABILITY and ACTIONS of LCO 3.2 and associated REQUIRED ACTIONS and COMPLETION TIMES to clarify the requirements for boron concentration measurements and the option to add boron to maintain the required minimum soluble boron concentration in the pool water.

- Revise Technical Specification 4.6.3, item 5, to change the Off-normal ambient temperature from -20 degrees F to -21 degrees F. This change is one of requested changes to the NUHOMS® HD System and is accompanied by a supporting thermal analysis documented in Chapter 4.

- Revise Technical Specification 5.2.5 to allow for an alternate method to monitor the HSM-H thermal performance. Thus any one of the two surveillance activities – Daily visual inspection (5.2.5b) or direct temperature measurement (new 5.2.5c) can be performed. This is justified because both these surveillance activities are equivalent and provide the required verification of the thermal performance of the HSM-H.

- Delete Table 1 "Fuel Specifications" since its contents have been absorbed in Technical Specification 2.1 and Table 2. This is justified because the information contained in this Table is redundant.

- Simplified Table 2 to provide for parameters that are dependent on the fuel assembly class (including CE 16x16) and not on the individual design. The maximum fuel assembly length and the maximum MTU per fuel assembly for all fuel classes are identical and are based on the bounding safety analyses.

- Revise Table 3 to include the gamma source term for the control components per DSC instead of per fuel assembly. Since the source term for reconstituted fuel assemblies is now determined by the requirements in Technical Specification 2.1, the maximum fuel radiological source terms for neutron and gamma are not required and are deleted.

- Revise Table 4 to include the fuel qualification for fuel assembly average initial enrichments below 1.5 wt. % U-235. This table is also revised to include qualification for reconstituted fuel assemblies. The examples are clarified by adding "Minimum Cooling Time" to the titles in the table.

- Delete Table 5 "NFAH Thermal Qualification" since its contents have been absorbed in Technical Specification 2.1 and Table 3.

- Revise Table 7 to include the enrichment limits for CE 14x14 class with control components and CE 16x16 class with and without control components. Replace BPRA for all assembly class by CC. Delete the individual assembly types and maintain the broader fuel assembly class terminology.

2.2 Changes to the NUHOMS® HD System UFSAR, Revision 1

Section #	Page #	Reason for Change
		Chapter 1
1.0	1-1	Replace Non Fuel Assembly Hardware (NFAH) with Control Components (CCs)
1.1	1-2	Addition of CCs
1.2.2.2	1-8	Helium only for DSC draindown
1.2.2.2	1-10	Helium only for DSC draindown
1.2.3	1-12	Include CCs, CE 16x16 Fuel and reconstituted fuel
		Chapter 2
2.1	2-1	Add CE16x16 Fuel, CCs and reconstituted fuel
2.1.1	2-2	Page shift
2.1.1	2-3	CCs, editorial
2.2.9	2-10	Reduction in ambient temperature to -21 °F
2.3.2.2	2-13	Delete nitrogen / air
2.3.4.1	2-14	CE 16x16, CCs
Table 2-1	2 pages	Change title, Identical to Technical Specification (T/S) Section 2.1
Table 2-2	4 pages	Modify FQT Table, Identical to T/S Table 4
Table 2-3	1 page	Identical to T/S Table 2
Table 2-4		Identical to T/S Table 3
Table 2-6	2 pages	Add New Table, Identical to T/S Table 7
		Chapter 3
3.5.4	3-32	Delete reference to Vacuum "drying procedures"
3.6.1.1	3-36	Delete Nitrogen
		Appendix 3.9.1
3.9.1.2.3	3.9.1-12	Include transfer cask backfill / delete vacuum drying "procedures"
3.9.1.2.3	3.9.1-13	Include transfer cask backfill / delete vacuum drying "procedures" and -21°F ambient
3.9.1.3.2	3.9.1-43	delete vacuum drying "procedures"
3.9.1.4.4	3.9.1-85	Include transfer cask backfill / delete vacuum drying "procedures"
3.9.1.4.4	3.9.1-86	Include transfer cask backfill / delete vacuum drying "procedures"
3.9.1.4.4	3.9.1-87	Include transfer cask backfill / delete vacuum drying "procedures"
3.9.1.4.4	3.9.1-88	Include transfer cask backfill / delete vacuum drying "procedures"
		Chapter 4
4.1	4-2	Change minimum off-normal temperature to -21°F (-29.4°C).
4.1		Add sentence pointing to appendix 4.16.3.
4.1		Add sentence pointing to appendix 4.16.4.
4.5.1	4-29	Delete Vacuum drying "procedures" / Include Water in the TC annulus and Helium Only for draindown and vacuum drying.
4.5.1.1	4-30	Clarification of transient analysis of TC annulus backfill.
4.5.1.1	4-31	Clarification of transient analysis of TC annulus backfill.
4.5.1.2	4-32	Clarification of discussion on TC annulus backfill operations
4.5.1.2	4-33	Discuss the results to obtain time limits for TC annulus backfill operations.
4.5.2	4-34	Blank Page as a result of page shift
4.6.2	4-37	Delete use of Nitrogen
4.8.2-4	4-45	For conservatism air is used for vacuum drying and TC backfill calcs
Table 4-8, Table 4-9	1 page	Clarify TC/DSC annulus backfill operations temperatures Table 4-9 is deleted

Section #	Page #	Reason for Change
Figure 4-34	1 page	Clarify figure title, Temperatures for TC backfill operations
Figure 4-35	1 page	Figure Deleted
Figure 4-36	1 page	Figure Deleted
Figure 4-37	1 page	Clarify figure title, Time-Temp. History for TC backfill operations
		Appendix 4.16.3
	1 page	New Appendix to discuss the addition of CE 16x16 Fuel
		Appendix 4.16.4
	1 page	New Appendix to discuss reduction in ambient temperature to -21 °F
		Chapter 5
5.0	5-1	Add CCs, clarify fuel assembly class
5.1	5-2	Discuss low enrichment and Recon FQT, Add CCs
5.2	5-3	Add CCs
5.2	5-4	Describe low enrichment FQT, Recon FQT
5.2	5-5	Discuss neutron sources and other CCs
5.2.1	5-6	Add CCs
5.3	5-7	Page shift, plus an editorial (brackets added to a reference number)
5.3	5-8	Page shift
5.3	5-9	Page shift
5.4	5-10	Page shift
5.4.7	5-11	Add CCs
5.4.7	5-12	Add CCs and reconstituted fuel
5.4	5-13	Page shift
5.4	5-14	Page shift
5.4	5-15	Page shift
5.4	5-16	Page shift
		Chapter 6
6.1	6-3	Update results of CE 16x16
6.2	6-4	Add CCs and clarify reconstituted fuel
6.3.1	6-5	Add CCs
6.3.1	6-6	Add CE 16x16 model description
6.4	6-8	Consistency: Fuel Assembly Class definition
6.4.1.3	6-10	Add CCs and CE 16x16 model assumptions
6.4.1.4	6-12	Correct the definition of uncertainty
6.4.2.1	6-13	CE 16x16 models and Class definition
6.4.2.2	6-14	Page Shift
6.4.2.2	6-15	Describe CE 16x16 models
6.4.2.3	6-16	Additional results for CE 14x14 with CCs
6.4.2.3	6-17	Additional results for CE 16x16 with and without CCs
6.4.2.4	6-18	Clarification for CE 14x14 / CE 16x16 models
6.4.2.4	6-19	Clarification for CE 14x14 / CE 16x16 models
6.4.2.4	6-20	Clarification for CE 14x14 / CE 16x16 models
6.4.2.5	6-21	CE 14x14 / CE 16x16 models / Fuel Assembly Class
6.4.2.6	6-22	Additional results for CE 14x14 and CE 16x16
6.4.3	6-23	Additional results for CE 14x14 and CE 16x16
6.5	6-24	Correction of Type for Code Version
6.5.2	6-25	Delete Reference
6.6	6-26	Update list of references
Table 6-1	2 pages	Modified to include new results (including an extra page)

Section #	Page #	Reason for Change
Table 6-2	1 page	Modified to include new results
Table 6-3	1 page	Modified to include new fuel data
Table 6-4		Modified to include new fuel data
Table 6-10	First Page	Modified to include new results
Table 6-19	1 page	Modified to include new results
Table 6-20	Last 2 Pages	Changed to Continued and add new page to include new results
Table 6-21	Last Page	Modified to include new results
Table 6-22	Last Page	Modified to include new results
Table 6-23	1 page	Modified to include new results
Table 6-24	1 page	Modified to include new results
Table 6-25	1 page	Moved to new page because of shift
Table 6-28	1 page	Modified to include new results
Table 6-29	1 page	Modified to include new results
Table 6-32	1 page	Modified to include new results
Table 6-33	2 pages	Modified Title
Table 6-34	3 pages	New Table for CE 14x14 results. Old data moved to Table 6-37
Table 6-35	4 pages	New Table for CE 16x16 results
Table 6-36	4 pages	New Table for CE 16x16 results
Table 6-37	3 pages	Data from Old Table 6-34
Table 6-38	4 pages	New Table for CE 14x14 results
Table 6-39	4 pages	New Table for CE 16x16 results
Table 6-40	4 pages	New Table for CE 16x16 results
Figure 6-14	1 page	Modified to show CE 14x14 model
Figure 6-20	1 page	New Figure for CE 16x16 models with BPRA
		Chapter 8
8.0	8-1	Use Helium only for blowdown
8.1.1.2	8-3	Use Helium only for blowdown
8.1.1.3	8-4	Add Step 7a for monitoring the TC annulus level and delete the temperature monitoring from Step 9; Use Helium only for blowdown
8.1.1.3	8-5	Use Helium only for blowdown; Delete Step 14 and move note to 13; Delete Step 17 – Not necessary with Step 7a
8.1.1.3	8-6	Delete Step 23 – not required with helium; Delete the temperature monitoring from Step 27
8.1.1.3	8-7	Add caution statement on time limits in step 29
8.2.2	8-12	Delete Nitrogen
Table 8-1	1 page	Delete Nitrogen
		Chapter 9
9.1.3	9-1	Change Welds to Weld Seams
9.1.7.2	9-4	Add requirements for MMC with Integral Cladding (Tech Spec)
9.5.3.1	9-9	Add requirements for MMC with Integral Cladding
		Chapter 12
12	12-1	Delete Amendment Number
		Chapter B12
B12.2	B12-1	Adds Control Components (CCs), Update Technical Specification (T/S) Reference (from 12.XX to XX) changes report to NRC to 60days.

Section #	Page #	Reason for Change
B12.3	B12-2	Changes SR and LCO number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-3	Changes SR and LCO number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-4	Changes SR and LCO number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-5	Changes SR number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-6	Changes SR number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-7	Changes SR number from 12.3.XX to 3.XX consistent with T/S
B12.3	B12-8	Changes SR and LCO number from 12.3.XX to 3.XX consistent with T/S, Add clarification to reference the T/S section 1.4
B12.3.1	B12-9	Provide Bases to T/S 3.1.1 using helium as the only draindown and DSC backfill medium.
B12.3.1	B12-10	Provide Bases to T/S 3.1.1 using helium as the only draindown and DSC backfill medium.
B12.3.1	B12-11	Provide Bases to T/S 3.1.2 using helium as the only draindown and DSC backfill medium.
B12.3.1	B12-12	Provide Bases to T/S 3.1.2 using helium as the only draindown and DSC backfill medium.
B12.3.1	B12-13	Provide Bases to T/S 3.1.3 for time limits for helium backfill of the TC annulus
B12.3.1	B12-14	Provide Bases to T/S 3.1.3 for time limits for helium backfill of the TC annulus
		Appendix A.3.9.1
A.3.9.1.3.2	A.3.9.1-8	Vacuum drying temperature / delete vacuum drying "procedures"
		Appendix A.3.9.2
3.9.2.2.4	A.3.9.2-10	delete vacuum drying "procedure C"
		Chapter A.8
A.8.1.1.2	A.8-4	Step 12, Use Helium only for blowdown
A.8.1.1.3	A.8-5	Add Step 7a for monitoring the TC annulus level and delete the temperature monitoring from Step 9; Use Helium only for blowdown; Delete Step 14 and move note to 13
A.8.1.1.3	A.8-6	Delete Step 17 – Not necessary with Step 7a
A.8.1.1.3	A.8-7	Delete Step 23 – not required with helium; Delete the temperature monitoring from Step 27; Add caution statement on time limits in step 29.
A.8.2.2	A.8-10	Delete Nitrogen

3.0 JUSTIFICATION OF CHANGES

Transnuclear, Inc. is in discussions with certain utilities who would need to use the provisions of this amendment in November 2008. Accordingly, TN requests that the staff assign a priority for review of this application consistent with that timing.

4.0 EVALUATION OF CHANGES

Change No. 1:

Addition of CE 16x16 class fuel assemblies as authorized contents of the NUHOMS® HD system does not affect the structural, shielding or confinement design functions of the system. A thermal evaluation is performed to essentially demonstrate that the effective conductivity of the CE 16x16 fuel is bounded by those of the WE 15x15 and/or WE 17x17 fuel assemblies, thereby necessitating no additional evaluation. The criticality evaluation is expanded to include the models with CE 16x16 fuel and to determine the maximum assembly average initial enrichment as a function of soluble boron concentration and fixed poison loading. The total weight of a CE 16x16 fuel assembly plus control components is enveloped by the bounding weight used in the existing structural analysis.

Change No. 2:

A reduction in the minimum temperature (off-normal ambient) does not affect shielding, criticality or confinement design functions of the system. A thermal evaluation is performed to demonstrate that the change is insignificant and has no impact on the thermal or structural design function.

Change No. 3:

TN has evaluated the changes to allow for the storage of CCs within the CE 14x14 and CE 16x16 class fuel assemblies. These changes do not affect the structural, thermal or confinement evaluations significantly, since the resulting configurations are bounded by the design basis configurations previously evaluated in the UFSAR. However, small changes to the various Chapters in the UFSAR and the Technical Specifications have been made to include this change (definitions, terminology and scope of CCs). The criticality evaluation is expanded to include the effect of CCs on these fuel designs and is documented in Chapter 6 of the UFSAR. The design basis gamma source term of the fuel assembly with control components is not modified due to the expanded definition of control components. Since, the total CC source term is part of the Technical Specification limits, no additional source term or shielding evaluation is necessary.

Change No. 4:

A reduction in the minimum enrichment of fuel assemblies does not affect the structural, thermal, criticality and confinement evaluations and only affects the fuel qualification and hence the shielding evaluation, more specifically, the source term evaluation. Small changes to various chapters in the UFSAR and the Technical Specifications have been made to include this change. The fuel qualification is performed to limit the burnup of this low enrichment fuel assembly such that the existing design basis fuel source terms remain bounding.

Change No. 5:

Reconstituted fuel assemblies were already included as authorized contents of the NUHOMS® HD system. Clarification/discussion is provided in Chapter 5 of the UFSAR to include the qualification of reconstituted fuel assemblies, including assemblies with irradiated stainless steel rods. Finally, the technical specifications changes for reconstituted fuel assemblies conservatively limit their total number to 4 per DSC. The limitations placed on the irradiated stainless steel rods and total number of irradiated rod assemblies assure that the design basis source term used in the existing shielding analysis is still bounding for these reconstituted fuel assemblies.

Change No. 6:

Currently, the specifications for MMCs include a maximum B_4C loading of 40% and a minimum density of 98% of theoretical density. For MMCs with integral aluminum cladding, the maximum B_4C loading is increased to 50% and the minimum density is reduced to 97% of theoretical density. The presence of integrated aluminum cladding provides additional protection to MMC. The loading requirements are consistent with the current requirements of other cladded poison materials like Boral®.

Change No. 7:

The requirement to use only helium for water removal from DSC and maintaining water level in the DSC/TC annulus during vacuum drying operations simplifies the operations by removing the time limit for vacuum drying operations and ensures complete adherence to the requirements of ISG-21 to prevent fuel oxidation. The thermal evaluations performed with Air and Nitrogen environments are bounding for helium and as required, this change is effected throughout the UFSAR. This change results in the use of only helium as a cover gas during blowdown operations and the elimination of all the previous vacuum drying "procedures." The requirements of helium backfill in the DSC/TC annulus are also clarified to be consistent with the thermal analyses in Chapter 4.

In addition, various corrections, clarifications and simplifications are effected that improves the readability of the UFSAR.

Enclosure 3 to TN E-25747

Proposed Changes to the NUHOMS® HD Technical Specifications, Amendment 0 and to the NUHOMS® HD System Updated Final Safety Analysis Report, Revision 1

APPENDIX A TO CERTIFICATE OF COMPLIANCE NO. 1030

NUHOMS® HD SYSTEM GENERIC TECHNICAL SPECIFICATIONS

Amendment 1

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List of Tables

List of Figures

1.0 USE AND APPLICATION

1.1 Definitions

-- NOTE --
The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
ACTIONS	ACTIONS shall be that part of a Specification that prescribes Required Actions to be taken under designated Conditions within specified Completion Times.
HORIZONTAL STORAGE MODULE (HSM-H)	The HSM-H is a reinforced concrete structure for storage of a loaded 32PTH DSC at a spent fuel storage installation.
DAMAGED FUEL ASSEMBLY	A DAMAGED FUEL ASSEMBLY is a fuel assembly with known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. *Fuel assemblies with damage greater than this can not be stored as damaged fuel assemblies.*
DRY SHIELDED CANISTER (32PTH DSC)	A 32PTH DSC is a welded pressure vessel that provides confinement of INTACT or DAMAGED FUEL ASSEMBLIES in an inert atmosphere.
INDEPENDENT SPENT FUEL STORAGE INSTALLATION (ISFSI)	The facility within a perimeter fence licensed for storage of spent fuel within HSM-Hs.
INTACT FUEL ASSEMBLY	Spent Nuclear Fuel Assemblies without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means.
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on a 32PTH DSC while it is being loaded with INTACT or DAMAGED FUEL ASSEMBLIES, and in a TRANSFER CASK while it is being loaded with a 32PTH DSC containing INTACT or DAMAGED FUEL ASSEMBLIES. LOADING OPERATIONS begin when the first INTACT or DAMAGED FUEL ASSEMBLY is placed in the 32PTH DSC and end when the TRANSFER CASK is ready for TRANSFER OPERATIONS.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI while a 32PTH DSC containing INTACT or DAMAGED FUEL ASSEMBLIES is located in an HSM-H on the storage pad within the ISFSI perimeter.

1.1 Definitions (continued)

TRANSFER CASK (TC)	The TRANSFER CASK consists of a licensed NUHOMS® OS187H onsite transfer cask. The TRANSFER CASK will be placed on a transfer trailer for movement of a 32PTH DSC to the HSM-H.
TRANSFER OPERATIONS	TRANSFER OPERATIONS include all licensed activities involving the movement of a TRANSFER CASK loaded with a 32PTH DSC containing INTACT or DAMAGED FUEL ASSEMBLIES. TRANSFER OPERATIONS begin when the TRANSFER CASK is placed *horizontal* on the transfer trailer *ready for TRANSFER* OPERATIONS and end when the 32PTH DSC is located in an HSM-H on the storage pad within the ISFSI perimeter.
UNLOADING OPERATIONS	UNLOADING OPERATIONS include all licensed activities on a 32PTH DSC to unload INTACT or DAMAGED FUEL ASSEMBLIES. UNLOADING OPERATIONS begin when the 32PTH DSC is removed from the HSM-H and end when the last INTACT or DAMAGED FUEL ASSEMBLY has been removed from the 32PTH DSC.

1.2 Logical Connectors

PURPOSE

The purpose of this section is to explain the meaning of logical connectors.

Logical connectors are used in Technical Specifications (TS) to discriminate between, and yet connect, Discrete Conditions, Required Actions, Completion Times, Surveillances, and Frequencies. The only logical connectors that appear in TS are AND and OR. The physical arrangement of these connectors constitutes logical conventions with specific meanings.

BACKGROUND

Several levels of logic may be used to state Required Actions. These levels are identified by the placement (or nesting) of the logical connectors and by the number assigned to each Required Action. The first level of logic is identified by the first digit of the number assigned to a Required Action and the placement of the logical connector in the first level of nesting (i.e., left justified with the number of the Required Action). The successive levels of logic are identified by additional digits of the Required Action number and by successive indentions of the logical connectors.

When logical connectors are used to state a Condition, Completion Time, Surveillance, or Frequency, only the first level of logic is used, and the logical connector is left justified with the statement of the Condition, Completion Time, Surveillance, or Frequency.

EXAMPLES

The following examples illustrate the use of logical connectors:

EXAMPLE 1.2-1

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO (Limiting Condition for Operation) not met.	A.1 Verify... AND A.2 Restore...	

In this example the logical connector AND is used to indicate that when in Condition A, both Required Actions A.1 and A.2 must be completed.

(continued)

1.2 Logical Connectors (continued)

EXAMPLES (continued)

EXAMPLE 1.2-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Stop... OR A.2 A.2.1 Verify... AND A.2.2 A.2.2.1 Reduce... OR A.2.2.2 Perform... OR A.3 Remove...	

This example represents a more complicated use of logical connectors. Required Actions A.1, A.2, and A.3 are alternative choices, only one of which must be performed as indicated by the use of the logical connector OR and the left justified placement. Any one of these three Actions may be chosen. If A.2 is chosen, then both A.2.1 and A.2.2 must be performed as indicated by the logical connector AND. Required Action A.2.2 is met by performing A.2.2.1 or A.2.2.2. The indented position of the logical connector OR indicates that A.2.2.1 and A.2.2.2 are alternative choices, only one of which must be performed.

1.3 Completion Times

PURPOSE	The purpose of this section is to establish the Completion Time convention and to provide guidance for its use.
BACKGROUND	Limiting Conditions for Operation (LCOs) specify the lowest functional capability or performance levels of equipment required for safe operation of the facility. The ACTIONS associated with an LCO state Conditions that typically describe the ways in which the requirements of the LCO are not met. Specified with each stated Condition are Required Action(s) and Completion Times(s).
DESCRIPTION	The Completion Time is the amount of time allowed for completing a Required Action. It is referenced to the time of discovery of a situation (e.g., equipment or variable not within limits) that requires entering an ACTIONS Condition unless otherwise specified, providing the facility is in a specified condition stated in the Applicability of the LCO. Required Actions must be completed prior to the expiration of the specified Completion Time. An ACTIONS Condition remains in effect and the Required Actions apply until the Condition no longer exists or the facility is not within the LCO Applicability. Once a Condition has been entered, subsequent subsystems, components, or variables expressed in the Condition, discovered to be not within limits, will not result in separate entry into the Condition unless specifically stated. The Required Actions of the Condition continue to apply to each additional failure, with Completion Times based on initial entry into the Condition.

(continued)

1.3 Completion Times (continued)

EXAMPLES

The following examples illustrate the use of Completion Times with different types of Conditions and Changing Conditions.

EXAMPLE 1.3-1

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1 AND B.2 Perform Action B.2	12 hours 36 hours

Condition B has two Required Actions. Each Required Action has its own separate Completion Time. Each Completion Time is referenced to the time that Condition B is entered.

The Required Actions of Condition B are to complete action B.1 within 12 hours AND complete action B.2 within 36 hours. A total of 12 hours is allowed for completing action B.1 and a total of 36 hours (not 48 hours) is allowed for completing action B.2 from the time that Condition B was entered. If action B.1 is completed within 6 hours, the time allowed for completing action B.2 is the next 30 hours because the total time allowed for completing action B.2 is 36 hours.

EXAMPLES

EXAMPLE 1.3-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One system not within limit.	A.1 Restore system to within limit.	7 days
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	12 hours 36 hours

When a system is determined to not meet the LCO, Condition A is entered. If the system is not restored within 7 days, Condition B is also entered and the Completion Time clocks for Required Actions B.1 and B.2 start. If the system is restored after Condition B is entered, Condition A and B are exited, and therefore, the Required Actions of Condition B may be terminated.

(continued)

1.3 Completion Times (continued)

EXAMPLES (continued)

EXAMPLE 1.3-3

ACTIONS

------------------------NOTE------------------------

Separate Condition entry is allowed for each component.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Restore compliance with LCO.	4 hours
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	6 hours 12 hours

The Note above the ACTIONS Table is a method of modifying how the Completion Time is tracked. If this method of modifying how the Completion Time is tracked was applicable only to a specific Condition, the Note would appear in that Condition rather than at the top of the ACTIONS Table.

The Note allows Condition A to be entered separately for each component, and Completion Times tracked on a per component basis. When a component is determined to not meet the LCO, Condition A is entered and its Completion Time starts. If subsequent components are determined to not meet the LCO, Condition A is entered for each component and separate Completion Times start and are tracked for each component.

IMMEDIATE COMPLETION TIME

When "Immediately" is used as a Completion Time, the Required Action should be pursued without delay and in a controlled manner.

1.4 Frequency

PURPOSE	The purpose of this section is to define the proper use and application of Frequency requirements
DESCRIPTION	Each Surveillance Requirement (SR) has a specified Frequency in which the Surveillance must be met in order to meet the associated Limiting Condition for Operation (LCO). An understanding of the correct application of the specified Frequency is necessary for compliance with the SR. The "Specified Frequency" is referred to throughout this section and each of the Specifications of Section 3.0, Limiting Condition for Operation (LCO) and Surveillance Requirement (SR) Applicability. The "Specified Frequency" consists of the requirements of the Frequency column of each SR, as well as certain Notes in the Surveillance column that modify performance requirements. Situations where a Surveillance could be required (i.e., its Frequency could expire), but where it is not possible or not desired that it be performed until sometime after the associated LCO is within its Applicability, represent potential SR 3.0.4 conflicts. To avoid these conflicts, the SR (i.e., the Surveillance or the Frequency) is stated such that it is only "required" when it can be and should be performed. With a SR satisfied, SR 3.0.4 imposes no restriction. (continued)

1.4 Frequency (continued)

EXAMPLES (continued)

The following examples illustrate the various ways that Frequencies are specified:

EXAMPLE 1.4-1

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify pressure within limit.	12 hours

Example 1.4-1 contains the type of SR most often encountered in the Technical Specifications (TS). The Frequency specifies an interval (12 hours) during which the associated Surveillance must be performed at least one time. Performance of the Surveillance initiates the subsequent interval. Although the Frequency is stated as 12 hours, an extension of the time interval to 1.25 times the stated Frequency is allowed by SR 3.0.2 for operational flexibility. The measurement of this interval continues at all times, even when the SR is not required to be met per SR 3.0.1 (such as when the equipment is determined to not meet the LCO, a variable is outside specified limits, or the unit is outside the Applicability of the LCO). If the interval specified by SR 3.0.2 is exceeded while the facility is in a condition specified in the Applicability of the LCO, the LCO is not met in accordance with SR 3.0.1.

If the interval as specified by SR 3.0.2 is exceeded while the facility is not in a condition specified in the Applicability of the LCO for which performance of the SR is required, the Surveillance must be performed within the Frequency requirements of SR 3.0.2 prior to entry into the specified condition. Failure to do so would result in a violation of SR 3.0.4.

(continued)

1.4 Frequency (continued)

EXAMPLES (continued)

EXAMPLE 1.4-2

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify flow is within limits.	Once within 12 hours prior to starting activity AND 24 hours thereafter

Example 1.4-2 has two Frequencies. The first is a one-time performance Frequency, and the second is of the type shown in Example 1.4-1. The logical connector "AND" indicates that both Frequency requirements must be met. Each time the example activity is to be performed, the Surveillance must be performed prior to starting the activity.

The use of "once" indicates a single performance will satisfy the specified Frequency (assuming no other Frequencies are connected by "AND"). This type of Frequency does not qualify for the 25% extension allowed by SR 3.0.2.

"Thereafter" indicates future performances must be established per SR 3.0.2, but only after a specified condition is first met (i.e., the "once" performance in this example). If the specified activity is canceled or not performed, the measurement of both intervals stops. New intervals start upon preparing to restart the specified activity.

(continued)

1.4 Frequency (continued)

EXAMPLES (continued)

EXAMPLE 1.4-3

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
-------------------- NOTE -------------------- *Not required to be met until 96 hours after verifying the helium leak rate is within limit.*	Once after verifying the helium leak rate is within limit.
Verify 32PTH DSC vacuum drying pressure is within limit.	

As the Note modifies the required performance of the Surveillance, it is construed to be part of the "specified Frequency." Should the vacuum drying pressure not be met immediately following verification of the helium leak rate while in LOADING OPERATIONS, this Note allows 96 hours to perform the Surveillance. The Surveillance is still considered to be performed within the "specified Frequency."

Once the helium leak rate has been verified to be acceptable, 96 hours, plus the extension allowed by SR 3.0.2, would be allowed for completing the Surveillance for the vacuum drying pressure. If the Surveillance was not performed within this 96 hour interval, there would then be a failure to perform the Surveillance within the specified Frequency, and the provisions of SR 3.0.3 would apply.

2.0 FUNCTIONAL AND OPERATING LIMITS

2.1 Fuel to be Stored in the 32PTH DSC

Physical Parameters:	
Fuel Class	*Intact or damaged Westinghouse 17x17 (WE 17x17), Westinghouse 15x15 (WE 15x15), Combustion Engineering 16x16 (CE 16x16) and Combustion Engineering 14x14 (CE 14x14) class PWR assemblies (with or without control components) that are enveloped by the fuel assembly design characteristics listed in Table 2. Reload fuel manufactured by the same or other vendors but bounded by the design characteristics listed in Table 2 is also acceptable.*
Reconstituted Fuel Assemblies:	
• *Maximum No. of Reconstituted Assemblies per DSC With Irradiated Stainless Steel Rods*	*4*
• *Maximum No. of Irradiated Stainless Steel Rods per Reconstituted Fuel Assembly*	*10*
• *Maximum No. of Reconstituted Assemblies per DSC with unlimited number of low enriched UO_2 rods, or Zr Rods or Zr Pellets or Unirradiated Stainless Steel Rods*	*32*
Control Components (CCs)	• *Up to 32 CCs are authorized for storage in 32PTH DSC.* • *Authorized CCs include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies (TPAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster Control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs) and Neutron Sources.* • *Design basis thermal and radiological characteristics for the CCs are listed in Table 3.*
No. of Intact Assemblies	*≤ 32*

No. and Location of Damaged Assemblies	*Up to 16 damaged fuel assemblies with balance intact fuel assemblies, or dummy assemblies are authorized for storage in 32PTH DSC.* *Damaged fuel assemblies are to be placed in the center 16 locations as shown in Figure 1. The DSC basket cells which store damaged fuel assemblies are provided with top and bottom end caps to assure retrievability.*
Maximum Assembly plus CC Weight	*1585 lbs*
<u>THERMAL/RADIOLOGICAL PARAMETERS:</u> *Burnup, Enrichment, and Minimum Cooling Time for the 32PTH DSC*	*Per Table 4*
Maximum Assembly Average Initial Fuel Enrichment	*5.0 wt. % U-235*
Maximum Decay Heat Limits for Heat Load Zones 1a, 1b, 2 and 3 fuel.	*Per Figure 2*
Decay Heat per DSC	*≤ 34.8 kW for WE 15x15, WE 17x17 and CE 16x16 class fuel assemblies*
	≤ 33.8 kW for CE 14x14 class fuel assemblies

2.2 Functional and Operating Limits Violations

If any Functional and Operating Limit of 2.1 is violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within *60* days, submit a special report which describes the cause of the violation and the actions taken to restore compliance and prevent recurrence.

3.0 LIMITING CONDITION FOR OPERATION (LCO) AND SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

LCO 3.0.1	LCOs shall be met during specified conditions in the Applicability, except as provided in LCO 3.0.2.
LCO 3.0.2	Upon discovery of a failure to meet an LCO, the Required Actions of the associated Conditions shall be met, except as provided in LCO 3.0.5. If the LCO is met or is no longer applicable prior to expiration of the specified Completion Time(s), completion of the Required Action(s) is not required, unless otherwise stated.
LCO 3.0.3	Not applicable to a spent fuel storage cask.
LCO 3.0.4	When an LCO is not met, entry into a specified condition in the Applicability shall not be made except when the associated ACTIONS to be entered permit continued operation in the specified condition in the Applicability for an unlimited period of time. This Specification shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS, or that are related to the unloading of a 32PTH DSC. Exceptions to this Specification are stated in the individual Specifications. These exceptions allow entry into specified conditions in the Applicability when the associated ACTIONS to be entered allow operation in the specified condition in the Applicability only for a limited period of time.
LCO 3.0.5	Equipment removed from service or not in service in compliance with ACTIONS may be returned to service under administrative control solely to perform testing required to demonstrate it meets the LCO or that other equipment meets the LCO. This is an exception to LCO 3.0.2 for the system returned to service under administrative control to perform the testing required to demonstrate that the LCO is met.
LCO 3.0.6	Not applicable to a spent fuel storage cask.
LCO 3.0.7	Not applicable to a spent fuel storage cask.

(continued)

3.0 Limiting Condition for Operation (LCO) and Surveillance Requirement (SR) Applicability (continued)

SR 3.0.1	SRs shall be met during the specified conditions in the Applicability for individual LCOs, unless otherwise stated in the SR. Failure to meet a Surveillance, whether such failure is experienced during the performance of the Surveillance or between performances of the Surveillance, shall be failure to meet the LCO. Failure to perform a Surveillance within the specified Frequency shall be failure to meet the LCO except as provided in SR 3.0.3. Surveillances do not have to be performed on equipment or variables outside specified limits.
SR 3.0.2	The specified Frequency for each SR is met if the Surveillance is performed within 1.25 times the interval specified in the Frequency, as measured from the previous performance or as measured from the time a specified condition of the Frequency is met. For Frequencies specified as "once," the above interval extension does not apply. If a Completion Time requires periodic performance on a "once per . . ." basis, the above Frequency extension applies to each performance after the initial performance. Exceptions to this Specification are stated in the individual Specifications.
SR 3.0.3	If it is discovered that a Surveillance was not performed within its specified Frequency, then compliance with the requirement to declare the LCO not met may be delayed, from the time of discovery, up to 24 hours or up to the limit of the specified Frequency, whichever is less. This delay period is permitted to allow performance of the Surveillance. If the Surveillance is not performed within the delay period, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered. When the Surveillance is performed within the delay period and the Surveillance is not met, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.
SR 3.0.4	Entry into a specified condition in the Applicability of an LCO shall not be made unless the LCO's Surveillances have been met within their specified Frequency. This provision shall not prevent entry into specified conditions in the Applicability that are required to comply with ACTIONS or that are related to the unloading of a 32PTH DSC.

3.1 DSC Fuel Integrity

3.1.1 DSC Bulkwater Removal Medium and Vacuum Drying Pressure

LCO 3.1.1	*Medium:* *Helium shall be used for cover gas during drainage of bulk water (blowdown or draindown) from the DSC.* *Pressure:* *The DSC vacuum drying pressure shall be sustained at or below 3 Torr (3 mm Hg) absolute for a period of at least 30 minutes following evacuation.*
APPLICABILITY:	*During LOADING OPERATIONS but before TRANSFER OPERATIONS.*

3.1 DSC Fuel Integrity (continued)

ACTIONS

-----------------------------------NOTE---
This specification is applicable to all 32PTH DSCs.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. If the required vacuum pressure cannot be obtained.	*A.1* *A.1.1 Confirm that the vacuum drying system is properly installed. Check and repair the vacuum drying system as necessary.* *<u>OR</u>* *A.1.2 Establish helium pressure of at least 0.5 atm and no greater than 15 psig in the DSC.*	*30 days*
	<u>OR</u> *A.2 Flood the DSC with spent fuel pool water or water meeting the requirements of LCO 3.2.1 if applicable submerging all fuel assemblies.*	*30 days*

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1	Verify that the 32PTH DSC vacuum pressure is less than, or equal to, 3 Torr (3 mm Hg) absolute for at least 30 minutes *following evacuation.*	Once per 32PTH DSC, after an acceptable NDE of the inner top cover/shield plug *assembly to DSC shell* weld.

3.1 *Fuel Integrity (continued)*

3.1.2 32PTH DSC Helium Backfill Pressure

LCO 3.1.2 32PTH DSC helium backfill pressure shall be 2.5 ± 1 psig (stable for 30 minutes after filling) after completion of vacuum drying.

APPLICABILITY: During LOADING OPERATIONS *but before TRANSFER OPERATIONS.*

ACTIONS

-- NOTE --

This specification is applicable to all 32PTH DSCs.

CONDITION	REQUIRED ACTION	COMPLETION TIME
------------------ *NOTE* ------------------ *Not applicable until SR 3.1.2 is performed.* A. The required backfill pressure cannot be obtained or stabilized.	*A.1* *A.1.1 Maintain helium atmosphere in the DSC cavity.* *AND* *A.1.2 Confirm, check and repair or replace as necessary the vacuum drying system, helium source and pressure gauge.*	*14 days*
	OR *A.2 Establish the DSC helium backfill pressure to within the limit. If pressure exceeds the criterion, release a sufficient quantity of helium to lower the DSC cavity pressure within the limit.*	*14 days*

(continued)

	<u>*OR*</u> *A.3* *Flood the DSC with spent fuel pool water or water meeting the requirements of LCO 3.2.1 if applicable submerging all fuel assemblies.*	*14 days*

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2	Verify that the 32PTH DSC helium backfill pressure is 2.5 ± 1 psig *stable for 30 minutes after filling.*	Once per 32PTH DSC, after the completion of *SR* 3.1.1 *requirement.*

3.1 *Fuel Integrity (continued)*

3.1.3 Transfer Cask Cavity Helium Backfill Pressure

LCO 3.1.3 *Duration: OS187H transfer cask cavity / annulus helium backfill shall be initiated within 28 hours after drainage of TC cavity / annulus water during LOADING OPERATIONS* *OR* *after retracting the DSC into TC during UNLOADING OPERATIONS.*

APPLICABILITY: During LOADING, *TRANSFER* and UNLOADING OPERATIONS.

ACTIONS

-- NOTE --

This specification is applicable to all 32PTH DSCs/OS187H TC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. The transfer cask cavity/ annulus helium backfill cannot be initiated within *26 hours after drainage of TC cavity / annulus water* during *LOADING OPERATIONS* OR within *26* hrs of retracting the DSC into the TC during *UNLOADING OPERATIONS.* --------------------NOTE-------------------- *Not applicable until SR 3.1.3.1 or 3.1.3.2 is performed.* --	A.1 Flood the TC cavity/annulus with water	2 hours
B. The required backfill pressure cannot be obtained or stabilized.	B.1 Establish the TC cavity/annulus helium backfill pressure to within the limit. OR B.2 Flood the TC cavity/annulus with water.	18 hours 18 hours

3.1 *Fuel Integrity (concluded)*

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.3.*1*	Verify that the OS187H cavity/annulus helium backfill pressure is 2.0 ± 1 psig, stable for 30 minutes after filling. <u>OR</u>	*If SR 3.1.3.1 is used, then* once per 32PTH DSC, after the completion of *SR* 3.1.2 *requirements and* after the installation of the TC lid.
SR 3.1.3.2	Monitor the OS187H cavity/annulus pressure during transfer operation to verify it does not drop below 1.0 psig.	*If SR 3.1.3.2 is used then every 4 hours during TRANSFER and UNLOADING OPERATIONS.*

3.2 Cask Criticality Control

LCO 3.2.1 The dissolved boron concentration of the spent fuel pool water and the water added to the cavity of a loaded DSC shall be at least the boron concentration shown in Table 7 for the basket type and fuel enrichment selected.

APPLICABILITY: During LOADING and UNLOADING OPERATIONS *with fuel and liquid water in the DSC cavity.*

ACTIONS

------------------------------------ NOTE ------------------------------------

This specification is applicable to all 32PTH DSCs/OS187H TC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Dissolved boron concentration limit not met.	A.1 Suspend loading of fuel assemblies into DSC AND *A.2* *A.2.1 Add boron and re-sample, and test the concentration until the boron concentration is shown to be greater than that required* *OR* *A.2.2 Remove all fuel assemblies from DSC*	Immediately *Immediately* *Immediately*

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.2.1	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the DSC cavity is met using two independent measurements.	Within 4 hours prior to commencing LOADING OPERATIONS AND 48 hours thereafter while the DSC is in the spent fuel pool or while water is in the DSC.

SR 3.2.2	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the DSC cavity is met using two independent measurements.	Once within 4 hours prior to flooding DSC during UNLOADING OPERATIONS AND 48 hours thereafter while the DSC is in the spent fuel pool or while water is in the DSC.

4.0 DESIGN FEATURES

The specifications in this section include the design characteristics of special importance to each of the physical barriers and to maintenance of safety margins in the NUHOMS® HD System design. The principal objective of this section is to describe the design envelope that may constrain any physical changes to essential equipment. Included in this section are the site environmental parameters that provide the bases for design, but are not inherently suited for description as LCOs.

4.1 Site

4.1.1 Site Location

Because this FSAR is prepared for a general license, a discussion of a site-specific ISFSI location is not applicable.

4.2 Storage System Features

4.2.1 Storage Capacity

The total storage capacity of the ISFSI is governed by the plant-specific license conditions.

4.2.2 Storage Pad

For sites for which soil-structure interaction is considered important, the licensee is to perform site-specific analysis considering the effects of soil-structure interaction. Amplified seismic spectra at the location of the HSM-H center of gravity (CG) is to be developed based on the SSI responses. HSM-H seismic analysis information is provided in FSAR Appendix 3.9.9.10.2.

The storage pad location shall have no potential for liquefaction at the site-specific SSE level earthquake.

Additional requirements for the pad configuration are provided in Section 4.6.2.

(continued)

4.0 Design Features (continued)

4.3 Canister Criticality Control

The NUHOMS®-32PTH is designed for unirradiated fuel with an assembly average initial enrichment of less than or equal to 5.0 wt. % U-235 taking credit for soluble boron in the DSC cavity water during loading operations and the boron content in the poison plates of the DSC basket. The 32PTH DSC has multiple basket configurations, based on the material type and boron content in the poison plates, as listed in Table 6. Table 7 defines the requirements for boron concentration in the DSC cavity water as a function of the DSC basket type for the various intact and damaged fuel classes (most reactive) authorized for storage in the 32PTH DSC.

A Type I basket contains poison plates that are either borated aluminum or MMC while a Type II basket contains Boral® poison plates. The basket types are further defined by the B-10 areal density in the plates, ranging from the lowest, Type A to the highest, Type E.

4.3.1 Neutron Absorber Tests

Borated Aluminum, MMCs, or Boral® shall be supplied in accordance with FSAR Sections 9.1.7.1, 9.1.7.2, 9.1.7.3, 9.5.2, 9.5.3.5 and 9.5.4.3, with the minimum B10 areal density specified in Table 6. These sections of the FSAR are hereby incorporated into the NUHOMS® HD CoC.

4.4 Codes and Standards

4.4.1 Horizontal Storage Module (HSM-H)

The reinforced concrete HSM-H is designed to meet the requirements of ACI 349-97. Load combinations specified in ANSI 57.9-1984, Section 6.17.3.1 are used for combining normal operating, off-normal, and accident loads for the HSM-H.

If an independent spent fuel storage installation site is located in a coastal salt water marine atmosphere, then any load-bearing carbon steel DSC support structure rail components of any associated HSM-H shall be procured with a minimum 0.20 percent copper content for corrosion resistance.

4.4.2 Dry Shielded Canister (32PTH DSC)

The 32PTH DSC is designed, fabricated and inspected to the maximum practical extent in accordance with ASME Boiler and Pressure Vessel Code Section III, Division 1, 1998 Edition with Addenda through 2000, Subsections NB, NF, and NG for Class 1 components and supports. Code alternatives are discussed in 4.4.4.

4.4.3 Transfer Cask (OS187H)

The OS187H Transfer Cask is designed, fabricated and inspected to the maximum practical extent in accordance with ASME Boiler and Pressure Vessel Code Section III, 1998 Edition with Addenda through 2000, Subsection NC for Class 2 vessels.

4.4.4 Alternatives to Codes and Standards

ASME Code alternatives for the 32PTH DSC are listed below:

DSC ASME Code Alternatives, Subsection NB

Reference ASME Code Section/Article	Code Requirement	Justification & Compensatory Measures
NCA	All	Not compliant with NCA
NB-1100	Requirements for Code Stamping of Components	The canister shell, the inner top cover/shield plug, the inner bottom cover, and the siphon/vent port cover are designed & fabricated in accordance with the ASME Code, Section III, Subsection NB to the maximum extent practical. However, Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME "N" or "NPT" stamp, or to be ASME Certified.
NB-2130 NB-4121	Material must be supplied by ASME approved material suppliers Material Certification by Certificate Holder	Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NB-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program.
NB-4243 and NB-5230	Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints. These welds shall be examined by UT or RT and either PT or MT.	The shell to the outer top cover weld, the shell to the inner top cover/shield plug weld (including option 2 or option 3 inner top cover as described in the FSAR), and the siphon/vent cover welds, are all partial penetration welds. As an alternative to the NDE requirements of NB-5230, for Category C welds, all of these closure welds will be multi-layer welds and receive a root and final PT examination, except for the shell to the outer top cover weld. The shell to the outer top cover weld will be a multi-layer weld and receive multi-level PT examination in accordance with the guidance provided in ISG-15 for NDE. The multi-level PT examination provides reasonable assurance that flaws of interest will be identified. The PT examination is done by qualified personnel, in accordance with Section V and the acceptance standards of Section III, Subsection NB-5000. All of these welds will be designed to meet the guidance provided in ISG-15 for stress reduction factor.
NB-2531	Vent & siphon Port Cover; straight beam UT per SA-578 for all plates for vessel	SA-578 applies to 3/8" and thicker plate only; allow alternate UT techniques to achieve meaningful UT results.

DSC ASME Code Alternatives, Subsection NB (concluded)

Reference ASME Code Section/Article	Code Requirement	Justification & Compensatory Measures
NB-6000	All completed pressure retaining systems shall be pressure tested	The 32PTH is not a complete or "installed" pressure vessel until the top closure is welded following placement of Fuel Assemblies within the DSC. Due to the inaccessibility of the shell and lower end closure welds following fuel loading and top closure welding, as an alternative, the pressure testing of the DSC is performed in two parts. The DSC shell, shell bottom, including all longitudinal and circumferential welds, is pneumatically tested and examined at the fabrication facility. The shell to the inner top cover/shield plug closure weld (including option 2 or option 3 inner top cover as described in the FSAR) are pressure tested and examined for leakage in accordance with NB-6300 in the field. The siphon/vent cover welds will not be pressure tested; these welds and the shell to the inner top cover/shield plug closure weld (including option 2 or option 3 inner top cover as described in the FSAR) are helium leak tested after the pressure test. Per NB-6324 the examination for leakage shall be done at a pressure equal to the greater of the Design pressure or three-fourths of the test pressure. As an alternative, if the examination for leakage of these field welds, following the pressure test, is performed using helium leak detection techniques, the examination pressure may be reduced to 1.5 psig. This is acceptable given the significantly greater sensitivity of the helium leak detection method.
NB-7000	Overpressure Protection	No overpressure protection is provided for the 32PTH DSC. The function of the 32PTH DSC is to contain radioactive materials under normal, off-normal, and hypothetical accident conditions postulated to occur during transportation. The 32PTH DSC is designed to withstand the maximum internal pressure considering 100% fuel rod failure at maximum accident temperature. The 32PTH DSC is pressure tested in accordance with the requirements of 10CFR71 and TN's approved QA program.
NB-8000	Requirements for nameplates, stamping & reports per NCA-8000	The 32PTH DSC nameplates provide the information required by 10CFR71, 49CFR173, and 10CFR72 as appropriate. Code stamping is not required for the 32PTH DSC. QA Data packages are prepared in accordance with the requirements of 10CFR71, 10CFR72, and TN's approved QA program.
NB-1132	Attachments with a pressure retaining function, including stiffeners, shall be considered part of the component.	Outer bottom cover, bottom plate, bottom casing plate, side casing plate, top shield plug casing plate, lifting posts, grapple ring and grapple ring support are outside code jurisdiction; these components together are much larger than required to provide stiffening for the confinement boundary cover. These component welds are subject to root and final PT examinations.

Basket ASME Code Alternatives, Subsection NG/NF

Reference ASME Code Section/Article	Code Requirement	Justification & Compensatory Measures
NCA	All	Not compliant with NCA
NG/NF-1100	Requirements for Code Stamping of Components	The 32PTH DSC baskets are designed & fabricated in accordance with the ASME Code, Section III, Subsection NG to the maximum extent practical as described in the FSAR, but Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME N or NPT stamp or be ASME Certified.
NG/NF-2130 NG/NF-4121	Material must be supplied by ASME approved material suppliers Material Certification by Certificate Holder	Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NG/NF-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program. The poison material and aluminum plates are not used for structural analysis, but to provide criticality control and heat transfer. They are not ASME Code Class I materials. See note 1.
NG/NF-8000	Requirements for nameplates, stamping & reports per NCA-8000	The 32PTH DSC nameplates provide the information required by 10CFR71, 49CFR173, and 10CFR72 as appropriate. Code stamping is not required for the 32PTH DSC. QA Data packages are prepared in accordance with the requirements of 10CFR71, 10CFR72, and TN's approved QA program.

Notes: 1. Because Subsection NCA does not apply, the NCA-3820 requirements for accreditation or qualification of material organizations do not apply. CMTR's shall be provided using NCA- 3862 for guidance.

Proposed alternatives to the ASME code, other than the aforementioned ASME Code alternatives may be used when authorized by the Director of the Office of Nuclear Material Safety and Safeguards, or designee. The applicant should demonstrate that:

1. The proposed alternatives would provide an acceptable level of quality and safety, or

2. Compliance with the specified requirements of ASME Code, Section III, 1998 Edition with Addenda through 2000 would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for exceptions in accordance with this section should be submitted in accordance with 10CFR 72.4.

4.0 Design Features (continued)

4.5 HSM-H Side Heat Shields

The HSM-H utilizes side heat shields to protect the HSM-H concrete surfaces and provide for enhanced heat transfer within the HSM-H. Three side heat shield configurations have been evaluated in the FSAR: finned anodized aluminum, flat (unfinned) anodized aluminum, and flat (unfinned) galvanized steel. Heat load limits for these three heat shield configurations and material types are established at 34.8 kW, 32.0 kW, and 26.1 kW per DSC, respectively. Alternate heat shield material types and configurations may be evaluated using the HSM-H thermal performance methodology described in the FSAR.

4.6 Storage Location Design Features

The following storage location design features and parameters shall be verified by the system user to assure technical agreement with this FSAR.

4.6.1 <u>Storage Configuration</u>

HSM-Hs are placed together in single rows or back to back arrays. An end shield wall is placed on the outside end of any loaded outside HSM-H. A rear shield wall is placed on the rear of any single row loaded HSM-H.

4.6.2 <u>Concrete Storage Pad Properties to Limit 32PTH DSC Gravitational Loadings Due to Postulated Drops</u>

The TC/32PTH DSC has been evaluated for drops of up to 80 inches onto a reinforced concrete storage pad. The evaluations are based on the concrete parameters specified in EPRI Report NP-7551, "Structural Design of Concrete Storage Pads for Spent Fuel Casks," August 1991.

(continued)

4.0 Design Features (con*cluded*)

4.6.3 Site Specific Parameters and Analyses

The following parameters and analyses shall be verified by the system user for applicability at their specific site. Other natural phenomena events, such as lightning, tsunamis, hurricanes, and seiches, are site specific and their effects are generally bounded by other events, but they should be evaluated by the user.

1. Tornado maximum wind speeds: 290 mph rotational
   70 mph translational

2. Flood levels up to 50 ft. and water velocity of 15 fps.

3. One-hundred year roof snow load of 110 psf.

4. Normal ambient temperatures of 0°F to 100°F.

5. Off-normal ambient temperature range of –21°F without solar insolation to 115°F with full solar insolation.

6. The potential for fires and explosions shall be addressed, based on site-specific considerations.

7. Supplemental Shielding: In cases where engineered features (i.e., berms, shield walls) are used to ensure that the requirements of 10CFR 72.104(a) are met, such features are to be considered important to safety and must be evaluated to determine the applicable Quality Assurance Category.

8. Seismic loads of up to 0.30g horizontal and up to 0.20g vertical.

5.0 ADMINISTRATIVE CONTROLS

5.1 Procedures

Each user of the NUHOMS® HD System will prepare, review, and approve written procedures for all normal operations, maintenance, and testing at the ISFSI prior to its operation. Written procedures shall be established, implemented, and maintained covering the following activities that are important to safety:

- Organization and management
- Routine ISFSI operations
- Alarms and annunciators
- Emergency operations
- Design control and facility change/modification
- Control of surveillances and tests
- Control of special processes
- Maintenance
- Health physics, including ALARA practices
- Special nuclear material accountability
- Quality assurance, inspection, and audits
- Physical security and safeguards
- Records management
- Reporting
- All programs specified in Section 5.2

5.2 Programs

Each user of the NUHOMS® HD System will implement the following programs to ensure the safe operation and maintenance of the ISFSI:

- Safety Review Program
- Training Program
- Radiological Environmental Monitoring Program
- Radiation Protection Program
- HSM-H Thermal Monitoring Program

5.2.1 Safety Review Program

Users shall conduct safety reviews in accordance with 10CFR 72.48 to determine whether proposed changes, tests, and experiments require NRC approval before implementation. Changes to the Technical Specification Bases and other licensing basis documents will be conducted in accordance with approved administrative procedures.

Changes may be made to Technical Specification Bases and other licensing basis documents without prior NRC approval, provided the changes meet the criteria of 10CFR 72.48.

The safety review process will contain provisions to ensure that the Technical Specification Bases and other licensing basis documents are maintained consistent with the FSAR.

Proposed changes that do not meet the criteria above will be reviewed and approved by the NRC before implementation. Changes to the Technical Specification Bases implemented without prior NRC approval will be provided to the NRC in accordance with 10CFR 72.48.

(continued)

5.2 Programs (continued)

5.2.2 Training Program

Training modules shall be developed as required by 10CFR 72. Training modules shall require a comprehensive program for the operation and maintenance of the NUHOMS® HD System and the independent spent fuel storage installation (ISFSI). The training modules shall include the following elements, at a minimum:

- NUHOMS® HD System design (overview)
- ISFSI Facility design (overview)
- Systems, Structures, and Components Important to Safety (overview)
- NUHOMS® HD System Final Safety Analysis Report (overview)
- NRC Safety Evaluation Report (overview)
- Certificate of Compliance conditions
- NUHOMS® HD System Technical Specifications
- Applicable Regulatory Requirements (e.g.,10CFR 72, Subpart K, 10CFR 20, 10 CFR Part 73)
- Required Instrumentation and Use
- Operating Experience Reviews
- NUHOMS® HD System and Maintenance procedures, including:
  - Fuel qualification and loading,
  - Rigging and handling,
  - Loading Operations as described in Chapter 8 of the FSAR,
  - Unloading Operations including reflooding,
  - Auxiliary equipment operations and maintenance (i.e., welding operations, vacuum drying, helium backfilling and leak testing, reflooding),
  - Transfer operations including loading and unloading of the Transfer Vehicle,
  - ISFSI Surveillance operations,
  - Radiation Protection,
  - Maintenance, as described in Section 9.2 of the FSAR,
  - Security, and
  - Off-normal and accident conditions, responses and corrective actions.

5.2.3 Radiological Environmental Monitoring Program

a) A radiological environmental monitoring program will be implemented to ensure that the annual dose equivalent to an individual located outside the ISFSI controlled area does not exceed the annual dose limits specified in 10CFR 72.104(a).

b) Operation of the ISFSI will not create any radioactive materials or result in any credible liquid or gaseous effluent release.

(continued)

5.2 Programs (continued)

5.2.4 Radiation Protection Program

The Radiation Protection Program will establish administrative controls to limit personnel exposure to As Low As Reasonably Achievable (ALARA) levels in accordance with 10CFR Part 20 and Part 72.

a) As part of its evaluation pursuant to 10CFR 72.212, the licensee shall perform an analysis to confirm that the limits of 10CFR 20 and 10CFR 72.104 will be satisfied under the actual site conditions and configurations considering the planned number of 32PTH DSCs to be used and the planned fuel loading conditions.

b) A monitoring program to ensure the annual dose equivalent to any real individual located outside the ISFSI controlled area does not exceed regulatory limits is incorporated as part of the environmental monitoring program in the Radiological Environmental Monitoring Program of Section 5.2.3.

c) Following completion of the welding of 32PTH DSC inner top cover/shield plug, siphon and vent cover plates, these welds are leak tested to demonstrate that these welds meet the "leak-light" criterion ($\leq 1.0 \times 10^{-7}$ reference cm^3/sec) as defined in "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials," ANSI N14.5-1997. If the leakage rate exceeds 1.0×10^{-7} reference cm^3/sec, check and repair these welds.

This specification ensures that an inert helium atmosphere will be maintained around the fuel and radiological consequences will be negligible.

d) Following placement of each loaded Transfer Cask into the cask decontamination area and prior to transfer to the ISFSI, the 32PTH DSC smearable surface contamination levels on the outer top 1 foot surface of the 32PTH DSC shall be less than 2,200 dpm/100 cm^2 from beta and gamma emitting sources, and less than 220 dpm/100 cm^2 from alpha emitting sources.

The contamination limits specified above are based on the allowed removable external radioactive contamination specified in 49 CFR 173.443 (as referenced in 10 CFR 71.87(i)) the system provides significant additional protection for the 32PTH DSC surface than the transportation configuration. The HSM-H will protect the 32PTH DSC from direct exposure to the elements and will therefore limit potential releases of removable contamination. The probability of any removable contamination being entrapped in the HSM-H air flow path released outside the HSM-H is considered extremely small.

(continued)

5.2 Programs (continued)

5.2.5 HSM-H Thermal Monitoring Program

This program provides guidance for temperature measurements that are used to monitor the thermal performance of each HSM-H. The intent of the program is to prevent conditions that could lead to exceeding the concrete and fuel clad temperature criteria.

a) HSM-H Air Temperature Difference

Following initial 32PTH DSC transfer to the HSM-H, the air temperature difference between ambient temperature and the roof vent temperature will be measured 24 hours after DSC insertion into the HSM and again 7 days after insertion into the HSM-H. If the air temperature differential is greater than 70°F, the air inlets and exits should be checked for blockage. If after removing any blockage found, the temperature difference is still ≥100°F, corrective actions and analysis of existing conditions will be performed in accordance with the site corrective action program to confirm that conditions adversely affecting the concrete or fuel cladding do not exist.

The specified air temperature rise ensures the fuel clad and concrete temperatures are maintained at or below acceptable long-term storage limits. If the temperature rise is ≤100°F, then the HSM-H and 32PTH DSC are performing as designed and no further temperature measurements are required.

Note: Only one of the two alternate surveillance activities listed below (5.2.5b or 5.2.5c) shall be performed for monitoring the HSM-H thermal performance.

b) *Daily Visual Inspection of* HSM-H Inlets and Outlets (Front Wall and Roof Bird Screens)

Since the HSM-Hs are located outdoors, there is a possibility that the HSM-H air inlet and outlet openings could become blocked by debris. Although the ISFSI security fence and HSM-H bird screens reduce the probability of HSM-H air vent blockage, the ISFSI FSAR postulates and analyzes the effects of air vent blockage.

The HSM-H design and accident analyses demonstrate the ability of the ISFSI to function safely if obstructions in the air inlets or outlets impair airflow through the HSM-H for extended periods. This specification ensures that blockage will not exist for periods longer than assumed in the analyses.

Site personnel will conduct a daily visual inspection of the air vents to ensure that HSM-H air vents are not blocked for more than 34 hours and that blockage will not exist for periods longer than assumed in the safety analysis. *If the surveillance shows blockage of air vents, they shall be cleared. If the bird screen is damaged, it shall be replaced.*

(concluded)

c). *Verify the thermal performance of each HSM-H via a direct temperature measurement on a daily basis. The temperature measurement could be any parameter such as (1) a direct measurement of the HSM-H temperatures, (2) a direct measurement of the DSC temperatures, (3) a comparison of the inlet and outlet temperature difference to predicted temperature differences for each individual HSM-H, or (4) other means that would identify and allow for the correction of off-normal thermal conditions that could lead to exceeding the concrete and fuel clad temperature criteria. If air temperatures are measured, they must be measured in such a manner as to obtain representative values of inlet and outlet air temperatures. Also, due to the proximity of adjacent HSM-H modules, care must be exercised to ensure that measured air temperatures reflect only the thermal performance of an individual module, and not the combined performance of adjacent modules.*

If the temperature measurement shows a significant unexplained difference, so as to indicate the approach of materials to the concrete or fuel clad temperature criteria, take appropriate action to determine the cause and return the canister to normal operation. If the measurement or other evidence suggests that the concrete accident temperature criteria (the elevated temperature used in Section 5.5 to perform concrete testing for HSM-H) has been exceeded for more than 24 hours, the licensee can provide analysis results and/or test results in accordance with ACI-349, appendix A.4.3, demonstrating that the structural strength of the HSM-H has an adequate margin of safety. Take additional appropriate actions if necessary based on the results of the evaluation above.

The temperature measurement program should be of sufficient scope to provide the licensee with a positive means to identify conditions which threaten to approach temperature criteria for proper HSM-H operation and allow for the correction of off-normal thermal conditions that could lead to exceeding the concrete and fuel clad temperature criteria.

5.3 Lifting Controls

5.3.1 Transfer Cask Lifting Heights

The lifting height of a loaded transfer cask/32PTH DSC, is limited as a function of location, as follows:

a) The maximum lift height and handling height for all TRANSFER OPERATIONS where the TC/32PTH is in the horizontal position on the trailer shall be 80 inches.

b) The maximum lift height of the transfer cask/32PTH DSC shall be restricted by site (10CFR50) limits for all handling operations except those listed in 5.3.1a above. An evaluation of the fuel cladding structural integrity shall be performed for all credible drops under the user's 10CFR50 heavy loads program.

These restrictions ensure that any 32PTH DSC drop as a function of location is within the bounds of the accident analysis.

5.3.2 Cask Drop

Inspection Requirement

The 32PTH DSC will be inspected for damage after any transfer cask drop of fifteen inches or greater.

Background

TC/32PTH DSC handling and loading activities are controlled under the 10CFR 50 license until a loaded TC/32PTH DSC is placed on the transporter, at which time fuel handling activities are controlled under the 10CFR 72 license. Although the probability of dropping a loaded TC/32PTH DSC while en route from the Fuel Handling Building to the ISFSI is small, the potential exists to drop the cask 15 inches or more.

(continued)

5.3 Lifting Controls (*concluded*)

5.3.2 Cask Drop (*concluded*)

Safety Analysis

The analysis of bounding drop scenarios shows that the transfer cask will maintain the structural integrity of the 32PTH DSC confinement boundary from an analyzed side drop height of 80 inches. The 80-inch drop height envelopes the maximum height from the bottom of the transfer cask when secured to the transfer trailer while en route to the ISFSI.

Although analyses performed for cask drop accidents at various orientations indicate much greater resistance to damage, requiring the inspection of the DSC after a drop of 15 inches or greater ensures that:

1. The DSC will continue to provide confinement.

2. The transfer cask can continue to perform its design function regarding DSC transfer and shielding.

5.4 HSM-H Dose Rate Evaluation Program

This program provides a means to help ensure that the cask (DSC) is loaded properly and that the facility will meet the off-site dose requirements of 72.104(a).

1. As part of its evaluation pursuant to 10 CFR 72.212, the licensee shall perform an analysis to confirm that the limits of 10 CFR Part 20 and 10 CFR 72.104 will be satisfied under the actual site conditions and configurations considering the planned number of HSMs to be used and the planned fuel loading conditions.

2. On the basis of the analysis in TS 5.4.1, the licensee shall establish a set of HSM-H dose rate limits which are to be applied to 32PTH DSCs used at the site. Limits shall establish peak dose rates for:

   a. HSM-H front surface,
   b. HSM-H door centerline, and
   c. End shield wall exterior.

3. Notwithstanding the limits established in TS 5.4.2, the dose rate limits may not exceed the following values as calculated for a content of design basis fuel as follows:

   a. 800 mrem/hr at the front bird screen,
   b. 2 mrem/hr at the door centerline, and
   c. 2 mrem/hr at the end shield wall exterior.

4. If the measured dose rates do not meet the limits of TS 5.4.2 or TS 5.4.3, whichever are lower, the licensee shall take the following actions:

   a. Notify the U.S. Nuclear Regulatory Commission (Director of the Office of Nuclear Material Safety and Safeguards) within 30 days,
   b. Administratively verify that the correct fuel was loaded,
   c. Ensure proper installation of the HSM-H door,
   d. Ensure that the DSC is properly positioned on the support rails, and
   e. Perform an analysis to determine that placement of the as-loaded DSC at the ISFSI will not cause the ISFSI to exceed the radiation exposure limits of 10 CFR Part 20 and 72 and/or provide additional shielding to assure exposure limits are not exceeded.

5.5 Concrete Testing

HSM-H concrete shall be tested for elevated temperatures to verify that there are no significant signs of spalling or cracking and that the concrete compressive strength is greater than that assumed in the structural analysis. Tests shall be performed at or above the calculated peak temperature and for a period no less than the 40 hour duration of HSM-H blocked vent transient for components exceeding 350 degrees F.

Table 1
Fuel Specifications

This table has been deleted and replaced by revised Technical Specification 2.1 "Fuel to be Stored in the 32PTH DSC."

Table 2
Fuel Assembly Design Characteristics for the NUHOMS®-32PTH DSC

Assembly Class		WE 17x17	WE 15x15	CE 14x14	CE 16x16
Max Unirradiated Length (in)(1)	32PTH	165.75	165.75	165.75	165.75
	32PTH Type 1	171.93	171.93	171.93	171.93
Fissile Material		UO_2	UO_2	UO_2	UO_2
Cladding Material		Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5
Maximum MTU/Assembly(2)		0.476	0.476	0.476	0.476
Maximum Number of Fuel Rods		264	204	176	236
Maximum Number of Guide/ Instrument Tubes		25	21	5	5

Notes:
(1) Maximum Assembly + Control Component Length (unirradiated)
(2) The maximum MTU/assembly is based on the shielding analysis. The listed value is higher than the actual.

Table 3
Maximum *Control Component* Source Terms

Parameter	*Control Component Source Term*
Gamma Source (γ/sec/*DSC*)	*7.36 E+15*
Decay heat (Watts/*assy*)	*9*

Table 4
Fuel Qualification Table(s)

Fuel qualification for the 32PTH DSC is shown below:

1) The maximum allowable assembly burnup as a function of assembly average initial enrichment is shown below.

Assembly Average Initial Enrichment (X2) wt.% U-235)	*Maximum Assembly Burnup (X1) (GWD/MTU)*
$0.2 \leq X2 < 0.3$	20
$0.3 \leq X2 < 0.7$	25
$0.7 \leq X2 < 1.5$	32
$1.5 \leq X2 < 2.5$	55
$2.5 \leq X2 < 5.00$	60

2). For an assembly average initial enrichment (wt. % U-235) greater than or equal to 1.50, an equation shown below to calculate the decay heat shall be employed.

The Decay Heat (DH) in watts is expressed as:

$$F1 = A + B*X1 + C*X2 + D*X1^2 + E*X1*X2 + F*X2^2$$
$$DH = F1*Exp(\{[1-(5/X3)]*G\}*[(X3/X1)^H]*[(X2/X1)^I])$$

where,

F1 Intermediate Function, basically the Thermal source at 5 year cooling
X1 Assembly Burnup in GWD/MTU
X2 Maximum Assembly Average Initial Enrichment in wt. % U-235 (max 5%, min: Zone 1- 1.5%, Zone 2 -1.6%, Zone 3- 2.5%)
X3 Cooling Time in Years (min 5 yrs)

A = 13.69479 B =25.79539 C = -3.547739 D = 0.307917 E = -3.809025
F = 14.00256 G = -0.831522 H = 0.078607 I = -0.095900

All fuel assemblies that are acceptable from a thermal standpoint (heat load zone from Figure 2) are acceptable from a radiological source term standpoint. When irradiated stainless steel rods are present in the reconstituted fuel assembly, add an additional year of cooling time for cooling times less than 10 years.

Table 4

Fuel Qualification Table(s) (continued)

3) For an assembly average initial enrichment less than 1.5 wt. % U-235, the following qualification shall be employed.

Enrichment Range (wt% U-235)	*Max BU (GWD/MTU)*	*Cooling Time (Years)*	*Decay Heat (Watts)*
0.7 ≤ X2 < 1.5	*32*	*5*	*1100*
	32	*6*	*900*
	32	*7*	*780*
	32	*10*	*540*
0.3 ≤ X2 < 0.7	*25*	*5*	*970*
	25	*6*	*800*
	25	*10*	*620*
0.2 ≤ X2 < 0.3	*20*	*5*	*652*

For an assembly average enrichment between 0.2 and 0.3 wt. % U-235, fuel assemblies with a burnup below 20 GWD/MTU and a cooling time greater than 5 years are qualified for storage anywhere in the basket.

For an assembly average enrichment between 0.3 and 0.7 wt. % U-235, fuel assemblies with a burnup below 25 GWD/MTU and a cooling time greater than 6 years are qualified for storage anywhere in the basket.

For an assembly average enrichment between 0.7 and 1.5 wt. % U-235, fuel assemblies with a burnup below 32 GWD/MTU and a cooling time greater than 7 years are qualified for storage anywhere in the basket.

Table 4
Fuel Qualification Table(s) (continued)

Example Fuel Qualification Tables for the various heat load zones that provide the maximum allowable burnup (GWD/MTU) as a function of assembly average initial enrichment (wt. % U-235) and cooling time (years) are shown below.

Examples for Zone 1a -1050 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	***Minimum Cooling Time***					
	5 Years	**6 Years**	**7 Years**	**8 Years**	**10 Years**	**15 Years**
1.50	32.8	37.2	40.7	43.7	48.1	55.2
2.50	34.7	39.2	42.7	45.6	50.0	57.0
3.00	35.5	40.1	43.6	46.5	51.0	57.9
3.50	36.2	40.9	44.5	47.4	52.0	58.9
4.00	36.8	41.5	45.3	48.3	52.8	59.9
4.50	37.2	42.1	45.9	49.0	53.7	60.0

Examples for Zone 1b -800 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	***Minimum Cooling Time***					
	5 Years	**6 Years**	**7 Years**	**8 Years**	**10 Years**	**15 Years**
1.50	26.3	30.0	32.9	35.4	39.2	45.2
2.00	27.1	30.8	33.8	36.2	40.0	46.0
2.50	27.7	31.5	34.5	37.0	40.8	46.7
3.00	28.2	32.1	35.2	37.7	41.5	47.5
3.50	28.5	32.5	35.7	38.3	42.2	48.3
4.00	28.5	32.9	36.2	38.8	42.8	49.0
4.50	28.5	33.0	36.4	39.2	43.3	49.7

Examples for Zone 2 -1100 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	***Minimum Cooling Time***					
	5 Years	**6 Years**	**7 Years**	**8 Years**	**10 Years**	**15 Years**
1.60	34.2	39.8	42.4	45.4	50.0	57.3
2.50	36.0	40.6	44.2	47.2	51.7	58.9
3.00	36.9	41.5	45.2	48.2	52.8	59.9
3.50	37.6	42.4	46.1	49.1	53.7	60.0
4.00	38.3	43.1	46.9	50.0	54.7	60.0
4.50	38.7	43.8	47.7	50.8	55.6	60.0

Table 4
Fuel Qualification Table(s) (concluded)

Examples for Zone 3 -1500 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	*Minimum Cooling Time*			
	5 Years	**6 Years**	**7 Years**	**8 Years**
3.50	47.9	53.5	57.8	60.0
4.00	48.9	54.6	59.0	60.0
4.25	49.4	55.1	59.5	60.0
4.50	49.9	55.6	60.0	60.0

Table 5
NFAH Thermal Qualification

This table has been deleted and replaced by revised Technical Specification 2.1 "Fuel to be Stored in the 32PTH DSC" and Table 3.

Table 6
B10 Specification for the NUHOMS®-32PTH Poison Plates

NUHOMS®-32PTH DSC Basket Type	**Minimum B10 Areal Density, gm/cm²**	
	Natural or Enriched Boron Aluminum Alloy / Metal Matrix Composite (MMC) (Type I)	Boral® (Type II)
A	0.007	0.009
B	0.015	0.019
C	0.020	0.025
D	0.032	N/A
E	0.050	N/A

Table 7
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Intact Fuel Assembly (without CC)	A	4.05	4.40	4.45	4.55
	B	4.55	4.90	5.00	-
	C	4.70	5.00	-	-
	D	5.00	-	-	-
	E	-	-	-	-
CE 14x14 Intact Fuel Assembly (with CC)	*A*	*3.95*	*4.25*	*4.35*	*4.45*
	B	*4.35*	*4.70*	*4.80*	*4.90*
	C	*4.50*	*4.85*	*5.00*	-
	D	*4.75*	*5.00*	-	-
	E	*5.00*	-	-	-
CE 16x16 Intact Fuel Assembly (without CC)	*A*	*3.90*	*4.10*	*4.20*	*4.30*
	B	*4.30*	*4.60*	*4.70*	*4.80*
	C	*4.50*	*4.80*	*4.90*	*5.00*
	D	*4.80*	*5.00*	*5.00*	*5.00*
	E	*5.00*	*5.00*	*5.00*	*5.00*
CE 16x16 Intact Fuel Assembly (with CC)	*A*	*3.80*	*4.00*	*4.10*	*4.20*
	B	*4.20*	*4.50*	*4.60*	*4.70*
	C	*4.40*	*4.70*	*4.80*	*4.90*
	D	*4.70*	*4.90*	*5.00*	*5.00*
	E	*4.90*	*5.00*	*5.00*	*5.00*
WE 15x15 Intact Fuel Assembly (with and without *CCs*)	A	3.50	3.70	3.80	3.90
	B	3.80	4.10	4.20	4.30
	C	3.95	4.25	4.35	4.45
	D	4.20	4.50	4.70	4.80
	E	4.50	4.80	4.90	5.00
WE 17x17 Intact Fuel Assembly (with and without *CCs*)	A	3.50	3.70	3.80	3.90
	B	3.80	4.10	4.20	4.30
	C	3.95	4.25	4.35	4.45
	D	4.20	4.50	4.60	4.70
	E	4.45	4.70	4.90	5.00

Table 7
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading (concluded)

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Damaged Fuel Assembly (without CC)	A	3.90	4.20	4.25	4.35
	B	4.35	4.70	4.80	4.90
	C	4.50	4.85	4.95	5.00
	D	4.85	5.00	-	-
	E	5.00	-	-	-
CE 14x14 Damaged Fuel Assembly (with CC)	*A*	*3.70*	*3.95*	*4.05*	*4.10*
	B	*4.10*	*4.40*	*4.50*	*4.60*
	C	*4.20*	*4.55*	*4.65*	*4.75*
	D	*4.50*	*4.85*	*5.00*	-
	E	*4.75*	*5.00*	-	-
CE 16x16 Damaged Fuel Assembly (without CC)	*A*	*3.65*	*3.90*	*4.00*	*4.05*
	B	*4.05*	*4.30*	*4.40*	*4.50*
	C	*4.20*	*4.50*	*4.60*	*4.70*
	D	*4.50*	*4.80*	*4.90*	*5.00*
	E	*4.75*	*5.00*	*5.00*	*5.00*
CE 16x16 Damaged Fuel Assembly (with CC)	*A*	*3.60*	*3.80*	*3.90*	*4.00*
	B	*3.95*	*4.20*	*4.30*	*4.40*
	C	*4.10*	*4.40*	*4.50*	*4.60*
	D	*4.40*	*4.70*	*4.80*	*4.90*
	E	*4.65*	*4.90*	*5.00*	*5.00*
WE 15x15 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.35	4.70	4.80	4.90
WE 17x17 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.30	4.65	4.80	4.90

Note: '—' represents those fixed poison loading (basket type) and soluble boron concentration combinations where fuel assemblies with a maximum assembly average initial enrichment of 5.00 wt % U-235 can be loaded

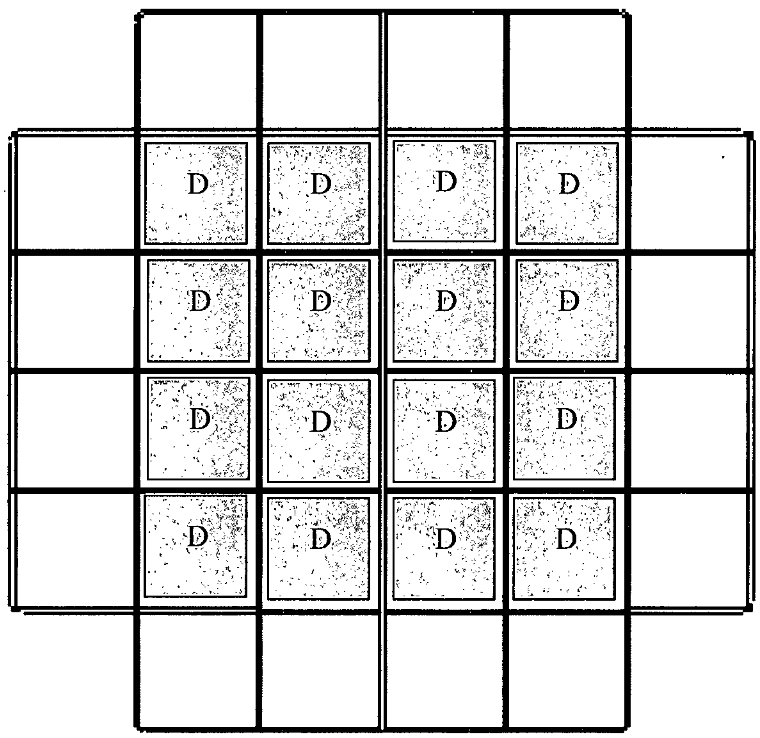
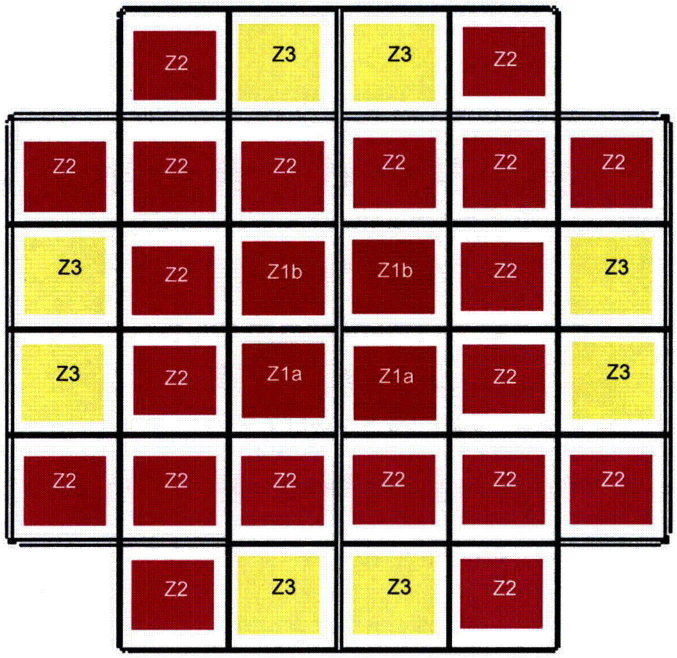


Figure 1
Damaged Fuel Assembly Locations



For CE 14x14 Assemblies

- Q_{zi} is the maximum decay heat per assembly in zone i
- Total Decay Heat ≤ 33.8 kW
- 4 fuel assemblies in zone 1 with Q_{z1} ≤0.775 kW
- 20 fuel assemblies in zone 2 with Q_{z2} ≤ 1.068 kW
- 8 fuel assemblies in zone 3 with Q_{z3} ≤ 1.5 kW

For other Assemblies

- Q_{zi} is the maximum decay heat per assembly in zone i
- Total Decay Heat ≤ 34.8 kW
- 4 fuel assemblies in zone 1 with
  - total decay heat ≤ 3.2 kW
  - Q_{z1a} ≤ 1.05 kW in the lower compartments
  - Q_{z1b} ≤ 0.8 kW in the upper compartments
- 20 fuel assemblies in zone 2 with Q_{z2} ≤ 1.1 kW
- 8 fuel assemblies in zone 3 with Q_{z3} ≤ 1.5 kW

Figure 2
Heat Load Zones

1. GENERAL INFORMATION

This Safety Analysis Report (SAR) describes the design and forms the licensing basis for 10CFR 72[1], Subpart L certification of the NUHOMS® HD dry spent fuel storage system. The NUHOMS® HD System provides for the horizontal storage of high burnup spent Pressurized Water Reactor (PWR) fuel assemblies in a dry shielded canister (DSC) that is placed in a Horizontal Storage Module (HSM-H) utilizing an OS187H transfer cask. The NUHOMS® HD System is designed to be installed in an Independent Spent Fuel Storage Installation (ISFSI) at power reactor sites under the provision of a general license in accordance with 10CFR 72, Subpart K. This system has been specifically optimized for high thermal loads, limited space, and needs for superior radiation shielding performance.

The QA program applicable to this design satisfies the requirements of 10CFR 72, Subpart G and is described in Chapter 13. The format of this SAR follows the guidance of NRC Regulatory Guide 3.61[2]. To facilitate NRC review of this application, this SAR has been prepared in compliance with the information and methods defined in NUREG-1536 [3], "Standard Review Plan for Dry Cask Storage Systems" and the associated Interim Staff Guidance (ISGs).

The NUHOMS® HD System is an improved version of the Standardized NUHOMS® System described in Certificate of Compliance (C of C) 72-1004 [4]. The 32PTH DSC included in this application is similar to the 24PTH DSC previously included in the license for the Standardized NUHOMS® System [5]. The HSM-H is virtually identical to the HSM-H in the 24PTH amendment. The OS187H transfer cask (TC) is very similar to the previously licensed OS197 transfer cask but with a slightly larger diameter and closures containing seals.

The NUHOMS® HD System has been designed for enhanced heat rejection capabilities, and to permit storage of Control Components (CCs) with the fuel and/or damaged spent fuel assemblies. Protection afforded to the public is equivalent to or has been increased relative to standardized HSM designs [5] by substantially reducing radiation dose rates. Details of the system design, analyses, operation, and margins are provided in the remainder of this SAR.

The NUHOMS® HD system also includes a longer DSC and a corresponding TC, designated the 32PTH Type 1 DSC and OS187H Type 1 TC, respectively. A detailed description of the 32PTH Type 1 DSC and OS187H Type 1 TC are provided in Appendix A. The 32PTH Type 1 DSC is stored in an HSM-H with a slightly increased support rail length. The design details of these additional HD system components are provided in the drawings shown in Section A.1.5.

1.1 Introduction

The type of fuel to be stored in the NUHOMS® HD System is Light Water Reactor (LWR) fuel of the PWR type. The NUHOMS® HD System accommodates up to 32 PWR fuel assemblies with zircaloy, (zirlo, M5) cladding, uranium dioxide (UO_2), and CCs. Provisions have been made, as discussed in Chapter 2, for storage of up to sixteen damaged fuel assemblies in the 32PTH DSC. The physical and radiological characteristics of these payloads are provided in Chapter 2.

The NUHOMS® HD System consists of the following components as shown in Figure 1-1, Figure 1-2, and Figure 1-6:

- A Horizontal Storage Module (HSM-H) that provides spent fuel decay heat removal, physical and radiological protection for the 32PTH DSC. The HSM-H consists primarily of thick concrete walls, a steel support structure for the 32PTH DSC, and a thick concrete door. Each HSM-H includes provisions for thermal monitoring instrumentation. The HSM-H is virtually identical to the HSM-H for the NUHOMS® 24PTH DSC included in UFSAR Revision 9 [5].

- A Dry Shielded Canister (32PTH DSC) that provides confinement, an inert environment, structural support, and criticality control for 32 PWR fuel assemblies. The 32PTH DSC shell is a welded stainless steel pressure vessel that includes thick shield plugs at either end to maintain occupational exposures ALARA. The 32PTH DSC basket consists of stainless steel square tubes and support strips for structural support, and geometry control; and aluminum/borated aluminum for heat transfer and criticality control. The 32PTH DSC is very similar to the 24PTH DSC.

- The OS187H TC provides shielding and protection from potential hazards during the DSC closure operations and transfer to the HSM-H. It also provides a helium environment around the DSC during transfer operations. It is very similar to the previously licensed OS197 transfer cask for the Standardized NUHOMS® System.

- HSM-Hs are arranged in arrays to minimize space and maximize self-shielding. The 32PTH DSC is longitudinally restrained to prevent movement during seismic events. Arrays are fully expandable to permit modular expansion in support of operating power plants.

- The HSM-H provides the bulk of the radiation shielding for the 32PTH DSC. The HSM-Hs can be arranged in either a single-row or a back-to-back arrangement. Thick concrete supplemental shield walls are used at either end of an HSM-H array and along the back wall of single-row arrays to minimize radiation dose rates both onsite and offsite.

Approval of the NUHOMS® HD System components described above is sought under the provisions of 10CFR 72, Subpart L for use under the general license provisions of 10CFR 72, Subpart K. The components are intended for storage on a reinforced concrete pad at a nuclear power plant. In addition to these components, the system requires use of an onsite transfer cask,

1.2.2.1 Dry Run Operations

A dry run utilizing a 32PTH DSC loaded with mock-up fuel assemblies will be performed prior to loading the first canister by each licensee to demonstrate the adequacy of training, familiarity of system components and operational procedures. Mock-up fuel assemblies shall provide a representation of the maximum fuel assembly cross sectional envelope and provide a reasonable approximation of fuel assembly length and weight. The licensee shall determine the quantity of mock-up fuel assemblies required for the dry run to demonstrate that the loading and unloading processes are sound and the operations personnel are adequately trained.

The loading and unloading operations which have an impact on safety will be verified and recorded according to the requirements detailed in Chapter 8. The operations include loading and identifying fuel assemblies, ensuring the fuel assemblies meet the fuel acceptance criteria, drying, backfilling and pressurizing the canister, gas sampling and transferring the loaded canister to the HSM-H. Additionally, the ability to weld the top cover plates and open a sealed canister shall be demonstrated.

1.2.2.2 SFA Loading Operations

The primary operations (in sequence of occurrence) for the NUHOMS® HD System are:

1. Transfer Cask Preparation
2. 32PTH DSC Preparation
3. Place 32PTH DSC in Transfer Cask
4. Fill Transfer Cask/32PTH DSC Annulus with Clean Water and Seal
5. Fill 32PTH DSC Cavity with Fuel Pool Water (may be accomplished in step 6)
6. Lift Transfer Cask and Place in Fuel Pool
7. Spent Fuel Loading
8. Top Shield Plug Placement
9. Lifting Transfer Cask from Pool (DSC water may be drained and replaced with helium during draindown.)
10. Inner Top Cover/Top Shield Plug Assembly Sealing
11. Vacuum Drying and Backfilling
12. Pressure Test
13. Leak Test
14. Outer Top Cover Plate Sealing

Lifting Transfer Cask from Pool: The loaded transfer cask is lifted out of the pool and placed (in the vertical position) on the drying pad in the decontamination pit. This operation is similar to that used for shipping cask handling operations.

Inner Top Cover/Shield Plug[1] Sealing: The water contained in the space above the inner top cover plate/shield plug[1] is drained. The inner top cover plate/shield plug[1] is welded to the shell. This weld provides the top (confinement) seal for the 32PTH DSC.

Vacuum Drying and Backfilling: The initial blowdown of the 32PTH DSC is accomplished by pressurizing the vent port with helium. The water in the cavity is forced out of the siphon tube and routed back to the fuel pool or to the plant's liquid radwaste processing system via appropriate size flexible hose or pipe, as appropriate. The cavity water may also be removed by pumping out the water using the siphon port/tube and replaced by helium. The 32PTH DSC is then evacuated to remove the residual liquid water, water vapor, and helium in the cavity. When the system pressure has stabilized, the 32PTH DSC is backfilled with helium.

Pressure Test: Perform a pressure test of inner top cover/shield plug[1] weld by backfilling the DSC cavity with helium.

After the pressure test, remove the helium lines then the vent and siphon cover plates are installed and welded to the inner top cover/shield plug[1].

Leak Test: Perform a leak test of the inner top cover/shield plug[1] to the DSC shell weld and siphon/vent cover welds using a temporary test head or any other alternative means.

Outer Top Cover Plate Sealing: After helium backfilling, the 32PTH DSC outer top cover plate is installed by using a partial penetration weld between the outer top cover plate and the DSC shell.

The outer cover plate to shell weld and inner top cover plate/shield plug[1] weld provide redundant seals at the upper end of the 32PTH DSC.

Transfer Cask/32PTH DSC Annulus Draining and Transfer Cask Top Cover Plate Placement: The transfer cask/32PTH DSC annulus is drained. A swipe is then taken over the 32PTH DSC exterior at the top cover plate and the upper portion of the shell. Demineralized water is flushed through the transfer cask/32PTH DSC annulus, as required, to remove any contamination left on the 32PTH DSC exterior. The transfer cask top cover plate is installed, using the plant's crane or other suitable lifting device, and bolted closed.

Backfill Transfer Cask Cavity with Helium: The TC cavity is evacuated and the cavity/annulus is backfilled to a positive pressure with helium.

Place Loaded Transfer Cask on Transfer Skid/Trailer: The transfer cask is lifted onto the transfer cask support skid and downended onto the transfer trailer from the vertical to horizontal position. The transfer cask is secured to the skid.

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[1] See Chapter 1 drawings for option 2 and option 3 designs and Chapter 7 for confinement boundary definitions.

1.2.3 32PTH DSC Contents

The 32PTH DSC is designed to store up to 32 intact PWR Westinghouse 15x15 (WE 15x15), Westinghouse 17x17 (WE 17x17), Combustion Engineering 14x14 (CE 14x14) and Combustion Engineering 16x16 (CE 16x16) class fuel assemblies. The 32PTH DSC is designed to store up to 32 Control Components (CCs) which include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies (TPAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs) and neutron sources

Reconstituted assemblies containing up to 10 replacement irradiated stainless steel rods per assembly or an unlimited number of lower enrichment UO_2 rods or Zr rods (or Zr pellets) or unirradiated stainless steel rods are acceptable for storage in 32PTH DSC as intact fuel assemblies with a slightly longer cooling time than that required for a standard assembly. The maximum number of reconstituted fuel assemblies with irradiated stainless steel rods per DSC is four, and 32 for all other reconstituted fuel assemblies.

The 32PTH DSC is also designed for storage of up to 16 damaged fuel assemblies, and remaining intact assemblies, utilizing top and bottom end caps. A description of the fuel assemblies including the damaged fuel assemblies is provided in Chapter 2.

The maximum allowable assembly average initial enrichment of the fuel to be stored is 5.00 weight % U-235 and the maximum assembly average burnup is 60,000 MWd/MTU. The fuel must be cooled at least 5 years prior to storage.

The criticality control features of the NUHOMS® HD System are designed to maintain the neutron multiplication factor k-effective (including uncertainties and calculational bias) at less than 0.95 under normal, off-normal, and accident conditions.

The quantity and type of radionuclides in the SFAs are described and tabulated in Chapter 5. Chapter 6 covers the criticality safety of the NUHOMS® HD System and its parameters. These parameters include rod pitch, rod outside diameter, material densities, moderator ratios, and geometric configurations. The maximum pressure buildup in the 32PTH DSC cavity is addressed in Chapter 4.

2. PRINCIPAL DESIGN CRITERIA

The design criteria described herein for the 32PTH DSC and the OS187H TC are also applicable to the 32PTH Type 1 DSC and the OS187H Type 1 TC discussed in Appendix A. Design criteria applicable specifically to the 32PTH DSC and the OS187H TC are described in Appendix A, Chapter A.2.

2.1 Spent Fuel to be Stored

The NUHOMS® HD System components have currently been designed for the storage of 32 intact and or up to 16 damaged with remaining intact, Westinghouse 15x15 (WE 15x15), Combustion Engineering 16x16 (CE 16x16), Westinghouse 17x17 (WE 17x17), and Combustion Engineering 14x14 (CE 14x14) class PWR fuel assemblies. Equivalent reload fuel assemblies that are enveloped by the fuel assembly design characteristics listed in Table 2-1 for a given assembly class are also acceptable. Additional payloads may be defined in future amendments to this application.

The thermal and radiological characteristics for the PWR spent fuel were generated using the SCALE computer code package [1]. The physical characteristics for the PWR fuel assembly types are shown in Table 2-3. Free volume in the 32PTH DSC cavity is addressed in Chapter 4. Specific gamma and neutron source spectra are given in Chapter 5.

Although analyses in this SAR are performed only for the design basis fuel, any other intact or damaged PWR fuel which falls within the geometric, thermal, and nuclear limits established for the design basis fuel can be stored in the 32PTH DSC.

2.1.1 Detailed Payload Description

The NUHOMS® HD System is designed to store intact (including reconstituted) and/or damaged PWR fuel assemblies as specified in Table 2-1 and Table 2-3. The fuel to be stored is limited to a maximum assembly average initial enrichment of 5.0 wt. % U-235. The maximum allowable assembly average burnup is limited to 60 GWd/MTU and the minimum cooling time is 5 years. The system is also designed to store Control Components (CCs) with thermal and radiological characteristics as listed in Table 2-4. The CCs include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies (TPAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster Control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs) and Neutron Sources.

Reconstituted assemblies containing up to 10 replacement irradiated stainless steel rods per assembly or an unlimited number of lower enrichment UO_2 rods or Zr rods or Zr pellets or unirradiated stainless steel rods are acceptable for storage in 32PTH DSC as intact fuel assemblies with a slightly longer cooling time than that required for a standard assembly. The stainless steel rods are assumed to have two-thirds the irradiation time as the same irradiation history as the entire fuel assembly. The reconstituted rods can be at any location in the fuel assemblies. The maximum number of reconstituted fuel assemblies with irradiated stainless steel replacement rods per DSC is four and 32 for all other reconstituted fuel assemblies.

The 32PTH DSC may store up to 32 PWR fuel assemblies arranged in accordance with a heat load zoning configuration as shown in Figure 2-1, with a maximum decay heat of 1.5 kW per assembly and a maximum heat load of 34.8 kW per DSC, (33.8 kW per DSC for CE 14x14).

The 32PTH DSC can accommodate up to 16 damaged fuel assemblies as defined in Chapter 12. Damaged fuel assemblies shall be placed into the sixteen inner most basket fuel compartments, as shown in Figure 2-2, which contain top and bottom end caps that confine any loose material and gross fuel particles to a known, sub-critical volume during normal, off-normal and accident conditions and to facilitate handling and retrievability. Reactor records, visual/videotape records, fuel sipping, ultrasonic examination, and radio chemistry are examples of techniques utilized by utilities to identify damaged fuel.

The end caps are sized to fit inside the fuel compartment (see drawing 10494-72-30). The bottom end cap is slid into the fuel compartment before loading the fuel, utilizing a special tool.

After fuel loading, a top end cap is placed into the fuel compartment. The end caps are not "attached" to the basket, but are a slip/friction fit into the basket compartment. The fuel assembly is thus enclosed/confined by the fuel compartment walls and the end caps. The DSC inner top cover prevents any significant movement of the top end cap. The damaged fuel assemblies can be retrieved simply by removing the top end cap and grappling the fuel assembly by normal means.

The NUHOMS®-32TH DSC basket is designed with three alternate poison materials: Borated Aluminum alloy, Boron Carbide/Aluminum Metal Matrix Composite (MMC) and Boral®.

The NUHOMS®-32PTH DSC basket is analyzed for seven alternate basket configurations, depending on the boron loadings and poison materials.

A summary of the alternate poison loadings considered for each poison material as a function of basket types is presented below:

NUHOMS®-32PTH DSC Basket Type	**Minimum B10 Areal Density, g/cm²**	
	Natural or Enriched Boron Aluminum Alloy / Metal Matrix Composite (MMC) (Type I)	Boral® (Type II)
A	0.007	0.009
B	0.015	0.019
C	0.020	0.025
D	0.032	N/A
E	0.050	N/A

Table 2-2 shows a parametric equation that can be utilized to qualify spent fuel assemblies for the defined decay heat load zones. The decay heat load can be calculated based on a fuel assembly's burnup, cool time, and initial enrichment parameters. This table ensures that the fuel assembly decay heat load is within the appropriate zone. The development of this equation is provided in Appendix 4.16.2.

The maximum fuel cladding temperature limit of 400°C (752°F) is applicable to normal conditions of storage and all short term operations from spent fuel pool to ISFSI pad including vacuum drying and helium backfilling of the NUHOMS®-32PTH DSC per Interim Staff Guidance (ISG) No. 11, Revision 2 [15]. In addition, ISG-11 restricts the change in fuel cladding temperature to less than 65°C (117°F) and limits the numbers of cycles to less than 10 during DSC drying, backfilling and transfer operations.

The maximum fuel cladding temperature limit of 570°C (1058°F) is applicable to accidents or off-normal thermal transients [15].

Calculations were performed to determine the fuel assembly type which was most limiting for each of the analyses including shielding, criticality, thermal and confinement. These evaluations are performed in Chapters 5 and 6. The fuel assembly classes considered are listed in Table 2-1. It was determined that the Framatome ANP Advanced MK BW 17x17 (a WE 17x17 Class Assembly) is the enveloping fuel design for the shielding, thermal and confinement source term calculation because of its total assembly weight and highest initial heavy metal loading. The bounding source term for shielding analysis is described in Table 2-3. Table 2-4 presents the thermal and radiological source terms for the CCs.

These values are consistent with the cumulative exposures and cooling times of the fuel assemblies. The gamma spectra for the bounding fuel assembly and CCs are presented in Chapter 5.

The shielding evaluation is performed assuming 32 fuel assemblies with the parameters corresponding to a decay heat of 1.5kW per fuel assembly. Any fuel assembly that is thermally qualified by Table 2-2 is also acceptable from a shielding perspective since the maximum decay heat load is 1.5 kW and only eight (8) are allowed in the 32PTH DSC. The shielding analysis assumes 32, 1.5 kW assemblies are in the 32PTH DSC. Minimum initial enrichments are defined for each of the zones to assure the shielding evaluation is bounding.

For criticality safety, the WE 17x17 is the most reactive assembly type for a given enrichment. This assembly is used to determine the most reactive configuration in the DSC. Using this most reactive configuration, criticality analysis for all other fuel assembly classes is performed to determine the maximum enrichment allowed as a function of the soluble boron concentration and fixed poison plate loading. These results are shown in Table 2-6 and the analyses results are presented in Chapter 6.

For calculating the maximum internal pressure in the NUHOMS®-32PTH DSC, it is assumed that 1% of the fuel rods are damaged for normal conditions, up to 10% of the fuel rods are damaged for off normal conditions, and 100% of the fuel rods will be damaged following a design basis accident event. A minimum of 100% of the fill gas and 30% of the fission gases within the ruptured fuel rods are assumed to be available for release into the DSC cavity, consistent with NUREG-1536 [17].

The maximum internal pressures used in the structural analysis for the NUHOMS®-32PTH DSC are 15 and 20 psig for normal and off-normal storage and transfer conditions respectively and 120 and 70 psig during transfer and storage accident conditions respectively.

The structural integrity of the fuel cladding due to the side drop is analyzed in Section 3.5.3. The end and corner drops are not considered credible during storage and transfer. The structural integrity of the fuel cladding due to these loads will be addressed by the users under their site license (10CFR50).

2.2.9.3 Beginning of Storage Unloading

Beginning of storage unloading would occur if it were necessary to place the 32PTH DSC back into the pool at the beginning of storage after it had been loaded and reached thermal equilibrium. Prior to unloading fuel, the 32PTH DSC and fuel would be cooled by circulating water through the 32PTH DSC. Therefore, cool water would contact the hotter 32PTH DSC inner surfaces. The thermal gradients in the 32PTH DSC body due to this condition are small and would have an insignificant effect on the cask body. The fuel cladding stresses during beginning of storage unloading is evaluated in Chapters 3 and 4.

2.2.9.4 Ambient Variations

Because the combined HSM-H and 32PTH DSC thermal inertia is large, the 32PTH DSC temperature response to changes in atmospheric conditions will be relatively slow. Ambient temperature variations due to changes in atmospheric conditions i.e., sun, ice, snow, rain and wind will not affect the performance of the 32PTH DSC. The cyclical variation of insolation during a day will also create insignificant thermal gradients. The analysis provided in Appendix 4.16.4 demonstrates that the thermal analyses with -20 °F ambient temperature bound those for -21 °F ambient temperature. Therefore, the results of the structural analyses in Chapter 3 and thermal analyses in Chapter 4 including the appendices with -20 °F ambient temperature cases are also applicable to -21 °F ambient temperature cases.

The thermal effects due to ambient variations and conditions are discussed in further detail in Chapter 4.

2.2.9.5 Lightning

Thermal effects due to lightning are discussed in Chapter 11.

2.2.9.6 Fire

It is demonstrated in Chapter 11 that the 32PTH DSC will maintain confinement integrity during and after the postulated fire accident.

2.3.2.2 32PTH DSC Cooling

The HSM-H provides a means of removing spent fuel decay heat by a combination of radiation, conduction, and natural convection. The passive convective ventilation system is driven by the pressure difference due to the stack buoyancy effect (ΔP_s) provided by the temperature difference between the 32PTH DSC and the ambient air outlet. This pressure difference is larger than the flow pressure drop (ΔP_f) at the design air inlet and outlet temperatures.

There are no radioactive releases of effluents during normal and off-normal storage operations. Also, there are no credible accidents which cause releases of radioactive effluents from the 32PTH DSC. Therefore, an off-gas monitoring system is not required for the HSM-H. The only time an off-gas system is required is during 32PTH DSC drying operations. During this operation, the spent fuel pool or plant's radwaste system is used to process the helium evacuated from the 32PTH DSC.

During transfer of the DSC from the reactor building to the HSM, cooling of the DSC is maintained by utilizing a helium environment inside the transfer cask.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.2.2 Equipment

The HSM-H, 32PTH DSC, and transfer cask encompass equipment which is important to safety. Other equipment important to safety associated with the NUHOMS® 32PTH System includes the equipment required for handling operations within the plant's fuel/reactor building. This equipment is regulated by the plant's 10CFR 50 [16] operating license.

2.3.3.2 Instrumentation

The NUHOMS® HD System is a totally passive system. No safety-related instrumentation is necessary for monitoring the 32PTH DSC. The maximum temperatures and pressures are conservatively bounded by analyses. Therefore, there is no need for monitoring the internal cavity of the 32PTH DSC for pressure or temperature during normal operations. The 32PTH DSC is conservatively designed to perform its confinement function during all worst case normal, off-normal, and postulated accident conditions.

2.3.4 Nuclear Criticality Safety

2.3.4.1 Control Methods for Prevention of Criticality

The design criteria for criticality is that an upper sub-critical limit (USL) of 0.95 minus statistical uncertainties and bias, shall be limiting for all postulated arrangements of fuel within the canister. The 32PTH DSC incorporates borated aluminum material(s) as fixed neutron absorbing materials to provide criticality control. Criticality control is discussed in Chapter 6.

The 32PTH DSC is designed to assure an ample margin of safety against criticality under the conditions of fresh fuel (fuel without burnup credit) in a canister flooded with borated pool water. The methods of criticality control are in accordance with the requirements of 10CFR 72.124 [2].

Criticality analysis is performed using the SCALE computer code package [1] which is widely used for criticality analysis of shipping casks, fuel storage pools and storage systems. Benchmark problems are run to verify the codes, methodology and cross section library and to determine calculational bias and uncertainties. Chapter 6 of the SAR presents the NUHOMS® HD System criticality analyses.

In the criticality calculation, the fuel assemblies and canister geometries are explicitly modeled. Each fuel pin and each guide tube is represented within each assembly.

Reactivity analyses were performed for CE 14x14, CE 16x16, WE 15x15 and WE 17x17 class fuel assemblies. These analyses do not credit the neutron absorption capability of the CCs where applicable.

2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criterion used in Section 2.3.4.1. The criterion is common practice for licensing submittals. Because conservative assumptions are made in modeling, it is not necessary to introduce additional contingency for error.

2.3.4.3 Verification Analysis-Benchmarking

Evaluation and verification against critical benchmarking experiments are described in Chapter 6, Section 6.5.

2.3.5 Radiological Protection

The NUHOMS® HD System ISFSI is designed to maintain on-site and off-site doses as low as reasonably achievable (ALARA) during transfer operations and long-term storage conditions. ISFSI operating procedures, shielding design, and access controls provide the necessary radiological protection to assure radiological exposures to station personnel and the public are ALARA. Further details concerning on-site and off-site dose rates resulting from NUHOMS® 32PTH HD System, ISFSI operations and the ISFSI ALARA evaluation are provided in Chapter 10.

2.3.5.1 Access Control

The NUHOMS® HD System ISFSI will typically be located within the owner controlled area of an operating plant. A separate protected area consisting of a double fenced, double gated, lighted area may be installed around the ISFSI. Access is then controlled by locked gates, and guards are stationed when the gates are open. The licensee's Security Plan must describe the devices employed to detect unauthorized access to the facility. The specific procedures for controlling access to the ISFSI site and the restricted area within the site per 10CFR 72, Subpart H shall be addressed by the licensee's physical security and safeguards contingency plans. The system will not require the continuous presence of operators or maintenance personnel.

Table 2-1

Fuel to be Stored in the 32PTH DSC

PHYSICAL PARAMETERS: Fuel Class	 Intact or damaged Westinghouse 17x17 (WE 17x17), Westinghouse 15x15 (WE 15x15), Combustion Engineering 16x16 (CE 16x16) and Combustion Engineering 14x14 (CE 14x14) class PWR assemblies (with or without control components) that are enveloped by the fuel assembly design characteristics listed in Table 2-3. Reload fuel manufactured by the same or other vendors but enveloped by the design characteristics listed in Table 2-3 is also acceptable.
Reconstituted Fuel Assemblies: • Maximum No. of Reconstituted Assemblies per DSC With Irradiated Stainless Steel Rods • Maximum No. of Irradiated Stainless Steel Rods per Reconstituted Fuel Assembly • Maximum No. of Reconstituted Assemblies per DSC with unlimited number of low enriched UO_2 rods, or Zr Rods or Zr Pellets or Unirradiated Stainless Steel Rods	 4 10 32
Control Components (CCs)	• Up to 32 CCs are authorized for storage in 32PTH DSC. • Authorized CCs include Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Assemblies (TPAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster Control Assemblies (RCCAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Source Assemblies (NSAs) and Neutron Sources. • Design basis thermal and radiological characteristics for the CCs are listed in Table 2-4.
No. of Intact Assemblies	≤ 32

Table 2-1

Fuel to be Stored in the 32PTH DSC
(Concluded)

No. and Location of Damaged Assemblies	Up to 16 damaged fuel assemblies with balance intact fuel assemblies, or dummy assemblies are authorized for storage in 32PTH DSC. Damaged fuel assemblies are to be placed in the center 16 locations as shown in Figure 2-2. The DSC basket cells which store damaged fuel assemblies are provided with top and bottom end caps to assure retrievability.	
Maximum Assembly plus CC Weight	1585 lbs	
THERMAL/RADIOLOGICAL PARAMETERS: Burnup, Enrichment, and Minimum Cooling Time for the 32PTH DSC	Per Table 2-2	
Maximum Assembly Average Initial Fuel Enrichment	5.0 wt. % U-235	
Maximum Decay Heat Limits for Heat Load Zones 1a, 1b, 2 and 3 fuel.	Per Figure 2-1	
Decay Heat per DSC	≤ 34.8 kW for WE 15x15, WE 17x17 and CE 16x16 class fuel assemblies	
	≤ 33.8 kW for CE 14x14 class fuel assemblies	

Table 2-2

Fuel Qualification Table(s)

Fuel qualification for the 32PTH DSC is shown below:

1) The maximum allowable assembly burnup as a function of assembly average initial enrichment is shown below.

Assembly Average Initial Enrichment (X2) wt.% U-235)	Maximum Assembly Burnup (X1) (GWD/MTU)
$0.2 \leq X2 < 0.3$	20
$0.3 \leq X2 < 0.7$	25
$0.7 \leq X2 < 1.5$	32
$1.5 \leq X2 < 2.5$	55
$2.5 \leq X2 < 5.00$	60

2) For an assembly average initial enrichment (wt. % U-235) greater than or equal to 1.50, an equation shown below to calculate the decay heat shall be employed.

The Decay Heat (DH) in watts is expressed as:

$$F1 = A + B*X1 + C*X2 + D*X1^2 + E*X1*X2 + F*X2^2$$
$$DH = F1*Exp(\{[1-(5/X3)]*G\}*[(X3/X1)^H]*[(X2/X1)^I])$$

where,

F1 Intermediate Function, basically the Thermal source at 5 year cooling
X1 Assembly Burnup in GWD/MTU
X2 Maximum Assembly Average Initial Enrichment in wt. % U-235
(max 5%, min: Zone 1- 1.5%, Zone 2 -1.6%, Zone 3- 2.5%
X3 Cooling Time in Years (min 5 yrs)

A = 13.69479 B =25.79539 C=-3.547739 D= 0.307917 E=-3.809025
F = 14.00256 G=-0.831522 H= 0.078607 I =-0.095900

All fuel assemblies that are acceptable from a thermal standpoint (heat load zoning from Figure 2-1) are acceptable from a radiological source term standpoint. When irradiated stainless steel rods are present in the reconstituted fuel assembly, add an additional year of cooling time for cooling times less than 10 years.

Table 2-2
Fuel Qualification Table(s) (continued)

3). For an assembly average initial enrichment less than 1.5 wt. % U-235, the following qualification shall be employed.

Enrichment Range	Max BU (GWD/MTU)	Cooling Time (Years)	Decay Heat (Watts)
$0.7 \leq X2 < 1.5$	32	5	1100
	32	6	900
	32	7	780
	32	10	620
$0.3 \leq X2 < 0.7$	25	5	970
	25	6	800
	25	7	690
	25	10	540
$0.2 \leq X2 < 0.3$	20	5	652

For an assembly average enrichment between 0.2 and 0.3 wt. % U-235, fuel assemblies with a burnup below 20 GWD/MTU and a cooling time greater than 5 years are qualified for storage anywhere in the basket.

For an assembly average enrichment between 0.3 and 0.7 wt. % U-235, fuel assemblies with a burnup below 25 GWD/MTU and a cooling time greater than 6 years are qualified for storage anywhere in the basket.

For an assembly average enrichment between 0.7 and 1.5 wt. % U-235, fuel assemblies with a burnup below 32 GWD/MTU and a cooling time greater than 7 years are qualified for storage anywhere in the basket.

Table 2-2
Fuel Qualification Table(s) (continued)

Example fuel qualification tables for the various heat load zones that provide the maximum allowable burnup (GWD/MTU) as a function of assembly average initial enrichment (wt. % U-235) and cooling time (years) are shown below.

Examples for Zone 1a -1050 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	Minimum Cooling Time					
	5 Years	6 Years	7 Years	8 Years	10 Years	15 Years
1.50	32.8	37.2	40.7	43.7	48.1	55.2
2.50	34.7	39.2	42.7	45.6	50.0	57.0
3.00	35.5	40.1	43.6	46.5	51.0	57.9
3.50	36.2	40.9	44.5	47.4	52.0	58.9
4.00	36.8	41.5	45.3	48.3	52.8	59.9
4.50	37.2	42.1	45.9	49.0	53.7	60.0

Examples for Zone 1b -800 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	Minimum Cooling Time					
	5 Years	6 Years	7 Years	8 Years	10 Years	15 Years
1.50	26.3	30.0	32.9	35.4	39.2	45.2
2.00	27.1	30.8	33.8	36.2	40.0	46.0
2.50	27.7	31.5	34.5	37.0	40.8	46.7
3.00	28.2	32.1	35.2	37.7	41.5	47.5
3.50	28.5	32.5	35.7	38.3	42.2	48.3
4.00	28.5	32.9	36.2	38.8	42.8	49.0
4.50	28.5	33.0	36.4	39.2	43.3	49.7

Examples for Zone 2 -1100 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	Minimum Cooling Time					
	5 Years	6 Years	7 Years	8 Years	10 Years	15 Years
1.60	34.2	39.8	42.4	45.4	50.0	57.3
2.50	36.0	40.6	44.2	47.2	51.7	58.9
3.00	36.9	41.5	45.2	48.2	52.8	59.9
3.50	37.6	42.4	46.1	49.1	53.7	60.0
4.00	38.3	43.1	46.9	50.0	54.7	60.0
4.50	38.7	43.8	47.7	50.8	55.6	60.0

Table 2-2
Fuel Qualification Table(s) (concluded)

Examples for Zone 3 -1500 watts (Burnup GWD/MTU)

Maximum Assembly Average Initial Enrichment (wt. % U-235)	Minimum Cooling Time			
	5 Years	6 Years	7 Years	8 Years
3.50	47.9	53.5	57.8	60.0
4.00	48.9	54.6	59.0	60.0
4.25	49.4	55.1	59.5	60.0
4.50	49.9	55.6	60.0	60.0

Table 2-3
Spent Fuel Assembly Physical Characteristics

Assembly Class		WE 17x17	WE 15x15	CE 14x14	CE 16x16
Max Unirradiated Length (in)[1]	32PTH	165.75	165.75	165.75	165.75
	32PTH Type 1	171.93	171.93	171.93	171.93
Fissile Material		UO_2	UO_2	UO_2	UO_2
Cladding Material		Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5	Zircalloy / Zirlo / M5
Maximum MTU/Assembly[2]		0.476	0.476	0.476	0.476
Maximum Number of Fuel Rods		264	204	176	236
Maximum Number of Guide/ Instrument Tubes		25	21	5	5

Notes:
(1) Maximum Assembly + Control Component Length (unirradiated)
(2) The maximum MTU/assembly is based on the shielding analysis. The listed value is higher than the actual.

Table 2-4
Maximum Control Component Source Terms

Parameter	BPRA (Bounding)
Gamma Source (γ/sec/DSC)	7.36 E+15
Decay heat (Watts/assy)	9

Table 2-6
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Intact Fuel Assembly (without CCs)	A	4.05	4.40	4.45	4.55
	B	4.55	4.90	5.00	-
	C	4.70	5.00	-	-
	D	5.00	-	-	-
	E	-	-	-	-
CE 14x14 Intact Fuel Assembly (with CCs)	A	3.95	4.25	4.35	4.45
	B	4.35	4.70	4.80	4.90
	C	4.50	4.85	5.00	-
	D	4.75	5.00	-	-
	E	5.00	-	-	-
CE 16x16 Intact Fuel Assembly (without CCs)	A	3.90	4.10	4.20	4.30
	B	4.30	4.60	4.70	4.80
	C	4.50	4.80	4.90	5.00
	D	4.80	5.00	5.00	5.00
	E	5.00	5.00	5.00	5.00
CE 16x16 Intact Fuel Assembly (with CCs)	A	3.80	4.00	4.10	4.20
	B	4.20	4.50	4.60	4.70
	C	4.40	4.70	4.80	4.90
	D	4.70	4.90	5.00	5.00
	E	4.90	5.00	5.00	5.00
WE 15x15 Intact Fuel Assembly (with and without CCs)	A	3.50	3.70	3.80	3.90
	B	3.80	4.10	4.20	4.30
	C	3.95	4.25	4.35	4.45
	D	4.20	4.50	4.70	4.80
	E	4.50	4.80	4.90	5.00
WE 17x17 Intact Fuel Assembly (with and without CCs)	A	3.50	3.70	3.80	3.90
	B	3.80	4.10	4.20	4.30
	C	3.95	4.25	4.35	4.45
	D	4.20	4.50	4.60	4.70
	E	4.45	4.70	4.90	5.00

Table 2-6
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading
(Concluded)

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Damaged Fuel Assembly (without CCs)	A	3.90	4.20	4.25	4.35
	B	4.35	4.70	4.80	4.90
	C	4.50	4.85	4.95	5.00
	D	4.85	5.00	-	-
	E	5.00	-	-	-
CE 14x14 Damaged Fuel Assembly (with CCs)	A	3.70	3.95	4.05	4.10
	B	4.10	4.40	4.50	4.60
	C	4.20	4.55	4.65	4.75
	D	4.50	4.85	5.00	-
	E	4.75	5.00	-	-
CE 16x16 Damaged Fuel Assembly (without CCs)	A	3.65	3.90	4.00	4.05
	B	4.05	4.30	4.40	4.50
	C	4.20	4.50	4.60	4.70
	D	4.50	4.80	4.90	5.00
	E	4.75	5.00	5.00	5.00
CE 16x16 Damaged Fuel Assembly (with CCs)	A	3.60	3.80	3.90	4.00
	B	3.95	4.20	4.30	4.40
	C	4.10	4.40	4.50	4.60
	D	4.40	4.70	4.80	4.90
	E	4.65	4.90	5.00	5.00
WE 15x15 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.35	4.70	4.80	4.90
WE 17x17 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.30	4.65	4.80	4.90

Note: "—" represents those fixed poison loading (basket type) and soluble boron concentration combinations where fuel assemblies with a maximum assembly average initial enrichment of 5.00 wt % U-235 can be loaded

3.5.4 Fuel Unloading

For unloading operations, the DSC will be filled with the spent fuel pool water through the siphon port. During this filling, the DSC vent port is maintained open with effluents routed to the plant's off-gas monitoring system.

When the pool water is added to a DSC cavity containing hot fuel and basket components, some of the water will flash to steam causing internal cavity pressure to rise. The steam pressure is released through the vent port. The initial flow rate of the reflood water must be controlled such that the internal pressure in the DSC cavity does not exceed 20 psig. This is assured by monitoring the maximum internal pressure in the DSC cavity during reflood event. The reflood of the DSC is considered as a "Service Level D" event and the design pressure of the DSC is 120 psig. Therefore, there is sufficient margin in the DSC internal pressure during the reflooding event to assure that the DSC will not be over pressurized.

The maximum fuel cladding temperature during reflooding process is significantly less than the vacuum drying condition owing to the presence of water/steam in the DSC cavity. Hence, the peak cladding temperature during the reflooding operation will be less than 734°F calculated in Chapter 4, Section 4.5.1.

To evaluate the effects of the thermal loads on the fuel cladding during reflooding operations, a conservative high fuel rod temperature of 750°F and a conservative low quench water temperature of 50°F are used. These evaluations are performed in Chapter 4, Section 4.5.2. The calculated maximum fuel cladding stress is 25,910 psi. This calculated maximum stress is much less than the claddings yield stress of 69,500 psi. Therefore, cladding integrity is maintained during reflooding operation.

Under the loads of both the normal transfer and storage conditions, the stresses generated in the canister will not be significantly different between the canister designs with an one-piece top and with a composite top. SAR Drawing 10494–72–4, Rev. 0 shows the alternate composite top.

As described in Chapter 8, Section 8.1.1.3, operation steps 7 and 13, a maximum of 15 psig pressure may be applied at the canister vent port to assist draining of the water. Conservatively, the canister is structurally evaluated for a 60 psig internal pressure using the 2-D ANSYS finite element model described in Appendix 3.9.1, Section 3.9.1.3.2. The outer cover plate of the canister is removed from the 2-D model, since it is not yet installed during the application of this helium pressure. The maximum primary stress intensity and the maximum primary plus secondary stress intensity in the canister due to the 60 psig pressure load (conservatively used for stress calculation) are calculated to be 8,247 psi and 26,070 psi, respectively. Their corresponding stress limits as per ASME B&PV Code Subsection NB [12] are 16,400 psig and 49,200 psi, respectively. Based on this analysis, it concluded that the application of 15 psig pressure to the canister is conservative and acceptable.

Based on the results of these analyses, the design of the 32PTH DSC canister is structurally adequate with respect to both transfer and storage loads under the normal conditions.

B.3. Thermal Loads during Transfer

Generally, thermal stresses develop in the basket if its free thermal expansion is constrained by the peripheral rails or canister. The thermal expansion calculations in Section 3.9.1.4.4 show that the basket rails are free to grow due to the maximum operating temperature in the canister. The rails are attached to the basket with bolts in slotted holes. Thus rails also permit free thermal growth of basket boxes. Aluminum and poison plates are sandwiched by the compartment tubes. A thermal expansion gaps are provided to allow the aluminum/poison plates free to grow in the axial direction while oversize slots are provided to allow aluminum/poison plates free to grow in the radial direction (see TN drawing 10494-72-8). However, some thermal stresses in basket and rails can develop due to radial gradients (hot at center and cooler at periphery) for normal thermal conditions. Basket and Rail thermal stresses are therefore calculated for the 115° F (hot normal), -20° F (cold normal) ambient and vacuum drying process.

Thermal Stresses in Basket Fuel Compartments during Transfer

A three-dimensional finite element model of the basket is used for thermal and stress analyses of the basket, using ANSYS. This finite element model is described in Section 3.9.1.2.3A. Due to symmetry of temperature distribution, only a ¼ model (see Figure 3.9.1-8) is used in this analysis. The rails and canister are removed from the model, as they have no effect on the fuel compartment thermal stresses. The support rails are analyzed separately for the thermal loads.

In order to model realistic contact between the fuel compartments, the couplings are replaced by contact elements. The couplings at the fusion weld locations are replaced by pipe elements.

Two finite element analyses are required to compute the thermal stresses in the fuel basket. The first analysis is a thermal analysis that computes the temperature distribution at each node of the structural model, given the temperature distribution in the thermal model described in Chapter 4. The second finite element analysis computes the thermal stress distribution caused by the temperature distribution computed in the first analysis.

The four-node element SHELL57 (Thermal Shell) and LINK33 (Thermal Conduction Bar) are used in the thermal analysis. These elements are replaced by stress elements SHELL43 and PIPE20 in the stress analysis.

Thermal Analyses

Thermal analyses of a gross model of 32PTH DSC Canister, Basket, and OS187H Cask is conducted for hot and cold normal ambient conditions and for vacuum drying and transfer cask backfill operations in Chapter 4. Steady-state thermal analyses of the basket structural model are conducted to obtain the nodal temperatures by impressing the temperatures computed in the Chapter 4 analyses as the boundary conditions for 115° F, -20° F ambient and vacuum drying cases.

In Chapter 4, the basket and rail temperatures are computed for vacuum drying and TC backfill operations. The table below provides the maximum basket and rail temperatures and thermal gradients from these operations.

	Assumed in this Analysis Max. Temp (°F)	TC Backfill from Table 4-8 At 40 hours, Max. Temp (°F)
Basket Fuel Compartments	697	734
Basket Rails	531	591
Thermal Gradient, ΔT	166	143

From the above table, it is judged that the assumed temperature gradient (shown above in column 2) case will be critical for stresses due to the highest thermal gradient and is selected for the analysis.

Thermal material properties for material (type 304 stainless steel), taken from Reference 1, are reproduced in Table 3.9.1-2.

The thermal analysis resulting temperature distributions for -21° F and 115° F ambient and vacuum drying conditions closely match the temperature distributions presented in Chapter 4.

Thermal Stress Analysis

Elastic stress analyses of the basket structure are conducted in order to compute the thermal stresses. The nodal temperature distribution from the thermal analysis results is applied to obtain the thermal stresses in the model. The resulting nodal stress intensity distribution in the basket fuel compartments reveals that the maximum thermal stress occurs during the vacuum drying load case, and is 9.86 ksi.

Thermal Stresses in Support Rails during Transfer

The temperature distribution and the thermal stresses in peripheral rails are computed using the same methodology as given above for the fuel compartments. The finite element model of the rails is taken from the full basket model described in Section 3.9.1.2.3.A and is shown in Figure 3.9.1-9.

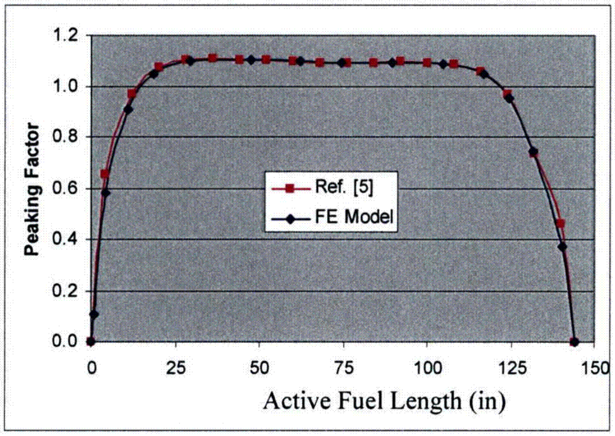
The resulting nodal stress intensity distribution in the support rails reveals that the maximum thermal stress occurs during the vacuum drying load case, and is 18.70 ksi.

D.3. Canister Finite Element Analysis for Transfer Loads

All analyzed load cases in this section are identified in Tables 3.9.1-9 and 3.9.1-10 and are described in detail in the following sections.

Transfer Load Case 1: Deadweight + 15 psig external pressure + Thermal (Vacuum Drying)

The metal temperature profile in the canister shell is assumed to be of the same shape as that of the decay heat peaking factor reported in Chapter 4. The distribution of the decay heat along the fuel effective length for normal condition is shown in the following figure.



The vacuum drying evaluation in Chapter 4 shows a maximum metal temperature of 515° F in the canister. A steady-state thermal calculation using a 2-D canister thermal model is performed to calculate the temperature distribution throughout the canister. In this model the maximum temperature of 522° F is applied to the canister shell in locations corresponding to that between 26 inches and 125 inches of the active fuel length, where the maximum decay heat peaking factor occurs. Also an ambient temperature of 100° F is applied to the outer surfaces of the canister top and bottom plates. A steady-state thermal analysis is conducted to calculate the temperature profile in the canister. This temperature profile is then used as the thermal load for the stress analysis. The stress analysis of this load case contains two load steps. Load step 1 includes the primary loads of 1*g* down deadweight and an external pressure of 15 psig. Load step 2 includes these primary loads plus the secondary thermal loads from the thermal analysis.

For load step 1, the maximum stress intensity in the canister shell is 1,637 psi. The maximum stress intensity in the area of closure weld between the shell and the top shield plug is 1,341 psi., and the maximum stress intensity in the area of closure weld between the shell and the top cover plate is 410 psi.

The following load step 2 is run based on maximum temperature. Since the maximum temperature increased to 522° F, a scale factor of 1.05 [(522-70) / (511-70) = 1.03] is used for

Thermal Expansion between the O.D. of Basket and I.D. of Canister Cavity

Max. OD of cold basket =	68.370 inch	[68.53 – .16 min. gap = 68.37]
Min. ID of cold canister cavity =	68.530 inch	[(69.75 – .12) – 2 × (.50 + .05) = 68.53]

Event	Case	T_{CNH}(2) (°F)	α_{CN} (in/in-°F)	T_{BKH}(3) (°F)	α_{BK} (in/in-°F)	D_{CNH} (in)	D_{BKH} (in)	D_{CNH} - D_{BKH} (in)
Vacuum Drying	TC Backfill	500	9.700E-06	550	9.800E-06	68.816	68.692	0.124
Transfer (34.8 kW)	115°F Amb. Basket Type I, Conf. # 1	460	9.620E-06	640	9.880E-06	68.787	68.755	0.032
	115°F Amb. Basket Type I, Conf. # 2	460	9.620E-06	625	9.850E-06	68.787	68.744	0.043
	115°F Amb. Basket Type I, Conf. # 3	460	9.620E-06	630	9.860E-06	68.787	68.748	0.040
	115°F Amb. Basket Type I, Conf. # 4	460	9.620E-06	640	9.880E-06	68.787	68.755	0.032
	-20°F Amb. Basket Type I, Conf. # 1	390	9.460E-06	570	9.800E-06	68.737	68.705	0.032
	115°F Amb. Basket Type II, Conf. # 1	460	9.620E-06	640	9.880E-06	68.787	68.755	0.032
Storage (34.8 kW)	115°F Amb. HSM-H w/ Finned Side Shield	400	9.500E-06	600	9.800E-06	68.745	68.725	0.020
	-20°F Amb. HSM-H w/ Finned Side Shield	280	9.160E-06	505	9.710E-06	68.662	68.659	0.003
Storage Blocked Vent (34.8 kW)	34 hours after Blockage HSM-H w/ Finned Side Shield	590	9.800E-06	740	1.000E-05	68.879	68.828	0.051

Note :

(1) NOT USED.
(2) Canister temperatures are conservatively decreased from the values calculated in thermal analyses.
(3) Basket temperatures are conservatively increased from the values calculated in thermal analyses.

$D_{CNH} = 68.53 \times [1+ \alpha_{CN} \times (T_{CNH} -70)]$
$D_{BKH} = 68.37 \times [1+ \alpha_{BK} \times (T_{BKH} -70)]$

T_{CNH} = Temperature of hot canister

α_{CN} = Thermal expansion coefficient of canister at T_{CNH} temperature

T_{BKH} = Temperature of hot basket

α_{BK} = Thermal expansion coefficient of basket at T_{BKH} temperature

D_{CNH} = ID of hot canister at T_{CNH} temperature

D_{BKH} = OD of hot basket at T_{BKH} temperature

D_{CNH} - D_{BKH} = diametrical clearance between the ID of the canister and the OD of the basket

C. Thermal Expansion between the Length of Basket and Canister Cavity

The maximum basket length at room temperature, L_b =162.120 inches.
The minimum canister cavity length at room temperature, L_c = 164.50 inches.

Max. cold basket length = 162.120 inch
Min. cold canister cavity length = 164.500 inch

Event	Case	T_{CNH} (1) (°F)	α_{CN} (in/in-°F)	T_{BKH} (2) (°F)	α_{BK} (in/in-°F)	L_{CNH} (in)	L_{BKH} (in)	L_{CNH} - L_{BKH} (in)
Vacuum Drying	TC Backfill	500	9.700E-06	550	9.800E-06	165.186	162.883	2.304
Transfer (34.8 kW)	115°F Amb. Basket Type I, Conf. # 1	460	9.620E-06	640	9.880E-06	165.117	163.033	2.084
	115°F Amb. Basket Type I, Conf. # 2	460	9.620E-06	625	9.850E-06	165.117	163.006	2.111
	115°F Amb. Basket Type I, Conf. # 3	460	9.620E-06	630	9.860E-06	165.117	163.015	2.102
	115°F Amb. Basket Type I, Conf. # 4	460	9.620E-06	640	9.880E-06	165.117	163.033	2.084
	-20°F Amb. Basket Type I, Conf. # 1	390	9.460E-06	570	9.800E-06	164.998	162.914	2.084
	115°F Amb. Basket Type II, Conf. # 1	460	9.620E-06	640	9.880E-06	165.117	163.033	2.084
Storage (34.8 kW)	115°F Amb. HSM-H w/ Finned Side Shield	400	9.500E-06	600	9.800E-06	165.016	162.962	2.054
	-20°F Amb. HSM-H w/ Finned Side Shield	280	9.160E-06	505	9.710E-06	164.816	162.805	2.012
Storage Blocked Vent (34.8 kW)	34 hours after Blockage HSM-H w/ Finned Side Shield	590	9.800E-06	740	1.000E-05	165.338	163.206	2.132

Note:

(1) Canister temperatures are conservatively decreased from the values calculated in thermal analyses.
(2) Basket temperatures are conservatively increased from the values calculated in thermal analyses.

Where,

$L_{CNH} = 164.5 \times [1 + \alpha_{CN} \times (T_{CNH} - 70)]$
$L_{CNH} = 162.12 \times [1 + \alpha_{BK} \times (T_{BKH} - 70)]$
T_{CNH} = Temperature of canister
α_{CN} = Thermal expansion coefficient of canister at T_{CNH} temperature
T_{BKH} = Average of temperatures of hot basket and basket rail
α_{BK} = Thermal expansion coefficient of basket at T_{BKH} temperature
L_{CNH} = Length of hot canister cavity at T_{CNH} temperature
L_{BKH} = Length of hot basket at T_{BKH} temperature
L_{CNH} - L_{BKH} = Hot clearance between the length of the canister cavity and the length of the basket

D. Thermal Expansion between the Outer Diameter of the Canister and the Inner Diameter of the Cask Body

Max. OD of cold canister = 69.870 inch
Min. ID of cold cask cavity = 70.350 inch

Event	Case	T_{CKH}(1) (°F)	α_{CK} (in/in-°F)	T_{CNH}(2) (°F)	α_{CN} (in/in-°F)	D_{CKH} (in)	D_{CNH} (in)	D_{CNH} - D_{BKH} (in)
Vacuum Drying	TC Backfill	265	9.130E-06	525	9.750E-06	70.475	70.180	0.295
Transfer (34.8 kW)	115°F Amb.	330	9.260E-06	485	9.670E-06	70.519	70.150	0.369
	-20°F Amb.	240	9.060E-06	500	9.700E-06	70.458	70.161	0.297

Note:

(1) Cask temperatures are conservatively decreased from the values calculated in thermal analyses.

(2) Canister temperatures are conservatively increased from the values calculated in thermal analyses.

Where,

$D_{CKH} = 70.35 \times [1+ \alpha_{CK} \times (T_{CKH} - 70)]$

$D_{CNH} = 69.87 \times [1+ \alpha_{CN} \times (T_{CNH} - 70)]$

T_{CKH} = Temperature of hot cask outer structural shell

α_{CK} = Thermal expansion coefficient of cask inner liner at T_{CKH} temperature

T_{CNH} = Temperature of hot canister shell

α_{CN} = Thermal expansion coefficient of canister shell at T_{CNH} temperature

D_{CKH} = ID of hot cask inner liner at T_{CKH} temperature

D_{CNH} = OD of hot canister shell at T_{CNH} temperature

D_{CKH} - D_{CNH} = diametrical hot clearance between the ID of the cask inner liner and the OD of the canister shell

E. Thermal Expansion between the Length of the Canister and the Transfer Cask Cavity

Max. length of cold canister = 185.750 inch
Min. length of cold cask cavity = 186.550 inch [186.60 – .05 = 186.55]

Event	Case	T_{CKH} (1) (°F)	α_{CK} (in/in-°F)	T_{CNH} (2) (°F)	α_{CN} (in/in-°F)	L_{CKH} (in)	L_{CNH} (in)	L_{CKH} - L_{CNH} (in)
Vacuum Drying	TC Backfill	265	9.130E-06	525	9.750E-06	186.882	186.574	0.308
Transfer (34.8 kW)	115°F Amb.	330	9.260E-06	485	9.670E-06	186.999	186.495	0.504
	-20°F Amb.	240	9.060E-06	500	9.700E-06	186.837	186.525	0.313

Note:

(1) Cask temperatures are conservatively decreased from the values calculated in thermal analyses.
(2) Canister temperatures are conservatively increased from the values calculated in thermal analyses.

$L_{CKH} = 186.55 \times [1 + \alpha_{CK} \times (T_{CKH} - 70)]$
$L_{CNH} = 185.75 \times [1 + \alpha_{CN} \times (T_{CNH} - 70)]$
T_{CKH} = Temperature of hot cask structural shell
α_{CK} = Thermal expansion coefficient of cask structural shell at T_{CKH} temperature
T_{CNH} = Temperature of hot canister
α_{CN} = Thermal expansion coefficient of canister at T_{CNH} temperature
L_{CKH} = Length of hot cask cavity at T_{CKH} temperature
L_{CNH} = Length of hot canister at T_{CNH} temperature
L_{CKH} - L_{CNH} = diametrical hot clearance between the length of the cask cavity and the length of the canister

3.9.1.4.5. Thermal Expansion Analysis Conclusions

This evaluation demonstrates that adequate clearance is provided between the 32PTH DSC fuel basket and canister shell, and between the 32PTH DSC canister and the OS87H Transfer Cask to permit free thermal expansions among these components due to all specified design and service conditions.

- The ambient temperature range for normal operation is 0 to 100°F (-18 to 38°C). The minimum and maximum off-normal ambient temperatures are -21°F (-29.4°C) and 115°F (46°C) respectively. In general, all the thermal criteria are associated with maximum temperature limits and not minimum temperatures. All materials can be subjected to a minimum environment temperature of -21°F (-29.4°C) without adverse effects.

- The maximum DSC internal pressure during normal and off-normal conditions must be below the design pressures of 15 psig and 20 psig respectively. For accident cases, the maximum DSC internal pressure must be lower than 70 psig during storage and lower than 120 psig during transfer operation.

The NUHOMS®-32PTH DSC is analyzed based on a maximum heat load of 34.8 kW from 32 fuel assemblies with a maximum heat load of 1.5 kW per assembly. For CE 14x14 fuel assembly the maximum total heat load is limited to 33.8 kW. The loading requirements described in Section 4.3.1.3 are used to develop the bounding load configurations.

Appendix 4.16.3 describes the analysis performed to include the CE 16X16 Fuel Assembly to the authorized content of the NUHOMS® HD System. Appendix 4.16.4 describes the analysis performed to change the minimum off-normal ambient temperature from -20 °F to -21 °F.

A description of the detailed analyses performed for normal/off-normal conditions is provided in Section 4.3, and accident conditions in Section 4.4. The thermal analyses performed for the loading and unloading conditions are described in Section 4.5. DSC internal pressures are discussed in Section 4.6.

The analyses consider the effect of the decay heat flux varying axially along a fuel assembly. The axial decay heat profile for a PWR fuel assembly is based on [4]. Section 4.7 describes the calculated peaking factors and the methodology to apply the axial heat profile in the model.

Fuel assemblies are considered as homogenized materials in the fuel compartments. The effective thermal conductivity of the fuel assemblies used in the thermal analysis is based on the conservative assumption that heat transfer within the fuel region occurs only by conduction and radiation where any convection heat transfer is neglected. The lowest effective properties among the applicable fuel assemblies are selected to perform the thermal analysis. Section 4.8 presents the calculation that determines the bounding effective thermal properties of the applicable fuel assemblies.

The thermal evaluation concludes that with a design basis heat load of 34.8 kW and the loading requirements described in Section 4.3.1.3, all design criteria are satisfied.

4.5 Thermal Evaluation for Loading and Unloading Conditions

Fuel loading and unloading operations occur in the fuel handling building. During loading operation fuel assemblies are submerged in pool water permitting heat dissipation. After fuel loading is complete, the TC and 32PTH DSC are removed from the pool and the DSC is drained (helium is used to assist removal of water), dried, backfilled with helium and sealed. The TC will be sealed and backfilled with helium after sealing the DSC.

4.5.1 Vacuum Drying

The loading condition evaluated is the heatup of the DSC before transfer to the storage site. The 32PTH DSC heatup occurs during draining, vacuum drying, backfilling, and sealing of the DSC, when the DSC is contained in the TC in the vertical position inside the fuel handling building. The water level in the annulus between the DSC and TC is monitored during the above operations to be approximately 12 inches below the top of the DSC shell. Water in the annulus is replenished, if required, to maintain the water in the annulus during vacuum drying operations.

It is assumed in this evaluation that the complete drainage of water from the 32PTH DSC cavity may occur either before or after welding the DSC top shield plug. Partial drainage of water from the DSC cavity and from the annulus between the DSC and the TC (approximately 12 inches below the top of the DSC shell) is required to perform the welding. Helium is used to assist removal of water from the DSC cavity and during backfilling. Maintaining a helium atmosphere within the DSC cavity is required after drainage of water.

Fuel cladding temperature must be maintained below 752°F as required in [2].

Since the DSC is backfilled with helium after drainage of water and water is maintained in the annulus between the DSC and TC, there is no time limit for completion of the vacuum drying process. The reason is the DSC shell temperature is maintained at temperatures lower than the values calculated for the storage conditions. With helium in the DSC cavity, the fuel cladding temperature is well below the values calculated for the off-normal storage conditions in Section 4.3.6, and would never approach the allowable limit of 752°F.

4.5.1.1 Transfer Cask Annulus Backfill

After completion of the vacuum drying, the DSC must be sealed, the annulus between the DSC and the transfer cask must be drained, the cask must be sealed and backfilled with helium. To ensure the integrity of the fuel cladding, a time limit is considered for performing the activities after drainage of the annulus water until backfilling of the transfer cask starts. This time limit is calculated in this section, as follows:

In the calculational model, the water in the annulus is assumed to be drained as soon as its temperature exceeds 180°F (conservative assumption). Two time limits are calculated for this scenario. The first time limit starts after complete DSC drainage. The second time limit includes the activities after drainage of the annulus water to the point that DSC backfilling starts. Even though helium is required as a cover gas during water draindown from the DSC cavity, to be conservative, it is assumed that backfilling of the DSC with helium starts not immediately after drainage of the DSC water, but occurs after drainage of the annulus water.

Transient thermal analyses are performed to determine the time limits. A bounding initial average temperature is considered to start the transient analysis.

The three-dimensional model of the 32PTH DSC within the TC described in Section 4.4.1.1 is slightly modified to analyze this operation. The model contains a half slice of the 32PTH DSC within the TC. The modifications are:

- The DSC is centered in the transfer cask cavity
- The effective conductivity of fuel assemblies are changed to the values reported for vacuum conditions in Section 4.2
- Air conductivity is given to the elements representing the gas and gaps within the basket
- It is considered that the annulus between the DSC and the TC is initially filled with water
- Radiation is not considered between the basket rails and the DSC shell

All the other material properties remain unchanged.

Free convection and radiation are combined together to calculate the total heat transfer coefficient from the TC outer surface to the ambient. Due to the large outer diameter of the TC, the free convection coefficient approaches that for a vertical flat plate. The correlations to calculate the free convection coefficient on vertical plates are discussed in Section 4.11. Following inputs are considered to calculate the total heat transfer coefficient on the outer surface of the transfer cask in this evaluation.

- Ambient temperature in the fuel handling building is 100°F.
- Height of the cylinder is 173", which is approximately the length of the neutron shield panel.
- Surface emissivity of the transfer cask is 0.9 (see Section 4.2 for painted surfaces)

A decay heat load of 34.8 kW is considered for the transient runs. The decay heat is applied as heat generating boundary conditions on the elements representing the homogenized fuel assemblies with a peaking factor of 1.1. Loading configuration 1 is considered for this purpose. Adiabatic boundary conditions are applied on the top and bottom faces of the slice model for conservatism.

Conduction and free convection heat transfer are combined together to calculate an effective conductivity for the water in the annulus. The calculation of the effective conductivity for the water in the annulus is discussed in detail in Section 4.9.

After draining the water from the annulus, thermal properties of air (conduction only) are considered for the elements in the annulus between the 32PTH DSC and the TC. Free convection and radiation boundary conditions are applied on the outer surface of the TC using the total heat transfer coefficient described in Section 4.11.

As described earlier, helium is required as a cover gas during water draindown from the DSC cavity. However, to be conservative the following assumptions are made. To calculate the time limit to backfill the transfer cask with helium after completion of the vacuum drying, the properties of the DSC backfill gas is changed to that of helium, and the fuel effective conductivities are changed to those calculated for helium atmosphere. Time of this change is 14 hours after complete drainage of DSC water. It is considered that it takes three hours until the helium replaces the water vapor within the DSC cavity completely. After the three hour period, the conductivity of back fill gas is changed to that of helium, and the fuel effective conductivities are changed to those calculated for helium atmosphere.

An average, initial temperature at the beginning of the transient runs is calculated for the 32PTH DSC and transfer cask as follows.

Initial Temperature 1 = initial pool temperature +
average heat up rate with water in DSC × duration of lifting +
average heat up rate without water in DSC × duration of drainage
when water from the DSC cavity is drained completely before the welding process

and

Initial Temperature 2 = initial pool temperature +
average heat up rate with water in DSC × duration of lifting +
average heat up rate with water in DSC × duration of welding
when water from the DSC cavity is drained completely after the welding process

Following assumptions are considered to calculate the initial temperature:

- Initial pool temperature is 115°F
- No heat dissipation occurs from the transfer cask outer surface
- All the decay heat is used to heat up the transfer cask and its content
- Lifting the transfer cask from the pool to the fuel handling building and performing the required inspections take 2 hours

- Drainage (pumping) of water from the DSC takes 4 hours

The average heat up rate is defined as:

$$heat\ up\ rate = \frac{Q}{M\ \overline{C}_p}$$

Q = total decay heat load = 34.8 kW (118748 Btu/hr)
M = total weight (lbm)
$\overline{C}_p$ = average specific heat (Btu/lbm-°F)

The average specific heat is the mass average specific heat of all of the components.

$$\overline{C}_p = \frac{\sum m_i\ C_{p,i}}{M}$$

The components volumes and weights are taken from Chapter 3. Specific heat values increase generally at higher temperatures. Specific heats of the components are taken at about 100°F, which results in higher initial temperature and increases the conservatism in the model. A summary of the heat up rate calculation is shown in Table 4-7. The initial average temperature of the transfer cask and its content is then:

Initial average temp 1 = 115 + 3.2 × 2 + 4.5 × 4 = 139.4°F
with initial pool temperature =115°F
average heat up rate during lifting = 3.2°F /hr (see Table 1)
duration of lifting = 2 hrs
average heat up rate after drainage of DSC = 4.5 °F /hr (see Table 1)
duration of draining water from DSC = 4 hrs

Initial average temp 2 = 115 + 3.2 × 2 + 3.2 × 10 = 153.4°F
with initial pool temperature =115°F
average heat up rate during lifting = 3.2°F /hr (see Table 1)
duration of lifting = 2 hrs
average heat up rate before drainage of DSC = 3.2°F /hr (see Table 1)
duration of welding the DSC shield plug = 10 hrs

For conservatism, an initial temperature of 160°F is considered for the TC and its content at the start of the transient runs.

4.5.1.2 Evaluation of Vacuum Drying and TC Backfill Operations

The maximum fuel cladding temperatures during TC backfill operations are summarized in Table 4-8. Typical temperature distributions at the end of vacuum drying process are shown in Figure 4-34. Histories of the maximum component temperatures are shown in Figure 4-37.

The time limit to start backfilling of the transfer cask with helium must be within 28 hours after drainage of the annulus water based on the time-temperature history curve shown in Figure 4-37.

Vacuum drying operations preclude any thermal cycling of fuel cladding. Backfilling the DSC with helium gas causes a one time temperature drop, which is not considered as a repeated thermal cycling. Re-evacuation of the DSC under helium atmosphere does not reduce the pressure sufficiently to decrease the thermal conductivity of helium. Therefore, evacuation and re-pressurizing the DSC under helium atmosphere proceed on a descending curve to the minimum steady state temperatures, and does not include any thermal cycling. It concludes that the limit of 65°C (118°F) considered for thermal cycling is not applicable for NUHOMS®-32PTH system.

As discussed in Section 4-5.1, there is no time limit for completion of the DSC vacuum drying process because helium is used to assist drainage of water from DSC. In this case the maximum fuel cladding temperature remains below the allowable limit of 752 °F (400 °C)

The time limit for the helium backfilling of the DSC/TC annulus is 28 hours starting from the time of drainage of the annulus water.

4.5.2 Reflooding

For unloading operations, the DSC will be filled with the spend fuel pool water through the siphon port. During this filling, the DSC vent port is maintained open with effluents routed to the plant's off-gas monitoring system.

When the pool water is added to a DSC cavity containing hot fuel and basket components, some of the water will flash to steam causing internal cavity pressure to rise. The steam pressure is released through the vent port. The initial flow rate of the reflood water must be controlled such that the internal pressure in the DSC cavity does not exceed 20 psig. This is assured by monitoring the maximum internal pressure in the DSC cavity during reflood event. The reflood of the DSC is considered as a "Service Level D" event and the design pressure of the DSC is 120 psig. Therefore, there is sufficient margin in the DSC internal pressure during the reflooding event to ensure that the DSC will not be over pressurized.

The maximum fuel cladding temperature during reflooding process is significantly less than the vacuum drying condition owing to the presence of water/steam in the DSC cavity. Hence, the peak cladding temperature during the reflooding operation will be less than 734°F calculated for procedure A in Section 4.5.1 when water circulates in the annulus between the DSC and transfer cask.

To evaluate the effects of the thermal loads on the fuel cladding during reflooding operations, a conservative high fuel rod temperature of 750°F and a conservative low quench water temperature of 50°F are used.

The following material properties, corresponding to 750°F, are used in the evaluation.

Modulus of elasticity, $E = 10.4 \times 10^6$ psi $= 7.17 \times 10^{10}$	(Pa)	[26]
Modulus of rigidity, $G = 2.47 \times 10^{10}$	(PaPa)	[31]
Thermal expansion coefficient, $\alpha = 6.72 \times 10^{-6}$	(1/K)	[31]
Yield stress, Sy = 80,500 psi $= 5.55 \times 10^8$	(Pa)	[26]
Poisson's ratio, $\upsilon = \dfrac{E}{2G} - 1$		[27]

The fuel cladding stress is evaluated as a hollow cylinder with an outer surface temperature of T (50°F), and the inner surface temperature of T+ΔT (750°F) using the following equations from [27].

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Gas volume in the void space of DSC = Total DSC cavity volume – Gas volume in the fuel compartments
Total DSC cavity volume (V_{cavity}) = 308,146 in^3 [Chapter 3]
Gas volume in fuel compartments = 243,889 in^3
Gas volume in void space of DSC (V_{void}) = 64,257 in^3

The average gas temperature in the 32PTH DSC is calculated as follows:

$$\overline{T}_{DSC} = \frac{T_{avg,fuel} \times V_{He,comp} - T_{avg,void} \times V_{void}}{V_{cavity}}$$

For an average gas temperature, the mass and volume average temperatures are equal. The results are summarized below.

Operating Condition		$\overline{T}_{DSC}(^oF)$
Storage	Normal	515
	Off-Normal	515
	Accident [7]	647
Transfer	Normal	537
	Off-Normal	537
	Accident [8]	961

Using Al-6061 instead of Al-1100 for rail inserts and back plates increases the DSC component temperature by at most 4 °F as discussed in Section 4.3.2. A noted in Table 4-2, the DSC component temperatures for normal and off-normal storage conditions are based on maximum DSC shell temperature of 422°F instead of 407°F for conservatism. This conservatism compensates more than adequate the temperature increase due to use of Al-6061. Therefore, the average gas temperatures in the above table remain bounding for storage conditions.

The temperature increase of 4°F for transfer conditions results in an increase of at most 0.3% for absolute average gas temperature within DSC cavity.

Temp. Increase / Absolute Fuel Cladding Temp. [Table 4-2] = 4/(723 + 460) = 0.3%

4.6.2 Amount of Initial Helium Backfill

The initial helium fill pressure within the canister is 2.5±1.0 psig after vacuum drying. An initial pressure of 3.5 psig (18.2 psia) is considered here to maximize the amount of helium gas. The finite element model developed to analyze the vacuum drying process (Section 4.5.1) is run for steady state conditions with helium atmosphere to consider the minimum initial DSC temperature before backfilling, which gives the maximum amount of initial helium gas. The average gas temperature is then calculated using the same methodology described in section 4.6.1. The initial temperature of the backfill gas within the canister is 469°F.

[7] After 48 hours of vent blockage
[8] At the end of cool down period, 120 hours after beginning of the fire

4. Air at low pressure (0.1 bar)

Temperature (K)	Conductivity [5] (W/m-k)	Temperature (°F)	Conductivity (Btu/hr-in-°F)
200	0.0180	-100	0.0009
300	0.0263	80	0.0013
400	0.0336	260	0.0016
500	0.0403	440	0.0019
600	0.0466	620	0.0022
800	0.0577	980	0.0028
1000	0.0681	1340	0.0033

The air conductivity at low pressure is used to calculate the effective transverse conductivity for vacuum drying conditions. Air is not allowed for blowdown operations. Only helium is allowed. For conservatism, air conductivity is utilized in the calculational models (for 14 hours) for vacuum drying and transfer cask backfill operations.

5. Stainless Steel SA-240, Type 304

A stainless steel emissivity of 0.3, a value lower than the measured values from Reference [14] is used in the analysis for conservatism.

4.8.3 Effective Fuel Conductivity

4.8.3.1 Transverse Effective Conductivity

The purpose of the effective conductivity in the transverse direction of a fuel assembly is to relate the temperature drop of a homogeneous heat generating square to the temperature drop across an actual assembly cross section for a given heat load. This relationship is established by the following equation obtained from Reference [32]:

$$k_{eff} = \frac{Q}{4L_a\,(T_c - T_o)}(0.29468)$$

where:

k_{eff} = Effective thermal conductivity (Btu/hr-in.-°F)
Q = Assembly head generation (Btu/hr)
Q_{react} = Reaction solution retrieved from quarter model (Btu/hr)

$Q = 4 \times Q_{react} \times L_a$ for WE and MK BW assemblies with quarter symmetric models

$Q = Q_{react} \times L_a$ for CE 14x14 assembly with full-scale model

Q_{react} = Reaction solution retrieved from the ANSYS model (Btu/hr-in)
L_a = Assembly active length (in.)
T_o = Maximum temperature (°F)
T_s = Surface temperature (°F)

Discrete finite element models of the fuel assemblies to be stored in the NUHOMS®-32PTH DSC are developed using the ANSYS computer code [16]. These two-dimensional models simulate heat transfer by radiation and conduction and include the geometry of the fuel rods and fuel pellets. Helium or air properties are used as the fill gas in the fuel assembly. A fuel

Table 4-8
Maximum Temperatures during TC Backfill Operations

Component	TC Backfill[a] T_{max} (°F)	Allowable Limit (°F)
Fuel assembly	734	752 [2]
Basket Al plates	714	---
Basket rails	591	---
DSC shell	515	---
TC inner shell	278	---
Lead gamma shield	275	---
TC Structural shell	219	---
Liquid neutron shield – T_{max}	215	---
Liquid neutron shield – T_{bulk}	208	---
Neutron shield panel	205	---

[a]28 hours after drainage of the annulus water with helium in the DSC cavity

Table 4-9
Maximum Decay Heat Load without Time Limitation for TC Backfill

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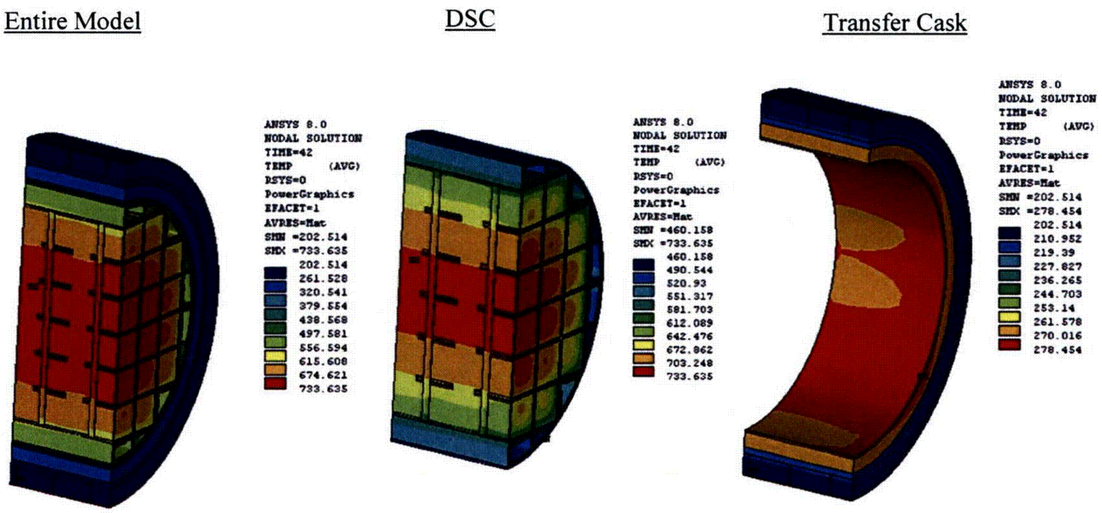

Figure 4-34
Temperature Distribution for TC Backfill Operations

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Figure 4-35

FIGURE IS DELETED IN ITS ENTIRETY

Figure 4-36

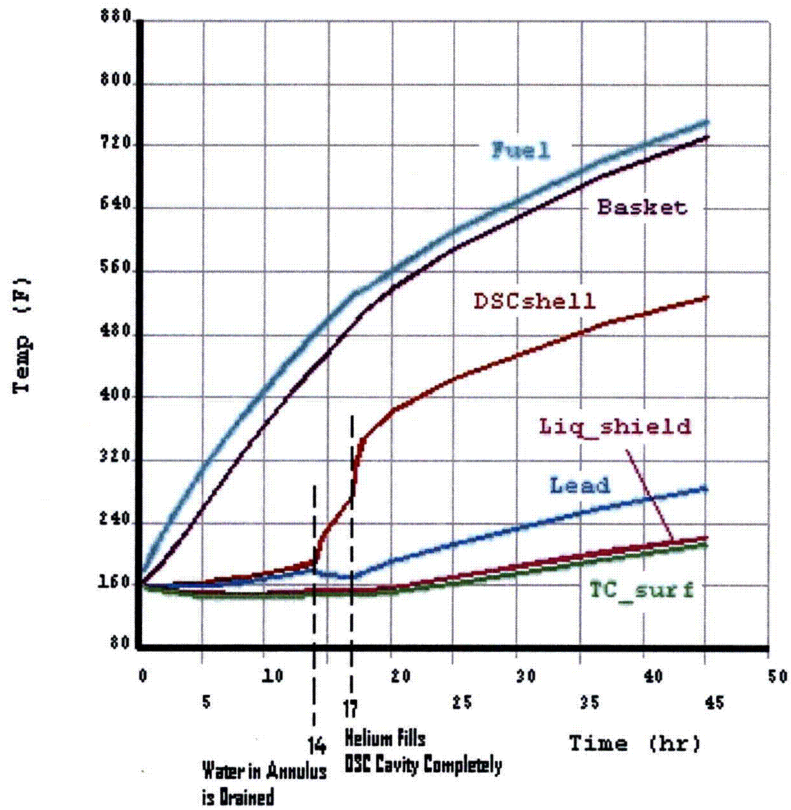

Figure 4-37
Time-Temperature History for TC Backfill Operations

APPENDIX 4.16.3 ADDITION OF CE 16x16 FUEL ASSEMBLIES

4.16.3.1 Effective Thermal Conductivity

CE 16x16 fuel assembly effective properties are calculated using the methodology described in Chapter 4, Section 4.8. The values calculated in Section 4.8 are lower than the values for the CE 16x16 fuel assemblies. Therefore, the thermal analysis results calculated using the existing thermal properties also remain bounding for the CE 16x16 Fuel Assemblies. Therefore, there is no change in thermal properties used for 32PTH system thermal analyses and 32PTH bounding thermal results remain unchanged.

The effective transverse conductivity of fuel assemblies are plotted in Figure 4.16.3-1, which includes CE 16x16 fuel. The bounding values shown herein correspond to those from Chapter 4, Figure 4-41.

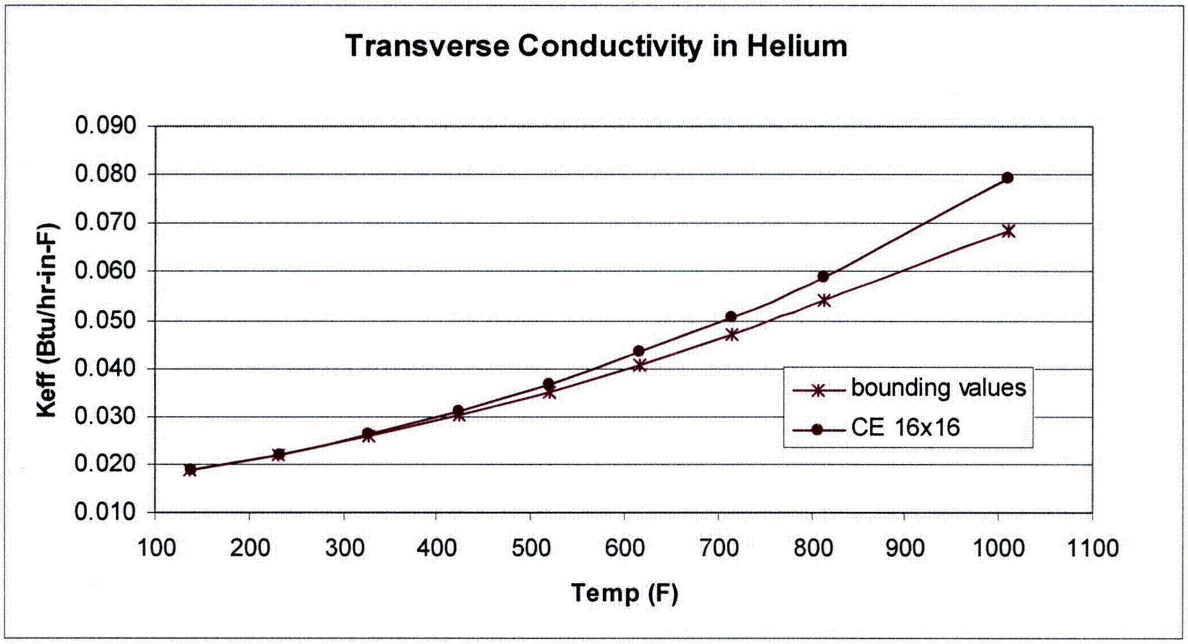

Figure 4.16.3-1
Existing Bounding Fuel and CE 16x16 Fuel Effective Transverse Fuel Conductivity in Helium

APPENDIX 4.16.4
EFFECT OF CHANGE IN MINIMUM OFF-NORMAL AMBIENT TEMPERATURE TO −21 °F

The analysis provided below shows that the effect of a 1 °F reduction in the minimum off-normal ambient temperature is bounded by the conservatism included in the −20 °F minimum ambient temperature case.

The air flow calculation for minimum ambient conditions is described in Section 4.13 for a minimum ambient temperature of -20 °F. The thermal response of the HSM and DSC for temperature variations during the day is relatively slow because of the large thermal inertia of the system. Therefore, consideration of an average minimum temperature over a 24-hour period is reasonable to calculate temperatures and thermal gradients for the HSM, TC, and DSC using steady state boundary conditions. For a day with a minimum temperature of −21 °F, a 24-hour average ambient temperature will be higher than −20 °F (since the minimum mean daily temperature range is about 10 °F as shown in Chapter 24, Table 1 of the ASHRAE Handbook—reference 4.18). Therefore, the air flow, HSM-H, TC, and DSC temperature and internal DSC pressure values calculated for a minimum ambient temperature of −20 °F in Section 4.13 bound those for a minimum ambient temperature of −21 °F, due to the conservatisms included in the current analyses.

5. SHIELDING EVALUATION

The shielding evaluation presented for the NUHOMS® 32PTH System demonstrates adequacy of the shielding design for the payload described in Chapter 2. The geometry of the NUHOMS® System is described in Chapter 1. The heavy concrete walls and roof of the Horizontal Storage Module (HSM-H) provide the bulk of the shielding for the payload in the storage condition. During fuel loading and transfer operations, the combination of thick steel shield plugs at the ends of the 32PTH-DSC and heavy steel/lead/neutron shield material of the OS187H transfer cask provide shielding for personnel loading and transferring the 32PTH-DSC to the HSM-H. Figure 5-1 through Figure 5-4 and Table 5-1 provide the general configuration and material thicknesses of the important components of the NUHOMS® 32PTH System.

For this shielding evaluation, source terms are calculated for the bounding Framatome ANP Advanced MK BW 17x17 (MK BW 17x17) fuel assembly, a WE 17x17 class fuel assembly. This fuel assembly is bounding because it contains the greatest mass of fuel.

The 32PTH DSC is also designed to store up to 32 intact standard PWR fuel assemblies with or without Control Components (CCs) such as burnable poison rod assemblies (BPRAs), Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), Rod Cluster Control Assemblies (RCCAs), Thimble Plug Assemblies (TPAs), Axial Power Shaping Rod Assemblies (APSRAs), Orifice Rod Assemblies (ORAs), Vibration Suppression Inserts (VSIs), Neutron Sources, and Neutron Source Assemblies (NSAs). The design basis CC for shielding evaluation is the BPRA.

Several burnup/enrichment combinations with minimum 5 year cooling times are addressed for the fuel to provide more flexibility in qualifying fuel for storage. These combinations form the basis for the NUHOMS® 32PTH System fuel specifications in Chapter 12. Bounding operating histories are assumed for the BPRA with a minimum cooling time of 4 days. The methodology, assumptions, and criteria used in this evaluation are summarized in the following subsections.

Section 5.4 provides a three dimensional (3-D) shielding analysis for the NUHOMS® 32PTH System using MCNP [2,6]

The shielding evaluation described in this chapter 5.0 is applicable to the 32PTH DSC in the OS187H TC and HSM-H. See Appendix A, Chapter A.5 for discussion of applicability of these analyses for the 32PTH Type 1 DSC in the OS187H Type 1 TC and HSM-H.

5.1 Discussion and Results

The maximum and average dose rates due to 32 design basis PWR fuel assemblies stored with 32 design basis CCs (BPRAs) in the NUHOMS® 32PTH System are summarized in Table 5-2 through Table 5-5. Table 5-2 provides the dose rates on the surface of the HSM-H while Table 5-3 through Table 5-5 provide the dose rates on and around the Transfer Cask (top, bottom and sides) during fuel loading, and transfer operations.

As previously stated, the NUHOMS® HD System is capable of storing PWR spent fuel, and CCs. Based on the source term calculations presented in Section 5.2, the design basis fuel source term is the Framatome MK BW 17x17 fuel assembly with 60 GWD/MTU burnup, a minimum initial enrichment of 4.0 weight % U-235 and a cooling time of 7 years. The design basis CC source term is a BPRA assembly irradiated to 30 GWD/MTU and a cooled for 4 days.

Fuel qualification tables are developed (based on a decay heat equation) that determine the eligibility of fuel assemblies to be stored in the 32PTH DSC. Since bounding parameters are utilized in all the 32 fuel assembly locations in the shielding evaluation, fuel qualification is limited only by the heat capacity of the DSC. This qualification covers fuel assemblies with a minimum enrichment of 0.2 wt. % U-235 and a minimum cooling time of 5 years. Fuel assemblies with enrichment between 0.2 wt. % U-235 and 1.5 wt. % U-235 are qualified by limiting their burnup. This ensures that the shielding analysis is also bounding for these fuel assemblies.

Reconstituted fuel assemblies where fuel pins that are replaced by lower-enriched pins or non-fuel pins are also authorized for storage. A discussion on the qualification methodology is provided in Section 5.2.

A discussion of the method used to determine the design basis fuel and CC source terms is included in Section 5.2,. The model specification and shielding material densities are given in Section 5.3. The method used to determine the dose rates due to 32 design basis fuel assemblies with 32 design basis CC in the NUHOMS® 32PTH System is provided in Section 5.4.

Normal and off-normal conditions are modeled with the NUHOMS® 32PTH System intact, including the filled neutron shield in the transfer cask. The shielding calculations are performed using the MCNP Monte Carlo transport code [2]. Average and peak dose rates on the front, side, top and back of the HSM-H and the OS187H Transfer Cask System are calculated. Occupational doses during loading, transfer to the ISFSI, and maintenance and surveillance operations are provided in Chapter 10. Locations where streaming could occur are discussed in Chapter 10.

For accident conditions (e.g., cask drop, fire), the transfer cask neutron shield water (shown in Figure 5-4 is assumed to be removed and a 1 inch void in the lead due to "lead slump' is also assumed at the top and/or bottom. Site dose and occupational dose analyses are addressed in Chapter 10 (including requirements for site specific 72.104 and 72.106 analyses).

5.2 Source Specification

Source terms are calculated with the SAS2H (ORIGEN-S) module of SCALE 4.4 [1]. The following sub-sections provide a discussion of the fuel assembly and CC material weights and composition, gamma and neutron source terms and energy spectrum. The SAS2H results are used to develop source terms suitable for use in the shielding calculations.

There are five principal sources of radiation associated with the NUHOMS® 32PTH System that are of concern for radiation protection. These are:

1. Primary gamma radiation from the spent fuel
2. Primary gamma radiation from activation products in the structural materials found in the spent fuel assembly and the CC
3. Primary neutron radiation from the spent fuel
4. Neutrons produced from sub-critical multiplication in the fuel
5. Capture gammas from (n,γ) reactions in the NUHOMS® 32PTH System materials

The first three sources of radiation are evaluated using SAS2H. The capture gamma radiation and sub-critical multiplication are handled as part of the shielding analysis which is performed with MCNP.

The neutron flux during reactor operation is peaked in the active fuel (in-core) region of the fuel assembly and drops off rapidly outside the in-core region. Much of the fuel assembly hardware is outside of the in-core region of the fuel assembly. To account for this reduction in neutron flux, each fuel assembly type is divided into four exposure zones. A neutron flux (fluence) correction is applied to each region to account for this reduction in neutron flux outside the in-core region. The correction factors are given in Table 5-6. The four exposure zones, or regions are [4]:

Bottom—location of fuel assembly bottom nozzle and fuel rod end plugs
In-core—location of active fuel
Plenum—location of fuel rod plenum spring and top plug
Top—location of top nozzle

The Framatome MK BW 17x17 assembly is the bounding fuel assembly design for shielding purposes because it has the highest initial heavy metal loading as compared to the 14x14, 15x15, and other 17x17 fuel assemblies which are also authorized contents of the NUHOMS®-32PTH DSC and described in Chapter 2. The SAS2H/ORIGEN-S modules of the SCALE code with the 44 group ENDF/B-V library are used to generate the gamma and neutron source terms. For the bounding MK BW 17x17 fuel assembly, an initial enrichment of 4.0 wt% U-235 is assumed. The fuel assembly is irradiated with a constant specific power of 25 MW/assy to a total burnup of 60 GWD/MTU. A conservative three-cycle operating history is utilized with a 20 day down time between each cycle. The fuel assembly masses for each irradiation region are listed in Table 5-7

Data for the WE 17x17 assembly is from Reference [7]. Some values for the WE 15x15 were assumed to be the same as the WE 17x17. The design-basis heavy metal weight is 0.476 MTU. These masses are irradiated in the appropriate fuel assembly region in the SAS2H/ORIGEN-S models. The mass of hardware for the MK BW 17x17 assembly is the greatest; however, the source term from the irradiated hardware for the WE 17x17 is bounding.

The maximum burnup of fuel assemblies with enrichments between 0.7 wt% U-235 and 1.5 wt % U-235 is limited to 32 GWD/MTU to ensure that their gamma and neutron source terms are bounded by those of the design basis fuel assembly. Similarly, the maximum burnup of fuel assemblies with enrichments between 0.3 wt.% U-235 and 0.7 wt.% U-235 is limited to 25 GWD/MTU. The maximum burnup of fuel assemblies with enrichments between 0.2 wt.% U-235 and 0.3 wt.% U-235 is limited to 20 GWD/MTU.

RECONSTITUTED FUEL ASSEMBLIES

The maximum number of reconstituted fuel assemblies that can be loaded per DSC is 32. Fuel assemblies may contain up to 10 rods that are reconstituted with stainless steel that is irradiated. There is no limit on the number of rods reconstituted with unirradiated stainless steel or Zircalloy or low enriched UO_2. There is no effect on the source terms/shielding due to the position of the reconstituted rods in the fuel rod array. Reconstituted fuel has a rather small effect on the dose rate such that for cooling times less than 10 years, 1 year of cooling time is added if reconstituted rods (with irradiated stainless steel) are present in fuel assemblies that are cooled to 10 or fewer years.

If reconstituted fuel assemblies (considered as intact fuel in the criticality analyses) with stainless steel rods undergo further irradiation, their gamma source term on a per DSC basis shall be bounded by the total design basis gamma source terms shown (on an assembly basis) in Table 5-10 for the design basis fuel assembly.

As explained above, reconstituted fuel assemblies may contain up to 10 irradiated stainless steel rods that replace damaged fuel rods. Because steel rods replace fuel rods, the decay heat of a reconstituted assembly is typically less than the decay heat of an equivalent standard assembly. Conversely, because steel contains Co-59 which activates to form Co-60, for low cooling times a reconstituted assembly typically generates higher dose rates than an equivalent standard assembly. As the half-life of Co-60 is 5.27 years, after 10 years the Co-60 activity has reduced by almost a factor of four and a reconstituted assembly no longer generates higher dose rates than an equivalent standard assembly. To bound this effect, the fuel qualification tables require that for fuel assembly with irradiated reconstituted steel rods with cooling times less than 10 years, additional one year of cooling time is required. For cooling times of 10 years or greater, no additional cooling time is required to bound the reconstituted fuel with steel rods.

TPA

The TPA materials and masses for each irradiation zone are listed in Table 5-8. These materials are irradiated in the appropriate zone for fourteen cycles of operation. The TPA is irradiated to an equivalent assembly life burnup of 210 GWd/MTU over 14 cycles. The model assumes that the TPA is irradiated in an assembly each with an initial enrichment of 3.50 weight % U-235.The fuel assembly, containing the TPA, is burned for three cycles with a burnup of 15 GWd/MTU per cycle. This is equivalent to an assembly life burnup of 45 GWd/MTU over the three cycles. The results for a cooling time of 20 years are increased by the ratio of 14/3 to achieve the equivalent 210 GWD/MTU source.

BPRA

The BPRA materials and masses for each irradiation zone are also listed in Table 5-8. These materials are irradiated in the appropriate zone for three cycles of operation. The model assumes that the BPRA is irradiated in an assembly each with an initial enrichment of 3.50 weight % U-235. The fuel assembly containing the BPRA is burned for three cycles with a burnup of 10 GWd/MTU per cycle. This is equivalent to an assembly life burnup of 30 GWd/MTU over the three cycles. The source term for the BPRA is taken at 4 days cooling time.

VSI

VSIs are very similar in design to burnable poison rod assemblies: the stainless steel baseplate and hold-down spring assembly designs are identical to those used on older Westinghouse BPRAs. Each VSI contains 24 solid Zircalloy-4 damper rods that are attached to the hold-down assembly using a crimp nut top connector. The damper rods are the same diameter and length as BPRA rodlets. The VSIs are assumed to be equivalent in source strength to BPRAs.

Neutron Sources

Neutron sources usually consist of a single pin containing the source material. They are typically irradiated for several cycles prior to final discharge. The neutron source term from these series is several orders of magnitude lower than that of the spent fuel. The gamma source term is bounded by that of a BPRA.

Other CCs

All other CCs listed in Section 5 are not evaluated explicitly. However, the resulting source term from these CCs to be bounded by that of the design basis BPRA as described above.

Elemental Compositions of Structural Materials

To account for the source terms due to the elemental composition of the fuel assembly and CC structural materials the following methodology is used:

1) The material composition for each irradiation region is determined for the assembly and CC type.

2) The elemental compositions for each of the structural materials present in each region is determined by multiplying the total weight of each material in a specific irradiation zone (Table 5-7) by the elemental compositions. The fuel assembly and NFAH elemental composition, including impurities, for each material are taken from Reference [7].

3) The results of each material are summed to determine the total elemental composition for each irradiation zone.

4) The elemental composition is multiplied by the appropriate flux factor given in Table 5-6.

5) Finally, the elemental composition is entered in the light element card of the SAS2H input. The elemental composition for the fuel assembly is shown in Table 5-9.

The SAS2H calculation applies the total flux to the light elements; therefore, the total composition must be adjusted by the appropriate flux factor in the input. A SAS2H input is created for each irradiation zone of each fuel assembly and CC type. An example input file for the active fuel zone is shown in Section 5.5.2.

5.2.1 Gamma Sources

Source terms for the fuel bounding Framatome MK BW 17x17 fuel assembly and associated burnup/initial enrichment/cooling times and CCs are calculated with SAS2H module and the 44 group ENDF/B-V library. The SAS2H calculated contributions from actinides, fission products, and activation products, as applicable, are included for each irradiation region. The 7-year post irradiation cooling time results for the MK BW 17x17 fuel with 60 GWD/MTU burnup, and 4.0 wt % U-235 initial enrichment are shown in Table 5-10. The post irradiation cooling time results for the TPA, and BPRA are shown in Table 5-11, and Table 5-12, respectively.

Based on the results presented in Table 5-11 and Table 5-12 (maximum gamma source term) the design basis CC is the BPRA. The spectrum is dominated by Co-60 for all CC. These design basis fuel assembly sources with the BPRA source are used in the MCNP calculations to determine the bounding dose rates on and around the NUHOMS® 32PTH System, including the Transfer Cask.

5.2.2 Neutron Source

The total neutron source for the NUHOMS® 32PTH System is also calculated with SAS2H. The total neutron sources for the MK BW 17x17 assembly is summarized in Table 5-13. Again, the design basis source term is for 60 GWd/MTU burnup, 4.00 weight % U-235 initial enrichment and 7-year cooling time. The neutron source term consists primarily of spontaneous fission neutrons (largely from Cm-244) with (α,O-18) sources of lesser importance, both causing secondary fission neutrons. The overall spectrum is well represented by the Cm-244 fission spectrum.

5.3 Model Specification

The neutron and gamma dose rates on the surface of the HSM-H, and on the surface, and at 1.5 and 3 feet from the surface of the OS187H Transfer Cask are evaluated with the Monte Carlo transport code MCNP [2, 6]. The flux-to-dose conversion factors specified by the ANSI/ANS 6.1.1-1977 [5], are used and provided in Table 5-14.

5.3.1 Description of the Radial and Axial Shielding Configurations

Figure 5-1 is a sketch of an HSM-H cut away at the mid-vertical plane. Figure 5-3 is also a cut through the vertical mid-plane, the 32PTH-DSC is shown in phantom lines, and the front door is at the left hand side. The rear wall of the HSM-H module has a minimum thickness of 1 foot. A 3-foot shield wall is placed along the rear and sides of the HSM-H, as shown in Figure 5-1.

The MCNP computer models are built to evaluate the dose rate along the front wall surface, the rear shield wall surface, the vent openings, the roof surface, and on the side shield walls.

Figure 5-4 shows the shielding configuration of the OS187H transfer cask.

5.3.1.1 Storage Configuration

A three-dimensional MCNP model was developed for the HSM-H Model. The HSM length was designated as the x axis (North-South direction), the width as the y axis (East-West direction), and the HSM height as the z axis. The HSM door is designated as the S side and the –x direction, with the E wall as the –y direction. The roof is the +z direction. The E wall is designated as a reflective boundary and an end shield wall (3 ft thick) is attached to the W wall. The geometry of nearly all components of the HSM is Cartesian, except for the 32PTH-DSC, which is cylindrical. The MCNP model is a full 3-D representation of a single DSC inside the HSM-H with the reflective boundary, end and side shield walls. A three foot thick concrete shield wall is placed at the rear of the HSM. A NUHOMS®-32PTH-DSC MCNP model was developed for the transfer cask analysis, discussed below. This model was revised slightly and located within the HSM model. The DSC support rails are not included in the model. The heat shields are modeled as flat plates without fins or louvers and horizontal vent "liner" plates (2cm thk) are modeled in the top side vents.

Two liners are used for gamma dose attenuation at the bottom vents. The "top" liner is a 1-inch steel plate, positioned at the roof of the bottom vent. The "front" liner is a 1-inch steel plate, at the side of the inlet vent (near the HSM front). Due to modeling constraints the "front" liner is modeled as part of the vent. This simplification does not impact the overall gamma dose rates.

5.3.1.2 Loading/Unloading Configurations

The dose rates on the surface, and at 1.5 and 3 feet from the surface of the 32PTH-DSC/ Transfer Cask are evaluated with MCNP. Three different key configurations in the loading/unloading of the spent fuel are analyzed. The three different stages modeled are, (1) Decontamination, (2) Dry Welding and (3) Transfer. Calculations are performed assuming no temporary shielding is utilized for in the configurations, which is normally done at the sites.

Definition of Transfer Cask and 32PTH-DSC Loading Stages

1) Decontamination. The water level in the 32PTH-DSC cavity is assumed to be lowered four inches below the bottom of the top shield plug. The Cask/32PTH-DSC annulus is assumed to remain completely filled with water. (No DSC top cover or cask lid)
2) Dry welding. The 32PTH-DSC cavity is assumed to be completely dry, the 32PTH-DSC inner and outer top cover plates have been installed. The Cask/32PTH-DSC annulus is assumed to remain completely filled with water. (no cask lid)
3) Transfer. The 32PTH-DSC and 32PTH-DSC/Cask annulus are dry.

Dose analysis results for the above conditions are provided in Table 5-22 and Table 5-23.

5.3.1.3 Transfer Configuration

For the transfer configuration the Transfer Cask/32PTH-DSC annulus is completely dry. The 32PTH-DSC inner and outer top cover plates are installed. The top end of the Transfer Cask is in place which consists of a 3" thick steel cover plate and a 2" thick solid neutron shield, and a ¼" thick steel plate cover is over the solid neutron shield.

A three-dimensional MCNP model was developed for the OS-187H transfer cask containing the NUHOMS®-32PTH DSC. The cask/canister length was designated as the z axis (axial direction), the radial direction as the x and y axis. The 32PTH-DSC basket compartments and

rails were discreetly modeled in MCNP. The basket was simply modeled as the 8.70" sq, 0.187" thk SS compartments, each compartment surrounded by 0.5" of aluminum. Conservatively, neither boron in the aluminum, nor the SS strips were included in the MCNP basket model. Each of the 32 fuel assemblies was modeled in four axial regions; bottom fitting, fuel, plenum, and top fitting. The axial length of each fuel assembly region modeled was; 4.17", 144", 6.95", and 6.17", respectively. The lead thickness (3.60" nom) in the OS-187H is modeled as 3.56" of lead with a 0.04" void and the density of the lead is reduced to 0.985 TD.

The neutron shield support rings provide support for the skin, which contains the water for the neutron shield. The rings are modeled explicitly in the water filled neutron shield. The trunnions penetrate the neutron shield, which locally changes the shielding configuration of the neutron shield. The trunnions which are explicitly modeled are thick steel structures filled with solid resin neutron shielding material. These structures provide more gamma and neutron shielding than the water that they replace, because they protrude well past the neutron shield and are made of materials which provide more gamma shielding and comparable neutron shielding as compared to the water that they replace.

5.3.2 Shield Regional Densities

Table 5-7 shows the material masses for the four fuel assembly regions. Based on these material masses, and the material compositions [7], material densities for the fuel assembly regions are determined and provided in Tables 5-15 and 5-16 (loading configuration 1 above).

The mass of materials in each fuel assembly region is homogenized over the volume of the region (x-section = 71 in^2). Tables 5-17 and 5-18 provide the shield regional densities for the 32PTH-DSC and OS187H TC.

The concrete for the HSM-H is chosen to be "plain" concrete with a density of 143 lbs/ft^3 with the rebar conservatively neglected. Table 5-19 provides the concrete densities.

The actual fuel layout in the 32PTH-DSC is a cartesian array of fuel assemblies inside stainless steel compartments surrounded by sheets of aluminum material. These regions are modeled discretely as are the rails on the periphery of the basket. A source is modeled for each of the four homogenized fuel assembly regions for all 32 fuel assemblies. The source regions are cuboid in shape with the same 8.426" x 8.426" (17 times the Pitch) x-section and the appropriate axial length.

When the transfer cask/32PTH-DSC annulus and 32PTH-DSC are filled with water, the wet axial densities are used for the homogenized regions.

5.4 Shielding Evaluation

5.4.1 Computer Programs

MCNP [2, 6] is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Pointwise (continuous energy) cross-section data are used. For neutrons, all reactions given in a particular cross-section evaluation are accounted for in the cross section set. For photons, the code takes account of incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation, and bremsstrahlung. Important standard features that make MCNP very versatile and easy to use include a powerful general source; an extensive collection of cross-section data; and an extensive collection of variance reduction techniques that can be employed to track particles through very complex deep penetration problems.

5.4.2 Spatial Source Distribution

The source components are:

- A neutron source due to the active fuel regions of the 32 fuel assemblies,
- A gamma source due to the active fuel regions of the 32 fuel assemblies,
- A gamma source due to the plenum regions of the 32 fuel assemblies,
- A gamma source due to the top nozzle regions of the 32 fuel assemblies,
- A gamma source due to the bottom nozzle region of the 32 fuel assemblies,
- A gamma source due to the 32 BPRAs in the top nozzle, plenum and fuel regions of the 32 fuel assemblies

Axial burnup peaking factors for PWR fuel are taken from Reference [4]. These peaking factors are assumed to match the gamma axial source distribution because the gamma source is proportional to burnup. The neutron source is approximately proportional to the fourth power of the burnup. Therefore, the axial neutron source distribution may be determined as the fourth power of the axial burnup profile.

Axial peaking changes with increasing burnup. The axial peaking factors used are provided in Table 5-20. The OS187H TC and HSM-H calculations use peaking factors for a burnup >46 GWd/MTU because the design basis source occurs at a burnup of 60 GWd/MTU. The neutron and gamma peaking factors are shown as a function of the core height in Table 5-20. These factors are directly applied to each MCNP interval in the fuel region.

The average values of the axial peaking distributions are also provided in Table 5-20. For the gamma distribution, the average value is 1.00. However, for the neutron distribution, the average value of the distribution is greater than 1.00. The average value of the axial neutron distribution may be interpreted as the ratio of the true total neutron source in an assembly to the neutron source calculated by SAS2H/ORIGEN-S for an average assembly burnup.

Therefore, to properly correct the magnitude of the neutron source, the neutron source per assembly as reported in Table 5-13 is multiplied by the average value of the neutron source distribution as reported in Table 5-20.

5.4.3 Cross-Section Data

The cross-section data used is the continuous energy ENDF/B provided with the MCNP code. The cross-section data allows coupled neutron/gamma-ray dose rate evaluation to be made to account for secondary gamma radiation (n,γ), if desired. All of the transfer cask dose rate calculations account for the dose rate due to secondary gamma radiation. For the HSM-H dose rate calculation, the dose rate contribution from the secondary gamma radiation is ignored because it is insignificant.

5.4.4 Flux-to-Dose-Rate Conversion

The flux distribution calculated by the MCNP code is converted to dose rates using flux-to-dose rate conversion factors from ANSI/ANS-6.1.1-1977 [5] given in Table 5-14.

5.4.5 Model Geometry

Figure 5-5 through Figure 5-7 are the MCNP models for the Transfer Cask (TC) containing the 32PTH-DSC. Figures 5-8 through Figure 5-11 are the MCNP models of the HSM-H with the DSC . The figures show dimensions in cm with MCNP surface numbers in brackets. Figures 5-12 and 5-13 show the location of the detectors cells on the HSM surfaces.

5.4.6 Methodology

The methodology used in the shielding analysis of the 32PTH system utilizes the 3-D MCNP code. MCNP allows for explicit 3-D modeling of any shielding configuration and reduces the number of approximations needed. The methodology used herein is summarized below.

1. Sources are developed for all fuel regions using the source term data developed in Section 5.2. Source regions include the active fuel region, bottom end fitting (including all materials below the active fuel region), plenum, and top end fitting (including all materials above the active fuel region). Sources for CC are added group-by-group to the fuel sources.
2. Suitable shielding material densities are calculated for all regions modeled.
3. The 3-D Monte Carlo transport code MCNP is used to calculate dose rates on and around the HSM-H and theOS187H TC. The MCNP4 code is selected because of its ability to handle thick, multi-layered shields and account for streaming through both the HSM-H air vents and cask/DSC annulus using 3-D geometry. MCNP4C2 results are used to calculate offsite exposures (see Chapter 10).
4. For the TC, weight windows are utilized for variance reduction. Segmented surface (ring) detectors are used to tally surfaces for dose rate determinations.

For the HSM-H, importance biasing is utilized for variance reduction and tally cells and segmented tally cells are used to determine average and maximum dose rates around the HSM-H.

5. MCNP models are also generated to determine the effects of accident scenarios, such as loss of cask neutron shield, for the OS187H TC.

5.4.7 Assumptions

The following general assumptions are used in the analyses.

5.4.7.1 Source Term Assumptions

1. The primary neutron source in LWR spent fuel is the spontaneous fission of ^{244}Cm. For the ranges of exposures, enrichments, and cooling times in the fuel qualification tables, ^{244}Cm represents more than 85% of the total neutron source. The neutron spectrum is, therefore, relatively constant for the fuel parameters addressed herein and is assumed to follow the ^{244}Cm fission spectrum.

2. Surface gamma dose rates are calculated for the HSM and cask surfaces using the actual photon spectrum applicable for each case.

3. The PWR heavy metal weight is assumed to be 0.476 MTU per assembly to bound existing PWR fuel designs.

4. The source term associated with the BPRAs are bounding for all CCs.

5. The source terms for an assembly reconstituted with stainless steel pins are bounding for all other reconstituted assemblies.

5.4.7.2 HSM-H Dose Rate Analysis Assumptions

1. Planes of reflection are used to simulate adjacent HSM-Hs.

2. Embedments and rebar in the HSM-H concrete are conservatively neglected.

3. The borated neutron absorber sheets in the 32PTH-DSC are modeled as aluminum.

4. Axial source distribution assumed as shown in Table 5-20.

5. Fuel is homogenized within the fuel compartment and source region, although the 32PTH-DSC basket is modeled explicitly.

5.4.7.3 OS187H TC Dose Rate Analysis Assumptions

1. The 32PTH-DSC is modeled within the OS187H TC.

2. The OS187H is modeled for the welding operation. No supplemental neutron shielding is assumed to be placed on top of the 32PTH-DSC cover plates during welding.

3. During the accident case, the cask neutron shield (water) is assumed to be lost and a lead slump of 1" is assumed in the cask end.

4. The borated neutron absorber sheets in the 32PTH- DSC are modeled as aluminum.

5. The stainless steel strip plates are conservatively modeled as aluminum.

6. Axial source distribution assumed as shown in Table 5-20.

7. Fuel is homogenized within the fuel compartments and the source regions, although the 32PTH-DSC baskets are modeled explicitly.

8. In the OS187H TC model, the lead shield is assumed at the minimum thickness and with reduced density.

5.4.8 Normal Condition Models

Two basic MCNP models are developed: (1) 32PTH- DSC in the HSM-H and (2) 32PTH-DSC in the OS187H TC. These models are described in subsequent sections.

5.4.8.1 32PTH DSC in HSM-H

Two, three-dimensional MCNP4C2 models are developed for the 32PTH-DSC within a HSM-H, one model for neutrons and the other for gammas. These models are presented in Figures 5-8 through Figure 5-11. The HSM-H length is designated as the x axis, the width as the y axis, and the height as the z axis. The HSM-H door is designated as the south side and the –x direction, with the east wall as the –y direction. The roof is the +z direction. The east wall is designated as a reflective boundary and an end shield wall (3 ft thick) is attached to the west wall.

The bottom (bottom of bottom fitting) of the fuel assembly is assigned to an x plane at -213.84 cm. The center of the HSM-H is at y=0 and z=0. The 32PTH-DSC lid is located 5" from the HSM-H rear wall (x=254.84 cm) which places the bottom of the DSC at x=-215.69 cm, about 20 inches from the door interior. The 32PTH-DSC support rails are not included in the model. The heat shields are modeled as flat plates without fins or louvers, and horizontal vent "liner" plates (2 cm thick) are modeled in the top side vents.

Dose rates are calculated on thin cells surrounding the HSM-H and are segmented into 30 cm increments to capture the peak dose rates. Dose rates are also calculated at the inlet and outlet vents. Dose rates for this scenario are provided in Table 5-21. Dose rates for the front, roof, and side shield wall surface at DSC centerline of the HSM-H are also plotted as a function of distance in Figures 5-17 and 5-18 respectively.

A sample MCNP4C2 model input file of HSM-H with 32PTH-DSC is included in Section 5.5.2.

5.4.8.2 32PTH- DSC in OS187H TC

Two three-dimensional MCNP4B models are employed for shielding analyses of the 32PTH-DSC within an OS187H TC, one model for neutrons and the other for gammas. These models are presented in Figure 5-5 through Figure 5-7. The DSC/TC length was designated as the z-axis in the MCNP models. Select features within the cask and on its surface are neglected because they produce only localized effects and have minimal impact on operational dose rates. Examples of neglected features include relief valves, clevises, and eyebolts.

These items are local features that increase the shielding in a small area without replacing any of the shielding material which is included in the model. The additional shielding material that these features provide is not smeared into the bulk shielding, nor is any credit taken for it in the occupational exposure calculation. The neutron shield support rings provide support for the neutron shield skin, which contains the water for the neutron shield. The fifteen rings are modeled explicitly within the neutron shield.

The trunnions penetrate the neutron shield, which locally changes the shielding configuration of the neutron shield. The trunnions are thick steel structures filled with solid neutron shielding material. These structures protrude well past the neutron shield and are made of materials which provide more gamma shielding and comparable neutron shielding as compared to the 0.96 g/cm^3 water that these replace. The trunnions are also modeled explicitly in MCNP.

Design features relevant to the shielding analysis of the OS187H TC and 32PTH-DSC are modeled in MCNP4B. The overall length of the OS187H TC is 193.32". The outer diameter of the OS187H TC is 92.20" (neutron shield included). The outer diameter excluding the neutron shield is 82.70". The bottom of the OS187H TC is designed to mate with a 32PTH-DSC. The overall length of the 32PTH-DSC is 185.75" (excluding the grapple) and its outer diameter is 69.75". The bottom end of the 32PTH-DSC is in contact with the structural shell assembly of the transfer cask.

In section 5.3.1.2 and 5.3.1.3, the three transfer cask scenarios are described. The basic MCNP models for the OS187H TC described above are modified as described below to represent the loading/transfer configurations.

A. Cask Decontamination

The 32PTH-DSC and the OS187H TC are assumed to be filled with water, including the region between 32PTH-DSC and cask, which is referred to as the "cask/32PTH-DSC annulus." The water in the DSC is assumed to be approximately 4" below the shield plug. The 32PTH-DSC shield plug is assumed to be in place and the temporary shielding has not yet been installed. The DSC top cover and cask lid are not installed. Results for this case are provided in Table5-22.

B. Welding and DSC Draining

Before the start of welding operation, water in the DSC cavity is removed to reduce the potential due to hydrogen generation. A dry DSC cavity is assumed in all welding models to be conservative. Temporary shielding is not installed. In addition, the cask lid is not installed. The cask/32PTH-DSC annulus is assumed to remain completely filled with water. Results for this case are provided in Table 5-22.

C. Transfer

In preparation for transfer to the HSM, the DSC is drained, dried, the tops welded on, the annulus drained, and the cask lid installed. Results for this case are provided in Table 5-23 along with accident dose rates (loss of water in neutron shield tank and 1" lead slump).

Dose rates at the sides, top, and bottom of this cask are presented graphically in Figure 5-14 through Figure 5-16.

A sample MCNP4B model input file for OS187H TC with 32PTH-DSC is included in Section 5.2.2.

5.5 Supplemental Information

5.5.1 References

1. Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6.

2. MCNP4B2, "Monte Carlo N-Particle Transport Code System," Los Alamos National Laboratory, CCC-660, RSIC, January 1998.

3. Radiation Shielding, J. Kenneth Shultis and Richard E. Faw, Pretence Hall, 1996.

4. "Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses," NUREG/CR-6801, March 2003.

5. "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors". ANSI/ANS-6.1.1-1977, American Nuclear Society, La Grange Park, Illinois. March 1977.

6. MCNP4C2, "Monte Carlo N-Particle Transport Code System," Los Alamos National Laboratory, CCC-701, RSIC, June 2001.

7. Ludwig, S.B., and J.P. Renier, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Computer Code," ORNL/TM-11018, Oak Ridge National Laboratory, December 1989.

Then criticality calculations evaluate a variety of fuel assembly types, initial enrichments and poison loadings (fixed and soluble poison). Finally, the maximum allowed initial enrichment and the number of damaged assemblies per DSC for each fuel assembly type as a function of soluble boron concentration and fixed poison loading is determined and is also shown in Table 6-1.

These calculations determine k_{eff} with the CSAS25 control module of SCALE-4.4 [3] for each assembly type and initial enrichment, including all uncertainties to assure criticality safety under all credible conditions.

The results of these calculations demonstrate that the maximum expected k_{eff}, including statistical uncertainty, will be less than the Upper Subcritical Limit (USL) determined from a statistical analysis of benchmark criticality experiments. The statistical analysis procedure includes a confidence band with an administrative safety margin of 0.05. A series of benchmark calculations were performed with the SCALE 4.4 PC/CSAS25 [3] package using the 44-group cross-section library as presented in Section 6.5. The minimum value of the Upper Subcritical Limit (USL) was determined to be 0.9419.

The results of the limiting criticality analyses are summarized in Table 6-2. The maximum k_{eff} for the normal fuel geometry is 0.9407 ($k_{eff}+2\sigma$) and is based on the Combustion Engineering (CE 16x16) class fuel assembly design. The maximum k_{eff} for the damaged fuel geometry is 0.9402 ($k_{eff}+2\sigma$) and is based on the WE 17x17 fuel assembly design.

6.2 Spent Fuel Loading

This section provides a summary of the maximum spent fuel loading and spent fuel parameters for the 32PTH DSC.

The NUHOMS®-32PTH DSC is capable of transferring and storing a maximum 32 intact PWR fuel assemblies. Additionally, a maximum of 16 locations (out of the 32 locations) per DSC can be loaded with damaged PWR fuel assemblies with the remaining locations loaded with intact PWR fuel assemblies. The required placement of the damaged fuel assemblies is defined in Chapter 12. Damaged fuel includes assemblies with known or suspected cladding defects greater than hairline cracks or pinhole leaks. The reactivity of a DSC loaded with less than 32 PWR fuel assemblies is expected to be lower than that calculated in this report since the more absorbing borated water replaces the fuel in the empty locations. Reconstituted fuel assemblies, where the fuel pins are replaced by lower enriched fuel pins or non-fuel (prior to initial irradiation or following initial irradiation) pins that displace the same amount of borated water, are considered intact fuel assemblies. Table 6-3 lists the fuel assemblies considered as authorized contents of the NUHOMS®-32PTH DSC.

Table 6-4 lists the fuel design parameters for the PWR fuel assemblies. Reload fuel from other manufacturers with the same parameters are also considered as authorized contents.

For the fuel assemblies to be loaded in the NUHOMS®-32PTH DSC control components (CCs) are also included as authorized contents. The only change to the package fuel loading is the addition of CCs that are modeled as $^{11}B_4C$. Since CCs displace borated moderator in the assembly guide tubes, an evaluation is performed to determine the potential impact of the storage of CCs such as BPRAs, CRAs that extend into the active fuel region, on the system reactivity. For these CCs (bounded by BPRA) no credit is taken for BPRA cladding and absorbers; rather the BPRA is modeled as $^{11}B_4C$ in the entire guide tube of the respective design. Thus, the highly borated moderator between the guide tube and the BPRA rodlet is modeled as $^{11}B_4C$. The inclusion of more Boron-11 and carbon enhances neutron scattering causing the neutron population in the fuel assembly to be slightly increased which increases reactivity. Therefore, these calculations bound any CC design that is compatible with WE 17x17, CE 16x16, WE 15x15 and CE 14x14 class assemblies. CCs that do not extend into the active fuel region of the assembly do not have any effect on the reactivity of the system as evaluated because only the active fuel region is modeled in this evaluation with periodic boundary conditions making the model infinite in the axial direction. The fuel assembly dimensions reported in Table 6-4 remains unchanged for the BPRA cases. The models that include BPRAs only differ in that the region inside the guide tubes and instrument tube are modeled as $^{11}B_4C$ instead of moderator. Additionally, the presences of non-multiplying sources like the NSAs have no impact on criticality calculations. Therefore all CCs are bounded by the BPRAs for criticality purposes and will be referred to as BPRAs for the rest of the report. Since the criticality analysis models simulate on the active fuel height, any CC that is inserted into the fuel assembly such that it does not extend into the active fuel region is considered as authorized for storage without adjustment to the soluble boron content or initial enrichment as required for control components that extend into the active fuel region. For example, TPAs or ORAs are permitted for storage within a fuel assembly without adjusting the maximum initial enrichment or minimum soluble boron content given in Table 6-1, since TPAs or ORAs do not extend into the active fuel region.

6.3 Model Specification

The following subsections describe the physical models and materials of the NUHOMS®-32PTH DSC as loaded and transferred in the NUHOMS® OS187H TC used for input to the CSAS25 module of SCALE-4.4 3 to perform the criticality evaluation. The reactivity of the DSC under storage conditions is bounded by the TC analysis with zero internal moderator density case. The TC analysis with zero internal moderator density case bounds the storage conditions in the HSM because (1) the DSC internals are always dry (purged and backfilled with He) while in the HSM, and (2) the TC contains materials such as steel and lead which provide close reflection of fast neutrons back into the fueled basket while the HSM materials (concrete) are much further from the sides of the DSC and thereby tend to reflect thermalized neutrons back to the DSC which are absorbed in the DSC materials reducing the system reactivity.

6.3.1 Description of Criticality Analysis Model

The transfer cask and DSC are explicitly modeled using the appropriate geometry options in KENO V.a of the CSAS25 module in SCALE-4.4. Several models are developed to evaluate the fabrication tolerances of the DSC, fuel assembly locations, fuel assembly type, initial enrichments, fixed poison loading, soluble boron concentration and storage of CCs.

The basket design modeled in the calculation is based on the 32PTH basket detailed in Chapter 1 with a section length of 15.03" (13.28" basket section + 1.75" steel plate). The key basket dimensions utilized in the calculation are shown in Table 6-5. The key transfer cask dimensions utilized in the calculation are shown in Table 6-6. The fixed poison modeled in the calculation is based on borated aluminum alloy. A credit of 90% is taken for the fixed poison loading in the analysis. Alternatively, Boral® can be used as a fixed poison. However, the criticality analysis with Boral® assumes crediting only 75% of the fixed poison loading. Therefore, the Boral® loading requirements are appropriately (and conservatively) adjusted and the fixed poison loading requirements are shown in Table 6-7.

The basic calculational KENO model is a 15.03-inch axial section and full-radial cross section of the DSC and cask with periodic boundary conditions at the axial boundaries (top and bottom) and reflective boundary conditions at the radial boundaries (sides). This axial section essentially models one building block of the egg crate basket structure. Periodic boundary conditions ensure that the resulting KENO model is essentially infinite in the axial direction. The model does not explicitly include the water neutron shield; however the infinite array of casks without the neutron shield does contain unborated water between the casks and in the canister - transfer cask gap. This basic building block is shown in Figure 6-1.

The fuel assemblies within the basket are modeled explicitly. The fuel compartment surrounds each fuel assembly which is bounded by the basket plates consisting of 0.50" Aluminum/Borated Aluminum plates (modeled as two 0.25"-thick plates). These plates are arranged to represent an egg-crate design with the 0.075" or 0.187"-Borated Aluminum and the remaining-Aluminum plate. The thermal expansion and egg-crate slot gaps are not modeled (conservative) assuming plate continuity, thus replacing the more absorbing internal moderator with aluminum plate. KENO model plots in 2D for the various views of the basket compartment are shown in Figure 6-2 through Figure 6-7.

There are a total of 10 poison plates in the NUHOMS®-32PTH basket. They are located at all the faces where six fuel assemblies are lined up. Thus, all the interior 16 fuel assemblies are surrounded by poison plates on all four faces and the outer 16 fuel assemblies do not have poison plates on the radially outward looking face. The fuel assembly and poison plate positions (and the aluminum plate positions) in the KENO model of the basket is shown in Figure 6-8. Even though the poison and aluminum plates have been shown as discrete plates around the fuel compartment, they are all continuous running from one end of the basket to the other.

The basket structure is connected to the DSC shell by perimeter rail assemblies. The rail material is aluminum and SS304 and provide for a heat conduction path from the basket to the DSC shell. These rails are not modeled explicitly in the basic KENO model. They are, however, modeled in KENO as a homogenous (as illustrated in Figure 6-9) mixture of unborated water, Aluminum and SS304. The KENO unit numbers used for the fuel assembly positions are shown in Figure 6-9.

A list of all the geometry units used in the basic KENO model is shown in Table 6-8. Figure 6-10 shows the various radial "cylinders" utilized in the KENO model surrounding the fuel assemblies. Basically, this shows the canister and transfer cask details. For the parametric calculations to determine the most reactive geometry, the fuel assemblies are modeled with an initial enrichment of 4.30 wt. % U-235, a soluble boron concentration of 2500 ppm and a fixed poison loading of 15 mg B-10/cm^2 (Type B basket with a 90% credit for Borated Aluminum poison in the analysis).

In addition, a detailed KENO model with explicit representation of the rail structure, within the limitations of the KENO geometry, is also developed to demonstrate the adequacy and conservatism of the simplified KENO model with "homogenous" rail structure. A radial cross section of the basket with the "detailed" KENO model is shown in Figure 6-11.

The basic KENO model is used to determine the most reactive fuel assembly for a given enrichment, most reactive assembly-to-assembly pitch, and to determine the most reactive DSC configuration accounting for manufacturing tolerances including rail material homogenzation. The second model is of the most reactive configuration identified above. This model is used to determine the maximum allowable initial enrichment for each assembly type as a function of the soluble boron concentration and fixed poison loading, as appropriate.

A slightly different, yet a more conservative 32PTH basket model is used in the evaluation of the CE 16x16 fuel assemblies. This model is discussed in Section 6.4.

This basic KENO model is modified to model the various damaged fuel configurations like single shear, double shear, optimum pitch and axial fuel shifting. These models are analyzed to determine the most reactive damaged fuel configuration for each fuel assembly class. The second model is based on the most reactive configuration identified above. This model is used to determine the maximum number of damaged fuel assemblies per DSC and the maximum allowable initial enrichment for each assembly type as a function of the soluble boron concentration and fixed poison loading, as appropriate.

6.4 Criticality Calculation

This section describes the analysis methodology utilized for the criticality analysis. The analyses are performed with the CSAS25 module of the SCALE system. A series of calculations are performed to determine the relative reactivity of the various fuel assembly designs evaluated and to determine the most reactive configuration without BPRAs. The most reactive intact fuel design, for a given enrichment, as demonstrated by the analyses, is the WE 17x17 standard assembly. The most reactive credible configuration is an infinite array of flooded casks, each containing 32 fuel assemblies, with minimum fuel compartment ID, minimum basket structure thickness and minimum assembly-to-assembly pitch.

A series of calculations are also performed to determine the relative reactivity of the various damaged fuel configurations for each fuel assembly class. The most reactive damaged fuel configuration for the WE 17x17 and WE 15x15 class occurs due to a postulated double-ended shear. The most reactive damaged fuel configuration for the CE 14x14 and CE 16x16 class occurs when the fuel rods are arranged in an optimum pitch configuration. The most reactive credible configuration analyzed in this calculation is an infinite array of flooded casks, each containing a maximum of 32 damaged fuel assemblies with BPRAs, with minimum fuel compartment ID, minimum basket structure thickness and minimum assembly-to-assembly pitch.

As mentioned in Section 6.1, the NUHOMS®-32PTH DSC is evaluated to determine the maximum initial enrichment of the fuel assemblies (both damaged and intact) per DSC for each assembly class as a function of fixed poison loading and soluble boron concentration levels.

6.4.1 Calculational Method

6.4.1.1 Computer Codes

Criticality analyses were performed using the microcomputer application KENO-Va and the 44 neutron group library based on ENDF-B Version 5 cross-section data that are part of the SCALE 4.4 code package [3]. Validation and benchmarking of these codes is performed in accordance with applicable QA program requirements (see Chapter 13) and is discussed in Section 6.5.

SCALE 4.4 [3] is an extensive computer package which has many applications including cross section processing, criticality studies, and heat transfer analyses among others. The package is comprised of many functional modules, which can be run independently of each other. Control Modules were created to combine certain functional modules in order to make the input requirements less complex. For the purpose of criticality analysis, only four functional modules are used and one control module. These Modules are CSAS25, which includes the three dimensional criticality code KENO-Va and the preprocessing codes BONAMI-S, NITAWL-II and XSDRNPM-S.

KENO-Va, in conjunction with a suitable working library of nuclear cross section data, is used to calculate the multiplication factor, k_{eff}, of systems of fissile material. It can also compute lifetime and generation time, energy dependent leakages, energy and region-dependent absorptions, fissions, fluxes, and fission densities. KENO-Va utilizes a three-dimensional Monte-Carlo computation scheme. KENO-Va is capable of modeling complex geometries including facilities for handling arrays, arrays of arrays, and holes.

6.4.1.3 Bases and Assumptions

The analytical results reported in Section 3.7 demonstrate that the TC containment boundary and canister basket structure do not experience any significant distortion under hypothetical accident conditions. Therefore, for both normal and hypothetical accident conditions the TC geometry is identical except for the neutron shield and skin. As discussed above, the neutron shield and skin are conservatively removed and the interstitial space modeled as water.

The TC is modeled with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries. The following conservative assumptions are also incorporated into the criticality calculations:

(1) No burnable poisons like IFBA, Gadolinia, Erbia, B_4C or any other absorber, accounted for in the fuel.

(2) CCs like BPRA, TPA, and VSI are conservatively assumed to exhibit neutronic properties similar to $^{11}B_4C$. There is no neutron absorption from any of these hardware and are collectively referred to as BPRAs.

(3) Water density at optimum moderator density.

(4) Unirradiated fuel – no credit taken for fissile depletion due to burnup or fission product poisoning.

(5) The fuel pins are modeled assuming a stack density of 97.5% theoretical density with no allowance for dishing or chamfer. This assumption conservatively increases the total fuel content in the model.

(6) Temperature at 20°C (293K).

(7) The maximum fuel enrichment is modeled as uniform everywhere throughout the assembly. Natural Uranium blankets and axial or radial enrichment zones are modeled as enriched uranium with an average enrichment.

(8) All fuel rods are filled with full density water in the pellet/cladding gap.

(9) Only a 15.03-inch (for the CE 16x16 models, this section is 13.48″) section of the basket with fuel assemblies is explicitly modeled with periodic axial boundary conditions, therefore the model is effectively infinitely long.

(10) It is assumed that for all cases the neutron shield and stainless steel skin of the cask are stripped away and the infinite array of casks are pushed close together with moderator in the interstitial spaces.

(5) The single-ended fuel rod shear cases assume that fuel rods that form one assembly face shear in one place and are displaced to new locations. The fuel pellets are assumed to remain in the fuel rods.

(6) The double-ended fuel rod shear cases assume that the fuel rods that form one assembly face shear in two places and the intact fuel rod pieces are separated from the parent fuel rods.

(7) Although only 16 damaged fuel assemblies are authorized contents for the DSC, all 32 fuel assemblies are considered to be damaged in the criticality analyses for damaged fuel.

6.4.1.4 Determination of k_{eff}

The Monte Carlo calculations performed with CSAS25 (KENO V.a) use a flat neutron starting distribution. The total number of histories traced for each calculation is approximately 800,000. This number of histories is sufficient to achieve source convergence and produce standard deviations of less than 0.0010 in Δk_{eff}. The maximum k_{eff} for the calculation is determined with the following formula:

$$k_{eff} = k_{KENO} + 2\sigma_{KENO}.$$

6.4.2 Fuel Loading Optimization

The criticality analysis is performed for the 32PTH DSC loaded with 32 intact or 32 damaged fuel assemblies. The following sub-sections describe the various analyses performed with the intact fuel assemblies.

6.4.2.1 Most Reactive Fuel Assembly and Assembly Position Studies

The first series of analyses determines the most reactive fuel assembly design and the most reactive fuel positioning within the steel tubes. The first KENO run models the fuel assemblies as being centered within the basket compartment tubes. The off-center fuel assembly positioning is modeled by shifting all the fuel assemblies radially inward such that the fuel pins come in contact with the two faces of the compartment tubes. This is "inward" positioning and the fuel assemblies are at the closest approach relative to the center of the basket.

These calculations are repeated for all four fuel assembly classes listed in Table 6-3. These runs are carried out at nominal compartment dimensions with varying internal moderator density assuming a Type B basket and fuel at 4.30 wt% U-235 and a boron concentration of 2500 ppm. The CE 16x16 calculations are carried out at an enrichment of 4.25 wt. % U-235, a fixed poison loading of 18.75 mg B-10/cm^2. All input and output files are included on the attached compact disk. In all other respects, the model is the same as that described in Sections 6.3.1 and 6.3.2. The 2D KENO plots are shown in Figure 6-12 and Figure 6-13 and the results are shown in Table 6-10.

The peripheral rails were not modeled for these calculations. The rail material was assumed to be completely replaced by the internal moderator (borated water at 2500 ppm). This assumption does not affect this parametric study. For the CE 16x16 calculations, the rail structure was modeled with solid aluminum.

The most reactive fuel assembly design is the WE 17x17 standard fuel assembly for the WE 17x17 class, the WE 15x15 standard fuel assembly for the WE 15x15 class the CE 16x16 System 80 fuel assembly for the CE 16x16 class and the CE 14x14 Fort Calhoun Fuel assembly for the CE 14x14 class of fuel assemblies. The "inward" positioning of fuel assemblies is most reactive.

6.4.2.2 Determination of the Most Reactive Configuration

The fuel loading configuration of the canister/cask affects the reactivity of the package. Several series of analyses determined the most reactive configuration for the canister/cask.

For this analysis, the most reactive fuel type is used to determine the most reactive configuration. The canister/cask is modeled, with the WE 17x17 standard assembly, over a 15.03-inch axial section with periodic axial boundary conditions and reflective radial boundary conditions. This represents an infinite array in the x-y direction of canister/casks that are infinite in length which is conservative for criticality analysis. The starting model is identical to the model used above. The canister/cask model for this evaluation differs from the actual design in the following ways:

- The boron 10 content in the poison plates is 10% lower than the minimum required,

- The stainless steel and aluminum basket rails, which provide support to the fuel compartment grid, are modeled using a homogenized material and,
- The neutron shield and the skin of the cask are conservatively replaced with water between the casks.

Each evaluation is performed at various internal moderator density (IMD) values to determine the optimum moderator density where the reactivity is maximized. All input and output files are included on the attached compact disk.

The first set of analyses determines the effect of rail material composition variation on the reactivity of the basket. The most reactive configuration from the previous section is utilized as the base case for this evaluation. Four different variations in the rail material compositions are considered in this evaluation. The previous evaluation utilized borated water as the rail material. In this evaluation, the rail materials used are unborated water at 100% density, composition 3 (30% water, 35% aluminum, 35% ss304 by volume), composition 4 (40% water, 30% aluminum, 30% ss304 by volume) and composition 5 (50% water, 25% aluminum, 25% ss304 by volume). The rails are also modeled discretely based on the detailed model, as shown in Figure 6-11, for a comparison of the results.

Based on the actual volume fraction of rail materials, it is expected that the volume of water does not go below 30%. Also, such a variation (composition 3 through 5) adequately accounts for the fabrication tolerances associated with the rail materials. The results of this evaluation are shown in Table 6-11 including the most reactive results from the previous study and the results based on the detailed model. These results indicate that the most reactive rail composition is the one based on composition 3. The results also indicate that the change is k_{eff} due to variation in composition is statistically insignificant. The comparison of k_{eff} results with composition 3 and detailed model indicates that the simplified model (based on homogenous rail) is both adequate and conservative. Therefore, for the rest of the calculation, the rail assemblies will be modeled with a homogenous rail assumption with the material based on composition 3.

The next set of calculations determines the effect of variation in the poison plate thickness in the reactivity of the system. The poison plate thickness is varied from a maximum of 0.187 inches (for the Type D basket) to a minimum of 0.050 inches (for the Type A basket) based on a poison loading of 15.0 mg B-10/cm^2 (Borated Aluminum poison, Type B basket loading). Even though, this large variation in thickness is not expected for a single basket type, these calculations are intended to demonstrate that the effect of variation is statistically insignificant. The variation in the poison plate thickness also results in a compensatory variation in the aluminum plate thickness in order to maintain the total thickness of 0.25 inches. Therefore, the study also indirectly evaluates the effect of variation in the aluminum plate thickness. The results of these calculations are shown in Table 6-12 along with the most reactive results from the previous evaluation.

The results of this evaluation indicate that the effect of variation in the poison plate thickness is statistically insignificant and that the maximum k_{eff} values at all plate thicknesses are about the same. As stated above, the variation in the thickness considered in this evaluation is not expected to represent physical reality; however, the results demonstrate that within the tolerance band for the thicknesses of various basket types, the variation in k_{eff} is statistically insignificant.

These results also indicate that there would be no significant effect on k_{eff} due to the presence of aluminum cladding in case of Boral® poison due to the fact that this study also evaluates the effect of aluminum plate thickness.

The next set of analyses determines the effect of fuel compartment size on the system reactivity. The model starts with the most reactive geometry determined from the previous study. For this evaluation, the compartment size is varied from 8.650 inches (square) to 8.750 inches (square). These results are shown in Table 6-13. These results indicate that the most reactive configuration is with the minimum fuel compartment size because the assembly-to-assembly pitch is minimized.

The next set of analyses determines the effect of fuel compartment box thickness on the system reactivity. The model starts with the minimum fuel compartment width from the previous study and the compartment thickness is varied from 0.1775 inches to 0.2325 inches. The results in Table 6-14 show that the most reactive calculated condition occurs with nominal compartment box thickness. The results indicate that the system reactivity is not very sensitive to the box thickness and that the difference in k_{eff} between the nominal and minimum thickness cases is within statistical uncertainty. The balance of this evaluation uses the nominal box thickness because it represents the most reactive configuration from this study.

For the CE 16x16 models, as discussed in Section 6.4.2.1, the basket transition rails are modeled, conservatively, with solid aluminum. This is conservative because the presence of aluminum allows for the neutrons to scatter through to the adjacent cask and interact with the fuel rather than being absorbed in the water/steel mixture. Another difference is that the basket is modeled with a section height of 13.48 in. instead of 15.03 in. This modeling feature is also slightly conservative because this results in a slight reduction in the amount of poison per unit length of the basket. In addition, other minor differences that are expected to have no significant impact on criticality are listed below:

- the inner shell radius is modeled as 34.5 in. instead of 35 in.
- the DSC / Cask gap is modeled as 0.37 in instead of 0.50 in.
- the inner shell thickness is modeled as 0.63 in. instead of 0.50 in.

6.4.2.3 Determination of Maximum Initial Enrichment for Intact Assemblies

The most reactive configuration determined based on parametric studies is with the rail structure represented with Composition 3, poison and aluminum plates at nominal thickness, fuel compartment at minimum width and nominal thickness and the fuel assemblies positioned in the "inward" position. The following analysis uses this configuration to determine the maximum allowable initial enrichment as a function of poison plate loading and soluble boron concentration for the three (WE 17x17, WE 15x15 and CE 14x14) fuel assembly classes. For the CE 16x16 fuel assembly class, the model with solid aluminum rails described above is utilized. Only the fuel assembly type, the fixed and soluble poison loading is changed for each model. In addition, the internal moderator density is varied to determine the peak reactivity for the specific configuration.

The canister / cask model for this evaluation differs from the actual design in the following ways:

- the boron-10 content in the borated aluminum poison plates is 10% lower than the minimum required and the boron-10 content in the Boral® poison plates is 25% lower than the minimum required
- the neutron shield and the skin of the cask are conservatively replaced with water between the casks, and
- the worst case geometry and material conditions, as determined in the previous sections, are modeled.

Five different fixed poison loadings are analyzed in the criticality calculations as described in Section 6.3, corresponding to the five different types of basket based on fixed poison loading (Type A, B, C, D and E). Four different soluble boron concentration levels are analyzed: 2000 ppm, 2300 ppm, 2400 ppm and 2500 ppm. The maximum analyzed initial enrichment is 5.0 wt. % U-235.

Calculations are also performed with the presence of BPRAs (bounding for all CCs) in the guide tubes to determine the maximum allowable enrichment for the WE 15x15 and WE 17x17 fuel assembly classes with CCs. These calculations are applicable to intact fuel assemblies only. Reconstituted fuel assemblies, where the fuel pins are replaced by non-fuel pins are also considered intact fuel assemblies provided they displace the same amount of moderator.

CE 14x14 Class Assemblies

The most reactive CE 14x14 class assembly is the CE 14x14 Fort Calhoun type fuel assembly with the larger fuel pellet OD. The results for the CE 14x14 class of fuel assemblies without BPRAs are shown in Table 6-33. The results for CE 14x14 class of fuel assemblies with BPRAs are shown in Table 6-34. These results indicate that the presence of BPRAs increases the reactivity of the system and consequently a reduction in the allowable enrichment.

WE 15x15 Class Assemblies

The most reactive WE 15x15 class assembly is the WE 15x15 standard fuel assembly. The results for the WE 15x15 class of fuel assemblies without BPRAs are shown in Table 6-15. The results for WE 15x15 class of fuel assemblies with BPRAs are shown in Table 6-16. These results indicate that the presence of BPRAs increases the reactivity of the system and consequently a reduction in the allowable enrichment.

WE 17x17 Class Assemblies

The most reactive WE 17x17 class assembly is the WE 17x17 standard fuel assembly. The results for the WE 17x17 class of fuel assemblies without BPRAs are shown in Table 6-17. The results for WE 17x17 class of fuel assemblies with BPRAs are shown in Table 6-18. These results also indicate that the presence of BPRAs increases the reactivity of the system and consequently a reduction in the allowable enrichment. For calculations with Type C basket, the WE 17x17 assembly results are conservatively applied to WE 15x15 assembly.

CE 16x16 Class Assemblies

The most reactive CE 16x16 class assembly is the CE 16x16 System 80 type fuel assembly with the larger fuel pellet OD. The results for the CE 16x16 class of fuel assemblies without BPRAs are shown in Table 6-35. The results for the CE 16x16 class of fuel assemblies with BPRAs are shown in Table 6-36. These results indicate that the presence of BPRAs increases the reactivity of the system and consequently a reduction in the allowable enrichment.

6.4.2.4 Determination of the Most Reactive Damaged Fuel Configuration

There are several mechanisms by which a fuel rod may be breached. These mechanisms may occur while the fuel is loaded in the reactor core, in the spent fuel pool, during transport, while in temporary dry storage, and while in permanent dry storage. In addition, the type and extent of fuel rod breach can be broken down into several categories. For this calculation, the method by which the fuel rod is breached is not as important as the extent of the resultant damage. The worst case gross damage resulting from a cask drop accident is assumed to be either a single-ended or double-ended rod shear with moderator intrusion. The bent or bowed fuel rod cases assume that the fuel is intact but not in its nominal fuel rod pitch. It is possible that the fuel rods may be crushed inwards or bowed outwards to a certain degree. Therefore, this will be evaluated by varying the fuel rod pitch from a minimum pitch (based on clad OD) to a maximum based on the fuel compartment size for each fuel assembly class. All pitch variations assume a uniform rod pitch throughout the entire fuel matrix.

The single-ended fuel rod shear cases assume that a fuel rod shears in one place and is displaced to a new location. The fuel pellets are assumed to remain in the fuel rod. This case will be evaluated by displacing one row of rods from the base fuel assembly matrix at small increments towards the side of the fuel compartment. The base fuel assembly matrix will be at nominal pitch and positioned in the "inward" position within the 32PTH DSC to maximize the separation distance between the fuel array and the sheared row of fuel rods. A smaller rod pitch for the base fuel assembly matrix was not chosen because it has been shown from the pitch cases that decreasing the rod pitch decreases reactivity. Increasing the base fuel assembly rod pitch will increase reactivity, however, the resulting model is similar to and is bounded by the rod pitch varying cases presented above and therefore will not be duplicated here. The single shear cases are analyzed for the two fuel assembly classes.

The double-ended fuel rod shear cases assume that the fuel rod shears in two places and the intact fuel rod piece is separated from the parent fuel rod. Three resulting conditions are exhibited by the occurrence of a double-ended rod shear. These are, the fuel rod piece can remain in place, it can be displaced in the same plane, or it can be displaced to a different plane. The "remain in place" situation results in no deviation from the base fuel assembly matrix, and is therefore considered trivial and will not be evaluated separately. The fuel rod piece displaced in the same plane is equivalent to the single-ended rod shear case discussed above and will not be reevaluated in these cases. The fuel rod piece displaced in a different plane results in two possibilities: an added rod or a removed rod. As in the single-ended shear cases, the base fuel assembly matrix will be positioned in the "inward" position of the 32PTH DSC to allow room for a row of displaced fuel rods. One row of fuel rods of different lengths will be removed from a section of the assembly and added to another to determine if the system exhibits any trends. The nominal rod pitch is used for the base fuel matrix just as in the single-ended shear rod cases. The two fuel assembly classes are analyzed for the double-ended shear configuration.

In order to determine the effect of an axial shift in the fuel assemblies beyond the poison during transfer, bounding calculations that consider a 4" axial shift of fuel assemblies are performed. The nominal rod pitch is used for these cases and both the fuel assembly classes are analyzed for this configuration.

The first step is to determine the most reactive damaged fuel assembly geometry. This was completed using limiting fixed poison loading, soluble boron concentration and assembly enrichment for the various fuel assembly classes. The limiting parameters used for this study are shown in Table 6-19. All 32 assembly locations were filled with damaged fuel assemblies. The intent of these calculations was to determine the most reactive geometry, not to meet the USL. The following is a breakdown of runs made in this analysis:

- Optimum Rod Pitch Study (for fuel assemblies and rod storage baskets).
- Single-ended Shear Study.
- Double-ended Shear Study.
- Shifting of fuel assemblies beyond (4 inches above) the poison sheet height.

With the selection of the most reactive damaged fuel assembly geometry, the next set of analyses determined the maximum k_{eff} for various damaged fuel assembly loading configurations in the NUHOMS® 32PTH DSC. The most reactive damaged fuel assembly geometry for each fuel assembly class determined will be used to determine the maximum enrichment as a function of fixed poison loading and soluble boron concentration for loading 32 damaged fuel assemblies in the basket. In other words, cases are analyzed for all the configurations described in Table 6-1.

Rod Pitch Study:

The first set of damaged fuel analyses involved a study on the effect of the fuel rod pitch on system reactivity. KENO models with rod pitches ranging from a minimum corresponding to the clad OD to a maximum limited by the fuel compartment size are developed for each fuel assembly class. The results of the rod pitch study are shown in Table 6-20 and a discussion of these results is as follows. For the CE 14x14 fuel assembly class, the optimum pitch was calculated to be 0.620". For the WE 15x15 fuel assembly class, the largest pitch (limited by the fuel compartment size) resulted in the most reactive configuration. For the WE 17x17 fuel assembly class, the second largest pitch resulted in the most reactive configuration. For the CE 16x16 fuel assembly class, the optimum pitch was calculated to be 0.545 in.

This study also bounds damaged fuel configurations with missing rods. A separate study to determine the effect on reactivity due to removal of fuel rods at optimum pitch is not necessary due to the presence of soluble boron in the moderator. The removal fuel rods would ensure that the fissile fuel rods are replaced with boron poison and would result in a reduction in k_{eff}. Therefore, the rod pitch study is completed by determining the optimum pitch and the associated maximum k_{eff} at optimum moderator density. The 2D KENO plot for the CE 14x14 fuel assembly (without BPRAs) is shown in Figure 6-14. The 2D KENO plot for the CE 16x16 fuel assembly (with BPRAs) is shown in Figure 6-20.

Single Ended Rod Shear Study:

The next set of analyses performed is for the Single-ended rod shear. The Single-ended rod shear study depicts the fuel assembly with its last row of rods separated from the rest of the assembly. The displacement of the sheared row of rods varies radially from fuel assembly up to a maximum that is governed by the fuel assembly width and the fuel compartment size.

To model this in KENO, the base case was slightly modified. First, for a given fuel lattice, the fuel assemblies are modeled as a XX by (XX-1) array where XX corresponds to the fuel assembly class. For example, the WE 15 fuel assembly is modeled as a 15x14 array. Unit 200 is a XX by 1 array comprising of the single sheared row of rods. The units 201, 204, 211 and 214, therefore consist of two arrays, the array describing the truncated fuel assembly and the sheared row of fuel rods. The displaced row of rod array is then shifted (separation distance is "d") away from the fuel assembly. The amount of fuel remains the same, i.e. no new fuel is added to the system. Nominal rod pitch for all of the fuel assembly classes is used for the base XX by (XX-1) fuel assembly. In the cask drop accident scenarios, it is more likely that the fuel assembly will be crushed as a result of the drop and therefore cause local decreases in the rod pitch of the assembly. However, the rod pitch studies outlined above show that a decrease in the fuel rod pitch results in a decrease in system reactivity, therefore for the single-ended rod shear study runs, rod pitch is modeled at nominal value. The study is repeated for all the fuel assembly classes and at varying moderator density for important separation distances. An example plot of a single ended shear configuration with WE 17x17 fuel assembly is shown in Figure 6-15. The results of this evaluation are shown in Table 6-21. The results indicate that there exists an optimum shear row separation distance for each class of fuel assembly where the reactivity is highest.

Double Ended Rod Shear Study:

The three Double-ended Rod Shear cases model a row (XX by 1 array) of dislocated rods severed at different sections axially and then displacing to other sections of the DSC in order to define a conservative bounding condition for fuel rod location subsequent to a double-ended rod shear. To model this in KENO, the base case was accordingly modified. A new KENO unit, UNIT 11 forms one axial section of the basket that models the un-sheared fuel assemblies. The sheared fuel assemblies depleted by one row of fuel rods are modeled as a XX by (XX-1) array where XX corresponds to the fuel assembly class. The corresponding KENO units for the fuel assembly positions are 301, 304, 311, 314, 302, 303, 305 and 312. The unit 12 forms the axial section of the basket that models this depleted array of fuel assemblies. The fuel assemblies that contain the sheared-migrated row of fuel rods are modeled as a XX by (XX+1) array where XX corresponds to the fuel assembly class. The corresponding KENO units for the fuel assembly positions are 401, 404, 411 414, 402, 403, 405 and 412. The unit 13 forms the axial section of the basket that models this depleted array of fuel assemblies. Depending on the fraction of double shear, the array 11 (an axial array of units 11, 12 and 13) is constructed to calculate the reactivity effect. Due to the height of a single axial segment (15.03"), the total axial height of the model for these studies is 150.30" (15.03*10). However, periodic axial boundary conditions are applied making the model essentially infinite. The same rod pitch assumptions made for the Single-ended Shear runs also apply here.

Basically three types of double ended shear studies are evaluated. The first is a half shear where the sheared row breaks into two equal sections resulting in one-half of the fuel assembly being defined by a rod array containing an extra row of fuel rods while the other half is defined by an array depleted by one row of fuel rods. The half shear is represented in this calculation as a $(5/10)^{th}$ shear. The second is a one-third shear where the sheared row breaks into two unequal sections measuring a third of the fuel assembly length and two-third of the fuel assembly length respectively. Therefore, the fuel assembly can be defined by three axially equal sections, one with a regular array of fuel rods, one with an extra row of fuel rods and the other with a depleted row of fuel rods. This is modeled as $(3/10)^{th}$ which is about the same as one-third. The same mechanism can be extended to other shear ratios but the effect on reactivity is expected to reduce with reduction in the shear ratio. The one-fifth shear is also analyzed in this study as $(2/10)^{th}$ shear. The internal moderator density is varied to determine the k_{eff} at optimum density.

Results of the double-ended rod shear study show that the movement of one exterior row of half of the fuel assembly length is the most reactive. The CE 14x14 and CE 16x16 fuel is only evaluated for the half shear condition since the evaluation results show this is the most reactive. An example plot of a double ended shear configuration with WE 15x15 fuel assembly is shown in Figure 6-16. The results of the evaluation are shown Table 6-22.

Shifting of Fuel Beyond Fixed Poison:

This study analyzes the effect of shifting of loose rods beyond the height of the poison plates. Two types of shifting of fuel rods beyond the poison plates are analyzed in this study. The first calculational model assumes that a four-inch axial section of the entire fuel assembly shifts beyond the poison plates. The height of the axial shift, four-inches, is more than the maximum difference between the basket height and the canister cavity height (about 2.5 inches). The second calculational model involves a shifting of 8 of the outermost rows of fuel rods (basically two concentric rings of fuel rods) beyond the poison plates by six inches. In KENO, this six-inch section is modeled like a regular fuel assembly with fuel pins defining the 8 outer most rows (and columns) with aluminum occupying the space in the middle. This is done to simulate the sliding of fuel rods around the inlet or outlet nozzle during an accident. These models conservatively bound all the cases associated with the shifting of fuel rods beyond poison like sliding of a single rod, sliding of a row of single sheared rods etc.

To model these in KENO, the base case was modified. First, a new KENO unit, UNIT 11 forms one axial section of the basket that models the fuel assemblies covered with poison. For the shifting of fuel assemblies (first model), a four-inch axial section of the fuel assemblies containing the uncovered fuel assemblies are modeled with the KENO units 301, 304, 311 and 314. The unit 12 forms the axial section of the basket that models this uncovered section of fuel assemblies. Finally, the array 11 (an axial array of units 11 and 12) is constructed to calculate the reactivity effect. Periodic axial boundary conditions are utilized to make this model essentially infinite in length. For the sliding of fuel assemblies (second model), a six-inch axial section of the fuel assemblies containing the eight uncovered rows of fuel rods with aluminum in the middle portion are modeled with the KENO units 301, 304, 311 and 314. The unit 12 forms the axial section of the basket that models this uncovered section of fuel assemblies. Finally, the array 11 (an axial array of units 11 and 12) is constructed to calculate the reactivity effect. Periodic axial boundary conditions are utilized to make this model essentially infinite in length. This study is performed for the two fuel assembly classes with varying moderator density. Since the four-inch shift configuration is always found to be more reactive than the six-inch slide configuration, only the four-inch shift configuration was evaluated for the CE 16x16 fuel assembly class.

The results of these evaluations are shown in Table 6-23. An example plot of a shifting configuration with WE 17x17 fuel assembly is shown in Figure 6-17. An example plot of a sliding configuration with WE 15x15 fuel assembly is shown in Figure 6-18.

6.4.2.5 Determination of the Most Reactive Damaged Configuration

The fuel-loading configuration of the canister/cask affects the reactivity of the package. Several series of analyses performed in the previous sections evaluated the various damaged assembly configurations. A comparison of the maximum k_{eff} due to the various damaged assembly configurations is shown in Table 6-24. The most reactive damaged assembly configuration for the CE 14x14 and CE 16x16 fuel is the optimum pitch configuration of the rods and for the WE 15x15 and WE 17x17 fuel is the double-ended rod shear with a shear ratio of one-half.

Additionally, the one-half (5/10) double-ended shear configuration is modified to include BPRAs to obtain a bounding damaged assembly configuration. The results of this evaluation, shown in Table 6-25, demonstrate that the configuration with BPRAs is bounding. Therefore, this configuration is the design basis configuration for the WE 15x15 and WE 17x17 fuel assembly classes and will be utilized to determine the k_{eff} of the NUHOMS®-32PTH DSC containing damaged fuel assemblies. An example plot of a double ended shear configuration with WE 15x15 fuel assembly with BPRAs is shown in Figure 6-19.

6.4.2.6 Determination of Maximum Initial Enrichment for Damaged Assemblies

The most reactive damaged assembly configuration for the WE 15x15 and WE 17x17 fuel is based on the double-ended shear model with a shear ratio of one-half with BPRAs while the most reactive damaged assembly configuration for the CE 14x14 and CE 16x16 fuel is based on an optimum pitch arrangement of rods. The following analysis uses these configurations to determine the maximum allowable initial enrichment as a function of poison plate loading and soluble boron concentration for all the fuel assembly classes. The analysis is carried out with the NUHOMS®-32PTH DSC containing 32 design basis damaged assemblies. Only the fuel assembly type, the fixed and soluble poison loading is changed for each model. In addition, the internal moderator density is varied to determine the peak reactivity for the specific configuration. All calculations for the WE 15x15 and WE 17x17 fuel are performed with the presence of BPRAs (bounding for all CC and no CC cases) in the guide tubes to determine the maximum allowable enrichment for these two fuel assembly classes with and without CCs. The

CE 14x14 and CE 16x16 fuel assembly classes are evaluated separately with and without BPRAs. For ease of modeling the guide tubes and BPRAs are modeled as cuboids with an equivalent area rather than cylinders.

The canister / cask model for this evaluation differs from the actual design in the following ways:

- the boron-10 content in the borated aluminum poison plates is 10% lower than the minimum required and the boron-10 content in the boral® poison plates is 25% lower than the minimum required
- the neutron shield and the skin of the cask are conservatively replaced with water between the casks, and
- the worst case geometry and material conditions as determined in Section 6.4.2.2 and the worst case damaged assembly configuration as determined in Section 6.4.2.5, are modeled.

Five different fixed poison loadings are analyzed in the criticality calculations as described in Section 4.2, corresponding to the four different types of basket based on fixed poison loading (Type A, B, C, D and E). Four different soluble boron concentration levels are analyzed - 2000 ppm, 2300 ppm, 2400 ppm and 2500 ppm. The maximum analyzed initial enrichment is 5.0 wt. % U-235.

CE 14x14 Class Assemblies

The results for CE 14x14 class of fuel assemblies without BPRAs are shown in Table 6-37. The results for the CE 14x14 class of fuel assemblies with BPRAs are shown in Table 6-38.

CE 16x16 Class Assemblies

The results for CE 16x16 class of fuel assemblies without BPRAs are shown in Table 6-39. The results for the CE 16x16 class of fuel assemblies with BPRAs are shown in Table 6-40.

WE 15x15 Class Assemblies

The results for WE 15x15 class of fuel assemblies with BPRAs are shown in Table 6-26.

WE 17x17 Class Assemblies

The most reactive WE 17x17 class assembly is the WE 17x17 standard fuel assembly. The results for the WE 17x17 class of fuel assemblies with BPRAs are shown in Table 6-27. For calculations with Type C basket, the WE 17x17 assembly results are conservatively applied to WE 15x15 assembly.

6.4.3 Criticality Results

This section presents the results of the analyses used to demonstrate the acceptability of storing qualified fuel in the 32PTH DSC under normal, off-normal, and accident conditions for fuel loading, handling, and storage.

Table 6-28 lists the bounding results for intact fuel assemblies for all conditions of storage. The highest calculated k_{eff}, including 2σ uncertainty, is for the CE 16x16 class fuel assembly with an initial enrichment of 4.80 wt. % U-235, 2000 ppm soluble boron and a poison loading of 28.8 mg B-10/cm^2 (Type D Basket) without BPRAs. The maximum allowable initial enrichment with BPRAs for the WE 15x15 and WE 17x17 (bounding for cases without BPRAs) fuel assembly types and with and without BPRAs for the CE 14x14 and CE 16x16 fuel assembly type as a function of fixed poison loading and soluble boron concentration is given in Table 6-1. The input files for the cases with the highest calculated reactivity (with and without BPRAs) are included in the Appendix A.

Table 6-29 lists the bounding results for damaged fuel assemblies for all conditions of storage. The highest calculated k_{eff}, including 2σ uncertainty for the damaged assembly calculations, is 0.9402 and it occurs for the WE 17x17 Standard fuel assembly with an initial enrichment of 4.80 wt. % U-235, 2400 ppm soluble boron and a poison loading of 50.0 mg B-10/cm^2 (Type E Basket). The maximum allowable initial enrichment with BPRAs for the WE 15x15 and WE 17x17 (bounding for cases without BPRAs) fuel assembly types and without BPRAs for the CE 14x14 fuel assembly type as a function of fixed poison loading and soluble boron concentration is given in Table 6-1.

ANS/ANSI-8.1 [5] recommends that calculational methods used in determining criticality safety limits for applications outside reactors be validated by comparison with appropriate critical experiments. An Upper Subcritical Limit (USL) provides a high degree of confidence that a given system is subcritical if a criticality calculation based on the system yields a k_{eff} below the USL.

The criterion for subcriticality is that

$$k_{KENO} + 2\sigma_{KENO} \leq USL,$$

Where USL is the upper subcritical limit established by an analysis of benchmark criticality experiments. In Section 6.5, the minimum USL over the parameter range is determined to be is 0.9419. From Table 6-28 and Table 6-29, for the most reactive case,

$$k_{KENO} + 2\sigma_{KENO} = 0.9391 + 2\,(0.0008) = 0.9407 \leq 0.9419.$$

This indicates that the fuel will remain subcritical. Conclusions regarding specific aspects of the methods used or the analyses presented can be drawn from the quantitative results presented in the associated tables.

6.5 Critical Benchmark Experiments

The criticality safety analysis of the NUHOMS® OS 187H TC containing the NUHOMS® -32PTH DSC uses the CSAS25 module of the SCALE system of codes. The CSAS25 control module allows simplified data input to the functional modules BONAMI-S, NITAWL-II, and KENO V.a. These modules process the required cross-section data and calculate the k_{eff} of the system. BONAMI-S performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-II applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the effective neutron multiplication (k_{eff}) of a 3-D system.

The analysis presented herein uses the fresh fuel assumption for criticality analysis. The analysis employs the 44-group ENDF/B-V cross-section library because it has a small bias, as determined by 121 benchmark calculations. The Upper Subcritical Limit (USL-1) was determined using the results of these 121 benchmark calculations.

The benchmark problems used in this verification are representative of benchmarks of commercial light water reactor (LWR) fuels with the following characteristics:

A. water moderation

B. boron neutron absorbers

C. unirradiated light water reactor type fuel (no fission products or "burnup credit")

D. close reflection

E. near room temperature (vs. reactor operating temperature)

F. Uranium oxide fuels.

Criticality codes are verified by comparing benchmark calculations to actual critical benchmark experiments. The difference between the calculated reactivity and the experimental reactivity is referred to as 'calculational' bias. This bias may be a function of system parameters such as fuel lattice separation, fuel enrichment, neutron absorber properties, reflector properties, or fuel/moderator volume ratio; or, there may be no specific correlation with system parameters. These experiments are discussed in detail in reference 6.

6.5.1 Benchmark Experiments and Applicability

The benchmark data used for determination of the USL is provided in Table 6.5-1. The set of criticality experiments used as benchmarks are representative of the composition, configuration, and nuclear characteristics of the system modeled. Six parameters were selected in order to demonstrate the applicability of the SCALE 44-group ENDF/B-V cross-section library for the range of conditions spanned by the calculation models. The results of these evaluations are provided in Table 6.5-2. Only those experiments with the parameter in question were used to determine the USL for that parameter. The methodology used to calculate the USL is based on NUREG/CR-6361 6, USL method 1.

USL-1 applies a statistical calculation of the bias and its uncertainty plus an administrative margin (0.05 Δk) to the linear fit of results of the experimental benchmark data developed. The USL from the data set with the best correlation is used as the acceptance criteria for subsequent criticality evaluations. Since there was not a strong correlation for any of the data sets, i.e., the correlation was essentially random and the lowest possible USL-1 result was used as the USL.

The uncertainty due to modeling approximations does not impact the calculated k_{eff}. Worst case tolerances (as specified in the design drawings presented in Chapter 1) are used in the analysis to maximize k_{eff}. Only the tolerances of those dimensions that had a positive effect on k_{eff} were included in the SCALE geometry models.

6.5.2 Results of the Benchmark Calculations

A summary of all of the pertinent parameters for each experiment along with the results of each case is included in Table 6-30. The USL benchmark calculations are also shown in Table 6-30. The best correlation (linear regression correlation for each parameter vs. k_{eff}) is observed for fuel assembly separation distance, with a correlation of 0.656. All other parameters show much lower correlation ratios indicating no real correlation. All parameters were evaluated for trends and to determine the most conservative USL. Since there was no observable correlation, the worst case USL was selected for the identified parameters. Results from the USL evaluation are presented in Table 6-31.

The criticality evaluation presented here used the same cross section library, fuel materials and similar material/geometry options that were used in the 121 benchmark calculations as shown in Table 6-30. The modeling techniques and the applicable parameters for the actual criticality evaluations fall within the range of those addressed by the benchmarks in Table 6-31. The results from the comparisons of physical parameters of each of the fuel assembly types to the applicable USL value are presented in Table 6-32. The minimum value of the USL-1 was determined to be 0.9419 based on comparisons to the most limiting assembly parameters.

6.6 Supplemental Information

6.6.1 References

1. Title 10 Code of Federal Regulations, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste."

2. Not Used

3. "SCALE, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," NUREG/CR-0200, Rev. 6 (ORNL/NUREG/CSD-2/R6), Vol. I-III, September 1998.

4. ANSI/ANS 57.2, Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants, 1983.

5. ANS/ANSI-8.1, American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, 1983.

6. U.S. Nuclear Regulatory Commission, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages," NUREG/CR-6361, ORNL-TM-13211, March 1997.

7. U.S. Nuclear Regulatory Commission, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," NUREG/CR-5661, ORNL/TM-11936, April 1997.

8. NOT USED

9. NOT USED

Table 6-1
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Intact Fuel Assembly (without CC)	**A**	**4.05**	**4.40**	**4.45**	**4.55**
	B	**4.55**	**4.90**	**5.00**	**-**
	C	**4.70**	**5.00**	**-**	**-**
	D	**5.00**	**-**	**-**	**-**
	E	**-**	**-**	**-**	**-**
CE 14x14 Intact Fuel Assembly (with CC)	**A**	**3.95**	**4.25**	**4.35**	**4.45**
	B	**4.35**	**4.70**	**4.80**	**4.90**
	C	**4.50**	**4.85**	**5.00**	**-**
	D	**4.75**	**5.00**	**-**	**-**
	E	**5.00**	**-**	**-**	**-**
CE 16x16 Intact Fuel Assembly (without CC)	**A**	**3.90**	**4.10**	**4.20**	**4.30**
	B	**4.30**	**4.60**	**4.70**	**4.80**
	C	**4.50**	**4.80**	**4.90**	**5.00**
	D	**4.80**	**5.00**	**5.00**	**5.00**
	E	**5.00**	**5.00**	**5.00**	**5.00**
CE 16x16 Intact Fuel Assembly (with CC)	**A**	**3.80**	**4.00**	**4.10**	**4.20**
	B	**4.20**	**4.50**	**4.60**	**4.70**
	C	**4.40**	**4.70**	**4.80**	**4.90**
	D	**4.70**	**4.90**	**5.00**	**5.00**
	E	**4.90**	**5.00**	**5.00**	**5.00**
WE 15x15 Intact Fuel Assembly (with and without CCs)	**A**	**3.50**	**3.70**	**3.80**	**3.90**
	B	**3.80**	**4.10**	**4.20**	**4.30**
	C	**3.95**	**4.25**	**4.35**	**4.45**
	D	**4.20**	**4.50**	**4.70**	**4.80**
	E	**4.50**	**4.80**	**4.90**	**5.00**
WE 17x17 Intact Fuel Assembly (with and without CCs)	**A**	**3.50**	**3.70**	**3.80**	**3.90**
	B	**3.80**	**4.10**	**4.20**	**4.30**
	C	**3.95**	**4.25**	**4.35**	**4.45**
	D	**4.20**	**4.50**	**4.60**	**4.70**
	E	**4.45**	**4.70**	**4.90**	**5.00**

Table 6-1
Maximum Assembly Average Initial Enrichment for Intact and Damaged Fuel Loading
(Concluded)

Assembly Class	Maximum Assembly Average Initial Enrichment of U-235 as a Function of Soluble Boron Concentration and Fixed Poison Loading (Basket Type)				
	Basket Type	Minimum Soluble Boron Concentration			
		2000 ppm	2300 ppm	2400 ppm	2500 ppm
CE 14x14 Damaged Fuel Assembly (without CC)	A	3.90	4.20	4.25	4.35
	B	4.35	4.70	4.80	4.90
	C	4.50	4.85	4.95	5.00
	D	4.85	5.00	-	-
	E	5.00	-	-	-
CE 14x14 Damaged Fuel Assembly (with CC)	A	3.70	3.95	4.05	4.10
	B	4.10	4.40	4.50	4.60
	C	4.20	4.55	4.65	4.75
	D	4.50	4.85	5.00	-
	E	4.75	5.00	-	-
CE 16x16 Damaged Fuel Assembly (without CC)	A	3.65	3.90	4.00	4.05
	B	4.05	4.30	4.40	4.50
	C	4.20	4.50	4.60	4.70
	D	4.50	4.80	4.90	5.00
	E	4.75	5.00	5.00	5.00
CE 16x16 Damaged Fuel Assembly (with CC)	A	3.60	3.80	3.90	4.00
	B	3.95	4.20	4.30	4.40
	C	4.10	4.40	4.50	4.60
	D	4.40	4.70	4.80	4.90
	E	4.65	4.90	5.00	5.00
WE 15x15 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.35	4.70	4.80	4.90
WE 17x17 Damaged Fuel Assembly (with and without CCs)	A	3.40	3.60	3.70	3.80
	B	3.75	4.00	4.10	4.20
	C	3.85	4.15	4.25	4.35
	D	4.10	4.40	4.50	4.60
	E	4.30	4.65	4.80	4.90

Note: '—' represents those fixed poison loading (basket type) and soluble boron concentration combinations where fuel assemblies with a maximum assembly average initial enrichment of 5.00 wt % U-235 can be loaded

Table 6-2
Summary of Limiting Criticality Evaluations for all Fuel Assemblies

Limiting Assembly Position- The fuel assembly is located in the corner of each compartment tube closest to the 32PTH DSC centerline.				
CE 14x14 Fuel Assembly				
Case	**K_{eff}**	**σ**	**K_{eff} + 2σ**	**USL**
Intact Fuel - 90% IMD, Type B Basket (15.0 mg B-10/cm²), 2300 ppm Boron, 4.4 wt. % U-235	0.9383	0.0009	0.9401	0.9419
Damaged Fuel – Optimum Pitch, 70% IMD Type B Basket (15.0 mg B-10/cm²), 2400 ppm Boron, 4.8 wt. % U-235	0.9386	0.0007	0.9400	0.9419
WE 15x15 Fuel Assembly				
Case	**K_{eff}**	**σ**	**K_{eff} + 2σ**	**USL**
Intact Fuel - 90% IMD, No BPRA, Type D Basket (32.0 mg B-10/cm²), 2500 ppm Boron, 4.9 wt. % U-235	0.9383	0.0008	0.9399	0.9419
Intact Fuel - Full IMD, With BPRA, Type D Basket (32.0 mg B-10/cm²), 2400 ppm Boron, 4.7 wt. % U-235	0.9388	0.0007	0.9402	0.9419
Damaged Fuel - Double Ended Shear Full IMD, With BPRA, Type E Basket (50.0 mg B-10/cm²), 2300 ppm Boron, 4.7 wt. % U-235	0.9361	0.0007	0.9375	0.9419
WE 17x17 Fuel Assembly				
Case	**K_{eff}**	**σ**	**K_{eff} + 2σ**	**USL**
Intact Fuel - 70% IMD, No BPRA, Type A Basket (7.0 mg B-10/cm²), 2300 ppm Boron, 3.8 wt. % U-235	0.9390	0.0007	0.9404	0.9419
Intact Fuel - 80% IMD, With BPRA, Type A Basket (7.0 mg B-10/cm²), 2500 ppm Boron, 3.9 wt. % U-235	0.9381	0.0008	0.9397	0.9419
Damaged Fuel - Double Ended Shear Full IMD, With BPRA, Type E Basket (50.0 mg B-10/cm²), 2400 ppm Boron, 4.8 wt. % U-235	0.9388	0.0007	0.9402	0.9419
CE 16x16 Fuel Assembly				
Case	**K_{eff}**	**σ**	**K_{eff} + 2σ**	**USL**
Intact Fuel, IMD 80% No BPRA, Type D Basket, 2000 ppm, 4.80 wt. %	0.9391	0.0008	0.9407	0.9419
Damaged Fuel, IMD 90% with BPRA Type E Basket, 2000 ppm Boron, 4.65 wt% U-235	0.9384	0.0007	0.9398	0.9419

Table 6-3
Authorized Contents for NUHOMS®-32PTH DSC

Assembly Type(1)	Array/Class
Westinghouse 17x17 Standard (WE 17x17) Vantage 5H/OFA	17x17
Framatome ANP Advanced MK BW 17x17 (MK BW 17x17)	17x17
Westinghouse 15x15 Standard (WE 15x15) Westinghouse 15x15 Surry Improved (WES 15x15)	15x15
CE 14x14 Standard (CE 14x14)	14x14
CE 16x16 Standard/System 80 (CE 16x16)	16x16

(1) Equivalent reload fuel assemblies that are enveloped by the fuel assembly design characteristics listed above are also acceptable.

Table 6-4
Fuel Assembly Design Parameters for Criticality Analysis

Manufacturer(1)	Array	Version	Active Fuel Length (inches)	# Fuel Rods per Assembly	Pitch (inches)	Fuel Pellet OD (inches)
Westinghouse	17x17	Standard Vantage	144	264	0.4960	0.3225
Westinghouse	17x17	OFA	144	264	0.4960	0.3088
Framatome	17x17	MK BW	144	264	0.4960	0.3195
Westinghouse	15x15	Std / Surry	144	204	0.5630	0.3669
CE	14x14	Std	137	176	0.5800	0.3765
CE	14x14	Ft. Calhoun	128	176	0.5800	0.3815
CE	16x16	System 80	150	236	0.506	0.3255
CE	16x16	Standard	150	236	0.506	0.3255

Manufacturer(1)	Array	Version	Clad Thickness (inches)	Clad OD (inches)	Guide Tube OD Inst. Tube OD (inches)	Guide Tube ID Inst. Tube ID (inches)
Westinghouse	17x17	Standard Vantage	0.0225	0.374	24 @ 0.4820 1 @ 0.4740	24 @ 0.4500 1 @ 0.4440
Westinghouse	17x17	OFA	0.0225	0.360	24 @ 0.4820 1 @ 0.4740	24 @ 0.4500 1 @ 0.4440
Framatome	17x17	MK BW	0.0225	0.374	24 @ 0.4820 1 @ 0.4820	24 @ 0.4500 1 @ 0.4500
Westinghouse	15x15	Std / Surry	0.0243	0.422	20 @ 0.5450 1 @ 0.5450	20 @ 0.5100 1 @ 0.5100
CE	14x14	Std	0.0280	0.440	5 @ 1.115	5 @ 1.035
CE	14x14	Ft. Calhoun	0.0280	0.440	5 @ 1.115	5 @ 1.035
CE	16x16	System 80	0.0230	0.382	5@0.768	5@0.687
CE	16x16	Standard	0.0250	0.382	5@0.768	5@0.687

Note: All dimensions shown are nominal

(1) Equivalent reload fuel assemblies that are enveloped by the fuel assembly design characteristics listed above are also acceptable.

Table 6-10
Results of the Fuel Assembly Positioning Studies

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Framatome 17x17 MK BW Fuel Assembly				
Centered, 70% IMD	0.9216	0.0008	0.9232	adfr17mkb_c070.out:
Centered, 80% IMD	0.9235	0.0006	0.9247	adfr17mkb_c080.out:
Centered, 90% IMD	0.9219	0.0008	0.9235	adfr17mkb_c090.out:
Centered, 100% IMD	0.9153	0.0008	0.9169	adfr17mkb_c100.out:
Inward, 70% IMD	0.9239	0.0008	0.9255	adfr17mkb_o070.out:
Inward, 80% IMD	**0.9263**	**0.0007**	**0.9277**	**adfr17mkb_o080.out:**
Inward, 90% IMD	0.9250	0.0007	0.9264	adfr17mkb_o090.out:
Inward, 100% IMD	0.9194	0.0007	0.9208	adfr17mkb_o100.out:
Westinghouse 15x15 Standard Fuel Assembly				
Centered, 70% IMD	0.9210	0.0007	0.9224	we15std_c070.out:
Centered, 80% IMD	0.9220	0.0007	0.9234	we15std_c080.out:
Centered, 90% IMD	0.9187	0.0007	0.9201	we15std_c090.out:
Centered, 100% IMD	0.9101	0.0007	0.9115	we15std_c100.out:
Inward, 70% IMD	**0.9242**	**0.0008**	**0.9258**	**we15std_o070.out:**
Inward, 80% IMD	0.9231	0.0008	0.9247	we15std_o080.out:
Inward, 90% IMD	0.9231	0.0008	0.9247	we15std_o090.out:
Inward, 100% IMD	0.9148	0.0008	0.9164	we15std_o100.out:
Westinghouse 17x17 OFA Fuel Assembly				
Centered, 70% IMD	0.9069	0.0007	0.9083	we17ofa_c070.out:
Centered, 80% IMD	0.9057	0.0008	0.9073	we17ofa_c080.out:
Centered, 90% IMD	0.9027	0.0007	0.9041	we17ofa_c090.out:
Centered, 100% IMD	0.8955	0.0007	0.8969	we17ofa_c100.out:
Inward, 70% IMD	0.9106	0.0007	0.9120	we17ofa_o070.out:
Inward, 80% IMD	**0.9108**	**0.0006**	**0.9120**	**we17ofa_o080.out:**
Inward, 90% IMD	0.9050	0.0007	0.9064	we17ofa_o090.out:
Inward, 100% IMD	0.8984	0.0006	0.8996	we17ofa_o100.out:
Combustion Engineering 16x16 Fuel Assembly				
CE 16x16 System 80 Centered, 100% IMD	0.8676	0.0007	0.8690	
CE 16x16 Standard Centered 100% IMD	0.8666	0.0006	0.8678	

Table 6-18
WE 17x17 Class Intact Assemblies with BPRAs – Final Results
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type D Basket (32.0 mg B-10/cm^2), 2500 ppm Boron, 4.7 wt. % U-235				
60% IMD	0.8992	0.0007	0.9006	we17bp25_p32e47_060.out:
70% IMD	0.9154	0.0007	0.9168	we17bp25_p32e47_070.out:
80% IMD	0.9272	0.0007	0.9286	we17bp25_p32e47_080.out:
90% IMD	0.9341	0.0007	0.9355	we17bp25_p32e47_090.out:
100% IMD	0.9356	0.0008	0.9372	we17bp25_p32e47_100.out:
Type E Basket (50.0 mg B-10/cm^2), 2500 ppm Boron, 5.0 wt. % U-235				
60% IMD	0.8871	0.0008	0.8887	we17bp25_p50e50_060.out:
70% IMD	0.9102	0.0007	0.9116	we17bp25_p50e50_070.out:
80% IMD	0.9260	0.0007	0.9274	we17bp25_p50e50_080.out:
90% IMD	0.9343	0.0008	0.9359	we17bp25_p50e50_090.out:
100% IMD	0.9379	0.0008	0.9395	we17bp25_p50e50_100.out:

Table 6-19
Limiting Parameters for Damaged Fuel Calculations

Fuel Assembly Type	Enrichment	Boron Concentration	Fixed Poison Loading
CE 14x14	4.90 wt. % U-235	2300 ppm	15 mg B-10/cm^2
Westinghouse 15x15	4.90 wt. % U-235	2500 ppm	32 mg B-10/cm^2
Westinghouse 17x17	4.80 wt. % U-235	2500 ppm	32 mg B-10/cm^2
CE 16x16	4.90 wt. % U-235	2400 ppm	25 mg B-10/cm^2

Table 6-20
Results of Optimum Pitch Studies
(Continued)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
CE 14x14, 4.9 wt. % U-235, 2300 ppm, 15 mg B-10/cm² (Type B Basket)				
Pitch = 0.4400", 70% IMD	0.6852	0.0007	0.6866	ce14_pitch_min_070.out:
Pitch = 0.4400", 80% IMD	0.6915	0.0008	0.6931	ce14_pitch_min_080.out:
Pitch = 0.4700", 70% IMD	0.7560	0.0008	0.7576	ce14_pitch_470_070.out:
Pitch = 0.4700", 80% IMD	0.7626	0.0009	0.7644	ce14_pitch_470_080.out:
Pitch = 0.5000", 70% IMD	0.8196	0.0008	0.8212	ce14_pitch_500_070.out:
Pitch = 0.5000", 80% IMD	0.8245	0.0008	0.8261	ce14_pitch_500_080.out:
Pitch = 0.5400", 70% IMD	0.8872	0.0008	0.8888	ce14_pitch_540_070.out:
Pitch = 0.5400", 80% IMD	0.8886	0.0009	0.8904	ce14_pitch_540_080.out:
Pitch = 0.5800", 70% IMD	0.9337	0.0007	0.9351	ce14_pitch_nom_070.out:
Pitch = 0.5800", 80% IMD	0.9336	0.0007	0.9350	ce14_pitch_nom_080.out:
Pitch = 0.6000", 70% IMD	0.9473	0.0007	0.9487	ce14_pitch_600_070.out:
Pitch = 0.6000", 80% IMD	0.9468	0.0007	0.9482	ce14_pitch_600_080.out:
Pitch = 0.6100", 60% IMD	0.9457	0.0008	0.9473	ce14_pitch_610_060.out:
Pitch = 0.6100", 70% IMD	0.9491	0.0008	0.9507	ce14_pitch_610_070.out:
Pitch = 0.6100", 80% IMD	0.9467	0.0007	0.9481	ce14_pitch_610_080.out:
Pitch = 0.6100", 90% IMD	0.9383	0.0008	0.9399	ce14_pitch_610_090.out:
Pitch = 0.6100", 100% IMD	0.9290	0.0007	0.9304	ce14_pitch_610_100.out:
Pitch = 0.6200", 60% IMD	0.9500	0.0007	0.9514	ce14_pitch_620_060.out:
Pitch = 0.6200", 70% IMD	**0.9512**	**0.0007**	**0.9526**	**ce14_pitch_620_070.out:**
Pitch = 0.6200", 80% IMD	0.9471	0.0007	0.9485	ce14_pitch_620_080.out:
Pitch = 0.6200", 90% IMD	0.9368	0.0008	0.9384	ce14_pitch_620_090.out:
Pitch = 0.6200", 100% IMD	0.9250	0.0007	0.9264	ce14_pitch_620_100.out:
Pitch = 0.6250", 60% IMD	0.9499	0.0007	0.9513	ce14_pitch_625_060.out:
Pitch = 0.6250", 70% IMD	0.9506	0.0007	0.9520	ce14_pitch_625_070.out:
Pitch = 0.6250", 80% IMD	0.9476	0.0008	0.9492	ce14_pitch_625_080.out:
Pitch = 0.6250", 90% IMD	0.9372	0.0007	0.9386	ce14_pitch_625_090.out:
Pitch = 0.6250", 100% IMD	0.9234	0.0008	0.9250	ce14_pitch_625_100.out:
Pitch = 0.6315", 60% IMD	0.9499	0.0007	0.9513	ce14_pitch_max_060.out:
Pitch = 0.6315", 70% IMD	0.9500	0.0008	0.9516	ce14_pitch_max_070.out:
Pitch = 0.6315", 80% IMD	0.9445	0.0007	0.9459	ce14_pitch_max_080.out:
Pitch = 0.6315", 90% IMD	0.9340	0.0008	0.9356	ce14_pitch_max_090.out:
Pitch = 0.6315", 100% IMD	0.9187	0.0007	0.9201	ce14_pitch_max_100.out:

Table 6-20
Results of Optimum Pitch Studies
(Concluded)

Model Description	k_{KENO}	1σ	k_{eff}
CE 16x16, 4.90 wt. % U-235, 2400 ppm, Type C Basket			
Pitch=0.3820", IMD=080%	0.6889	0.0008	0.6905
Pitch=0.4000", IMD=080%	0.7389	0.0008	0.7405
Pitch=0.4250", IMD=080%	0.7971	0.0009	0.7989
Pitch=0.4500", IMD=080%	0.8476	0.0007	0.8490
Pitch=0.4750", IMD=080%	0.8938	0.0008	0.8954
Pitch=0.5060", IMD=080%	0.9338	0.0007	0.9352
Pitch=0.5200", IMD=050%	0.9278	0.0007	0.9292
Pitch=0.5200", IMD=060%	0.9397	0.0009	0.9415
Pitch=0.5200", IMD=070%	0.9455	0.0008	0.9471
Pitch=0.5200", IMD=080%	0.9431	0.0007	0.9445
Pitch=0.5200", IMD=090%	0.9382	0.0007	0.9396
Pitch=0.5450", IMD=050%	0.9405	0.0007	0.9419
Pitch=0.5450", IMD=060%	0.9501	0.0008	0.9517
Pitch=0.5450", IMD=070%	**0.9537**	**0.0007**	**0.9551**
Pitch=0.5450", IMD=080%	0.9470	0.0007	0.9484
Pitch=0.5450", IMD=090%	0.9399	0.0007	0.9413
Pitch=0.5511", IMD=050%	0.9406	0.0008	0.9422
Pitch=0.5511", IMD=060%	0.9517	0.0007	0.9531
Pitch=0.5511", IMD=070%	0.9509	0.0007	0.9523
Pitch=0.5511", IMD=080%	0.9448	0.0006	0.9460
Pitch=0.5511", IMD=090%	0.9358	0.0006	0.9370

Table 6-21
Results of the Single Ended Rod Shear Studies
(Concluded)

Description	**K_{keno}**	**σ_{keno}**	**K_{eff}**	**Filename**
CE 14x14, 4.9 wt. % U-235, 2300 ppm, 15 mg B-10/cm^2 (Type B Basket)				
D=1.20 cm, 60% IMD	0.9336	0.0007	0.9350	ce14_ss120_060.out:
D=1.20 cm, 70% IMD	0.9402	0.0008	0.9418	ce14_ss120_070.out:
D=1.20 cm, 80% IMD	0.9384	0.0007	0.9398	ce14_ss120_080.out:
D=1.20 cm, 90% IMD	0.9325	0.0007	0.9339	ce14_ss120_090.out:
D=1.20 cm, 100% IMD	0.9235	0.0007	0.9249	ce14_ss120_100.out:
D=1.35 cm, 60% IMD	0.9341	0.0007	0.9355	ce14_ssmax_060.out:
D=1.35 cm, 70% IMD	0.9386	0.0007	0.9400	ce14_ssmax_070.out:
D=1.35 cm, 80% IMD	0.9363	0.0008	0.9379	ce14_ssmax_080.out:
D=1.35 cm, 90% IMD	0.9291	0.0008	0.9307	ce14_ssmax_090.out:
D=1.35 cm, 100% IMD	0.9203	0.0007	0.9217	ce14_ssmax_100.out:
Model Description	**K_{keno}**	**σ_{keno}**	**K_{eff}**	
CE 16x16 4.90 wt. % U-235, 2400 ppm, Type C Basket				
Nominal Pitch, IMD=080%	0.9338	0.0007	0.9352	
D=0.000 cm, IMD=080%	0.9339	0.0008	0.9355	
D=0.300 cm, IMD=080%	0.9364	0.0007	0.9378	
D=0.600 cm, IMD=080%	**0.9377**	**0.0007**	**0.9391**	
D=0.900 cm, IMD=080%	0.9370	0.0007	0.9384	
D=1.200 cm, IMD=080%	0.9374	0.0008	0.9390	
D=1.407 cm, IMD=080%	0.9348	0.0007	0.9362	

Table 6-22
Results of the Double Ended Rod Shear Studies
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
WE 17x17, 4.8 wt. % U-235, 2500 ppm, 32 mg B-10/cm^2 (Type D Basket)				
Ratio=0, 60% IMD	0.9149	0.0007	0.9163	we17_ds000_060.out:
Ratio=0, 70% IMD	0.9304	0.0009	0.9322	we17_ds000_070.out:
Ratio=0, 80% IMD	0.9354	0.0007	0.9368	we17_ds000_080.out:
Ratio=0, 90% IMD	0.9369	0.0007	0.9383	we17_ds000_090.out:
Ratio=0, 100% IMD	0.9355	0.0008	0.9371	we17_ds000_100.out:
Ratio=2/10, 60% IMD	0.9159	0.0008	0.9175	we17_ds210_060.out:
Ratio=2/10, 70% IMD	0.9299	0.0007	0.9313	we17_ds210_070.out:
Ratio=2/10, 80% IMD	0.9371	0.0008	0.9387	we17_ds210_080.out:
Ratio=2/10, 90% IMD	0.9386	0.0008	0.9402	we17_ds210_090.out:
Ratio=2/10, 100% IMD	0.9372	0.0008	0.9388	we17_ds210_100.out:
Ratio=3/10, 60% IMD	0.9184	0.0008	0.9200	we17_ds310_060.out:
Ratio=3/10, 70% IMD	0.9319	0.0008	0.9335	we17_ds310_070.out:
Ratio=3/10, 80% IMD	0.9382	0.0007	0.9396	we17_ds310_080.out:
Ratio=3/10, 90% IMD	0.9415	0.0007	0.9429	we17_ds310_090.out:
Ratio=3/10, 100% IMD	0.9386	0.0008	0.9402	we17_ds310_100.out:
Ratio=5/10, 60% IMD	0.9179	0.0008	0.9195	we17_ds510_060.out:
Ratio=5/10, 70% IMD	0.9324	0.0008	0.9340	we17_ds510_070.out:
Ratio=5/10, 80% IMD	0.9404	0.0007	0.9418	we17_ds510_080.out:
Ratio=5/10, 90% IMD	**0.9444**	**0.0008**	**0.9460**	**we17_ds510_090.out:**
Ratio=5/10, 100% IMD	0.9403	0.0007	0.9417	we17_ds510_100.out:
Model Description	K_{keno}	1σ	K_{eff}	
CE 16x16, 4.9 wt. % U-235, 2400 ppm, Type C Basket				
IMD=060%	0.9372	0.0007	0.9386	
IMD=070%	**0.9457**	**0.0008**	**0.9473**	
IMD=080%	0.9449	0.0008	0.9465	
IMD=090%	0.9413	0.0009	0.9431	

Table 6-23
Evaluation of the Shifting of Fuel Rods Beyond the Poison

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
CE 14x14, 4.9 wt. % U-235, 2300 ppm, 15 mg B-10/cm² (Type B Basket)				
Shift 4-inches, 60% IMD	0.9320	0.0008	0.9336	ce14_nopoison_04_060.out
Shift 4-inches, 70% IMD	0.9372	0.0008	0.9388	ce14_nopoison_04_070.out
Shift 4-inches, 80% IMD	**0.9371**	**0.0009**	**0.9389**	**ce14_nopoison_04_080.out**
Shift 4-inches, 90% IMD	0.9321	0.0008	0.9337	ce14_nopoison_04_090.out
Shift 4-inches, 100% IMD	0.9224	0.0008	0.9240	ce14_nopoison_04_100.out
Slide 6-inches, 60% IMD	0.9279	0.0008	0.9295	ce14_slide_06_060.out:
Slide 6-inches, 70% IMD	**0.9341**	**0.0007**	**0.9355**	**ce14_slide_06_070.out:**
Slide 6-inches, 80% IMD	0.9329	0.0008	0.9345	ce14_slide_06_080.out:
Slide 6-inches, 90% IMD	0.9276	0.0007	0.9290	ce14_slide_06_090.out:
Slide 6-inches, 100% IMD	0.9198	0.0007	0.9212	ce14_slide_06_100.out:
4" Shifting, WE 15x15, 4.9 wt. % U-235, 2500 ppm, 32 mg B-10/cm² (Type D Basket)				
Shift 4-inches, 60% IMD	0.9271	0.0009	0.9289	we15_np004_060.out:
Shift 4-inches, 70% IMD	0.9382	0.0008	0.9398	we15_np004_070.out:
Shift 4-inches, 80% IMD	**0.9424**	**0.0008**	**0.9440**	**we15_np004_080.out:**
Shift 4-inches, 90% IMD	0.9397	0.0008	0.9413	we15_np004_090.out:
Shift 4-inches, 100% IMD	0.9341	0.0007	0.9355	we15_np004_100.out:
6" Sliding, WE 15x15, 4.9 wt. % U-235, 2500 ppm, 32 mg B-10/cm² (Type D Basket)				
Slide 6-inches, 60% IMD	0.9190	0.0007	0.9204	we15_sl006_060.out:
Slide 6-inches, 70% IMD	0.9324	0.0008	0.9340	we15_sl006_070.out:
Slide 6-inches, 80% IMD	**0.9378**	**0.0008**	**0.9394**	**we15_sl006_080.out:**
Slide 6-inches, 90% IMD	0.9372	0.0008	0.9388	we15_sl006_090.out:
Slide 6-inches, 100% IMD	0.9319	0.0007	0.9333	we15_sl006_100.out:
WE 17x17, 4.8 wt. % U-235, 2500 ppm, 32 mg B-10/cm² (Type D Basket)				
Shift 4-inches, 60% IMD	0.9241	0.0009	0.9259	we17_np004_060.out:
Shift 4-inches, 70% IMD	0.9362	0.0007	0.9376	we17_np004_070.out:
Shift 4-inches, 80% IMD	0.9407	0.0007	0.9421	we17_np004_080.out:
Shift 4-inches, 90% IMD	**0.9411**	**0.0007**	**0.9425**	**we17_np004_090.out:**
Shift 4-inches, 100% IMD	0.9366	0.0008	0.9382	we17_np004_100.out:
6" Sliding, WE 17x17, 4.8 wt. % U-235, 2500 ppm, 32 mg B-10/cm² (Type D Basket)				
Slide 6-inches, 60% IMD	0.9153	0.0007	0.9167	we17_sl006_060.out:
Slide 6-inches, 70% IMD	0.9283	0.0007	0.9297	we17_sl006_070.out:
Slide 6-inches, 80% IMD	0.9344	0.0007	0.9358	we17_sl006_080.out:
Slide 6-inches, 90% IMD	**0.9364**	**0.0008**	**0.9380**	**we17_sl006_090.out:**
Slide 6-inches, 100% IMD	0.9346	0.0008	0.9362	we17_sl006_100.out:
Model Description	**k_{KENO}**	**1σ**	**k_{eff}**	
CE 16x16, 4.9 wt. % U-235, 2400 ppm, Type C Basket				
IMD=060%	0.9323	0.0008	0.9339	
IMD=070%	**0.9375**	**0.0007**	**0.9389**	
IMD=080%	0.9355	0.0007	0.9369	
IMD=090%	0.9288	0.0007	0.9302	

Table 6-24
Most Reactive Damaged Assembly Configuration

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
CE 14x14, 4.9 wt. % U-235, 2300 ppm, 15 mg B-10/cm^2 (Type B Basket)				
Optimum Pitch	**0.9512**	**0.0007**	**0.9526**	**ce14_pitch_620_070.out:**
Single Ended Shear	0.9411	0.0008	0.9427	ce14_ss080_080.out:
Double Ended Shear	0.9492	0.0008	0.9508	ce14_ds011_080.out:
Shift 4-inches	0.9371	0.0009	0.9389	ce14_nopoison_04_080.out
Slide 6-inches	0.9341	0.0007	0.9355	ce14_slide_06_070.out:
WE 15x15, 4.9 wt. % U-235, 2500 ppm, 32 mg B-10/cm^2 (Type D Basket), No BPRA				
Optimum Pitch	0.9417	0.0007	0.9431	we15_pitch5877_080.out:
Single Ended Shear	0.9403	0.0007	0.9417	we15_ss035_080.out:
Double Ended Shear	**0.9438**	**0.0008**	**0.9454**	**we15_ds510_080.out:**
Shift 4-inches	0.9424	0.0008	0.9440	we15_np004_080.out:
Slide 6-inches	0.9378	0.0008	0.9394	we15_sl006_080.out:
WE 17x17, 4.8 wt. % U-235, 2500 ppm, 32 mg B-10/cm^2 (Type D Basket), No BPRA				
Optimum Pitch	0.9405	0.0008	0.9421	we17_pitch5100_090.out:
Single Ended Shear	0.9398	0.0008	0.9414	we17_ss015_090.out:
Double Ended Shear	**0.9444**	**0.0008**	**0.9460**	**we17_ds510_090.out:**
Shift 4-inches	0.9411	0.0007	0.9425	we17_np004_090.out:
Slide 6-inches	0.9364	0.0008	0.9380	we17_sl006_090.out:
Model Description	k_{KENO}	1σ	k_{eff}	
CE 16x16, 4.9 wt. % U-235, 2400 ppm, Type C Basket				
Optimum Pitch	0.9537	0.0007	0.9551	
Single Shear	0.9377	0.0007	0.9391	
Double Shear	0.9457	0.0008	0.9473	
4" Shift	0.9375	0.0007	0.9389	

Table 6-25
Double Ended Rod Shear Study with BPRAs

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
WE 15x15, 4.9 wt. % U-235, 2500 ppm, 32 mg B-10/cm^2 (Type D Basket), BPRA				
Ratio=5/10, 60% IMD	0.9132	0.0008	0.9148	we15bp_ds510_060.out:
Ratio=5/10, 70% IMD	0.9316	0.0008	0.9332	we15bp_ds510_070.out:
Ratio=5/10, 80% IMD	0.9410	0.0009	0.9428	we15bp_ds510_080.out:
Ratio=5/10, 90% IMD	0.9483	0.0008	0.9499	we15bp_ds510_090.out:
Ratio=5/10, 100% IMD	**0.9514**	**0.0007**	**0.9528**	**we15bp_ds510_100.out:**
WE 17x17, 4.8 wt. % U-235, 2500 ppm, 32 mg B-10/cm^2 (Type D Basket), BPRA				
Ratio=5/10, 60% IMD	0.9052	0.0008	0.9068	we17bp_ds510_060.out:
Ratio=5/10, 70% IMD	0.9257	0.0007	0.9271	we17bp_ds510_070.out:
Ratio=5/10, 80% IMD	0.9387	0.0007	0.9401	we17bp_ds510_080.out:
Ratio=5/10, 90% IMD	0.9462	0.0008	0.9478	we17bp_ds510_090.out:
Ratio=5/10, 100% IMD	**0.9478**	**0.0008**	**0.9494**	**we17bp_ds510_100.out:**

Table 6-28
Maximum k_{eff} for Intact Assemblies - Final Results

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
CE 14x14, No BPRA, Type D Basket (7.0 mg B-10/cm²), 2300 ppm Boron, 4.4 wt. % U-235				
70% IMD	0.9383	0.0007	0.9397	ce14b23_p07e44_070.out:
WE 15x15, No BPRA, Type D Basket (32.0 mg B-10/cm²), 2500 ppm Boron, 4.9 wt. % U-235				
90% IMD	0.9383	0.0008	0.9399	we15b25_p32e49_090.out:
Dry	0.5340	0.0004	0.5348	we15b25_p32e49_000.out:
WE 15x15, BPRA, Type D Basket (32.0 mg B-10/cm²), 2400 ppm Boron, 4.7 wt. % U-235				
100% IMD	0.9388	0.0007	0.9402	we15bp24_p32e47_100.out:
Dry	0.5408	0.0005	0.5418	we15bp24_p32e47_000.out:
WE 17x17, No BPRA, Type A Basket (7.0 mg B-10/cm²), 2300 ppm Boron, 3.8 wt. % U-235				
70% IMD	0.9390	0.0007	0.9404	we17b23_p07e38_070.out:
Dry	0.5286	0.0004	0.5294	we17b23_p07e38_000.out:
WE 17x17, BPRA, Type A Basket (7.0 mg B-10/cm²), 2500 ppm Boron, 3.9 wt. % U-235				
80% IMD	0.9381	0.0008	0.9397	we17bp25_p07e39_080.out:
Dry	0.5554	0.0004	0.5562	we17bp25_p07e39_000.out:
CE 16x16, No BPRA, Type D Basket, 2000 ppm Boron, 4.80 wt. % U-235				
80% IMD	0.9391	0.0008	0.9407	
Regulatory Requirements				
Dry Storage : Bounded by Infinite array of Dry Casks	0.5554	0.0004	0.5562	we17bp25_p07e39_000.out:
Normal Conditions: Wet Loading	0.9388	0.0007	0.9402	we15bp24_p32e47_100.out:
Accident Conditions: Damaged Transfer Cask While Fuel Still Wet	0.9391	0.0008	0.9407	

Table 6-29
Maximum k_{eff} for Damaged Assemblies - Final Results

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
CE 14x14, No BPRA, Type D Basket (15.0 mg B-10/cm^2), 2400 ppm Boron, 4.8 wt. % U-235				
70% IMD	0.9386	0.0007	0.9400	ce14d24_p15e48_070.out:
WE 15x15, BPRA, Type B Basket (15.0 mg B-10/cm^2), 2000 ppm Boron, 3.75 wt. % U-235				
100% IMD	0.9372	0.0007	0.9386	we15bpds_p15e38_100.out:
WE 17x17, BPRA, Type E Basket (50.0 mg B-10/cm^2), 2400 ppm Boron, 4.8 wt. % U-235				
100% IMD	0.9388	0.0007	0.9402	we17bpds_p50e48_100.out:
Dry	0.5264	0.0004	0.5272	we17bpds_p50e48_000.out:
CE 16x16, BPRA, Type E Basket, 2000 ppm Boron, 4.65 wt. % U-235				
90% IMD	0.9384	0.0007	0.9398	
Regulatory Requirements				
Dry Storage : Bounded by Infinite array of Dry Casks	0.5264	0.0004	0.5272	we17bpds_p50e48_000.out:
Normal Conditions: Wet Loading	0.9388	0.0007	0.9402	we17bpds_p50e48_100.out:
Accident Conditions: Damaged Transfer Cask While Fuel Still Wet	0.9386	0.0007	0.9400	ce14d24_p15e48_070.out:

Table 6-32
USL Determination for Criticality Analysis

Parameter	**Value from Limiting WE 17x17 Analysis**	**Bounding USL-1**
Pin Pitch (cm)	**1.25984**	**0.9419**
Water to Fuel Volume Ratio	1.6668	0.9433
Average Energy Group Causing Fission (AEG)	30.9147	0.9438
Assembly Separation (cm)	2.222	0.9420
Boron Concentration (ppm)	2300	0.9447
Enrichment (wt. % U-235)	3.700 (min)	0.9442
Parameter	**Value from Limiting WE 15x15 Analysis**	**Bounding USL**
Pin Pitch (cm)	1.43002	0.9426
Water to Fuel Volume Ratio	1.6751	0.9433
Average Energy Group Causing Fission (AEG)	31.3557	0.9438
Assembly Separation (cm)	2.222	0.9420
Boron Concentration (ppm)	2400	0.9448
Enrichment (wt. % U-235)	3.700 (min)	0.9442
Parameter	**Value from Limiting CE 14x14 Analysis**	**Bounding USL**
Pin Pitch (cm)	1.4732	0.9428
Water to Fuel Volume Ratio	1.6127	0.9433
Average Energy Group Causing Fission (AEG)	30.5980	0.9440
Assembly Separation (cm)	2.222	0.9420
Boron Concentration (ppm)	2400	0.9448
Enrichment (wt. % U-235)	3.700 (min)	0.9442
Parameter	**Value from Limiting CE 16x16 Analysis**	**Bounding USL**
Pin Pitch (cm)	1.28524	0.9421
Water to Fuel Volume Ratio	1.700	0.9424
Average Energy Group Causing Fission (AEG)	31.1626	0.9439
Assembly Separation (cm)	2.222	0.9420
Boron Concentration (ppm)	2000	0.9446
Enrichment (wt. % U-235)	3.700 (min)	0.9442

Table 6-33
CE 14x14 Class Intact Assemblies without BPRAs – Final Results

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type A Basket (7.0 mg B-10/cm^2), 2000 ppm Boron, 4.05 wt. % U-235				
60% IMD	0.9290	0.0008	0.9306	ce14b20_p07e40_060.out:
70% IMD	0.9344	0.0009	0.9362	ce14b20_p07e40_070.out:
80% IMD	0.9338	0.0008	0.9354	ce14b20_p07e40_080.out:
90% IMD	0.9281	0.0007	0.9295	ce14b20_p07e40_090.out:
100% IMD	0.9192	0.0007	0.9206	ce14b20_p07e40_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2000 ppm Boron, 4.55 wt. % U-235				
60% IMD	0.9239	0.0009	0.9257	ce14b20_p15e45_060.out:
70% IMD	0.9349	0.0008	0.9365	ce14b20_p15e45_070.out:
80% IMD	0.9364	0.0007	0.9378	ce14b20_p15e45_080.out:
90% IMD	0.9359	0.0008	0.9375	ce14b20_p15e45_090.out:
100% IMD	0.9299	0.0007	0.9313	ce14b20_p15e45_100.out:
Type C Basket (20.0 mg B-10/cm^2), 2000 ppm Boron, 4.70 wt. % U-235				
60% IMD	0.9183	0.0009	0.9201	ce14b20_p20e47_060.out:
70% IMD	0.9311	0.0007	0.9325	ce14b20_p20e47_070.out:
80% IMD	0.9357	0.0007	0.9371	ce14b20_p20e47_080.out:
90% IMD	0.9324	0.0007	0.9338	ce14b20_p20e47_090.out:
100% IMD	0.9294	0.0009	0.9312	ce14b20_p20e47_100.out:
Type D Basket (32.0 mg B-10/cm^2), 2000 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9091	0.0007	0.9105	ce14b20_p32e50_060.out:
70% IMD	0.9242	0.0009	0.9260	ce14b20_p32e50_070.out:
80% IMD	0.9320	0.0007	0.9334	ce14b20_p32e50_080.out:
90% IMD	0.9347	0.0008	0.9363	ce14b20_p32e50_090.out:
100% IMD	0.9317	0.0007	0.9331	ce14b20_p32e50_100.out:
Type A Basket (7.0 mg B-10/cm^2), 2300 ppm Boron, 4.40 wt. % U-235				
60% IMD	0.9356	0.0008	0.9372	ce14b23_p07e44_060.out:
70% IMD	**0.9383**	**0.0007**	**0.9397**	**ce14b23_p07e44_070.out:**
80% IMD	0.9338	0.0007	0.9352	ce14b23_p07e44_080.out:
90% IMD	0.9282	0.0008	0.9298	ce14b23_p07e44_090.out:
100% IMD	0.9159	0.0008	0.9175	ce14b23_p07e44_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2300 ppm Boron, 4.90 wt. % U-235				
60% IMD	0.9286	0.0007	0.9300	ce14b23_p15e49_060.out:
70% IMD	0.9359	0.0009	0.9377	ce14b23_p15e49_070.out:
80% IMD	0.9377	0.0008	0.9393	ce14b23_p15e49_080.out:
90% IMD	0.9327	0.0007	0.9341	ce14b23_p15e49_090.out:
100% IMD	0.9256	0.0007	0.9270	ce14b23_p15e49_100.out:

Table 6-33
CE 14x14 Class Intact Assemblies without BPRAs – Final Results
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type C Basket (20.0 mg B-10/cm^2), 2300 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9196	0.0007	0.9210	ce14b23_p20e50_060.out:
70% IMD	0.9295	0.0007	0.9309	ce14b23_p20e50_070.out:
80% IMD	0.9305	0.0008	0.9321	ce14b23_p20e50_080.out:
90% IMD	0.9285	0.0008	0.9301	ce14b23_p20e50_090.out:
100% IMD	0.9223	0.0007	0.9237	ce14b23_p20e50_100.out:
Type A Basket (07.0 mg B-10/cm^2), 2400 ppm Boron, 4.45 wt. % U-235				
60% IMD	0.9317	0.0007	0.9331	ce14b24_p07e44_060.out:
70% IMD	0.9347	0.0007	0.9361	ce14b24_p07e44_070.out:
80% IMD	0.9305	0.0008	0.9321	ce14b24_p07e44_080.out:
90% IMD	0.9221	0.0007	0.9235	ce14b24_p07e44_090.out:
100% IMD	0.9124	0.0008	0.9140	ce14b24_p07e44_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2400 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9290	0.0007	0.9304	ce14b24_p15e50_060.out:
70% IMD	0.9358	0.0008	0.9374	ce14b24_p15e50_070.out:
80% IMD	0.9358	0.0007	0.9372	ce14b24_p15e50_080.out:
90% IMD	0.9306	0.0007	0.9320	ce14b24_p15e50_090.out:
100% IMD	0.9238	0.0007	0.9252	ce14b24_p15e50_100.out:
Type A Basket (07.0 mg B-10/cm^2), 2500 ppm Boron, 4.55 wt. % U-235				
60% IMD	0.9345	0.0007	0.9359	ce14b25_p07e45_060.out:
70% IMD	0.9370	0.0008	0.9386	ce14b25_p07e45_070.out:
80% IMD	0.9295	0.0008	0.9311	ce14b25_p07e45_080.out:
90% IMD	0.9237	0.0007	0.9251	ce14b25_p07e45_090.out:
100% IMD	0.9139	0.0007	0.9153	ce14b25_p07e45_100.out:

Table 6-34
CE 14x14 Class Assembly Final Results with BPRAs (Intact)

Description	K_{keno}	σ_{keno}	K_{eff}
Type A Basket (7.0 mg B-10/cm^2), 2000 ppm Boron, 3.95 wt. % U-235			
60% IMD	0.9213	0.0006	0.9225
70% IMD	0.9323	0.0007	0.9337
80% IMD	0.9363	0.0007	0.9377
90% IMD	0.9376	0.0007	0.9390
100% IMD	0.9349	0.0007	0.9363
Type B Basket (15.0 mg B-10/cm^2), 2000 ppm Boron, 4.35 wt. % U-235			
60% IMD	0.9081	0.0008	0.9097
70% IMD	0.9229	0.0008	0.9245
80% IMD	0.9331	0.0008	0.9347
90% IMD	0.9353	0.0007	0.9367
100% IMD	0.9374	0.0008	0.9390
Type C Basket (20.0 mg B-10/cm^2), 2000 ppm Boron, 4.50 wt. % U-235			
60% IMD	0.9012	0.0007	0.9026
70% IMD	0.9190	0.0008	0.9206
80% IMD	0.9294	0.0009	0.9312
90% IMD	0.9359	0.0007	0.9373
100% IMD	0.9372	0.0009	0.9390
Type D Basket (32.0 mg B-10/cm^2), 2000 ppm Boron, 4.75 wt. % U-235			
60% IMD	0.8882	0.0008	0.8898
70% IMD	0.9083	0.0008	0.9099
80% IMD	0.9224	0.0007	0.9238
90% IMD	0.9322	0.0007	0.9336
100% IMD	0.9340	0.0008	0.9356
Type E Basket (50.0 mg B-10/cm^2), 2000 ppm Boron, 5.00 wt. % U-235			
60% IMD	0.8762	0.0008	0.8778
70% IMD	0.9006	0.0009	0.9024
80% IMD	0.9156	0.0007	0.9170
90% IMD	0.9268	0.0008	0.9284
100% IMD	0.9316	0.0008	0.9332

Table 6-34
CE 14x14 Class Assembly Final Results with BPRAs (Intact)
(Continued)

Description	K_{keno}	σ_{keno}	K_{eff}
Type A Basket (7.0 mg B-10/cm^2), 2300 ppm Boron, 4.25 wt. % U-235			
60% IMD	0.9265	0.0007	0.9279
70% IMD	0.9361	0.0008	0.9377
80% IMD	0.9380	0.0007	0.9394
90% IMD	0.9370	0.0007	0.9384
100% IMD	0.9320	0.0008	0.9336
Type B Basket (15.0 mg B-10/cm^2), 2300 ppm Boron, 4.70 wt. % U-235			
60% IMD	0.9138	0.0008	0.9154
70% IMD	0.9270	0.0008	0.9286
80% IMD	0.9345	0.0007	0.9359
90% IMD	**0.9383**	**0.0009**	**0.9401**
100% IMD	0.9356	0.0008	0.9372
Type C Basket (20.0 mg B-10/cm^2), 2300 ppm Boron, 4.85 wt. % U-235			
60% IMD	0.9087	0.0008	0.9103
70% IMD	0.9227	0.0007	0.9241
80% IMD	0.9310	0.0009	0.9328
90% IMD	0.9361	0.0009	0.9379
100% IMD	0.9347	0.0008	0.9363
Type D Basket (32.0 mg B-10/cm^2), 2300 ppm Boron, 5.00 wt. % U-235			
60% IMD	0.8952	0.0009	0.8970
70% IMD	0.9072	0.0008	0.9088
80% IMD	0.9109	0.0007	0.9123
90% IMD	0.9119	0.0007	0.9133
100% IMD	0.9081	0.0007	0.9095
Type A Basket (7.0 mg B-10/cm^2), 2400 ppm Boron, 4.35 wt. % U-235			
60% IMD	0.9277	0.0008	0.9293
70% IMD	0.9369	0.0007	0.9383
80% IMD	0.9382	0.0007	0.9396
90% IMD	0.9349	0.0008	0.9365
100% IMD	0.9318	0.0007	0.9332

Table 6-34
CE 14x14 Class Assembly Final Results with BPRAs (Intact)
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}
Type B Basket (15.0 mg B-10/cm^2), 2400 ppm Boron, 4.80 wt. % U-235			
60% IMD	0.9153	0.0008	0.9169
70% IMD	0.9275	0.0009	0.9293
80% IMD	0.9341	0.0007	0.9355
90% IMD	0.9372	0.0006	0.9384
100% IMD	0.9352	0.0007	0.9366
Type C Basket (20.0 mg B-10/cm^2), 2400 ppm Boron, 5.00 wt. % U-235			
60% IMD	0.9108	0.0008	0.9124
70% IMD	0.9272	0.0008	0.9288
80% IMD	0.9351	0.0008	0.9367
90% IMD	0.9368	0.0008	0.9384
100% IMD	0.9372	0.0008	0.9388
Type A Basket (7.0 mg B-10/cm^2), 2500 ppm Boron, 4.45 wt. % U-235			
60% IMD	0.9289	0.0008	0.9305
70% IMD	0.9374	0.0008	0.9390
80% IMD	0.9376	0.0007	0.9390
90% IMD	0.9352	0.0008	0.9368
100% IMD	0.9309	0.0008	0.9325
Type B Basket (15.0 mg B-10/cm^2), 2500 ppm Boron, 4.90 wt. % U-235			
60% IMD	0.9173	0.0008	0.9189
70% IMD	0.9290	0.0007	0.9304
80% IMD	0.9349	0.0008	0.9365
90% IMD	0.9354	0.0008	0.9370
100% IMD	0.9332	0.0009	0.9350

Table 6-35
Intact CE 16x16 Class Assembly without BPRAs, Final Results

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.90 wt. % U-235, Soluble Boron = 2000 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9306	0.0008	0.9322
Internal Moderator Density = 80 %	0.9367	0.0007	0.9381
Internal Moderator Density = 70 %	0.9383	0.0007	0.9397
Internal Moderator Density = 60 %	0.9368	0.0007	0.9382
Internal Moderator Density = 50 %	0.9248	0.0008	0.9264
Enrichment = 4.30 wt. % U-235, Soluble Boron = 2000 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9353	0.0007	0.9367
Internal Moderator Density = 80 %	0.9364	0.0008	0.9380
Internal Moderator Density = 70 %	0.9357	0.0007	0.9371
Internal Moderator Density = 60 %	0.9274	0.0007	0.9288
Internal Moderator Density = 50 %	0.9120	0.0007	0.9134
Enrichment = 4.50 wt. % U-235, Soluble Boron = 2000 ppm, Type C Basket			
Internal Moderator Density = 90 %	0.9359	0.0007	0.9373
Internal Moderator Density = 80 %	0.9388	0.0008	0.9404
Internal Moderator Density = 70 %	0.9348	0.0008	0.9364
Internal Moderator Density = 60 %	0.9244	0.0008	0.9260
Internal Moderator Density = 50 %	0.9081	0.0007	0.9095
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2000 ppm, Type D Basket			
Internal Moderator Density = 100 %	0.9347	0.0008	0.9363
Internal Moderator Density = 90 %	0.9382	0.0008	0.9398
Internal Moderator Density = 80 %	**0.9391**	**0.0008**	**0.9407**
Internal Moderator Density = 70 %	0.9317	0.0008	0.9333
Internal Moderator Density = 60 %	0.9185	0.0008	0.9201
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2000 ppm, Type E Basket			
Internal Moderator Density = 100 %	0.9334	0.0008	0.9350
Internal Moderator Density = 90 %	0.9340	0.0008	0.9356
Internal Moderator Density = 80 %	0.9306	0.0008	0.9322
Internal Moderator Density = 70 %	0.9212	0.0009	0.9230
Internal Moderator Density = 60 %	0.9065	0.0008	0.9081

Table 6-35
Intact CE 16x16 Class Assembly without BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.10 wt. % U-235, Soluble Boron = 2300 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9199	0.0007	0.9213
Internal Moderator Density = 80 %	0.9270	0.0007	0.9284
Internal Moderator Density = 70 %	0.9320	0.0009	0.9338
Internal Moderator Density = 60 %	0.9327	0.0007	0.9341
Internal Moderator Density = 50 %	0.9245	0.0007	0.9259
Enrichment = 4.60 wt. % U-235, Soluble Boron = 2300 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9303	0.0007	0.9317
Internal Moderator Density = 80 %	0.9359	0.0007	0.9373
Internal Moderator Density = 70 %	0.9358	0.0008	0.9374
Internal Moderator Density = 60 %	0.9295	0.0009	0.9313
Internal Moderator Density = 50 %	0.9179	0.0008	0.9195
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2300 ppm, Type C Basket			
Internal Moderator Density = 90 %	0.9314	0.0007	0.9328
Internal Moderator Density = 80 %	0.9352	0.0007	0.9366
Internal Moderator Density = 70 %	0.9340	0.0007	0.9354
Internal Moderator Density = 60 %	0.9271	0.0009	0.9289
Internal Moderator Density = 50 %	0.9133	0.0008	0.9149
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2300 ppm, Type D Basket			
Internal Moderator Density = 100 %	0.9231	0.0009	0.9249
Internal Moderator Density = 90 %	0.9275	0.0008	0.9291
Internal Moderator Density = 80 %	0.9268	0.0007	0.9282
Internal Moderator Density = 70 %	0.9235	0.0007	0.9249
Internal Moderator Density = 60 %	0.9163	0.0008	0.9179

Table 6-35
Intact CE 16x16 Class Assembly without BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.20 wt. % U-235, Soluble Boron = 2400 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9210	0.0007	0.9224
Internal Moderator Density = 80 %	0.9286	0.0007	0.9300
Internal Moderator Density = 70 %	0.9333	0.0008	0.9349
Internal Moderator Density = 60 %	0.9338	0.0008	0.9354
Internal Moderator Density = 50 %	0.9268	0.0007	0.9282
Enrichment = 4.70 wt. % U-235, Soluble Boron = 2400 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9284	0.0007	0.9298
Internal Moderator Density = 80 %	0.9344	0.0007	0.9358
Internal Moderator Density = 70 %	0.9348	0.0008	0.9364
Internal Moderator Density = 60 %	0.9317	0.0009	0.9335
Internal Moderator Density = 50 %	0.9191	0.0007	0.9205
Enrichment = 4.90 wt. % U-235, Soluble Boron = 2400 ppm, Type C Basket			
Internal Moderator Density = 90 %	0.9313	0.0008	0.9329
Internal Moderator Density = 80 %	0.9344	0.0007	0.9358
Internal Moderator Density = 70 %	0.9342	0.0007	0.9356
Internal Moderator Density = 60 %	0.9295	0.0007	0.9309
Internal Moderator Density = 50 %	0.9134	0.0007	0.9148

Table 6-35
Intact CE 16x16 Class Assembly without CCs, Final Results
(Concluded)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.30 wt. % U-235, Soluble Boron = 2500 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9176	0.0009	0.9194
Internal Moderator Density = 80 %	0.9288	0.0008	0.9304
Internal Moderator Density = 70 %	0.9338	0.0006	0.9350
Internal Moderator Density = 60 %	0.9359	0.0006	0.9371
Internal Moderator Density = 50 %	0.9301	0.0006	0.9313
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2500 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9282	0.0007	0.9296
Internal Moderator Density = 80 %	0.9324	0.0007	0.9338
Internal Moderator Density = 70 %	0.9353	0.0007	0.9367
Internal Moderator Density = 60 %	0.9302	0.0007	0.9316
Internal Moderator Density = 50 %	0.9211	0.0008	0.9227
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2500 ppm, Type C Basket			
Internal Moderator Density = 90 %	0.9298	0.0007	0.9312
Internal Moderator Density = 80 %	0.9345	0.0008	0.9361
Internal Moderator Density = 70 %	0.9360	0.0008	0.9376
Internal Moderator Density = 60 %	0.9283	0.0010	0.9303
Internal Moderator Density = 50 %	0.9142	0.0007	0.9156

Table 6-36
Intact CE 16x16 Class Assembly with BPRAs, Final Results

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.85 wt. % U-235, Soluble Boron = 2000 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9351	0.0007	0.9365
Internal Moderator Density = 80 %	0.9379	0.0008	0.9395
Internal Moderator Density = 70 %	0.9381	0.0007	0.9395
Internal Moderator Density = 60 %	0.9326	0.0008	0.9342
Internal Moderator Density = 50 %	0.9191	0.0006	0.9203
Enrichment = 4.25 wt. % U-235, Soluble Boron = 2000 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9380	0.0008	0.9396
Internal Moderator Density = 80 %	0.9380	0.0008	0.9396
Internal Moderator Density = 70 %	0.9337	0.0007	0.9351
Internal Moderator Density = 60 %	0.9241	0.0007	0.9255
Internal Moderator Density = 50 %	0.9044	0.0008	0.9060
Enrichment = 4.40 wt. % U-235, Soluble Boron = 2000 ppm, Type C Basket			
Internal Moderator Density = 100 %	0.9358	0.0008	0.9374
Internal Moderator Density = 90 %	0.9371	0.0009	0.9389
Internal Moderator Density = 80 %	0.9355	0.0007	0.9369
Internal Moderator Density = 70 %	0.9294	0.0007	0.9308
Internal Moderator Density = 60 %	0.9188	0.0008	0.9204
Enrichment = 4.70 wt. % U-235, Soluble Boron = 2000 ppm, Type D Basket			
Internal Moderator Density = 100 %	0.9389	0.0007	0.9403
Internal Moderator Density = 90 %	0.9389	0.0008	0.9405
Internal Moderator Density = 80 %	0.9360	0.0008	0.9376
Internal Moderator Density = 70 %	0.9262	0.0008	0.9278
Internal Moderator Density = 60 %	0.9115	0.0007	0.9129
Enrichment = 4.90 wt. % U-235, Soluble Boron = 2000 ppm, Type E Basket			
Internal Moderator Density = 100 %	0.9358	0.0008	0.9374
Internal Moderator Density = 90 %	0.9339	0.0007	0.9353
Internal Moderator Density = 80 %	0.9282	0.0007	0.9296
Internal Moderator Density = 70 %	0.9154	0.0009	0.9172
Internal Moderator Density = 60 %	0.8984	0.0008	0.9000

Table 6-36
Intact CE 16x16 Class Assembly with BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.10 wt. % U-235, Soluble Boron = 2300 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9318	0.0007	0.9332
Internal Moderator Density = 80 %	0.9347	0.0008	0.9363
Internal Moderator Density = 70 %	0.9371	0.0007	0.9385
Internal Moderator Density = 60 %	0.9344	0.0007	0.9358
Internal Moderator Density = 50 %	0.9225	0.0007	0.9239
Enrichment = 4.55 wt. % U-235, Soluble Boron = 2300 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9343	0.0007	0.9357
Internal Moderator Density = 80 %	0.9374	0.0007	0.9388
Internal Moderator Density = 70 %	0.9369	0.0009	0.9387
Internal Moderator Density = 60 %	0.9258	0.0007	0.9272
Internal Moderator Density = 50 %	0.9108	0.0007	0.9122
Enrichment = 4.70 wt. % U-235, Soluble Boron = 2300 ppm, Type C Basket			
Internal Moderator Density = 100 %	0.9298	0.0007	0.9312
Internal Moderator Density = 90 %	0.9348	0.0007	0.9362
Internal Moderator Density = 80 %	0.9346	0.0007	0.9360
Internal Moderator Density = 70 %	0.9296	0.0007	0.9310
Internal Moderator Density = 60 %	0.9216	0.0007	0.9230
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2300 ppm, Type D Basket			
Internal Moderator Density = 100 %	0.9333	0.0009	0.9351
Internal Moderator Density = 90 %	0.9349	0.0008	0.9365
Internal Moderator Density = 80 %	0.9333	0.0008	0.9349
Internal Moderator Density = 70 %	0.9266	0.0007	0.9280
Internal Moderator Density = 60 %	0.9124	0.0008	0.9140

Table 6-36
Intact CE 16x16 Class Assembly with BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.20 wt. % U-235, Soluble Boron = 2400 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9294	0.0008	0.9310
Internal Moderator Density = 80 %	0.9343	0.0008	0.9359
Internal Moderator Density = 70 %	0.9374	0.0008	0.9390
Internal Moderator Density = 60 %	0.9343	0.0008	0.9359
Internal Moderator Density = 50 %	0.9257	0.0008	0.9273
Enrichment = 4.65 wt. % U-235, Soluble Boron = 2400 ppm, Type B Basket			
Internal Moderator Density = 100 %	0.9307	0.0008	0.9323
Internal Moderator Density = 90 %	0.9349	0.0009	0.9367
Internal Moderator Density = 80 %	0.9371	0.0007	0.9385
Internal Moderator Density = 70 %	0.9361	0.0007	0.9375
Internal Moderator Density = 60 %	0.9285	0.0007	0.9299
Enrichment = 4.85 wt. % U-235, Soluble Boron = 2400 ppm, Type C Basket			
Internal Moderator Density = 100 %	0.9322	0.0007	0.9336
Internal Moderator Density = 90 %	0.9367	0.0007	0.9381
Internal Moderator Density = 80 %	0.9369	0.0007	0.9383
Internal Moderator Density = 70 %	0.9331	0.0007	0.9345
Internal Moderator Density = 60 %	0.9242	0.0008	0.9258

Table 6-36
Intact CE 16x16 Class Assembly with BPRAs, Final Results
(Concluded)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.30 wt. % U-235, Soluble Boron = 2500 ppm, Type A Basket			
Internal Moderator Density = 90 %	0.9290	0.0008	0.9306
Internal Moderator Density = 80 %	0.9350	0.0007	0.9364
Internal Moderator Density = 70 %	**0.9395**	**0.0008**	**0.9411**
Internal Moderator Density = 60 %	0.9357	0.0007	0.9371
Internal Moderator Density = 50 %	0.9285	0.0007	0.9299
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2500 ppm, Type B Basket			
Internal Moderator Density = 90 %	0.9369	0.0008	0.9385
Internal Moderator Density = 80 %	0.9391	0.0008	0.9407
Internal Moderator Density = 70 %	0.9380	0.0006	0.9392
Internal Moderator Density = 60 %	0.9303	0.0007	0.9317
Internal Moderator Density = 50 %	0.9174	0.0007	0.9188
Enrichment = 4.95 wt. % U-235, Soluble Boron = 2500 ppm, Type C Basket			
Internal Moderator Density = 100 %	0.9306	0.0008	0.9322
Internal Moderator Density = 90 %	0.9366	0.0008	0.9382
Internal Moderator Density = 80 %	0.9367	0.0007	0.9381
Internal Moderator Density = 70 %	0.9334	0.0008	0.9350
Internal Moderator Density = 60 %	0.9258	0.0007	0.9272

Table 6-37
CE 14x14 Class Damaged Assemblies without BPRAs – Final Results

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type A Basket (7.0 mg B-10/cm^2), 2000 ppm Boron, 3.90 wt. % U-235				
60% IMD	0.9371	0.0007	0.9385	ce14d20_p07e39_060.out:
70% IMD	0.9375	0.0007	0.9389	ce14d20_p07e39_070.out:
80% IMD	0.9304	0.0007	0.9318	ce14d20_p07e39_080.out:
90% IMD	0.9181	0.0007	0.9195	ce14d20_p07e39_090.out:
100% IMD	0.9046	0.0008	0.9062	ce14d20_p07e39_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2000 ppm Boron, 4.35 wt. % U-235				
60% IMD	0.9331	0.0008	0.9347	ce14d20_p15e43_060.out:
70% IMD	0.9381	0.0007	0.9395	ce14d20_p15e43_070.out:
80% IMD	0.9354	0.0008	0.9370	ce14d20_p15e43_080.out:
90% IMD	0.9282	0.0007	0.9296	ce14d20_p15e43_090.out:
100% IMD	0.9180	0.0007	0.9194	ce14d20_p15e43_100.out:
Type C Basket (20.0 mg B-10/cm^2), 2000 ppm Boron, 4.50 wt. % U-235				
60% IMD	0.9293	0.0007	0.9307	ce14d20_p20e45_060.out:
70% IMD	0.9348	0.0007	0.9362	ce14d20_p20e45_070.out:
80% IMD	0.9342	0.0007	0.9356	ce14d20_p20e45_080.out:
90% IMD	0.9273	0.0007	0.9287	ce14d20_p20e45_090.out:
100% IMD	0.9187	0.0007	0.9201	ce14d20_p20e45_100.out:
Type D Basket (32.0 mg B-10/cm^2), 2000 ppm Boron, 4.85 wt. % U-235				
60% IMD	0.9263	0.0007	0.9277	ce14d20_p32e48_060.out:
70% IMD	0.9370	0.0008	0.9386	ce14d20_p32e48_070.out:
80% IMD	0.9385	0.0006	0.9397	ce14d20_p32e48_080.out:
90% IMD	0.9338	0.0007	0.9352	ce14d20_p32e48_090.out:
100% IMD	0.9257	0.0008	0.9273	ce14d20_p32e48_100.out:
Type E Basket (50.0 mg B-10/cm^2), 2000 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9111	0.0007	0.9125	ce14d20_p50e50_060.out:
70% IMD	0.9240	0.0008	0.9256	ce14d20_p50e50_070.out:
80% IMD	0.9296	0.0008	0.9312	ce14d20_p50e50_080.out:
90% IMD	0.9253	0.0007	0.9267	ce14d20_p50e50_090.out:
100% IMD	0.9197	0.0008	0.9213	ce14d20_p50e50_100.out:
Type A Basket (7.0 mg B-10/cm^2), 2300 ppm Boron, 4.20 wt. % U-235				
60% IMD	0.9382	0.0007	0.9396	ce14d23_p07e42_060.out:
70% IMD	0.9363	0.0007	0.9377	ce14d23_p07e42_070.out:
80% IMD	0.9280	0.0008	0.9296	ce14d23_p07e42_080.out:
90% IMD	0.9161	0.0007	0.9175	ce14d23_p07e42_090.out:
100% IMD	0.8999	0.0007	0.9013	ce14d23_p07e42_100.out:

Table 6-37
CE 14x14 Damaged Assemblies without BPRAs – **Final Results**
(Continued)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type B Basket (15.0 mg B-10/cm^2), 2300 ppm Boron, 4.70 wt. % U-235				
60% IMD	0.9369	0.0009	0.9387	ce14d23_p15e47_060.out:
70% IMD	0.9380	0.0007	0.9394	ce14d23_p15e47_070.out:
80% IMD	0.9349	0.0007	0.9363	ce14d23_p15e47_080.out:
90% IMD	0.9242	0.0007	0.9256	ce14d23_p15e47_090.out:
100% IMD	0.9118	0.0008	0.9134	ce14d23_p15e47_100.out:
Type C Basket (20.0 mg B-10/cm^2), 2300 ppm Boron, 4.85 wt. % U-235				
60% IMD	0.9314	0.0008	0.9330	ce14d23_p20e48_060.out:
70% IMD	0.9357	0.0008	0.9373	ce14d23_p20e48_070.out:
80% IMD	0.9346	0.0008	0.9362	ce14d23_p20e48_080.out:
90% IMD	0.9260	0.0007	0.9274	ce14d23_p20e48_090.out:
100% IMD	0.9135	0.0007	0.9149	ce14d23_p20e48_100.out:
Type D Basket (32.0 mg B-10/cm^2), 2300 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9170	0.0007	0.9184	ce14d23_p32e50_060.out:
70% IMD	0.9231	0.0007	0.9245	ce14d23_p32e50_070.out:
80% IMD	0.9237	0.0007	0.9251	ce14d23_p32e50_080.out:
90% IMD	0.9173	0.0007	0.9187	ce14d23_p32e50_090.out:
100% IMD	0.9081	0.0007	0.9095	ce14d23_p32e50_100.out:
Type A Basket (07.0 mg B-10/cm^2), 2400 ppm Boron, 4.25 wt. % U-235				
60% IMD	0.9356	0.0007	0.9370	ce14d24_p07e42_060.out:
70% IMD	0.9322	0.0007	0.9336	ce14d24_p07e42_070.out:
80% IMD	0.9235	0.0007	0.9249	ce14d24_p07e42_080.out:
90% IMD	0.9113	0.0007	0.9127	ce14d24_p07e42_090.out:
100% IMD	0.8952	0.0006	0.8964	ce14d24_p07e42_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2400 ppm Boron, 4.80 wt. % U-235				
60% IMD	0.9366	0.0007	0.9380	ce14d24_p15e48_060.out:
70% IMD	**0.9386**	**0.0007**	**0.9400**	**ce14d24_p15e48_070.out:**
80% IMD	0.9323	0.0007	0.9337	ce14d24_p15e48_080.out:
90% IMD	0.9242	0.0007	0.9256	ce14d24_p15e48_090.out:
100% IMD	0.9115	0.0007	0.9129	ce14d24_p15e48_100.out:
Type C Basket (20.0 mg B-10/cm^2), 2400 ppm Boron, 4.95 wt. % U-235				
60% IMD	0.9318	0.0008	0.9334	ce14d24_p20e49_060.out:
70% IMD	0.9354	0.0008	0.9370	ce14d24_p20e49_070.out:
80% IMD	0.9313	0.0008	0.9329	ce14d24_p20e49_080.out:
90% IMD	0.9247	0.0007	0.9261	ce14d24_p20e49_090.out:
100% IMD	0.9121	0.0007	0.9135	ce14d24_p20e49_100.out:

Table 6-37
CE 14x14 Class Damaged Assemblies without BPRAs – **Final Results**
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}	Filename
Type A Basket (07.0 mg B-10/cm^2), 2500 ppm Boron, 4.35 wt. % U-235				
60% IMD	0.9364	0.0007	0.9378	ce14d25_p07e43_060.out:
70% IMD	0.9323	0.0007	0.9337	ce14d25_p07e43_070.out:
80% IMD	0.9235	0.0006	0.9247	ce14d25_p07e43_080.out:
90% IMD	0.9087	0.0007	0.9101	ce14d25_p07e43_090.out:
100% IMD	0.8926	0.0007	0.8940	ce14d25_p07e43_100.out:
Type B Basket (15.0 mg B-10/cm^2), 2500 ppm Boron, 4.90 wt. % U-235				
60% IMD	0.9375	0.0009	0.9393	ce14d25_p15e49_060.out:
70% IMD	0.9380	0.0007	0.9394	ce14d25_p15e49_070.out:
80% IMD	0.9327	0.0008	0.9343	ce14d25_p15e49_080.out:
90% IMD	0.9220	0.0007	0.9234	ce14d25_p15e49_090.out:
100% IMD	0.9077	0.0008	0.9093	ce14d25_p15e49_100.out:
Type C Basket (20.0 mg B-10/cm^2), 2500 ppm Boron, 5.00 wt. % U-235				
60% IMD	0.9297	0.0007	0.9311	ce14d25_p20e50_060.out:
70% IMD	0.9326	0.0007	0.9340	ce14d25_p20e50_070.out:
80% IMD	0.9277	0.0007	0.9291	ce14d25_p20e50_080.out:
90% IMD	0.9178	0.0007	0.9192	ce14d25_p20e50_090.out:
100% IMD	0.9059	0.0007	0.9073	ce14d25_p20e50_100.out:

Table 6-38
CE 14x14 Class Assembly Final Results with BPRAs (Damaged)

Description	K_{keno}	σ_{keno}	K_{eff}
Type A Basket (7.0 mg B-10/cm^2), 2000 ppm Boron, 3.70 wt. % U-235			
60% IMD	0.9287	0.0006	0.9299
70% IMD	0.9352	0.0007	0.9366
80% IMD	0.9367	0.0006	0.9379
90% IMD	0.9333	0.0007	0.9347
100% IMD	0.9246	0.0007	0.9260
Type B Basket (15.0 mg B-10/cm^2), 2000 ppm Boron, 4.10 wt. % U-235			
60% IMD	0.9212	0.0007	0.9226
70% IMD	0.9323	0.0008	0.9339
80% IMD	0.9379	0.0008	0.9395
90% IMD	**0.9381**	**0.0008**	**0.9397**
100% IMD	0.9327	0.0008	0.9343
Type C Basket (20.0 mg B-10/cm^2), 2000 ppm Boron, 4.20 wt. % U-235			
60% IMD	0.9132	0.0007	0.9146
70% IMD	0.9261	0.0007	0.9275
80% IMD	0.9332	0.0008	0.9348
90% IMD	0.9350	0.0007	0.9364
100% IMD	0.9315	0.0007	0.9329
Type D Basket (32.0 mg B-10/cm^2), 2000 ppm Boron, 4.50 wt. % U-235			
60% IMD	0.9079	0.0007	0.9093
70% IMD	0.9236	0.0007	0.9250
80% IMD	0.9352	0.0007	0.9366
90% IMD	0.9365	0.0007	0.9379
100% IMD	0.9364	0.0007	0.9378
Type E Basket (50.0 mg B-10/cm^2), 2000 ppm Boron, 4.75 wt. % U-235			
60% IMD	0.8951	0.0007	0.8965
70% IMD	0.9159	0.0008	0.9175
80% IMD	0.9301	0.0008	0.9317
90% IMD	0.9350	0.0007	0.9364
100% IMD	0.9363	0.0008	0.9379

Table 6-38
CE 14x14 Class Assembly Final Results with BPRAs (Damaged)
(Continued)

Description	K_{keno}	σ_{keno}	K_{eff}
Type A Basket (7.0 mg B-10/cm^2), 2300 ppm Boron, 3.95 wt. % U-235			
60% IMD	0.9295	0.0007	0.9309
70% IMD	0.9372	0.0007	0.9386
80% IMD	0.9356	0.0008	0.9372
90% IMD	0.9289	0.0006	0.9301
100% IMD	0.9201	0.0008	0.9217
Type B Basket (15.0 mg B-10/cm^2), 2300 ppm Boron, 4.40 wt. % U-235			
60% IMD	0.9239	0.0007	0.9253
70% IMD	0.9331	0.0007	0.9345
80% IMD	0.9374	0.0008	0.9390
90% IMD	0.9343	0.0008	0.9359
100% IMD	0.9293	0.0007	0.9307
Type C Basket (20.0 mg B-10/cm^2), 2300 ppm Boron, 4.55 wt. % U-235			
60% IMD	0.9185	0.0008	0.9201
70% IMD	0.9315	0.0008	0.9331
80% IMD	0.9362	0.0008	0.9378
90% IMD	0.9360	0.0007	0.9374
100% IMD	0.9303	0.0007	0.9317
Type D Basket (32.0 mg B-10/cm^2), 2300 ppm Boron, 4.85 wt. % U-235			
60% IMD	0.9113	0.0007	0.9127
70% IMD	0.9288	0.0008	0.9304
80% IMD	0.9336	0.0007	0.9350
90% IMD	0.9368	0.0007	0.9382
100% IMD	0.9333	0.0007	0.9347
Type E Basket (50.0 mg B-10/cm^2), 2300 ppm Boron, 5.00 wt. % U-235			
60% IMD	0.8956	0.0007	0.8970
70% IMD	0.9147	0.0008	0.9163
80% IMD	0.9236	0.0008	0.9252
90% IMD	0.9262	0.0007	0.9276
100% IMD	0.9259	0.0008	0.9275

Table 6-38
CE 14x14 Class Assembly Final Results with BPRAs (Damaged)
(Continued)

Description	K_{keno}	σ_{keno}	K_{eff}
Type A Basket (7.0 mg B-10/cm^2), 2400 ppm Boron, 4.05 wt. % U-235			
60% IMD	0.9323	0.0008	0.9339
70% IMD	0.9369	0.0007	0.9383
80% IMD	0.9362	0.0006	0.9374
90% IMD	0.9297	0.0006	0.9309
100% IMD	0.9192	0.0006	0.9204
Type B Basket (15.0 mg B-10/cm^2), 2400 ppm Boron, 4.50 wt. % U-235			
60% IMD	0.9248	0.0008	0.9264
70% IMD	0.9349	0.0009	0.9367
80% IMD	0.9382	0.0007	0.9396
90% IMD	0.9380	0.0008	0.9396
100% IMD	0.9278	0.0008	0.9294
Type C Basket (20.0 mg B-10/cm^2), 2400 ppm Boron, 4.65 wt. % U-235			
60% IMD	0.9206	0.0008	0.9222
70% IMD	0.9311	0.0007	0.9325
80% IMD	0.9356	0.0006	0.9368
90% IMD	0.9340	0.0007	0.9354
100% IMD	0.9304	0.0007	0.9318
Type D Basket (32.0 mg B-10/cm^2), 2400 ppm Boron, 5.00 wt. % U-235			
60% IMD	0.9155	0.0008	0.9171
70% IMD	0.9287	0.0008	0.9303
80% IMD	0.9361	0.0008	0.9377
90% IMD	0.9371	0.0008	0.9387
100% IMD	0.9341	0.0007	0.9355
Type A Basket (7.0 mg B-10/cm^2), 2500 ppm Boron, 4.10 wt. % U-235			
60% IMD	0.9304	0.0007	0.9318
70% IMD	0.9353	0.0007	0.9367
80% IMD	0.9322	0.0007	0.9336
90% IMD	0.9232	0.0008	0.9248
100% IMD	0.9154	0.0007	0.9168

Table 6-38
CE 14x14 Class Assembly Final Results with BPRAs (Damaged)
(Concluded)

Description	K_{keno}	σ_{keno}	K_{eff}
Type B Basket (15.0 mg B-10/cm^2), 2500 ppm Boron, 4.60 wt. % U-235			
60% IMD	0.9263	0.0007	0.9277
70% IMD	0.9375	0.0007	0.9389
80% IMD	0.9370	0.0007	0.9384
90% IMD	0.9342	0.0007	0.9356
100% IMD	0.9275	0.0007	0.9289
Type C Basket (20.0 mg B-10/cm^2), 2500 ppm Boron, 4.75 wt. % U-235			
60% IMD	0.9206	0.0007	0.9220
70% IMD	0.9329	0.0007	0.9343
80% IMD	0.9355	0.0007	0.9369
90% IMD	0.9339	0.0008	0.9355
100% IMD	0.9254	0.0009	0.9272

Table 6-39
Damaged CE 16x16 Class Assembly without BPRAs, Final Results

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.65 wt. % U-235, Soluble Boron = 2000 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9289	0.0007	0.9303
Internal Moderator Density = 060 %	0.9369	0.0007	0.9383
Internal Moderator Density = 070 %	0.9347	0.0007	0.9361
Internal Moderator Density = 080 %	0.9298	0.0007	0.9312
Internal Moderator Density = 090 %	0.9176	0.0006	0.9188
Enrichment = 4.05 wt. % U-235, Soluble Boron = 2000 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9334	0.0007	0.9348
Internal Moderator Density = 070 %	0.9363	0.0007	0.9377
Internal Moderator Density = 080 %	0.9329	0.0007	0.9343
Internal Moderator Density = 090 %	0.9280	0.0007	0.9294
Internal Moderator Density = 100 %	0.9159	0.0007	0.9173
Enrichment = 4.20 wt. % U-235, Soluble Boron = 2000 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9313	0.0008	0.9329
Internal Moderator Density = 070 %	0.9365	0.0007	0.9379
Internal Moderator Density = 080 %	0.9338	0.0007	0.9352
Internal Moderator Density = 090 %	0.9286	0.0007	0.9300
Internal Moderator Density = 100 %	0.9189	0.0007	0.9203
Enrichment = 4.50 wt. % U-235, Soluble Boron = 2000 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9278	0.0007	0.9292
Internal Moderator Density = 070 %	0.9357	0.0007	0.9371
Internal Moderator Density = 080 %	0.9378	0.0007	0.9392
Internal Moderator Density = 090 %	0.9338	0.0007	0.9352
Internal Moderator Density = 100 %	0.9275	0.0007	0.9289
Enrichment = 4.75 wt. % U-235, Soluble Boron = 2000 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9213	0.0007	0.9227
Internal Moderator Density = 070 %	0.9307	0.0007	0.9321
Internal Moderator Density = 080 %	0.9376	0.0007	0.9390
Internal Moderator Density = 090 %	0.9354	0.0008	0.9370
Internal Moderator Density = 100 %	0.9289	0.0007	0.9303

Table 6-39
Damaged CE 16x16 Class Assembly without BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.90 wt. % U-235, Soluble Boron = 2300 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9325	0.0007	0.9339
Internal Moderator Density = 060 %	0.9369	0.0006	0.9381
Internal Moderator Density = 070 %	0.9328	0.0007	0.9342
Internal Moderator Density = 080 %	0.9238	0.0008	0.9254
Internal Moderator Density = 090 %	0.9116	0.0007	0.9130
Enrichment = 4.30 wt. % U-235, Soluble Boron = 2300 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9323	0.0006	0.9335
Internal Moderator Density = 070 %	0.9329	0.0007	0.9343
Internal Moderator Density = 080 %	0.9284	0.0008	0.9300
Internal Moderator Density = 090 %	0.9198	0.0007	0.9212
Internal Moderator Density = 100 %	0.9068	0.0007	0.9082
Enrichment = 4.50 wt. % U-235, Soluble Boron = 2300 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9308	0.0006	0.9320
Internal Moderator Density = 070 %	0.9343	0.0007	0.9357
Internal Moderator Density = 080 %	0.9315	0.0008	0.9331
Internal Moderator Density = 090 %	0.9240	0.0007	0.9254
Internal Moderator Density = 100 %	0.9119	0.0006	0.9131
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2300 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9292	0.0007	0.9306
Internal Moderator Density = 070 %	0.9345	0.0008	0.9361
Internal Moderator Density = 080 %	0.9340	0.0007	0.9354
Internal Moderator Density = 090 %	0.9284	0.0007	0.9298
Internal Moderator Density = 100 %	0.9190	0.0007	0.9204
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2300 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9184	0.0008	0.9200
Internal Moderator Density = 070 %	0.9269	0.0008	0.9285
Internal Moderator Density = 080 %	0.9278	0.0008	0.9294
Internal Moderator Density = 090 %	0.9236	0.0007	0.9250
Internal Moderator Density = 100 %	0.9169	0.0006	0.9181

Table 6-39
Damaged CE 16x16 Class Assembly without BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.00 wt. % U-235, Soluble Boron = 2400 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9343	0.0007	0.9357
Internal Moderator Density = 060 %	0.9368	0.0007	0.9382
Internal Moderator Density = 070 %	0.9327	0.0006	0.9339
Internal Moderator Density = 080 %	0.9236	0.0006	0.9248
Internal Moderator Density = 090 %	0.9107	0.0006	0.9119
Enrichment = 4.40 wt. % U-235, Soluble Boron = 2400 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9334	0.0007	0.9348
Internal Moderator Density = 070 %	0.9339	0.0006	0.9351
Internal Moderator Density = 080 %	0.9275	0.0007	0.9289
Internal Moderator Density = 090 %	0.9188	0.0007	0.9202
Internal Moderator Density = 100 %	0.9060	0.0006	0.9072
Enrichment = 4.60 wt. % U-235, Soluble Boron = 2400 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9326	0.0007	0.9340
Internal Moderator Density = 070 %	0.9336	0.0007	0.9350
Internal Moderator Density = 080 %	0.9315	0.0006	0.9327
Internal Moderator Density = 090 %	0.9231	0.0008	0.9247
Internal Moderator Density = 100 %	0.9107	0.0007	0.9121
Enrichment = 4.90 wt. % U-235, Soluble Boron = 2400 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9269	0.0007	0.9283
Internal Moderator Density = 070 %	0.9333	0.0007	0.9347
Internal Moderator Density = 080 %	0.9325	0.0007	0.9339
Internal Moderator Density = 090 %	0.9259	0.0007	0.9273
Internal Moderator Density = 100 %	0.9162	0.0007	0.9176
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2400 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9127	0.0007	0.9141
Internal Moderator Density = 070 %	0.9198	0.0008	0.9214
Internal Moderator Density = 080 %	0.9203	0.0008	0.9219
Internal Moderator Density = 090 %	0.9164	0.0007	0.9178
Internal Moderator Density = 100 %	0.9088	0.0007	0.9102

Table 6-39
Damaged CE 16x16 Class Assembly without BPRAs, Final Results
(Concluded)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.05 wt. % U-235, Soluble Boron = 2500 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9308	0.0007	0.9322
Internal Moderator Density = 060 %	0.9348	0.0006	0.9360
Internal Moderator Density = 070 %	0.9304	0.0006	0.9316
Internal Moderator Density = 080 %	0.9199	0.0007	0.9213
Internal Moderator Density = 090 %	0.9062	0.0006	0.9074
Enrichment = 4.50 wt. % U-235, Soluble Boron = 2500 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9329	0.0008	0.9345
Internal Moderator Density = 070 %	0.9336	0.0008	0.9352
Internal Moderator Density = 080 %	0.9272	0.0007	0.9286
Internal Moderator Density = 090 %	0.9161	0.0006	0.9173
Internal Moderator Density = 100 %	0.9036	0.0007	0.9050
Enrichment = 4.70 wt. % U-235, Soluble Boron = 2500 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9318	0.0007	0.9332
Internal Moderator Density = 070 %	0.9343	0.0008	0.9359
Internal Moderator Density = 080 %	0.9305	0.0007	0.9319
Internal Moderator Density = 090 %	0.9204	0.0008	0.9220
Internal Moderator Density = 100 %	0.9086	0.0007	0.9100
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2500 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9287	0.0007	0.9301
Internal Moderator Density = 070 %	0.9321	0.0008	0.9337
Internal Moderator Density = 080 %	0.9316	0.0007	0.9330
Internal Moderator Density = 090 %	0.9246	0.0007	0.9260
Internal Moderator Density = 100 %	0.9131	0.0007	0.9145
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2500 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9077	0.0007	0.9091
Internal Moderator Density = 070 %	0.9138	0.0007	0.9152
Internal Moderator Density = 080 %	0.9138	0.0008	0.9154
Internal Moderator Density = 090 %	0.9093	0.0007	0.9107
Internal Moderator Density = 100 %	0.9003	0.0008	0.9019

Table 6-40
Damaged CE 16x16 Class Assembly with BPRAs, Final Results

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.60 wt. % U-235, Soluble Boron = 2000 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9255	0.0007	0.9269
Internal Moderator Density = 060 %	0.9353	0.0008	0.9369
Internal Moderator Density = 070 %	0.9380	0.0007	0.9394
Internal Moderator Density = 080 %	0.9347	0.0006	0.9359
Internal Moderator Density = 090 %	0.9261	0.0006	0.9273
Enrichment = 3.95 wt. % U-235, Soluble Boron = 2000 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9274	0.0007	0.9288
Internal Moderator Density = 070 %	0.9354	0.0007	0.9368
Internal Moderator Density = 080 %	0.9353	0.0008	0.9369
Internal Moderator Density = 090 %	0.9303	0.0008	0.9319
Internal Moderator Density = 100 %	0.9220	0.0007	0.9234
Enrichment = 4.10 wt. % U-235, Soluble Boron = 2000 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9245	0.0006	0.9257
Internal Moderator Density = 070 %	0.9334	0.0007	0.9348
Internal Moderator Density = 080 %	0.9358	0.0006	0.9370
Internal Moderator Density = 090 %	0.9312	0.0007	0.9326
Internal Moderator Density = 100 %	0.9245	0.0007	0.9259
Enrichment = 4.40 wt. % U-235, Soluble Boron = 2000 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9218	0.0007	0.9232
Internal Moderator Density = 070 %	0.9337	0.0007	0.9351
Internal Moderator Density = 080 %	0.9383	0.0007	0.9397
Internal Moderator Density = 090 %	0.9364	0.0007	0.9378
Internal Moderator Density = 100 %	0.9322	0.0008	0.9338
Enrichment = 4.65 wt. % U-235, Soluble Boron = 2000 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9155	0.0007	0.9169
Internal Moderator Density = 070 %	0.9293	0.0007	0.9307
Internal Moderator Density = 080 %	0.9380	0.0007	0.9394
Internal Moderator Density = 090 %	0.9384	0.0007	0.9398
Internal Moderator Density = 100 %	0.9353	0.0007	0.9367

Table 6-40
Damaged CE 16x16 Class Assembly with BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.80 wt. % U-235, Soluble Boron = 2300 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9238	0.0007	0.9252
Internal Moderator Density = 060 %	0.9330	0.0008	0.9346
Internal Moderator Density = 070 %	0.9321	0.0006	0.9333
Internal Moderator Density = 080 %	0.9275	0.0007	0.9289
Internal Moderator Density = 090 %	0.9169	0.0007	0.9183
Enrichment = 4.20 wt. % U-235, Soluble Boron = 2300 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9282	0.0007	0.9296
Internal Moderator Density = 070 %	0.9321	0.0006	0.9333
Internal Moderator Density = 080 %	0.9302	0.0008	0.9318
Internal Moderator Density = 090 %	0.9242	0.0007	0.9256
Internal Moderator Density = 100 %	0.9141	0.0007	0.9155
Enrichment = 4.40 wt. % U-235, Soluble Boron = 2300 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9298	0.0008	0.9314
Internal Moderator Density = 070 %	0.9337	0.0007	0.9351
Internal Moderator Density = 080 %	0.9344	0.0007	0.9358
Internal Moderator Density = 090 %	0.9288	0.0007	0.9302
Internal Moderator Density = 100 %	0.9206	0.0007	0.9220
Enrichment = 4.70 wt. % U-235, Soluble Boron = 2300 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9247	0.0007	0.9261
Internal Moderator Density = 070 %	0.9332	0.0008	0.9348
Internal Moderator Density = 080 %	0.9360	0.0007	0.9374
Internal Moderator Density = 090 %	0.9325	0.0008	0.9341
Internal Moderator Density = 100 %	0.9252	0.0008	0.9268
Enrichment = 4.90 wt. % U-235, Soluble Boron = 2300 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9125	0.0007	0.9139
Internal Moderator Density = 070 %	0.9267	0.0008	0.9283
Internal Moderator Density = 080 %	0.9317	0.0007	0.9331
Internal Moderator Density = 090 %	0.9302	0.0007	0.9316
Internal Moderator Density = 100 %	0.9268	0.0008	0.9284

Table 6-40
Damaged CE 16x16 Class Assembly with BPRAs, Final Results
(Continued)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 3.90 wt. % U-235, Soluble Boron = 2400 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9281	0.0007	0.9295
Internal Moderator Density = 060 %	0.9346	0.0007	0.9360
Internal Moderator Density = 070 %	0.9329	0.0007	0.9343
Internal Moderator Density = 080 %	0.9270	0.0007	0.9284
Internal Moderator Density = 090 %	0.9158	0.0006	0.9170
Enrichment = 4.30 wt. % U-235, Soluble Boron = 2400 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9298	0.0007	0.9312
Internal Moderator Density = 070 %	0.9331	0.0007	0.9345
Internal Moderator Density = 080 %	0.9314	0.0006	0.9326
Internal Moderator Density = 090 %	0.9231	0.0007	0.9245
Internal Moderator Density = 100 %	0.9138	0.0007	0.9152
Enrichment = 4.50 wt. % U-235, Soluble Boron = 2400 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9288	0.0007	0.9302
Internal Moderator Density = 070 %	0.9355	0.0007	0.9369
Internal Moderator Density = 080 %	0.9327	0.0006	0.9339
Internal Moderator Density = 090 %	0.9273	0.0007	0.9287
Internal Moderator Density = 100 %	0.9185	0.0007	0.9199
Enrichment = 4.80 wt. % U-235, Soluble Boron = 2400 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9247	0.0007	0.9261
Internal Moderator Density = 070 %	0.9343	0.0007	0.9357
Internal Moderator Density = 080 %	0.9347	0.0008	0.9363
Internal Moderator Density = 090 %	0.9322	0.0008	0.9338
Internal Moderator Density = 100 %	0.9247	0.0007	0.9261
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2400 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9079	0.0007	0.9093
Internal Moderator Density = 070 %	0.9193	0.0007	0.9207
Internal Moderator Density = 080 %	0.9236	0.0007	0.9250
Internal Moderator Density = 090 %	0.9217	0.0007	0.9231
Internal Moderator Density = 100 %	0.9157	0.0007	0.9171

Table 6-40
Damaged CE 16x16 Class Assembly with BPRAs, Final Results
(Concluded)

Model Description	k_{KENO}	1σ	k_{eff}
Enrichment = 4.00 wt. % U-235, Soluble Boron = 2500 ppm, Type A Basket			
Internal Moderator Density = 050 %	0.9310	0.0007	0.9324
Internal Moderator Density = 060 %	0.9365	0.0008	0.9381
Internal Moderator Density = 070 %	0.9348	0.0007	0.9362
Internal Moderator Density = 080 %	0.9278	0.0006	0.9290
Internal Moderator Density = 090 %	0.9170	0.0007	0.9184
Enrichment = 4.40 wt. % U-235, Soluble Boron = 2500 ppm, Type B Basket			
Internal Moderator Density = 060 %	0.9318	0.0006	0.9330
Internal Moderator Density = 070 %	0.9344	0.0007	0.9358
Internal Moderator Density = 080 %	0.9299	0.0007	0.9313
Internal Moderator Density = 090 %	0.9223	0.0006	0.9235
Internal Moderator Density = 100 %	0.9127	0.0007	0.9141
Enrichment = 4.60 wt. % U-235, Soluble Boron = 2500 ppm, Type C Basket			
Internal Moderator Density = 060 %	0.9298	0.0006	0.9310
Internal Moderator Density = 070 %	0.9338	0.0009	0.9356
Internal Moderator Density = 080 %	0.9330	0.0007	0.9344
Internal Moderator Density = 090 %	0.9271	0.0007	0.9285
Internal Moderator Density = 100 %	0.9181	0.0006	0.9193
Enrichment = 4.90 wt. % U-235, Soluble Boron = 2500 ppm, Type D Basket			
Internal Moderator Density = 060 %	0.9257	0.0007	0.9271
Internal Moderator Density = 070 %	0.9336	0.0007	0.9350
Internal Moderator Density = 080 %	0.9351	0.0007	0.9365
Internal Moderator Density = 090 %	0.9310	0.0007	0.9324
Internal Moderator Density = 100 %	0.9235	0.0008	0.9251
Enrichment = 5.00 wt. % U-235, Soluble Boron = 2500 ppm, Type E Basket			
Internal Moderator Density = 060 %	0.9087	0.0008	0.9103
Internal Moderator Density = 070 %	0.9203	0.0008	0.9219
Internal Moderator Density = 080 %	0.9240	0.0008	0.9256
Internal Moderator Density = 090 %	0.9215	0.0007	0.9229
Internal Moderator Density = 100 %	0.9140	0.0007	0.9154

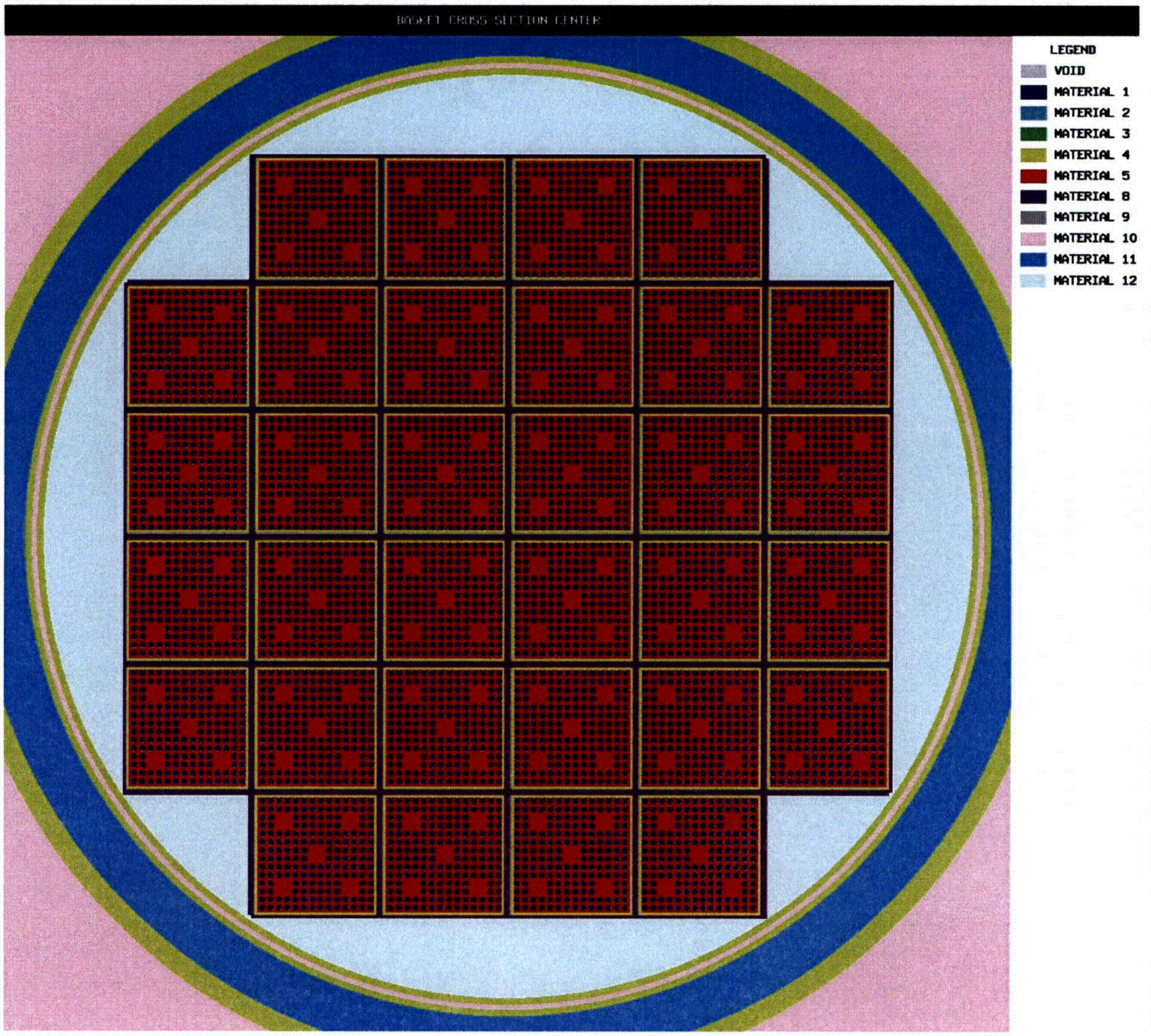

Figure 6-14
CE 14x14 Fuel Assembly : Optimum Pitch Study

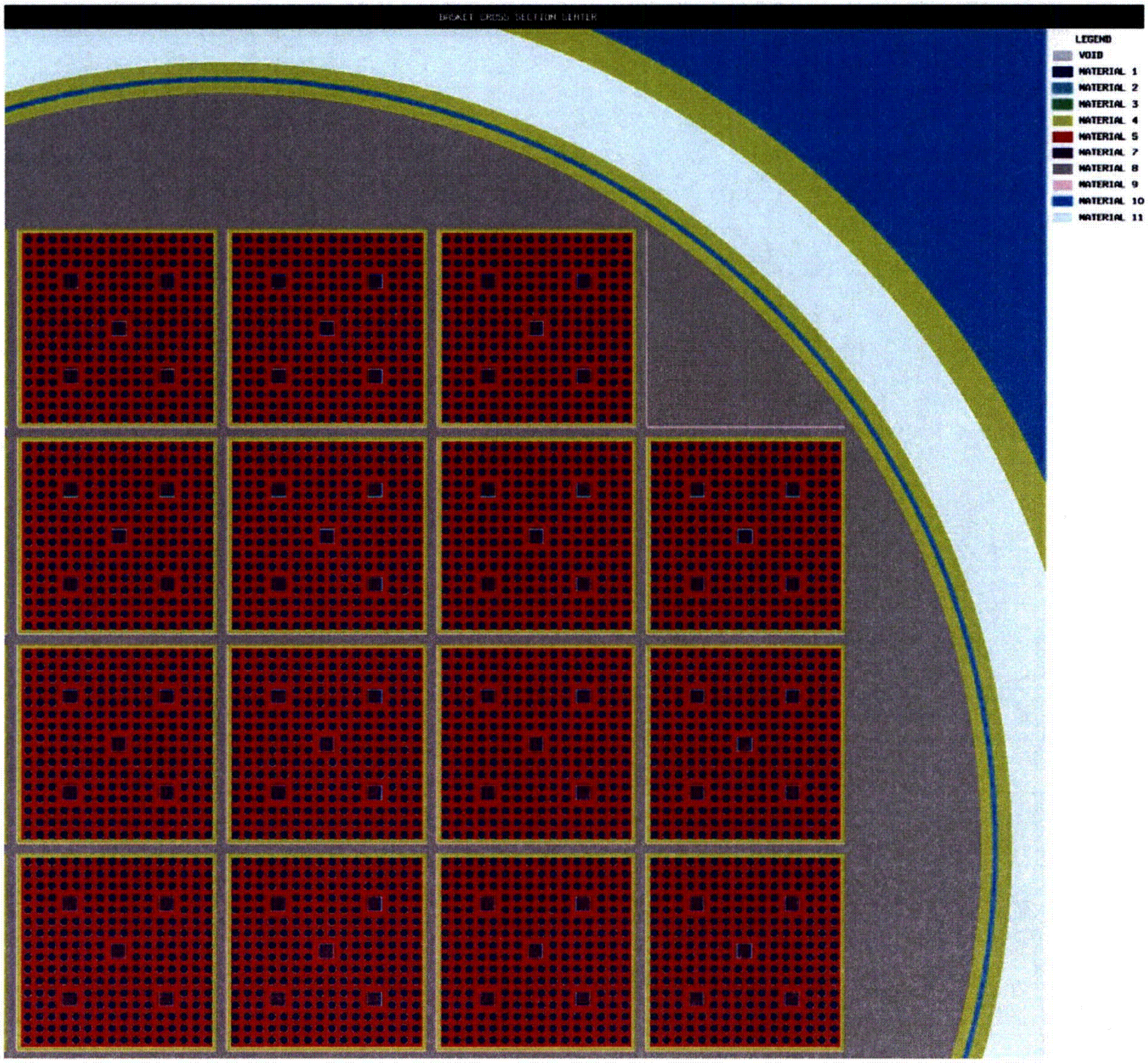

Figure 6-20
CE 16x16 Class Assembly – Optimum Pitch KENO Model with BPRAs

8.0 OPERATING PROCEDURES

This chapter outlines a sequence of operations to be incorporated into procedures for preparation of the NUHOMS® HD System DSC, loading of fuel, closure of the DSC, transport to the ISFSI, transfer into the HSM-H, monitoring operations, and retrieval and unloading. Operations are presented in their anticipated approximate performance sequence. Alternate sequencing that achieves the same purpose is acceptable. Temporary shielding may be used throughout as appropriate to maintain doses as low as reasonably achievable (ALARA). Only the use of helium is authorized to assist in removal of water. After water is drained from the DSC, (sections 8.1.1.2 & 8.1.1.3), the DSC shall be backfilled only with helium.

As stated in Appendix A, Chapter A.8, the operational steps described here in Chapter 8 apply in their entirety and without change to the 32PTH Type 1 DSC (described in Appendix A) when the optional two-part top end closure assembly (which is similar to the 32PTH DSC) is used. The 32PTH Type 1 DSC also features a three-part top end closure assembly. Appendix A, Chapter A.8 provides a description of the changes in operational sequences that are applicable when using that alternative.

8.1 Procedures for Loading the DSC and Transfer to the HSM-H

8.1.1 Narrative Description

The following steps describe the recommended generic operating procedures for the NUHOMS® System. A list of major equipment used during loading and unloading operations is provided in Table 8-1. A pictorial representation of key phases of this process is provided in Figure 8-1.

8.1.1.1 Transfer Cask and DSC Preparation

1. Verify by plant records or other means that candidate fuel assemblies meet the physical, thermal and radiological criteria specified in the Technical Specifications.
2. Clean or decontaminate the transfer cask as necessary to meet licensee pool and ALARA requirements, and to minimize transfer of contamination from the cask cavity to the DSC exterior.
3. Examine the transfer cask cavity for any physical damage.
4. Verify specified lubrication of the transfer cask rails.
5. Examine the DSC for any physical damage and for cleanliness. Verify that bottom fuel spacers or damaged fuel bottom end caps, if required, are present in all fuel compartments. Remove damaged fuel top end caps if they are in place. Record the DSC serial number which is located on the grappling ring. Verify the basket type by identifying the last character in the serial number.
6. If not already installed, install lifting rods into the four threaded sockets in the bottom of the DSC cavity in accordance with the design drawing.
7. Lift the DSC into the cask cavity and rotate the DSC to match the transfer cask alignment marks.
8. Remove the lifting rods.
9. Fill the transfer cask/DSC annulus with clean water.
10. Seal the top of the annulus, using for example an inflatable seal.

exterior surface of the cask with clean water to minimize surface adhesion of contamination.

4. Place the cask in the location of the fuel pool designated as the cask loading area.

5. Disengage the lifting yoke from the transfer cask lifting trunnions and move the yoke clear of the cask. Spray the lifting yoke with clean water if it is raised out of the fuel pool.

6. Load pre-selected spent fuel assemblies into the DSC basket compartments. The licensee shall develop procedures to verify that the boron content of the water conforms to the Technical Specifications, and that fuel identifications are verified and documented. Damaged fuel must be loaded only in designated compartments fitted with a damaged fuel bottom end cap.

7. After all the fuel assemblies have been placed into the DSC and their identities verified, install damaged fuel top end caps into designated compartments containing damaged fuel.

8. Lower the inner top cover/shield plug[1] in the DSC, aligning it with the guide on the DSC wall, and engaging the drain tube, until it seats on its support ring.

9. Visually verify that the inner top cover/shield plug is properly seated in the DSC. Reseat if necessary.

10. Position the lifting yoke and verify that it is properly engaged with the transfer cask trunnions.

11. Lift the transfer cask to the pool surface and spray the exposed portion of the cask with clean water.

12. Drain any water from above the inner top cover/shield plug back to the spent fuel pool. Up to 1300 gallons of water may be removed from the DSC prior to lifting the transfer cask clear of the pool surface. Up to 15 psig of helium may only be used to assist the removal of water. The DSC shall be backfilled only with helium after drainage of bulk water.

13. Lift the cask from the fuel pool, continuing to spray the cask with clean water.

14. Move the cask with loaded DSC to the area designated for DSC draining and closure operations. The set-down area should be level, or if slightly sloped, the transfer cask and DSC should be placed with the slope down toward the DSC drain/siphon tube.

[1] Including option 2 or option 3 inner top cover as described in Chapter 1 drawings.

8.1.1.3 DSC Closing, Drying, and Backfilling

1. Fill the transfer cask liquid neutron shield if it was drained for weight reduction during preceding operations.

2. Decontaminate the transfer cask exterior.

3. Disengage the rigging from the inner top cover/shield plug, and remove the eyebolts. Disengage the lifting yoke from the trunnions.

4. Disconnect the annulus overpressure tank if one was used, decontaminate the exposed surfaces of the DSC shell perimeter, remove any remaining water from the top of the annulus seal, and remove the seal.

5. Open the cask cavity drain port and allow water from the annulus to drain out until the water level is approximately twelve inches below the top of the DSC shell. Take swipes around the outer surface of the DSC shell to verify conformance with Technical Specification limits.

6. Cover the transfer cask / DSC annulus to prevent debris and weld splatter from entering the annulus.

7. If water was not drained from the DSC earlier, connect a pump to the DSC drain port and remove up to 1300 gallons of water. Only use helium to assist the removal of water. This lowers the water sufficiently to allow welding of the inner top cover/shield plug. Up to 15 psig of helium gas may be applied at the vent port to assist the water pump down.

   CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

7a. Monitor TC/DSC annulus water level to be approximately twelve inches below the top of the DSC shell and replenish as necessary until drained.

8. Install the automated welding machine onto the inner top cover/shield plug.

9. Hydrogen monitoring is required prior to commencing and continuously during the welding of the inner top cover / shield plug [1]. Insert a hydrogen monitor intake line through the vent port such that it terminates just below the inner top cover/shield plug.

10. Verify that the hydrogen concentration does not exceed 2.4% [1]. If this limit is exceeded, stop all welding operations and purge the DSC cavity with helium via the vent port to reduce hydrogen concentration safely below the 2.4% limit.

11. Complete the inner top cover/shield plug welding and perform the non-destructive examinations as required by the Technical Specifications. The weld must be made in at least two layers.

12. Remove the automated welding machine.

13. Pump remaining water from the DSC. Remove as much free standing water as possible to shorten vacuum drying time. Up to 15 psig of helium gas may be applied at the vent port to assist the water pump down. All helium used in backfilling operations shall be at least 99.99% pure (this may be done as part of step 15).

    NOTE: Proceed cautiously when evacuating the dry shielded canister (DSC) to avoid freezing consequences.

14. DELETED

15. Connect a vacuum pump / helium backfill manifold to the vent port or to both the vent and drain ports. The quick connect fittings may be removed and replaced with stainless steel pipe nipple / vacuum hose adapters to improve vacuum conductance. Make provision to prevent icing, for example by avoiding traps (low sections) in the vacuum line. Provide appropriate measures as required to control any airborne radionuclides in the vacuum pump exhaust. Purge air from the helium backfill manifold.

    Optionally, leak test the manifold and the connections to the DSC. The DSC may be pressurized to no more than 15 psig for leak testing.

    CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

16. Evacuate the DSC to the pressure required by the Technical Specification for vacuum drying, and isolate the vacuum pump. The isolation valve should be as near to the DSC as practicable, with a pressure gauge on the DSC side of the valve. Prior to performing the vacuum hold for 30 minutes as required by the Technical Specification, the vacuum pump must be turned off; or if the pump is <u>not</u> turned off, provide a tee and valve (or other means) to open the line to atmosphere between the pump and the DSC isolation valve.

17. DELETED

18. If the Technical Specification is satisfied, i.e., if the pressure remains below the specified limit for the required duration with the pump isolated, continue to the next step. If not, repeat step 16.

19a. Purge air from the backfill manifold, open the isolation valve, and backfill the DSC cavity with helium to 16.5 to 18 psig and hold for 10 minutes.

19b. Reduce the DSC cavity pressure to atmospheric pressure, or slightly over.

20. If the quick connect fittings were removed for vacuum drying, remove the vacuum line adapters from the ports, and re-install the quick connect fittings using suitable pipe thread sealant.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

21. Evacuate the DSC through the vent port quick connect fitting to a pressure 100 mbar or less.

22. Backfill the DSC with helium to the pressure specified in the Technical Specifications, and disconnect the vacuum / backfill manifold from the DSC.

23. DELETED

24a. Weld the covers over the vent and drain ports, performing non-destructive examination as required by the Technical Specifications. The welds shall have at least two layers.

24b. Install a temporary test head fixture (or any other alternative means). Perform a leak test of the inner top cover/shield plug to the DSC shell welds and siphon/vent cover welds in accordance with the Technical Specification limits. Verify that the personnel performing the leak test are qualified in accordance with SNT-TC-1A.

25. Place the outer top cover plate onto the DSC and verify correct rotational alignment of the cover and the DSC shell. Install the automated welding machine onto the outer top cover plate. As an option, the welding machine may be mounted onto the cover plate and then placed together on the DSC.

26. Complete the outer top cover welding and perform the non-destructive examinations as required by the Technical Specifications. The weld must be made in at least two layers.

27. Remove everything except the DSC from the transfer cask cavity: welding machine, protective covering from the transfer cask / DSC annulus, temporary shielding, etc., and drain the water from the transfer cask/DSC annulus.

28. Install the transfer cask lid and bolt it.

29. Evacuate the transfer cask cavity to below 100 mbar, and backfill the transfer cask annulus with helium in accordance with the Technical Specifications pressure tolerance and time limit.

    CAUTION: Monitor the applicable time limits of the Technical specifications for transfer cask annulus helium backfill.

8.1.1.4 Transfer Cask Downending and Transport to ISFSI

1. Deleted.

2. The transfer trailer should be positioned so that the cask support skid is accessible to the crane with the trailer supported on its vertical jacks. If required due to space limitations, the crane may remain in a stationary position while the cask support skid and trailer translate underneath the cask as it is downended, (the trailer cannot be supported on the vertical jacks.)

3. Engage the lifting yoke and lift the transfer cask over the cask support skid onto the transfer trailer.

4. Position the cask lower trunnions onto the transfer trailer support skid pillow blocks.

5. Move the crane while simultaneously lowering the cask until the cask upper trunnions are just above the support skid upper trunnion pillow blocks. Alternatively, if the crane is to remain stationary as identified above, slowly move the trailer and support skid as the cask is lowered until the upper trunnions are just above the support skid upper trunnion pillow blocks.

6. Verify that the cask and trunnion pillow blocks are properly aligned.

7. Lower the cask onto the skid until the weight of the cask is distributed to the trunnion pillow blocks.

8. Verify the trunnions are properly seated onto the skid and install the trunnion tower closure plates.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

12. Obtain a sample of the DSC atmosphere. Confirm acceptable hydrogen concentration and check for presence of fission gas indicative of degraded fuel cladding.

13. If degraded fuel is suspected, additional measures appropriate for the specific conditions are to be planned, reviewed, and implemented to minimize exposures to workers and radiological releases to the environment.

14. Verify that the boron content of the fill water conforms to the Technical Specifications. Fill the DSC with water from the fuel pool or equivalent source through the drain port with the vent port open. The vented cavity gas may include steam, water, and radioactive material, and should be routed accordingly. Monitor the vent pressure and regulate the water fill rate to ensure that the pressure does not exceed 15 psig.

15. Provide for continuous hydrogen monitoring of the DSC cavity atmosphere during all subsequent cutting operations to ensure that hydrogen concentration does not exceed 2.4%. Purge with helium as necessary to maintain the hydrogen concentration below this limit.

16. Provide suitable protection for the transfer cask during cutting operations.

17. Using a suitable method, such as mechanical cutting, remove the weld of the outer top cover plate to the DSC shell.

18. Remove the outer top cover plate.

19. Remove the weld of the inner top cover/shield plug to the shell in the same manner as the outer cover plate. Do not remove the inner top cover/shield plug at this time unless the removal is being done remotely in a dry transfer system.

20. Remove any remaining excess material on the inside shell surface by grinding.

21. Clean the transfer cask surface of dirt and any debris which may be on the transfer cask surface as a result of the weld removal operation.

22. Engage the yoke onto the trunnions, install eyebolts or other lifting attachment(s) into the inner top cover/shield plug, and connect the rigging cables to the eyebolts/lifting attachment(s).

23. Verify that the lifting hooks of the yoke are properly positioned on the trunnions.

Table 8-1
Major Equipment Used During NUHOMS® HD System Loading and Unloading Operations

NUHOMS® HD System	Function
Dry Shielded Canister (DSC)	Fuel confinement.
Horizontal Storage Module (HSM-H)	Shielding, physical protection
Transfer Cask	Handling and transport of loaded DSC
Transfer trailer with support frame, ram, alignment system, and hydraulic power pack, pressure gauges and pressure relief	Transport of loaded transfer cask, and transfer of DSC into or retrieval from HSM-H; monitor and limit force applied to DSC by ram

Other Equipment and Instruments	Function
Lift yoke	Lifting transfer cask empty or loaded, in conformance to NUREG-0612 [2]
Lifting eyes, slings, rigging, etc.	Lifting the empty DSC, DSC covers, and the transfer cask lid in conformance to NUREG-0612 [2]
Water pump, hoses, connectors, fittings	Draining the DSC
Transfer cask / DSC annulus seal	Contamination control of the DSC exterior by pool water
Small water tank and hose	Maintaining positive pressure in annulus
Vacuum pump / helium backfill manifold, valves, hoses, fittings, adapters, pressure and vacuum gauges, etc.	Pressure test, vacuum drying and backfill of DSC; helium backfill of transfer cask cavity
Helium leak test equipment, including test head	Leak test closure welds
Gas bottles	Pressurize canister cavity for blowdown pressure test, helium backfill, etc.
Tractor	Towing the transfer trailer
Mobile crane and rigging	Removal of HSM-H door and transfer cask lid at ISFSI
Scaffolding, manlifts, etc	As required for easy access during operations
Temporary shielding	As required to maintain doses ALARA
Automatic welder	Remote welding of inner and outer top covers
Manual or automatic welder	Welding of vent and drain cover plates
Radiation detectors	Surveys to maintain doses ALARA
Transit with platform	Align transfer cask and ram with HSM-H
Hydrogen detector	Monitoring DSC cavity hydrogen during welding (loading) or cutting (unloading) of inner top cover
Temperature sensor and/or water circulation system	Optional, monitoring or circulation of water in transfer cask / DSC annulus

DSC Opening Equipment and Instruments	Function
Plasma torch or other cutting machine	Removal of lids for unloading of fuel
Portable drill press and annular cutters	Removal of vent and siphon covers
Gas sampling cylinder with quick connect adapter	Sampling of cavity gas prior to opening of DSC
Pressure gauge and water flow control valve	Limiting DSC pressure during reflooding

9. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

As noted in Chapter A.9, this chapter is also applicable to the 32PTH Type 1 DSC and OS187H Type 1 TC.

9.1 Acceptance Criteria

9.1.1 Visual Inspection and Non-Destructive Examination (NDE)

Visual inspections are performed at the fabricator's facility to ensure that the 32PTH DSC, the OS187H Transfer Cask and the HSM-H conform to the drawings and specifications. The visual inspections include weld, dimensional, surface finish, and cleanliness inspections. Visual inspections specified by codes applicable to a component are performed in accordance with the requirements and acceptance criteria of those codes.

All weld inspection is performed using qualified processes and qualified personnel according to the applicable code requirements, e.g., ASME or AWS. Non-destructive examination (NDE) requirements for welds are specified on the drawings provided in Chapter 1; acceptance criteria are as specified by the governing code. NDE personnel are qualified in accordance with SNT-TC-1A [2].

The confinement welds on the DSC are inspected in accordance with ASME B&PV Code Subsection NB [1] including alternatives to ASME Code specified in SAR Section 3.10.

DSC non-confinement welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NG or NF, based on the applicable code for the components welded.

The Transfer Cask welds are inspected in accordance with ASME B&PV Code Subsection NC for class 2 components, as modified by code alternates identified in Section 3.10 of Chapter 3.

9.1.2 Structural and Pressure Tests

The DSC confinement boundary except inner top cover/shield plug (including option 2 or option 3 inner top cover as described in the SAR) to the DSC shell weld is pressure tested at the fabricator's shop in accordance with ASME Article NB-6300. For future transportation licensing considerations, a conservative pressure of 20 psig is substituted for the design pressure (Section 4.1) to determine compliance test pressures during fabrication.

The inner top cover/shield plug (including option 2 or option 3 inner top cover) to the DSC shell weld is also pressure tested between 16.5 to 18 psig at the field after the fuel assemblies are loaded in the canister. This test is in accordance with the alternatives to the ASME code specified in SAR Section 3.10.

HSM-H reinforcement and concrete are tested as described in Section 2.5.2 and footnotes to Tables 4.1-5 and 4.4-3.

The Transfer Cask lifting (top) trunnions will be load tested in accordance with ANSI N14.6 [3] for a single failure proof design, i.e., three times the design load. The design load is conservatively set at 250,000 lbs (Section 3.2.2); therefore, the test load is 750,000 lbs (375,000 lbs/trunnion).

9.1.3 Leak Tests

DSC confinement weld seams in the DSC shell and bottom are leak tested at the fabricator's shop to an acceptance criterion of 1x10-7 ref cm3/s, i.e., "leaktight" as defined in ANSI N14.5 [4]. Personnel performing the leak test are qualified in accordance with SNT-TC-1A [2].

abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surface, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

9.1.7.2 Boron Carbide / Aluminum Metal Matrix Composites (MMC)

See the Caution in Section 9.1.7 before deletion or modification to this section.

The material is a composite of fine boron carbide particles in an aluminum or aluminum alloy matrix. The material shall be produced by either direct chill casting, permanent mold casting, powder metallurgy, or thermal spray techniques. It is a low-porosity product, with a metallurgically bonded matrix. The boron carbide content shall not exceed 40% by volume. The boron carbide content for MMCs with an integral aluminum cladding shall not exceed 50% by volume.

Prior to use in the 32PTH DSC, MMCs shall pass the qualification testing specified in Section 9.5.3, and shall subsequently be subject to the process controls specified in Section 9.5.4.

The criticality calculations take credit for 90% of the minimum specified B10 areal density of MMCs. The basis for this credit is the B10 areal density acceptance testing, which is specified in Section 9.5.2. The specified acceptance testing assures that at any location in the final product, the minimum specified areal density of B10 will be found with 95% probability and 95% confidence.

Visual inspections shall follow the recommendations in Aluminum Standards and Data, Chapter 4 "Quality Control, Visual Inspection of Aluminum Mill Products and Castings" [5]. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores, or discoloration are acceptable. Widespread blisters, rough surfaces, or cracking shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

References to metal matrix composites throughout this chapter are not intended to refer to Boral®, which is described in the following section.

9.1.7.3 Boral®

See the Caution in Section 9.1.7 before deletion or modification to this section.

This material consists of a core of aluminum and boron carbide powders between two outer layers of aluminum, mechanically bonded by hot-rolling an "ingot" consisting of an aluminum box filled with blended boron carbide and aluminum powders. The core, which is exposed at the edges of the sheet, is slightly porous. The average size of the boron carbide particles in the finished product is approximately 50 microns after rolling. The nominal boron carbide content shall be limited to 65% (+ 2% tolerance limit) of the core by weight.

The criticality calculations take credit for 75% of the minimum specified B10 areal density of Boral®. B10 areal density will be verified by chemical analysis and by certification of the B10 isotopic fraction for the boron carbide powder, or by neutron transmission testing. Areal density testing is performed on an approximately 1 cm^2 area of a coupon taken near

composed of a homogeneous boron compound without other significant neutron absorbers. For example, boron carbide, zirconium diboride or titanium diboride sheets are acceptable standards. These standards are paired with aluminum shims sized to match the effect of neutron scattering by aluminum in the test coupons. Uniform but non-homogeneous materials such as metal matrix composites may be used for standards, provided that testing shows them to provide neutron attenuation equivalent to a homogeneous standard.

Alternatively, digital image analysis may be used to compare neutron radioscopic images of the test coupon to images of the standards. The area of image analysis shall be up to 1.1 cm^2.

The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level or better. The following illustrates one acceptable method.

The acceptance criterion for individual plates is determined from a statistical analysis of the test results for their lot. The minimum B10 areal densities determined by neutron transmission are converted to volume density, i.e., the minimum B10 areal density is divided by the thickness at the location of the neutron transmission measurement or the maximum thickness of the coupon. The lower tolerance limit of B10 volume density is then determined, defined as the mean value of B10 volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for a normal distribution with 95% probability and 95% confidence [7].

Finally, the minimum specified value of B10 areal density is divided by the lower tolerance limit of B10 volume density to arrive at the minimum plate thickness which provides the specified B10 areal density.

Any plate which is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as non-conforming, with the following exception. Local depressions are acceptable, so long as they total no more than 0.5% of the area on any given plate, and the thickness at their location is not less than 90% of the minimum design thickness.

Non-conforming material shall be evaluated for acceptance in accordance with the Certificate Holder's QA procedures.

9.5.3 Specification for Qualification Testing of Metal Matrix Composites

9.5.3.1 Applicability and Scope

Metal matrix composites (MMCs) shall consist of fine boron carbide particles in an aluminum or aluminum alloy matrix. The ingot shall be produced by either powder metallurgy (PM), thermal spray techniques, or by direct chill (DC) or permanent mold casting. In any case, the final MMC product shall have density greater than 98% of theoretical, a metallurgically bonded matrix, and boron carbide content no greater than 40% by volume (for MMCs with an integral aluminum cladding, the maximum boron carbide content shall be no greater than 50% by volume and the density shall be greater than 97% of theoretical density). Boron carbide particles for the products considered here typically have an average size in the range 10-40 microns, although the actual specification may be by mesh size, rather than by average particle size. No more than 10% of the

12 OPERATING CONTROLS AND LIMITS

The Technical Specifications for the NUHOMS® HD system are included in Attachment A to NUHOMS® HD CoC 1030 (Docket No. 72-1030).

B 12.2 FUNCTIONAL AND OPERATING LIMITS

BASES

BACKGROUND

The 32PTH DSC design requires certain limits on spent fuel parameters, including fuel type, maximum allowable enrichment prior to irradiation, maximum burnup, minimum acceptable cooling time prior to storage in the 32PTH DSC, and physical condition of the spent fuel (i.e., intact or damaged fuel assemblies). Other important limitations are the radiological source terms from Control Components (CCs) associated Burnable Poison Rod Assemblies (BPRAs), Vibration Suppressor Inserts (VSIs), and Thimble Plug Assemblies (TPAs). These limitations are included in the thermal, structural, radiological, and criticality evaluations performed for the canister.

APPLICABLE SAFETY ANALYSIS

Various analyses have been performed that use these fuel parameters as assumptions. These assumptions are included in the thermal, criticality, structural, shielding and confinement analyses.

Technical Specification Tables 1, 2, 3, 4, and 5 provide the key fuel parameters that require confirmation prior to 32PH DSC loading.

FUNCTIONAL AND OPERATING LIMITS VIOLATIONS

If Functional and Operating Limits are violated, the limitations on the fuel assemblies in the canister have not been met. Actions must be taken to place the affected fuel assemblies in a safe condition. This safe condition may be established by returning the affected fuel assemblies to the spent fuel pool. However, it is acceptable for the affected fuel assemblies to remain in the canister if that is determined to be a safe condition.

Notification of the violation of a Functional and Operating Limit to the NRC is required within 24 hours. Written reporting of the violation must be accomplished within 60 days. This notification and written report are independent of any reports and notification that may be required by 10CFR 72.75.

REFERENCES

SAR Chapter 2

B 12.3 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs

LCO 3.0.1, 3.0.2, 3.0.4 and 3.0.5 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

LCO 3.0.1

LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the canister is in the specified conditions of the Applicability statement of each Specification).

LCO 3.0.2

LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS Condition is applicable from the point in time that an ACTIONS Condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that:

a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and

b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified.

There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. If this type of Required Action is not completed within the specified Completion Time, the canister may have to be placed in the spent fuel pool and unloaded. (Whether stated as a Required Action or not, correction of the entered Condition is an action that may always be considered upon entering ACTIONS.) The second type of Required Action specifies the remedial measures that permit continued operation of the unit that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

Individual Specifications may specify a time limit for performing an SR when equipment is removed from service or bypassed for testing. In this case, the Completion Times of the Required Actions are applicable when this time limit expires if the equipment remains removed from service or bypassed.

When a change in specified condition is required to comply with Required Actions, the equipment may enter a specified condition in which another Specification becomes applicable. In this case, the Completion Times of the associated Required Actions would apply from the point in time that the new Specification becomes applicable and the ACTIONS Condition(s) are entered.

LCO 3.0.3

This specification is not applicable to the NUHOMS® HD System. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.4

LCO 3.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the NUHOMS® HD System in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following exist:

a. Conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and

b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in the equipment being required to exit the Applicability desired to be entered to comply with the Required Actions.

Compliance with Required Actions that permit continued operation of the equipment for an unlimited period of time in specified condition provides an acceptable level of safety for continued operation. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

The provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of a canister.

Exceptions to LCO 3.0.4 are stated in the individual Specifications.

Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.

Surveillances do not have to be performed on the associated equipment out of service (or on variables outside the specified limits), as permitted by SR 3.0.1. Therefore, changing specified conditions while in an ACTIONS Condition, either in compliance with LCO 3.0.4 or where an exception to LCO 3.0.4 is stated, is not a violation of SR 3.0.1 or SR 3.0.4 for those Surveillances that do not have to be performed due to the associated out of service equipment.

LCO 3.0.5

LCO 3.0.5 establishes the allowance for restoring equipment to service under administrative controls when it has been removed from service or not in service in compliance with ACTIONS. The sole purpose of this Specification is to provide an exception to LCO 3.0.2 (e.g., to not comply with the applicable Required Action(s)) to allow the performance of required testing to demonstrate:

a. The equipment being returned to service meets the LCO; or

b. Other equipment meets the applicable LCOs.

The administrative controls ensure the time the equipment is returned to service in conflict with the requirements of the ACTIONS is limited to the time absolutely necessary to perform the allowed required testing. This Specification does not provide time to perform any other preventive or corrective maintenance.

LCO 3.0.6

This specification is not applicable to the NUHOMS® HD System. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.7

This specification is not applicable to the NUHOMS® HD System. The placeholder is retained for consistency with the power reactor technical specifications.

B 12.3 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs

SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications in Sections 3.1 and 3.2 and apply at all times, unless otherwise stated.

SR 3.0.1

SR 3.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify systems and components, and that variables are within specified limits. Failure to meet a Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; or

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the equipment is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment that has been determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning equipment to service.

Upon completion of maintenance, appropriate post maintenance testing is required to declare equipment within its LCO. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2. Post maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary equipment parameters not having been established. In these situations, the equipment may be considered to meet the LCO provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function.

This will allow operation to proceed to a specified condition where other necessary post maintenance tests can be completed.

SR 3.0.2

SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per..." interval.

SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers plant operating conditions that may not be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications. The requirements of regulations take precedence over the TS. Therefore, when a test interval is specified in the regulations, the test interval cannot be extended by the TS, and the SR includes a Note in the Frequency stating, "SR 3.0.2 is not applicable".

As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the equipment in an alternative manner.

The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals (other than those consistent with refueling intervals) or periodic Completion Time intervals beyond those specified.

SR 3.0.3

SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when a Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the

Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of a surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance. The basis for this delay period includes consideration of unit conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements.

When a Surveillance with a Frequency based not on time intervals, but upon specified unit conditions or operational situations, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility which is not intended to be used as an operational convenience to extend Surveillance intervals.

If a Surveillance is not completed within the allowed delay period, then the equipment is considered not in service or the variable is considered outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If a Surveillance is failed within the delay period, then the equipment is not in service, or the variable is outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance. Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4 SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry in the Applicability for which these systems and components ensure safe operation of the facility.

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components to an appropriate status before entering an associated specified condition in the Applicability. However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified condition. When a system, subsystem, division, component, device, or variable is outside its specified limits, the associated SR(s) are not required to be performed, per SR 3.0.1, which states that Surveillances do not have to be performed on such equipment. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified Frequency does not result in an SR 3.0.4 restriction to changing specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

The provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of a HSM-H or 32PTH DSC.

The precise requirements for performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of a Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met. Alternatively, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further discussion of the specific formats of SR annotation is found in Technical Specifications Section 1.4, operation to proceed to a specified condition where other necessary post maintenance tests can be completed.

B 12.3.1 FUEL INTEGRITY

B 12.3.1.1 DSC Bulkwater Removal Medium and Vacuum Drying Pressure

BASES

BACKGROUND

A 32PTH DSC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. An inner top cover/shield plug assembly or shield plug is then placed on the 32PTH DSC. Subsequent operations involve moving the 32PTH DSC to the decontamination area and removing water from the 32PTH DSC (using helium as a cover gas for assisting in the drainage of bulk water). After the 32PTH DSC inner top cover/shield plug is secured, vacuum drying of the 32PTH DSC is performed, and the 32PTH DSC is backfilled with helium. During normal storage conditions, the fuel assemblies are stored in the 32PTH DSC with an inert helium atmosphere which results in lower fuel clad temperatures and provides an inert atmosphere during storage conditions.

32PTH DSC vacuum drying is utilized to remove residual moisture from the cavity after the 32PTH DSC has been drained of water. Any water which was not drained from the 32PTH DSC evaporates from fuel or basket surfaces due to the vacuum. This vacuum drying operation is aided by the temperature increase due to the heat generation of the fuel.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a 32PTH DSC is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are the fuel pellet matrix, the fuel cladding tubes in which the fuel pellets are contained, and the 32PTH DSC in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This protective environment is accomplished by removing water from the 32PTH DSC (using helium for assisting in the drainage of bulk water) and backfilling the 32PTH DSC with helium. The removal of water is necessary to prevent phase change–related pressure increase upon heatup. The analysis in Chapter 4 demonstrates that if helium is used as a cover gas for bulk water removal operations, the conductivity of helium during vacuum drying operations assure that cladding temperature remains below the cladding temperature limit. The DSC / Transfer cask annulus contains water during the vacuum drying process. This SAR evaluates and documents that the 32PTH DSC confinement boundary is not compromised due to any normal, off-normal or accident condition postulated (SAR Chapter 3 and 11 structural analyses) and the fuel clad temperature remains below allowable values (SAR Chapter 4).

LCO

Utilizing helium as the medium to assist during drainage of bulk water ensures that the fuel cladding remains under the limits during the entire vacuum drying operations.
A stable vacuum pressure of < 3 torr further ensures that all liquid water has evaporated in the 32PTH DSC cavity, and that the resulting inventory of oxidizing gases in the 32PTH DSC is below 0.25 volume %.

APPLICABILITY

This is applicable to all 32PTH DSCs during LOADING OPERATIONS but before TRANSFER OPERATIONS.

ACTIONS

The actions specified require checking for any leaks in the vacuum drying system or welds and correcting them or establishment of a helium pressure of at least 0.5 atmosphere within the time limits specified in the LCO. The timeframe specified applies to the vacuum drying operations and the helium backfill operations. If the required vacuum can not be established within the timeframe specified in the Condition column of the Actions table, a helium atmosphere (with a pressure of at least 0.5 atmosphere) is to be established within 30 days or perform an assessment and implementation of corrective actions to return the 32PTH DSC to an analyzed condition or reflood the DSC submerging all fuel assemblies. The 15 psig limit in the action section is conservatively below the maximum analyzed blowdown pressure.

SURVEILLANCE REQUIREMENTS

Ensure a minimum oxidizing gas content and maintain cladding integrity.

REFERENCES

SAR Chapters 3 and 4

B12.3.1 FUEL INTEGRITY

B 12.3.1.2 32PTH DSC Helium Backfill Pressure

BASES

BACKGROUND

A 32PTH DSC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. An inner top cover/shield plug assembly or shield plug is then placed on the 32PTH DSC. Subsequent operations involve moving the 32PTH DSC to the decontamination area and removing water from the 32PTH DSC using helium to assist in the drainage of bulk water. After the 32PTH DSC inner top cover/shield plug is welded, vacuum drying of the 32PTH DSC is performed, and the 32PTH DSC is backfilled with helium. During normal storage conditions, the 32PTH DSC is backfilled with helium which results in lower fuel clad temperatures. The inert helium environment protects the fuel from potential oxidizing environments.

APPLICABLE SAFETY ANALYSIS

Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. SAR section 3.5 evaluates the effect of long term storage and short term temperature transients on fuel cladding integrity. Credit for the helium backfill pressure is taken to limit the potential for corrosion of the fuel cladding. SAR Chapter 4 evaluates the 32PTH DSC maximum pressure under normal, off-normal, and accident conditions.

LCO

32PTH DSC backpressure is maintained within a range of pressure that will ensure maintenance of the helium backfill pressure over time and will not result in excessive 32PTH DSC pressure in normal, off-normal and accident conditions.

APPLICABILITY

This specification is applicable to all 32PTH DSCs during LOADING OPERATIONS but before TRANSFER OPERATIONS.

ACTIONS

The actions required and associated completion times are associated with the time limits established in technical specification 3.1.2. The total time for helium backfill is specified in technical specification 3.1.2. The thermal analysis in Chapter 4 demonstrates that with water in the DSC/cask annulus and helium atmosphere in the DSC cavity, fuel cladding temperatures are below the cladding material temperature limits. These time limits are imposed to ensure that there is sufficient time to complete the required actions and the 32PTH DSC fuel cladding will not exceed maximum allowable temperatures.

SURVEILLANCE REQUIREMENTS

To ensure that: (1) the atmosphere surrounding the irradiated fuel is a non-oxidizing inert gas; (2) the atmosphere is favorable for the transfer of decay heat.

REFERENCES

SAR Chapters 3 and 4

B12.3.1 FUEL INTEGRITY

B 12.3.1.3 Transfer Cask Cavity Helium Backfill Pressure

BASES

BACKGROUND

A 32PTH DSC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. An inner top cover/shield plug assembly or shield plug is then placed on the 32PTH DSC. Subsequent operations involve moving the 32PTH DSC to the decontamination area and removing water from the 32PTH DSC using helium to assist in the drainage of bulk water. After the 32PTH DSC inner top cover/shield plug is welded, vacuum drying of the 32PTH DSC is performed, and the 32PTH DSC is backfilled with helium. The 32PTH DSC outer top cover plate is welded, and, subsequently, the water drained from the transfer cask (TC) annulus. After installation of the TC lid, the TC cavity is backfilled with helium to assure adequate heat transfer which maintains the fuel cladding temperatures below the maximum allowable temperature.

APPLICABLE SAFETY ANALYSIS

Long-term integrity of the fuel cladding depends on storage in an inert atmosphere and maintaining fuel cladding temperature below an acceptable limit. SAR Chapter 4 evaluates the 32PTH DSC temperatures under normal, off-normal, and accident conditions. The thermal analysis in SAR Chapter 4 demonstrates that with helium in the DSC/TC annulus and helium in the DSC cavity, the fuel cladding temperatures are below the cladding material temperature limits. Monitoring of the TC cavity annulus pressure during transfer operation or verification after filling ensures that helium will be present in the annulus during transfer operations to keep the temperatures within analyzed conditions.

LCO

The OS187H cavity is maintained within a range of pressure that will ensure maintenance of the helium backfill pressure over the transfer time and will not result in excessive pressure in normal, off-normal and accident conditions. The cavity helium backfill must commence within 26 hours after the drainage of the water in the annulus.

APPLICABILITY

This specification is applicable to OS187H transfer cask with loaded 32PTH DSC during LOADING, TRANSFER, and UNLOADING OPERATIONS.

ACTIONS

Should the helium pressure not meet the requirements of this specification, the TC/32PTH DSC must be returned to an analyzed condition.

SURVEILLANCE REQUIREMENTS

To ensure the transfer cask cavity is in a helium environment during LOADING, UNLOADING, and TRANSFER OPERATIONS.

REFERENCES

SAR Chapter 4

D.3. DSC Shell Assembly Stress Evaluation for Transfer Loads

All analyzed load cases in this section are identified in Tables A.3.9.1-3 and A.3.9.1-4 and are described in detail in the following sections.

Transfer Load Case 1: **Deadweight + 15 psig external pressure + thermal (vacuum drying)**

The temperature profile utilized for the analysis of Transfer Load Case 1 for the 32PTH DSC described in Section 3.9.1.3.2 (D.3) was adjusted by linearly scaling to the maximum vacuum drying temperature of 522 °F, which is greater than the maximum temperature for vacuum drying 511 °F, as calculated in Chapter 4. This adjusted temperature profile is used for the analysis of Transfer Load Case 1 for the 32PTH Type 1 DSC.

The weight of the canister internals (basket and fuel assemblies) is accounted for by applying equivalent pressures on the support surfaces of the canister. The actual weights of the basket and fuel assemblies are 29,451 lb and 50,720 lb, respectively (see Section A.3.2.1). Therefore, the total weight of the canister internals is 80,171 lbs. A weight of 83,000 lbs is conservatively used in this analysis. The canister cavity inner radius is 34.375 in. Therefore, the pressure load equivalent to the inertial load of the internals, P_{ia}, is,

$$P_{ia} = [83{,}000 / (\pi \times 34.375^2)] = 22.36 \text{ psi.}$$

An elastic analysis is performed using the ANSYS 2-D axisymmetric model. The analysis was run in 2 load steps. The first load step includes dead weight, 15 psig external pressure, and the temperature profile discussed above, but it does not include coefficient of thermal expansion. The second load step includes the coefficient of thermal expansion and all of the above mentioned loads. The results from the first load step are compared against the P_m and $P_m + P_b$ allowable stresses and the results from the second load step are compared against the $P_m + P_b + Q$ allowable stresses.

The maximum primary stress intensity in the canister was calculated to be 2.05 ksi in Load Step 1. The maximum primary stress intensity in the closure welds is calculated to be 1.52 ksi.

The maximum primary plus secondary stress intensity in the canister was calculated to be 22.69 ksi in Load Step 2. These stresses are summarized in Table A.3.9.1-6. The maximum primary stress intensity in the closure welds is calculated to be 2.07 ksi.

Transfer Load Case 2: **Handling, 2 *g* axial + 2 *g* transverse + 2 *g* vertical + 30 psig int. pressure + thermal (115 °F ambient)**

The handling 2 *g* inertial loads applied to the canister when inside the transfer cask in the horizontal orientation are analyzed as part of the basket model described in Section 3.9.1.2.3 (B.2) (the basket model includes a segment of the canister shell). It is judged that under the relatively light handling loads the maximum stresses in the canister will occur in the shell section and can be obtained from the results calculated in Section 3.9.1.2.3 (B.2). The maximum primary membrane stress intensity and primary membrane plus bending stress intensity in the canister shell due to the handling load of 2 *g*, calculated in Section 3.9.1.2.3 (B.2), are 880 psi and 9740 psi, respectively. These stresses are summarized in Table A.3.9.1-6.

σ_p = external pressure × the mean structural shell radius / the minimum structural shell thickness
= 15 psi × (78.87 + 1.50)/2 in. / 1.50 in. = 402 psi

The stress generated in the structural shell by the 1g axial load is conservatively computed assuming that the weight of the entire TC is taken by the cross sectional area of the structural shell. The weight of the TC is conservatively taken to be 250,000 lb. The 1g axial stress in the structural shell, σ_g, is computed as follows.

σ_g = 1g × maximum TC weight / minimum cross sectional area of the structural shell
= 1g × 250,000 / [$(\pi/4)\times(81.87^2 - 78.87^2)$] = 660 psi

The maximum hoop stress generated by the radial thermal gradient during the vacuum drying process will occur in the outer structural shell due to the thermal expansion of the lead gamma shield. From Chapter 4, the maximum temperature difference between the lead gamma shield and the structural shell occurs during the drying process when the lead and structural shell are at 275 °F and 219 °F, respectively.

The change in the outer radius of the lead gamma shield, ΔR_l, is computed as follows.

$\Delta R_l = R_l \times \alpha_l \times \Delta T_l$ = 39.435 in. × 17.34 ×10^{-6} in./in. °F (@300 °F) × (275 – 70) °F
= 0.1402 in.

The change in the inner radius of the structural shell, ΔR_s, is computed as follows.

$\Delta R_s = R_s \times \alpha_s \times \Delta T_s$ = 39.435 in. × 8.9 ×10^{-6} in./in. °F (@200 °F) × (219 – 70) °F
= 0.0523 in.

Therefore the differential radial expansion between the lead and structural shell, ΔR, is as follows.

ΔR = 0.1402 in. – 0.0523 in. = 0.0879 in.

Therefore, the lead cylinder, if it were free, would grow 0.0879 in. more than the inner surface of the structural shell. If all of the differential expansion is accommodated in the lead, the lead strain, ε_l, would be the following.

$\varepsilon_l = \Delta R/R_l$ = 0.0879 in./39.435 in. = 0.00223 in./in.

If the lead remained linear elastic, the maximum hoop stress in the lead would be,

$\sigma_l = E_l \times \varepsilon_l$ = 2.06×10^6 psi (@300 °F) × 0.00223 in./in. = 4,594 psi

Conservatively assuming that the lead remains linear elastic, the interference pressure on the outer structural shell required to exert an average hoop stress of 4,594 psi in the lead can be determined in the following way.

$P_{interface} = \sigma_l$ × lead thickness/$R_{interface}$ = 4,594 psi × 3.56 in./39.435 in. = 415 psi

6. Load pre-selected spent fuel assemblies into the DSC basket compartments. The licensee shall develop procedures to verify that the boron content of the water conforms to the Technical Specifications, and that fuel identifications are verified and documented. Damaged fuel must be loaded only in designated compartments fitted with a damaged fuel bottom end cap.

7. After all the fuel assemblies have been placed into the DSC and their identities verified, install damaged fuel top end caps into designated compartments containing damaged fuel.

8. Lower the top shield plug into the DSC.

9. Visually verify that the top shield plug is properly seated in the DSC. Reseat if necessary.

10. Position the lifting yoke and verify that it is properly engaged with the transfer cask trunnions.

11. Lift the transfer cask to the pool surface and spray the exposed portion of the cask with clean water.

12. Drain any water from above the top shield plug back to the spent fuel pool. Up to 1300 gallons of water may be removed from the DSC prior to lifting the transfer cask clear of the pool surface. Up to 15 psig of helium may only be used to assist the removal of water. The DSC shall be backfilled only with helium after drainage of bulk water.

13. Lift the cask from the fuel pool, continuing to spray the cask with clean water.

14. Move the cask with loaded DSC to the area designated for DSC draining and closure operations. The set-down area should be level, or if slightly sloped, the transfer cask and DSC should be placed with the slope down toward the DSC drain/siphon tube.

A.8.1.1.3 DSC Closing, Drying, and Backfilling

1. Fill the transfer cask liquid neutron shield if it was drained for weight reduction during preceding operations.

2. Decontaminate the transfer cask exterior.

3. Disengage the rigging from the top shield plug, and remove the eyebolts. Disengage the lifting yoke from the trunnions.

4. Disconnect the annulus overpressure tank if one was used, decontaminate the exposed surfaces of the DSC shell perimeter, remove any remaining water from the top of the annulus seal, and remove the seal.

5. Open the cask cavity drain port and allow water from the annulus to drain out until the water level is approximately twelve inches below the top of the DSC shell. Take swipes around the outer surface of the DSC shell to verify conformance with Technical Specification limits.

6. Cover the transfer cask/DSC annulus to prevent debris and weld splatter from entering the annulus.

7. If water was not drained from the DSC earlier, connect a pump to the DSC drain port and remove up to 1,300 gallons of water. Use only helium to assist the removal of water. This lowers the water sufficiently to allow welding of the inner top cover, while keeping a sufficient volume of water in the DSC to cool the spent fuel. Up to 15 psig of helium gas may be applied at the vent port to assist the water pump down.

   CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

7a. Monitor TC/DSC annulus water level to be approximately twelve inches below the top of the DSC shell and replenish as necessary until drained.

8. Install the automated welding machine onto the inner top cover and place the inner top cover with the automatic welding machine onto the DSC. Optionally, the inner top cover and the automatic welding machine can be place separately. Verify proper fit up of the inner top cover with the DSC shell.

9. Hydrogen monitoring is required prior to commencing and continuously during the welding of the inner top cover. Insert a hydrogen monitor intake line through the vent port such that it terminates just below the top shield plug.

10. Verify that the hydrogen concentration does not exceed 2.4% [1]. If this limit is exceeded, stop all welding operations and purge the DSC cavity with helium via the vent port to reduce hydrogen concentration safely below the 2.4% limit.

11. Complete the inner top cover welding and perform the non-destructive examinations as required by the Technical Specifications. The weld must be made in at least two layers.

12. Remove the automated welding machine.

13. Pump remaining water from the DSC. Remove as much free standing water as possible to shorten vacuum drying time. Up to 15 psig of helium gas may be applied at the vent port to assist the water pump down. All helium used in backfilling operations shall be at least 99.99% pure (this may be done as part of step 15).

    (NOTE: Proceed cautiously when evacuating the dry shielded canister (DSC) to avoid freezing consequences.)

14. DELETED

15. Connect a vacuum pump/helium backfill manifold to the vent port or to both the vent and drain ports. The quick connect fittings may be removed and replaced with stainless steel pipe nipple/vacuum hose adapters to improve vacuum conductance. Make provision to prevent icing, for example by avoiding traps (low sections) in the vacuum line. Provide appropriate measures as required to control any airborne radionuclides in the vacuum pump exhaust. Purge air from the helium backfill manifold.

    Optionally, leak test the manifold and the connections to the DSC. The DSC may be pressurized to no more than 15 psig for leak testing.

    CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

16. Evacuate the DSC to the pressure required by the Technical Specification for vacuum drying, and isolate the vacuum pump. The isolation valve should be as near to the DSC as practicable, with a pressure gauge on the DSC side of the valve. Prior to performing the vacuum hold for 30 minutes as required by the Technical Specification, the vacuum pump must be turned off; or if the pump is **not** turned off, provide a tee and valve (or other means) to open the line to atmosphere between the pump and the DSC isolation valve.

17. DELETED

18. If the Technical Specification is satisfied, i.e., if the pressure remains below the specified limit for the required duration with the pump isolated, continue to the next step. If not, repeat step 16.

19a. Purge air from the backfill manifold, open the isolation valve, and backfill the DSC cavity with helium to 16.5 to 18 psig and hold for 10 minutes.

19b. Reduce the DSC cavity pressure to atmospheric pressure, or slightly over.

20. If the quick connect fittings were removed for vacuum drying, remove the vacuum line adapters from the ports, and re-install the quick connect fittings using suitable pipe thread sealant.

    CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

21. Evacuate the DSC through the vent port quick connect fitting to a pressure of 100 mbar or less.

22. Backfill the DSC with helium to the pressure specified in the Technical Specifications, and disconnect the vacuum/backfill manifold from the DSC.

23. DELETED

24a. Weld the covers over the vent and drain ports, performing non-destructive examination as required by the Technical Specifications. The welds shall have at least two layers.

24b. Install a temporary test head fixture (or any other alternative means). Perform a leak test of the inner top cover to the DSC shell welds and siphon/vent cover welds in accordance with the Technical Specification limits. Verify that the personnel performing the leak test are qualified in accordance with SNT-TC-1A.

25. Place the outer top cover plate onto the DSC and verify correct rotational alignment of the cover and the DSC shell. Install the automated welding machine onto the outer top cover plate. As an option, the welding machine may be mounted onto the cover plate and then placed together on the DSC.

26. Complete the outer top cover welding and perform the non-destructive examinations as required by the Technical Specifications. The weld must be made in at least two layers.

27. Remove everything except the DSC from the transfer cask cavity: welding machine, protective covering from the transfer cask/DSC annulus, temporary shielding, etc., and drain the water from the transfer cask/DSC annulus.

28. Install the transfer cask lid and bolt it.

29. Evacuate the transfer cask cavity to below 100 mbar, and backfill the transfer cask annulus with helium in accordance with the Technical Specifications pressure tolerance and time limit.

    CAUTION: Monitor the applicable time limits of the Technical specifications for transfer cask annulus helium backfill.

A.8.1.1.4 Transfer Cask Downending and Transport to ISFSI

No change. See Section 8.1.1.4.

A.8.1.1.5 DSC Transfer to the HSM-H

No change. See Section 8.1.1.5.

CAUTION: Radiation dose rates are expected to be high at the vent and siphon port locations. Use proper ALARA practices (e.g., use of temporary shielding, appropriate positioning of personnel, etc.) to minimize personnel exposure.

12. Obtain a sample of the DSC atmosphere. Confirm acceptable hydrogen concentration and check for presence of fission gas indicative of degraded fuel cladding.

13. If degraded fuel is suspected, additional measures appropriate for the specific conditions are to be planned, reviewed, and implemented to minimize exposures to workers and radiological releases to the environment.

14. Verify that the boron content of the fill water conforms to the Technical Specifications. Fill the DSC with water from the fuel pool or equivalent source through the drain port with the vent port open. The vented cavity gas may include steam, water, and radioactive material, and should be routed accordingly. Monitor the vent pressure and regulate the water fill rate to ensure that the pressure does not exceed 15 psig.

15. Provide for continuous hydrogen monitoring of the DSC cavity atmosphere during all subsequent cutting operations to ensure that hydrogen concentration does not exceed 2.4%. Purge with helium as necessary to maintain the hydrogen concentration below this limit.

16. Provide suitable protection for the transfer cask during cutting operations.

17. Using a suitable method, such as mechanical cutting, remove the weld of the outer top cover plate to the DSC shell.

18. Remove the outer top cover plate.

19. Remove the weld of the inner top cover to the shell in the same manner as the outer cover plate. Remove the inner top cover. Do not remove the top shield plug at this time unless the removal is being done remotely in a dry transfer system.

20. Remove any remaining excess material on the inside shell surface by grinding.

21. Clean the transfer cask surface of dirt and any debris which may be on the transfer cask surface as a result of the weld removal operation.

22. Engage the yoke onto the trunnions, install eyebolts or other lifting attachment(s) into the top shield plug, and connect the rigging cables to the eyebolts/lifting attachment(s).

23. Verify that the lifting hooks of the yoke are properly positioned on the trunnions.

24. Lift the transfer cask just far enough to allow the weight of the transfer cask to be distributed onto the yoke lifting hooks. Verify that the lifting hooks are properly positioned on the trunnions.

Enclosure 4 to TN E-25747

Listing of Input/Output Computer Files Provided with this Application
(all files are Proprietary)
(all files are on one CD)

Discipline	Size	File Series (topics)	Number of Files
Thermal	(58.6 MB)	A001-kHe_CE16x16.inp A002-kHe_CE16x16.db A003-kHe_CE16x16.out A004-kHe_CE16x16.rth (Effective Conductivity of CE 16x16 Fuel)	A001 to A004 for a total of 4
Criticality	(600 kb)	B001-C16_D_2000_080.in B002-C16_D_2000_080.out (Bounding criticality run for CE 16x16 Fuel)	B001 to B002 for a total of 2

Enclosure 5 to TN E-25747

Compact disk containing the proprietary computer files listed in Enclosure 4

Non-Proprietary Version

Note: All of the computer files on the compact disk are proprietary; therefore no disk is included in this non-proprietary version of the amendment application.