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Attachment 4

Licensing Report for Seabrook Spent Fuel Pool and New Fuel Vault Analyses (Holtec International document HI-2114996, Revision 2, Non-Proprietary)

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LICENSING REPORT FOR SEABROOK SPENT FUEL POOL AND NEW FUEL VAULT ANALYSES

FOR

NextEra Energy Seabrook

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Revision 0: Original Issue

Revision 1: Editorial changes are made to address client's comments. All changes are denoted with revision bars.

Revision 2: All changes in Revision 1 have been accepted. Editorial changes are made to denote some proprietary information with shaded area. All new changes are denoted with revision bars.

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1. INTRODUCTION AND SUMMARY

This report documents the safety evaluation to address the potential degradation of neutron absorbers in the Region 1 and Region 2 spent fuel storage racks at the Seabrook Unit 1 nuclear power plant operated by NextEra Energy Seabrook, LLC [21].

- Region 1: These racks were originally designed with BORAL™ panels as the neutron absorber material in a flux-trap rack configuration. Ongoing coupon surveillance has revealed evidence of blistering and thinning/spalling of the aluminum clad on the BORAL™ panels. To account for these conditions, criticality calculations use a reduced B-10 areal density in the BORAL™, and assume a voided space on one side of each panel.
- Region 2: These racks were originally designed with BORAFLEX™ as the neutron absorber material in a flux-trap rack configuration. Due to the BORAFLEX™ degradation, future credit for BORAFLEX™ in these racks is not feasible. The criticality safety evaluations of the Region 2 racks are therefore performed without credit for BORAFLEX™.

In addition to the results of the criticality calculations, a qualitative evaluation of the thermal hydraulic impact of the neutron absorber degradation [22] is documented.

Under the degraded neutron absorber conditions, the evaluations qualify the following fuel loading configurations, with details documented in Section 4 of this report.

- Region 1: Storage of fresh and spent fuel assemblies in a checkerboard configuration of fresh fuel assemblies with a maximum nominal enrichment of 5.0 wt% ^{235}U and spent fuel assemblies with a minimum specified burnup as a function of the initial enrichment.
- Region 2:
  - Storage of spent fuel assemblies with specific burnup requirements as a function of initial enrichment between 1.5 wt% and 5.0 wt% ^{235}U, decay time, and presence of up to 2 RCCAs in the assemblies in an 2x2 cell array.
  - Storage of spent fuel assemblies in the Rows 1 and 2 on the periphery of Racks 3, 4 and 5 adjacent to the west side of pool wall (See Figure 4.5.7), which require unusual plant actions to reach the fuel and allow crediting higher periphery leakages for these locations.

The review of the thermal-hydraulic analyses of record and evaluation of the potential impact of changes in the physical condition of the BORAL™ (or BORAFLEX™) demonstrates that there are no potential adverse thermal-hydraulic impacts of degradation of these neutron absorbing materials.

Additionally, this report documents the fuel storage rack criticality calculations performed for the Seabrook Unit 1 New Fuel Vault (NFV) [23]. The calculations qualify the NFV to store up to 90 fresh Westinghouse 17x17 assemblies with enrichment up to a maximum of 5.0 wt% ^{235}U.

2. EFFECTS OF NEUTRON ABSORBER DEGRADATION ON SPENT FUEL POOL THERMAL-HYDRAULICS

2.1 INTRODUCTION

This Section provides an evaluation that qualitatively assesses the impact of the anticipated BORAL™ blistering phenomena on each of the pertinent considerations addressed in the Plant's thermal-hydraulic analysis of record. Specifically, the following areas of concern are addressed:

1. The effect of the displacement of water due to BORAL™ degradation on the bulk temperature of the spent fuel pool.
2. The effect of BORAL™ degradation in reducing flow in a spent fuel cell, to ensure that local thermal-hydraulic requirements are satisfied.
3. The effect of the presence or absence of the volumetric displacement of water due to BORAFLEX™ (used in the Region 2 spent fuel racks).
4. Expected thermal-hydraulic performance issues related to BORAL™ degradation in conjunction with items possibly in fuel assemblies, such as RCCAs.

2.2 EFFECT OF BORAL™ DEGRADATION ON BULK TEMPERATURES

2.2.1 Steady State Conditions

The steady state condition is the condition where the decay heat generation rate is equal to the heat rejection rate. The decay heat generation rate is the result of the ongoing radioactive decay of the isotopes in the spent fuel. As such it cannot be affected by the condition of the BORAL™. The heat rejection rate is a function of the design of the spent fuel pool cooling system and the temperature of the cooling water supplied to it, neither of which can be affected by the condition of the BORAL™. As these two terms are both unaffected by the condition of the BORAL™, it is apparent that the licensing-basis spent fuel pool bulk temperature cannot be affected by any BORAL™ degradation.

2.2.2 Time-to-Boil

The dimensions of the BORAL™ panels are 141" x 7.5" x 0.075", and the number of BORAL™-equipped rack cells is 576. The maximum BORAL™ blister thickness is 45-mils (0.045"). Conservatively assuming that there are four BORAL™ panels affixed to each cell, the theoretical maximum possible increase in the racks displaced volume is 475 gallons. This additional volume displaced by the blistered BORAL™ would reduce the pool water volume. This corresponds to a 0.09% reduction in pool water volume. The pool water thermal capacity is proportional to the water volume, so the thermal capacity is also reduced by 0.09%. The rate of change of the bulk temperature is inversely proportional to the thermal capacity, so the rate of change would increase

by 0.09% and the time-to-boil would decrease by 0.09%. It is apparent that the licensing-basis spent fuel pool time-to-boil analyses would only be negligibly affected by the theoretical maximum worst-case BORAL™ degradation.

2.3 EFFECT OF BORAL™ DEGRADATION ON LOCAL TEMPERATURES

BORAL™ panels are mounted on the outsides of the boxes that form the rack storage cells, meaning the panels are in the inter-cell water gaps. As the panels are outside of the storage cells, blistering and spalling of the BORAL™ surface could not reduce the flow area through the storage cells and the equivalent hydraulic diameter used in the local temperature analysis model could not be affected. Based on this observation, the licensing-basis spent fuel pool local temperature analysis is not affected by BORAL™ degradation.

2.4 EFFECT OF THE PRESENCE OR ABSENSE OF BORAFLEX™

If the BORAFLEX™ were absent, the volume of water in the spent fuel pool would increase. As described in Section 2.2.1 of this report, the normal condition bulk temperatures are steady-state values and cannot be affected by the volume of water. Also, as described in Section 2.2.2, the time-to-boil analyses would only be adversely affected if the volume of water in the pool were reduced. Thus, the absence of the BORAFLEX™ will not adversely affect the licensing-basis thermal-hydraulic analysis.

2.5 EFFECT OF BORAL™ DEGRADATION COMBINED WITH ITEMS IN FUEL ASSEMBLIES

Degradation of the BORAL™ could potentially release small amounts of the constituent materials of BORAL™, namely aluminum and boron carbide, into the spent fuel pool water. Boron carbide is an extremely inert material that will not react with any other material, and therefore poses no potential for adverse interactions with any items in the fuel assemblies. In the presence of water, aluminum rapidly passivates to form aluminum oxide, which is also extremely non-reactive and also poses no potential for adverse interactions with any items in the fuel assemblies.

BORAL™ is manufactured from small particles of boron carbide and aluminum, formed into flat sheets under high temperature and pressure. Any loss of materials from the BORAL™ panels would therefore be expected to result in very small particles that are much smaller than the flow passages in the fuel assemblies. Any small particles would be safely collected by the spent fuel pool cleanup system.

2.6 CONCLUSIONS

A review of the thermal-hydraulic analyses of record and evaluation of the potential impact of changes in the physical condition of the BORAL™ (or BORAFLEX™) has demonstrated that there

are no potential adverse thermal-hydraulic impacts of degradation of these neutron absorbing materials.

3. CRITICALITY EVALUATION OF NEW FUEL VAULT

3.1 INTRODUCTION

This Section documents the fuel storage rack criticality calculations performed for NextEra Energy for the Seabrook Unit 1 New Fuel Vault (NFV). The purpose of Section 3 of this report is to qualify the capability of the Seabrook Unit 1 NFV to store up to 90 fresh Westinghouse 17x17 assemblies with enrichment up to a maximum of 5.0 wt% ^{235}U.

The objective of the calculations is to demonstrate that the effective neutron multiplication factor (k_{eff}) in the NFV is less than or equal to 0.95 for the fully flooded condition with un-borated water and less than or equal to 0.98 for optimum moderation conditions, with the storage racks fully loaded with fuel of the highest anticipated reactivity. The maximum calculated reactivity includes a margin for uncertainty in reactivity calculations including manufacturing tolerances and is shown to be less than the regulatory limit with a 95% probability at a 95% confidence level.

3.2 METHODOLOGY

3.2.1 General Approach

The analysis is performed in a manner such that the results are below the regulatory limit with a 95% probability at a 95% confidence level. The calculations are performed using the statistical analysis approach with respect to the various calculation parameters. The approach considered for each parameter is discussed below.

3.2.2 Computer Codes and Cross Section Libraries

The principal method for the criticality analysis of the NFV is the use of the three-dimensional Monte Carlo code MCNP5-1.51 [2]. MCNP5 is a continuous energy three-dimensional Monte Carlo code developed at the Los Alamos National Laboratory. MCNP5 was selected because it has been used previously and verified for criticality analyses and has all of the necessary features for this analysis. In this analysis MCNP5 calculations used continuous energy cross-section data predominantly based on ENDF/B-V.

[redacted]

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. The MCNP5 criticality output contains a

great deal of useful information that may be used to determine the acceptability of the problem convergence. This information has been used in parametric studies to develop appropriate values for the aforementioned criticality parameters to be used in storage rack criticality calculations. [redacted] and the initial source was usually specified as uniform over the fueled regions (assemblies). Further, the output was reviewed to ensure that each calculation achieved acceptable convergence. These parameters represent an acceptable compromise between calculation precision and computational time.

3.2.3 Analysis Methods

3.2.3.1 Design Basis Fuel Assembly

Three types of 17x17 fuel assemblies (Standard design, Vantage 5 and RFA) have been used for Seabrook station. However, Standard design assemblies were only used during initial cycles of operation (Cycles 1-4), Vantage 5 assemblies were only used for Cycles 5-8 and further operation of these assembly types is not supposed. Therefore only RFA assemblies which are employed most recently are considered in this analysis. This way, the single set of parameters of RFA assemblies is used in all design basis calculations for NFV analysis.

3.2.3.2 Reactivity Effect of Water Temperature and Density

The Seabrook NFV is intended to be dry during all normal operation condition. However, the worst case accident, when the NFV is flooded with water is considered. The main effect of changes in the NFV water temperature is the impact of the difference in water density. Additionally there may be temperature-dependent cross section effects that need to be considered. To ensure that the appropriate temperature is used for each case, calculations at the lower end of the temperature range - 80.33 °F (300K) and at the higher end of the temperature range – 212 °F (373K) are performed. Note that one of the temperature adjustments, S (alpha, beta), is only available at fixed temperatures of 300K and 400K in MCNP5. Calculations are therefore performed at both temperatures for 5.0 wt% ^{235}U enrichment cases, and the temperature identified to result in higher reactivity is determined. The calculations are all performed with unborated water.

3.2.3.3 Fuel and Rack Uncertainties

In the calculation of the final k_{eff} for Seabrook NFV, the effect of manufacturing tolerances on reactivity must be included. MCNP5 was used to perform these calculations. As allowed in [3], the sensitivity study approaches is employed to calculate the tolerance effects. The evaluations include tolerances of the fuel dimensions and tolerances of the racks dimensions. The reference condition is the condition with nominal dimensions and properties. To determine the Δk associated with a specific manufacturing tolerance, the reactivity calculated for the reference condition is compared to the reactivity from a calculation with the tolerance included. The uncertainty associated with each individual calculation is statistically combined and added to the k_{calc} calculation according to the following equation [6]:

$$\Delta k_{calc} = (k_{calc2} - k_{calc1}) + 2 * \sqrt{(\sigma_2^2 + \sigma_1^2)}$$

All of the Δk values from the various tolerances are statistically combined (square root of the sum of the squares) to determine the final reactivity allowance for manufacturing tolerances. In some cases it is not obvious whether an increase or decrease of the parameter will lead to an increase in reactivity. In these cases, the reactivity effect of both increase and decrease of the parameter are calculated, and the maximum value of reactivity effect is used when calculating the statistical combination. The fuel and rack tolerances included in this analysis for the NFV are described below:

Fuel Tolerances

- Increased Fuel Density: [redacted]
- Fuel Rod Cladding Outside Diameter: [redacted]
- Fuel Rod Pitch: [redacted]
- Fuel Rod Cladding Inside Diameter: [redacted]
- Fuel Pellet Outside Diameter: [redacted]
- Guide Tube Outside Diameter: [redacted]
- Guide Tube Inside Diameter: [redacted]
- Increased Fuel Enrichment: +0.05 wt% ^{235}U

Rack Tolerances

- Cell Inside Diameter: [redacted]
- Box Wall Thickness: [redacted]

The maximum enrichment value in the Seabrook Unit 1 Technical Specifications is 5.0 wt% ^{235}U. Therefore, NextEra Energy designs (and the fuel vendor provides) a maximum enrichment in the fresh fuel that will guarantee that no fuel assembly could exceed the Technical Specification limit with all uncertainties applied. Therefore, the highest possible enrichment of 5.0 wt% ^{235}U is used in all calculations.

3.2.3.4 Eccentric Fuel Positioning

The eccentric fuel positioning case should be included in the tolerance calculations. The MCNP5 model consists of the following eccentric fuel positioning case in NFV analyses:

- All the fuel positioned at the closest approach with the storage cell to the center point of the whole NFV model.
- All the fuel positioned within the storage cell away from the center point of the whole NFV model.
- In each 2x2 array, all the fuel positioned at the closest approach with the storage cell to the center point of the 2x2 array.
- In each 2x2 array, all the fuel positioned within the storage cell away from the center point of the 2x2 array.

The maximum positive reactivity effect among these cases is used when calculating the statistical combination of the tolerance.

3.2.3.5 Rack Deformation

Rack deformation is not considered in this calculation due to that it is not considered a credible accident scenario. See Section 3.6.5.

3.2.3.6 Calculation of Maximum k_{eff}

The calculated k_{eff} are determined for fully flooded and optimum moderation conditions. The maximum k_{eff} for each case is therefore determined from the MCNP5 calculated k_{eff}, the calculation bias, and the applicable uncertainties and tolerances (bias uncertainty, calculation uncertainty, fuel and rack tolerances, and eccentric fuel positioning) using the following formula:

$$\text{Max } k_{eff} = \text{Calculated } k_{eff} + \text{biases} + [\textstyle\sum_i (\text{Uncertainty})^2]^{1/2}$$

In the geometric models used for the calculations, each fuel rod and its cladding were described explicitly.

The regulatory limit for NFV analysis is that at the optimum moderation condition, a maximum k_{eff} should be less than 0.98 at the 95/95 level; while at the full flooded condition with un-borated water, a maximum k_{eff} should be less than 0.95 at the 95/95 level. The target k_{eff} used in this analysis retain a 0.01 delta-k margin to the regulatory limit.

3.2.3.7 Other Accident Conditions

The consideration of two accident conditions: fully flooded and optimum moderation have been included in the analysis of the NFV. The double contingency principal of ANS-8.1/N16.1-1975 [4] specifies that it shall require at least two unlikely, independent and concurrent events to produce a criticality accident. This principle precludes the necessity of considering the simultaneous occurrence of multiple accident conditions. No additional calculations are required for accident conditions.

3.2.3.8 Effect of the IFBA Rods

Obviously the presence of the IFBA rods in the fresh fuel assemblies reduces the reactivity due to the integrated neutron absorber. However, this absorber may change the behavior of the fuel assemblies in the low temperature area. To ensure that the fresh fuel assembly without IFBA rods is bounding the criticality calculations are performed and discussed in Section 3.6.7.

3.2.3.9 Effect of the NFV Concrete Wall Thickness

In the criticality analysis the wall thickness of 40 inches is assumed. The additional calculations are performed with a concrete thickness of 12 inches. See Section 3.6.8.

3.2.3.10 Effect of the Non-Fuel Hardware

The non-fuel hardware such as Thimble Plugs (TP), Rod Cluster Control Assemblies (RCCAs) and non-activated sources are acceptable to storage with the fuel assemblies. Non-fuel hardware is

inserted in the guide tubes of the assemblies. For pure water, the reactivity of any fuel assembly with inserts is bounded by (i.e. lower than) the reactivity of the same assembly without the insert. This is due to the fact that the insert reduces the amount of moderator in the assembly, while the amount of fissile material remains unchanged.

Therefore, from a criticality safety perspective, the presence of inserts does not impact the analysis.

3.3 ACCEPTANCE CRITERIA

The PWR storage racks for Seabrook Unit 1 NFV are designed in accordance with the applicable codes and standards listed below. The objective of this analysis is to show that the effective neutron multiplication factor, k_{eff}, is less than or equal to the target k_{eff} of 0.97 for the NFV at optimum moderation conditions (low density water) and less than or equal to the target k_{eff} of 0.94 with the NFV vault flooded with pure water with a density of 1.0 g/cm^3, when the NFV is fully loaded with fuel of the highest anticipated reactivity. The maximum calculated reactivity includes a margin for uncertainty in reactivity calculations including manufacturing tolerances and is shown to be less than the limit with a 95% probability at a 95% confidence level [1].

Applicable codes, standard, and regulations or pertinent sections thereof, include the following:

- Code of Federal Regulations, Title 10, Part 50, Appendix A, General Design Criterion 62, "Prevention of Criticality in Fuel Storage and Handling."
- USNRC Standard Review Plan, NUREG-0800, Section 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling, Rev. 3 – March 2007.
- L. Kopp, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," NRC Memorandum from L. Kopp to T. Collins, August 19, 1998.
- USNRC Regulatory Guide 1.13, Spent Fuel Storage Facility Design Basis, Rev. 2, March 2007.
- ANSI ANS-8.17-2004, Criticality Safety Criteria for the Handling, Storage and Transportation of LWR Fuel outside Reactors.
- Code of Federal Regulations, Title 10, Part 50, Section 68, "Criticality Accident Requirements"
- ANSI/ANS-8.1-1998 (R2007), "Nuclear Criticality Safety in Operations with Fissionable Materials outside Reactors."

3.4 ASSUMPTIONS

To assure the true reactivity will always be less than the calculated reactivity, the following conservative design criteria and assumptions were employed:

1) A fuel pellet stack density assumed to be equal to the pellet density, and is conservatively modeled as a solid right cylinder over the entire active length, neglecting dishing and chamfering;

2) Neutron absorption in minor structural members is neglected, i.e., spacer grids and mixing vanes are replaced by water.

3) The concrete wall thickness of 40 inches is assumed;

4) The maximum planar average enrichment is assumed to be 5.0 wt% ^{235}U;

5) [redacted]

3.5 INPUT DATA

3.5.1 Fuel Assembly Specification

The NFV is designed to accommodate the RFA 17x17 Westinghouse fuel assembly. The design specification for RFA fuel assembly is presented in Table 3.5.1.

3.5.2 Burnable Absorbers Specification

There is the potential for burnable absorbers to be located in the assembly. The Seabrook Unit 1 fuel makes use of burnable poison rod assemblies (BPRAs) of B_2O_3 and integrated fuel burnable absorber (IFBA) rods with a thin coating of ZrB_2 on the UO_2 pellet. The BPRAs were only utilized in Cycle 1 and then replaced with IFBA rods for the remaining cycles, therefore only IFBA rods are considered in the calculations of this section. The design specifications for the IFBA rods are given in Table 3.5.1.

3.5.3 New Fuel Vault and Storage Rack Specification

The NFV and storage cell characteristics that were used in the criticality analysis are summarized in Table 3.5.2.

The NFV MCNP5 model is a finite model that consists of a storage array of five cells (East-West) by eighteen cells (South-North) with the dimensions given in Table 3.5.2. The model includes the gaps between the storage racks and the walls. The concrete walls have some variation in the thickness (three walls at 12 inches and one at a maximum of 72 inches). In the model, the concrete wall is assumed to be 40 inches thick. Above the fuel is a 12 inch reflector with the water density of 1.0 g/cm^3 and the same temperature as within the fuel region and below the fuel is the concrete floor

with thickness of 40 inches. The model containing the 17 x 17 fuel assembly, as drawn by the two-dimensional plotter, is shown in Figures 3.5.1 and 3.5.2. The calculations are described in Section 3.6.

3.6 ANALYSIS

This section describes the calculations that were used to determine that the storage racks meet the acceptance criteria as discussed in Section 3.3.

Unless otherwise stated, all calculations assumed nominal characteristics for the fuel and the fuel storage cell dimensions. The effect of the fuel tolerances is accounted for with a reactivity adjustment as discussed below.

3.6.1 Design Basis Fuel Assembly

The RFA 17 x 17 PWR fuel assembly used in the analysis is described in Table 3.5.1. It was evaluated at 5.0 wt% ^{235}U enrichment and conservatively modeled without spacer grids or other non-fuel hardware.

3.6.2 Temperature and Water Density Effects

Water temperature effects on reactivity in the NFV have been evaluated for the fuel with 5.0 wt% ^{235}U enrichment at 80.33 °F (300K) and 212 °F (373K). The results presented in Table 3.6.1 show that the water temperature coefficient of reactivity is positive, i.e. the higher temperature of 212 °F results in a higher reactivity. Based on the results, it was also determined that the 100% moderator condition, i.e. 1.0 g/cm^3, represent the maximum reactivity condition and 6% moderator condition, i.e., 0.06 g/cm^3, represent optimum hypothetical low density moderation (i.e., fog or foam). Therefore, all the following cases are performed with 100% and 6% moderator density at temperature of 212 °F.

3.6.3 Uncertainties Due to Fuel and Rack Tolerances

In the calculation of the final k_{eff}, the effect of manufacturing tolerances on reactivity is included as discussed in Section 3.2.3.3. The evaluations include tolerances of the fuel and rack dimensions. These tolerances are provided in Table 3.5.1. The reference condition is the condition with nominal dimensions and properties. To determine the Δk associated with a specific manufacturing tolerance, the k_{eff} calculated for the reference condition is compared to the k_{eff} from a calculation with the tolerance included. The results are presented in Table 3.6.2.

3.6.4 Eccentric Fuel Positioning

Four different eccentric fuel positioning models discussed in Section 3.2.3.4 are analyzed by the MCNP5 code. The reactivity effect of eccentric fuel positioning is included in the tolerance calculations as shown in Table 3.6.2.

3.6.5 Rack Deformation

Rack deformation is not considered in this calculation due to that it is not considered a credible accident scenario. The k_{eff} value is below 0.65 (see Table 3.6.1) for dry conditions, therefore rack deformation could not cause the reactivity of the system to exceed the regulatory limit. Note that considering rack deformation under moderated conditions would fall under the double contingency principle, as two accident scenarios would have to take place (moderator filling the NFV and rack deformation occurring).

3.6.6 Calculation of Maximum k_{eff}

The maximum k_{eff} values, based on the formula in Section 3.2.3.6, were calculated for the fuel assembly described in Table 3.5.1 with enrichment of 5.0 wt% ^{235}U. The results presented in Table 3.6.3 show the maximum k_{eff} values for different moderation conditions and confirm that k_{eff} values are well below the target k_{eff} of 0.97 at optimum moderation and the target k_{eff} of 0.94 when fully flooded with un-borated water at a 95% probability and at a 95% confidence level.

3.6.7 Effect of the IFBA Rods

The criticality calculations to confirm that the presence of the IFBA rods in the fresh fuel assemblies reduces the reactivity are performed. The results presented in Table 3.6.4 show that the reference case without IFBA rods has a maximum k_{eff} value. The minimum difference between the no IFBA case and 16 IFBA rods case is about 0.011, which is sufficient margin to cover any tolerances in the IFBA rod. Therefore, all fuel assemblies with IFBA rods are bounded by the reference case without IFBA and are acceptable for storage in the Seabrook NFV. Note also that for the reactivity calculation a longer IFBA length (current cycle) is bounded by the shorter length.

3.6.8 Effect of the NFV Concrete Wall Thickness

As discussed in Section 3.2.3.9, the additional calculations with a concrete thickness of 12 inches are performed. The results presented in Table 3.6.5 show the reactivity effect of the NFV concrete wall thickness is statistically insignificant. Therefore, assumed reference NFV concrete thickness of 40 inches is acceptable.

3.7 CONCLUSIONS

Section 3 of this report documents the criticality analysis for the storage of 17 x 17 PWR fresh fuel assemblies with an initial planar average enrichment of up to 5.0 wt% ^{235}U in the NFV at the Seabrook Unit 1 Nuclear Power Plant. Calculations were made with the continuous energy MCNP5-1.51 code package, a three-dimensional Monte Carlo analytical technique, with fresh fuel assemblies enriched to 5.0 wt% ^{235}U without IFBA rods. These calculations were made for various moderator densities, and the results shown in Figure 3.6.1 indicate that the peak reactivity (full moderation) occurs at 100% moderator density and the optimum hypothetical low density moderation (i.e., fog or foam) occurs at 6% moderator density. The effective neutron multiplication factor (k_{eff}) for the NFV is less than 0.97 for the optimum moderation condition and less than 0.94

for the fully flooded with un-borated water condition. The maximum calculated reactivity includes a margin for uncertainty in reactivity calculations with a 95% probability at a 95% confidence level.

Table 3.5.1
PWR Fuel Assembly Specifications

Fuel Assembly Type	**17x17 RFA**
Fuel Rod Data	
Fuel Pellet Outside Diameter, in.	0.3225
Cladding Inside Diameter, in.	0.3290
Cladding Outside Diameter, in.	0.3740
Cladding Material	ZIRLO
Maximum Pellet Density, g/cc	10.505
Maximum Enrichment, wt% ^{235}U	5.0
ZrB_2 Coating Loading (mg ^{10}B/inch)	2.355
ZrB_2 Coating Thickness[1], in.	0.000657
ZrB_2 Coating Length, in.	120[2]
Fuel Assembly Data	
Fuel Rod Array	17x17
Number of Fuel Rods	264
Fuel Rod Pitch, in.	0.496
Fuel Assembly Width, in.	8.426
Fuel Assembly Length, in.	159.975
Active Fuel Length, in.	144
Bottom of Active Fuel Length to Bottom of Assembly, in.	3.278
Guide/Instrument Tube Data	
Number of Guide Thimbles	24
Number of Instrument Tubes	1
Guide Thimble Upper Region Inside Diameter, in.	0.442
Guide Thimble Upper Region Outside Diameter, in.	0.482
Guide Thimble Dashpot Region Inside Diameter, in.	0.3970
Guide Thimble Dashpot Region Outside Diameter, in.	0.4390
Instrument Tube Inside Diameter, in.	0.442
Instrument Tube Outside Diameter, in.	0.482
Guide/Instrument Tube Material	ZIRLO

[1] The coating thickness was not available. The values provided are calculated.
[2] For Cycle 15, the coating length has been increased from 120 to 122 inches.

Table 3.5.2
New Fuel Vault Storage Racks Specification

Parameter	Value
Storage Cells Array	5 (East-West) x 18 (South-North)
Storage Cell Inside Dimension, in.	9.00
Storage Cell Wall Thickness, in.	0.093
Storage Cell Pitch[3], in.	21 or 33
Storage Cell Material	SS304
Cell Array Width, in.	125.1875 (East-West) x 373 (South-North)
Cell Array to Wall Distance North Face, in.	4
Cell Array to Wall Distance South Face, in.	4
Cell Array to Wall Distance East Face, in.	3.375
Cell Array to Wall Distance West Face, in.	3.4375
Concrete Wall Thickness, in.	12 - 72

[3] The cell pitch is 21 inches center to center between the cells in the (South-North) 18-cell array direction. The cell pitch for the (East-West) 5-cell array direction is 33inches center to center between the 2nd and 3rd and between the 3rd and 4th cell, and 21inches center to center between the 1st and 2nd and between the 4th and 5th cell.

Table 3.6.1

Summary of the MCNP5 NFV Calculations for Different Water Density and Temperature - 5.0 wt% ^{235}U

% Moderator Density	80.33 °F (Reference)	212 °F	
	Calculated k_{calc}	Calculated k_{calc}	Delta k_{calc}
0	0.6263	0.6469	0.0206
3	0.8410	0.8607	0.0197
4	0.8809	0.9027	0.0218
5	0.8981	0.9254	0.0273
6	0.9022	**0.9330**	0.0308
7	0.8950	0.9295	0.0345
8	0.8809	0.9193	0.0384
9	0.8603	0.9034	0.0431
10	0.8396	0.8850	0.0454
15	0.7393	0.7890	0.0497
20	0.6704	0.7170	0.0466
30	0.6081	0.6491	0.0410
60	0.7094	0.7309	0.0215
90	0.8603	0.8736	0.0133
95	0.8828	0.8949	0.0121
100	0.9043	**0.9151**	0.0108

Table 3.6.2
Results of the NFV Tolerance Calculations - 5.0 wt% ^{235}U

Calculation Description	6 % Moderator Density			100% Moderator Density		
	k_{calc}	σ	Delta k_{calc}	k_{calc}	σ	Delta k_{calc}
Reference keff	0.9330	0.0005	n/a	0.9151	0.0005	n/a
Pellet Density max	0.9342	0.0005	0.0026	0.9155	0.0005	0.0018
Clad OD max	0.9330	0.0005	0.0014	0.9136	0.0005	-0.0029
Clad OD min	0.9342	0.0005	0.0026	0.9164	0.0006	0.0029
Pin Pitch max	0.9334	0.0005	0.0018	0.9158	0.0006	0.0023
Pin Pitch min	0.9326	0.0005	-0.0018	0.9145	0.0005	-0.0020
Clad ID max	0.9328	0.0005	-0.0016	0.9152	0.0006	0.0017
Clad ID min	0.9337	0.0005	0.0021	0.9153	0.0006	0.0018
Pellet OD max	0.9341	0.0005	0.0025	0.9153	0.0005	0.0016
Pellet OD min	0.9326	0.0004	-0.0017	0.9149	0.0006	-0.0018
GT OD max	0.9323	0.0005	-0.0021	0.9149	0.0006	-0.0018
GT OD min	0.9329	0.0005	-0.0015	0.9162	0.0005	0.0025
GT ID max	0.9340	0.0005	0.0024	0.9152	0.0005	0.0015
GT ID min	0.9324	0.0005	-0.0020	0.9154	0.0005	0.0017
Eccentric Position #1	0.9359	0.0005	0.0043	0.9187	0.0006	0.0052
Eccentric Position #2	0.9307	0.0004	-0.0036	0.9182	0.0006	0.0047
Eccentric Position #3	0.9322	0.0005	-0.0022	0.9188	0.0005	0.0051
Eccentric Position #4	0.9352	0.0005	0.0036	0.9181	0.0006	0.0046
Cell ID max	0.9324	0.0005	-0.0020	0.9155	0.0006	0.0020
Cell ID min	0.9333	0.0005	0.0017	0.9148	0.0006	-0.0019
Wall Thk max	0.9215	0.0005	-0.0129	0.9126	0.0005	-0.0039
Wall Thk min	0.9446	0.0005	0.0130	0.9180	0.0006	0.0045
Square Root Sum of the Squares			0.0151			0.0091
2 Sigma (max of all cases)			0.0010			0.0012

Note: The maximum positive value of the tolerance effect for each case was used.

Table 3.6.3
Results of the NFV MCNP5 Calculations

Parameter	Value	
Enrichment, wt%	5.0%	5.0%
Moderator Density	6.0%	100.0%
Uncertainties:		
MCNP5 Code Bias Uncertainty	0.0085	0.0085
MCNP5 Calculation Statistics (95%/95%, 2σ)	0.0010	0.0012
Calculated Tolerances	0.0151	0.0091
Statistical Combination of Uncertainties	0.0173	0.0125
Calculated MCNP5 k_{eff}	0.9330	0.9151
MCNP5 Code Bias	0.0043	0.0043
Maximum k_{eff}	0.9546	0.9319
Target k_{eff}	0.9700	0.9400
Regulatory Limit	0.9800	0.9500

Table 3.6.4
Results of the IFBA Calculations

Calculation Description	6.0 % Moderator Density		100% Moderator Density	
	k_{calc}	σ	k_{calc}	σ
	212 °F			
Reference (No IFBA)	0.9330	0.0005	0.9151	0.0005
16 IFBAs	0.9215	0.0005	0.8917	0.0006
32 IFBAs	0.9062	0.0005	0.8793	0.0006
48 IFBAs	0.8902	0.0005	0.8723	0.0006
64 IFBAs	0.8794	0.0005	0.8694	0.0006
80 IFBAs	0.8633	0.0004	0.8667	0.0005
104 IFBAs	0.8490	0.0005	0.8634	0.0006
128 IFBAs	0.8155	0.0005	0.8607	0.0005
156 IFBAs	0.7901	0.0004	0.8597	0.0006
	80.33 °F			
Reference (No IFBA)	0.9022	0.0005	0.9043	0.0005
16 IFBAs	0.8911	0.0005	0.8819	0.0006
32 IFBAs	0.8784	0.0005	0.8683	0.0005
48 IFBAs	0.8624	0.0005	0.8613	0.0006
64 IFBAs	0.8526	0.0005	0.8585	0.0005
80 IFBAs	0.8376	0.0004	0.8562	0.0005
104 IFBAs	0.8243	0.0005	0.8520	0.0006
128 IFBAs	0.7897	0.0004	0.8503	0.0006
156 IFBAs	0.7660	0.0005	0.8485	0.0006

Table 3.6.5
Results of the NFV Calculations for Different Wall Thickness - 5.0 wt% ^{235}U

Calculation Description	**k_{calc}**	**σ**	**Delta k_{calc}**
	6 % Moderator Density		
40" (Reference)	0.9330	0.0005	n/a
12"	0.9329	0.0005	0
	100% Moderator Density		
40" (Reference)	0.9151	0.0005	n/a
12"	0.9145	0.0006	0

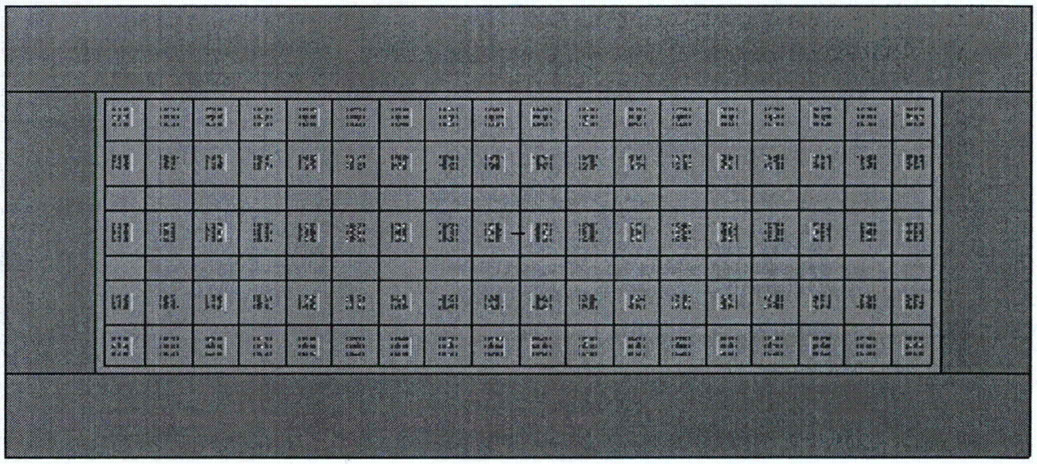


Figure 3.5.1
A Two Dimensional Representation of the NFV Model (Radial Section)

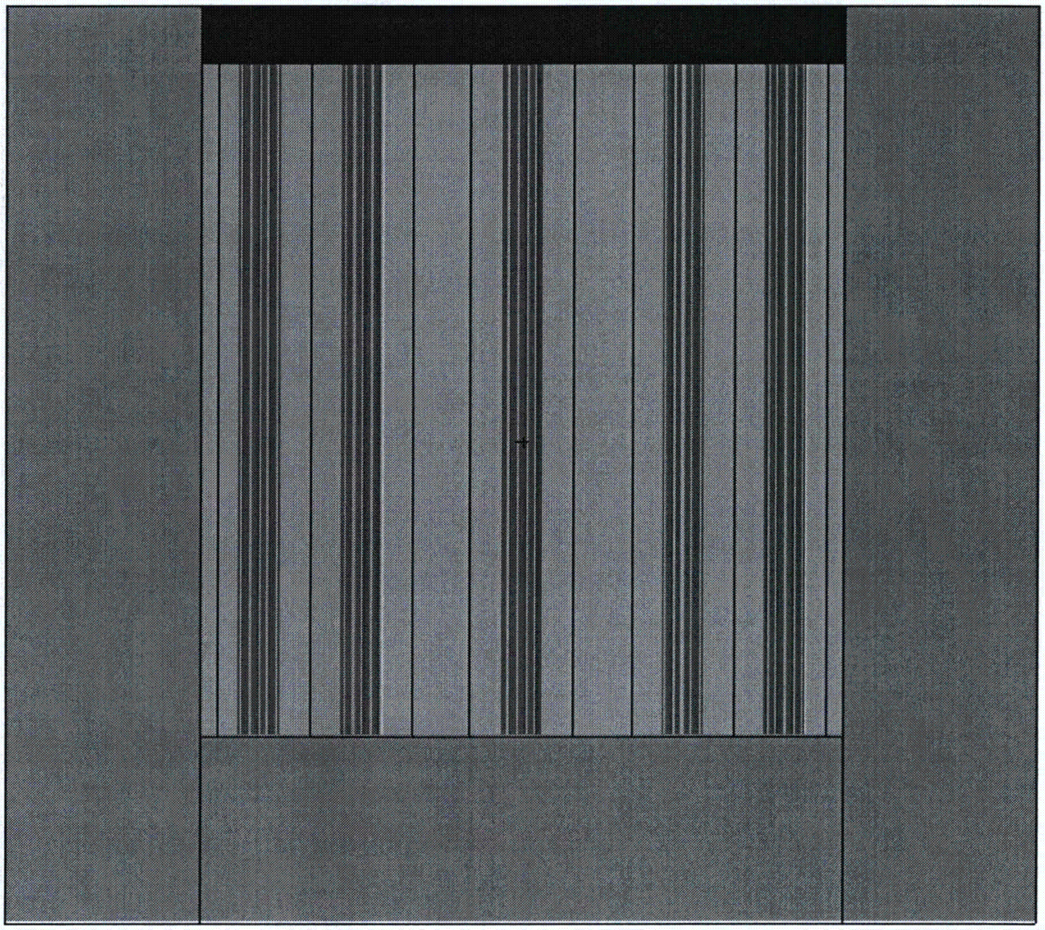
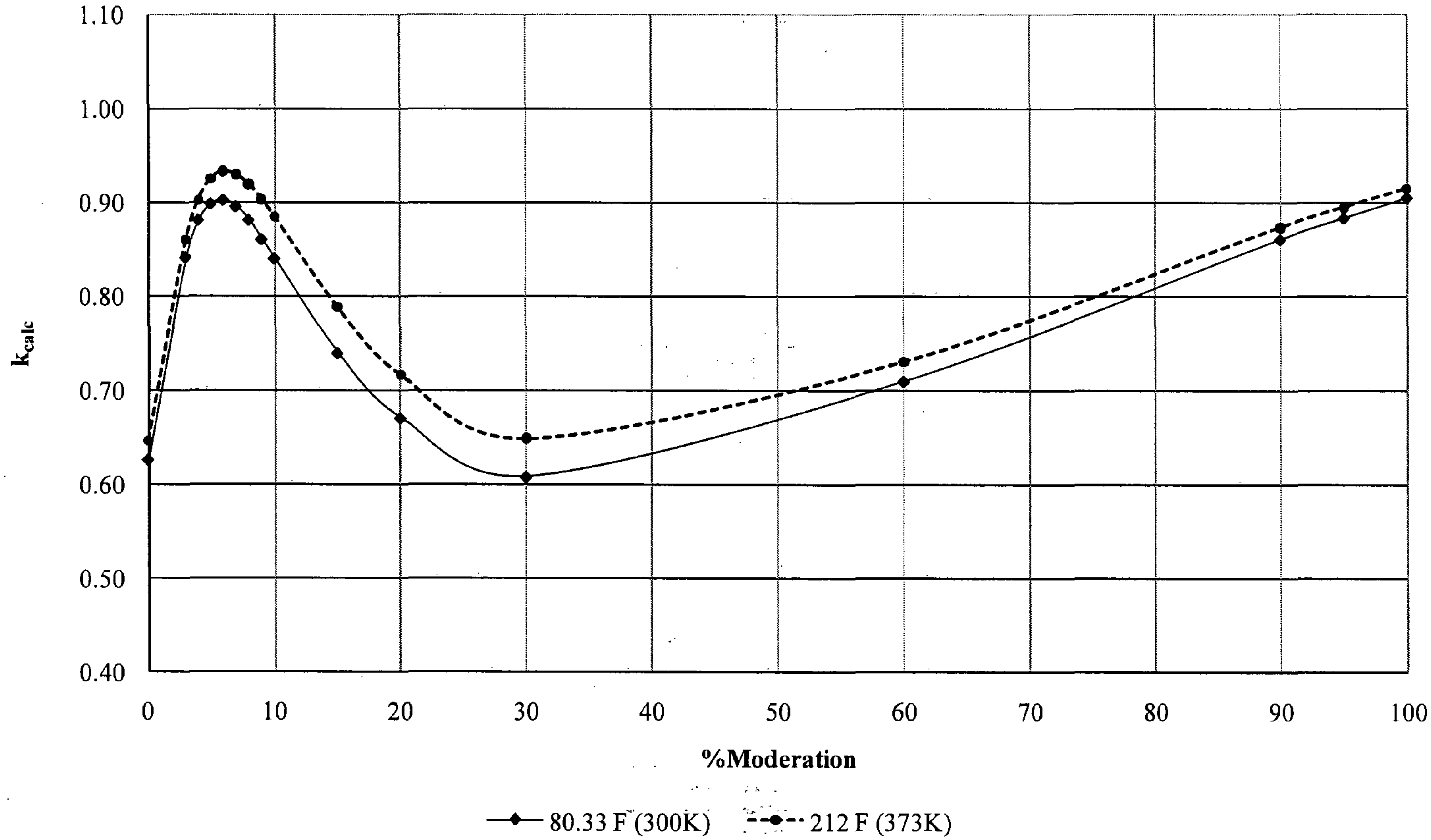


Figure 3.5.2
A Two Dimensional Representation of the NFV Model (Axial Section)

Figure 3.6.1
New Fuel Vault Reactivity for 5.0 wt% Fuel at Different Moderation Condition



4. CRITICALITY EVALUATION OF SPENT FUEL POOL

4.1 INTRODUCTION

This chapter documents the criticality safety evaluation for the storage of PWR fresh and spent nuclear fuel in Region 1 & 2 spent fuel storage racks at the Seabrook nuclear power plant operated by NextEra Energy.

The Seabrook SFP (Spent Fuel Pool) has two separate rack designs (BORAL™ and BORAFLEX™) which are designated as Region 1 and Region 2 respectively. These designations do not refer to the rack geometry as both rack designs are of the flux-trap style. Region 1 SFRs (Spent Fuel Racks) have six modules with BORAL™ as the credited neutron absorber with space for 576 fuel assemblies; Region 2 SFRs contain six modules with a non-credited BORAFLEX™ absorber that allow storage of 660 fuel assemblies. RCCAs (Rod Cluster Control Assemblies) have been evaluated and may be credited for neutron absorption in selected fuel assemblies in Region 2. The maximum pool capacity is 1236 assemblies.

Criticality control in the SFP relies on the following:

- For Region 1 racks:
  - Fixed Neutron Absorbers
    - BORAL™. The BORAL™ areal density is taken as lower limit value.
  - Administrative controls
    - Fuel Burnup as a function of initial enrichment.
  - Soluble boron for normal and accident conditions in accordance with 10CFR50.68(4)(b).

- For Region 2 racks:
  - Peripheral leakage (ONLY for the fuel in Rows 1 and 2 on the periphery of the Region 2 racks adjacent to the pool wall, i.e., the periphery of Racks 3, 4, and 5 adjacent to the west side of the pool shown in Figure 4.5.5, see Section 4.6.11.3.2).
  - Administrative controls
    - Fuel Burnup as a function of initial enrichment.
    - Cooling time of fuel assemblies.
    - RCCAs in guide tubes for selected patterns.
  - Soluble boron for normal and accident conditions in accordance with 10CFR50.68(4)(b)

Criticality control in the SFP does NOT rely on

- Radial neutron leakages, i.e. all configurations are considered radially infinite, except for the evaluation of the single assembly in water (see Sections 4.6.11.3.1 and 4.6.12.2) and the

assemblies stored on the periphery of the Region 2 racks adjacent to the pool wall (see Section 4.6.11.3.2).

- BORAFLEX™ in the Region 2 racks, i.e., it is assumed for this analysis that the B4C in the BORAFLEX™ is not credited for neutron absorption.

The criticality calculations qualify fresh and spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U in the following storage rack configurations hereby denoted by Pattern names:

- **Pattern A:** Region 1 storage rack 2x2 array with a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, and spent fuel assemblies with an initial enrichment of 1.5 to 5.0 wt% ^{235}U. No credit for cooling time. All four cells contain BORAL™ panels in each side of the cells. A BORAL™ areal density of 0.015 gm/cm^2 is considered.
- **Pattern B:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, with any two of the four cells containing RCCAs in the fuel assemblies, and the consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. No credit for BORAFLEX™ panels. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.
- **Pattern C:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, with any one of the four cells containing RCCAs in the fuel assemblies, and the consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. No credit for BORAFLEX™ panels. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.
- **Pattern D:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, without any RCCAs in the fuel assemblies, and the consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. No credit for BORAFLEX™ panels. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.

The spent fuel assemblies stored on the periphery of the Region 2 rack adjacent to the pool wall are also qualified by taking credit of the periphery leakages for these locations.

Additionally, the fuel rod storage basket is qualified for all locations that are qualified for any fresh or spent fuel in above cases.

4.2 METHODOLOGY

4.2.1 General Approach

Typically, in order to show that the results of the analyses are below the regulatory limit with a 95% probability at a 95% confidence level, independent uncertainties are considered by adding a statistical combination of their reactivity effects (square root of the sum of squares) to calculations performed at nominal conditions. However, usually only a few tolerances have a large effect, while most of them have an effect that is only of the order of the typical statistical

uncertainties of the reactivity. Modeling each of these small effect tolerance requires significant effort so a conservative method has been devised using a modified limit value approach. This modified approach utilizes mostly nominal parameters in design basis calculations but for each design basis case two additional calculations are performed which provides an overall conservative result. For fuel tolerances, a single calculation is conducted where the four most dominating parameters are assumed to be at the limiting condition. Likewise for rack tolerances, a single calculation is performed where the two most dominating parameters are assumed to be at the limiting condition. For each of those cases, the reactivity difference to the corresponding nominal case would be calculated, and then those two uncertainties would be statistically combined with the other uncertainties of the design basis calculation. The conservatism of this approach is large enough to allow neglecting the effect of some minor tolerances or uncertainties. To show that this approach is in fact more conservative, a comparison of this approach is performed with the approach using the statistical combination for a representative number of cases covering all aspects of the fuel and storage systems.

4.2.2 Computer Codes and Cross Section Libraries

4.2.2.1 MCNP5

MCNP5 Version 1.51 [2] is used for the criticality analyses. MCNP5 calculations use continuous energy cross-section data predominantly based on ENDF/B-V and ENDF/B-VI [2]. [redacted]

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. [redacted] The initial source is specified as uniform over the fueled regions (assemblies) and the source distribution was confirmed to converge.

4.2.2.1.1 MCNP5 Validation

4.2.2.1.1.1 Actinides

As discussed in Section 3.3.2, benchmarking of MCNP5 for criticality calculations is documented in [5].

[redacted]

4.2.2.1.1.2 Fission Products

Little relevant critical experiments are publicly available for fission products. The uncertainty in the reactivity worth of those isotopes is therefore determined based on consideration of uncertainties of cross sections of fission products documented in [12]. The overall uncertainty is derived from the uncertainty associated with each individual isotope's cross section for lumped fission products (LFPs) and all the other fission products (FPs) separately. [redacted]

Also note that recent studies [13] indicate that the total cross section uncertainty for 16 prominent fission products is only about 1% (one standard deviation), i.e. 2% at 95% probability at a 95% confidence level [redacted]. This value is much higher, and presents a margin that may be reduced in the future based on additional information or evaluations.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

These two values are then statistically combined with the other uncertainties in the determination of the maximum k_{eff} for those cases where fuel assembly burnup is credited.

Area of Applicability: All conditions analyzed here have neutron spectra in the thermal energy range and the fission products are predominantly thermal absorbers. Additionally, fission processes are affected by the resonance integrals of the absorbers. The fission product cross section uncertainty is evaluated for the thermal neutron energy range and the resonance integral. The uncertainties are therefore directly applicable to the calculations performed here.

4.2.2.2 CASMO-4

Fuel depletion analyses during core operation were performed with CASMO-4 (using the 70-group cross-section library), a two-dimensional multigroup transport theory code based on the Method of Characteristics [8]. Note that CASMO-4 is not used for any criticality calculations, i.e. to calculate a k_{eff} or k_{inf} value. A validation for CASMO-4 to calculate reactivities is therefore not required here, but an uncertainty in the spent fuel isotopic composition is considered (see below).

4.2.2.2.1 Uncertainty in the Isotopic Content of Spent Fuel

To account for the uncertainty in the depletion calculations performed in CASMO, a 5% depletion uncertainty factor as described in [3, 10] is used.

The uncertainty is applied by multiplying it with the reactivity difference (at 95%/95%) between the MCNP5 calculation with spent fuel and a corresponding MCNP5 calculation with fresh fuel:

$$\text{Uncertainty}_{\text{Isotopics}} = [(k_{calc\text{-}1} - k_{calc\text{-}2}) + 2 * \sqrt{(\sigma_{calc\text{-}1}^2 + \sigma_{calc\text{-}2}^2)}\ ] * 0.05$$

With

$k_{calc\text{-}1} = k_{calc}$ with fresh fuel
$k_{calc\text{-}2} = k_{calc}$ with spent fuel
$\sigma_{calc\text{-}1}$ = Standard Deviation of $k_{calc\text{-}1}$
$\sigma_{calc\text{-}2}$ = Standard Deviation of $k_{calc\text{-}2}$

This value is then statistically combined with the other uncertainties in the determination of the maximum k_{eff} where fuel assembly burnup is credited.

The value of 5% depletion uncertainty is discussed in [3, 10] in the direct context of spent fuel criticality calculation, and is therefore directly applicable to the calculations performed here.

4.2.3 Analysis Methods

4.2.3.1 Design Basis Fuel Assembly

The Seabrook SFP contains three types of Westinghouse 17x17 fuel assemblies: the Standard design, Vantage 5 and RFA. The goal is to find a single type of fuel assembly that is limiting under all conditions. This way, this single set of parameters can be used in all design basis calculations, and it is not necessary to perform some design basis calculations with different sets of parameters, or to consider interfaces between areas with different fuel types. To determine this limiting set, calculations are performed for all cases, and for representative burnup and enrichment combinations. If one set shows results that either bound or are statistically equivalent to the others, then that set is used as the design basis in all further analyses. If there are minor discrepancies in some cases or burnup and enrichment combinations, it may still be possible to use one set as a single design basis assembly if those discrepancies can be shown to be easily covered by the overall margins. If none of the actual sets of dimensions and operating parameters fulfills the stated goal, then a "hybrid" set of parameters may be established, combining those parameters that result in higher k-values, or appropriate bias values may be applied to selected analyses. Note that some parameters of fuel design, for example, the fuel pellet density has changed over time. Such variations in the fuel design are examined and the most reactive parameters are used in all design basis calculations.

4.2.3.2 Reactivity Effect of Spent Fuel Pool Water Temperature

The main effect of changes in the SFP water temperature is the impact of the difference in water density. Additionally there may be temperature-dependent cross section effects that need to be considered. The optimum condition may therefore be different from case to case in this analysis. To ensure that the optimum condition is used for each case, calculations are performed for each case with representative burnup and enrichment combinations. To cover all normal and accident conditions, those calculations are performed for the following conditions, using MCNP5:

- Normal Ambient Temperature (about 300 K, which is also the standard temperature for MCNP and its cross sections). However, an upper bound water density of 1.0 g/cm^3 is used for those cases, which also covers potential lower water temperatures since this density corresponds to a water temperature of 4 °C. These calculations are performed for 0 and 500 ppm soluble boron.
- Maximum normal SFP temperature. The input files for those conditions use the appropriate water density and S (alpha, beta) according to the temperature. Note that S (alpha, beta), is only available at fixed temperatures of 300K and 400K in MCNP5. Calculations are therefore performed with the adjustment for both temperatures, and the reactivity for the maximum pool temperature is determined by interpolation. These calculations are performed for 0 and 500ppm soluble boron.

- Temperature accident condition. For this, the saturation temperature at the submergence depth of the fuel in SFP of about 260 F (400 K) is used, with and without boiling. Boiling is simulated by assuming a void of 10%, i.e. a reduction in the water density by 10%. These calculations are performed for 1000 ppm soluble boron.

After the results of those studies are determined, the design basis calculations then use the water density and temperature adjustment identified to result in higher reactivities for each pattern.

4.2.3.3 Fuel and Storage Rack Manufacturing Tolerances

Traditionally, fuel and storage rack manufacturing tolerances, and other uncertainties such as positioning of fuel in the rack cells, are accounted for by evaluating the reactivity effect of each uncertainty, and then combining those statistically with the other uncertainties (e.g. from validation). In order to ensure that uncertainties are considered appropriately, those calculations need to be performed for all cases, for a bounding set of burnup, enrichment and cooling time combinations, and for water with and without soluble boron. The calculational effort of this approach is enormous, specifically when Monte Carlo codes are used to determine individual reactivity effects. However, the contribution of the tolerances to the total uncertainty is rather moderate. In order to simplify this process, a different approach is used in the current analysis. This different approach is based on an observation that is made for many uncertainty analyses using the traditional approach stated above: there are only a few parameters that have significant reactivity effect, while the majority of the parameters have small individual reactivity effect, which is almost insignificant when statistically combined with all other larger uncertainties. Modeling those small effect tolerances with reasonable accuracy would require very long computer run times. But ignoring those tolerances completely could be considered mildly non-conservative. However, it should be relatively easy to show that the effect of several most dominant fuel tolerances considered *together* (i.e. a calculation where both parameters are considered to be at its limit) would bound the statistical combination of all fuel tolerances. The same is true for the rack tolerances.

The overall process using this approach is therefore as follows:

- Design basis calculations are performed with nominal parameters (as in the traditional approach)
- For each design basis case, two additional MCNP calculations are performed:
  - For fuel tolerances, a single calculation where the four most dominating parameters are assumed to be at the limiting condition. In this analysis, those parameters are fuel enrichment, fuel density, pin pitch and clad OD.
  - Likewise for rack tolerances, a single calculation where the two most dominating parameters are assumed to be at the limiting condition, but the bounding assumptions are different between Region 1 and Region 2 racks. The dominating parameters are flux trap and cell ID for Region 1 racks, flux trap and wall thickness for Region 2 racks.

- For each of those cases, the reactivity difference to the corresponding nominal case would be calculated at a 95/95 confidence level, and then those two uncertainties would be statistically combined with the other uncertainties of the calculation.
- A comparison of this approach is performed with the approach using the statistical combination for a representative number of cases covering all aspects of the fuel and storage systems, to show that those values in fact bound a "traditional" statistical combination of all uncertainties for fuel and racks. If the discrepancy between the two approaches is too large (either high or low), then the number of dominating parameters used in the two calculations would be adjusted.
- This is similar to the approach for FPs or LFPs, or for the depletion uncertainty, where additional MCNP calculations are performed for each design basis calculation to evaluate specific uncertainties.

The advantages of this approach are as follows:

- The calculated fuel and rack tolerance are still conservative.
- All uncertainty and tolerances are still considered.
- Numbers of calculations increase only moderately (only two per design basis case) compared to the traditional approach.
- The uncertainty is now calculated appropriately for each design basis case, but not as a bounding value for all calculations.

4.2.3.4 Fuel Radial Positioning

Studies are performed to determine the reactivity effects of the fuel radial positioning. The studies consider both 2x2 array of cells as well as larger arrays that represent an entire rack. This way, both local and global effects of the radial positioning are accounted for. The resulting reactivity effects are then considered as uncertainties in the calculations of maximum k_{eff} to determine the loading curves.

4.2.3.5 Spent Fuel Reactivity Calculations

4.2.3.5.1 Operating Parameters

Principal operating parameters of the fuel discussed here are moderator temperature, fuel temperature, soluble boron concentration in the core, and the power density. Other parameters such as axial burnup distribution and effect of burnable absorbers are discussed in some of the following sections. Generic studies [14, 15] indicate that the operating parameters that result in higher reactivities are the upper bound moderator temperature, fuel temperature, and soluble boron concentration, while the power density has a comparatively small effect with no clear trend or even a possibly higher reactivity at lower power density. Upper bound values are therefore used for the first three parameters. For the power density, a lower bound value would

be inconsistent with the higher fuel temperature. Therefore, consistent with the guidance in [10], a nominal value is used for the power density. Additionally, sensitivity studies are performed to show the effect of the individual parameters, and to confirm that the selected values are in fact conservative.

4.2.3.5.2 Spent Fuel Isotopic Composition

To perform the criticality evaluation for spent fuel in MCNP5, the isotopic composition of the fuel is calculated with the depletion code CASMO-4 and then specified as input data into MCNP5. [redacted]

Isotopic compositions are calculated in CASMO-4 for a range of enrichments, for burnups in increments of about 2.5 GWd/mtU, and for cooling times between 0 and 20 years. [redacted]

Note that there may be some uncertainty associated with the isotopic composition of the fuel at the specified cooling time which is not already considered by the depletion uncertainty (Section 4.2.2.2.1), the burnup uncertainty (Section 4.2.3.5.4) or the FP/LFP uncertainty (Section 4.2.2.1.1.2). The uncertainty of the cooling time on reactivity is therefore determined by performing cooling time studies. These studies are described in Section 4.2.3.5.7.

Note that CASMO-4 has the capability to track isotopic compositions both as assembly average and for each pin ("pin-wise"). The design basis calculations use the assembly average option for simplicity and conservatism. To check if this approach is acceptable, pin-wise studies are performed where pin-specific isotopic compositions are extracted from the CASMO-4 calculations and assigned to the corresponding pins in the MCNP5 calculation. These pin-wise studies are performed in conjunction with the studies for burnable absorbers and reactivity control devices (see Section 4.2.3.5.3). Calculations are performed with the 2x2 array models and cover the range of burnups for selected fuel design. The positive reactivity effect is applied as a bias to account for the reactivity effect of the reactivity control devices and the presence of pin specific isotopic composition in determination of the maximum k_{eff} in Section 4.6.11.

4.2.3.5.3 Burnable Absorbers and Reactivity Control Devices

4.2.3.5.3.1 Burnable Absorbers

Both integral burnable absorber and non-integral burnable absorber were used for Seabrook. The integrated fuel burnable absorber (IFBA) rods with a thin coating of ZrB_2 on the UO_2 pellet were used to replace certain fuel rods in certain assemblies for all the cycles except for Cycle 1. Generic studies [9] have investigated the effect of integral burnable absorbers (IFBAs). These studies have concluded that there is a small positive reactivity effect associated with the presence of IFBA rods, compared to an assembly configuration where all rods contain fuel and no neutron absorber. This is mainly because of the spectrum hardening caused by the thermal neutron absorber. To confirm the conclusion from [9] is applicable to the Seabrook fuel, studies are performed for selected cases where the absorber is explicitly modeled in the depletion analyses, so the fuel composition transferred to the MCNP criticality calculation (without any residual absorber and on a pin-by-pin basis) contains the effect of the absorber.

The burnable poison rod assemblies (BPRAs) were only utilized for low enrichment fuel in Cycle 1 (see Section 4.5.3) and then replaced with IFBA rods for the remaining cycles. Therefore, in this analysis, their potential reactivity effect is only evaluated for Standard design fuel assembly (which is the only fuel type utilized for Cycle 1) for fuel with enrichment less than 3.6 wt% ^{235}U.

Following these studies, all design basis calculations are still performed without any burnable absorbers and reactivity control devices. However, in order to account for the presence of the burnable absorbers, for fuel with enrichment less than 3.6 wt% ^{235}U, the maximum positive reactivity effect associated with both IFBA and BPRA configurations is applied in the design basis calculations as a bias; for fuel with enrichment equal to and larger than 3.6 wt% ^{235}U, only the maximum positive reactivity effect of IFBA rods is used as a bias.

4.2.3.5.3.2 Reactivity Control Devices

The Seabrook reactor typically operates ARO (All Rods Out) at full power operations, where the control components are above the top of the active region. Special consideration of those control components on the reactivity of the assemblies is therefore not necessary.

4.2.3.5.4 Burnup Uncertainty

In order to account for the uncertainty in the recorded burnup in reactor records, an uncertainty of 5% is used for the burnup measurement uncertainty. The reactivity effect of this uncertainty is considered and statistically combined with the other uncertainties in the determination of the maximum k_{eff}. The calculations performed at various burnups for each enrichment that are used to interpolate the burnup for the target k_{eff} (see Section 4.2.3.7) are used to determine this reactivity effect. To consider the reactivity difference at the 95/95 confidence level, the following equation is used:

$$\text{Delta } k_{calc} = ((k_{calc2} - k_{calc1}) + 2 * \sqrt{(\sigma_1^2 + \sigma_2^2)})/(bu_1 - bu_2) *(5\% * bu_1)$$

With

k_{calc2}, σ_2 Calculated k_{eff} and standard variation at (lower) burnup bu_2
k_{calc1}, σ_1 Calculated k_{eff} and standard variation at (higher) burnup bu_1

Note that in this approach, the lower burnup bu_2 is 0 GWd/MtU, and the higher burnup bu_1 is higher than the burnup at the target k_{eff}.

4.2.3.5.5 Axial Burnup Profiles and Axial Enrichment Variations

Two different enrichment distributions have been used at Seabrook:

- Fuel with enriched blankets. Annular fuel pellet was used for enriched blankets at the top and bottom of the fuel.
- Fuel without blankets, i.e. with an axially constant enrichment

Each distribution results in different axial burnup profiles. Separate profiles are therefore determined based on a large number of plant-specific assembly information or generic profiles, and bounding profiles as a function of burnup are established. Additionally, a uniform burnup profile (constant burnup over height) is used, since this may result in a higher reactivity. This flat burnup profile is only used with an axially constant enrichment. To ensure that the bounding condition is considered in the design basis calculations, all applicable profiles and the uniform profile are analyzed and the case with the highest maximum k_{eff} is then used for each condition. See Section 4.6.10 for more discussions for axial burnup profiles used in the analyses.

4.2.3.5.6 Fuel Creep and Growth

During irradiation the fuel bundle can experience both fuel rod cladding creep down and fuel rod growth. Both of these changes have the potential to change the fuel-to-moderator ratio in both the depletion and in storage rack geometry, thus potentially increasing reactivity. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.2.3.5.7 Cooling Time Uncertainty

[redacted]

4.2.3.5.8 BORAFLEX™ Gap Material

The residual B-10 (B_4C) in the BORAFLEX™ in the Region 2 racks is not credited in this analysis. The volumes initially occupied by BORAFLEX™ are therefore filled with the BORAFLEX™ material without B_4C. BORAFLEX™ is a polymer and replacing it entirely with water in the analysis could be justified. A comparison of configurations with an absorber gap filled with polymer (BORAFLEX™ material without B_4C) and an absorber gap filled with water is therefore performed to show which material is more reactive.

4.2.3.5.9 Grid Spacers

Grid spacers are placed in regular intervals along the length of the assembly. The current fuel design has the bottom and top grid fabricated from Inconel while the mid-span grids are made from Zircalloy. Previous designs had the same number of grids but different numbers of Inconel and Zircalloy grids. In all cases, the grid spacers reduce the amount of water within the assembly but do not provide any substantial additional neutron absorption, however they do change the local neutron spectrum during depletion. Calculations are conducted by increasing the clad thickness and clad OD of fuel rods to reduce the same amount of water that grid spacers should have reduced. The change is applied for both the depletion calculations and the SFP calculations. The evaluation is performed with and without boron to demonstrate that the effect of grid spacers on reactivity in the SFP is negligible.

4.2.3.5.10 RCCA Type and Configuration

As stated in Section 4.1, RCCAs are credited for neutron absorption in selected fuel assemblies in the Region 2 racks. Analyses are therefore to consider 2x2 arrays containing 0, 1 and 2 RCCAs. Two types of RCCAs, EP-RCCA and RCCA (OEM) may be placed in those selected fuel assemblies. RCCA placement for the two RCCA case can be either adjacent or checkerboarded. Evaluation is performed and the RCCA type and configuration which provide the most limiting results is determined and used in the design basis calculations for each pattern.

Studies are also performed for the Region 2 racks to demonstrate the effect of tolerances of RCCA specifications on reactivity in the SFP.

4.2.3.5.11 Model Simplifications

While the fuel and rack models used in the analyses are very detailed, to assure the true reactivity will always be less than the calculated reactivity, a number of conservative design criteria and assumptions were still necessary to be employed. The following is a list of all those simplifications, together with a brief discussion of the possible effect, and an identification of those simplifications where additional studies may be necessary (and performed in Section 4.6) to show that they are acceptable.

1) Moderator is borated or unborated water at a temperature in the operating range that results in the highest reactivity, as determined by the analysis.

2) Dishing and chamfering of the fuel pellets is neglected, i.e. the fuel is always modeled as solid cylinder inside the cladding. This is acceptable since the amount of fuel is maintained, and the water-to-fuel ratio and the principal location of the fuel remain unchanged.

3) For the criticality analysis, the axial noding is consistent with the cold dimensions and the thermal expanded nodal information is not utilized.

4) All fuel cladding materials are modeled as pure zirconium, while the actual fuel cladding consists of one of several zirconium alloys. This is acceptable since the model neglects the trace elements in the alloy which provide additional neutron absorption.

5) Minor parts of the fuel and rack construction are neglected and replaced by water. Those include grid straps and similar items. Calculations and studies are performed to demonstrate that this is conservative.

6) All fuel and rack structures above and below the active region of the fuel are neglected and replaced by unborated water, even when borated water is used in the active region. This is a standard approach for spent fuel analyses, and while it may neglect some reflection from steel structures in those areas, it also neglects the absorption in those steel structures, and maximizes the axial water reflection. It is therefore considered appropriate and conservative.

7) The neutron absorber (BORAL™) length in the Region 1 racks is 141 inches, which is shorter than the active length of the fuel of 144 inches. In the calculations it is conservatively assumed that 3 inches at the top of the active fuel and 3 inches at the bottom of the active fuel are not covered by the neutron absorber.

8) To account for potential blistering of the BORAL™ panels in the Region 1 racks, a uniform 0.045 inch void is assumed to extend outward from the BORAL™ panels. The BORAL™ panels are assumed to touch the box wall of racks. The total thickness of poison gap used in the analysis is therefore the sum of BORAL™ thickness (0.075 inch) and BORAL™ void thickness (0.045 inch), which is 0.12 inch. It is 0.03 inch larger than the original poison gap thickness of 0.09 inch. Accordingly, the flux trap of Region 1 racks is reduced from 1.05 inch to 0.99 inch since the BORAL™ panels are on both side of the flux trap.

9) No Boron credit is taken for the BORAFLEX™ neutron absorber panels in the Region 2 racks. The BORAFLEX™ panels are replaced by polymer (all B4C is removed in BORAFLEX™) in the calculational models. Calculations are performed to demonstrate that this is more conservative than using water to replace the BORAFLEX™ panels.

10) The total length of absorber sections of RCCA used in the Region 2 racks is 142 inches, which is shorter than the active length of the fuel of 144 inches. In the calculations, to allow for fit-up and manufacturing flexibility, the tip of absorber rod to the bottom of active fuel is conservatively assumed as 6 inches, i.e., the total length of RCCA absorber in the active fuel region is conservatively assumed as 138 inches.

11) For the fuel assemblies that contain IFBAs, the ZrB_2 coating only covers the center section of the active region. However, in this analysis it is conservatively assumed to cover the entire active length of the fuel, i.e., the coating length of IFBA is conservatively assumed as 144 inches.

12) For the calculations with BPRAs, the BPRAs are conservatively considered to be present along the entire length of the active region.

4.2.3.6 Synergistic Effects

Synergistic effects would be those where the concurrent occurrence of a specific aspect yields a different overall effect than the combination of the effects of the occurrence of each individual aspect. As an (arbitrary) example, it could be that the reactivity effect of the change in wall thickness of a rack is different when the cell ID is at its minimum, compared to a nominal cell ID. However, the statistical combination used in the traditional consideration of uncertainties reduces the impact of small changes from the individual component, while the approach used here that considers a conservative combination of tolerances already implicitly includes synergistic effects. No additional evaluations or calculations are therefore performed here to detect any synergistic effects not already explicitly included in the analyses.

4.2.3.7 Calculations to Determine k_{eff} Values and Loading Curves

4.2.3.7.1 Calculation of a Single k_{eff} Value

Applying all the considerations from the previous sections, the calculation of a single k_{eff} value for the design basis calculations consists of the following steps:

- The depletion calculation is performed in CASMO-4 for the desired enrichment(s), a range of burnups, and the desired cooling time, using the bounding set of assembly dimensions and operating conditions. For assemblies with blankets, two CASMO-4 calculations are necessary, one at the enrichment of the axial blanket, and one at the enrichment of the center of the assembly.
- From the desired assembly-average burnup and the axial burnup profile, the burnup of each axial section of fuel is calculated.
- The average isotopic composition of the fuel is then extracted from the CASMO-4 calculation for each axial section, using interpolation between burnup steps if necessary.
- The isotopic compositions are then specified in the input to the MCNP calculation.
- The MCNP models use nominal values for all parameters of fuel, rack and inserts tolerances, for assembly locations in the rack cells, and for the water density.
- The calculated k (kcalc) is determined. As discussed in Section 4.2.3.2, the design basis calculations use the water density and temperature identified to result in higher reactivities at normal conditions. Note that one of the temperature adjustments, S (alpha, beta), is only available at fixed temperatures of 300K and 400K in MCNP5. Calculations are therefore performed with the adjustment for both temperatures, and the reactivity for the pool temperature can be determined by interpolation.
- The maximum k_{eff} value is then calculated by adding all biases, and a statistical combination of all remaining uncertainties. The uncertainties include:
    - Uncertainties from validation (criticality benchmarking)
    - Statistical uncertainty of the calculation (95/95)

- 5% Depletion uncertainty. To determine this, a second MCNP calculation is performed with fresh fuel at the same enrichment.
- 5% Burnup uncertainty. As discussed in Section 4.2.3.5.4, this is determined from the calculations performed at various burnups for the interpolation process. Note that 0 GWd/MtU is used as the lower burnup in the calculation.
- [redacted]
- Fuel uncertainty. As discussed in Section 4.2.3.3, to determine this, a fifth MCNP calculation is performed where the four most dominating fuel parameters are assumed to be at the limiting condition.
- Rack uncertainty. As discussed in Section 4.2.3.3, to determine this, a sixth MCNP calculation is performed where the two most dominating rack parameters are assumed to be at the limiting condition.
- Eccentric positioning uncertainty. As discussed in Section 4.2.3.4, to determine this, MCNP studies are performed to determine the reactivity effects of the fuel radial positioning. The maximum reactivity effect is used for each pattern.
- [redacted]

The biases include:

- Code bias from validation (criticality benchmarking)
- Other bias, which includes pin-specific isotopic composition bias and burnable absorber rods bias. As discussed in Section 4.2.3.5.3, to determine this, MCNP studies are performed to determine the reactivity effects of pin-specific isotopic composition, the presence of the IFBA rods and/or the BPRA rods. For each pattern, for fuel with enrichment less than 3.6 wt% ^{235}U, the maximum positive reactivity effect associated with both IFBA and BPRA configurations is applied in the design basis calculations as a bias; for fuel with enrichment equal to or larger than 3.6 wt% ^{235}U, only the maximum positive reactivity effect of IFBA rods is used as a bias.

4.2.3.7.2 Target k_{eff}

The approach used here takes credit for soluble boron under normal conditions (see Section 4.3). Under this approach, the limiting condition is the non-borated condition, which needs to be shown to result in maximum k_{eff} of less than 1.0. Many aspects of the overall approach use conservative assumptions and bounding values, which will add additional margin. However, the overall magnitude of this margin cannot always be clearly determined, and will be different between cases. To provide additional margin that is applicable to all calculations, a target k_{eff} value of 0.99 is used, which provides an additional margin of 0.01 delta-k for each calculation

compared to the regulatory limit. Similarly, for the cases with credit for soluble boron, where the regulatory limit is 0.95, a target k_{eff} of 0.94 is defined to provide 0.01 delta-k additional margin.

4.2.3.7.3 Determination of Loading Curves

The loading curves consist of the burnups that meet the target k_{eff} for the given range of enrichments and cases. There is no direct way to determine this burnup, and a "trial and error" approach would use an excessive number of calculations. Therefore, an interpolation approach is used, where k_{eff} values are calculated for several burnups, and the burnup that meets the target k_{eff} is then determined by a linear interpolation between two burnups. Burnups are selected as multiples of 5 GWd/mtU. If interpolation is not possible, i.e. if the burnup corresponding to the target k_{eff} is outside the burnup range analyzed, then additional higher or lower burnups are analyzed until an interpolation can be performed.

Since several axial profiles need to be analyzed, k_{eff} values for all applicable profiles are calculated, and the maximum k_{eff} value for any of those profiles is used in the interpolation process. This approach avoids the pre-determination of a "cross-over" burnup above and below which different axial profiles may be bounding.

4.2.3.7.4 Soluble Boron Concentrations

Calculations for normal and accident conditions for compliance with the regulatory limit of 0.95 are performed at fixed soluble boron levels, selected such that the limit is met for all cases and conditions. Note that the calculations with soluble boron are performed at a bounding water temperature for each case.

4.2.4 Normal Conditions

The normal conditions considered in the analyses are all those conditions that can normally occur with fuel in the pool and include the following:

- Normal locations of fuel in the racks according to the analyzed cases and patterns.
- Single fresh fuel assembly in water. This condition bounds all situations during normal fuel movement in the pool, since only a single assembly can be moved at a time. It also bounds the situation of a fuel assembly raised on pedestal or placed in the fresh fuel elevator during fuel inspection.
- The process of inserting and removing fuel assemblies into and from the racks. Two aspects are to be considered here, the insertion and removal of an assembly from a location that requires RCCAs, and the conditions of a partially inserted assembly, which places different sections of neighboring fuel assemblies closer to each other:
    - o Depending on the fuel and the pattern, it may be necessary to remove a fuel assembly that contains RCCA, while all patterns in and around the cell where the fuel assembly needs to be removed still correspond to one of the analyzed cases. This way, additional analyses are required for this operation to confirm that it is acceptable to replace any fuel assembly that contains RCCAs with a water hole (empty cell).

Within each pattern, the reactivity is maximized by the fact that axial sections that dominate reactivity are aligned between neighboring assemblies. For example, for highly burned assemblies the dominating area is the lower burned upper section of the active region. The analyses utilize an infinite array of identical assemblies, i.e. those dominating regions are perfectly aligned. When one assembly is being removed from the rack, this alignment is locally disturbed, i.e. dominating regions are no longer aligned between the assembly that is being removed and those around it. The process of removal (or insertion) of an assembly will therefore maintain or reduce the reactivity, but cannot result in an increase in reactivity. No further analysis is therefore required for this process.

- The fuel currently stored in Rows 1 and 2 on the periphery of the Region 2 rack adjacent to the pool wall (the periphery of Racks 3, 4, and 5 adjacent to the west side of the pool shown in Figure 4.5.5) require unusual plant actions to be reached. They are nozzle-less handling tool assemblies and can not currently be safely moved. It is also difficult to place RCCAs in these locations. Based on the specification (burnup, enrichment and cooling time) of those assemblies, they can be not covered by the loading curve of Pattern D (Uniform loading of spent fuel assemblies without any RCCAs in Region 2) directly, therefore additional analysis is required to determine the requirement to place those fuel assemblies there.
- The debris/trash storage baskets, RCCAs may be stored in empty rack cells, no calculations are necessary since the non-fuel parts would always replace fuel in a cell, and would result in a reduction in reactivity.
- Minor damage to cells, i.e. damage that results in only minor distortion of the cell geometry, and no relocation of the poison (if credited), has an insignificant effect. No additional analysis is needed.
- All the following normal condition and activities are also covered:
  - Ultrasonic Testing (UT) of fuel assembly to determine leaking rods.
  - Reconstitution of fuel assembly
  - Fuel rod inspection (ECT, visuals, etc)
  - Storage of damaged fuel rods, fuel rod inserted in FRSB
  - Fuel assembly inspection
  - UT fuel assembly cleaning
  - Bottom nozzle inspections
  - Fuel assembly debris removal
  - Top Nozzle Separation visual inspection

4.2.5 Accident Conditions

The credible accidents considered are the effect of temperature exceeding the normal range, dropped assemblies, misloaded and mislocated single fresh assemblies, a missing RCCA, and the multiple misload of burned assemblies. Those are briefly discussed in the following sections, and cases are identified that need to be analyzed specifically in Section 4.6.12 of this report. Note that the double contingency principle as stated in [3] specifies that "two unlikely independent and concurrent incidents or postulated accidents are beyond the scope of the required analysis."

This principle precludes the necessity of considering the simultaneous occurrence of multiple accident conditions.

4.2.5.1 Temperature and Water Density Effects

The approach that considers temperatures exceeding the normal operating range of the SFP is discussed in Section 4.2.3.2.

4.2.5.2 Dropped Assembly - Horizontal

For the case in which a fuel assembly is assumed to be dropped on top of a rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the active fuel region of more than 12 inches, which is sufficient to preclude neutron coupling (i.e., an effectively infinite separation). Consequently, the horizontal fuel assembly drop accident will not result in a significant increase in reactivity. Furthermore, any reactivity increase would be small compared to the reactivity increase created by the misloading of a fresh assembly discussed in one of the following sections. The horizontal drop is therefore bounded by this misloading accident and no separate calculation is performed for this drop accident.

4.2.5.3 Dropped Assembly – Vertical into a Storage Cell

It is also possible to vertically drop an assembly into a location that might be occupied by another assembly or that might be empty. Such a vertical impact would at most cause a small compression of the stored assembly, if present, or result in a small deformation of the baseplate for an empty cell. These deformations could potentially increase reactivity. However, the reactivity increase would be small compared to the reactivity increase created by the misloading of a fresh assembly discussed in the following section. The vertical drop is therefore bounded by this misloading accident and no separate calculation is performed for this drop accident.

4.2.5.4 Misloaded Fresh Fuel Assembly

The misload of a single fresh assembly is considered the bounding condition for a single assembly misload. As a bounding approach, the misload is considered in a cell that is required to be a burned assembly which would maximize the reactivity effect of the misloaded assembly according to the analyzed cases. The various configurations for this misload are analyzed for all patterns in Region 1 and Region 2.

4.2.5.5 Mislocated Fresh Fuel Assembly

The mislocation of a fresh unburned fuel assembly could possibly occur if a fresh fuel assembly of the highest permissible enrichment (5.0 wt% ^{235}U) were to be accidentally mislocated outside of a storage rack adjacent to other fuel assemblies. Conservatively, this location was chosen by assuming the mislocated assembly is in the corner junction of two racks. It is important to note that even for Region 1 racks there is no BORAL™ panel on the peripheral of storage cell modules,

except for the portion of the racks facing the other region. An assembly located outside is therefore not separated from the assemblies in the rack by BORAL™ plates.

Further, an assembly could be accidentally placed next to the new fuel elevator while another assembly is in this elevator, and two assemblies could be at a close approach for fuel cleaning. These accident conditions are conservatively evaluated by assuming two fresh assemblies in water at close distance.

4.2.5.6 Missing RCCAs

Since RCCAs are credited for reactivity control, the accident of a single missing RCCA is considered for Patterns B and C. However, this condition is bounded by the misloading accident discussed in Section 4.2.5.4, since the misloading accident includes a condition where a fuel assembly that contains a RCCA is replaced by a fresh fuel assembly. Therefore no additional calculation is needed. For multiple missing RCCAs see the following section.

4.2.5.7 Incorrect Loading Curve

While several independent misloads are precluded by the double contingency principle, a multiple misload could be the result of an incorrect application of the loading curves. This would be most likely between cases that are very similar, such as Patterns B and C which are both in Region 2 racks, and both contain RCCAs. The misload of Pattern B fuel that would need 2 RCCAs in every four cells into a Pattern C configuration (1 insert in every four cells) is therefore considered for a radially infinite array of cells. This condition could also be interpreted as multiple missing absorber rods, one in each 2x2 section. Calculations are therefore performed for the Pattern C configuration with the enrichment and burnup requirements from Pattern B, and the Pattern D configuration with the enrichment and burnup requirements from Pattern C.

4.2.6 Interfaces

With two different rack types and three configurations (patterns) for each rack type, there are three interface situations that need to be considered:

- Interfaces of different patterns within one rack;
- Interfaces between different racks of the same type; and
- Interfaces between different rack types

The approach taken in each of those cases is discussed in the following subsections.

4.2.6.1 Interfaces of Different Patterns within One Rack

Although it is desirable to use the same case over a larger area of the pool (e.g. in an entire rack), it may also be beneficial to have transitions between patterns within a rack. Placing case configurations directly next to each other without any further considerations may be

unacceptable. This problem is often approached by defining special interface patterns, which are then individually shown to be acceptable. This not only increases the calculational effort, but also the complexity of patterns in the pool. [redacted]

4.2.6.2 Interfaces between Different Racks of the Same Type

The interface cell pitch between racks of the same type is larger than the cell pitch within the racks for both Region 1 and Region 2. This additional assembly separation reduces the reactivity at the periphery of the racks. However, a credit for this effect would significantly increase the calculational effort and the complexity of the loading patterns in the pool. Therefore, all rack-to-rack gaps are neglected, i.e. each rack type is assumed to be a single large rack. This way, no additional calculations for assemblies placed on rack periphery are required. If there is a difference in the pattern (or case) on the two sides of a rack-to-rack interface, then it needs to be addressed in the same way as case interfaces within a single rack. See the previous section for details on this subject.

4.2.6.3 Interfaces between different rack types

Region 1 and Region 2 racks are almost identical in design except that the BORAL™ panels are placed instead of BORAFLEX™ in the Region 1 rack cells. This allows for an easy consideration of the Region 1 to Region 2 interface that does not require any additional patterns and analyses. This is simply achieved by requiring that the first row of the Region 1 cells next to Region 2 cells have to be loaded as Region 2 cells. This is acceptable without any further analyses since the BORAL™ in the Region 1 cells will provide additional neutron absorption, so for the same fuel, the reactivity in Region 1 cells is always lower than in Region 2 cells. With this permission, all 2x2 arrays that span the Region 1 to Region 2 interface can be loaded with any of the cases qualified for Region 2. Expressed differently, this permission enforces a barrier row of assemblies, on the Region 1 side of the interface, which complies with both a Region 2 and Region 1 case. Note that the interface cell pitch between different types of racks is also larger than the cell pitch within the racks for both Region 1 and Region 2. This additional assembly separation actually reduces the reactivity at the interface of the racks.

4.2.7 Guidance DSS-ISG-2010-01

The most recently issued spent fuel pool regulatory guidance provided by the Nuclear Regulatory Commission (NRC) is ISG-2010-01. A summary of this new ISG guidance and

approach used here, together with a reference to the appropriate section of this report, is provided here.

1. Fuel assembly selection: A single bounding fuel assembly is used. See Section 4.2.3.1.
2. Depletion analysis: the methodology for performing depletion calculations meets the guidance as follows:
   a. A reactivity decrement of 5% is only used to cover the uncertainty of the spent fuel isotopic number densities. This uncertainty is determined using fresh fuel with no integral burnable absorbers. This methodology is discussed in Section 4.2.2.2.1.
   b. The reactor parameters selected are bounding values with appropriate references and are shown to be bounding by sensitivity. This methodology is discussed in Section 4.2.3.5.1.
   c. BPRAs and IFBAs were used at Seabrook. Analyses are presented to address the effect of those absorbers, based on the configurations used at Seabrook. This methodology is discussed in Section 4.2.3.5.3.1.
   d. Rodded operation has been considered and it has been determined that the Seabrook reactor does not typically operate with control rods inserted significantly into the active fuel region during depletion.
3. Criticality Analysis: the methodology for performing criticality calculations meets the guidance as follows:
   a. Axial burnup profiles are developed for blanketed fuel from a large set of site specific axial burnup profiles, while generic profiles are used for non-blanketed fuel since most of plant specific profiles are not available. The analyses use both uniform burnup and various axial burnup profiles, depending on the axial enrichment variations, and then use whichever is most reactive. This methodology is discussed in Section 4.2.3.5.5.
   b. Rack model: The storage rack models used are based on appropriate references, and the model considers nominal dimensions of parameters.
   c. The analysis considers the minimum B-10 loading in the BORAL™^{TM} panels which is below the manufacturing specifications.
   d. Interfaces: the interfaces between storage rack loading configurations is discussed in Section 4.2.6 and is appropriate for regulatory compliance at the 95 percent probability at a 95 percent confidence level.
   e. Normal conditions: all normal conditions such as fuel storage and fuel movement as well as fuel inspection/reconstitution and fuel in the fuel elevator have been considered. See Section 4.2.4.
   f. Accident conditions: all credible accidents have been considered. See Section 4.2.5.
4. Criticality Code Validation: the methodology for performing criticality code validation demonstrates compliance by the following:
   a. Area of Applicability: The area of applicability is clearly defined by the benchmark and is appropriate for use in this criticality analysis. See Section 4.2.2.1.1.1.

i. Actinides have been validated directly using the HTC experiments. Since no direct validation for fission product reactivity worths are available, uncertainties are accounted for by applying a conservative uncertainty factor to the reactivity effect of the fission products.
ii. The selection of experiments for the benchmark is appropriate, since they include the HTC experiments that were performed specifically for storage conditions of spent fuel, and since the parameters in this analyses are consistent with those covered by the experiments.
iii. An appropriate number of experiments have been used.

b. Trend analysis: the benchmark report performs the appropriate trend analysis on each parameter used to define the area of applicability, provides justification of the criteria used to accept or reject trends (or possible trends), and all trends (if any) have been fully evaluated and appropriately applied.
c. Statistical Treatment: The statistical treatment used considers the variance of the population about the mean, uses appropriate confidence factors, and non-normal distributions (if any) are treated using appropriate statistical methods.
d. Lumped Fission Products: the use of LFP has been accounted for appropriately by applying a conservative uncertainty factor to its reactivity effect. See Section 4.2.2.1.1.2.
e. Code to code comparisons: no code to code comparisons are used to directly validate the criticality codes used in this analysis.

5. Miscellaneous:
   a. Precedent: no precedent is explicitly being credited in this analysis.
   b. References: all the references used are appropriate.
   c. Assumptions: all assumptions are clearly explained, applicable and justified. See Section 4.2.3.5.11 and Section 4.4.

4.3 ACCEPTANCE CRITERIA

The spent fuel PWR storage racks for Seabrook unit 1 are analyzed in accordance with the applicable codes and standards listed below. The objective of this analysis is to ensure that the effective neutron multiplication factor (k_{eff}) is less than 1.0 with the storage racks fully loaded with fuel of the highest permissible reactivity and no credit for soluble boron, i.e., assuming unborated water in the spent fuel pool. In addition, it is demonstrated that k_{eff} is less than or equal to 0.95 with the storage racks fully loaded with fuel of the highest permissible reactivity and the pool flooded with borated water at a temperature corresponding to the highest reactivity. The maximum calculated reactivities include a margin for uncertainty in reactivity calculations, including manufacturing tolerances, and are calculated with a 95% probability at a 95% confidence level [1].

Applicable codes, standards, and regulations or pertinent sections thereof, include the following:

- *Code of Federal Regulations*, Title 10, Part 50, Appendix A, General Design Criterion

62, "Prevention of Criticality in Fuel Storage and Handling."

- L. Kopp, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," NRC Memorandum from L. Kopp to T. Collins, August 19, 1998. [3]
- ANSI ANS-8.17-2004, Criticality Safety Criteria for the Handling, Storage and Transportation of LWR Fuel Outside Reactors.
- Code of Federal Regulation 10CFR50.68, Criticality Accident Requirements (for soluble boron)
- ANSI ANS-8.27-2008, Burnup Credit for LWR Fuel.
- USNRC Standard Review Plan, NUREG-0800, Section 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling, Rev. 3 – March 2007.
- DSS-ISG-2010-01: Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools.

4.4 ASSUMPTIONS

The analyses apply a number of assumptions, either for conservatism or to simplify the calculation approach. Each assumption is appropriately discussed and justified in the text. Important aspects of applying those assumptions are as follows:

1) Bounding or sufficiently conservative inputs and assumptions are used essentially throughout the entire analyses, and in most cases, studies are presented to show that the selected inputs and parameters are in fact conservative or bounding.

2) An evaluation is performed to estimate the overall margins of the analyses. This evaluation includes considerations for potential non-conservatisms throughout the analyses, to ensure those are covered by the margin.

4.5 INPUT DATA

4.5.1 Fuel Assembly Specification

The spent fuel storage racks are designed to accommodate three types of 17x17 fuel assemblies The standard design fuel assembly was used during initial cycles of operation, Vantage 5 was used for Cycles 5-8, and more recently, the RFA design has been employed. The design specifications for these fuel assemblies, which were used for this analysis, are given in Table 4.5.1.

4.5.2 Core Operating Parameters

Core operating parameters are necessary for fuel depletion calculations performed with CASMO-4. The core parameters used for the depletion calculations are presented in Table 4.5.2. Temperature and soluble boron values are taken as the upper bound (most conservative) of the core operating parameters of Seabrook. The neutron spectrum is hardened by each of these parameters, leading to a greater production of plutonium during depletion, which results in conservative reactivity values.

4.5.3 Burnable Absorbers

The Seabrook fuel have made use of burnable poison rod assemblies (BPRAs) of B_2O_3 and integrated fuel burnable absorber (IFBA) rods with a thin coating of ZrB_2 on the UO_2 pellet. The BPRAs were only utilized in Cycle 1 and then replaced with IFBA rods for the remaining cycles. The design specifications for the IFBA rods and BPRA rods are given in Table 4.5.1 and Table 4.5.3 respectively. At Seabrook, both blanketed and non-blanketed fuels were used for fuel assemblies with IFBA, but only non-blanketed fuel was burned with BPRA rods. Table 4.5.4 shows the enrichment range and axial enrichment distributions for the fuel assemblies with IFBA, and Table 4.5.5 presents the enrichment range for the fuel assemblies that were burned with BPRA rods.

4.5.4 SEABROOK Storage Rack Specification

The storage cell characteristics that are used in the criticality evaluations is summarized in Tables 4.5.6 and 4.5.7. Additional information, including layouts, can be found in Figures 4.5.1 and 4.5.2 in this document.

4.5.4.1 Region 1 Style Storage Racks

The Region 1 storage cells are composed of stainless steel boxes separated by a gap with BORAL™ neutron absorber panels (attached by stainless steel sheathing), centered on each side of the storage cells. The steel walls define the storage cells and the stainless steel sheathing supports the BORAL™ neutron absorber panel and defines the boundary of the flux-trap water-gap used to augment reactivity control. Stainless steel channels connect the storage cells in a rigid structure and define the flux-trap between the sheathing of the neutron absorber panels. Figure 4.5.1 provides a sketch of the Region 1 racks along with the critical dimensions.

The design basis calculational models consist of a 2x2 configuration of storage cells with periodic boundary conditions through the centerline of the water gap on the outer boundary of the cluster of four cells, thus simulating an infinite array of Region 1 storage cells. The analyses are performed for ^{10}B loading of 0.015 g/cm^2. Note that the value is minimum value that is assumed in the analyses without any additional consideration for uncertainty. Localized variation on B-10 areal density is also analyzed in the Region 1 racks, such that the average

value of panels matches the specification. Figure 4.5.3 shows the MCNP calculational model of the Region 1 spent fuel storage cells, as drawn by the two-dimensional plotter in MCNP for the 2x2 configuration of storage cells model.

4.5.4.2 Region 2 Style Storage Racks

The Region 2 storage cells are composed of stainless steel boxes separated by a gap with BORAFLEX™ neutron absorber panels (attached by stainless steel sheathing), centered on each side of the storage cells. The analysis takes no Boron credit for the BORAFLEX™ neutron absorber panels, i.e. the panels are modeled as polymer without any B_4C. The steel walls define the storage cells and the stainless steel sheathing supports the BORAFLEX™ neutron absorber panel and defines the boundary of the flux-trap water-gap previously used to augment reactivity control. Stainless steel channels connect the storage cells in a rigid structure and define the flux-trap between the sheathing of the neutron absorber panels. Figure 4.5.2 provides a sketch of the Region 2 racks along with the critical dimensions.

The calculational models consist of 2x2 configuration of storage cells with periodic boundary conditions through the centerline of the water gap on the outer boundary of the cells, thus simulating an infinite array of Region 2 storage cells. Some cases analyzed in the Region 2 racks credit the presence of RCCAs for criticality control. Table 4.5.9 shows the specification of those RCCAs. Figure 4.5.4 shows the MCNP calculational model of the Region 2 spent fuel storage cell with 1 RCCAs (Pattern C), as drawn by the two-dimensional plotter in MCNP for the 2x2 configuration of storage cells model.

4.5.4.3 Gaps between Adjacent Racks

Figure 4.5.5 shows a diagram of the spent fuel pool layout with the locations of the Region 1 and Region 2 racks. The cell-to-cell pitches within racks, and between racks across the gaps, are listed in Table 4.5.8.

4.5.4.4 Fuel Rod Storage Basket

The Seabrook SFP has a Fuel Rod Storage Basket (FRSB) with the dimensions shown in Table 4.5.10 and presented in Figure 4.5.6. The FRSB is a basket that contains fuel rods or fuel rod debris and that is stored in a fuel storage rack cell in the SFP. For the purposes of this analysis the FRSB was modeled as shown in Figure 4.5.6, fully loaded with fresh fuel pins at 5.0 wt% ^{235}U. The model contains fuel rods only, conservatively neglecting the steel box walls.

4.5.5 Material Composition

Table 4.5.11 shows the material compositions of all materials except fuel that is used in the analyses.

4.6 ANALYSIS

This section describes the calculations that were used to determine the acceptable storage criteria for the Region 1 and Region 2 style racks. In addition, this section discusses the possible abnormal and accident conditions.

Unless otherwise stated, all calculations assumed nominal characteristics for the fuel and the fuel storage cells. The effect of the manufacturing tolerances is accounted for with a reactivity adjustment as discussed below.

4.6.1 Design Basis Fuel Assembly

For the Region 1 and Region 2 racks (Patterns A through D), the three assembly types shown in Table 4.5.1 were evaluated for a low and high enrichment each. The calculations are listed in Tables 4.6.1 and 4.6.2. For all assemblies, the presence of burnable absorbers in the fuel assembly (BPRA, IFBA) was neglected for determination of the design basis fuel assembly (see Section 4.6.7 for a discussion of the effect of burnable poison). Also note that only non-blanketed fuel was used for Standard design, only enriched blanketed fuel was used for RFA, but both non-blanketed and enriched blanketed fuel were used for Vantage 5. Calculations were therefore performed to compare Vantage 5 and Standard design with the axial profile for the non-blanketed assemblies, and compare Vantage 5 and RFA with the axial profile for the non-blanketed assemblies.

The results show that the Vantage 5 assembly has the highest reactivity or statistically equivalent reactivity for all cases when it is compared with Standard design and RFA assembly. Hence, the Vantage 5 assembly type is used as the single design basis assembly in all subsequent calculations.

4.6.2 RCCA Type and Configuration

For Pattern B and Pattern C with RCCAs in the Region 2 racks, calculations were performed to evaluate the reactivity of the two types of RCCA shown in Table 4.5.9. The results presented in Table 4.6.3 show that reactivity with RCCA (OEM) is statistically identical to that with EP-RCCA. RCCA (OEM) is therefore used in the RCCA models for design basis cases.

Further note that for Pattern C, the following configurations are considered:

- Storage rack 2x2 array uniformly loaded, with one of the four cells containing RCCAs in the fuel assemblies.
- Storage rack 2x2 array is uniformly loaded, with one of the four cells is empty.

For Pattern B where two RCCAs are credited, the following configurations are considered:

- Storage rack 2x2 array uniformly loaded, with two adjacent of the four cells containing RCCAs in the fuel assemblies.

- Storage rack 2x2 array uniformly loaded, with two diagonal cells of the four cells containing RCCAs in the fuel assemblies.
- Storage rack 2x2 array loaded with three assemblies, with one of the three cells containing an RCCA in the fuel assemblies. An empty cell is adjacent with the cell containing an RCCA.
- Storage rack 2x2 array loaded with three assemblies, with one of the three cells containing an RCCA in the fuel assemblies. The empty cell and the cell containing an RCCA are diagonal.

Based on the results in Table 4.6.3, the configuration with one RCCA shows the highest reactivity for Pattern C, and the configuration with two RCCAs in adjacent cells shows the highest reactivity for Pattern B, therefore, they are selected for all subsequent calculations unless otherwise stated.

As described in Section 4.2.3.5.10, in order to identify the effect of RCCA tolerances on reactivity, calculations were therefore performed with high and low burnup conditions for the configuration with one RCCA (OEM) for Pattern C, and the configuration with two RCCAs (OEM) in adjacent cells for Pattern B. Results of RCCA tolerances are included in Tables 4.6.56 and 4.6.57, and rows with the following information are presented:

- **Reference (All Nominal Parameters)** – Reference case includes all nominal parameters of RCCA specifications. The same parameters are used in all further cases except for changes that are described below;
- **RCCA Tolerances – Individual uncertainties are determined by changing selected parameters and then comparing the result to the that of the reference calculation;**
    - **RCCA – Absorber Density Increased**: absorber (Ag-In-Cd) density is increased [redacted];
    - **RCCA – Absorber Density Decreased**: absorber (Ag-In-Cd) density is decreased [redacted];
    - **RCCA – Absorber OD Increased**: increasing of the absorber outside diameter is analyzed;
    - **RCCA – Absorber OD Decreased**: decreasing of the absorber outside diameter is analyzed;
    - **RCCA – Cladding Thickness Increased**: maximum absorber rod thickness is analyzed.
    - **RCCA – Cladding Thickness Decreased**: minimum absorber rod thickness is analyzed.
    - **RCCA – Cladding OD Increased**: maximum fuel rod cladding outside diameter is analyzed.
    - **RCCA – Cladding OD Decreased**: minimum fuel rod cladding outside diameter is analyzed.
    - **RCCA – Silver Content Increased**: silver content in the absorber is increased [redacted], accordingly, both indium and cadmium contents are decreased [redacted].
    - **RCCA – Silver Content Decreased**: silver content in the absorber is decreased [redacted], accordingly, both indium and cadmium contents are increased [redacted]

- **RCCA – Indium Content Increased**: indium content in the absorber is increased [redacted], accordingly, both silver and cadmium contents are decreased [redacted]
- **RCCA – Indium Content Decreased**: indium content in the absorber is decreased [redacted], accordingly, both silver and cadmium contents are increased [redacted]
- **RCCA – Cadmium Content Increased**: cadmium content in the absorber is increased [redacted], accordingly, both indium and silver contents are decreased [redacted].
- **RCCA – Cadmium Content Decreased**: cadmium content in the absorber is decreased [redacted], accordingly, both indium and silver contents are increased [redacted].

- **Total, RCCA Tolerances:** This is the statistical combination of all RCCA tolerances. Note that the maximum value of tolerance for each parameter (absorber OD, cladding thickness, etc.) was used.

<u>Calculation and Display of delta-k Values</u>: Note that in Tables 4.6.56 and 4.6.57, and in other tables as indicated in the analyses, if a difference (delta-k) is less than or equal to its uncertainty it is listed as 0. For example, 0.0005 ± 0.0009 would be listed as 0 to indicate that the difference is statistically insignificant. If a difference is positive and larger than the uncertainty, the uncertainty is added. For example, +0.0025 ± 0.0009 would be listed as +0.0034. And if a difference is negative and the absolute value is larger than the uncertainty, then the uncertainty is subtracted. For example, -0.0025 ± 0.0009 would be listed as -0.0034.

Regarding the tolerance calculations, it also needs to be noted the reactivity effect of both increase and decrease of the parameter are calculated, and only the maximum positive value of reactivity effect for each parameter is used when calculating the statistical combination.

The results show that the reactivity effects of RCCA tolerances are statistically insignificant for Patterns B and C. Therefore, they are not considered for the final determination of maximum k_{eff} in Section 4.6.11.

4.6.3 Reactivity Effect of SFP Water Temperature and Density

As described in Section 4.2.3.2, calculations are performed for the various SFP water temperature conditions with and without soluble boron. Note that for the maximum normal operating temperature of the SFP of 185 F, the corresponding water density is 0.968 g/cm^3. Results of the studies are presented in Table 4.6.4 for pure unborated water and in Table 4.6.5 for borated water, which support the following conclusions.

- Unborated Water:
  For unborated water, the lower temperature is bounding for Region 1 racks, while the higher water temperature is more reactive for the Region 2 racks, with a reactivity difference up to around 0.01 delta-k. This is generally expected, since Region 1 racks has the higher amount of neutron absorber in the form of BORAL™ panels, which is known to result in a negative

temperature coefficient. To account for this in a simple way, for the design basis calculations, all patterns with unborated water are performed at the lower temperature for Region 1 racks, and at the higher temperature for Region 2 racks. The difference between upper and lower temperature including uncertainty of the difference, listed in Table 4.6.4 for each case.

- Normal Conditions (500 ppm):
  For borated water with 500 ppm soluble boron, similarly, the lower temperature results in higher reactivities for Region 1 racks, while the maximum normal temperature results in a higher reactivity in Region 2 racks. The results are shown in Table 4.6.5. All design basis calculations at that soluble boron level are performed at the lower temperature and the corresponding water density for Region 1 racks, and at the maximum normal temperature and the corresponding water density for Region 2 racks.
- Accident Conditions, except temperature accident:
  Comparison of the calculations at 0 and 500 ppm soluble boron shows that the bounding temperature for Region 2 racks is still the maximum pool temperature with the soluble boron. This would also be true at the higher soluble boron level required for the accident conditions. All misloading accident conditions for Region 2 racks are therefore evaluated at the maximum normal spent fuel pool temperature and corresponding water density. For Region 1 racks, all misloading accident conditions for are still evaluated at the minimum normal spent fuel pool temperature and corresponding water density since it is bounding.
- Temperature Accident Condition (1000 ppm):
  To evaluate temperature accident condition, i.e. exceeding the maximum normal pool operating conditions, calculations were performed at 1000 ppm soluble boron and a temperature of 400K, which corresponds approximately to the boiling temperature of water at the submergence depth of the racks. Calculations are performed at 100% water density corresponding to that temperature, and at 90% to simulate boiling with 10% void. In Table 4.6.5, the condition (100% or 90% water density) that results in the highest reactivity is highlighted in bold. In all cases the calculated reactivities are well below the value for the normal condition at 500 ppm soluble boron. The soluble boron amount of 1000 ppm credited for the temperature accident condition therefore more than offsets the effect of the increase temperature including boiling.

4.6.4 Fuel Assembly Positioning

As described in Section 4.2.3.4, calculations with various fuel and insert positioning were performed. The results are listed in Tables 4.6.6 through 4.6.9 for Patterns A through D respectively. The following conditions are analyzed:

- 2x2 array surrounded by periodic boundary conditions, which is the same configuration that is used in the design basis calculations for each case.
  - Reference (Design Basis): Assemblies centered in the cells.
  - All assemblies moved closest to the center of the 2x2 array. With the boundary condition, this creates a laterally infinite arrangement of 2x2 arrays where the assemblies are close together in each 2x2 array. Note that a configuration with

assemblies moved away from the center in each 2x2 array would be equivalent due to the boundary condition and is therefore not separately considered
    - All assemblies moved towards the same corner of the cell. This creates a laterally infinite configuration with assemblies moved towards the same corner of each cell.
- Large array where all assemblies are moved closest to the center of that array. This essentially represents entire racks and therefore captures global positioning effects, where the 2x2 arrays evaluate more local effects. A periodic boundary condition is also used on the periphery of the model. This neglects the gap between adjacent racks, and is therefore conservative and simplifies model generation. Calculations were performed for two types of arrays:
    - 8x8 array
    - 10x10 array

For Pattern A in Region 1 racks, it shows that the condition where the fuel assemblies centered in the cells (reference case) is the most bounding condition. For Patterns B, C and D used in the Region 2 racks, the condition where all assemblies are moved closest to the center of large array is the bounding condition. It is also shown in the tables that for each pattern, the results for 8x8 array and 10x10 array are essentially the same. The maximum reactivity effects of these conditions for each pattern are then considered as uncertainties to determine the maximum k_{eff} in Section 4.6.11.

4.6.5 Core Operating Parameters

As described in Section 4.2.3.5.1, a sensitivity study is performed on the effect of the core operating parameters. The results are listed in Tables 4.6.10 through 4.6.13 for patterns A through D respectively. They show that for Region 1 racks, all parameters have very small effects because of low fuel burnup; while for Region 2 racks that contain fuel with a higher burnup, higher moderator and fuel temperature and higher soluble boron concentration result in higher reactivity, while the power density has a small effect. Therefore, conservative high values are selected for all parameters except the power density. The values used, and listed in Table 4.5.2, are based on the following considerations:

- The moderator temperature is taken as the peak power assembly exit temperature.
- Fuel temperature: A conservatively high value was utilized [redacted].
- Soluble boron concentration: the value utilized in the analysis is very conservative compared to the past and expected future cycle average values listed in Table 4.6.58.
- Power Density: Core average values are used for power density, consistent with the discussion in Section 4.2.3.5.1 and the small effect of this parameter.

4.6.6 Cooling Time Uncertainty

[redacted]

[redacted] Since cooling time credit is only taken for Region 2 racks, the calculations are only performed for Patterns B, C and D. [redacted]

4.6.7 Reactivity Control Devices

As discussed in Section 4.2.3.5.3, The Seabrook fuel makes use of burnable poison rod assemblies (BPRAs) of B_2O_3 and integrated fuel burnable absorber (IFBA) rods with a thin coating of ZrB_2 on the UO_2 pellet.

4.6.7.1 IFBA Rods

IFBA rods were used for all the cycles except for Cycle 1. As shown in Table 4.5.4, various patterns of IFBA rods have been used for three types of fuel assemblies.

- For the Standard design fuel assemblies, all fuel with IFBA rods is non-blanketed. IFBA rods calculations were therefore performed with Standard design fuel assemblies to determine the appropriate bias for non-blanketed fuel. The IFBA bias for the non-blanketed fuel is then calculated from the IFBA rods calculations (with Standard design) compared to design basis calculations (with Vantage 5). The enrichment range for non-blanketed fuel with IFBA rods is from 3.4 wt% to 4.4 wt% ^{235}U.
- For the Vantage 5 and RFA fuel assemblies, all fuel with IFBA rods has enriched blanket. Since it is confirmed in Tables 4.6.1 and 4.6.2 that Vantage 5 assembly has the higher reactivity than RFA assembly, IFBA rods calculations were performed only with Vantage 5 assembly for enriched blanketed fuel. Calculations were also performed for enriched blanketed fuel without IFBA (with Vantage 5) as the base cases, and then the IFBA bias for the enriched blanketed fuel was determined. The enrichment range for enriched-blanketed fuel with IFBA rods is from 3.6 wt% to 5.0 wt% ^{235}U except for the top and bottom axial blanket (for which the enrichment is 2.6 wt% ^{235}U).

In all the calculations, cooling time of both 0 and 20 years are used for upper limit of enrichment range for Pattern B, C and D. The values compared are those of the MCNP calculations, using the isotopic compositions from depletion calculations with and without the IFBA rods.

Note that as discussed in Section 4.2.3.5.2, planar average rather than pin-specific isotopic fuel compositions are used in the MCNP calculations for the base cases without any Integral Reactivity Control Devices. To determine the reactivity effect of pin-wise isotopic compositions, for all the cases with IFBA rods, isotopic compositions are assigned on a pin-by-pin basis.

The calculations are performed with and without boron in the water. The results are listed in Tables 4.6.17 through 4.6.20 for non-blanketed fuel (Standard design), and Tables 4.6.22 through 4.6.25 for enriched blanketed fuel (Vantage 5), and the conclusions are as follows:

- For non-blanketed fuel, the IFBA rods calculations are compared with the design basis calculations. It is shown that IFBA rods have a negligible effect for fuel in the Region 1 racks, but have significant positive reactivity effect for fuel in the Region 2 racks.
- For enriched blanketed fuel, comparisons are made between the cases with IFBA and the reference cases (enriched blanketed fuel without IFBA). It is shown that the reactivity effect of IFBA rods for enriched blanketed fuel is positive and larger than the IFBA effect for non-blanketed fuel for all patterns. However, it should be noted that based on the conclusion in Section 4.6.11, for Region 2 racks it is the non-blanketed fuel not enriched blanketed fuel that is bounding and used in the design basis cases to determine loading curves. The reactivity difference between design basis cases and reference cases is large enough to offset all the reactivity effect of IFBA rods for enriched blanketed fuel, therefore, the IFBA bias from the non-blanketed cases will be utilized.

4.6.7.2 BPRA Rods

To evaluate the reactivity effects of BPRA rods, the case with the maximum number (24) of BPRA rods is modeled. Since BPRAs were just utilized in Cycle 1, only non-blanketed Standard design fuel assembly is evaluated with BPRAs, within enrichment range of 2.4 wt% to 3.1 wt% ^{235}U which is shown in Table 4.5.5. The BPRA rods calculations are performed by using pin-wise isotopic compositions, with and without boron in the water, and compared with the design basis calculations. Results listed in Table 4.6.21 show that for Region 2 racks, BPRA rods have significant positive reactivity effect, which is larger than the maximum reactivity effect of IFBA rods. However, for Region 1 racks, BPRA rods have a negligible effect.

4.6.7.3 IFBA/BPRA Bias Used in the Loading Curve Determination

Based on the enrichment range of the fuel with specified type of burnable absorber rods and the results shown in Tables 4.6.17 through 4.6.25, to account for the reactivity effects of IFBA and BPRA rods, bias is applied in the loading curve determination as follows:

- For Region 1 racks, since BPRA and IFBA rods with non-blanketed fuel have negligible effects on reactivity, the only positive reactivity effect is of IFBA rods for enriched blanketed fuel, so it is used as a bias to account for the presence of the poison rods in order to determine the maximum k_{eff} in Section 4.6.11.1. All design basis calculations are still performed without any burnable absorber rods.
- For Region 2 racks,
  - For fuel with the enrichment less than 3.6 wt% ^{235}U, the reactivity effect of BPRA rods is bounding, therefore the maximum positive reactivity effect of BPRA rods is applied as a bias.
  - For fuel with enrichment equal to or larger than 3.6 wt% ^{235}U, BPRA rods were not used. The IFBA penalty is taken from the maximum positive reactivity effect of IFBA rods for the non-blanketed fuel. This is appropriate, since the loading curves are based on the

non-blanketed results and Tables 4.6.22 through 4.6.25 clearly show that even considering the blanketed IFBA penalty the non-blanketed cases are bounding.

Also note that only the most limiting effect for the case without boron in the water is used as bias in the development of the loading curves; while the effect for the case with boron in the water is only considered to determine the maximum k_{eff} for calculations with soluble boron content discussed in Section 4.6.11.2 and 4.6.12.

4.6.8 Additional Studies and Evaluations

4.6.8.1 BORAFLEX™ Gap Material

As described in Section 4.2.3.5.8, for Region 2 racks, a comparison of configurations with an absorber gap filled with polymer (BORAFLEX™ material without B_4C) and an absorber gap filled with water is performed, results shown in Table 4.6.26 indicate that using an absorber gap filled with polymer is more conservative. Therefore, it is used in the design basis calculations.

4.6.8.2 Grid Spacers

As described in Section 4.2.3.5.9, to find the reactivity effects of grid spacers additional calculations are conducted by increasing the clad thickness and clad OD of fuel rods to reduce the same amount of water that grid spacers should have reduced. The evaluation was performed with and without boron in the water. The results presented in Table 4.6.27 show that the change in the amount of water by grid spacers has a negligible effect on reactivity. The grid spacers are therefore not considered in the geometric models utilized in the analyses.

4.6.8.3 Fuel Creep and Growth

[redacted]

4.6.9 Fuel and Rack Tolerances Evaluations

This section presents the calculations of uncertainties from fuel and rack tolerances, and on the basis of those, it provides estimates of the margin from the use of selected bounding tolerances and modeling assumptions in the design basis calculations.

As described in Section 4.2.3.3, calculations were performed to identify fuel and rack tolerances with high and low impact on reactivity, in the following termed major and minor tolerances. Results of fuel tolerances are included in Tables 4.6.29 through 4.6.32 for Patterns A through D, respectively, while rack tolerances are presented in Tables 4.6.33 through 4.6.36 for Patterns A through D, separately. For all the cases calculations were performed for a high and low burnup condition. For the Region 1 racks that include the fresh fuel, calculations were performed with fresh fuel at 5.0 wt%.

In Tables 4.6.29 through 4.6.32, rows with the following information are presented:

- **Reference (Design Basis)** – Design basis case includes all nominal parameters. The same parameters are used in all further cases except for changes that are described below;
- **Fuel Uncertainties – Individual uncertainties are determined by changing selected parameters and then comparing the result to the that of the reference calculation**
  - **Fuel – Enrichment Increased**: enrichment uncertainty effect was estimated simply by increasing 0.05 wt% enrichment;
  - **Fuel – Density Increased**: fuel density is increased [redacted];
  - **Fuel – Pellet OD Increased**: increasing of the pellet outside diameter is analyzed;
  - **Fuel – Pellet OD Decreased**: decreasing of the pellet outside diameter is analyzed;
  - **Fuel – Rod Pitch Increased**: maximum fuel rod pitch is analyzed;
  - **Fuel – Rod Pitch Decreased**: minimum fuel rod pitch is analyzed;
  - **Fuel – Cladding OD Increased**: maximum fuel rod cladding outside diameter is analyzed.
  - **Fuel – Cladding OD Decreased**: minimum fuel rod cladding outside diameter is analyzed.
  - **Fuel – Cladding ID Increased**: maximum fuel rod cladding inside diameter is analyzed.
  - **Fuel – Cladding ID Decreased**: minimum fuel rod cladding inside diameter is analyzed.
  - **Fuel – GT/IT OD Increased**: maximum outside diameter of the guide/instrument tube is used.
  - **Fuel – GT/IT OD Decreased**: minimum outside diameter of the guide/instrument tube is used.
  - **Fuel – GT/IT ID Increased**: maximum inside diameter of the guide/instrument tube is used.
  - **Fuel – GT/IT ID Decreased**: minimum inside diameter of the guide/instrument tube is used.
- **Total, Fuel Uncertainties:** This is the statistical combination of all fuel uncertainties. Note that the maximum value of tolerance for each parameter (rod pitch, cladding ID, etc.) was used.
- **Fuel - Dominating Parameters** – Four most dominating fuel parameters are assumed to be at the limiting condition. Maximum fuel enrichment, maximum fuel density, maximum rod pitch and minimum clad OD are selected in this analysis.
- **Difference from Dominant Fuel Parameters:** This is the difference between the values in the two previous rows.

In Tables 4.6.33 through 4.6.36, rows with the following information are presented:

- **Reference (Design Basis)** – Design basis case includes all nominal parameters. The same parameters are used in all further cases except for changes that are described below;
- **Rack Uncertainties – Individual uncertainties are determined by changing selected parameters and then comparing the result to the that of the reference calculation**
  - **Rack – Flux Trap Increased:** maximum cell pitch is analyzed.
  - **Rack – Flux Trap Decreased:** minimum cell pitch is analyzed.
  - **Rack – Cell ID Increased:** maximum cell inner diameter is analyzed.
  - **Rack – Cell ID Decreased:** minimum cell inner diameter is analyzed.
  - **Rack –Wall Thickness Increased:** maximum box wall thickness is analyzed.
  - **Rack –Wall Thickness Decreased:** minimum box wall thickness is analyzed.
  - **Rack– Sheathing Thickness Increased:** maximum sheathing thickness is analyzed.
  - **Rack– Sheathing Thickness Decreased:** minimum sheathing thickness is analyzed.
  - **Rack – Poison Gap Increased:** increasing of the poison gap are analyzed.
  - **Rack – Poison Gap Decreased:** decreasing of the poison gap are analyzed.
  - **Rack – Poison Thickness Increased:** maximum thickness of the poison (BORAL™ for Region 1 racks, BORAFLEX™ without B4C for Region 2 racks) was used;
  - **Rack – Poison Thickness Decreased:** minimum thickness of the poison was used;
  - **Rack – Poison Width Increased:** maximum width of the poison was used;
  - **Rack – Poison Width Decreased:** minimum width of the poison was used;
  - **Rack – Localized Variation on B-10:** Localized Variation on B-10 Areal Density of BORAL™ is analyzed in the Region 1 racks. To account for local variations of B-10 areal density, calculations were performed for the 2x2 array where the 8 panel on the inside of the array have an areal density reduced by 20%, whereas the 8 panels on the outside of the array have an areal density increased by 20%.
- **Total, Rack Uncertainties:** This is the statistical combination of all rack uncertainties. Note that the maximum value of tolerance for each parameter (cell pitch, cell ID, etc.) was used.
- **Dominating Rack Parameters** – two most dominating rack parameters are assumed to be at the limiting condition.
  - Maximum cell ID and minimum flux trap are used for the Region 1 racks;
  - Minimum box wall thickness and minimum flux trap are used for the Region 2 racks.
- **Difference from Dominant Rack Parameters:** This is the difference between the values in the two previous rows.

Regarding the tolerance calculations for traditional approach, it needs to be noted the reactivity effect of both increase and decrease of the parameter are calculated, and only the maximum positive value of reactivity effect for each parameter is used when calculating the statistical combination.

As discussed in Section 4.2.3.3, reactivity difference of the new approach using dominating parameters in comparison to the traditional approach (statistical combination of uncertainties) are calculated and listed in Tables 4.6.29 through 4.6.36 to indicate the level of conservatism introduced by the new approach. Depending on the case, the additional level of conservatism

using the new approach is up to 0.005 delta-k for fuel tolerance, and 0.0039 delta-k for rack tolerance. Only for one case in Table 4.6.35, a negative difference of -0.0002 is shown. However, this value is much smaller than calculation uncertainty of delta-k values, and it is more than covered by the margin of the analyses and therefore does not affect the validity of the results.

4.6.10 Axial Burnup Profiles

Fuel at Seabrook has used two different axial enrichment variations over time. Initially, the fuel without any axial blankets was used, i.e. the enrichment was axially constant. After a few cycles, blanketed fuel with 2.6 wt% enriched blankets was used. Axial burnup profiles were determined separately for both axial enrichment distributions, so that calculations can be performed with the appropriate burnup profile for each enrichment profile (however, note that loading curves are determined in a bounding fashion so that they cover all axial distributions with a single curve rather than having separate curves for assemblies with different axial profiles.). The profiles are determined in a bounding fashion, based on a large number of plant-specific and generic burnup profiles. The approach is described below, followed by a description of the profile database used, and the resulting profiles. Note that the term profile always refers to the profile of relative burnups, i.e. the nodal burnups divided by the assembly average burnup.

4.6.10.1 Approach

For each axial node in each profile type, the nodal values are considered as a function of the assembly average burnup, and a linear expression is determined that bounds the values in *all* profiles for this node. This way profiles are determined that bound every node of every profile in the database at the assembly average burnup, and excessive over-conservatism is avoided since the burnup-dependence of the profile form is considered. Also, since a linear function is selected instead of a step function (as in [18]), this approach avoids steps in the loading curves. Note that the individual profiles are not re-normalized (i.e. the average of all nodes is less than 1.0). This adds an unspecified conservatism, although this would be very small. Since there are only few profiles available above a burnup of about 45 GWd/mtU, the value in each node is considered constant and at the value of 45 GWd/mtU for all burnups above that limit. This is conservative since it neglects the further flattening of the profiles with higher burnups.

4.6.10.2 Profile Databases

For the blanketed assemblies, the profile database consists of a total of 3474 profiles, from Cycle 6 and Cycles 8 through 15 of the plant. Note that because many of the profiles are from radial nodes of a single fuel assembly, where some fuel assemblies give 4 radial nodes and some only give 1 radial node, therefore, for many of the 3474 profiles, the average burnup is not the actual fuel assembly average burnup, but only the radial node average burnup. Those profiles cover all profiles for fuel with enriched blankets as well as some non-blanketed fuel from Cycle 6. It is noted that the profiles from Cycle 15 have 26 nodes which is different from 24 nodes that provided by other cycles. However, the axial segments for 24 node and 26 node profiles are

actually very close. The 26 nodes profiles are therefore converted into 24 nodes profiles and a bounding profile is found.

For the non-blanketed assemblies, most of the plant-specific profiles were not available, since this fuel was only used in earlier cycles of the plant. Therefore, those profiles were determined based on the generic profile database [17], which is also used as the basis for [18]. From this database, assembly profile for the WE-type 17x17 assemblies which is identical or similar to that used at Seabrook was developed in [19] and selected for determining the bounding profile in this analysis. All the generic profiles used for the non-blanketed assemblies are with 18 nodes.

4.6.10.3 Resulting Profiles

The profiles are listed in Tables 4.6.37 and 4.6.38. In each case, the linear function in each node is specified by listing the relative burnup at 0 and 45 GWd/mtU. As an illustration, profiles at 30 and 45 GWd/mtU are shown for each axial enrichment distribution in Figures 4.6.1 and 4.6.2. Note that the lengths of the axial sections were selected based on the cold condition and the thermal expanded nodal information is not utilized.

4.6.11 Normal Conditions

4.6.11.1 Patterns A through D with Pure Water

Using the calculational model shown in Figures 4.5.3 and 4.5.4, and the reference 17x17 Vantage 5 fuel assemblies, the k_{eff} values in the spent fuel storage racks have been calculated by MCNP5 for all applicable profiles with different enrichments. Since Pattern A through Pattern D all credit fuel burnup, loading curves (minimum burnup as a function of enrichment) are determined by using the maximum k_{eff} value for any of those profiles in the interpolation process for those cases. For pattern A, a single curve is determined for 0 cooling time. For each of patterns B, C, and D several curves are determined, for various cooling times. The approach to determine the individual points of the loading curves follow the process outlined in Section 4.2.3.7.3. Note that based on the results in Section 4.6.3, for Region 1 racks, all the design basis calculations are performed at the water temperature of 4 °C, and the reactivities with S(alpha, beta) of 300K are used to determine the maximum k_{eff} value; for Region 2 racks, all the design basis calculations are performed at the maximum pool temperature with the S(alpha, beta) adjustment for both 300K and 400K, and the reactivity for the maximum pool temperature is determined by interpolation. One calculation for each case is listed as an example in Table 4.6.39. Note that in Table 4.6.39 only results for the axial burnup/enrichment profile that result in the highest k_{eff} and therefore establish the minimum burnup are listed. The calculation results show that for most of cases it is the non-blanketed fuel not enriched blanketed fuel that is limiting. The full specifications of the loading curves, i.e. the minimum burnup as a function of various initial enrichments are summarized in Table 4.6.40 for Region 1 racks, Table 4.6.41 for fuel with enrichment from less than 3.6 wt% ^{235}U in Region 2 racks, and Table 4.6.42 for fuel with enrichment no less than 3.6 wt% ^{235}U in Region 2 racks. Note that calculations are also performed for the step of 3.6 wt% ^{235}U in Table 4.6.41, so that the burnup can be calculated from

the polynomial functions with BPRA requirements for the fuel within the enrichment range of 2.6 -3.6 wt% ^{235}U. Data was then fitted to second order polynomial functions in the form of

$$BU = A + B*E + C*E^2$$

With

BU Minimum Burnup in GWd/mtU
E Enrichment in wt%
A, B, C Coefficients

The coefficients of those polynomial functions are listed in Table 4.6.43, 4.6.44 and 4.6.45, and the corresponding burnups at the enrichments used in the analyses are listed in Table 4.6.46, 4.6.47 and 4.6.48 accordingly. Note that the coefficients were selected so that the burnup calculated from the polynomial functions and shown in Tables 4.6.43 through 4.6.45 are always equal to or higher than the values listed in Tables 4.6.40 through 4.6.42. The loading curves are also shown graphically in Figures 4.6.3 through 4.6.6, which show the results from MCNP calculations and the polynomial functions.

Additionally, to confirm that it is acceptable to replace either of the assemblies required to have an RCCA with an empty cell (water hole) for Region 2 racks, the following additional MCNP calculations are performed for Patterns B and C by utilizing the loading curves in Tables 4.6.47 and 4.6.48.

- with enrichment of 2.6 wt% ^{235}U and cooling time of 0 years at the minimum required burnup
- with enrichment of 5.0 wt% ^{235}U and cooling time of 0 an 20 years at the minimum required burnup.

The detailed results are all listed in Table 4.6.49, which show the maximum k_{eff} values for the additional cases are well below the target k_{eff} of 0.99 specified in Section 4.2.3.7.2.

4.6.11.2 Patterns A through D with Borated Water

To ensure that the effective neutron multiplication factor (k_{eff}) is less than the regulatory limit with the storage racks fully loaded with fuel of the highest permissible reactivity and the pool flooded with borated water at a temperature corresponding to the highest reactivity, the calculations with soluble boron content of 500 ppm for lower and higher enrichment and corresponding burnup/cooling time from loading curve are performed. The bounding profiles for appropriate cases were used. Note that these profiles were also used for all the subsequent normal and accident conditions. The results of the calculations are presented in Table 4.6.50, and show that the maximum k_{eff} values for all cases are less than the target k_{eff} of 0.94 specified in Section 4.2.3.7.2.

4.6.11.3 Other Normal Conditions

4.6.11.3.1 Single Assembly in Water

As described in Section 4.2.4, a single fresh fuel assembly in water was analyzed. This bounds any conditions during movements of a single assembly in the pool, including an assembly located in the fuel elevator. Result is presented in Table 4.6.51 and show that the reactivity for this condition is well below the regulatory limit.

4.6.11.3.2 The Fuel Stored on the Periphery of the Region 2 Rack

As described in Section 4.2.4, the fuel currently stored in Rows 1 and 2 on the periphery of the Region 2 rack adjacent to the pool wall (the periphery of Racks 3, 4, and 5 adjacent to the west side of the pool shown in Figure 4.5.5) require unusual plant actions to be reached. They can not currently be safely moved and it is also difficult to place RCCAs in these locations. All those assemblies are with enrichment of 3.1 wt% and cooling time of more than 15 years, the minimum burnup of those assemblies is 24.727 GWD/MTU, which is slightly less than the value of burnup requirement determined by the loading curve of Pattern D (Uniform loading of spent fuel assemblies without any RCCAs in Region 2). However, Additional analysis is performed to confirm that the water next to the two outer rows should offset the slightly reduced burnups in those fuel assemblies. The analyzed configuration is shown in Figure 4.6.7, and a more conservative burnup value of 24 GWD/MTU for those assemblies is used in the calculation. The results are presented in Table 4.6.52 and show that the reactivity for the analyzed configuration is below the reactivity of reference case (infinite array calculation) of Pattern D, and therefore the fuel assemblies stored on the periphery of the Region 2 rack meet the regulatory requirements.

4.6.11.3.3 Interfaces

Interfaces between racks, as described in Section 4.2.6.3, were considered. Figure 4.5.5 is a layout of the existing Seabrook spent fuel pool, with the gaps between racks detailed for each interface. Further details on the gaps are shown in Table 4.5.8, which shows the assembly center-to-center distance across the rack interfaces in comparison to the corresponding value within the racks. The minimum distances across the gaps are defined by the base plates extensions of the racks, and are considered in the evaluations in this section. During seismic events, the base plate extensions prevent the racks to be any closer. Therefore, seismic event are bounded by the evaluations in this section and do not require any additional calculations.

4.6.11.3.3.1 Gaps between Region 1 Racks

Region 1 racks have poison panels on all peripheral walls facing other racks. Further, the assembly distance across the gaps between Region 1 racks is larger than the assembly distance within the racks. Since all the normal patterns must be followed between Region 1 racks, the condition in the gap is therefore bounded by the infinite array calculations. In this analysis, the gaps are conservatively ignored and no further evaluations are necessary.

4.6.11.3.3.2 Gaps between Region 2 Racks

The assembly distance across the gaps between Region 2 racks is larger than the assembly distance within these racks. Since all the normal patterns must be followed between Region 1 racks, the condition in the gap is therefore bounded by the infinite array calculations. In this analysis, the gaps are conservatively ignored and no further evaluations are necessary.

4.6.11.3.3.3 Gaps between Region 1 and Region 2 Racks

As described in Section 4.2.6.3, the Region 1 to Region 2 interface does not require any additional patterns and analyses. [redacted]

4.6.11.3.3.4 Interface between Row 1 and 2 and the Remainder of the Pool

For the fuel currently stored on the periphery of the Region 2 rack adjacent to the pool wall discussed in Section 4.6.11.3.2, the interface between Row 1 and 2 and the remainder of the Pool does not require any additional patterns and analyses. [redacted]

4.6.11.3.4 Fuel Rod Storage Basket

The FRSB is modeled as described in Section 4.5.4.4 and shown in Figure 4.5.6, as bare fuel pins with fresh fuel enriched to 5.0 wt % ^{235}U. The FRSB was modeled to replace the least reactive fuel assembly in each pattern, i.e. the spent fuel assembly in Patterns A and D, or the spent fuel assembly with an RCCA in Patterns B and C. The results of these calculations are presented in Table 4.6.53 and show that any of the fuel assembly in any pattern may be replaced with a FRSB.

4.6.11.3.5 Other Conditions

There are a number of other conditions in the spent fuel pool that is considered acceptable without explicit evaluation based on the following discussions:

- Cells that are required to be empty as part of the respective specification for a given case are generally not permitted to contain any non-fuel hardware. However, insertion of non-fuel hardware in the cells allowed to contain fresh or spent fuel is permitted. Also, storage of inserts or control rods in the empty cells is considered acceptable, since those devices only replace a very small amount of water, while at the same time adding a substantial amount of neutron absorber.
- As already discussed in Section 4.2.4, insertion and removal of fuel assemblies does not require any further evaluation. This is then also applicable to conditions where fuel assemblies are placed in cells on pedestals for inspections or repair.
- As discussed in Section 4.2.4, the minor damage that results in only minor distortion of the cell geometry, and no relocation of the poison (if credited), has an insignificant reactivity effect.

- All the following normal condition and activities have been already covered by the analyzed normal conditions in this report.
  - Ultrasonic Testing (UT) of fuel assembly to determine leaking rods.
  - Reconstitution of fuel assembly
  - Fuel rod inspection (ECT, visuals, etc)
  - Storage of damaged fuel rods, fuel rod inserted in FRSB
  - Fuel assembly inspection
  - UT fuel assembly cleaning
  - Bottom nozzle inspections
  - Fuel assembly debris removal
  - Top Nozzle Separation visual inspection

4.6.12 Accident Conditions

Accidents considered are the single fresh assembly misload or mislocation, single missing RCCAs, and accidents with multiple missing RCCAs. For mislocated assembly accident conditions in Region 1 racks, a soluble boron level of 1600 ppm is used. For all the other accident conditions, a soluble boron level of 1400 ppm is used. All results are summarized in Table 4.6.54, and are all below the regulatory limit of 0.95 with 0.01 delta-k additional margin. All calculations except for the mislocation are performed using an 8x8 array of cells surrounded by periodic boundary conditions, which creates a laterally infinite array with an accident in each 8x8 section. Further details are presented in the following subsection.

4.6.12.1 Single Fresh Assembly Misload

The misload of a single fresh assembly in a cell could possibly occur if a fresh fuel assembly of the highest permissible enrichment (5 wt%) were to be inadvertently misloaded into a storage cell intended to be used for spent fuel. This is evaluated for all patterns, as described in Section 4.2.5.4.

4.6.12.2 Single Fresh Assembly Mislocation

The MCNP model consists of an array of Region 1 and Region 2 fuel storage cells with a single fresh, unburned assembly placed adjacent to the rack. The example of configuration is shown in Figure 4.6.8. The mislocated fuel assembly is placed as close to the rack faces as possible to maximize the possible reactivity effect. Conservatively, it is assumed that the mislocated assembly faces rack cells on two sides, and all the fuel assemblies in the rack are pushed to the corner closest to the mislocated assembly outside.

The condition of two fresh assemblies in close proximity in water which bounds the accidental placement of an assembly next to the loaded fuel elevator is analyzed.

4.6.12.3 Single Missing RCCA

As described in Section 4.2.5.6, the accident of a single missing RCCA for Patterns B and C is bounded by the accident of the misload of a single fresh assembly discussed in Section 4.6.12.1.

4.6.12.4 Multiple RCCAs Misload

Multiple assembly misload which also could be interpreted as multiple missing RCCAs is considered. The Pattern C configuration with the enrichment and burnup requirements from Pattern B, and the Pattern D configuration with the enrichment and burnup requirements from Pattern C, as described in Section 4.2.5.7, were analyzed.

4.7 CONCLUSIONS

Section 4 of this report documents the criticality analysis for the storage of PWR spent nuclear fuel in the Region 1 and Region 2 spent fuel storage racks for both fresh and spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U at the Seabrook nuclear power plant. The analysis demonstrates that the effective neutron multiplication factor (k_{eff}) is less than 1.0 with unborated water and less than or equal to 0.95 with soluble boron credit at a 95% probability with a 95% confidence level. Further, the reactivity effects of abnormal and accident conditions have been evaluated to assure that under credible abnormal and accident conditions, the reactivity will not exceed 0.95 with soluble boron credit at a 95% probability with a 95% confidence level. The maximum calculated reactivity includes a margin for uncertainty in reactivity calculations including manufacturing tolerances and is shown to be less than the regulatory limit with a 95% probability at a 95% confidence level. The minimum required burnups as a function of the initial enrichment is listed in Tables 4.6.46 through 4.6.48.

The following patterns were qualified:

- **Pattern A:** Region 1 storage rack 2x2 array with a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, and spent fuel assemblies with an initial enrichment of 1.5 to 5.0 wt% ^{235}U. All four cells contain BORAL™ panels with an areal density of 0.015 gm/cm^2 in each side of the cells. No credit for cooling time.
- **Pattern B:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, with any two of the four cells containing RCCAs in the fuel assemblies, and the consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. The B4C in the BORAFLEX™ is not credited for neutron absorption. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.
- **Pattern C:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, with any one of the four cells containing RCCAs in the fuel assemblies, and the consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. The B4C in the BORAFLEX™ is not credited for neutron absorption. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.
- **Pattern D:** Region 2 storage rack 2x2 array uniformly loaded with spent fuel with an initial enrichment of 1.5 to 5.0 wt% ^{235}U, without any RCCAs in the fuel assemblies, and the

consideration of cooling times of 0, 2.5, 5, 10, 15, and 20 years. The B4C in the BORAFLEX™ is not credited for neutron absorption. Additionally, it is acceptable to replace any cells that contain fuel assemblies with empty water cells.

For all cases with spent fuel, loading curves were determined as polynomial functions in the form.

$$BU = A + B*E + C*E^2$$

With

BU Minimum Burnup in GWd/mtU
E Enrichment in wt%
A, B, C Coefficients

The coefficients of these functions are listed in Tables 4.6.43 through 4.6.45. When curves for several cooling times are specified, no interpolation for intermediate cooling times are permitted, i.e. the curve for a cooling time at or below the actual cooling time of the assembly must be used.

Additionally, all the normal conditions discussed in Section 4.2.4 were analyzed and qualified. Particularly,

- The fuel rod storage basket is qualified for all locations that are qualified for any fresh or spent fuel in above cases.
- The Rows 1 and 2 on the periphery of Region 2 racks adjacent to the pool wall, i.e., the periphery of Racks 3, 4, and 5 adjacent to the west side of the pool shown in Figure 4.5.5, are analyzed and qualified for higher reactive fuel, crediting the higher neutron leakage in this area.

The interface situations have also been considered. By requiring that that not only neighboring patterns, but also all overlapping patterns meet one of the analyzed cases for every 2x2 array in the pool, and the first row of the Region 1 cells next to Region 2 cells have to be loaded as Region 2 cells, the reactivity will not exceed the regulatory limit for all interface situations.

A soluble boron level of 500 ppm is sufficient to ensure that the maximum k_{eff} is below the regulatory limit under all qualified normal conditions.

For accident conditions, a soluble boron level of 1600 ppm is sufficient to ensure that the maximum k_{eff} is below regulatory limit.

Table 4.2.1

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Table 4.5.1: PWR Fuel Assembly Specifications

	17x17 Standard design	17x17 Vantage 5	17x17 RFA
Fuel Rod Data			
Fuel pellet outside diameter, in.	0.3225 [redacted]	0.3225 [redacted]	0.3225 [redacted]
Cladding inside diameter[4], in.	0.3290	0.3290	0.3290 [redacted]
Cladding outside diameter, in.	0.3740 [redacted]	0.3740 [redacted]	0.3740 [redacted]
Cladding material	Zr-4	ZIRLO	ZIRLO
Maximum Pellet density, g/cc	10.462 [redacted]	10.517 [redacted]	10.505 [redacted]
Maximum enrichment, wt% ^{235}U	4.402	5.0	5.0
ZrB_2 Coating Loading (mg ^{10}B/inch)	1.57[5]	2.355	2.355
ZrB_2 Coating Thickness[6], in.	0.000437	0.000657	0.000657
ZrB_2 Coating Length[7], in.	132	120	120[8]
Fuel Assembly Data			
Fuel rod array	17x17	17x17	17x17
Number of fuel rods	264	264	264
Fuel rod pitch, in.	0.496 [redacted]	0.496 [redacted]	0.496 [redacted]
Fuel Assembly Width, in.	8.426	8.426	8.426
Fuel Assembly Length, in.	159.975	159.975	159.975
Active fuel Length, in.	144	144	144
Bottom of Active Fuel Length to Bottom of Assembly, in.	3.168 to 4.168	3.278	3.278
Guide/Instrument Tube Data			
Number of Guide Thimbles	24	24	24
Number of Instrument Tubes	1	1	1
Guide Thimble Upper Region Inside Diameter, in.	0.448 [redacted]	0.442 [redacted]	0.442 [redacted]
Guide Thimble Upper Region Outside Diameter, in.	0.484 [redacted]	0.474 [redacted]	0.482 [redacted]
Guide Thimble Dashpot Region Inside Diameter, in.	0.395 [redacted]	0.3970 [redacted]	0.3970 [redacted]
Guide Thimble Dashpot Region Outside Diameter, in.	0.431 [redacted]	0.4300 [redacted]	0.4390 [redacted]
Instrument Tube Inside Diameter, in.	0.448 [redacted]	0.448 [redacted]	0.442 [redacted]
Instrument Tube Outside Diameter, in.	0.484 [redacted]	0.484 [redacted]	0.482 [redacted]
Guide/Instrument Tube Material	Zr-4	ZIRLO	ZIRLO

[4] The tolerances of cladding inside diameter for Standard design and Vantage 5 assemblies were not available; the tolerance for RFA assembly was therefore used in analyses for all three types of assemblies.
[5] This does not represent Cycle 1. Cycle 1 included Borosilicate Glass with 12.5 w/o B_2O_3.
[6] The coating thickness was not available. The values provided are calculated. See Appendix C of [21].
[7] In this analysis, for all cases that contain IFBA, the coating length is conservatively assumed as 144 inches. See section 4.2.3.5.11.
[8] For Cycle 15, the coating length has been increased from 120 to 122 inches.

Table 4.5.2: Core Operating Parameter for Depletion Analyses

Parameter	Value
Soluble Boron Concentration (cycle average), ppm	1100
Uprated Core Nominal Power, MW	3648
Average Core Weight (MTU)	88.04064
Reactor Specific Power[9], MW/MTU	41.435
Conservative Fuel Temperature[10], °F	1656
Peak Power Assembly Exit Temperature, °F	646
In-Core Assembly Pitch, Inches	8.466

9 This value is calculated as the uprated core nominal power divided by the average core weight.

10 [redacted]

Table 4.5.3: BPRA Specifications

Parameter	Value
Number of BPRA Rods per Assembly	24 (Maximum)
Boric Oxide Content	12.5
Boron-10 Atom Percent	19.9
Burnable Absorber Material	Borosilicate Glass
Burnable Absorber Composition (wt %)	40.9006% Silicon, 55.2173% Oxygen, 0.698784% B-10, 3.18335% B-11[11]
Burnable Absorber Density (g/cm^3)	2.299
Burnable Absorber Inner Diameter (in.)	0.19
Burnable Absorber Outer Diameter(in.)	0.336
Burnable Absorber Clad Material	Stainless Steel 304
Burnable Absorber Inner Clad Thickness (in.)	0.007
Burnable Absorber Inner Clad O.D. (in.)	0.181
Burnable Absorber Outer Clad Thickness (in.)	0.0185
Burnable Absorber Outer Clad O.D. (in.)	0.381
Bottom of BA Referenced to Bottom of Fuel [12] (in.)	+1.987

[11] The Borosilicate Glass is assumed as SiO_2-B_2O_3. The density and composition of SiO_2-B_2O_3 is taken directly from [19].

[12] In this analysis, the BPRAs are conservatively considered to be present along the entire length of the active region. See section 4.2.3.5.11.

Table 4.5.4: Number of IFBA Rods vs. Enrichment Range for Various Fuel Types

Fuel Type	Number of IFBA Rods	Enrichment Range (wt %)	Axial Blanket (top and bottom)		
			Enrichment (wt %)	Length (inch)	Fuel Pellet Type
Standard design	0	1.6 - 4.4	NA	NA	NA
	64	3.4 - 4	NA	NA	NA
	80	3.4 - 4.4	NA	NA	NA
	104	3.4 - 4	NA	NA	NA
	128	3.6 - 4.4	NA	NA	NA
	156	4.4	NA	NA	NA
Vantage 5	0	2.4 - 4.2	NA or 2.6	NA or 6	NA or Annular
	32	3.8 - 4.95	2.6	6	Annular
	48	4.2	2.6	6	Annular
	80	3.8 - 4.95	2.6	6	Annular
	104	3.8 - 4.95	2.6	6	Annular
	128	4.8	2.6	6	Annular
	156	4 - 4.95	2.6	6	Annular
RFA	0	4 - 4.2	2.6	6	Annular
	16	4 - 4.7	2.6	6	Annular
	32	4.8 - 4.95	2.6	6	Annular
	48	3.6 - 4.8	2.6	6	Annular
	80	3.6 - 4.7	2.6	6	Annular
	104	3.6 - 4.95	2.6	6	Annular
	128	4 - 4.4	2.6	6	Annular
	156	4.2 - 4.95	2.6	6	Annular

Table 4.5.5: Number of BPRA Rods vs. Enrichment Range for Various Fuel Types

Fuel Type	Number of BPRA Rods	Enrichment Range (wt %)
Standard design[13]	0	1.6 - 3.1
	3	3.1
	4	2.4 -3.1
	8	2.4
	9	3.1
	12	2.4
	23[14]	3.1
	24	2.4 - 3.1

[13] All the Standard design fuel assemblies are non-blanketed.
[14] The design with 23 BPRA rods also included a primary source rod.

Table 4.5.6: Fuel Rack Specifications – Region 1 Racks

Parameter	Value
Storage Cell Inside Dimension, in.	8.9
Storage Cell Steel Thickness, in.	0.09
Storage Cell Sheathing Thickness, in.	0.02
Storage Cell Sheathing Width, in.	7.70
Storage Cell Poison Gap Thickness, in[15]	0.09
Storage Cell Flux Trap Width, in[16]	1.05 (Nominal)
Storage Cell Pitch, in	10.35
Storage Cell Material	SS304
BORAL™ Thickness, in.	0.075
BORAL™ Blistering Void Thickness, mil	45
BORAL™ ^{10}B Loading (min), g/cm^2	0.015
BORAL™ Width, in.	7.5
Poison Height, in. [17]	141.00

15 To account for BORAL™ blistering, the total thickness of the poison gap of 0.012 inch is actually used in the analysis. This value is the sum of poison thickness (0.075 inch) and BORAL™ void thickness (0.045 inch). See Section 4.2.3.5.11.

16 The flux trap of 0.99 inch is actually used in all cases except for the peripheral cells to account for BORAL™ blistering, see Section 4.2.3.5.11.

17 The poison height of 138 inch is actually used in analysis, see Section 4.2.3.5.11.

Table 4.5.7: Fuel Rack Specifications – Region 2 Racks

Parameter	Value
Storage Cell Inside Dimension, in.	8.9 [redacted]
Storage Cell Steel Thickness, in.	0.09 [redacted]
Storage Cell Sheathing Thickness, in.	0.02 [redacted]
Storage Cell Sheathing Width, in.	7.63 [redacted]
Storage Cell Poison Gap Thickness, in	0.09 [redacted]
Storage Cell Flux Trap Width, in	1.05 (Nominal)
Storage Cell Pitch, in	10.35 [redacted]
Storage Cell Material	SS304
BORAFLEX™ Thickness, in.	0.071 [redacted]
BORAFLEX™ ^{10}B Loading (min), g/cm^2	Neglected
BORAFLEX™ Width, in.	7.46 [redacted]
Poison Height, in.	141.25 [redacted]

Table 4.5.8: Interface Dimensions for Region 1 and Region 2 Racks[18]

	Interface Cell-to-Cell Pitch[19] (in)	**Rack Cell-to-Cell Pitch (in)**	**Cell Centerline to Baseplate Periphery[20] (in)**
Region 1-Region 1	11.06	10.35	5.53 Ref.
Region 2-Region 2	11.04	10.35	5.52
Region 1-Region 2	11.05	10.35	--

[18] The values listed in this table are not used in calculations but are provided for reference only.

[19] The "Interface Cell-to-Cell Pitch" is determined by combining the respective distances provided in the "Cell Centerline to Baseplate Periphery" Column.

[20] The "Cell Centerline to Baseplate Periphery" is taken directly from the referenced drawings and identifies the location of the centerline of the outermost rack cell with regards to the periphery of the rack baseplate.

Table 4.5.9: RCCAs Specifications

Parameter	**Value**[21]	
	RCCA (OEM)	EP-RCCA
Number of Control Rods per Cluster	24	24
Absorber OD, Zone 1, in.	0.341 [redacted]	0.341 [redacted]
Absorb Length, Zone 1, in.	142	130
Absorber OD, Zone 2, in.	-	0.336 [redacted]
Absorb Length, Zone 2, in.	-	12
Cladding Thickness, in.	0.0185 [redacted]	0.0185 [redacted]
Cladding OD, in.	0.385 [redacted]	0.381 [redacted]
Total Length of Absorber Sections, in.[22]	142	142
Neutron Absorber Material	Silver-Indium-Cadmium (AgInCd)	Silver-Indium-Cadmium (AgInCd)
Poison Density, g/cm^3	10.17 [redacted]	10.17 [redacted]
Silver Content, wt%	80 [redacted]	80 [redacted]
Indium Content, wt%	15 [redacted]	15 [redacted]
Cadmium Content, wt%	5 [redacted]	5 [redacted]
Cladding Material	SS304	SS304

[21] All the tolerances shown in this table are assumed values.
[22] The total length of absorber sections in the active fuel region is assumed as 138 inches, see Section 4.2.3.5.11.

Table 4.5.10: Fuel Rod Storage Basket Specifications

Parameter	Value
Number of Cells	52
Cell Pitch, in.	0.937
Array Type	8x8
Basket Wall Thickness, in.[23]	0.035
Storage Material	SS 304

[23] The cell walls are not modeled in the analysis and conservatively assumed as water.

Table 4.5.11: Material Composition

Parameter	Value	MCNP ZAID
Stainless Steel 304 (Density 7.84 g/cc, minimum)		
Cr (atoms/barn*cm)	0.0172	24000.50c
Mn (atoms/barn*cm)	0.00172	25055.51c
Fe (atoms/barn*cm)	0.058377	26000.55c
Ni (atoms/barn*cm)	0.008047	28000.50c
Zircaloy (Density = 6.5 g/cc)		
Zr-40 (atoms/barn*cm)	0.043239	40000.56c
Pure Water (Density = 1.0 g/cc)		
H-1 (atoms/barn*cm)	0.066854	1001.50c
O-16 (atoms/barn*cm)	0.03343	8016.50c
RCCA Absorber Rod (Density =10.17 g/cc)		
Ag (wt %)	80	47000.50c
In (wt %)	15	49000.60c
Cd (wt %)	5	48000.51c
500 ppm Soluble Boron in Water (Density = 1.0 g/cc)		
H-1 (weight fraction)	0.111840	1001.50c
O-16 (weight fraction)	0.88766	8016.50c
B-10 (weight fraction)	9.00E-05	5010.50c
B-11 (weight fraction)	4.1000E-04	5011.55c
1000 ppm Soluble Boron in Water (Density = 1.0 g/cc)		
H-1 (weight fraction)	0.11179	1001.50c
O-16 (weight fraction)	0.88721	8016.50c
B-10 (weight fraction)	1.800E-04	5010.50c
B-11 (weight fraction)	8.200E-04	5011.55c
BORAL™ with Areal Density = 0.015g/cm^2 (Density = 2.665 g/cc)		
B-10 (wt %)	2.95	5010.50c
B-11 (wt %)	13.46	5011.55c
C (wt %)	4.55	6000.50c
Al (wt %)	79.03	13027.50c
BORAFLEX™ without B_4C (Density = 1.38 g/cc)		
Si (wt %)	41	14000.51c
O (wt %)	37	1001.50c
H (wt %)	4.5	8016.50c
C (wt %)	17.5	6000.50c

Table 4.6.1
Effect of Different Type of Fuel Assembly for Fresh Unborated Pool Water

Pattern[24]	Enrichment	Burnup	Non-Blanketed Fuel Assembly				Enriched-Blanketed Fuel Assembly			
			Vantage 5	Standard design			Vantage 5	RFA		
	(wt%)	(GWd/mtU)	k-calc	k-calc	Delta k-calc	95/95 unc	k-calc	k-calc	Delta k-calc	95/95 unc
A	3.6	5	**0.9593**	0.9582	-0.0011	0.0014	**0.9586**	0.9566	-0.0020	0.0014
B	2.6	5	**0.9457**	0.9445	-0.0012	0.0011	**0.9433**	0.9428	-0.0005	0.0011
C	2.6	15	**0.9296**	0.9272	-0.0024	0.0011	**0.9198**	0.9191	-0.0007	0.0011
D	2.6	20	**0.9433**	0.9424	-0.0009	0.0011	**0.9301**	0.9294	-0.0007	0.0011
A	5	15	**0.9628**	0.9612	-0.0016	0.0014	**0.9603**	0.9590	-0.0013	0.0014
B	5	35	**0.9441**	0.9422	-0.0019	0.0014	**0.9287**	0.9267	-0.0020	0.0011
C	5	45	**0.9311**	0.9299	-0.0012	0.0011	**0.9187**	0.9171	-0.0016	0.0013
D	5	55	**0.9305**	0.9291	-0.0014	0.0011	**0.9129**	0.9125	-0.0004	0.0011

[24] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

Table 4.6.2
Effect of Different Type of Fuel Assembly for Pool Water with 500 ppm Soluble Boron

Pattern[25]	Enrichment	Burnup	Non-Blanketed Fuel Assembly				Enriched-Blanketed Fuel Assembly			
			Vantage 5	Standard design			Vantage 5	RFA		
	(wt%)	(GWd/mtU)	k-calc	k-calc	Delta k-calc	95/95 unc	k-calc	k-calc	Delta k-calc	95/95 unc
A	3.6	5	**0.9034**	0.9026	-0.0008	0.0014	**0.9025**	0.9016	-0.0009	0.0014
B	2.6	5	**0.8468**	0.8464	-0.0004	0.0011	**0.8449**	0.8443	-0.0006	0.0011
C	2.6	15	**0.8312**	0.8295	-0.0017	0.0011	**0.8237**	0.8224	-0.0013	0.0013
D	2.6	20	**0.8430**	0.8403	-0.0027	0.0011	**0.8318**	0.8316	-0.0002	0.0011
A	5	15	**0.9098**	0.9091	-0.0007	0.0014	0.9078	**0.9079**	0.0001	0.0014
B	5	35	**0.8622**	0.8610	-0.0012	0.0013	**0.8478**	0.8465	-0.0013	0.0011
C	5	45	**0.8481**	0.8473	-0.0008	0.0013	0.8363	**0.8366**	0.0003	0.0013
D	5	55	**0.8451**	0.8440	-0.0011	0.0011	**0.8304**	0.8303	-0.0001	0.0013

[25] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

Table 4.6.3 Reactivity Effect of RCCAs Type/Configuration

	K-calc	95/95 unc	K-calc	95/95 unc
Pattern B	2.6 wt% / 5 GWd/MTU		5.0 wt% / 35 GWd/MTU	
2 RCCAs (OEM) - Row	0.9457	0.0008	0.9441	0.0010
2 EP-RCCAs - Row	0.9459	0.0008	0.9446	0.0008
2 RCCAs (OEM) - Diagonal	0.9277	0.0008	0.9326	0.0008
2 EP-RCCAs - Diagonal	0.9277	0.0008	0.9324	0.0008
1 RCCA (OEM) & 1 Empty Cell - Row	0.9011	0.0010	0.8947	0.0010
1 EP-RCCA & 1 Empty Cell - Row	0.9008	0.0010	0.8947	0.0010
1 RCCA (OEM) & 1 Empty Cell - Diagonal	0.8569	0.0008	0.8567	0.0010
1 EP-RCCA & 1 Empty Cell - Diagonal	0.8568	0.0010	0.8562	0.0008
Pattern C	2.6 wt% / 15 GWd/MTU		5.0 wt% / 45 GWd/MTU	
1 RCCA (OEM)	0.9296	0.0008	0.9311	0.0008
1 EP-RCCA	0.9291	0.0008	0.9318	0.0008
1 Empty Cell	0.8815	0.0008	0.8795	0.0010

Table 4.6.4 Reactivity Effect of Water Density for Fresh Water

Unborated Water								
Water Density, g/cc			1.00	0.9680			Delta k-calc[26]
S(α,β)			300K	300K	400K	358.15K (185F)	
Pattern[27]	Enr	Bu	k-calc[28]	k-calc			
Pattern A	3.6	5	**0.9593**	0.9513	0.9469	0.9487	-0.0120
Pattern B	2.6	5	0.9464	0.9450	0.9560	**0.9514**	0.0061
Pattern C	2.6	15	0.9289	0.9284	0.9420	**0.9363**	0.0085
Pattern D	2.6	20	0.9424	0.9422	0.9588	**0.9519**	0.0106
Pattern A	5.0	15	**0.9628**	0.9540	0.9519	0.9528	-0.0114
Pattern B	5.0	35	0.9454	0.9435	0.9582	**0.9520**	0.0079
Pattern C	5.0	45	0.9319	0.9319	0.9496	**0.9422**	0.0114
Pattern D	5.0	55	0.9307	0.9297	0.9485	**0.9406**	0.0113

[26] The delta k-calc is calculated by the results of 1.00g/cc, 300K and 0.968g/cc, 358.15K.

[27] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

[28] The standard deviation of k-calc is around 0.0005 for all calculations.

Table 4.6.5 Reactivity Effect of Water Density for Borated Water

500 ppm									1000 ppm	
Water Density, g/cc			1.00	0.9680			Delta k-calc[29]		0.9390	0.8450
S(α,β)			300K	300K	400K	358.15K (185F)			400K	400K
Pattern[30]	Enr	Bu	k-calc[31]	k-calc					k-calc	k-calc
Pattern A	3.6	5	**0.9034**	0.8987	0.8971	0.8978	-0.0070		**0.8465**	0.8338
Pattern B	2.6	5	0.8457	0.8468	0.8562	**0.8523**	0.0078		0.7845	**0.7915**
Pattern C	2.6	15	0.8290	0.8301	0.8443	**0.8384**	0.0105		0.7733	**0.7837**
Pattern D	2.6	20	0.8405	0.8431	0.8565	**0.8509**	0.0115		0.7856	**0.7964**
Pattern A	5.0	15	**0.9098**	0.9047	0.9027	0.9035	-0.0077		**0.8567**	0.8431
Pattern B	5.0	35	0.8619	0.8623	0.8759	**0.8702**	0.0096		0.8155	**0.8171**
Pattern C	5.0	45	0.8482	0.8486	0.8643	**0.8577**	0.0109		0.8023	**0.8076**
Pattern D	5.0	55	0.8438	0.8454	0.8624	**0.8553**	0.0126		0.8013	**0.8072**

[29] The delta k-calc is calculated by the results of 1.00g/cc, 300K and 0.968g/cc, 358.15K.

[30] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

[31] The standard deviation of k-calc is around 0.0005 for all calculations.

Table 4.6.6
Reactivity Effect of Eccentric Positioning, Pattern A

Pattern	A				A (500 ppm)			
Enrichment, wt%	5.0/3.6		5.0/5.0		5.0/3.6		5.0/5.0	
Burnup, GWd/MTU	0/5		0/15		0/5		0/15	
Reference (centered assembly)	**0.9593**	-	**0.9628**	-	**0.9034**	-	**0.9098**	-
FA - Eccentric In	0.9561	-0.0046	0.9592	-0.0050	0.8991	-0.0057	0.9061	-0.0051
FA - Eccentric Corner	0.9529	-0.0078	0.9580	-0.0062	0.8965	-0.0083	0.9035	-0.0077
8x8 Rack - Eccentric In	0.9563	-0.0044	0.9597	-0.0045	0.8994	-0.0054	0.9060	-0.0052
10x10 Rack - Eccentric In	0.9557	-0.0050	0.9585	-0.0057	0.8982	-0.0066	0.9051	-0.0061

Table 4.6.7
Reactivity Effect of Eccentric Positioning, Pattern B

Pattern	B				B (500 ppm)			
Enrichment, wt%	2.6		5.0		2.6		5.0	
Burnup, GWd/MTU	05		35		05		35	
Reference (centered assembly)	0.9457	-	0.9441	-	0.8468	-	0.8622	-
FA - Eccentric In	0.9519	0.0073	0.9509	0.0081	0.8538	0.0084	0.8690	0.0082
FA - Eccentric Corner	0.9482	0.0036	0.9491	0.0064	0.8466	0.0000	0.8627	0.0000
8x8 Rack - Eccentric In	0.9577	0.0131	**0.9564**	0.0136	**0.8579**	0.0124	0.8736	0.0127
10x10 Rack - Eccentric In	**0.9578**	0.0132	0.9562	0.0134	0.8575	0.0120	**0.8743**	0.0134

Table 4.6.8
Reactivity Effect of Eccentric Positioning, Pattern C

Pattern	C				C (500 ppm)			
Enrichment, wt%	2.6		5.0		2.6		5.0	
Burnup, GWd/MTU	15		45		15		45	
Reference (centered assembly)	0.9296	-	0.9311	-	0.8312	-	0.8481	-
FA - Eccentric In	0.9367	0.0082	0.9390	0.0092	0.8385	0.0087	0.8569	0.0102
FA - Eccentric Corner	0.9330	0.0045	0.9356	0.0056	0.8307	0.0000	0.8496	0.0028
8x8 Rack - Eccentric In	0.9403	0.0118	**0.9450**	0.0150	0.8424	0.0126	0.8603	0.0136
10x10 Rack - Eccentric In	**0.9410**	0.0125	0.9442	0.0144	**0.8428**	0.0130	**0.8612**	0.0145

Table 4.6.9
Reactivity Effect of Eccentric Positioning, Pattern D

Pattern	D				D (500 ppm)			
Enrichment, wt%	2.6		5.0		2.6		5.0	
Burnup, GWd/MTU	20		55		20		55	
Reference (centered assembly)	0.9433	-	0.9305	-	0.8430	-	0.8451	-
FA - Eccentric In	0.9517	0.0095	0.9381	0.0089	0.8501	0.0082	0.8537	0.0097
FA - Eccentric Corner	0.9456	0.0034	0.9345	0.0051	0.8418	-0.0023	0.8461	0.0000
8x8 Rack - Eccentric In	0.9569	0.0147	0.9430	0.0136	**0.8544**	0.0127	0.8570	0.0132
10x10 Rack - Eccentric In	**0.9569**	0.0147	**0.9436**	0.0142	0.8543	0.0124	**0.8570**	0.0130

Table 4.6.10
Reactivity Effect of the Core Operating Parameters, Pattern A

Pattern	A					
Enrichment, wt%	5.0/3.6			5.0/5.0		
Burnup, GWd/MTU	0/5			0/15		
	K-calc	Delta k-calc	95/95 unc	K-calc	Delta k-calc	95/95 unc
Reference	0.9593	-	-	0.9628	-	-
Fuel Temp Decreased by 300F	0.9578	-0.0015	0.0014	0.9618	-0.0010	0.0014
Fuel Temp Increased by 300F	0.9607	0.0014	0.0016	0.9621	-0.0007	0.0014
Mod Temp Decreased by 25F	0.9599	0.0006	0.0014	0.9619	-0.0009	0.0014
Mod Temp Increased by 25F	0.9591	-0.0002	0.0014	0.9635	0.0007	0.0014
Soluble Boron Decreased by 300 ppm	0.9599	0.0006	0.0014	0.9629	0.0001	0.0014
Soluble Boron Increased by 300 ppm	0.9599	0.0006	0.0014	0.9622	-0.0006	0.0014
Specific Power Decreased by 5MW/MTU	0.9591	-0.0002	0.0014	0.9627	-0.0001	0.0016
Specific Power Increased by 5MW/MTU	0.9593	0.0000	0.0014	0.9628	0.0000	0.0014

Table 4.6.11
Reactivity Effect of the Core Operating Parameters, Pattern B

Pattern	B					
Enrichment, wt%	2.6			5.0		
Burnup, GWd/MTU	5			35		
	K-calc	Delta k-calc	95/95 unc	K-calc	Delta k-calc	95/95 unc
Reference	0.9457	-	-	0.9441	-	-
Fuel Temp Decreased by 300F	0.9450	-0.0007	0.0013	0.9423	-0.0018	0.0013
Fuel Temp Increased by 300F	0.9460	0.0003	0.0013	0.9451	0.0010	0.0013
Mod Temp Decreased by 25F	0.9441	-0.0016	0.0013	0.9404	-0.0037	0.0013
Mod Temp Increased by 25F	0.9493	0.0036	0.0013	0.9536	0.0095	0.0013
Soluble Boron Decreased by 300 ppm	0.9441	-0.0016	0.0013	0.9428	-0.0013	0.0013
Soluble Boron Increased by 300 ppm	0.9453	-0.0004	0.0013	0.9454	0.0013	0.0014
Specific Power Decreased by 5MW/MTU	0.9455	-0.0002	0.0013	0.9449	0.0008	0.0013
Specific Power Increased by 5MW/MTU	0.9449	-0.0008	0.0013	0.9442	0.0001	0.0014

Table 4.6.12
Reactivity Effect of the Core Operating Parameters, Pattern C

Pattern	C					
Enrichment, wt%	2.6			5.0		
Burnup, GWd/MTU	15			45		
	K-calc	Delta k-calc	95/95 unc	K-calc	Delta k-calc	95/95 unc
Reference	0.9296	-	-	0.9311	-	-
Fuel Temp Decreased by 300F	0.9269	-0.0027	0.0013	0.9285	-0.0026	0.0013
Fuel Temp Increased by 300F	0.9289	-0.0007	0.0013	0.9332	0.0021	0.0014
Mod Temp Decreased by 25F	0.9253	-0.0043	0.0013	0.9248	-0.0063	0.0013
Mod Temp Increased by 25F	0.9411	0.0115	0.0013	0.9487	0.0176	0.0013
Soluble Boron Decreased by 300 ppm	0.9275	-0.0021	0.0013	0.9296	-0.0015	0.0013
Soluble Boron Increased by 300 ppm	0.9298	0.0002	0.0014	0.9333	0.0022	0.0013
Specific Power Decreased by 5MW/MTU	0.9289	-0.0007	0.0013	0.9317	0.0006	0.0014
Specific Power Increased by 5MW/MTU	0.9285	-0.0011	0.0013	0.9305	-0.0006	0.0013

Table 4.6.13
Reactivity Effect of the Core Operating Parameters, Pattern D

Pattern	D					
Enrichment, wt%	2.6			5.0		
Burnup, GWd/MTU	20			55		
	K-calc	Delta k-calc	95/95 unc	K-calc	Delta k-calc	95/95 unc
Reference	0.9433	-	-	0.9305	-	-
Fuel Temp Decreased by 300F	0.9414	-0.0019	0.0013	0.9271	-0.0034	0.0013
Fuel Temp Increased by 300F	0.9445	0.0012	0.0013	0.9326	0.0021	0.0013
Mod Temp Decreased by 25F	0.9381	-0.0052	0.0013	0.9214	-0.0091	0.0013
Mod Temp Increased by 25F	0.9571	0.0138	0.0013	0.9532	0.0227	0.0013
Soluble Boron Decreased by 300 ppm	0.9409	-0.0024	0.0013	0.9285	-0.0020	0.0013
Soluble Boron Increased by 300 ppm	0.9456	0.0023	0.0013	0.9323	0.0018	0.0013
Specific Power Decreased by 5MW/MTU	0.9437	0.0004	0.0013	0.9300	-0.0005	0.0013
Specific Power Increased by 5MW/MTU	0.9430	-0.0003	0.0013	0.9287	-0.0018	0.0013

Table 4.6.14
Reactivity Effect of the Cooling Time Uncertainty for Pattern B

Enrichment, wt%		1.5		2.6		3.6		4.5		5	
Burnup (GWD/MTU)		5		15		30		40		45	
Cooling Time (years)	Case	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
2.5	Reference	0.8085	-	0.9441	-	0.9354	-	0.9380	-	0.9375	-
	Cooling Time Bounding	0.8077	0.0000	0.9434	0.0000	0.9366	0.0023	0.9369	0.0000	0.9377	0.0000
5	Reference	0.8053	-	0.9437	-	0.9336	-	0.9349	-	0.9348	-
	Cooling Time Bounding	0.8068	0.0026	0.9429	0.0000	0.9327	0.0000	0.9343	0.0000	0.9335	-0.0024
10	Reference	0.8046	-	0.9432	-	0.9297	-	0.9295	-	0.9280	-
	Cooling Time Bounding	0.8042	0.0000	0.9420	-0.0023	0.9305	0.0000	0.9296	0.0000	0.9276	0.0000
15	Reference	0.8040	-	0.9417	-	0.9264	-	0.9264	-	0.9235	-
	Cooling Time Bounding	0.8028	-0.0022	0.9414	0.0000	0.9269	0.0000	0.9258	0.0000	0.9218	-0.0028
20	Reference	0.8025	-	0.9411	-	0.9253	-	0.9226	-	0.9203	-
	Cooling Time Bounding	0.8013	-0.0023	0.9415	0.0000	0.9264	0.0000	0.9234	0.0000	0.9197	0.0000
Maximum Delta k-calc		0.0026		0.0000		0.0000		0.0000		0.0000	
Average Value of Delta k-calc		-0.0004		-0.0005		0.0000		0.0000		-0.0011	

Table 4.6.15
Reactivity Effect of the Cooling Time Uncertainty for Pattern C

Enrichment, wt%		1.5		2.6		3.6		4.5		5	
Burnup (GWD/MTU)		5		15		30		40		45	
Cooling Time (years)	Case	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
2.5	Reference	0.8485	-	0.9252	-	0.9230	-	0.9232	-	0.9220	-
	Cooling Time Bounding	0.8489	0.0000	0.9258	0.0000	0.9237	0.0000	0.9243	0.0000	0.9217	0.0000
5	Reference	0.8476	-	0.9216	-	0.9192	-	0.9189	-	0.9149	-
	Cooling Time Bounding	0.8473	0.0000	0.9225	0.0000	0.9194	0.0000	0.9182	0.0000	0.9151	0.0000
10	Reference	0.8446	-	0.9185	-	0.9118	-	0.9081	-	0.9036	-
	Cooling Time Bounding	0.8450	0.0000	0.9192	0.0000	0.9123	0.0000	0.9083	0.0000	0.9046	0.0000
15	Reference	0.8430	-	0.9168	-	0.9063	-	0.9005	-	0.8975	-
	Cooling Time Bounding	0.8434	0.0000	0.9161	0.0000	0.9073	0.0000	0.9020	0.0026	0.8976	0.0000
20	Reference	0.8423	-	0.9150	-	0.9032	-	0.8962	-	0.8915	-
	Cooling Time Bounding	0.8424	0.0000	0.9136	-0.0025	0.9032	0.0000	0.8961	0.0000	0.8910	0.0000
Maximum Delta k-calc		0.0000		0.0000		0.0000		0.0026		0.0000	
Average Value of Delta k-calc		0.0000		-0.0005		0.0000		0.0005		0.0000	

Table 4.6.16
Reactivity Effect of the Cooling Time Uncertainty for Pattern D

Enrichment, wt%		1.5		2.6		3.6		4.5		5	
Burnup (GWD/MTU)		5		20		35		45		55	
Cooling Time (years)	Case	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
2.5	Reference	0.8894	-	0.9377	-	0.9326	-	0.9300	-	0.9176	-
	Cooling Time Bounding	0.8888	0.0000	0.9371	0.0000	0.9339	0.0024	0.9302	0.0000	0.9183	0.0000
5	Reference	0.8877	-	0.9336	-	0.9272	-	0.9228	-	0.9100	-
	Cooling Time Bounding	0.8877	0.0000	0.9325	0.0000	0.9258	-0.0025	0.9222	0.0000	0.9103	0.0000
10	Reference	0.8855	-	0.9280	-	0.9168	-	0.9098	-	0.8966	-
	Cooling Time Bounding	0.8857	0.0000	0.9272	0.0000	0.9161	0.0000	0.9107	0.0000	0.8964	0.0000
15	Reference	0.8842	-	0.9234	-	0.9089	-	0.9008	-	0.8862	-
	Cooling Time Bounding	0.8839	0.0000	0.9233	0.0000	0.9102	0.0024	0.9012	0.0000	0.8865	0.0000
20	Reference	0.8825	-	0.9202	-	0.9042	-	0.8944	-	0.8796	-
	Cooling Time Bounding	0.8826	0.0000	0.9215	0.0024	0.9043	0.0000	0.8944	0.0000	0.8790	0.0000
Maximum Delta k-calc		0.0000		0.0024		0.0024		0.0000		0.0000	
Average Value of Delta k-calc		0.0000		0.0005		0.0005		0.0000		0.0000	

Table 4.6.17
Reactivity Effect of the IFBA Rods for Non-blanketed Fuel, Pattern A

Pattern		A				A (500 ppm)			
Cooling Time, years		0				0			
Enrichment, wt%		3.4		4.4		3.4		4.4	
Burnup, GWd/MTU		1		10		1		10	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9645	-	0.9620	-	0.9081	-	0.9098	-
2	*Bias*								
3	64 IFBAs	0.9641	0.0000	0.9620	0.0000	0.9064	-0.0031	0.9083	0.0000
4	80 IFBAs	0.9649	0.0000	0.9615	0.0000	0.9066	-0.0029	0.9084	0.0000
5	104 IFBAs	0.9646	0.0000	0.9628	0.0000	0.9066	-0.0029	0.9084	0.0000
6	128 IFBAs	0.9640	0.0000	0.9622	0.0000	0.9075	0.0000	0.9082	-0.0030
7	156 IFBAs	0.9653	0.0000	0.9630	0.0000	0.9063	-0.0032	0.9090	0.0000
8	Maximum Delta-k	**0.0000**		0.0000		0.0000		0.0000	

Table 4.6.18
Reactivity Effect of the IFBA Rods for Non-blanketed Fuel, Pattern B

Pattern		B						B (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.4		4.4		4.4		3.4		4.4		4.4	
Burnup, GWd/MTU		15		30		30		15		30		30	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9508	-	0.9388	-	0.9177	-	0.8589	-	0.8543	-	0.8334	-
2	*Bias*												
3	64 IFBAs	0.9515	0.0000	0.9389	0.0000	0.9170	0.0000	0.8595	0.0000	0.8541	0.0000	0.8335	0.0000
4	80 IFBAs	0.9508	0.0000	0.9376	0.0000	0.9182	0.0000	0.8585	0.0000	0.8545	0.0000	0.8344	0.0000
5	104 IFBAs	0.9512	0.0000	0.9392	0.0000	0.9176	0.0000	0.8595	0.0000	0.8551	0.0000	0.8345	0.0000
6	128 IFBAs	0.9525	0.0030	0.9387	0.0000	0.9187	0.0000	0.8605	0.0029	0.8550	0.0000	0.8343	0.0000
7	156 IFBAs	0.9513	0.0000	0.9403	0.0028	0.9204	0.0038	0.8608	0.0032	0.8557	0.0027	0.8343	0.0000
8	Maximum Delta-k	0.0030		0.0028		**0.0038**		0.0032		0.0027		0.0000	

Table 4.6.19
Reactivity Effect of the IFBA Rods for Non-blanketed Fuel, Pattern C

Pattern		C						C (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.4		4.4		4.4		3.4		4.4		4.4	
Burnup, GWd/MTU		25		40		40		25		40		40	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9418	-	0.9266	-	0.8898	-	0.8505	-	0.8413	-	0.8054	-
2	*Bias*												
3	64 IFBAs	0.9422	0.0000	0.9268	0.0000	0.8900	0.0000	0.8509	0.0000	0.8415	0.0000	0.8067	0.0024
4	80 IFBAs	0.9440	0.0033	0.9276	0.0000	0.8909	0.0000	0.8507	0.0000	0.8416	0.0000	0.8082	0.0041
5	104 IFBAs	0.9444	0.0037	0.9277	0.0000	0.8918	0.0031	0.8511	0.0000	0.8428	0.0028	0.8079	0.0036
6	128 IFBAs	0.9450	0.0043	0.9280	0.0025	0.8902	0.0000	0.8527	0.0035	0.8431	0.0029	0.8086	0.0043
7	156 IFBAs	0.9459	0.0052	0.9290	0.0035	0.8913	0.0026	0.8527	0.0033	0.8431	0.0031	0.8085	0.0042
8	Maximum Delta-k	**0.0052**		0.0035		0.0031		0.0035		0.0031		0.0043	

Table 4.6.20
Reactivity Effect of the IFBA Rods for Non-blanketed Fuel, Pattern D

Pattern		D						D (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.4		4.4		4.4		3.4		4.4		4.4	
Burnup, GWd/MTU		35		45		45		35		45		45	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9281	-	0.9356	-	0.8887	-	0.8355	-	0.8481	-	0.8034	-
2	*Bias*												
3	64 IFBAs	0.9290	0.0000	0.9355	0.0000	0.8885	0.0000	0.8373	0.0029	0.8489	0.0000	0.8040	0.0000
4	80 IFBAs	0.9302	0.0032	0.9361	0.0000	0.8893	0.0000	0.8362	0.0000	0.8489	0.0000	0.8042	0.0000
5	104 IFBAs	0.9306	0.0036	0.9363	0.0000	0.8897	0.0000	0.8367	0.0023	0.8504	0.0036	0.8047	0.0024
6	128 IFBAs	0.9301	0.0031	0.9387	0.0042	0.8901	0.0025	0.8383	0.0039	0.8503	0.0033	0.8054	0.0031
7	156 IFBAs	0.9311	0.0041	0.9382	0.0037	0.8898	0.0000	0.8387	0.0043	0.8500	0.0030	0.8053	0.0030
8	Maximum Delta-k	0.0041		**0.0042**		0.0025		0.0043		0.0036		0.0031	

Table 4.6.21
Reactivity Effect of BPRA Rods for Non-blanketed Fuel

Boron Concentration		0 ppm						500 ppm					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		2.4		3.1		3.1		2.4		3.1		3.1	
Burnup, GWd/MTU		15		30		30		15		30		30	
Pattern[32]		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
A	Reference (Design Basis)	0.9369	-	0.9571	-	-	-	0.8787	-	0.8993	-	-	-
	24 BPRAs	0.9367	**0.0000**	0.9571	0.0000	-	-	0.8781	0.0000	0.8988	0.0000	-	-
B	Reference (Design Basis)	0.9259	-	0.9290	-	0.9173	-	0.8266	-	0.8360	-	0.8260	-
	24 BPRAs	0.9317	0.0069	0.9369	**0.0090**	0.9220	0.0058	0.8331	0.0076	0.8462	0.0115	0.8330	0.0081
C	Reference (Design Basis)	0.9354	-	0.9457	-	0.9275	-	0.8361	-	0.8509	-	0.8344	-
	24 BPRAs	0.9468	**0.0125**	0.9542	0.0096	0.9350	0.0086	0.8471	0.0121	0.8609	0.0113	0.8418	0.0087
D	Reference (Design Basis)	0.9249	-	0.9322	-	0.8988	-	0.8232	-	0.8374	-	0.8058	-
	24 BPRAs	0.9381	**0.0143**	0.9449	0.0138	0.9091	0.0114	0.8390	0.0169	0.8516	0.0153	0.8177	0.0130

32 Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

Table 4.6.22
Reactivity Effect of IFBA Rods for Enriched Blanketed Fuel, Pattern A

Pattern		A				A (500 ppm)			
Cooling Time, years		0				0			
Enrichment, wt%		5.0/3.6		5.0/5.0		5.0/3.6		5.0/5.0	
Burnup, GWd/MTU		0/5		0/15		0/5		0/15	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference: Enriched-blanketed Fuel w/o IFBA	0.9579	-	0.9597	-	0.9029	-	0.9075	-
2	*Bias*								
3	16 IFBAs	0.9591	0.0000	0.9605	0.0000	0.9033	0.0000	0.9078	0.0000
4	32 IFBAs	0.9582	0.0000	0.9604	0.0000	0.9030	0.0000	0.9084	0.0000
5	48 IFBAs	0.9597	0.0034	0.9608	0.0000	0.9028	0.0000	0.9076	0.0000
6	64 IFBAs	0.9585	0.0000	0.9606	0.0000	0.9037	0.0000	0.9096	0.0035
7	80 IFBAs	0.9586	0.0000	0.9612	0.0029	0.9036	0.0000	0.9093	0.0032
8	104 IFBAs	0.9598	0.0033	0.9599	0.0000	0.9046	0.0031	0.9088	0.0000
9	128 IFBAs	0.9588	0.0000	0.9603	0.0000	0.9040	0.0000	0.9093	0.0032
10	156 IFBAs	0.9597	0.0032	0.9602	0.0000	0.9050	0.0035	0.9091	0.0030
11	Maximum Delta-k	**0.0034**		0.0029		0.0035		0.0035	
12	Design Basis Case: Non-blanketed Fuel w/o IFBA	0.9593	0.0000	0.9628	0.0045	0.9034	0.0000	0.9098	0.0037

Table 4.6.23
Reactivity Effect of IFBA Rods for Enriched Blanketed Fuel, Pattern B

Pattern		B						B (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.6		5		5		3.6		5		5	
Burnup, GWd/MTU		20		35		35		20		35		35	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference: Enriched-blanketed Fuel w/o IFBA	0.9251	-	0.9280	-	0.8925	-	0.8374	-	0.8478	-	0.8142	-
2	*Bias*												
3	16 IFBAs	0.9269	0.0029	0.9274	0	0.8926	0	0.8398	0.0035	0.8473	0	0.8146	0
4	32 IFBAs	0.9269	0.0031	0.9295	0.0028	0.8930	0	0.8391	0.0028	0.8480	0	0.8148	0
5	48 IFBAs	0.9278	0.0038	0.9298	0.0031	0.8938	0.0024	0.8407	0.0044	0.8491	0.0024	0.8146	0
6	64 IFBAs	0.9283	0.0043	0.9294	0.0027	0.8934	0	0.8410	0.0047	0.8483	0	0.8146	0
7	80 IFBAs	0.9289	0.0049	0.9294	0.0027	0.8935	0	0.8423	0.0062	0.8491	0.0024	0.8160	0.0029
8	104 IFBAs	0.9291	0.0051	0.9313	0.0046	0.8945	0.0031	0.8426	0.0065	0.8499	0.0032	0.8166	0.0035
9	128 IFBAs	0.9292	0.0052	0.9322	0.0055	0.8947	0.0035	0.8428	0.0065	0.8508	0.0041	0.8164	0.0033
10	156 IFBAs	0.9319	0.0079	0.9318	0.0051	0.8953	0.0039	0.8445	0.0082	0.8511	0.0046	0.8171	0.0040
11	Maximum Delta-k	**0.0079**		0.0055		0.0039		0.0082		0.0046		0.0040	
12	Design Basis Case: Non-blanketed Fuel w/o IFBA	0.9393	0.0155	0.9441	0.0175	0.9203	0.0291	0.8509	0.0148	0.8614	0.0147	0.8386	0.0258

Table 4.6.24
Reactivity Effect of IFBA Rods for Enriched Blanketed Fuel, Pattern C

Pattern		C						C (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.6		5		5		3.6		5		5	
Burnup, GWd/MTU		30		45		45		30		45		45	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference: Enriched-blanketed Fuel w/o IFBA	0.9137	-	0.9183	-	0.8677	-	0.8243	-	0.8375	-	0.7899	-
2	*Bias*												
3	16 IFBAs	0.9140	0	0.9182	0	0.8677	0	0.8253	0	0.8373	0	0.7896	0
4	32 IFBAs	0.9143	0	0.9191	0	0.8691	0.0025	0.8261	0.0031	0.8378	0	0.7887	-0.0023
5	48 IFBAs	0.9145	0	0.9203	0.0031	0.8686	0	0.8275	0.0045	0.8377	0	0.7906	0
6	64 IFBAs	0.9159	0.0035	0.9206	0.0034	0.8690	0.0024	0.8282	0.0052	0.8391	0.0027	0.7895	0
7	80 IFBAs	0.9155	0.0031	0.9207	0.0035	0.8695	0.0029	0.8274	0.0044	0.8395	0.0031	0.7906	0
8	104 IFBAs	0.9165	0.0041	0.9214	0.0042	0.8700	0.0034	0.8298	0.0068	0.8382	0	0.7914	0.0026
9	128 IFBAs	0.9177	0.0053	0.9227	0.0055	0.8712	0.0046	0.8304	0.0075	0.8398	0.0034	0.7921	0.0033
10	156 IFBAs	0.9189	0.0065	0.9231	0.0059	0.8718	0.0052	0.8313	0.0083	0.8415	0.0051	0.7929	0.0041
11	Maximum Delta-k	**0.0065**		0.0059		0.0052		0.0083		0.0051		0.0041	
12	Design Basis Case: Non-blanketed Fuel w/o IFBA	0.9311	0.0187	0.9311	0.0139	0.8915	0.0251	0.8407	0.0177	0.8475	0.0111	0.8105	0.0217

Table 4.6.25
Reactivity Effect of IFBA Rods for Enriched Blanketed Fuel, Pattern D

Pattern		D						D (500 ppm)					
Cooling Time, years		0				20		0				20	
Enrichment, wt%		3.6		5		5		3.6		5		5	
Burnup, GWd/MTU		35		55		55		35		55		55	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference: Enriched-blanketed Fuel w/o IFBA	0.9244	-	0.9129	-	0.8480	-	0.8351	-	0.8301	-	0.7697	-
2	*Bias*												
3	16 IFBAs	0.9257	0.0024	0.9126	0	0.8481	0	0.8346	0	0.8290	0	0.7689	0
4	32 IFBAs	0.9252	0	0.9120	0	0.8477	0	0.8356	0	0.8291	0	0.7697	0
5	48 IFBAs	0.9272	0.0039	0.9136	0	0.8479	0	0.8362	0	0.8305	0	0.7705	0
6	64 IFBAs	0.9277	0.0044	0.9129	0	0.8481	0	0.8364	0.0024	0.8303	0	0.7708	0
7	80 IFBAs	0.9280	0.0047	0.9131	0	0.8495	0.0026	0.8377	0.0037	0.8313	0.0023	0.7706	0
8	104 IFBAs	0.9291	0.0058	0.9146	0.0028	0.8497	0.0028	0.8377	0.0037	0.8304	0	0.7718	0.0032
9	128 IFBAs	0.9288	0.0055	0.9158	0.0040	0.8504	0.0035	0.8382	0.0042	0.8319	0.0029	0.7718	0.0032
10	156 IFBAs	0.9304	0.0071	0.9158	0.0040	0.8512	0.0043	0.8405	0.0065	0.8332	0.0042	0.7735	0.0049
11	Maximum Delta-k	**0.0071**		0.0040		0.0043		0.0065		0.0042		0.0049	
12	Design Basis Case: Non-blanketed Fuel w/o IFBA	0.9413	0.0180	0.9305	0.0187	0.8796	0.0327	0.8504	0.0164	0.8451	0.0161	0.7980	0.0296

Table 4.6.26
Modeling of the BORAFLEX™ Material

Enrichment, wt%	2.6					5				
Soluble Boron Content, ppm	Bu	0		500		Bu	0		500	
Pattern B		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Filled Absorber Gap -Polymer	5	0.9457	-	0.8468	-	35	0.9441	-	0.8622	-
Filled Absorber Gap -Water	5	0.9415	-0.0053	0.8400	-0.0079	35	0.9402	-0.0053	0.8564	-0.0071
Pattern C		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Filled Absorber Gap -Polymer	15	0.9296	-	0.8312	-	45	0.9311	-	0.8481	-
Filled Absorber Gap -Water	15	0.9246	-0.0061	0.8247	-0.0076	45	0.9276	-0.0046	0.8417	-0.0077
Pattern D		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Filled Absorber Gap -Polymer	20	0.9433	-	0.8430	-	55	0.9305	-	0.8451	-
Filled Absorber Gap -Water	20	0.9377	-0.0067	0.8361	-0.0080	55	0.9252	-0.0064	0.8385	-0.0079

Table 4.6.27
Reactivity Effect of the Grid Spacers

Enrichment, wt%	5.0/3.6					5.0/5.0				
Soluble Boron Content, ppm	Bu	0		500		Bu	0		500	
Pattern A		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	0/5	0.9593	-	0.9034	-	0/15	0.9628	-	0.9098	-
Grid Spacers	0/5	0.9563	-0.0044	0.9021	0	0/15	0.961	-0.0032	0.9088	0
Enrichment, wt%	2.6					5				
Soluble Boron Content, ppm	Bu	0		500		Bu	0		500	
Pattern B		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	5	0.9457	-	0.8468	-	35	0.9441	-	0.8622	-
Grid Spacers	5	0.9443	-0.0025	0.8453	-0.0028	35	0.9437	0	0.8610	0
Pattern C		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	15	0.9296	-	0.8312	-	45	0.9311	-	0.8481	-
Grid Spacers	15	0.9292	0	0.8306	0	45	0.9313	0	0.8482	0
Pattern D		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	20	0.9433	-	0.8430	-	55	0.9305	-	0.8451	-
Grid Spacers	20	0.9422	0	0.8423	0	55	0.9286	-0.0030	0.8456	0

Table 4.6.28
Reactivity Effect of the Fuel Creep and Growth

Enrichment, wt%	5.0/3.6					5.0/5.0				
Soluble Boron Content, ppm	Bu	0		500		Bu	0		500	
Pattern A		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	0/5	0.9593	-	0.9034	-	0/15	0.9628	-	0.9098	-
Fuel Creep and Growth	0/5	0.9618	**0.0039**	0.9047	0	0/15	0.964	0	0.9111	0
Enrichment, wt%	2.6					5				
Soluble Boron Content, ppm	Bu	0		500		Bu	0		500	
Pattern B		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	5	0.9457	-	0.8468	-	35	0.9441	-	0.8622	-
Fuel Creep and Growth	5	0.9488	**0.0042**	0.8482	0.0025	35	0.9468	0.0040	0.8641	0.0032
Pattern C		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	15	0.9296	-	0.8312	-	45	0.9311	-	0.8481	-
Fuel Creep and Growth	15	0.9313	0.0028	0.8321	0	45	0.9334	**0.0034**	0.8486	0
Pattern D		K-calc	Delta k-calc	K-calc	Delta k-calc		K-calc	Delta k-calc	K-calc	Delta k-calc
Reference	20	0.9433	-	0.8430	-	55	0.9305	-	0.8451	-
Fuel Creep and Growth	20	0.9449	0.0027	0.8438	0	55	0.9322	**0.0028**	0.8462	0

Table 4.6.29
Reactivity Effect of the Fuel Tolerances, Pattern A

Pattern		A				A (500 ppm)			
Enrichment, wt%		5.0/3.6		5.0/5.0		5.0/3.6		5.0/5.0	
Burnup, GWd/MTU		0/5		0/15		0/5		0/15	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9593	-	0.9628	-	0.9034	-	0.9098	-
2	*Fuel Uncertainties:*								
3	Fuel - Enrichment Increased	0.9612	0.0033	0.9645	0.0031	0.9059	0.0039	0.9125	0.0041
4	Fuel - Density Increased	0.9611	0.0032	0.9638	0.0000	0.9063	0.0043	0.9115	0.0031
5	Fuel - Pellet OD Increased	0.9594	0.0000	0.9635	0.0000	0.9046	0.0000	0.9106	0.0000
6	Fuel - Pellet OD Decreased	0.9582	0.0000	0.9619	0.0000	0.9032	0.0000	0.9099	0.0000
7	Fuel - Rod Pitch Increased	0.9620	0.0041	0.9641	0.0000	0.9049	0.0029	0.9117	0.0033
8	Fuel - Rod Pitch Decreased	0.9571	-0.0036	0.9618	0.0000	0.9021	0.0000	0.9078	-0.0034
9	Fuel - Clad OD Increased	0.9572	-0.0035	0.9603	-0.0039	0.9036	0.0000	0.9084	0.0000
10	Fuel - Clad OD Decreased	0.9612	0.0033	0.9651	0.0037	0.9047	0.0000	0.9107	0.0000
11	Fuel - Clad ID Increased	0.9600	0.0000	0.9625	0.0000	0.9034	0.0000	0.9100	0.0000
12	Fuel - Clad ID Decreased	0.9606	0.0000	0.9618	0.0000	0.9035	0.0000	0.9087	0.0000
13	Fuel - GT/IT OD Increased	0.9594	0.0000	0.9623	0.0000	0.9037	0.0000	0.9097	0.0000
14	Fuel - GT/IT OD Decreased	0.9604	0.0000	0.9633	0.0000	0.9038	0.0000	0.9096	0.0000
15	Fuel - GT/IT ID Increased	0.9590	0.0000	0.9628	0.0000	0.9030	0.0000	0.9099	0.0000
16	Fuel - GT/IT ID Decreased	0.9585	0.0000	0.9624	0.0000	0.9029	0.0000	0.9091	0.0000
17	Total, Fuel Uncertainties	0.0070		0.0048		0.0065		0.0061	
18	Fuel - Dominating Parameters	0.9671	0.0092	0.9693	0.0079	0.9098	0.0078	0.9165	0.0081
19	Difference from Dominant Fuel Parameters (18-17)	0.0022		0.0031		0.0013		0.0020	

Table 4.6.30
Reactivity Effect of the Fuel Tolerances, Pattern B

Pattern		B				B (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		5		35		5		35	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9457	-	0.9441	-	0.8468	-	0.8622	-
2	*Fuel Uncertainties:*								
3	Fuel - Enrichment Increased	0.9504	0.0058	0.9472	0.0044	0.8514	0.0057	0.8636	0.0000
4	Fuel - Density Increased	0.9476	0.0030	0.9451	0.0000	0.8491	0.0034	0.8640	0.0031
5	Fuel - Pellet OD Increased	0.9463	0.0000	0.9434	0.0000	0.8469	0.0000	0.8625	0.0000
6	Fuel - Pellet OD Decreased	0.9445	-0.0023	0.9433	0.0000	0.8450	-0.0029	0.8612	0.0000
7	Fuel - Rod Pitch Increased	0.9481	0.0035	0.9454	0.0026	0.8485	0.0028	0.8637	0.0028
8	Fuel - Rod Pitch Decreased	0.9437	-0.0031	0.9400	-0.0054	0.8449	-0.0030	0.8601	-0.0035
9	Fuel - Clad OD Increased	0.9443	-0.0025	0.9441	0.0000	0.8459	0.0000	0.8611	0.0000
10	Fuel - Clad OD Decreased	0.9456	0.0000	0.9451	0.0000	0.8468	0.0000	0.8614	0.0000
11	Fuel - Clad ID Increased	0.9457	0.0000	0.9435	0.0000	0.8465	0.0000	0.8619	0.0000
12	Fuel - Clad ID Decreased	0.9455	0.0000	0.9431	0.0000	0.8466	0.0000	0.8612	0.0000
13	Fuel - GT/IT OD Increased	0.9440	-0.0028	0.9442	0.0000	0.8458	0.0000	0.8620	0.0000
14	Fuel - GT/IT OD Decreased	0.9462	0.0000	0.9429	0.0000	0.8469	0.0000	0.8612	0.0000
15	Fuel - GT/IT ID Increased	0.9464	0.0000	0.9442	0.0000	0.8477	0.0000	0.8629	0.0000
16	Fuel - GT/IT ID Decreased	0.9445	-0.0023	0.9442	0.0000	0.8465	0.0000	0.8617	0.0000
17	Total, Fuel Uncertainties	0.0075		0.0051		0.0073		0.0041	
18	Fuel - Dominating Parameters	0.9557	0.0111	0.9510	0.0083	0.8560	0.0103	0.8689	0.0080
19	Difference from Dominant Fuel Parameters (18-17)	0.0037		0.0032		0.0031		0.0038	

Table 4.6.31
Reactivity Effect of the Fuel Tolerances, Pattern C

Pattern		C				C (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		10		45		10		45	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9296	-	0.9311	-	0.8312	-	0.8481	-
2	*Fuel Uncertainties:*								
3	Fuel - Enrichment Increased	0.9340	0.0055	0.9331	0.0031	0.8349	0.0050	0.8507	0.0040
4	Fuel - Density Increased	0.9306	0.0000	0.9333	0.0033	0.8337	0.0036	0.8494	0.0026
5	Fuel - Pellet OD Increased	0.9286	0.0000	0.9320	0.0000	0.8317	0.0000	0.8483	0.0000
6	Fuel - Pellet OD Decreased	0.9297	0.0000	0.9307	0.0000	0.8309	0.0000	0.8468	-0.0026
7	Fuel - Rod Pitch Increased	0.9308	0.0023	0.9331	0.0031	0.8328	0.0027	0.8499	0.0031
8	Fuel - Rod Pitch Decreased	0.9265	-0.0042	0.9293	-0.0029	0.8303	0.0000	0.8469	0.0000
9	Fuel - Clad OD Increased	0.9274	-0.0033	0.9310	0.0000	0.8313	0.0000	0.8477	0.0000
10	Fuel - Clad OD Decreased	0.9301	0.0000	0.9314	0.0000	0.8311	0.0000	0.8487	0.0000
11	Fuel - Clad ID Increased	0.9288	0.0000	0.9302	0.0000	0.8311	0.0000	0.8488	0.0000
12	Fuel - Clad ID Decreased	0.9289	0.0000	0.9319	0.0000	0.8303	0.0000	0.8478	0.0000
13	Fuel - GT/IT OD Increased	0.9289	0.0000	0.9310	0.0000	0.8311	0.0000	0.8486	0.0000
14	Fuel - GT/IT OD Decreased	0.9296	0.0000	0.9309	0.0000	0.8308	0.0000	0.8477	0.0000
15	Fuel - GT/IT ID Increased	0.9286	0.0000	0.9319	0.0000	0.8312	0.0000	0.8480	0.0000
16	Fuel - GT/IT ID Decreased	0.9278	-0.0029	0.9296	-0.0026	0.8308	0.0000	0.8477	0.0000
17	Total, Fuel Uncertainties	0.0060		0.0055		0.0067		0.0057	
18	Fuel - Dominating Parameters	0.9385	0.0100	0.9377	0.0077	0.8404	0.0103	0.8566	0.0099
19	Difference from Dominant Fuel Parameters (18-17)	0.0040		0.0022		0.0036		0.0042	

Table 4.6.32
Reactivity Effect of the Fuel Tolerances, Pattern D

Pattern		D				D (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		15		50		15		50	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9433	-	0.9305	-	0.8430	-	0.8451	-
2	*Fuel Uncertainties:*								
3	Fuel - Enrichment Increased	0.9476	0.0054	0.9321	0.0027	0.8462	0.0045	0.8482	0.0042
4	Fuel - Density Increased	0.9452	0.0030	0.9314	0.0000	0.8458	0.0039	0.8473	0.0033
5	Fuel - Pellet OD Increased	0.9429	0.0000	0.9310	0.0000	0.8437	0.0000	0.8455	0.0000
6	Fuel - Pellet OD Decreased	0.9439	0.0000	0.9297	0.0000	0.8411	-0.0030	0.8439	-0.0023
7	Fuel - Rod Pitch Increased	0.9453	0.0031	0.9326	0.0034	0.8433	0.0000	0.8468	0.0028
8	Fuel - Rod Pitch Decreased	0.9400	-0.0044	0.9272	-0.0044	0.8400	-0.0041	0.8426	-0.0036
9	Fuel - Clad OD Increased	0.9423	0.0000	0.9300	0.0000	0.8424	0.0000	0.8452	0.0000
10	Fuel - Clad OD Decreased	0.9432	0.0000	0.9296	0.0000	0.8425	0.0000	0.8454	0.0000
11	Fuel - Clad ID Increased	0.9424	0.0000	0.9300	0.0000	0.8422	0.0000	0.8442	0.0000
12	Fuel - Clad ID Decreased	0.9430	0.0000	0.9289	-0.0027	0.8429	0.0000	0.8444	0.0000
13	Fuel - GT/IT OD Increased	0.9426	0.0000	0.9291	-0.0025	0.8424	0.0000	0.8457	0.0000
14	Fuel - GT/IT OD Decreased	0.9432	0.0000	0.9290	-0.0026	0.8417	-0.0024	0.8450	0.0000
15	Fuel - GT/IT ID Increased	0.9433	0.0000	0.9307	0.0000	0.8429	0.0000	0.8450	0.0000
16	Fuel - GT/IT ID Decreased	0.9424	0.0000	0.9295	0.0000	0.8430	0.0000	0.8452	0.0000
17	Total, Fuel Uncertainties	0.0070		0.0050		0.0060		0.0061	
18	Fuel - Dominating Parameters	0.9523	0.0101	0.9363	0.0069	0.8528	0.0109	0.8524	0.0086
19	Difference from Dominant Fuel Parameters (18-17)	0.0032		0.0019		0.0050		0.0025	

Table 4.6.33
Reactivity Effect of the Rack Tolerances, Pattern A

Pattern		A				A (500 ppm)			
Enrichment, wt%		5.0/3.6		5.0/5.0		5.0/3.6		5.0/5.0	
Burnup, GWd/MTU		0/5		0/15		0/5		0/15	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9593	-	0.9628	-	0.9034	-	0.9098	-
2	*Rack Uncertainties:*								
3	Rack - Flux Trap Increased	0.9525	-0.0082	0.9549	-0.0093	0.8964	-0.0084	0.9027	-0.0085
4	Rack - Flux Trap Decreased	0.9681	0.0102	0.9695	0.0081	0.9112	0.0092	0.9174	0.0090
5	Rack - Cell ID Increased	0.9610	0.0031	0.9636	0.0000	0.9039	0.0000	0.9091	0.0000
6	Rack - Cell ID Decreased	0.9588	0.0000	0.9624	0.0000	0.9028	0.0000	0.9102	0.0000
7	Rack - Wall Thickness Increased	0.9594	0.0000	0.9622	0.0000	0.9040	0.0000	0.9106	0.0000
8	Rack - Wall Thickness Decreased	0.9593	0.0000	0.9628	0.0000	0.9035	0.0000	0.9097	0.0000
9	Rack - Sheathing Increased	0.9583	0.0000	0.9630	0.0000	0.9032	0.0000	0.9107	0.0000
10	Rack - Sheathing Decreased	0.9597	0.0000	0.9631	0.0000	0.9039	0.0000	0.9097	0.0000
11	Rack - Poison Gap Increased	0.9588	0.0000	0.9622	0.0000	0.9031	0.0000	0.9094	0.0000
12	Rack - Poison Gap Decreased	0.9608	0.0029	0.9637	0.0000	0.9040	0.0000	0.9103	0.0000
13	Rack - BORAL™ Thickness Increased	0.9584	0.0000	0.9601	-0.0043	0.9007	-0.0041	0.9074	-0.0038
14	Rack - BORAL™ Thickness Decreased	0.9619	0.0040	0.9655	0.0041	0.9070	0.0050	0.9113	0.0029
15	Rack - BORAL™ Width Increased	0.9585	0.0000	0.9611	-0.0031	0.9025	0.0000	0.9096	0.0000
16	Rack - BORAL™ Width Decreased	0.9602	0.0000	0.9636	0.0000	0.9044	0.0000	0.9106	0.0000
17	Rack - Localized Variation on B-10	0.9591	0.0000	0.9628	0.0000	0.9046	0.0000	0.9101	0.0000
18	Total, Rack Uncertainties	0.0118		0.0091		0.0105		0.0095	
19	Rack- Dominating Parameters	0.9714	0.0135	0.9744	0.0130	0.9138	0.0118	0.9202	0.0118
20	Difference from Dominant Rack Parameters (19-18)	0.0017		0.0039		0.0013		0.0023	

Table 4.6.34
Reactivity Effect of the Rack Tolerances, Pattern B

Pattern		B				B (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		5		35		5		35	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9457	-	0.9441	-	0.8468	-	0.8622	-
2	Rack Uncertainties:								
3	Rack - Flux Trap Increased	0.9392	-0.0076	0.9372	-0.0082	0.8399	-0.0080	0.8545	-0.0091
4	Rack - Flux Trap Decreased	0.9514	0.0068	0.9492	0.0064	0.8526	0.0069	0.8678	0.0069
5	Rack - Cell ID Increased	0.9414	-0.0054	0.9379	-0.0075	0.8423	-0.0058	0.8561	-0.0074
6	Rack - Cell ID Decreased	0.9476	0.0030	0.9465	0.0037	0.8488	0.0031	0.8639	0.0031
7	Rack - Wall Thickness Increased	0.9406	-0.0062	0.9384	-0.0070	0.8433	-0.0046	0.8578	-0.0058
8	Rack - Wall Thickness Decreased	0.9511	0.0065	0.9498	0.0070	0.8501	0.0046	0.8661	0.0052
9	Rack - Sheathing Increased	0.9446	0.0000	0.9428	-0.0026	0.8458	0.0000	0.8608	-0.0027
10	Rack - Sheathing Decreased	0.9473	0.0027	0.9459	0.0031	0.8480	0.0023	0.8629	0.0000
11	Rack - Poison Gap Increased	0.9438	-0.0032	0.9422	-0.0032	0.8440	-0.0039	0.8587	-0.0048
12	Rack - Poison Gap Decreased	0.9480	0.0034	0.9459	0.0031	0.8492	0.0035	0.8641	0.0032
13	Rack - Polymer Thickness Increased	0.9464	0.0000	0.9438	0.0000	0.8468	0.0000	0.8640	0.0031
14	Rack - Polymer Thickness Decreased	0.9450	0.0000	0.9429	0.0000	0.8456	-0.0023	0.8611	0.0000
15	Rack - Polymer Width Increased	0.9444	-0.0024	0.9441	0.0000	0.8467	0.0000	0.8627	0.0000
16	Rack - Polymer Width Decreased	0.9453	0.0000	0.9447	0.0000	0.8459	0.0000	0.8613	0.0000
17	Total, Rack Uncertainties	0.0109		0.0110		0.0098		0.0102	
18	Rack- Dominating Parameters	0.9577	0.0131	0.9540	0.0112	0.8572	0.0115	0.8729	0.0121
19	Difference from Dominant Rack Parameters (18-17)	0.0023		0.0001		0.0017		0.0019	

Table 4.6.35
Reactivity Effect of the Rack Tolerances, Pattern C

Pattern		C				C (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		10		45		10		45	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9296	-	0.9311	-	0.8312	-	0.8481	-
2	Rack Uncertainties:								
3	Rack - Flux Trap Increased	0.9224	-0.0083	0.9240	-0.0082	0.8240	-0.0083	0.8413	-0.0081
4	Rack - Flux Trap Decreased	0.9344	0.0059	0.9380	0.0080	0.8383	0.0082	0.8551	0.0083
5	Rack - Cell ID Increased	0.9243	-0.0064	0.9263	-0.0059	0.8256	-0.0067	0.8431	-0.0063
6	Rack - Cell ID Decreased	0.9323	0.0038	0.9337	0.0037	0.8336	0.0035	0.8510	0.0042
7	Rack - Wall Thickness Increased	0.9240	-0.0067	0.9264	-0.0058	0.8276	-0.0047	0.8441	-0.0053
8	Rack - Wall Thickness Decreased	0.9346	0.0061	0.9367	0.0067	0.8347	0.0048	0.8528	0.0060
9	Rack - Sheathing Increased	0.9272	-0.0035	0.9299	-0.0023	0.8291	-0.0032	0.8470	0.0000
10	Rack - Sheathing Decreased	0.9308	0.0023	0.9330	0.0030	0.8310	0.0000	0.8499	0.0031
11	Rack - Poison Gap Increased	0.9267	-0.0040	0.9290	-0.0032	0.8286	-0.0037	0.8460	-0.0034
12	Rack - Poison Gap Decreased	0.9300	0.0000	0.9333	0.0033	0.8329	0.0028	0.8498	0.0030
13	Rack - Polymer Thickness Increased	0.9295	0.0000	0.9311	0.0000	0.8310	0.0000	0.8496	0.0028
14	Rack - Polymer Thickness Decreased	0.9296	0.0000	0.9309	0.0000	0.8295	-0.0028	0.8467	0.0000
15	Rack - Polymer Width Increased	0.9287	0.0000	0.9313	0.0000	0.8308	0.0000	0.8493	0.0000
16	Rack - Polymer Width Decreased	0.9293	0.0000	0.9313	0.0000	0.8306	0.0000	0.8485	0.0000
17	Total, Rack Uncertainties	0.0096		0.0120		0.0105		0.0122	
18	Rack- Dominating Parameters	0.9407	0.0122	0.9429	0.0129	0.8418	0.0117	0.8588	0.0120
19	Difference from Dominant Rack Parameters (18-17)	0.0026		0.0009		0.0012		-0.0002	

Table 4.6.36
Reactivity Effect of the Rack Tolerances, Pattern D

Pattern		D				D (500 ppm)			
Enrichment, wt%		2.6		5		2.6		5	
Burnup, GWd/MTU		15		50		15		50	
Item		K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc	K-calc	Delta k-calc
1	Reference (Design Basis)	0.9433	-	0.9305	-	0.8430	-	0.8451	-
2	Rack Uncertainties:								
3	Rack - Flux Trap Increased	0.9368	-0.0076	0.9237	-0.0079	0.8354	-0.0087	0.8388	-0.0074
4	Rack - Flux Trap Decreased	0.9488	0.0066	0.9369	0.0075	0.8502	0.0083	0.8519	0.0081
5	Rack - Cell ID Increased	0.9373	-0.0071	0.9248	-0.0070	0.8370	-0.0071	0.8392	-0.0070
6	Rack - Cell ID Decreased	0.9464	0.0042	0.9321	0.0027	0.8447	0.0028	0.8479	0.0041
7	Rack - Wall Thickness Increased	0.9381	-0.0063	0.9249	-0.0067	0.8377	-0.0064	0.8406	-0.0056
8	Rack - Wall Thickness Decreased	0.9497	0.0075	0.9356	0.0062	0.8464	0.0045	0.8486	0.0046
9	Rack - Sheathing Increased	0.9421	-0.0023	0.9283	-0.0033	0.8421	0.0000	0.8445	0.0000
10	Rack - Sheathing Decreased	0.9439	0.0000	0.9315	0.0000	0.8437	0.0000	0.8455	0.0000
11	Rack - Poison Gap Increased	0.9409	-0.0035	0.9274	-0.0042	0.8399	-0.0042	0.8426	-0.0036
12	Rack - Poison Gap Decreased	0.9452	0.0030	0.9329	0.0035	0.8457	0.0038	0.8477	0.0039
13	Rack - Polymer Thickness Increased	0.9432	0.0000	0.9301	0.0000	0.8430	0.0000	0.8461	0.0000
14	Rack - Polymer Thickness Decreased	0.9430	0.0000	0.9296	0.0000	0.8420	0.0000	0.8437	-0.0025
15	Rack - Polymer Width Increased	0.9430	0.0000	0.9297	0.0000	0.8430	0.0000	0.8445	0.0000
16	Rack - Polymer Width Decreased	0.9426	0.0000	0.9299	0.0000	0.8423	0.0000	0.8453	0.0000
17	Total, Rack Uncertainties	0.0113		0.0107		0.0106		0.0109	
18	Rack- Dominating Parameters	0.9563	0.0141	0.9409	0.0115	0.8535	0.0116	0.8569	0.0129
19	Difference from Dominant Rack Parameters (18-17)	0.0028		0.0008		0.0010		0.0020	

Table 4.6.37
Axial Burnup Distribution, Enriched Blankets

Axial Section (1 = bottom)	Size, inches	Burnup, GWd/MTU	Relative Burnup	Burnup, GWd/MTU	Relative Burnup
1	6	0	0.3886	45	0.4238
2	6	0	0.6888	45	0.7983
3	6	0	0.9285	45	0.9738
4	6	0	1.0399	45	1.0470
5	6	0	1.0881	45	1.0744
6	6	0	1.1056	45	1.0840
7	6	0	1.1009	45	1.0847
8	6	0	1.0951	45	1.0824
9	6	0	1.0904	45	1.0798
10	6	0	1.0852	45	1.0780
11	6	0	1.0858	45	1.0783
12	6	0	1.0875	45	1.0824
13	6	0	1.0805	45	1.0804
14	6	0	1.0762	45	1.0760
15	6	0	1.0726	45	1.0718
16	6	0	1.0641	45	1.0670
17	6	0	1.0427	45	1.0618
18	6	0	1.0167	45	1.0545
19	6	0	0.9887	45	1.0397
20	6	0	0.9508	45	1.0129
21	6	0	0.8888	45	0.9648
22	6	0	0.7770	45	0.8774
23	6	0	0.5602	45	0.7253
24	6	0	0.3397	45	0.4278

Table 4.6.38
Axial Burnup Distribution, Non-Blanketed

Axial Section (1 = bottom)	Size, inches	Burnup, GWd/MTU	Relative Burnup	Burnup, GWd/MTU	Relative Burnup
1	8	0	0.4327	45	0.5735
2	8	0	0.7329	45	0.9174
3	8	0	0.9155	45	1.0332
4	8	0	1.0196	45	1.0412
5	8	0	1.0805	45	1.0609
6	8	0	1.0381	45	1.0453
7	8	0	1.0572	45	1.0656
8	8	0	1.0515	45	1.0646
9	8	0	1.0191	45	1.0465
10	8	0	1.0486	45	1.0635
11	8	0	1.0221	45	1.0497
12	8	0	1.0302	45	1.0594
13	8	0	1.0207	45	1.0549
14	8	0	1.0029	45	1.0320
15	8	0	0.9852	45	1.0318
16	8	0	0.8386	45	0.9862
17	8	0	0.4455	45	0.8318
18	8	0	0.0661	45	0.5121

Table 4.6.39
Examples of Calculation for Burnup Versus Enrichment Requirement

Pattern[33]	A		B		C		D	
Enrichment (wt% ^{235}U)	5		5		5		5	
Burnup (GWD/MTU)	15	10	35	30	45	40	55	50
Cooling time (yr)	0	0	0	0	0	0	0	0
Axial Profile	4	1	4	4	4	4	4	4
kcalc for Fresh Fuel	1.0061	1.0061	1.1417	1.1417	1.1901	1.1901	1.2369	1.2369
Standard deviation (σ)	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004
kcalc for S(alpha, beta)=300K	0.9628	0.9725	0.9441	0.9684	0.9311	0.9571	0.9305	0.9475
Calculation Uncertainty (σ)	0.0005	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004
Depletion Uncertainty	0.0022	0.0018	0.01	0.0087	0.013	0.0117	0.0154	0.0145
Burnup Uncertainty	0.0022	0.0018	0.01	0.0087	0.013	0.0117	0.0154	0.0145
kcalc for S(alpha, beta)=400K	0.959	0.9698	0.9583	0.9833	0.9475	0.9744	0.9477	0.966
Standard deviation (σ)	0.0005	0.0005	0.0005	0.0004	0.0005	0.0004	0.0004	0.0005
kcalc Used to Determine Max. keff[34]	0.9628	0.9725	0.9524	0.9771	0.9406	0.9672	0.9405	0.9583
kcalc for FP Uncertainty	0.9795	0.987	1.0068	1.0246	1.0098	1.0291	1.0181	1.0323
Standard deviation (σ)	0.0005	0.0005	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004
FP Uncertainty	0.0009	0.0008	0.0032	0.0029	0.004	0.0037	0.0044	0.0043
kcalc for LFP Uncertainty	0.9643	0.9743	0.953	0.974	0.9431	0.9671	0.9439	0.9611
Standard deviation (σ)	0.0005	0.0005	0.0004	0.0005	0.0004	0.0004	0.0004	0.0004
LFP Uncertainty	0.0004	0.0005	0.0015	0.0011	0.002	0.0017	0.0022	0.0022

[33] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U, the enrichments and burnups presented in the table are only for spent fuel.

[34] For Pattern A, kcalc for S(alpha, beta)=300K are used, for Patterns B, C and D, the values are interpolated for the temperature of 358.15K using kcalc for S(alpha, beta)=300K and kcalc for S(alpha, beta)=400K .

Table 4.6.39
Examples of Calculation for Burnup Versus Enrichment Requirement (Continued)

Pattern	A		B		C		D	
Enrichment (wt% ^{235}U)	5		5		5		5	
Burnup (GWD/MTU)	15	10	35	30	45	40	55	50
Cooling time (yr)	0	0	0	0	0	0	0	0
Axial Profile	4	1	4	4	4	4	4	4
kcalc for Fuel Uncertainty	0.9693	0.9802	0.951	0.975	0.9377	0.9648	0.9363	0.9546
Standard deviation (σ)	0.0005	0.0006	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004
Fuel Uncertainty	0.0079	0.0093	0.0083	0.008	0.0077	0.0088	0.0069	0.0082
kcalc for Rack Uncertainty	0.9701	0.9812	0.954	0.98	0.9429	0.9695	0.9409	0.9609
Standard deviation (σ)	0.0005	0.0005	0.0004	0.0005	0.0004	0.0005	0.0004	0.0004
Rack Uncertainty	0.0087	0.0101	0.0112	0.013	0.0129	0.0137	0.0115	0.0145
MCNP Code Uncertainty	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085	0.0085
Calculation Uncertainty (2σ)	0.001	0.001	0.001	0.001	0.0008	0.0008	0.0008	0.0008
Fuel Creep Uncertainty	0.0039	0.0039	0.0042	0.0042	0.0034	0.0034	0.0028	0.0028
Eccentric Positioning Uncertainty	0	0	0.0136	0.0136	0.015	0.015	0.0147	0.0147
Total Uncertainty (statistical combination)	0.0154	0.0169	0.0261	0.0259	0.0299	0.0294	0.0312	0.0319
Code Bias	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043
Other Bias (Pin Specific, Burnable Absorber)	0.0034	0.0034	0.0038	0.0038	0.0052	0.0052	0.0042	0.0042
Maximum k_{eff}	0.9859	0.9971	0.9866	1.0111	0.98	1.0061	0.9802	0.9987
Target k_{eff}	0.99		0.99		0.99		0.99	
Calculated Burnup (GWD/MTU)	13.17		34.31		43.08		52.35	

Table 4.6.40
Minimum Burnup Requirements (GWd/MTU) from MCNP Calculations for Region 1 Racks[35]

Enrichment	1.5	2.6	3.6	4.5	5
Pattern A	0.00	0.00	2.72	9.33	13.17

[35] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The minimum burnup requirements in the table are only applicable for spent fuel. In addition, the results in this table are calculated by MCNP directly and do not include the polynomial adjustment.

Table 4.6.41
Minimum Burnup Requirements (GWd/MTU) from MCNP Calculations for Fuel in Region 2 Racks with Enrichment Range up to 3.6 wt% ^{235}U [36]

Enrichment[37]	1.5	2.6
Pattern B, 0 years	0.00	4.85
Pattern B, 2.5 years	0.00	4.63
Pattern B, 5 years	0.00	4.43
Pattern B, 10 years	0.00	4.38
Pattern B, 15 years	0.00	4.32
Pattern B, 20 years	0.00	4.29

Enrichment	1.5	2.6
Pattern C, 0 years	0.00	12.81
Pattern C, 2.5 years	0.00	12.16
Pattern C, 5 years	0.00	11.78
Pattern C, 10 years	0.00	11.37
Pattern C, 15 years	0.00	10.96
Pattern C, 20 years	0.00	10.81

Enrichment	1.5	2.6
Pattern D, 0 years	0.00	21.42
Pattern D, 2.5 years	0.00	20.13
Pattern D, 5 years	0.00	19.49
Pattern D, 10 years	0.00	18.57
Pattern D, 15 years	0.00	18.02
Pattern D, 20 years	0.00	17.60

[36] The results in this table are calculated by MCNP directly and do not include the polynomial adjustment.
[37] Minimum Burnup Requirements in this table are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

Table 4.6.42
Minimum Burnup Requirements (GWd/MTU) from MCNP Calculations for Fuel in Region 2 Racks with Enrichment Range of 3.6 – 5.0 wt% ^{235}U [38]

Enrichment	3.6	4.5	5
Pattern B, 0 years	17.94	29.22	34.31
Pattern B, 2.5 years	17.08	28.24	33.21
Pattern B, 5 years	16.88	27.46	32.46
Pattern B, 10 years	16.28	26.56	31.64
Pattern B, 15 years	16.02	26.04	30.84
Pattern B, 20 years	15.74	25.76	30.56

Enrichment	3.6	4.5	5
Pattern C, 0 years	27.01	38.03	43.08
Pattern C, 2.5 years	26.09	36.60	41.42
Pattern C, 5 years	25.23	35.64	40.47
Pattern C, 10 years	24.37	34.43	38.95
Pattern C, 15 years	23.77	33.38	38.12
Pattern C, 20 years	23.34	32.82	37.47

Enrichment	3.6	4.5	5
Pattern D, 0 years	34.71	45.25	52.35
Pattern D, 2.5 years	33.13	43.29	49.59
Pattern D, 5 years	32.16	42.12	47.55
Pattern D, 10 years	30.81	40.30	44.84
Pattern D, 15 years	29.98	39.22	43.66
Pattern D, 20 years	29.31	38.54	42.85

[38] The results in this table are calculated by MCNP directly and do not include the polynomial adjustment.

Table 4.6.43
Bounding Polynomial Fits of Minimum Burnup Requirements for Region 1 Racks[39]

Coefficient	A	B	C
Pattern A	-24.1514	7.4643	0.0000

[39] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The polynomial fits of minimum burnup requirements are only applicable for spent fuel.

Table 4.6.44
Bounding Polynomial Fits of Minimum Burnup Requirements for Fuel in Region 2 Racks with Enrichment Range of up to 3.6 wt% ^{235}U [40]

Coefficient	A	B	C
Pattern B, 0 years	-46.6454	23.4858	-1.4154
Pattern B, 2.5 years	-45.0454	22.6125	-1.3487
Pattern B, 5 years	-41.2633	20.4058	-1.0890
Pattern B, 10 years	-38.5149	18.9692	-0.9504
Pattern B, 15 years	-37.8530	18.7075	-0.9566
Pattern B, 20 years	-37.3476	18.4617	-0.9412

Coefficient	A	B	C
Pattern C, 0 years	-44.6593	26.7356	-1.7815
Pattern C, 2.5 years	-45.2071	26.8990	-1.8595
Pattern C, 5 years	-42.4764	25.2213	-1.6744
Pattern C, 10 years	-41.0757	24.4119	-1.6310
Pattern C, 15 years	-40.4829	23.9210	-1.5905
Pattern C, 20 years	-39.4907	23.3811	-1.5518

Coefficient	A	B	C
Pattern D, 0 years	-26.8286	20.9095	-0.9048
Pattern D, 2.5 years	-28.1650	21.2508	-1.0292
Pattern D, 5 years	-29.2879	21.8885	-1.2030
Pattern D, 10 years	-30.6536	22.5737	-1.4006
Pattern D, 15 years	-31.8257	23.2386	-1.5643
Pattern D, 20 years	-30.5557	22.3502	-1.4726

[40] Minimum Burnup Requirements in this table are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

Table 4.6.45
Bounding Polynomial Fits of Minimum Burnup Requirements for Fuel in Region 2 Racks with Enrichment Range of 3.6 – 5.0 wt% ^{235}U

Coefficient	A	B	C
Pattern B, 0 years	-45.1986	22.2592	-1.2715
Pattern B, 2.5 years	-43.8453	21.4900	-1.2158
Pattern B, 5 years	-41.1255	19.9583	-1.0482
Pattern B, 10 years	-36.9034	17.6517	-0.7886
Pattern B, 15 years	-37.7850	18.3083	-0.9167
Pattern B, 20 years	-36.8808	17.8083	-0.8640

Coefficient	A	B	C
Pattern C, 0 years	-41.8843	24.6516	-1.5317
Pattern C, 2.5 years	-39.5300	23.4678	-1.4556
Pattern C, 5 years	-38.4729	22.5981	-1.3619
Pattern C, 10 years	-40.6071	23.5463	-1.5270
Pattern C, 15 years	-28.5300	17.6078	-0.8556
Pattern C, 20 years	-28.8514	17.6690	-0.8810

Coefficient	A	B	C
Pattern D, 0 years	21.3500	-2.6889	1.7778
Pattern D, 2.5 years	7.6614	3.7032	0.9365
Pattern D, 5 years	-10.0714	12.2624	-0.1476
Pattern D, 10 years	-24.0957	19.0173	-1.0460
Pattern D, 15 years	-23.0257	18.2895	-0.9905
Pattern D, 20 years	-26.5357	19.7184	-1.1683

Table 4.6.46
Minimum Burnup Requirements (GWd/MTU) from Polynomial Fits for Region 1 Rack[41]

Enrichment	1.5	2.6	3.6	4.5	5
Pattern A	0.00	0.00	2.72	9.44	13.17

[41] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The polynomial fits of minimum burnup requirements are only applicable for spent fuel.

Table 4.6.47

Minimum Burnup Requirements (GWd/MTU) from Polynomial Fits for Fuel in Region 2 Racks with Enrichment Range of up to 3.6 wt% ^{235}U

Enrichment[42]	1.5	2.6
Pattern B, 0 years	0.00	4.85
Pattern B, 2.5 years	0.00	4.63
Pattern B, 5 years	0.00	4.43
Pattern B, 10 years	0.00	4.38
Pattern B, 15 years	0.00	4.32
Pattern B, 20 years	0.00	4.29

Enrichment	1.5	2.6
Pattern C, 0 years	0.00	12.81
Pattern C, 2.5 years	0.00	12.16
Pattern C, 5 years	0.00	11.78
Pattern C, 10 years	0.00	11.37
Pattern C, 15 years	0.00	10.96
Pattern C, 20 years	0.00	10.81

Enrichment	1.5	2.6
Pattern D, 0 years	2.50	21.42
Pattern D, 2.5 years	1.40	20.13
Pattern D, 5 years	0.84	19.49
Pattern D, 10 years	0.06	18.57
Pattern D, 15 years	0.00	18.02
Pattern D, 20 years	0.00	17.60

[42] Minimum Burnup Requirements in this table are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

Table 4.6.48
Minimum Burnup Requirements (GWd/MTU) from Polynomial Fits for Fuel in Region 2 Racks with Enrichment Range of 3.6 – 5.0 wt% ^{235}U

Enrichment	3.6	4.5	5
Pattern B, 0 years	18.46	29.22	34.31
Pattern B, 2.5 years	17.76	28.24	33.21
Pattern B, 5 years	17.14	27.46	32.46
Pattern B, 10 years	16.42	26.56	31.64
Pattern B, 15 years	16.25	26.04	30.84
Pattern B, 20 years	16.03	25.76	30.56

Enrichment	3.6	4.5	5
Pattern C, 0 years	27.01	38.03	43.08
Pattern C, 2.5 years	26.09	36.60	41.42
Pattern C, 5 years	25.23	35.64	40.47
Pattern C, 10 years	24.37	34.43	38.95
Pattern C, 15 years	23.77	33.38	38.12
Pattern C, 20 years	23.34	32.82	37.47

Enrichment	3.6	4.5	5
Pattern D, 0 years	34.71	45.25	52.35
Pattern D, 2.5 years	33.13	43.29	49.59
Pattern D, 5 years	32.16	42.12	47.55
Pattern D, 10 years	30.81	40.30	44.84
Pattern D, 15 years	29.98	39.22	43.66
Pattern D, 20 years	29.31	38.54	42.85

Table 4.6.49
Summary of Additional Configuration for Pattern B and Pattern C

	Enr	Cooling time	Bu	K-calc	Unc[43]	K-calc + Unc
Pattern B, but 1 RCCA is replaced by Empty Cell	2.6	0	4.85	0.9083	0.0381	0.9464
	5.0	0	34.31	0.9052	0.0357	0.9409
	5.0	20	30.56	0.9050	0.0371	0.9421
Pattern C, but 1 RCCA is replaced by Empty Cell	2.6	0	12.81	0.8998	0.0424	0.9422
	5.0	0	43.08	0.8981	0.0406	0.9387
	5.0	20	37.47	0.8987	0.0407	0.9394

[43] The Unc is the total uncertainty and bias determined by the calculation of loading curve.

Table 4.6.50
Summary of Soluble Boron Calculations, 500 ppm[44]

	Enr	Cooling time	Bu	K-calc	Unc[45]	K-calc + Unc
Pattern A	3.4	0	0.00	0.9130	0.0248	0.9378
	5.0	0	13.17	0.9136	0.0252	0.9388
Pattern B	2.3	0	0.00	0.8516	0.0405	0.8921
	5.0	0	34.31	0.8780	0.0357	0.9137
	5.0	20	30.56	0.8764	0.0371	0.9135
Pattern C	1.9	0	0.00	0.8338	0.0434	0.8772
	5.0	0	43.08	0.8743	0.0406	0.9149
	5.0	20	37.47	0.8722	0.0407	0.9129
Pattern D	1.5	0	0.00	0.7961	0.0480	0.8441
	5.0	0	52.35	0.8705	0.0423	0.9128
	5.0	20	42.85	0.8702	0.0433	0.9135

[44]Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The enrichments and burnups presented in the table are only for spent fuel.

[45] For some cases, the Unc is larger than the total uncertainty and bias determined by the loading curve calculation, since the reactivity effect of the BPRA or IFBA rods for the 500 ppm case is considered. It may be larger than the reactivity effect for the 0 ppm case that applied in the loading curve calculation.

Table 4.6.51
Summary of Other Normal Conditions

	Enr	Bu	K-calc	Unc[46]	K-calc + Unc
Single Fuel Assembly (normal temperature)	5	0	0.9357	0.0422	0.9779
Single Fuel Assembly (off-normal temperature)	5	0	0.9379	0.0422	0.9801

[46] The Unc is the total uncertainty and bias determined by the calculation of loading curve.

Table 4.6.52
Summary of Pattern D with Two Peripheral Row

	Enr	Cooling time	Bu	K-calc
Pattern D (Reference)	3.1	15	25.18	0.9452
Pattern D with two peripheral row filled with 24 GWd/mtU FA	3.1	15	24	0.9392

Table 4.6.53
Summary of Calculations for the Fuel Rod Storage Basket[47]

Case	Enr	Bu	K-calc	Unc[48]	K-calc + Unc
Pattern A with a FRSB Full with Fresh Fuel Pins	5	13.17	0.9285	0.025	0.9535
Pattern D with a FRSB Full with Fresh Fuel Pins	5	52.35	0.9149	0.0422	0.9571
Pattern B with a FRSB Full with Fresh Fuel Pins	5	43.08	0.9461	0.0406	0.9867
Pattern C with a FRSB Full with Fresh Fuel Pins	5	34.31	0.9465	0.0357	0.9822

[47] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The enrichments and burnups presented in the table are only for spent fuel.
[48] The Unc is the total uncertainty and bias determined by the calculation of loading curve.

Table 4.6.54
Summary of Accident Conditions[49]

	Enr	Bu	Boron	K-calc	Unc[50]	K-calc + Unc
Misload Accidents						
Single Fuel Assembly	5	0	1400	0.8707	0.0423	0.9130
Misloaded Assembly Accidents						
Pattern A	5	13.17	1400	0.8383	0.0252	0.8635
Pattern B - RCCAs-Row	5	34.31	1400	0.8302	0.0357	0.8659
Pattern B - RCCAs-Diagonal	5	34.31	1400	0.8383	0.0357	0.8740
Pattern C	5	43.08	1400	0.8315	0.0406	0.8721
Pattern D	5	52.35	1400	0.8214	0.0423	0.8637
Multiple Assembly/Insert Misload						
Pattern C	5	34.31	1400	0.8081	0.0406	0.8487
Pattern D	5	43.08	1400	0.7987	0.0423	0.8410
Mislocated Assembly Accidents						
Pattern A	5	13.17	1600	0.9067	0.0252	0.9319
Pattern B	5	34.31	1400	0.8640	0.0357	0.8997
Pattern C	5	43.08	1400	0.8677	0.0406	0.9083
Pattern D	5	52.35	1400	0.8528	0.0423	0.8951

[49] Pattern A is a checkerboard of fresh fuel and spent fuel, with fresh fuel at the maximum nominal enrichment of 5.0 wt% ^{235}U. The enrichments and burnups presented in the table are only for spent fuel.

[50] For some cases, the Unc is larger than the total uncertainty and bias determined by the loading curve calculation, since the reactivity effect of the BPRA or IFBA rods for the 500 ppm case is considered. It may be larger than the reactivity effect for the 0 ppm case that applied in the loading curve calculation.

Table 4.6.55
Area of Applicability

Parameter	**Seabrook**	[redacted]
Fuel Assemblies	Fresh and Spent UO_2 fuel	[redacted]
Initial Fuel Enrichments	1.5 to 5 wt%	[redacted]
Fuel Density	up to 10.517 g/cc	[redacted]
Burnup Range	up to about 55GWD/MTU for 5% enrichment	[redacted]
Moderator Material	H_2O	[redacted]
Credited Soluble Boron	0 to 1600 ppm	[redacted]
Temperature	39 F to 185 F	[redacted]
Neutron Poison	B-10 (BORAL™ Panel), Ag-In-Cd (RCCA)	[redacted]
Interstitial Material	Steel	[redacted]
Fuel Cladding	Zirconium Alloy	[redacted]
Reflector	Reflective or Periodic Boundary	[redacted]
Neutron Energy	Thermal spectrum	[redacted]

Table 4.6.56
Reactivity Effect of the RCCA Tolerances, Pattern B

Pattern B	2.6 wt% / 5 GWd/MTU		5.0 wt% / 35 GWd/MTU	
	k-calc	delta-k	k-calc	delta-k
Reference - All Nominal Parameters	0.9457	-	0.9441	-
RCCA Tolerances				
RCCA - Absorber Density Increased	0.9458	0.0000	0.9440	0.0000
RCCA - Absorber Density Decreased	0.9458	0.0000	0.9439	0.0000
RCCA - Absorber OD Increased	0.9457	0.0000	0.9438	0.0000
RCCA - Absorber OD Decreased	0.9456	0.0000	0.9443	0.0000
RCCA - Cladding Thickness Increased	0.9457	0.0000	0.9431	0.0000
RCCA - Cladding Thickness Decreased	0.9454	0.0000	0.9431	0.0000
RCCA - Cladding OD Increased	0.9460	0.0000	0.9441	0.0000
RCCA - Cladding OD Decreased	0.9451	0.0000	0.9443	0.0000
RCCA - Silver Content Increased	0.9450	0.0000	0.9434	0.0000
RCCA - Silver Content Decreased	0.9455	0.0000	0.9438	0.0000
RCCA - Indium Content Increased	0.9456	0.0000	0.9435	0.0000
RCCA - Indium Content Decreased	0.9457	0.0000	0.9450	0.0000
RCCA - Cadmium Content Increased	0.9455	0.0000	0.9445	0.0000
RCCA - Cadmium Content Decreased	0.9456	0.0000	0.9439	0.0000
Total, RCCA Tolerances	0.0000		0.0000	

Table 4.6.57
Reactivity Effect of the RCCA Tolerances, Pattern C

Pattern C	2.6 wt% / 15 GWd/MTU		5.0 wt% / 45 GWd/MTU	
	k-calc	delta-k	k-calc	delta-k
Reference - All Nominal Parameters	0.9296	-	0.9311	-
RCCA Tolerances				
RCCA - Absorber Density Increased	0.9295	0.0000	0.9308	0.0000
RCCA - Absorber Density Decreased	0.9283	-0.0024	0.9311	0.0000
RCCA - Absorber OD Increased	0.9290	0.0000	0.9307	0.0000
RCCA - Absorber OD Decreased	0.9288	0.0000	0.9308	0.0000
RCCA - Cladding Thickness Increased	0.9289	0.0000	0.9313	0.0000
RCCA - Cladding Thickness Decreased	0.9294	0.0000	0.9306	0.0000
RCCA - Cladding OD Increased	0.9289	0.0000	0.9314	0.0000
RCCA - Cladding OD Decreased	0.9297	0.0000	0.9314	0.0000
RCCA - Silver Content Increased	0.9289	0.0000	0.9317	0.0000
RCCA - Silver Content Decreased	0.9289	0.0000	0.9314	0.0000
RCCA - Indium Content Increased	0.9287	0.0000	0.9305	0.0000
RCCA - Indium Content Decreased	0.9285	0.0000	0.9312	0.0000
RCCA - Cadmium Content Increased	0.9285	0.0000	0.9305	0.0000
RCCA - Cadmium Content Decreased	0.9289	0.0000	0.9318	0.0000
Total, RCCA Tolerances	0.0000		0.0000	

Table 4.6.58 Average Boron Concentration for Each Cycle

Cycle	Average Boron Concentration (ppm)
1	449.98
2	485.91
3	671.42
4	747.72
5	881.30
6	971.91
7	893.46
8	808.05
9	727.02
10	778.34
11	900.43
12	878.79
13	912.99
14	875.16

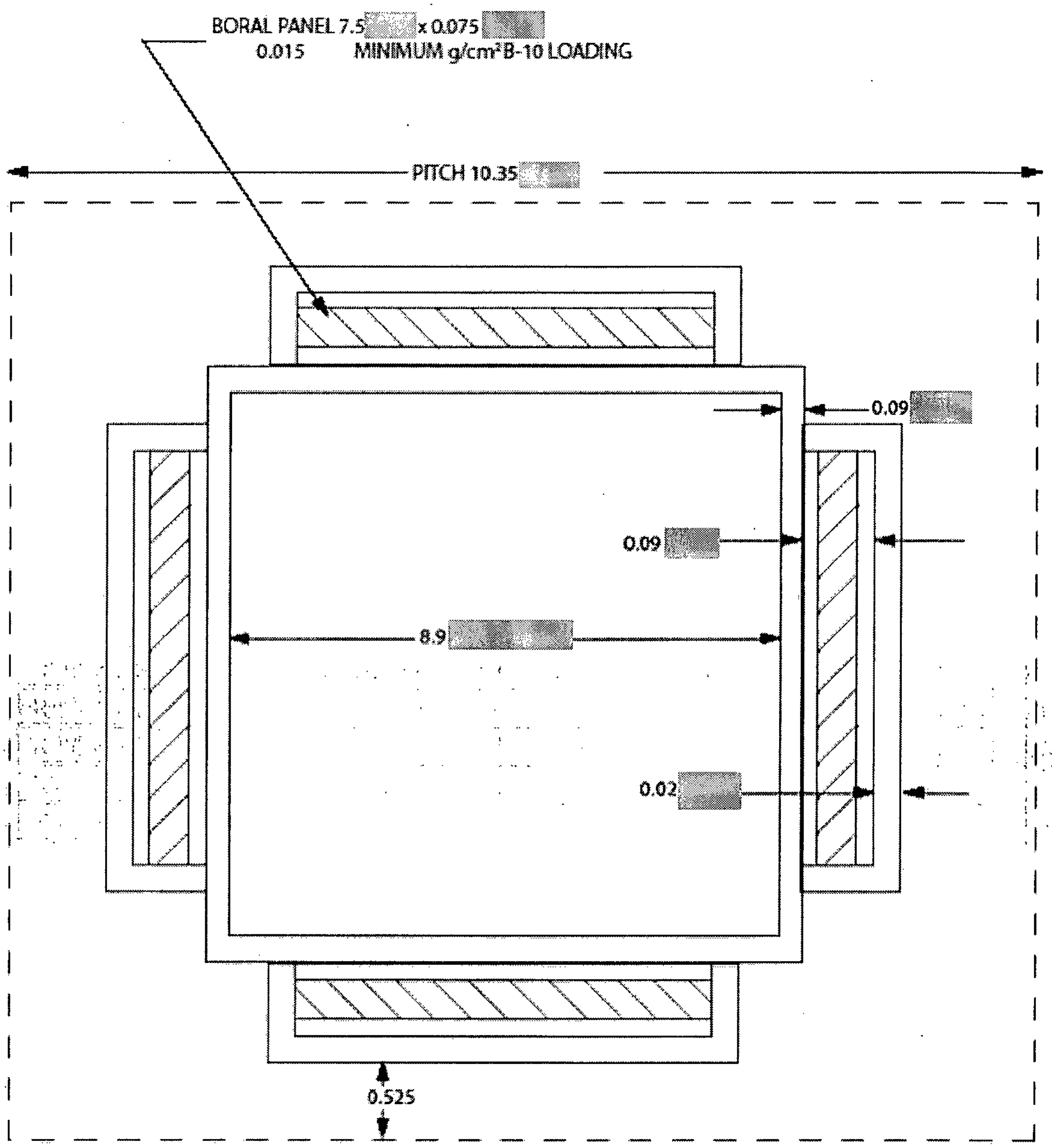

Figure 4.5.1: Sketch of Region 1 Racks, Detailing Important Dimensions [redacted] (NOT TO SCALE, all dimensions in inches)

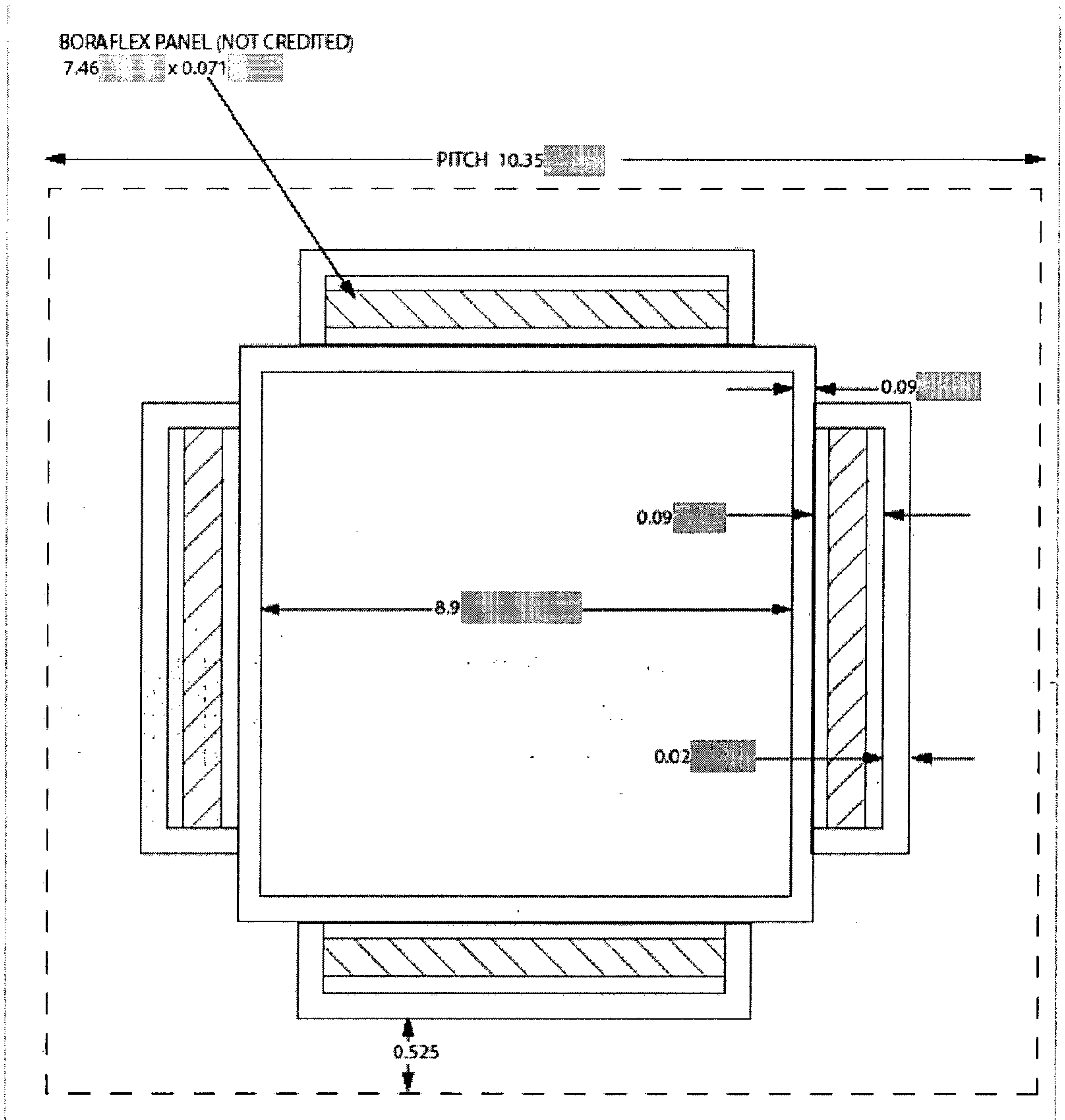

Figure 4.5.2: Sketch of Region 2 Racks, Detailing Important Dimensions . (NOT TO SCALE, all dimensions in inches)

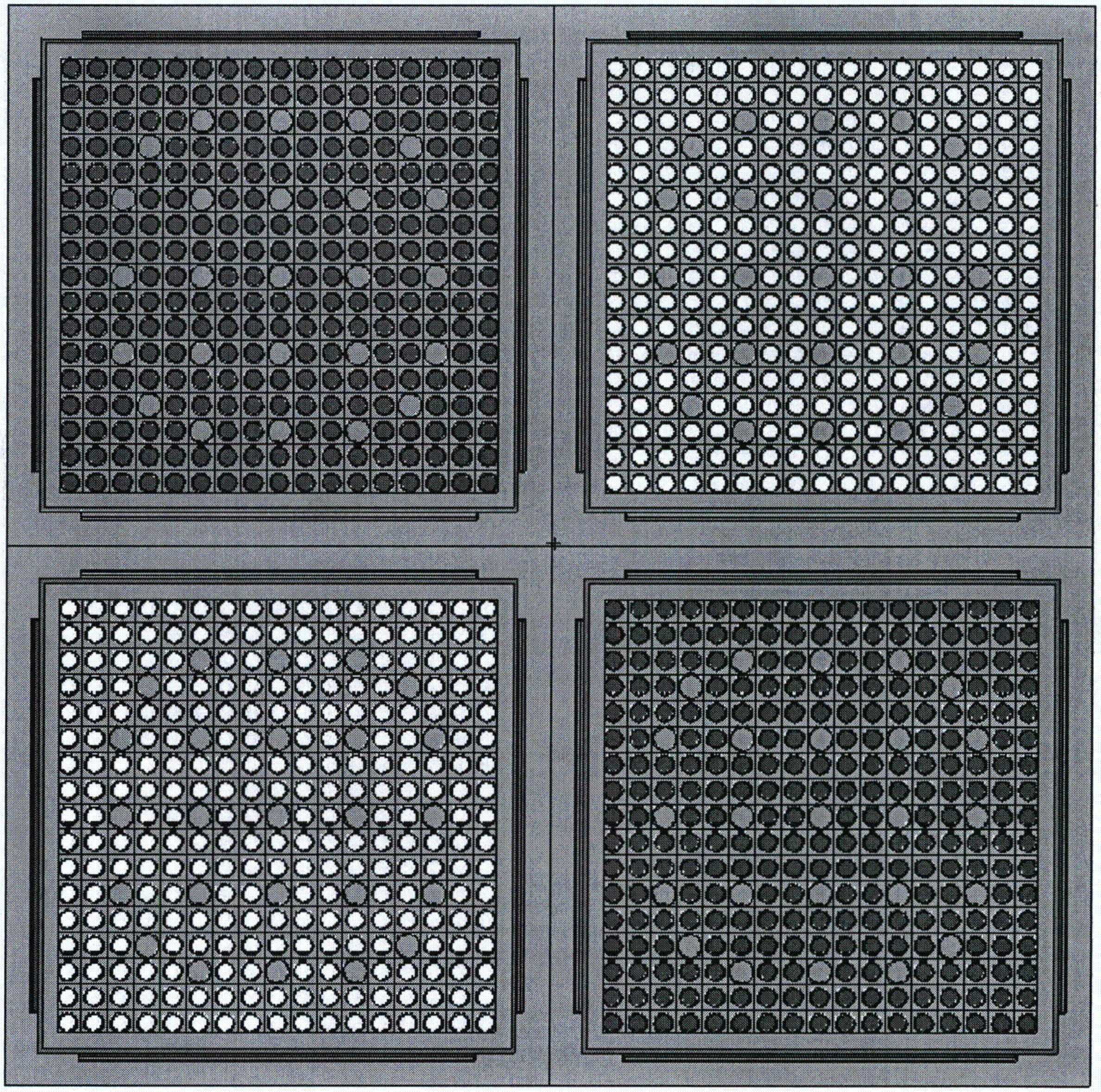

Figure 4.5.3: A Two-Dimensional Representation of the Actual Calculational Model Used for the Region 1 Rack Analysis (Pattern A)

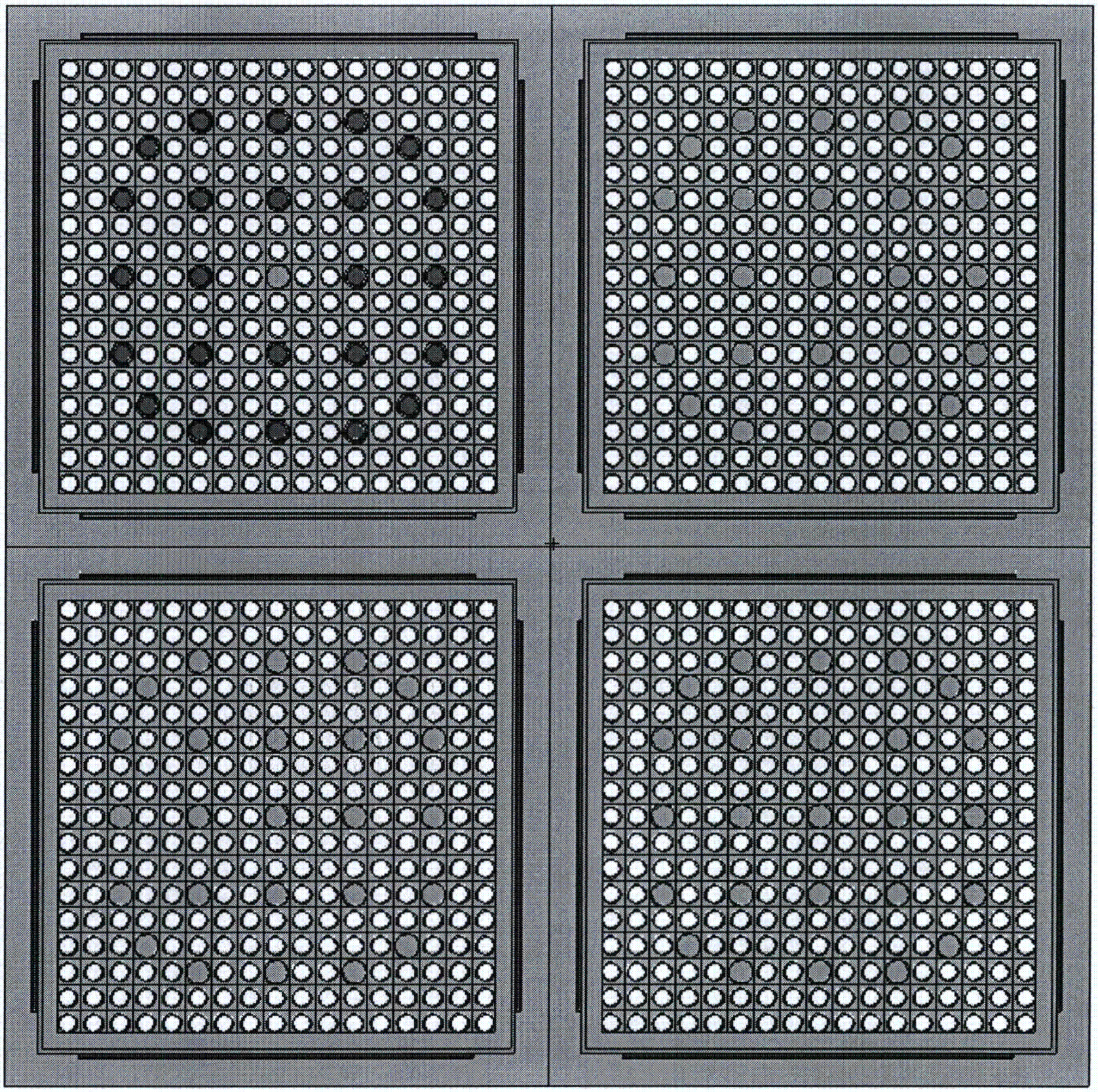

Figure 4.5.4: A Two-Dimensional Representation of the Actual Calculational Model Used for the Region 2 Rack Analyses (Pattern C that Contains 1 RCCA)

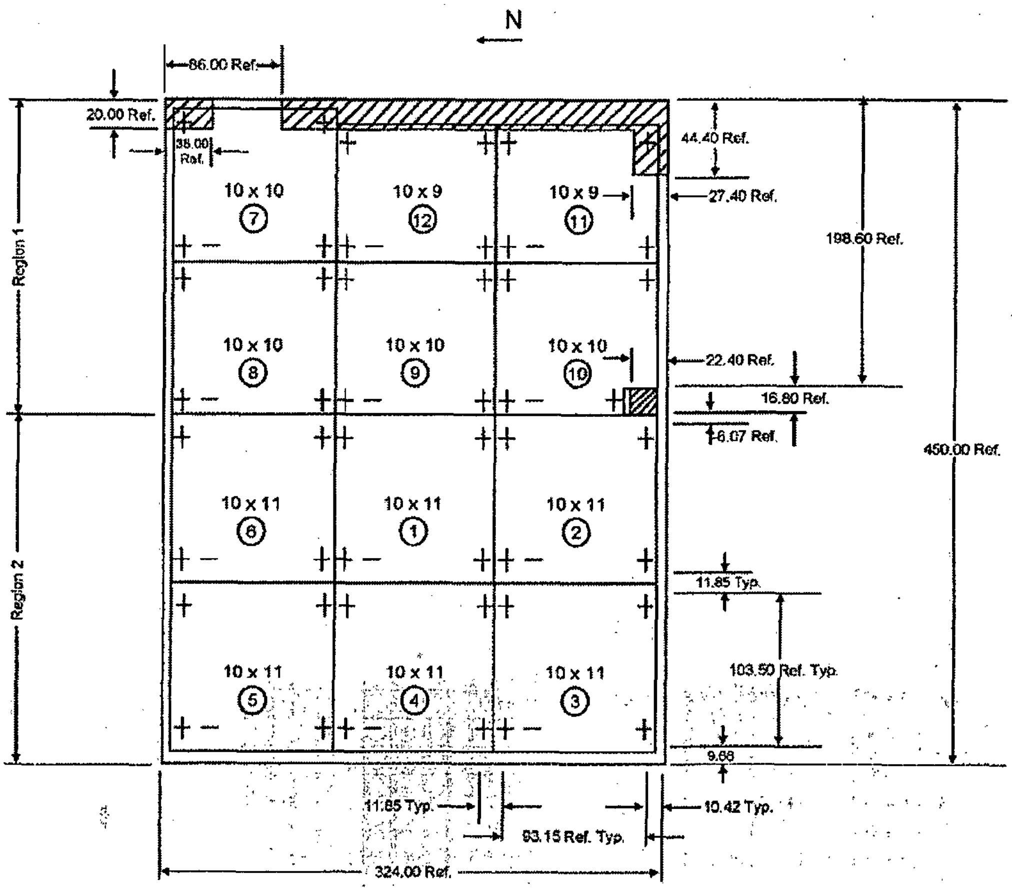

Figure 4.5.5: A Two-Dimensional Representation of the Existing Seabrook Spent Fuel Pool Layout with Rack Region Layout

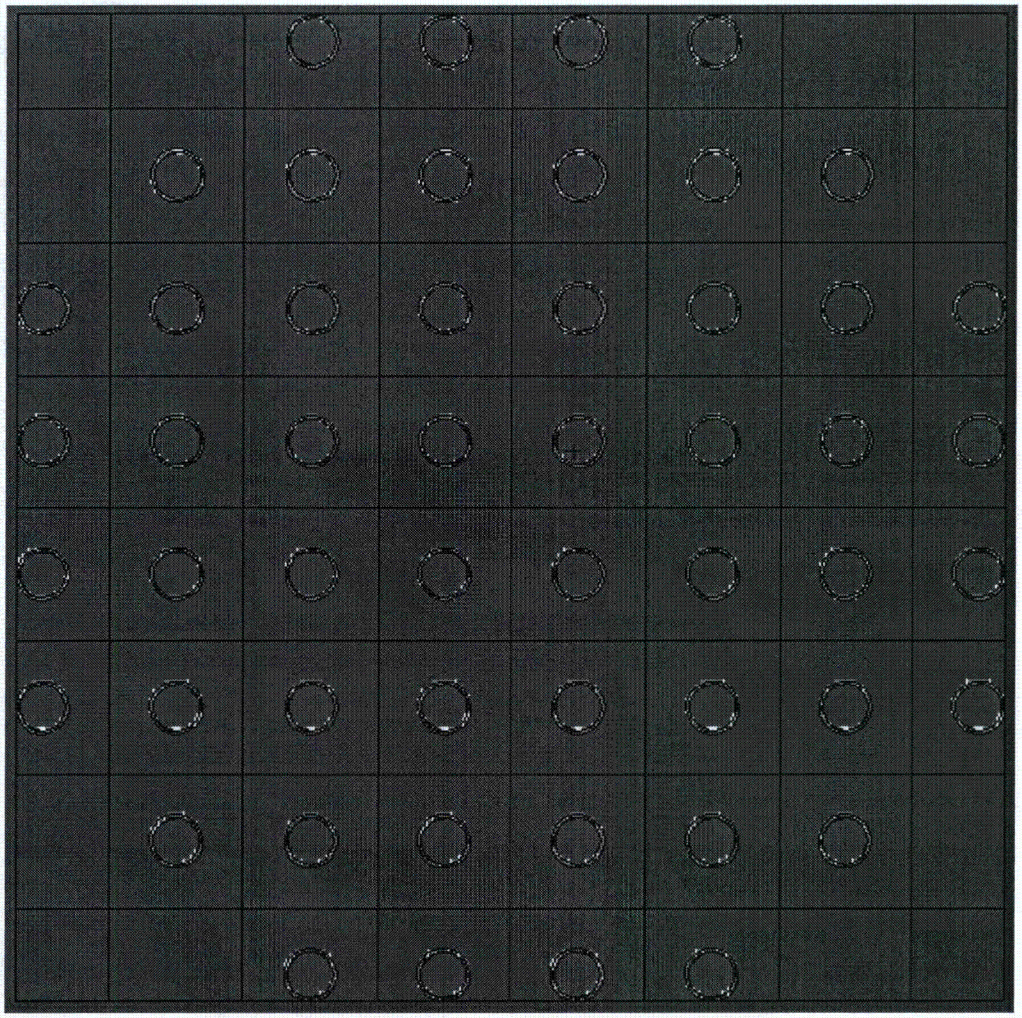

Figure 4.5.6: A Two-Dimensional Representation of the Actual Calculational Model Used for the Fuel Rod Basket Rack Analysis

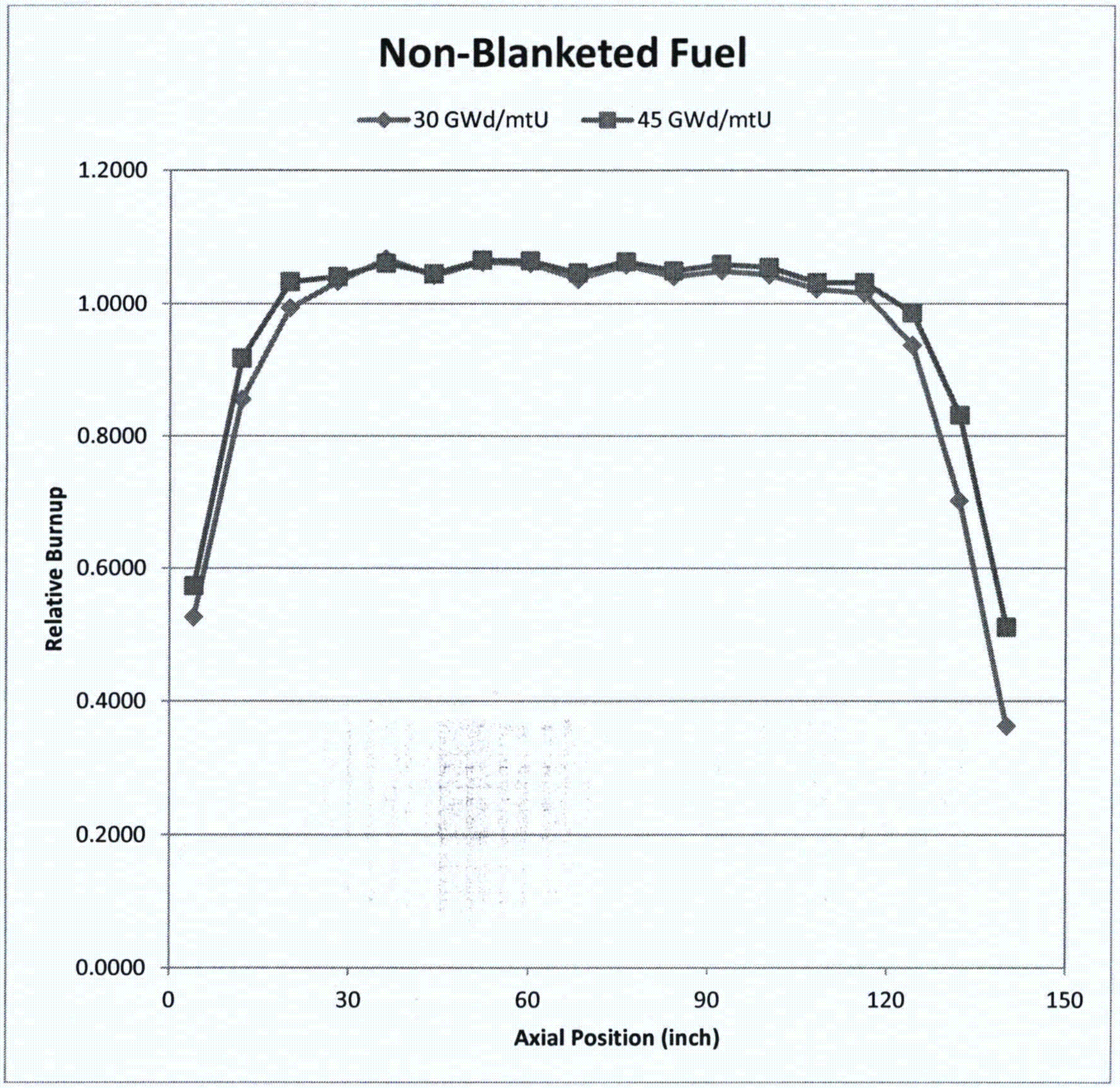

Figure 4.6.1 Axial Burnup Profiles for Non-Blanketed Fuel

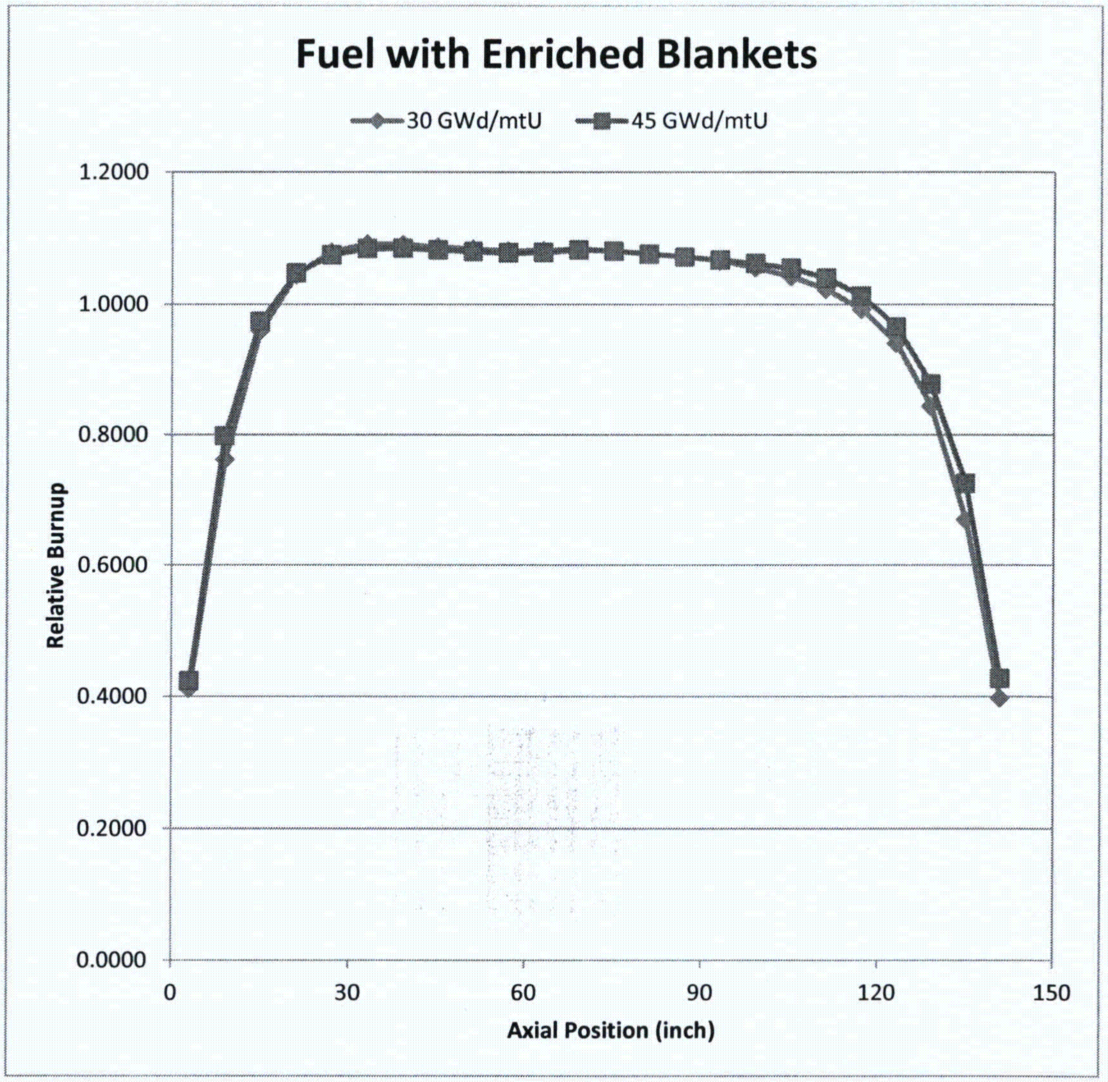

Figure 4.6.2: Axial Burnup Profiles for Fuel with Enriched Uranium Blankets

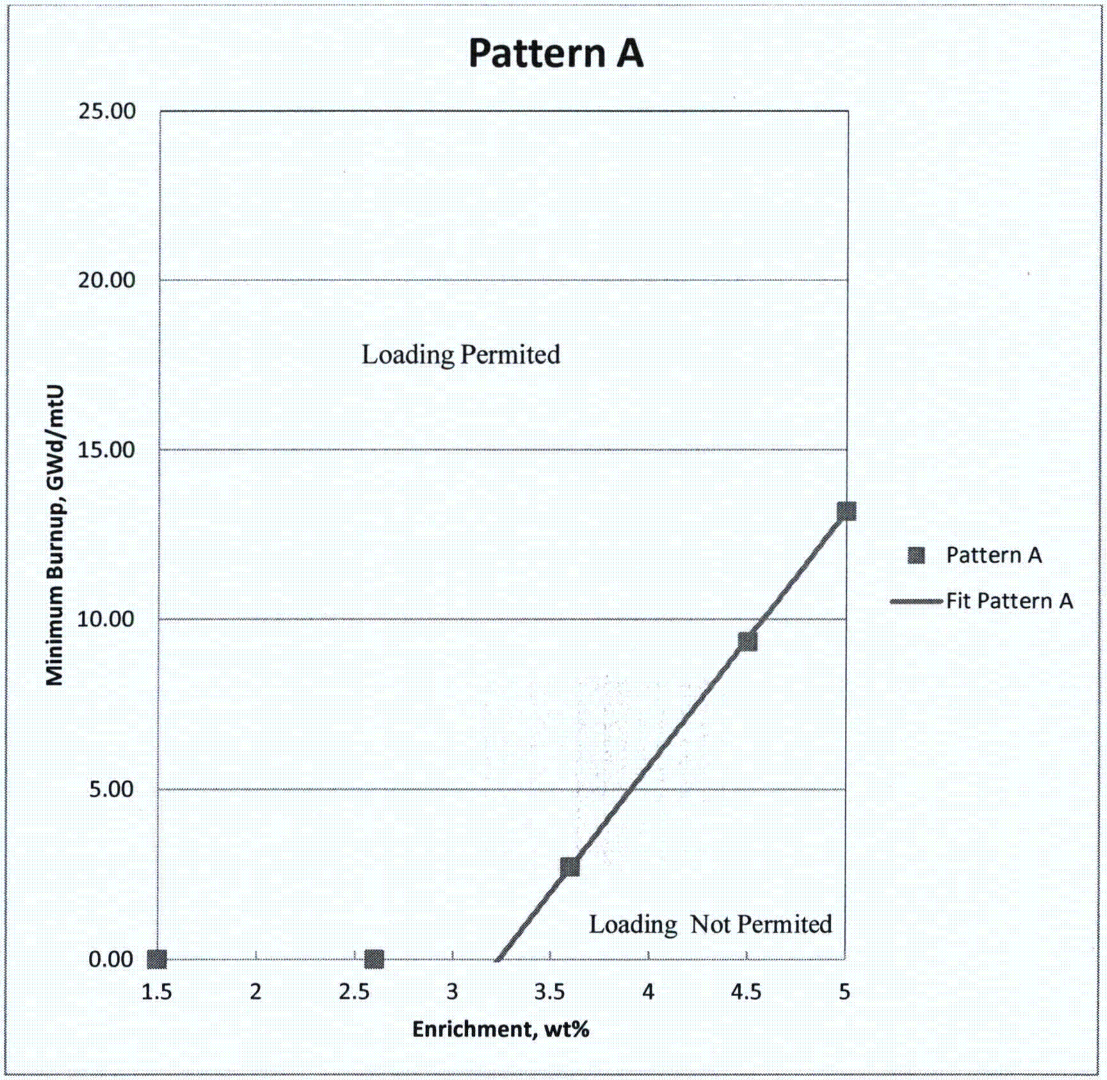

Figure 4.6.3: Loading Curve for Pattern A

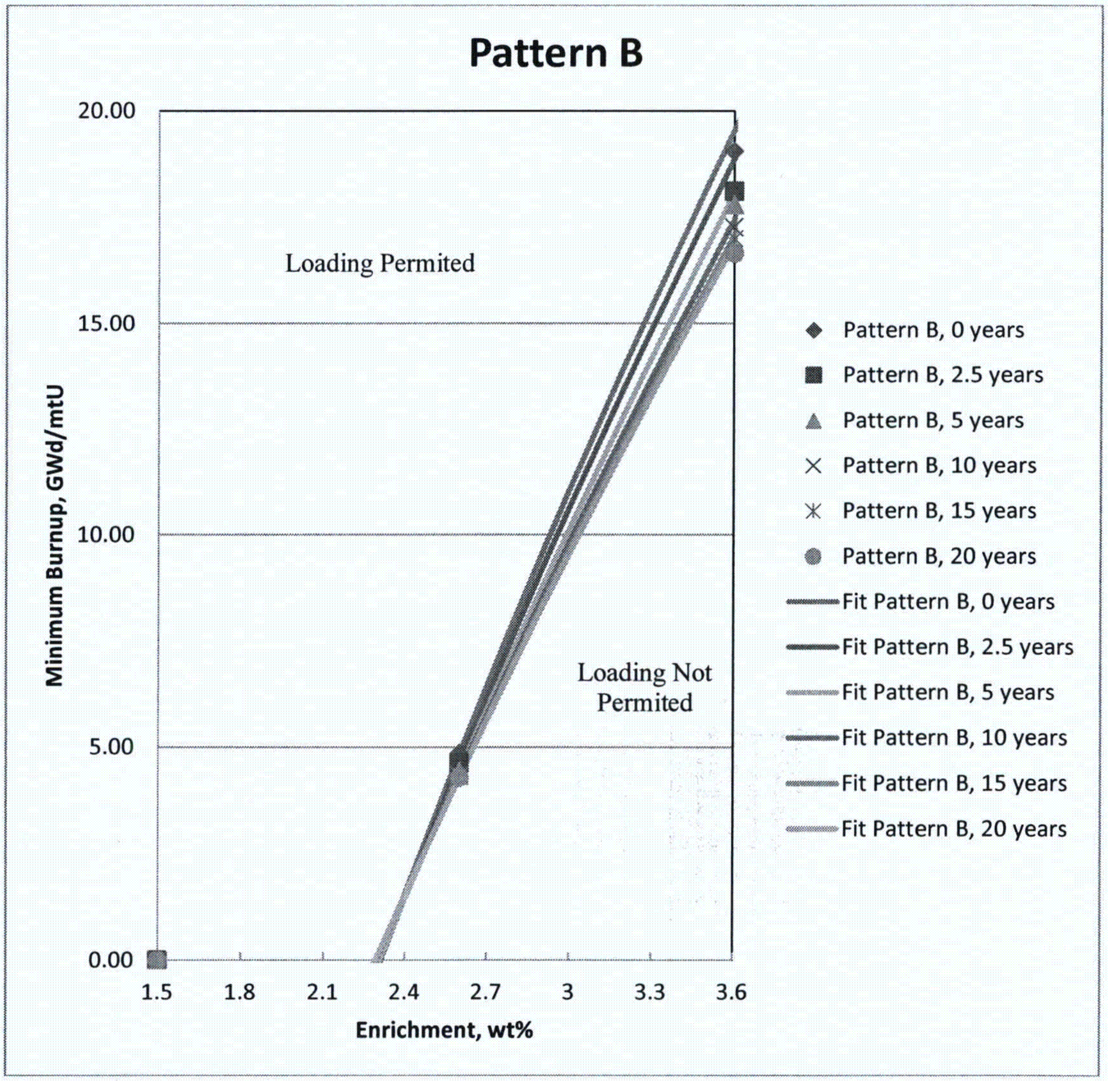

Figure 4.6.4.a: Loading Curves for Pattern B, Enrichment up to 3.6 wt%[51]

[51] Loading curves are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

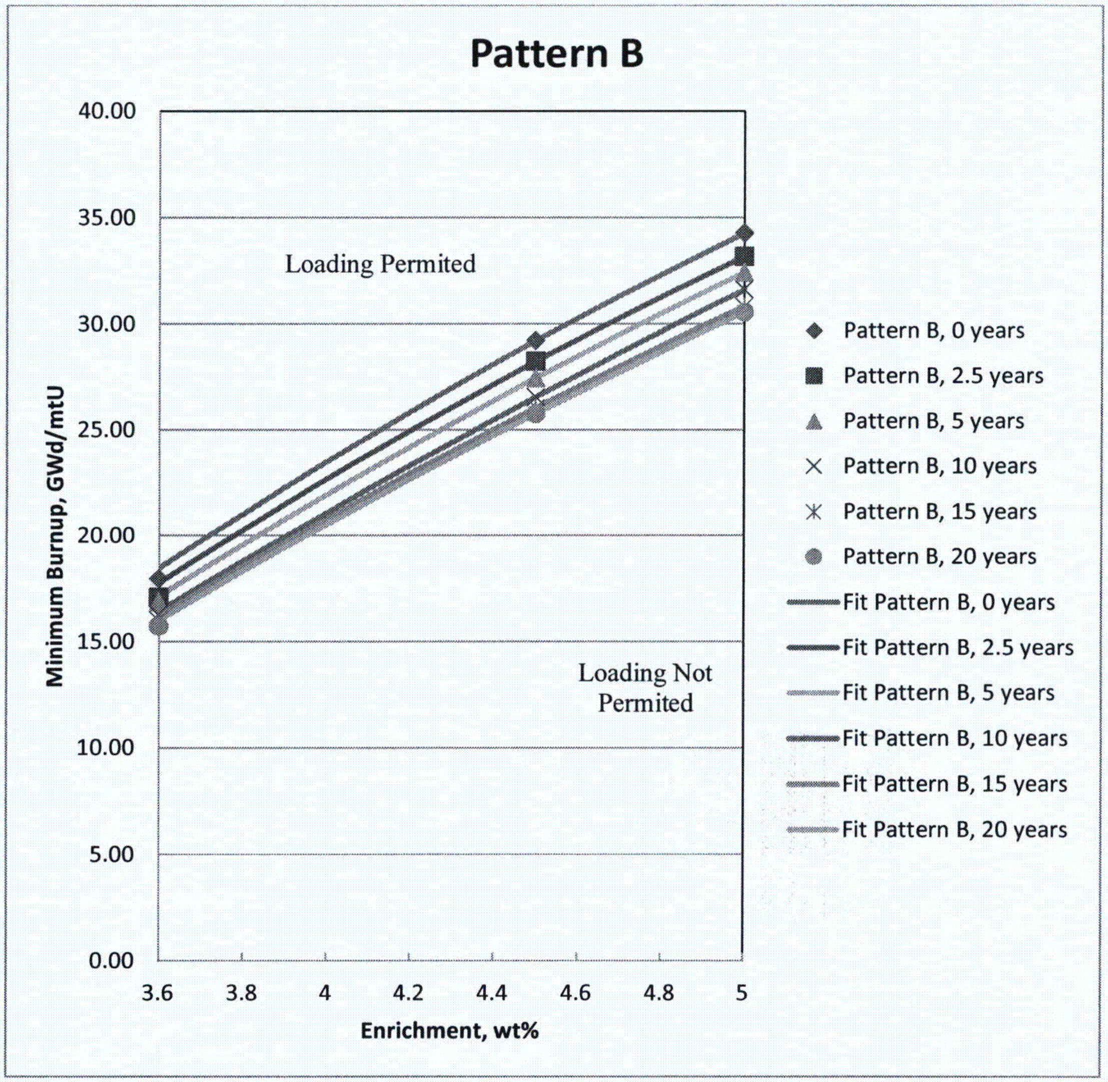

Figure 4.6.4.b: Loading Curves for Pattern B, Enrichment Range 3.6 -5.0 wt%

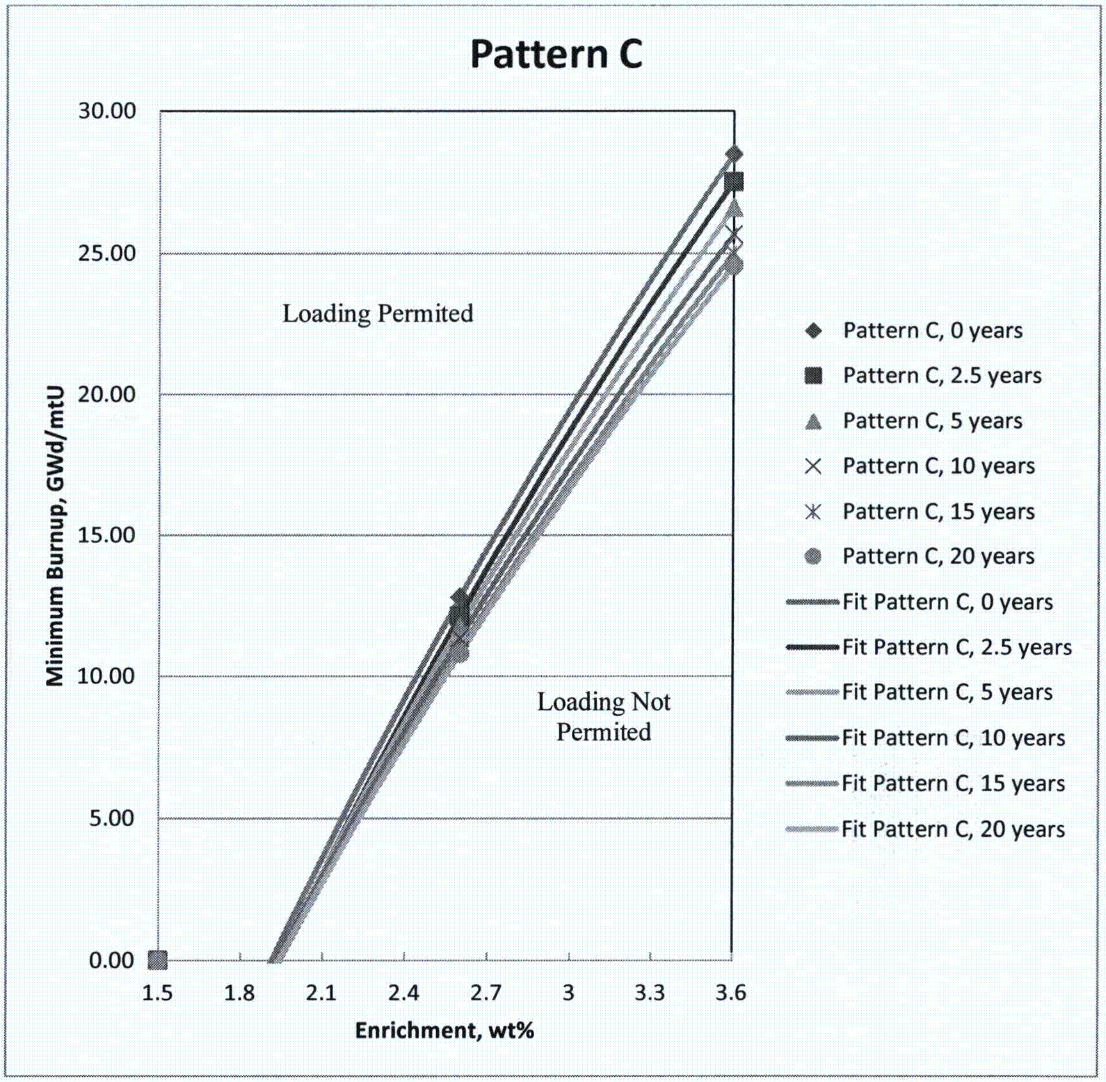

Figure 4.6.5.a: Loading Curves for Pattern C, Enrichment up to 3.6 wt%[52]

[52] Loading curves are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

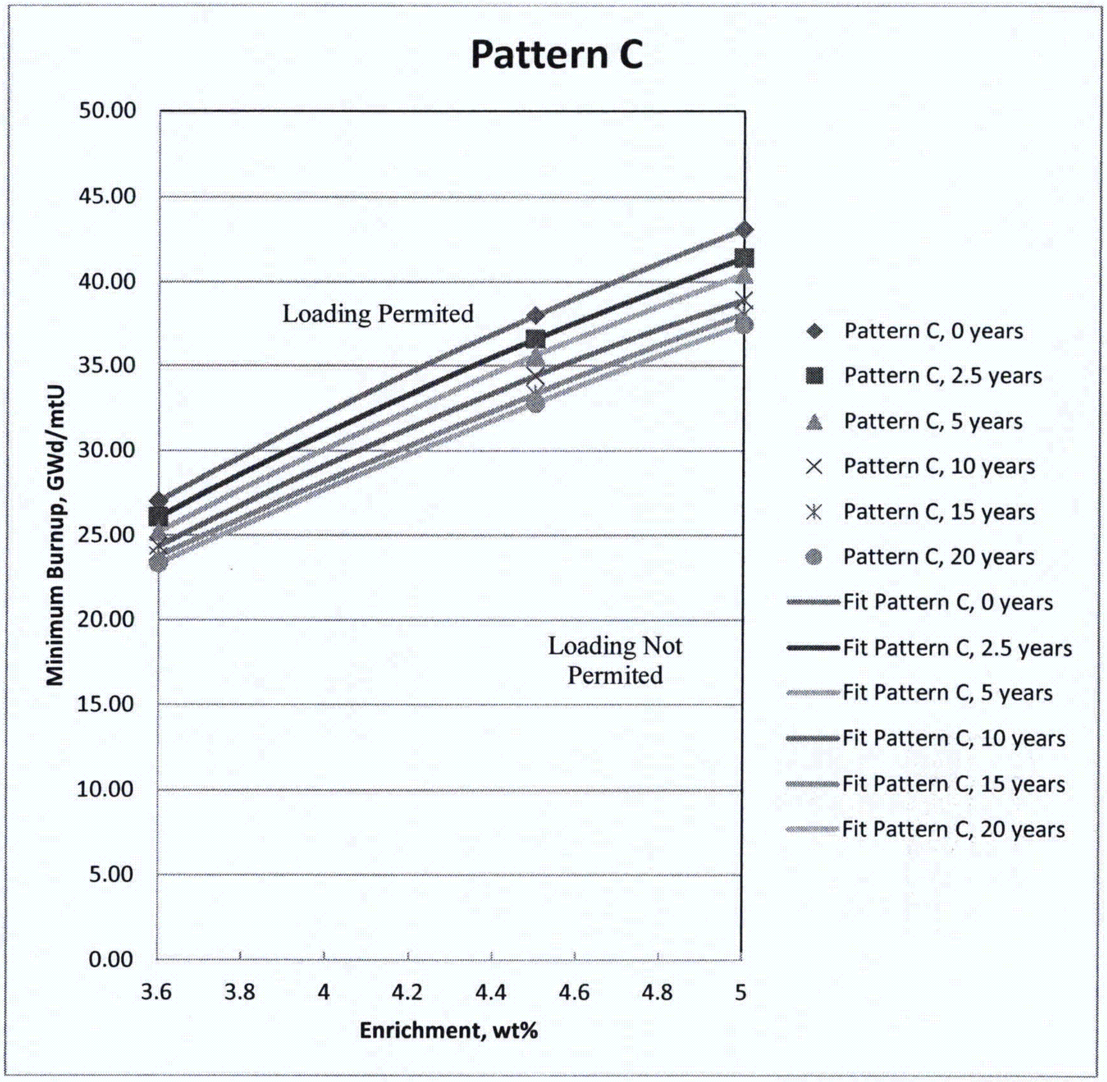

Figure 4.6.5.b: Loading Curves for Pattern C, Enrichment Range 3.6 -5.0 wt%

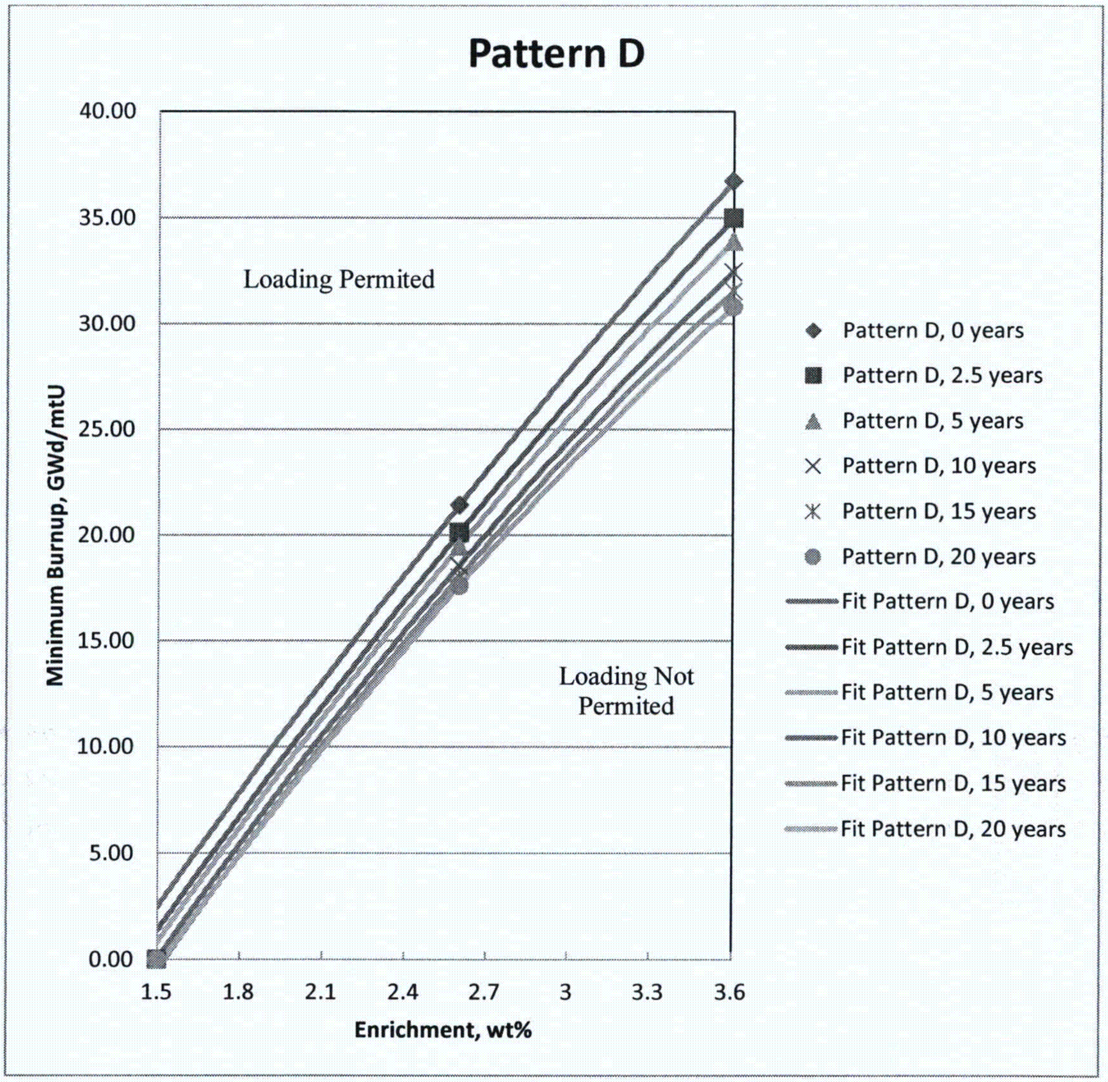

Figure 4.6.6.a: Loading Curves for Pattern D, Enrichment up to 3.6 wt%[53]

[53] Loading curves are applied for fuel with enrichment up to 3.6 wt%, but not including 3.6 wt%.

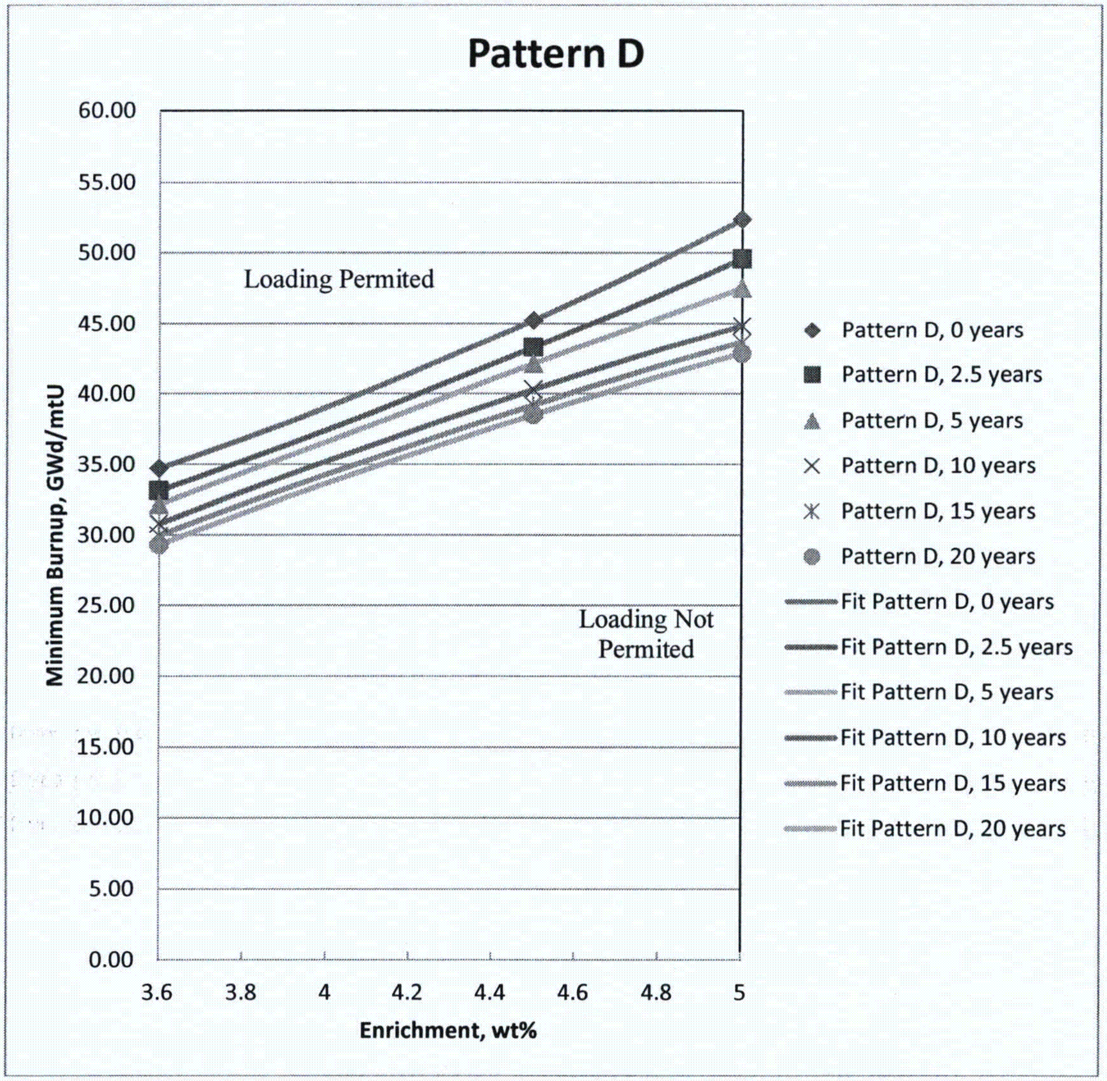

Figure 4.6.6.b: Loading Curves for Pattern D, Enrichment Range 3.6 -5.0 wt%

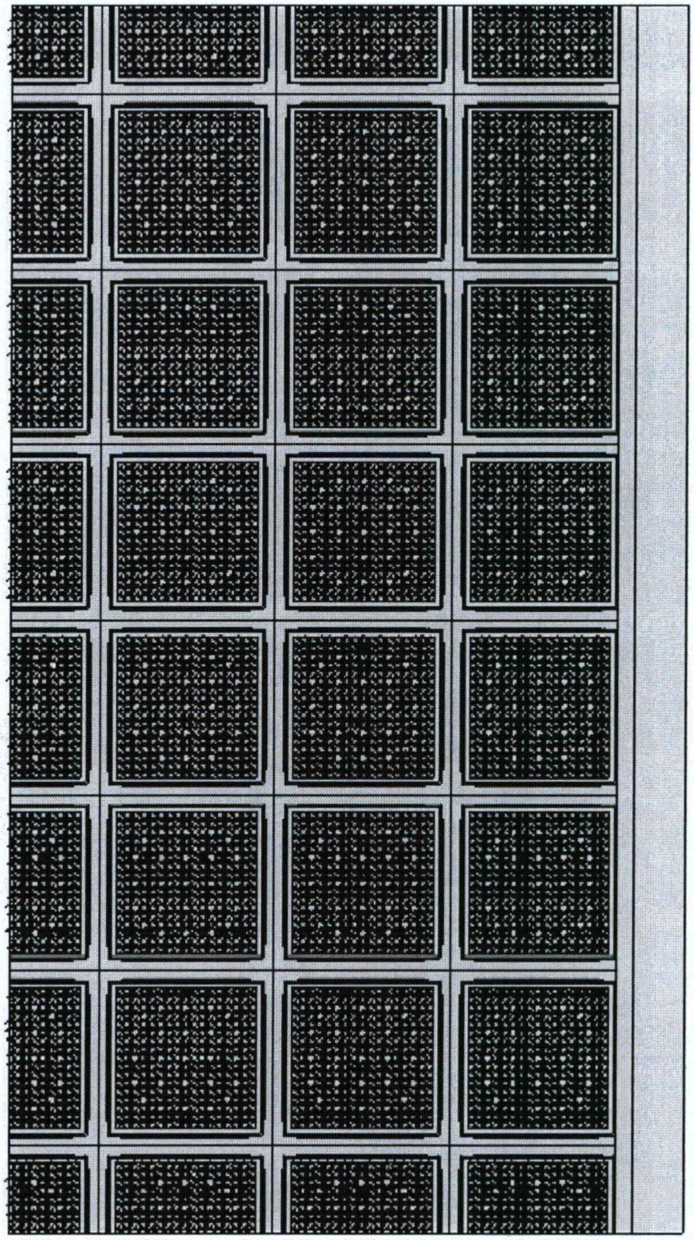

Figure 4.6.7: A Two-Dimensional Representation of the Actual Calculational Model Used for the Analysis of the Fuel Stored on the Periphery of the Region 2 Rack

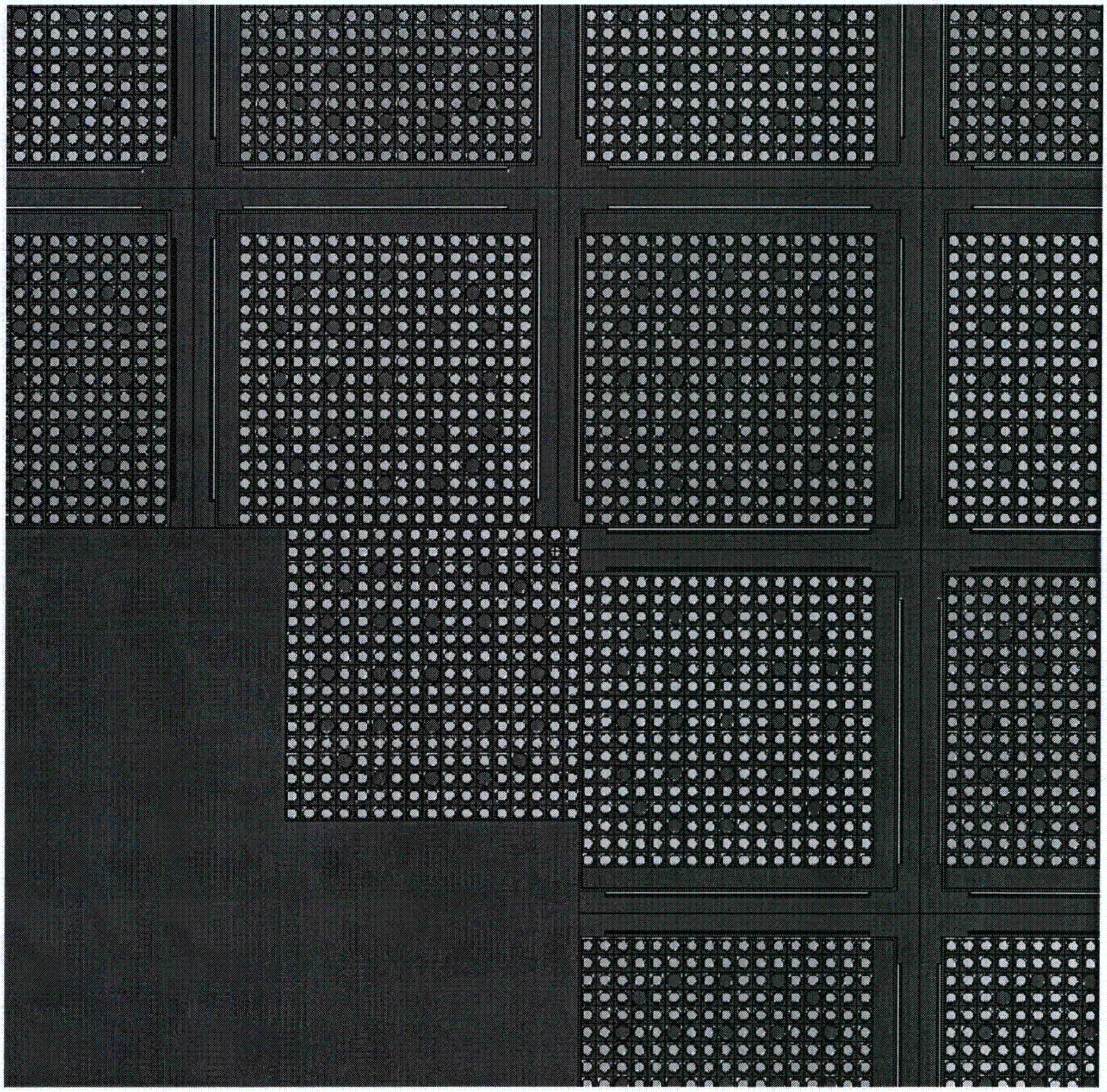

Figure 4.6.8: A Two-Dimensional Representation of the Actual Calculational Model Used for the Analysis for a Mislocated Fuel Assembly[54]

[54] This figure only presents the partial of the model which shows the position of the mislocated assembly.

5. REFERENCES

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22. "Effects of Neutron Absorber Degradation on Seabrook Spent Fuel Pool Thermal-Hydraulics", Holtec Report HI-2073799 Rev. 1, November 2007.

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Appendix A Applicability of Criticality Benchmark Calculations

Benchmarking of MCNP5-1.51 is documented in [5], based on a total set of 291 critical experiments. The bias and bias uncertainty is established in [5] for the entire set of those 291 experiments, and for various subsets of experiments. [redacted]

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Attachment 5

Marked-up Technical Specification Bases Pages

BASES

BASES

3/4.9.9 (THIS SPECIFICATION NUMBER IS NOT USED.)

3/4.9.10 and 3/4.9.11 WATER LEVEL - REACTOR VESSEL and STORAGE POOL

The restrictions on minimum water level ensure that sufficient water depth is available to remove 99% of the assumed 10% iodine gap activity released from the rupture of an irradiated fuel assembly. The minimum water depth is consistent with the assumptions of the safety analysis. Suspending fuel movement or crane operation does not preclude moving a component to a safe location.

3/4.9.12 FUEL STORAGE BUILDING EMERGENCY AIR CLEANING SYSTEM

The limitations on the Fuel Storage Building Emergency Air Cleaning System ensure that all radioactive material released from an irradiated fuel assembly will be filtered through the HEPA filters and charcoal adsorber prior to discharge to the atmosphere. Operation of the system with the heaters operating for at least 10 continuous hours in a 31-day period is sufficient to reduce the buildup of moisture on the adsorbers and HEPA filters. The OPERABILITY of this system and the resulting iodine removal capacity are consistent with the assumptions of the safety analyses. ANSI N510-1980 will be used as a procedural guide for surveillance testing. Suspending fuel movement or crane operation does not preclude moving a component to a safe location.

DELETE

One train of the Fuel Storage Building Emergency Air Cleaning System must be in operation during fuel movement. This requirement, however, does not apply to movement of a spent fuel cask containing irradiated fuel in preparation for transfer to dry storage. Movement of fuel after it has been inserted into a spent fuel cask and unlatched from the lifting tool is no longer a consideration with regard to this specification.

3/4.9.13 SPENT FUEL ASSEMBLY STORAGE

REPLACE WITH INSERT 1

Restrictions on placement of fuel assemblies of certain enrichments within the Spent Fuel Pool is dictated by Figure 3.9-1. These restrictions ensure that the K_{eff} of the Spent Fuel Pool will always remain less than 0.95 assuming the pool to be flooded with unborated water. The restrictions delineated in Figure 3.9-1 and the action statement are consistent with the criticality safety analysis performed for the Spent Fuel Pool as documented in the FSAR.

(THIS SPECIFICATION NUMBER IS NOT USED)

3/4.9.14 NEW FUEL ASSEMBLY STORAGE

Restrictions on placement of fuel assemblies of certain enrichments within the New Fuel Storage Vault is dictated by Specification 3/4.9.14. These restrictions ensure that the K_{eff} of the New Fuel Storage Vault will always remain less than 0.95 assuming the area to be flooded with unborated water. In addition, these restrictions ensure that the K_{eff} of the New Fuel Storage Vault will always remain less than 0.98 when aqueous foam moderation is assumed. The restrictions delineated in Specification 3/4.9.14 and the action statement are consistent with the criticality safety analysis performed for the New Fuel Storage Vault as documented in the FSAR.

→ ADD INSERT 2

3/4.9.13 SPENT FUEL ASSEMBLY STORAGE

INSERT 1

Restrictions on placement of fuel assemblies of certain enrichments within the Spent Fuel Pool is dictated by Specification 5.6.1.3. These restrictions ensure that the keff of the Spent Fuel Pool will always remain less than 1.0 assuming the pool to be flooded with unborated water and less than or equal 0.95 when flooded with water borated to 500 ppm. The restrictions delineated in Specification 5.6.1.3 and the action statement are consistent with the criticality safety analysis performed for the Spent Fuel Pool as documented in the FSAR.

3/4.9.15 SPENT FUEL POOL BORON CONCENTRATION

INSERT 2

The limitation on the Spent Fuel Pool boron concentration ensure that sufficient boron is present to maintain criticality margin during any potential spent fuel pool accident. The required boron concentration is also sufficient to ensure that no boron dilution event could reduce the spent fuel concentration below 500 ppm. The action statement requires immediately suspending movement of fuel until the boron concentration has been restored. This does not preclude movement of a fuel assembly to a safe position.